MARITIME SOLUTIONS FOR A CHANGING WORLD

#157 - WINTER 2019

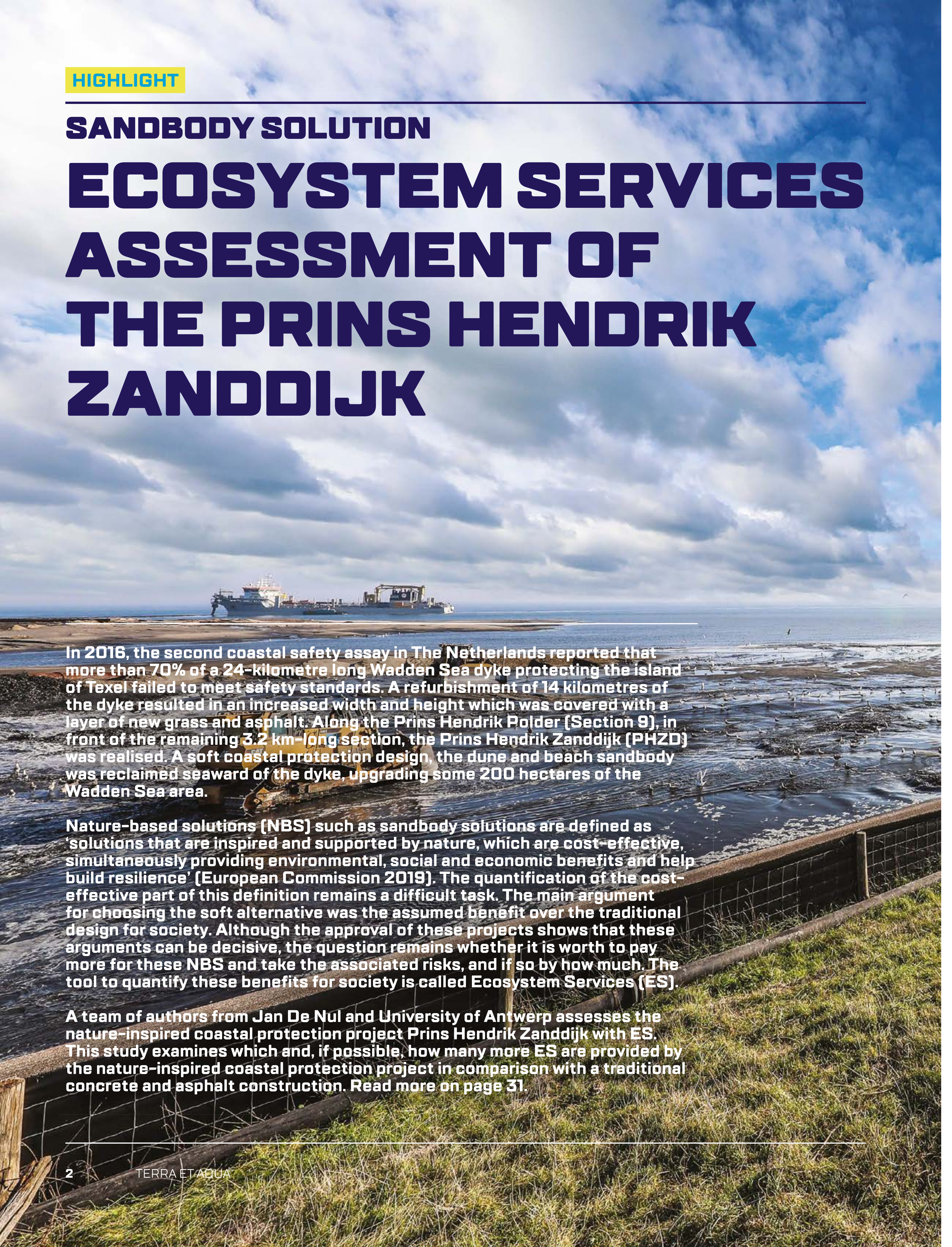
TERRA ET AQUA

PIPELINE CONNECTOR
Solution links floating pipes without human hands

REMEDIATED REFINERY
Removing residual toxins and restoring wetlands

SANDBODY SOLUTION

ECOSYSTEM SERVICES ASSESSMENT OF THE PRINS HENDRIK ZANDDIJK



HIGHLIGHT

SANDBODY SOLUTION

ECOSYSTEM SERVICES ASSESSMENT OF THE PRINS HENDRIK ZANDDIJK

In 2016, the second coastal safety assay in The Netherlands reported that more than 70% of a 24-kilometre long Wadden Sea dyke protecting the island of Texel failed to meet safety standards. A refurbishment of 14 kilometres of the dyke resulted in an increased width and height which was covered with a layer of new grass and asphalt. Along the Prins Hendrik Polder (Section 9), in front of the remaining 3.2 km-long section, the Prins Hendrik Zanddijk (PHZD) was realised. A soft coastal protection design, the dune and beach sandbody was reclaimed seaward of the dyke, upgrading some 200 hectares of the Wadden Sea area.

Nature-based solutions (NBS) such as sandbody solutions are defined as ‘solutions that are inspired and supported by nature, which are cost-effective, simultaneously providing environmental, social and economic benefits and help build resilience’ (European Commission 2019). The quantification of the cost-effective part of this definition remains a difficult task. The main argument for choosing the soft alternative was the assumed benefit over the traditional design for society. Although the approval of these projects shows that these arguments can be decisive, the question remains whether it is worth to pay more for these NBS and take the associated risks, and if so by how much. The tool to quantify these benefits for society is called Ecosystem Services (ES).

A team of authors from Jan De Nul and University of Antwerp assesses the nature-inspired coastal protection project Prins Hendrik Zanddijk with ES. This study examines which and, if possible, how many more ES are provided by the nature-inspired coastal protection project in comparison with a traditional concrete and asphalt construction. **Read more on page 31.**

CONTENTS

HOW CAN BANGLADESH CREATE SUSTAINABLE WATERWAYS?

Frank Verhoeven
President, IADC

The overarching question which was explored at the recent IADC Dredging for Sustainable Infrastructure Conference in October in New Delhi, India was 'How can dredging rise to the next level of sustainability?' Approximately 60 professionals from Southeast Asia and Europe convened to discuss the strategic topics derived from the IADC-CEDA book *Dredging for Sustainable Infrastructure*.

At the meeting, the challenges facing Bangladesh's waterway infrastructure came to the fore, as one of the invited keynote speakers was Mr Kabir Bin Anwar, the Bangladeshi Secretary of the Ministry of Water Resources and Chairperson of the Board of Trustees of the Center for Environmental and Geographic Information Services (CEGIS). CEGIS is a scientifically independent organisation which performs integrated environmental analysis to issues in sectors, such as water, land, agriculture, meteorology and forestry.

The sustainable management of water is key to achieving a stable future.

Mr Bin Anwar's home country has three rivers – the Padma (Ganges), Meghna and Jamuna rivers. All three flow into the Bay of Bengal, forming the nation's many waterways that create fertile plains and enable frequent travel by boat. There are hundreds of channels, 700 rivers, small and big, 5178 small canal, hundreds of thousands of wetlands and on the southern coast an enormous mangrove forest.

During his keynote, the Minister clearly stated: 'Bangladesh has two problems, scarcity of water in the dry season and huge amounts of water in the monsoon time'. Furthermore, many waterways and wetlands have been lost and the country is trying to restore what has been lost. He emphasised that Bangladesh must prioritise its problems and that includes water management.

Dredged material is very important for the reclamation of land and the future of Bangladesh. As a small country with a huge population, Bangladesh is planning to reclaim 10,000 square kilometres in the coming years. The sustainable technologies developed in the West are providing essential information and forums such as the IADC conference are a venue for exchanging this information.

This issue features articles on sustainability: the Ecosystems Services assessment of Jan De Nul's Nature-Based Solution for the Dutch island of Texel, and the wetland restoration of a former oil refinery in the Great Lakes region. It also presents two important award winners: the IADC's Safety Award 2019 winning innovation by Boskalis, the Floating Line Connecting System, and the Young Author Award-winning paper presented by Liesbeth De Keukelaere at CEDA Dredging Days 2019.

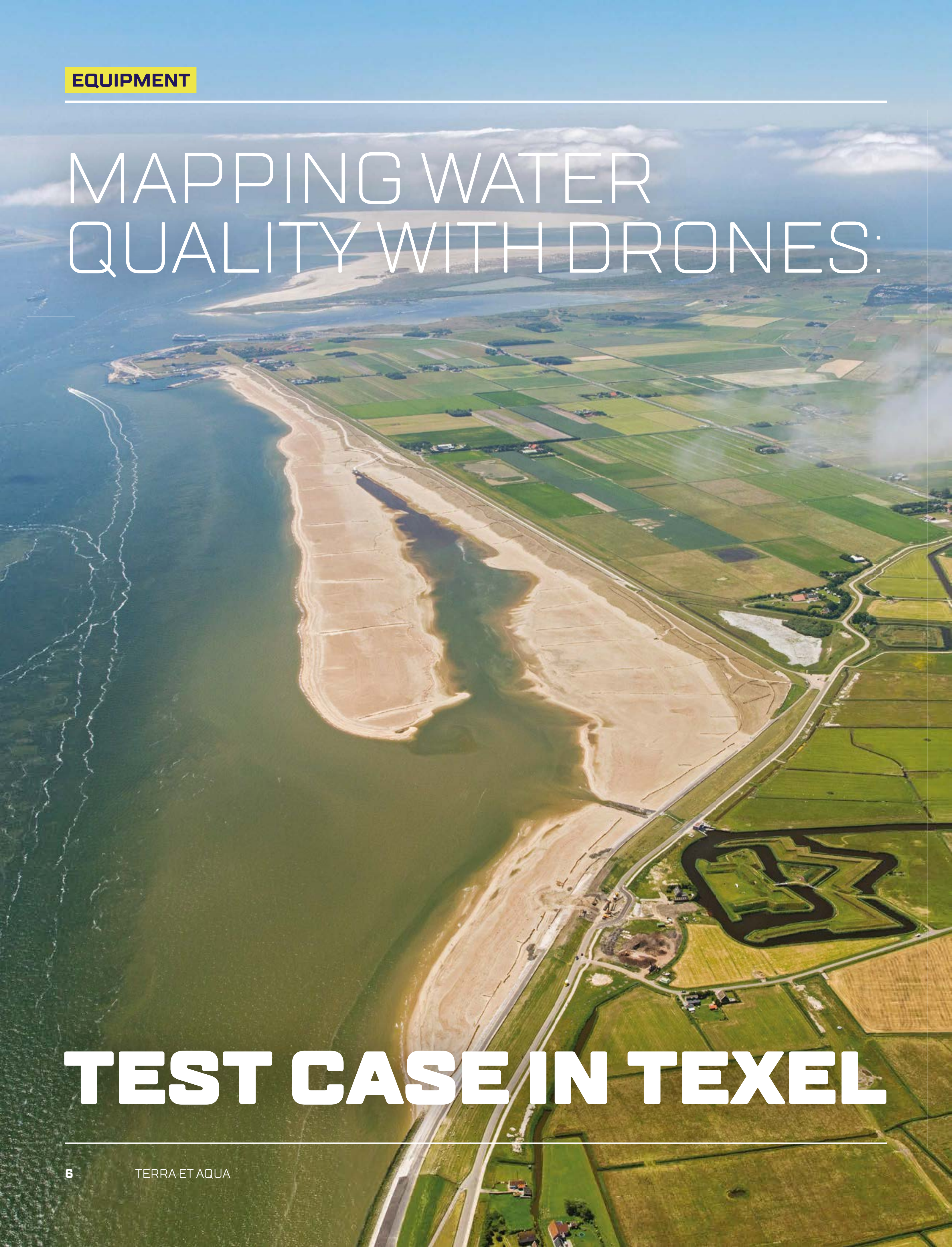
Through its proactive initiatives and activities, the dredging industry is leading by example by developing marine infrastructure which pushes sustainability to the next level. By hosting conferences and giving presentations, IADC and its members support the industry's efforts by spreading knowledge.

As Mr Bin Anwar said, 'We have to prioritise our problems, which is not possible without the sustainable management of water.'

EQUIPMENT

MAPPING WATER QUALITY WITH DRONES:

TEST CASE IN TEXEL



To demonstrate drone technology for water quality monitoring, a pilot test case was organised at the Prins Hendrik Zanddijk project in Texel, The Netherlands. Jan De Nul was working on creating a new dune area seaward of the existing dyke. The dune takes over the coastal protection function of the existing dyke and combines it with nature development, public services and recreational appeal.

Waves and white caps, typical for waters with a high dynamic nature, or bottom effects in shallow and clear waters, can alter the signal detected by the sensor.

Challenges in data collection

Recent advances in Remotely Piloted Aircraft Systems (RPAS), or airborne drones, have created an additional monitoring platform that provides an opportunity to capture spatial, spectral and temporal information that could benefit a wide range of applications. This with a relative small investment, especially compared to the cost of manned airborne systems or satellite missions. Drone systems are characterised by a high versatility, adaptability and flexibility and can be rapidly and repeatedly deployed for high spatial and temporal resolution data. They facilitate the collection of information in hard to reach or physically inaccessible areas, and under clouded circumstances.

Drone mapping over water

Although drone mapping over land is becoming more and more common practice (e.g. Ishida et al, 2018; Han et al, 2017), their use for water applications is lagging behind. The additional challenges faced when looking at water surfaces are certainly not an asset in this regard. First of all, water is a dynamic medium subjected to tides, waves, floating and settling particles and many more. The typically used geo-referencing technique, i.e. structure for motion (Westoby *et al.*, 2012), which looks at recognisable features within images to stitch these together into a mosaic, is thus not suitable for water. To know which part of the water surface your drone image captures, you fully rely on the Global Positioning System (GPS) with Inertial Measurement Unit (IMU) available on the drone platform. The second challenge is related to the optical properties of water bodies. Water surfaces act as a mirror. When sun light is reflected at the water surface and captured by the sensor, also called sun glint, this results in a gleaming colouring from which it is hard to obtain information on bio-physical properties of the water column itself (Kay et al., 2009). By adapting the flight plan accordingly, tilting the camera slightly and looking away from the sun, this can be avoided as much as possible. But also light scattered in the atmosphere (sky) itself and reflected at the water surface is detected by the sensor and adds a signal that is not related to the water column either. This phenomenon is called sky glint. The processing chain presented in this work corrects for these effects by simulating the cloud conditions and modelling the resulted reflectance signal of the water. This is done using an adapted version of the iCOR tool (De Keukelaere et al., 2017) for airborne drones. Waves and white caps, typical for waters with a high dynamic nature, or bottom effects in shallow and clear waters, can alter the signal detected by the sensor. Through filtering techniques these unwanted effects can be cancelled out. Since water itself is a strongly absorbing feature with low reflectance, the optical sensor has to be able to capture a low signal and noise can become more prominent (low signal to noise ratio).

The technology was tested in Texel, The Netherlands, where dune construction works were taking place. To estimate the impact of the construction activities on the water quality, monitoring efforts were established. Adding drone imagery to this database provides additional information on the spatial gradient of water quality at the surface. By tackling the aforementioned challenges one by one, raw drone data were converted into turbidity maps. At the end, a validation was performed with in-situ data collected simultaneously with the drone flights.

Field campaign

Test site: Texel, The Netherlands

The test was performed in Texel, The Netherlands, where dredging company Jan De Nul Group was working on the Prins Hendrik Zanddijk project. The existing dyke did not meet the requirements for coastal protection any more. In this project a new 3.2-kilometre long dune was being constructed, providing coastal protection combined with nature development, public services and recreational appeal. Soft sand used for construction was gathered at two locations offshore: Den Helder and Terschelling. Fine sediments are discharged with the overflow at the borrow area and coarser sand particles were transported to the reclamation site with the Trailer Suction Hopper Dredger Bartolomeu Dias (see Figure 1). At the dyke's construction site, the heavy sand is pumped ashore through a pipeline while earthmover machinery put all sand in place. Marram grass and sea buckthorn planted on top will reduce sand drift. The Wadden Sea area belongs to the marine world heritage of UNESCO.

The Prins Hendrik Zanddijk project was selected as test case for its convenience (not too far and easy access) but the methodology can be easily adapted to high sensitive areas like the vicinity of coral reefs or aquaculture sites. While current monitoring efforts can be quite intensive if one has to navigate from one buoy to another to collect data, drones can facilitate this process by providing a detailed spatial overview of the sediment plume at the surface.

A set of truecolour Sentinel-2 satellite images shows the progress of the construction works from August to November 2018 (see Figure 2). This satellite sensor contains spectral bands with a spatial

TABLE 1

Nomenclature

AIS	Automatic Identification System
DN	Digital Number
EEdd	Downwelling irradiance
FNU	Formazin Nephelometric Units
FSF	Field Spectroscopy Facility
GPS	Global Positioning System
IMU	Inertial Measurement Unit
LUT	Look-Up-Tables
L_{atm}	Atmospheric radiance
$L_{at-sens}$	At-sensor radiance
$L_{r,sky}$	Sky glint
$L_{r,sun}$	Sun glint
L_{spec}	Radiance from specular reflection at the water surface
L_w	Water-leaving radiance
MODTRAN5	Moderate-Resolution Atmospheric Radiance and Transmittance Model – version 5
NERC	Natural Environment Research Council
NIR	Near-Infrared
NTU	Nephelometric Turbidity Units
RPAS	Remotely Piloted Aircraft Systems
T	Turbidity
TSS	Total Suspended Solids
UTC	Coordinated Universal Time
ρ_w	Water-leaving reflectance
λ	Wavelength

A

B

FIGURE 1

Coarser sand particles were transported to the reclamation site with the Trailer Suction Hopper Dredger Bartolomeu Dias (A) and earthmover machinery put all sand in place (B).

FIGURE 2

Progress of dune construction in Texel (NL) as observed by Sentinel-2. Dates of image acquisition (in 2018: 04/08 (A), 13/09 (B), 13/10 (C), 28/10 (D), 17/11 (E).

resolution of 10 metres and has revisit time of ten days. Since two such satellites are in orbit (Sentinel-2A and Sentinel-2B), each area is covered every five days.

Drone data acquisition

On 25 October 2018, halfway of the construction works, drone data was collected simultaneously with in-situ measurements. Clouds were continuously present, ranging from a quite homogenous cloud cover to patchier clouds at the end of the day (see Figure 3). Varying illumination conditions is an additional challenge when working with optical sensors.

FIGURE 3

Cloud coverage at various moments throughout the day: 7:51 (A), 10:10 (B), 13:27 (C). Hours are expressed in Coordinated Universal Time (UTC).

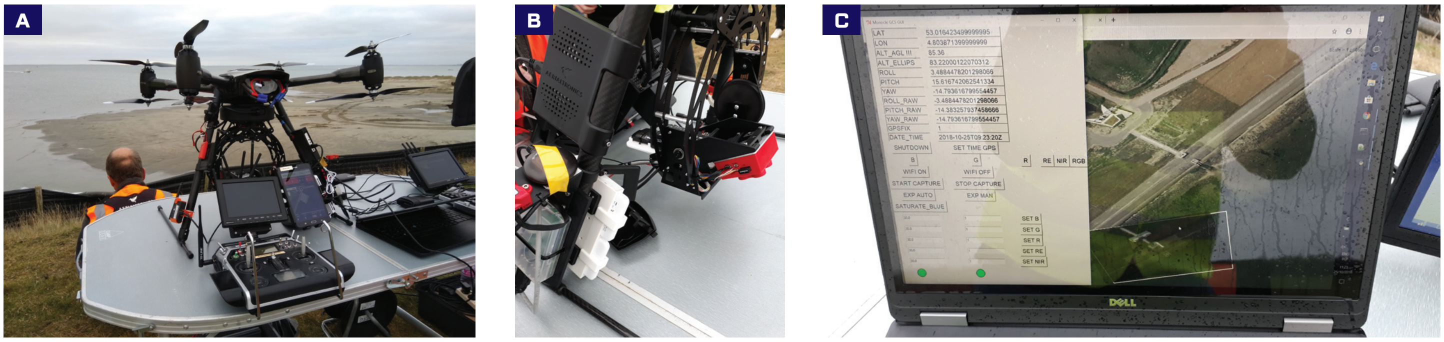


FIGURE 4

Airborne drone platform with controller (A), the payload with multispectral camera, GPS/IMU and irradiance sensor (B), and the base station showing real-time information of the drone flight (C).

An octocopter platform (Altura Zenith ATX-8) with a multispectral camera (MicaSense RedEdge-M) onboard performed the different test flights. The advantages of a multispectral camera are the availability of small spectral bands and the additional bands in the Near-Infrared (NIR) and Red-Edge region. The small bands make it easier to detect specific features, while the addition of the NIR and Red-Edge makes the camera suitable for water quality monitoring in low as well as high turbid regions. Compared to a default RGB camera, this multispectral sensor adds the possibility to derive additional parameters such as the chlorophyll-a concentration. The camera has been calibrated in the Natural Environment Research Council (NERC) Field Spectroscopy Facility (FSF) lab in Scotland to understand its sensitivity over the optical range. During flight operations the camera is slightly tilted and looks away from the sun. This is to avoid the reflection of direct sun light into the field of view of the sensor, a phenomenon called sun glint. Besides the camera, an additional GPS with IMU is attached to allow a better geometric correction. The GPS/IMU collects information on the latitude, longitude and flying height of drone, as well as the roll, pitch and yaw of the camera. Finally, an irradiance sensor is included to obtain information on changing light conditions.

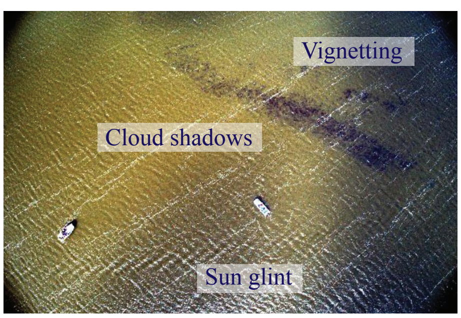


FIGURE 5

Example of an uncorrected truecolour image captured with the MicaSense RedEdge camera. The image shows vignetting effects towards the edges, sun glint effect at the bottom and cloud shadows in the middle of the picture.

Figure 4 shows the system set-up, including the used drone platform with pilot controller and the payload mounted underneath. The right image shows the base stations, which contains real-time information of the drone location, a projected truecolour image, the camera settings and position of neighbouring boats through Automatic Identification System (AIS). With this information, flight missions can be easily adapted and camera settings changed during flights. This allows a large flexibility in flight operations, leaving space to respond rapidly on events or interesting features.

Reference in-situ data

Simultaneously with drone data acquisition, in-situ data were collected for validation of the drone derived data. Turbidity data was obtained every five seconds using a multiparameter sensor, units expressed in Nephelometric Turbidity Units (NTU), according to the EPA 180.1 method (EPA, 1993). Samples from the water surface and dredged material were taken and analysed into resp. Total Suspended Solid (TSS) concentrations and particles size distribution. The particle size distribution of the transported sand yielded d50 values (i.e. the median diameter of the sample's mass) between 298 μm and 414 μm.

Data processing

The collected airborne drone imagery contains raw information expressed in Digital Numbers (DN) and is subjected to distortions from the camera as well as the atmosphere in between the target and the sensor. Figure 5 shows an example from a Scottish lake of an enhanced uncorrected truecolour image, which suffers from vignetting effects (i.e. darkening towards the edges of the image), sun glint effects at the bottom of the image and cloud shadow in the middle of the image. When not properly corrected for, inadequate results will be obtained.

Figure 6 shows the schematic overview of the drone image processing chain to convert raw airborne drone data into meaningful bio-physical data. The chain consists of three main steps, radiometric correction, geo-referencing and turbidity/algorithm (Raymaekers et al., 2017). The different steps are discussed in more detail in the next paragraphs.

Radiometric correction

The radiometric step converts the raw drone imagery from digital numbers to water

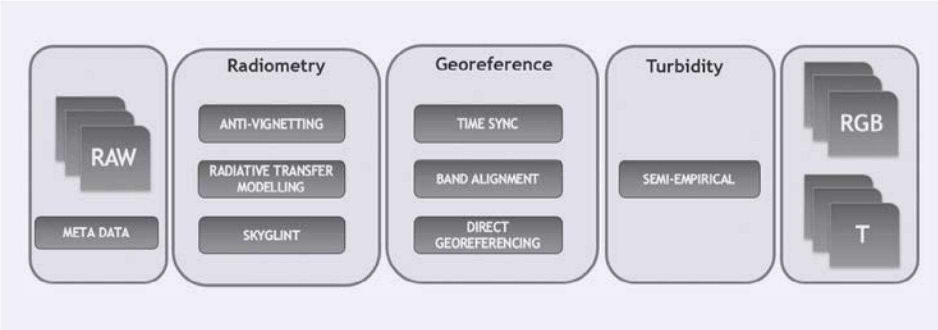


FIGURE 6

Schematic overview of the drone image processing chain to convert raw data into meaningful biophysical units and truecolour products.

leaving reflectance. The latter quantity is of interest because the light travelled through the water column and thus bears information regarding (optical) characteristics like turbidity. The first step performs an anti-vignetting of the image. Vignetting is the darkening of the image towards the edges and can be corrected for by normalising with a calibrated reference image. Secondly, the radiance signal received by the sensor can be converted into physically meaningful water-leaving reflectance through radiative transfer modelling. The at-sensor radiance (Lat-sens) is the sum of the atmospheric radiance (Latm), the specular reflection at the water surface (Lspec) and the water-leaving radiance (Lw):

$$L_{at-sens} = L_{atm} + L_{spec} + L_w$$

(1)

The specular reflection consists of two components: direct reflection of sun light, also called sun glint (Lr,sun), and scattering of the atmosphere to the water surface and reflected into the detector, i.e. sky glint (Lr,sky):

$$L_{spec} = L_{r,sun} + L_{r,sky}$$

(2)

When processing drone images, two assumptions can be made:

1. drones fly at limited height (especially when compared to satellites), so Latm can be neglected, and
2. the camera of the drone is slightly tilted to avoid sun glint and thus the LLrr,ssssss component can be ignored. This is however a simplification of reality, since the pixels of a frame camera have different viewing angles and (waves at the water surface can lead to occurrence of sun glint within the image.

The simplified radiative transfer formula is:

$$L_{at-sens} = L_{r,sky} + L_w$$

(3)

The sky glint contribution is modelled with the iCOR image processing tool (De Keukelaere et al., 2018) adapted for drone imagery. iCOR is an image-based atmospheric correction tool which relies on Moderate-Resolution Atmospheric Radiance and Transmittance Model – version 5 (MODTRAN5) (Berk et al., 2006) Look-Up-Tables (LUTs) to solve the radiative transfer equation based on a set of input parameters. The input parameters are height, solar and viewing angles and simulated cloud type and coverage (open sky, cumulus, stratus, etc.).

The quality of interest is water leaving reflectance (ρw), which is an optical property of water and can be related to bio-physical parameters like turbidity. ρw is expressed as:

$$\rho_w = \frac{L_w}{E_d}\pi$$

(4)

with Ed as the downwelling irradiance. The value for downwelling irradiance can be obtained from either spectral reference targets present in the field or an irradiance sensor mounted on the drone. An irradiance sensor allows to capture changing light conditions continuously, but is very sensitive to its viewing angle and is not straightforward to process. One of the difficulties in this perspective is the separation of direct sun light on the sensor and diffuse light. This separation is not measured in situ but must be done in post-processing. Its strong dependence on cloud cover, sensor orientation and time of the day make it more a backup solution. Nevertheless, advances are expected in the years to come. Another solution to measure irradiance is the use of spectral reference panels. They have a known and calibrated reflectance value (albedo) over the complete panel and can be fixed on a boat or at the shore-side. These panels have been used in the Texel case, and are depicted in Figure 7. The drone has to fly over these panels, and only the light conditions at the moment of the overpass are captured. When the measured radiance from the camera can be coupled with the known reflectance value, other measured radiance values

The radiometric step converts the raw drone imagery from digital numbers to water leaving reflectance.

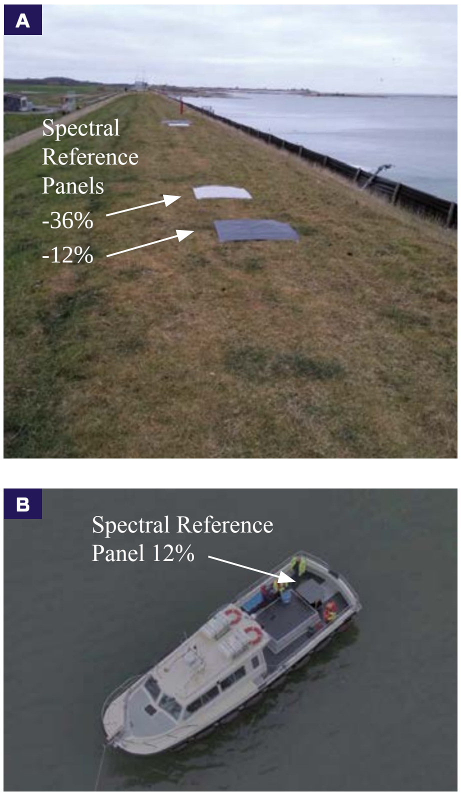


FIGURE 7

Two types of spectral reference panels placed at the shore-side (A) and fixed on a boat (B), with known spectral behavior. The light target has an albedo of 36%, while the albedo of the darker target is 12%.

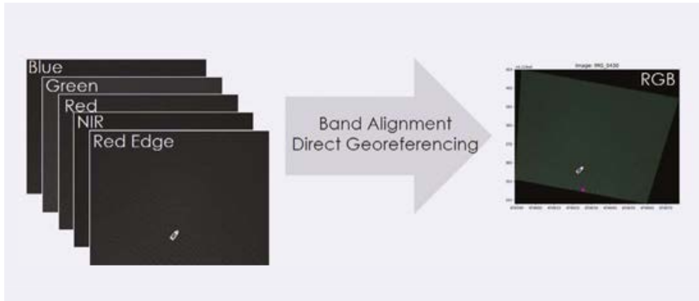


FIGURE 9

Schematic overview of the geometric correction.

can be translated into reflectance through interpolation. This method has satisfying results for uniform cloud conditions (like most of the Texel case) but is less appropriate under strong variations in cloud cover (patchy). Figure 8 shows the evolution of the measured radiance for the five spectral bands at the reflectance panels through one flight (approximately 15 minutes). From this figure, it becomes clear that using only the reflectance values at the start and end of the flight is not sufficient to cover the variations in light conditions.

Geometric correction

To know which part of the water body the drone image is covering, the images are georeferenced. A time synchronised triggering between the camera and auxiliary sensors is of utmost importance, since in a fraction of a second, the drone can be shifted or rotated and looks at a different part of the water surface. The separate spectral bands of the camera are aligned before the images are projected based on position, altitude and orientation of the drone and camera recorded by the GPS/IMU. In contrast to land application, no fixed recognisable features are present in water bodies, which excludes the use of structure-for motion techniques (Westoby *et al.*, 2012). The precision of the drone's auxiliary sensors determines the geometric accuracy of the final product which is projected through the so-called direct geo-referencing technique. A GPS system provides information on latitude, longitude and height of the camera, while an IMU sensor captures the roll, pitch and yaw of the camera. Applying translation, rotation, projection on a flat surface (water) and image warping results in an image georeferenced in space. Figure 9 summarises the geometric correction step.

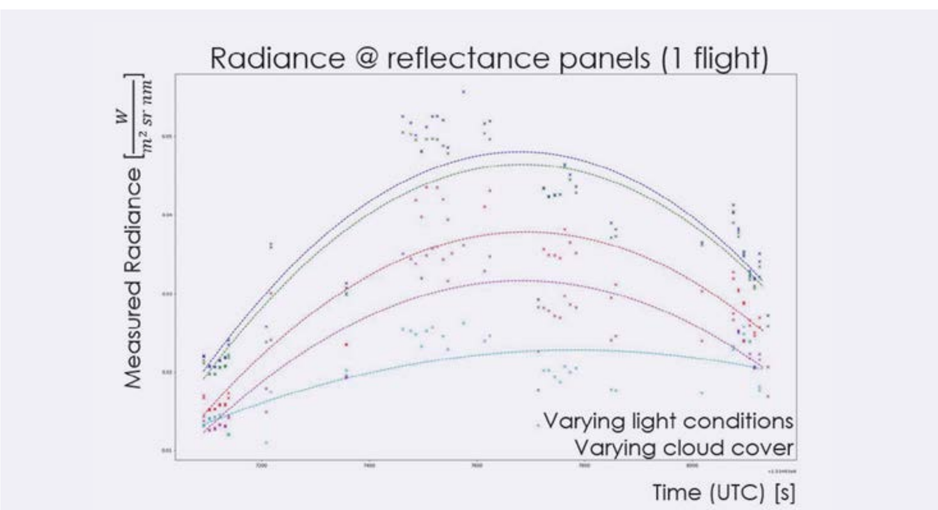


FIGURE 8

Radiance measured by the spectral reference panels (dots) for the 5 spectral bands of the MicaSense RedEdge camera. The lines show the interpolated results through the flight.

Turbidity retrieval

Turbidity derived from optical drone data are expressed in Formazin Nephelometric Units (FNU) units, according to the definition of the International Standards Organisation ISO 7027 (ISO, 1999), using the 90° side-scattering of light at 860 nm with respect to Formazin, a chemical standard. Although these units are slightly different compared to the continuous turbidity meter with units in NTU (see Section 2.3), both can be intercompared.

Turbidity (T) was derived using the formula of Dogliotti et al. (2015), without calibration or fine-tuning of the algorithm based on in-situ measurements:

$$T = \frac{A^{\lambda}\rho_w(\lambda)}{(1-\rho_w(\lambda)/C^{\lambda})} \quad [FNU]$$

(5)

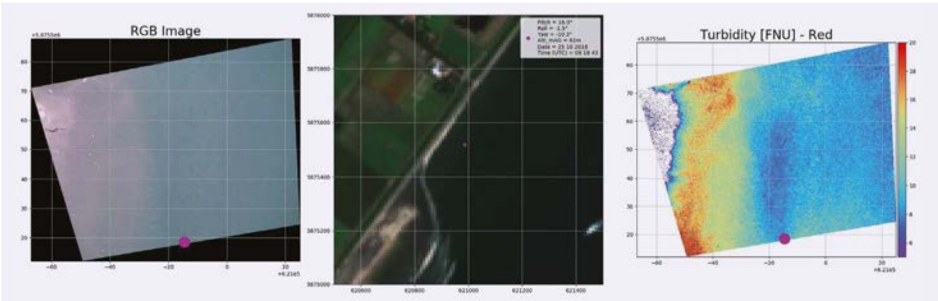


FIGURE 10

Drone image acquired at 09:18:43 UTC (53.016° N, 4.804° E). On the left the truecolour image and on the right the derived turbidity product is shown. The photo in the middle shows the position of the drone with a purple spot. This purple spot is also added in the truecolour and the turbidity maps.

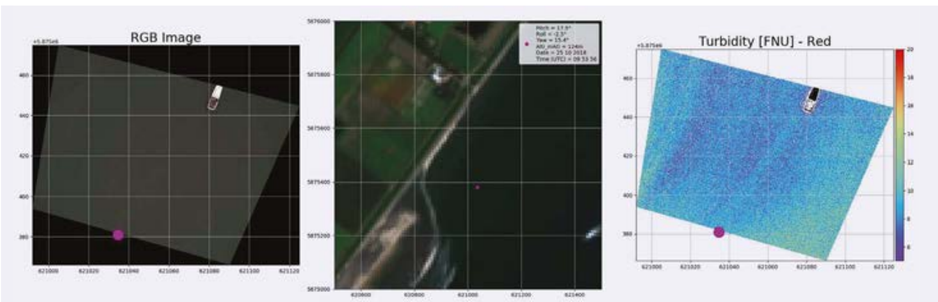


FIGURE 11

Drone image acquired at 09:45:32 UTC (53.014° N, 4.804° E). On the left the truecolour image and on the right the derived turbidity product is shown. The photo in the middle shows the position of the drone with a purple spot.

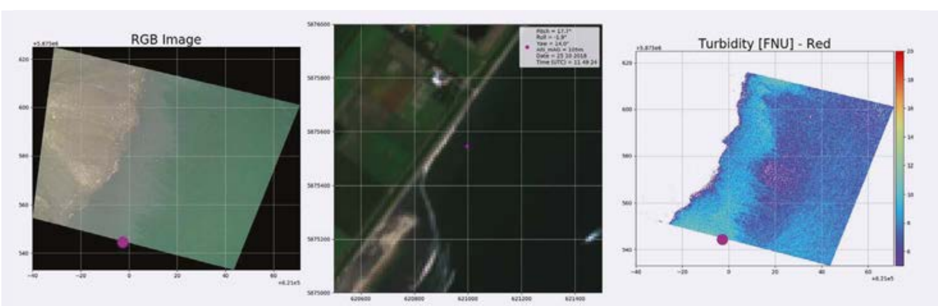


FIGURE 12

Drone image acquired at 11:49:24 UTC (53.016° N, 4.804° E). On the left the truecolour image and on the right the derived turbidity product is shown. The photo in the middle shows the position of the drone with a purple spot.

With A and C two wavelength-dependent (λ) calibration coefficients. A_λ and C_λ have been calculated for the MicaSense RedEdge camera through spectral resampling, which yielded a value of 366.14 and 0.19563 respectively. When an extensive match-up database is available for a specific region, these calibration coefficients can be further fine-tuned. As the amount of match-ups in Texel was limited in space and time, the collected in-situ data was only used for validation.

Results

Figures 10-12 show a few individual drone images captured during the test with corresponding derived turbidity product. The picture in the middle shows the location of the drone with a purple dot. This dot is also added in the truecolour and the turbidity map. The images were acquired on respectively 09:18:43, 09:45:32 and 11:49:24 UTC time.

Figure 13 shows the mosaic created from different individual images captured during one flight. A first limited validation is shown in Figure 14. These first results show that realistic values can be obtained from drone imagery.

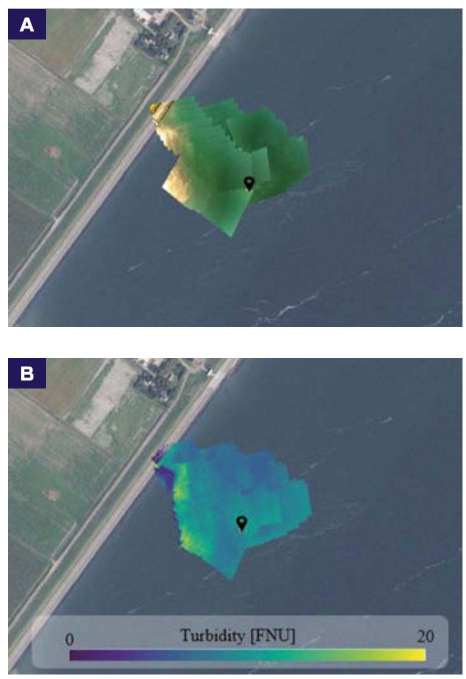


FIGURE 13

Mosaic of Truecolour images (A) and turbidity (B) captured during one flight. The location of the boat is highlighted with a black marker.

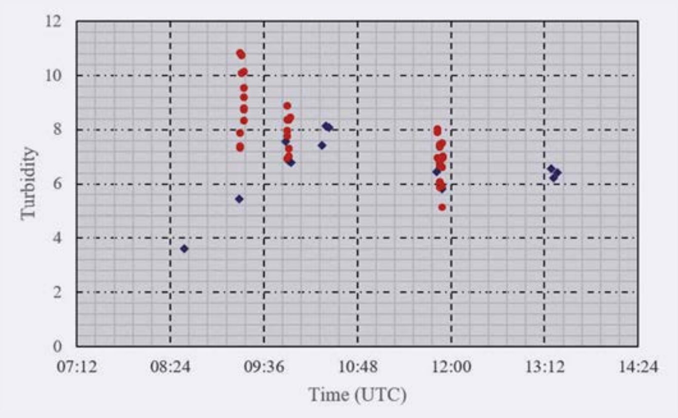


FIGURE 14
Validation of the turbidity measurements, expressed in FNU (red dots) with the reference in-situ data, in NTU (blue dots). Each red dot originates from a single image. Since images where captured every few seconds, multiple drone results are obtained during one in-situ data collection.

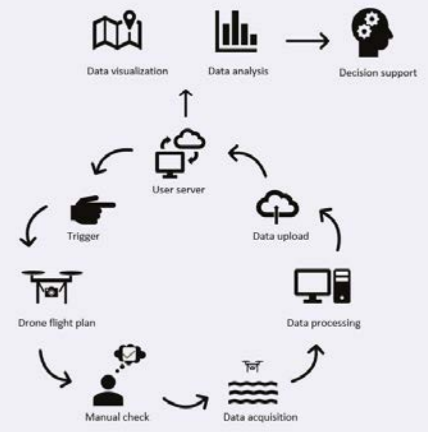


FIGURE 15
Conceptual representation of the (semi-) autonomous drone data collection.

During the drone flight, images were captured every few seconds. From each of these images the derived turbidity concentrations were extracted, which explains the different red dots (i.e. drone observations) around one in-situ measurement in Figure 14. The observed scattering can be caused by wave effects, changes in light conditions or viewing angles. By including noise filtering techniques this scattering can be reduced.

The turbidity values observed in the test area are very low, which means that small difference in absolute values can lead to large errors. Despite the small validation dataset available, turbidity values obtained from drone imagery are within the range of in-situ measurements. The offset around 09:30 can be related to inaccurate modelling of the cloud conditions. Through novel validation campaigns in waters covering a wider range of turbidity values, a larger validation database can be established, leading to a better understanding of the limitations and characterising the accuracy and uncertainty of this technology.

Outlook

Through field campaigns, the drone image processing chain can be further improved and validated. We will also investigate in solutions for improving signal-to-noise ratios and deriving time series information out of these datasets. To facilitate the collection of airborne drone data, a set of operational protocols will be generated that explain users how to collect such data over water bodies, taking into account the different challenges that have to be tackled.

The next step is to launch an end-to-end image processing solution, MAPEO, for water applications (https://remotesensing.vito.be/case/mapeo). Currently, MAPEO is available for drone-based phenotyping. Stakeholders can order drone flights, perform drone flights or order a pilot. They can upload their drone collected data on the online platform which are quality checked and performs image processing and analytics through cloud computing.

Going even one step further, we are evaluating a semi-autonomous drone data collection architecture where a drone can be triggered by other sensors (e.g. continuous turbidity buoy that detects an increased signal) and performs a predefined flight mission. The collected data can be automatically uploaded, processed and visualised (or downloaded) by the user in their preferred spatial data infrastructure. This will allow easy interpretation and data analysis. The concept of this process is schematically depicted in Figure 15.

Although drone data only capture information of the top-layer of the water column, it provides insight on the propagation of the sediment plume at the water surface. This information can be inserted in sediment modelling tools, together with in-situ turbidity measurements at different depths. At the end, a complete picture of the sediment plume propagation in three dimensions might become feasible.

Conclusion

In contrast to earlier presented work (Raymaekers et al., 2017), this study shows the performance of airborne drone data under sub-optimal illumination conditions for optical sensors: i.e. varying cloud conditions. The test site was the dune construction site in Texel, where dredging activities were performed by Jan De Nul Group. Through an automated image processing tool, raw airborne drone data were converted into physically meaningful water leaving reflectance values and further into projected turbidity maps. This without any calibration or fine-tuning of the implemented algorithms. Simultaneous with the drone flight, reference in-situ data were collected for validation of the dataset. A first limited validation, based on data captured during one day at one location, yielded realistic values. The drone flights in this project were executed with a custom made drone hardware, but efforts are being made to work with drone systems that are easily accessible for other users.

Summary

At the end of October 2018, a pilot test case at the Prins Hendrik Zanddijk project in Texel, The Netherlands, was organised to demonstrate drone technology for water quality monitoring. Jan De Nul was working on creating a new dune area seaward of the existing dike. This dune takes over the coastal protection function of the existing dyke and combines it with nature development, public services and recreational appeal. For the demo an octocopter drone platform, Altura Zenith ATX8, was used with a multispectral camera, MicaSense RedEdge M, underneath.

During drone flights, a base station shows real-time information on the location of the drone, a projected truecolour image captured by the camera and the position of neighbouring boats through Automatic Identification System (AIS). Thanks to this information it is easy to adapt flight missions according to the situation. The drone data were processed with dedicated software into turbidity maps. This independently from in-situ observations. Water samples, collected simultaneously with drone flights were used for the validation of the derived products.

First presented as a paper at the CEDA Dredging Days Conference 2019 in Rotterdam, this article has been published in a slightly adapted version with permission of the copyright holder, CEDA. At the conclusion of the conference, IADC's Secretary General René Kolman bestowed the Young Author Award to Liesbeth De Keukelaere to recognise her outstanding paper and presentation of the paper 'Mapping water quality with drones – test case in Texel'.

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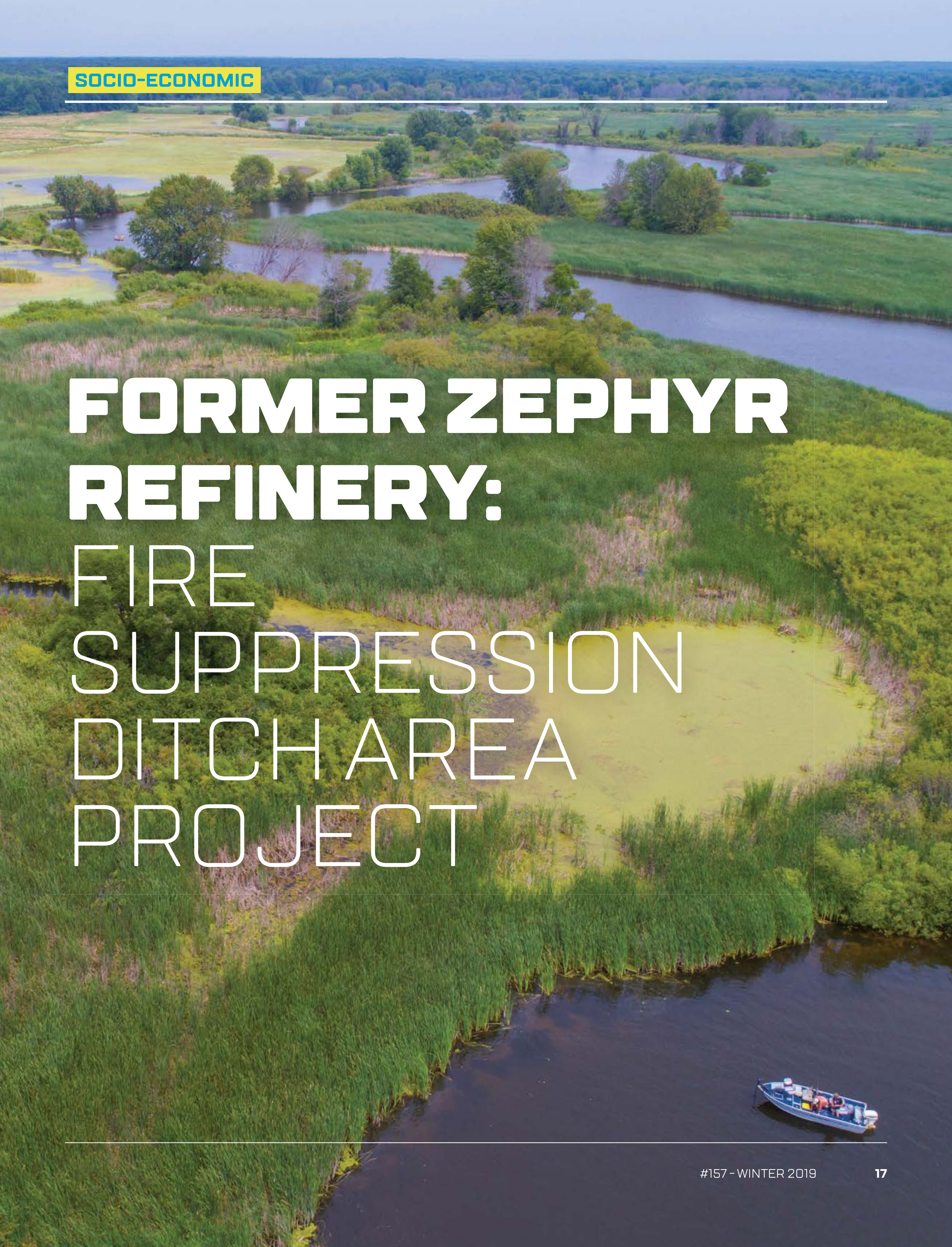
SOCIO-ECONOMIC

FORMER ZEPHYR REFINERY: FIRE SUPPRESSION DITCH AREA PROJECT



The innovative and invaluable partnerships that were created and utilised to complete this project proved to be a critical element in overcoming these challenges.

The Zephyr project site, located in a mixed industrial, commercial, and residential area, included sediment areas with hazardous levels of lead, involved organic sediments with highly variable moisture content, and confronted historically high water levels during construction. This presented numerous logistical and technical challenges.

The project team maintained continuous contact throughout the construction in order to efficiently respond to these challenges while including all stakeholders in the discussions which resulted in a successful wetland restoration that will benefit the site owners and the community at large.

The Zephyr project provided economic benefits through implementation of cost-saving measures and efficiencies during design and construction while contributing to the overall socio-economic impact of restoration work within the Muskegon Lake AOC and the Great Lakes Region.

Environmental benefits

The Zephyr project provided numerous environmental benefits related to the remediation of legacy sediment contamination as well as the restoration of low-quality wetland habitat with a more diverse wetland system.

Unique environmental challenges and mitigation measures

Unique environmental challenges that required mitigation were overcome in an expedited manner with minimal disruption to project schedule due to the nature of the project partnership between the USEPA and MDEQ as well as extensive coordination (including three construction progress calls per week) between both agencies, the design engineer (EA) and the dredge contractor (SES).

Contaminated sediments had high organic matter content with varying moisture levels requiring a strict dewatering management plan with a minimum five days of gravity dewatering prior to addition of stabilisation additives, which reduced disposal weights and costs.

Historically high Great Lakes water levels, which increased by approximately 2.5 feet between design and construction, posed challenges including redesign of the earthen cofferdam to allow placement of materials in a high-water environment and redesign of emergent wetland areas to allow for native vegetation establishment during high water and future vegetation creep as water levels fluctuate.

Hazardous lead levels in sediment required in-situ mixing to meet Resource Conservation and Recovery Act (RCRA) land disposal restrictions. Completed through use of a specialised equipment (Lang Tool) to mix the stabilisation agent with the hazardous sediment.

A historic production oil well was discovered following observations of oil bubbling up from a recently dredged section of the wetland. This resulted in coordination with a specialised drilling company to access the well area for over-drilling (300 feet) and capping. These activities required additional redesign of emergent wetland areas to facilitate access to the area for both the over-drilling and capping as well as provide for future access needs.

Discovery of asbestos-containing materials during initial shallow excavation in upland staging areas required immediate coordination between contractors and project partners. This required an interim removal of asbestos and soil and redesign and movement of the dewatering pad.

Unique combination of ditch and wetland sediments with extreme variations in moisture content and access limitations presented challenges. Mitigation included the use of multiple dredging methods including removal in the wet (ditch) and dry (wetlands) with both traditional excavation equipment and environmental bucket. Additional mitigation measures included sheet pile and access road installation for dredging of the ditch in the wet

FIGURE 1

Contractors staging native plantings in emergent wetlands.

and full site and zoned dewatering plans for excavation of the wetland in a relatively dry condition.

Working with and engineering with nature

The Zephyr project incorporated guiding principles of working with and engineering with nature including:

- **Holistic:** The Zephyr project was completed using a holistic approach—from the feasibility and design stages focusing on ecological risks and developing remedial action cleanup goals to benefit benthic microorganisms and wildlife, to the consideration of potential human health impacts during construction, such as fugitive dust and air contaminants requiring extensive air monitoring and mitigation measures (e.g., foam suppression for dust).
- **Sustainable:** The Zephyr project adjusted to high water levels by redesigning the wetland areas and adjusting the planting areas to allow the restoration to be sustainable in the future. These adjustments were made during construction to allow for establishment of native species that otherwise would not survive in the elevated water level. Emergent islands were created so that when the historically high water levels recede in the future, the submergent/emergent vegetation has a chance to propagate and spread down into new submergent/emergent areas.
- **Science-Based:** The remedial cleanup goals and dredging footprint were determined through a thorough site characterisation and feasibility study process that included an ecological risk assessment to determine potential impacts to benthic organisms and wildlife.
- **Collaborative:** Collaboration among multiple federal, state, and local agencies and contractors was critical to the efficient completion of the Zephyr project to meet all Remedial Action Objectives (RAOs). The collaboration comprised more than 10 entities including: USEPA GLNPO, USACE, MDEQ, Illinois Sea Grant, MDEQ–Oils, Gas and Minerals Division, West Michigan Shoreline Regional Development Commission, Michigan Department of

FIGURE 2

Planting native vegetation to preserve biodiversity.

FIGURE 3

Emergent wetland designed to adapt to fluctuating water levels.

Natural Resources Office of the Great Lakes, EA, and SES.

- **Efficient and Cost-Effective:** Multiple design elements led to an efficient and cost effective project, including dewatering to reduce disposal weights, reuse of on-site materials for habitat structures, and in-situ treatment of hazardous sediment to render non-hazardous. Construction-initiated savings included use of asphalt in place of stone for the dewatering pad, re-use of the haul road for an adjacent project, and redesign of the fertiliser pipe inlet.
- **Adaptive:** The project incorporated adaptive management throughout construction to respond to issues such as asbestos in soil, high water levels, a leaking historic oil production well, and redesign of emergent and deep marsh areas adjacent to the berm along the property boundary based on structural concerns.

FIGURE 4

Reuse of woody debris on site to create habitat structures.

Environmental Benefits by the Numbers

- Treated a total of 91.9 million gallons of contaminated water (process and contact water).
- Removed all contaminated sediments over a 13.6-acre wetland area with concentrations above 2,000 mg/kg total petroleum hydrocarbons and 128 mg/kg lead to protect benthic organisms and wildlife populations.
- Dredged a total of 49,491 CY of contaminated sediment from the site including: 38,272 CY from wetland areas.
- 11,219 CY from the approximately 1,350-linear-foot ditch portion of the site. Dredging of the ditch required a phased approach for sheet pile installation/removal to stabilise the ditch banks, allow for dredging in the wet, and provide stabilisation for haul roads which were constructed adjacent to the ditch to allow access along the entirety of the quarter-mile-long ditch and into the wetland areas.
- Treated 1,370 CY of characteristically hazardous sediment (lead) in-situ, rendering it non-hazardous via mixing with specialised equipment (Lang Tool) prior to removal.
- Restored a 13.6-acre monotypic submergent wetland dominated by invasive species with 3 acres of emergent marsh, 5.1 acres of submergent marsh, 1.2 acres of deep marsh, and mitigation of 4.3 acres of temporarily impacted wetland.
- Restored 1.6 acres of open water habitat (ditch).
- Planted 223 trees and shrubs and 13,620 live herbaceous plugs and bare-root native plants.
- Seeded over 1.5 acres of wetlands with native seed mix.
- Installed 6 habitat structures (root wads, brush piles, etc.) per acre of restored wetland.

Innovation
Groundbreaking and non-traditional environmental protection methods

In order to address some of the unique environmental challenges faced, the Zephyr project team took steps beyond traditional environmental protection efforts, including utilising emerging technology (bench-scale testing of multiple stabilisation agents) to determine appropriate in-situ stabilisation and an innovative tool (Lang Tool mixing head for excavator) to render characteristically hazardous lead sediments non-hazardous.

With the abundance of wet wastes in western Michigan, acceptance criteria presented by multiple landfills included challenging percent solids/percent moisture requirements. In order to address these challenges, the dewatering pad was configured with a combination of primary gravity dewatering bins and secondary stabilisation bins. Critical dewatering management practices were developed, including initial placement in gravity dewatering bin for 24 hours, followed by wet sediment being overturned and placed in a second gravity dewatering bin and further

Zephyr Project's Goals and Accomplishments

Goals

- Dredge wetlands and ditch to remove contaminated sediment.
- Meet clean-up goals for lead and total petroleum hydrocarbons.
- Remove and control invasive species.
- Restore wetlands and create diverse habitat.

Accomplishments

- Successful completion of the project on schedule and budget while in compliance with all applicable permits.
- Thorough public outreach resulted in zero complaints to the project hotline during construction.
- Limited disposal quantities and costs through innovative dredged material dewatering pad configuration and management practices.
- Rendered all hazardous sediment non-hazardous following first pass of in-situ mixing and stabilisation.
- Removed nearly 50,000 CY of contaminated sediment.
- Treated over 90 million gallons of water during construction due to historically high water levels.
- Preserved a healthy and safe work environment without incident (60,975 safe person-hours).
- Restored monotypic wetland dominated by invasive plant species with four different wetland types dominated by native plant species.
- Successfully completed project with no impacts to adjacent railroads, on-site buried petroleum pipelines, on-site commercial operations (fertiliser mixing), and adjacent residential properties.

division into six small stabilisation bins where wet sediments were mixed with Portland cement and then stacked to allow for a three-day cure. This vertical stacking drove out more free liquids and allowed the sediments to dewater for a longer period and produce materials that were acceptable to landfills using less Portland cement—ultimately saving material and disposal costs.

Sustainable approaches

Sustainable approaches were implemented, including the reuse of all woody debris/trees removed during remediation on the site for habitat structures as well as leaving approximately 8% of the haul road material in place for an upcoming restoration project on the adjacent property, therefore reducing disposal quantities and reusing material in a beneficial manner.

The greatest innovation employed for the project, however, is associated with the unique partnership employed through the GLLA between multiple federal, state, and local agencies as well as the utilisation of a new contracting model for the design and construction. These partnerships required a new way of thinking about the project 'client', as multiple agencies were funding work and shared a vested interest in the outcome. The project team maintained a highly responsive approach to communication between all stakeholders and contractors throughout construction, which proved essential in reacting in an expedited and efficient manner when unforeseen issues arose. This partnership and approach were critical to maintain project progress and engagement of all stakeholders and allowed the contractors to work through challenges quickly and effectively by maintaining an atmosphere of open communication, transparency, and consistent communication.

Economic benefits

Implementation, efficiencies and cost-savings

Implementation-related economic benefits included:

- utilisation of a 4-inch asphalt cap on the dewatering pad in place of 18 inches of stone. While this created a larger capital cost on the front end, cost-savings were realised during restoration as approximately 5,700 CY of stone did not require transport and disposal upon project completion;
- leaving approximately 8% of the haul roads in place, which provided a haul road for an adjacent and ongoing restoration project to utilise during construction. Economic

FIGURE 5

The design of restoration areas incorporated sustainable reuse of materials and utilised existing habitat in conjunction with dredged areas to create a diverse wetland system.

benefits were realised through the reduction of disposal quantities for road stone as well as the re-use of material;
- electrical power drop left in place for future on-site use, realising a future $10,000 savings;
- redesign of the water intake for the property owner's fertiliser operation from approximately 1,200 linear feet of pipe to 20 feet with a debris screen and inlet at the end of the ditch; and
- reduced disposal costs through in-situ stabilisation of hazardous sediments.

Socio-economic impacts and contributions to economy

While direct socio-economic impacts of the Zephyr project have not yet been identified since its completion in late 2018, the restoration project as a whole contributes to the economic impacts within the Muskegon Lake AOC as realised from past habitat restoration projects as detailed in *A socioeconomic analysis of habitat restoration in the Muskegon Lake area of concern* (Isley, P., et. al., 2017). Results of this analysis indicated that:

- property values around the shoreline of Muskegon Lake increased by $11.9 million,
- there is an estimated 6:1 return on investment based on the value of improved recreation and property values, and
- an additional $3.2 million in recreation is generated per year due to restoration.

As the Zephyr project also contributes to the overall socio-economic impacts related to similar restoration work completed in the Great Lakes Region under the Great Lakes Restoration Initiative (GLRI), the results of the *Socioeconomic Impacts of the Great Lakes Restoration Initiative* (University of Michigan Research Seminar in Quantitative Economics, September 30, 2018) can be utilised to assess the impacts of the Zephyr project. Results of this study, completed for the time period of 2010-2016, include:

- for every dollar spent on restoration, $3.35 of additional economic output is produced through f2036.
- every $1 of GLRI spending increased local house prices by $1.08, suggesting that restoration projects provide amenities that were valuable to residents. With the proximity of local residences to the Zephyr site, it is highly likely these benefits will be realised.
- additional tourism activity generated by restoration activities in the Great Lakes will increase regional economic output by $1.62 through 2036 for every $1 in federal government spending.

FIGURE 6

The contaminated sediment removal and restoration will support increased recreation along the Muskegon River.

Transferability

The Zephyr project included many elements that will be transferable and adaptable to future contaminated sediment remediation and restoration projects.

With the ever-growing issues related to climate change, the Great Lakes are impacted by unusually high precipitation events and have recently experienced record high water levels over the past three to four years. In dealing with these elevated water levels during construction at Zephyr, redesigns were necessary for wetland area in order to allow for establishment of native vegetation and ability for that vegetation to adapt to future changing water levels and climate. Designing these wetland areas and plantings to allow for the native vegetation to establish and then adapt and spread into the future is an element of the Zephyr project that will be carried forward in future restoration.

Reuse of materials is another lesson learned that will be transferred to other projects in the future. Working with property owners and other restoration or remediation projects adjacent to or in the vicinity of a project to identify all means of sustainable reuse of materials should be a priority of every contaminated sediment project. From electrical hookups, haul roads, dead trees on properties, and utilising earthen cofferdam material or haul road material as clean fill for restoration are some examples of this sustainable reuse that should be examined.

Outreach and education

The Zephyr project partners initiated an extensive public outreach and education program during remedial design activities. The program was carried through prior to and during remedial construction and restoration activities to ensure that all community members and concerned citizens potentially affected by this project were informed of the activities and had appropriate communication avenues to state concerns and ask questions.

FIGURE 7

Public outreach meetings were critical to inform local stakeholders of the project's status and gather support.

FIGURE 8

Site prior to remediation and restoration.

FIGURE 9

Sediment coring to delineate impacts.

Stakeholder involvement

Sea Grant created the Zephyr Outreach Team in 2015 with representatives from USEPA, Sea Grant, MDEQ, Michigan Department of Human and Health Services, West Michigan Shoreline Regional Development Commission, Muskegon Lake Watershed Partnership, Muskegon County, EA, SES, and the residential neighbourhood. It met regularly from 2015-2018 (approximately six to eight times per year) to establish outreach goals and target audiences and develop and implement an outreach plan.

Sea Grant performed a needs assessment in 2015, interviewing 27 diverse stakeholders to understand how the community had related to the Zephyr project site, perceived the sediment cleanup plan, and engaged in past outreach efforts. These findings were synthesised in a report and guided the Zephyr Outreach Team outreach plan.

The Zephyr Outreach Team created a comprehensive mailing list of 200 individuals, including those in the neighbourhood located next to the project as well as diverse stakeholders identified in the needs assessment. Three informational mailings were sent out in 2017 and 2018 to provide updates and invite the community to the public meetings.

The Zephyr Outreach Team went door-to-door in 2018, canvassing more than 150 homes in the project site neighbourhood with an updated project fact sheet, including a project hotline for complaints during construction and information about potential neighbourhood impacts.

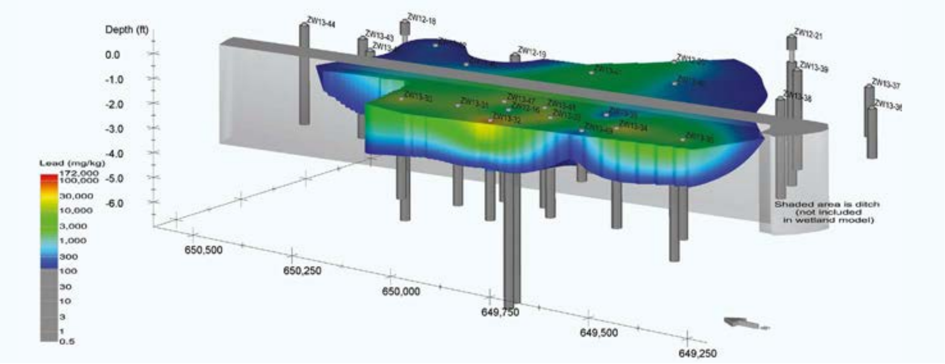


FIGURE 10

Porewater sampling to support design.

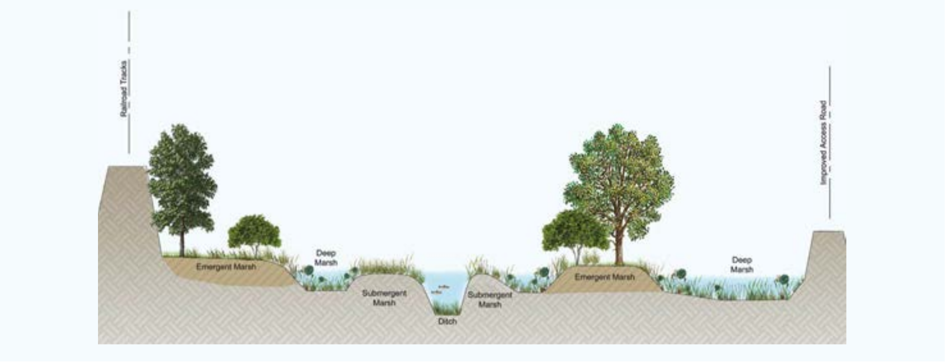


FIGURE 11

The design of restoration areas incorporated sustainable reuse of materials and utilised existing habitat in conjunction with dredged areas to create a diverse wetland system.

FIGURE 12
Porewater sampling to support design.

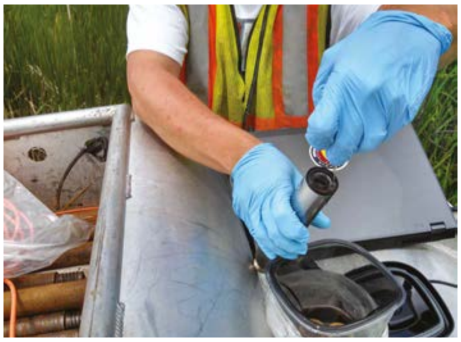


FIGURE 13
Cone pentrometer testing to determine geotechnical properties of sediment.

FIGURE 14
Sediment coring in Muskegon River.

Outreach and education

In partnership with the West Michigan Great Lakes Stewardship Initiative summer institute, in 2016 the Zephyr Outreach Team led more than 20 teachers from the Muskegon Intermediate School District on a tour of the project site, providing information on the site history, clean-up plan, and science classroom applications from the Helping Hands curriculum. The Helping Hands curriculum is aligned with Michigan state standards and Next Generation Science Standards.

In 2017, the Zephyr Outreach Team provided 250 Muskegon-area students a virtual bird's-eye view of the Zephyr project. The team visited 18 different classrooms to deliver

FIGURE 15
Protection of buried petroleum pipeline.

FIGURE 16
Air monitoring to determine if mitigation measures required.

FIGURE 17
Three-part cofferdam to control water level.

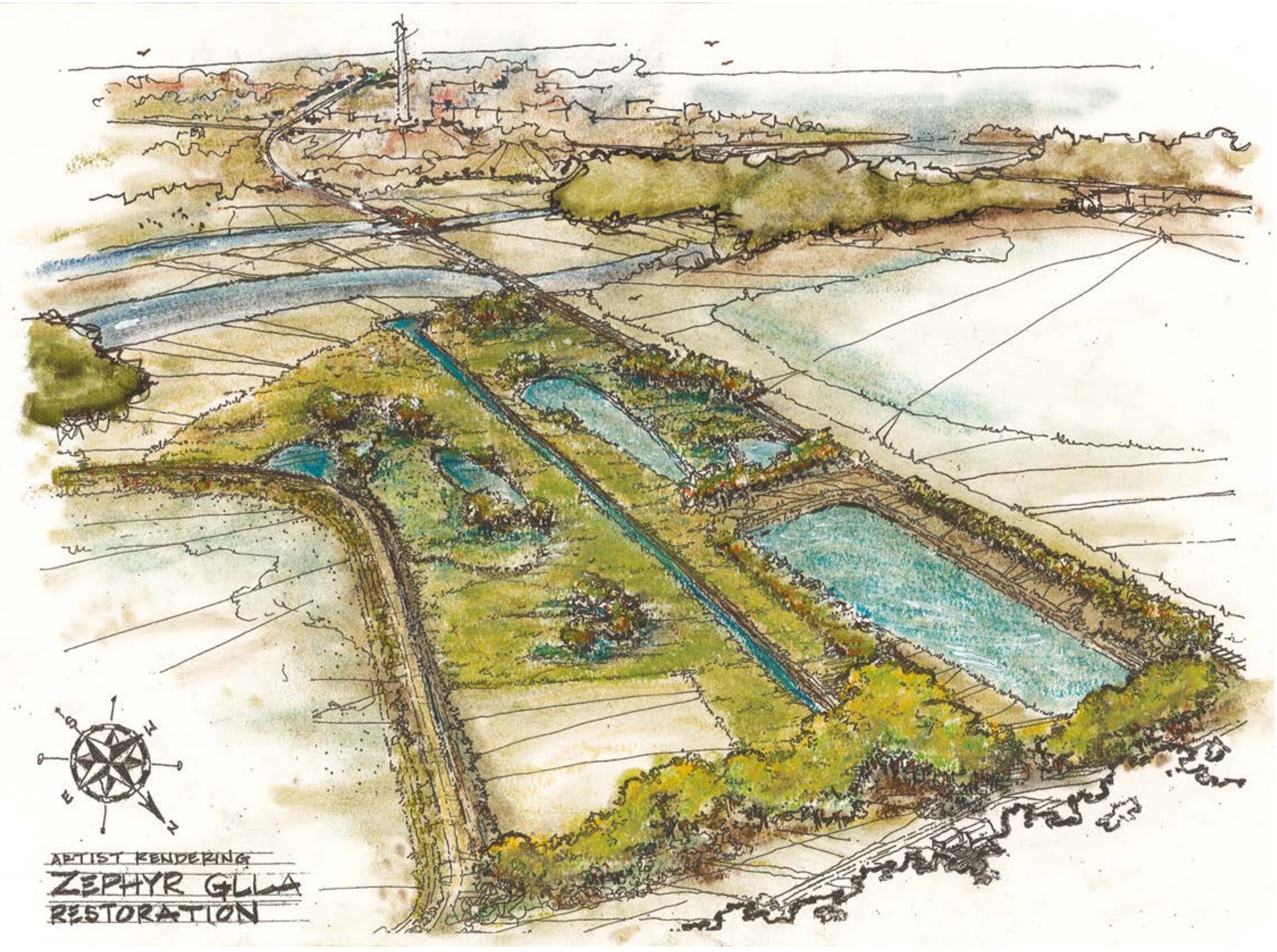


FIGURE 18

Artistic rendering of restored wetlands that was used for public outreach.

FIGURE 19

In-situ mixing to stabilise hazardous sediment.

FIGURE 20

Multiple dredging methods utilised and constructed haul roads for site access.

FIGURE 21

Portland cement addition as last step in dewatering of sediments.

FIGURE 22

Mitigating unique environmental challenges including capping historic oil well.

FIGURE 23

Innovative dewatering pad and process that was used during project.

The Zephyr project provided economic benefits through implementation of cost-saving measures.

FIGURE 24

Extensive sampling to confirm clean-up goals met.

FIGURE 25

Restoration included fill to create diverse wetland zones.

FIGURE 26

Redesign of emergent wetland 'islands' utilised to deal with historically high water levels and future fluctuations.

drone video footage, explaining the importance of sediment remediation for ecosystem health.

The Zephyr Outreach Team presented the Feasibility Study at the Muskegon Lake Watershed Partnership in 2015, the Remedial Design in 2017, and Remedial Action in 2018, with attendance well into the 40s for most meetings.

Since 2015, the Zephyr Outreach Team created and maintained a project website for the entire project (www.greatlakesmud.org/zephyr-site---muskegon-lake-aoc) which included information on the clean-up plan, community involvement opportunities, educational curriculum, and more.

The Zephyr Outreach Team created a flyer in 2018 describing short-term construction disruptions and long-term community benefits. They posted the flyer at more than 50 local businesses in the project site neighbourhood.

A project hotline was open throughout the construction activities to allow for the public to call in for any questions or complaints. No complaints were received during the project.

The Zephyr Outreach Team hosted a press event in 2018 with regional media, state and federal elected officials, project team VIPs, and dozens of community representatives to celebrate the completion of major remediation and restoration activities at the site.

An outreach video was produced to highlight successful project completion and partnerships and promote the GLLA.

Summary

EA Engineering, Science, and Technology, Inc., PBC (EA; Design Engineer), in conjunction with Sevenson Environmental Services (SES; Dredge Contractor) provided remedial and restoration services to the U.S. Environmental Protection Agency (USEPA) and project partner, Michigan Department of Environmental Quality (MDEQ) to remove contaminated (lead and petroleum) sediments from the Former Zephyr Refinery Fire Suppression Ditch (and surrounding wetlands) area located within the Muskegon Lake Area of Concern (AOC). This project was completed under the Great Lakes Legacy Act (GLLA) to support removal of beneficial use impairments (BUIs) such as the loss of fish and wildlife habitat.

The Zephyr project site, located in a mixed industrial, commercial, and residential area, included sediment areas with hazardous levels of lead, involved organic sediments with highly variable moisture content, and confronted historically high water levels during construction, which presented numerous logistical and technical challenges. The innovative and invaluable partnerships that were created and utilised to complete this project proved to be a critical element in overcoming these challenges. The project team maintained continuous contact throughout the construction in order to efficiently respond to these challenges while including all stakeholders in the discussions, resulting in a successful wetland restoration that will benefit the site owners and the community at large. The Zephyr project provided economic benefits through implementation of cost-saving measures and efficiencies during design and construction while contributing to the overall socio-economic impact of restoration work within the Muskegon Lake AOC and the Great Lakes Region.

This article was first published in the Proceedings of the Western Dredging Association's Dredging Summit & Expo '19 in June 2019 and is reprinted here in an adapted version with permission. This paper was awarded the 2019 WEDA Environmental Excellence Award for Environmental Dredging.

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SAFETY

DREDGING INNOVATION: FLOATING LINE CONNECTING SYSTEM

No one is in the line of fire anymore thanks to the Floating Line Connecting System developed by Boskalis. The innovation enables floating pipelines to be connected without using any manpower. All it takes is two hands to operate the remote control. The system was developed in-house by a diverse team and successfully tested on the Duqm port development project executed by the company in Oman.

We are continuously looking for ways of reducing physical labour for these types of operations and minimising risks involved.

Connecting floating pipelines is an operation involving many risks: the risk of hands and fingers getting caught in the ropes, the risk of falling off the pontoons, the risk of getting hit by a line in a snap-back zone. All risks that were apparently part of the job and the weather was the only factor on which you could base a decision: 'the wind is too strong and the waves too high, we'll wait, it's not safe'. All that is about to change, due to a revolutionary innovation called the Floating Line Connecting System (FLCS) that mechanises the connecting operation.

'We are continuously looking for ways of reducing physical labour for these types of operations and minimising risks involved', says Daan van de Zande, Operations Director of Boskalis' fleet of cutter suction dredgers, explaining the reason behind this development. 'Since the introduction of the Boskalis No Injuries No Accidents (NINA) safety awareness programme, people are more less likely to accept the label "accepted risk". We take responsibility for our own safety but we also take action if any unsafe situations arise.'

Four criteria

Van de Zande has been involved in the development of the system from day one. The first step was to make use of the developed twelve-metre-long self-floating pipelines suitable for pumping sharp dredged material. Due to the large bending angle, these pipelines could be used to assemble 100 metre sections rather than the 20 metre sections usually used for steel pipelines. This specifically meant that far fewer lines needed connecting. While this reduced the risks considerably, the actual connecting still had to be done by people, using the crane of the multicat.

Seeking to devise a method to mechanise this, various brainstorm sessions were held with people in the field. Van de Zande: 'This produced four design criteria: no one in the line of fire, no manual operations, no crew transfer, at least equal or higher workability than the conventional method. We made various designs based on these criteria but it always became too complex. Until, one day, I sat down with my colleague Bas Veenstra about the so-called Mooring Actuator – a system that makes manual mooring with lines obsolete – he had designed and the possibility of using it to connect floating lines. And it rolled on from there.'

The IADC Safety Award Winner 2019

This year the International Association of Dredging Companies Safety Committee and Board of Directors received fourteen outstanding safety nominations. After deliberations, the committee selected the innovative Boskalis Floating Line Connecting System as the winner. During a ceremony in mid-October at the IADC Annual General Meeting in New Delhi, IADC President Frank Verhoeven (right) announced the Safety Award 2019 winner and presented it to Hans Dieteren, Director of Boskalis Offshore (left) who accepted it on behalf of the company.

Strength

Using the ball, the U-shaped bollards and the remote control from the Mooring Actuator the Boskalis team developed a three-winch system that draws the lines together and connects them hydraulically. 'The strength of the system lies in its simplicity', says Pieter Verbiest, Fleet Manager Auxiliary Equipment and member of the working group. 'It meets

How the Mooring Actuator Works

Secured to a backhoe's bollards with heavy lines, a barge assists with the transport of material dredged by a backhoe. The Mooring Actuator was developed to enable the mooring of these barges alongside backhoes without any manual intervention making this operation much safer: the risk of falls or injury is considerably reduced, there is no more lugging around of heavy lines and no more time is lost adjusting the lines.

A backhoe dredger is fitted out with two swivel arms more than eight metres long, both with two large steel balls attached to chains. On barges that are being positioned alongside the backhoes, U-shaped bollards (catchers) are installed which catch the steel balls. Working from the backhoe, the swivel arm with the ball is turned towards the barge as it approaches. The ball is caught by the catcher, linking the two units. Specially developed constant tension winches then roll up the line and pull the barge to the backhoe. The winches maintain constant tension in the lines and so the barge is kept stable in exactly the right place throughout the loading operation. The entire process of mooring and stabilising the barges from the backhoe can be controlled remotely by a single person using an operating system developed in-house by Boskalis. The system has two winches and two balls on each swivel arm, making it possible to moor a split barge with four lines.

all four of the criteria we had set. And if the system fails, you can always fall back on the old working method, meaning continuity is guaranteed.' A patent for the system has been obtained recently.

Optimising

'Ten years is a long time to spend on research but it was more than worth it', says Richard Vermeeren, who as Chief Skipper of the cutter suction dredger Taurus was involved in the testing of the system. 'No more people on the pontoons, no more working with ropes, that really is progress in terms of safety. The new method is easily learned and the colleagues are very skillful. Now it is a matter of further optimising the system. I went to the Boskalis headquarters in Papendrecht to share my experiences as a user and to discuss possible improvements. I favour this approach as it enables us to optimise the system and achieve the best possible result. Furthermore, this way of working and learning helps us to improve continuity and increase engagement.'

The Boskalis Mooring Actuator

Secured to a backhoe's bollards with heavy lines, a barge assists with the transport of material dredged by a backhoe. The Mooring Actuator – a nomination for the IADC Safety Award 2017 – was developed to enable the mooring of these barges alongside backhoes without any manual intervention making this operation much safer: the risk of falls or injury is considerably reduced, there is no more lugging around of heavy lines and no more time is lost adjusting the lines.

AN ECOSYSTEM SERVICES ASSESSMENT OF THE PRINS HENDRIK ZANDDIJK

This study examines which and, if possible, how much more ecosystem services are provided by the most recent nature inspired coastal protection project Prins Hendrik Zanddijk.

The second coastal safety assay in The Netherlands, reported in 2006, showed that more than 70% of the 24-kilometre-long Wadden Sea dyke on the island of Texel failed to meet safety standards. A refurbishment was executed on 14 kilometres of the dyke, increasing its width and height, and adding a cover layer of grass and asphalt. Along the remaining 3.2-kilometre long section in front of the Prins Hendrik Polder (Section 9), a soft coastal protection design called the Prins Hendrik Zanddijk (PHZD) was realised. A dune and beach sandbody was reclaimed seaward of the dyke, upgrading some 200 hectares of the Wadden Sea area.

FIGURE 1

Location of Section 9 Wadden Sea Dyke (source: HHNK).

During the last decade, reclamation of a sandbody as a coastal protection measure has evolved into a viable and attractive alternative to handbook-engineering using concrete and asphalt. The latter, considered traditional coastal protection methods, offers the reassurance of multiple generations of engineering experience and reliability. Nature based solutions (NBS) are defined as 'solutions that are inspired and supported by nature, which are cost-effective, simultaneously providing environmental, social and economic benefits and help build resilience' (European Commission 2019). NBS such as sandbody designs must cope with dynamic behaviour and variability of the building material as well as with uncertainty of maintenance costs. The quantification of the cost-effective part of this definition remains however a difficult task.

Nevertheless, notable examples of nature-inspired sandbody designs have been constructed in The Netherlands, such as Zandmotor Ter Heijde, Kustwerk Katwijk and Zwakke Schakels Noord-Holland (Hondsbossche-Pettemer Zeewering).

The main argument for choosing the soft alternative was the assumed benefit over the traditional design for society both locally (habitants, farmers and visitors) and for society in general (air and water quality, creation of scarce habitats). Although the approval of these projects shows that these arguments can be decisive, the question remains whether it is worth to pay more for these NBS and take the associated risks, and if so by how much. The tool to quantify these benefits for society is called Ecosystem Services (ES).

This study examines which and, if possible, how much more ecosystem services are provided by the most recent nature inspired coastal protection project Prins Hendrik Zanddijk, in comparison with a traditional concrete and asphalt construction.

The choice between the hard solution (the refurbishment) and the soft alternative (sandbody) was not an obvious one. In fact, both scenarios have been developed in parallel in pre-tender phase. Partly to better understand the pros and cons of each solution, partly to mitigate the risk of a hick-up during the permitting process.

In this article, three different scenarios are compared:

I. **Dyke restoration:** refurbishment of the existing dyke consisting of a crest height increase and inland landfill to improve stability
II. **Tender design:** sandbody design used as the basis for the permitting process and provided to all tenderers.
III. **Final design**: realised sandbody design including extras proposed in the awarded offer.

The approach for the quantification of the benefits for society is based on the assessment framework developed to evaluate ecosystem services of marine infrastructure projects (Boerema et al., 2016). First, the type and size of habitats are identified for each scenario, and the services that each habitat delivers are subsequently identified. This step is mostly based on the results of five case studies (Boerema et al., 2016). For those habitats or services that are not covered, additional literature is searched to identify potential ecosystem services, including documentation directly linked to the project (EIA, Project Plan). Finally, the relevance of each ecosystem service is described and quantified based on the work done in Van der Biest et al. (2019). This ecosystem services quantification is complementary to the Social Cost Benefit Analysis (Hoogheemraadschap Hollands Noorderkwartier and Witteveen+Bos, 2013), performed during project permitting phase, where the focus was societal losses, whereas in this approach nature benefits are the central focus.

Habitat identification

Ten different habitats are identified within the footprint of the three different scenarios, and ordered below from land to sea.

I. Cropland: loss of cropland is inevitable for the dyke restauration scenario due to landfill required to stabilise the landside of the dyke. Cropland is also affected by salt water intrusion through aquifers under the dyke. Artesia estimated an average seepage flow of 1 m^3/m/day or about 1 mln m^3/year for the entire section (Caljé 2017). Loss of crop yield due to salt intrusion in dry periods of 17 to 89% was reported (Van Tol 2018).
II. Grassland on the dyke inland slope and crest is grazed by sheep. The sandbody designs include a bicycle path on part of the dyke crest, thereby reducing the grassland area by 0.3 ha.
III. Asphalt: the seaward slope of the dyke is covered with an impermeable asphalt layer, which is nearly completely covered in the sandbody designs. Knowledge on long term effects such as heat absorption and leaching is lacking and is therefore neglected in this study.
IV. Landward dune valley (NATURA2000 habitat type H2160): sheltered habitat between dyke and dune
V. Dune crest and seaward slope above NAP+3m, covered by planted marram grass (NATURA2000 habitat type H2130A).
VI. Shifting dunes (NATURA2000 habitat type H2120) on the seaward slope and foot of the dune.
VII. Tidal flat (NATURA2000 habitat type H1140A) unsheltered sandbars and tidal beach.

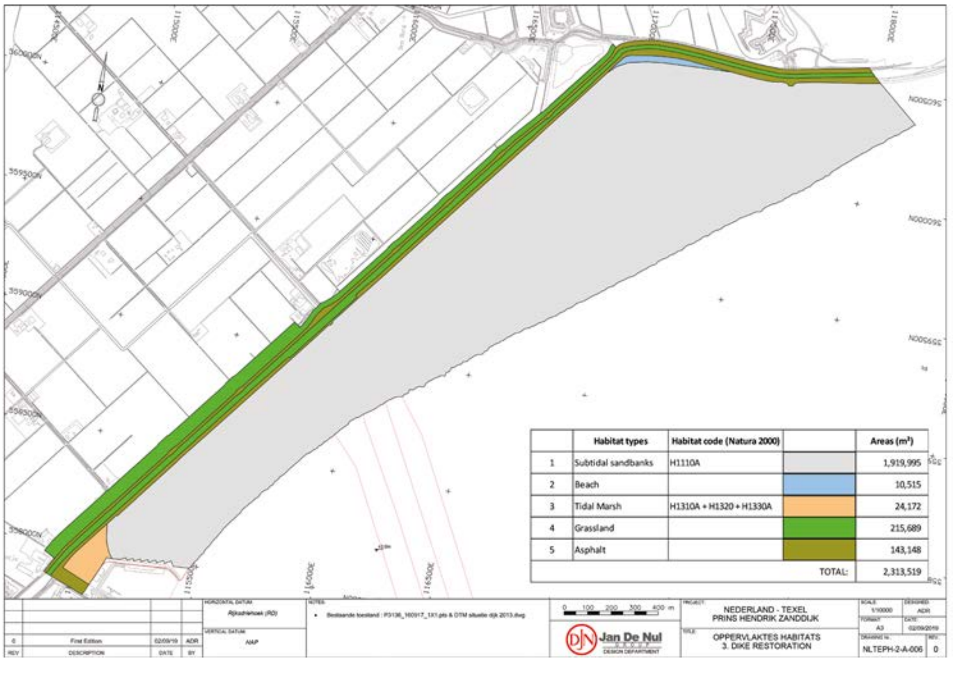

FIGURE 2

Total surface area covered by each habitat – dyke restoration scenario.

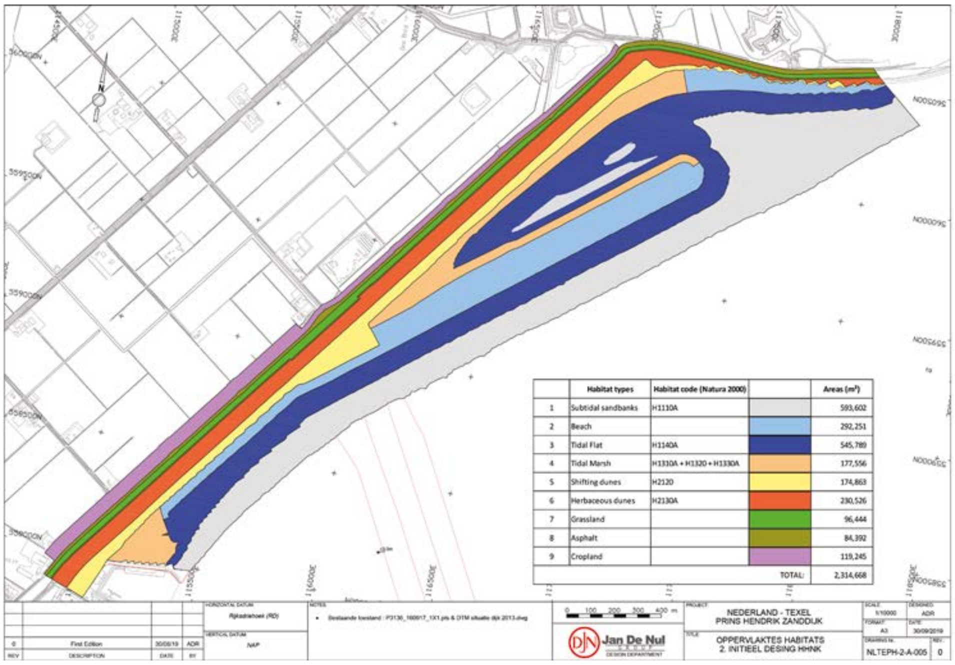

FIGURE 3

Total surface area covered by each habitat – tender design scenario.

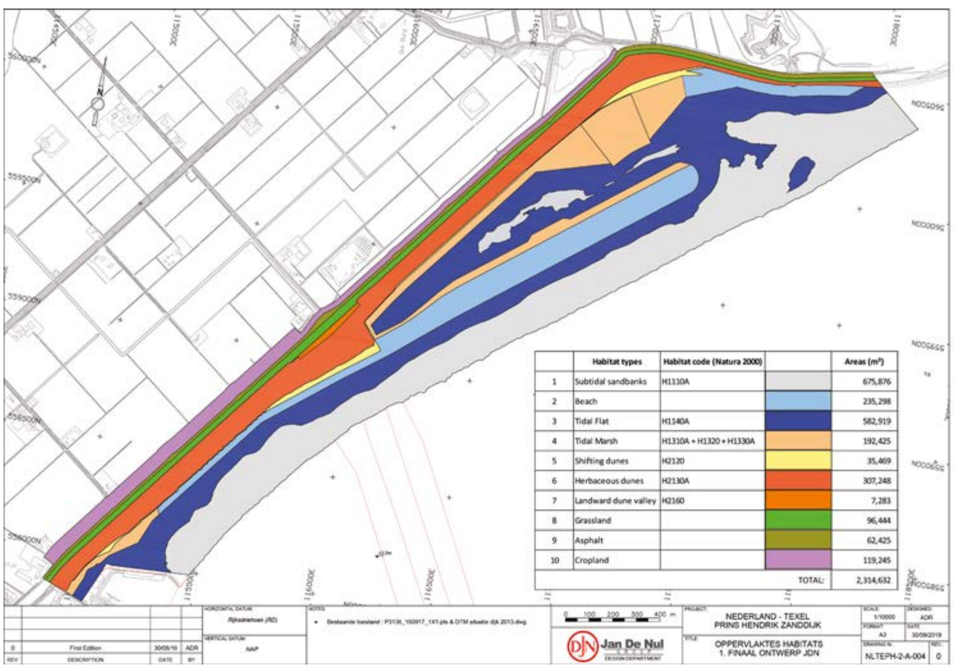

FIGURE 4

Total surface area covered by each habitat – final design scenario.

VIII. Tidal marsh (NATURA2000 habitat types H1310A + H1320 + H1330A): tidal areas sheltered by the NIOZ breakwater in the south and the sandspit in the northern part of the project area.
IX. Supratidal beach and sandspit.
X. Subtidal beach (NATURA2000 habitat type H1110A).

In Figures 2-4, an overview of the total surface area of the fully developed habitat areas – one to three years after project execution – for each of the three project scenarios is given.

Ecosystem services

For this study, we have selected ten relevant ecosystem services.

1. Flood protection

   Flood protection is a service to the hinterland considered equally fulfilled by all scenarios and therefore not included in this study. The quantification of this service remains however a pertinent question.

2. Agricultural production

   The area directly behind the primary flood defence – The Prins Hendrik Polder – is used for cultivation of a.o. flower bulbs. The refurbishment of the dyke requires the expropriation of a narrow strip of agricultural land due to a landfill required to ensure the stability of the landward side of the dyke. The value for agricultural production used in Boerema et al. (2016b) is 2,250 €/(ha.y). This value is based on the productivity of intensive cropland in Flanders. Maximum flower bulb yield in The Netherlands is estimated at 21,447 €/(ha.y) (Van Tol 2018).

3. Fish production

   The Wadden Sea is an important nursery area for various commercial and non-commercial fish species (Tulp et al., 2008). For the study area, sampling of the H1110A habitat has shown that the habitat is an average quality nursery ground due to the low biomass (Hoogheemraadschap Hollands Noorderkwartier and Witteveen+Bos 2017).

   De Groot (1992) estimated the value of the Wadden Sea wetlands to support fisheries production to be 281 €/(ha.y). A comparable estimate of 227 €/(ha.y) (consumer price index 2006 and today's exchange rate; value based on estimates from different continents) was found by Brander et al. (2006) (in Folmer et al., 2010), who used a market price based direct use value of fish. We here take the average of both studies, which is 254 €/(ha.y) for the nursery function of tidal marshes.

Lower benthos biomass and absence of structural complexity lead to conclude that the foreshore sandbanks in the study area are less important for this ecosystem service.

4. Fresh water production
Water abstraction from Texel dunes for drinking water purposes has been abandoned since 1993 a.o. due to increasing tourism and water needs and for nature purposes (Duinen en Mensen 2013). The newly developed dunes are relatively small. Water abstraction from these dunes may affect other ecosystem services and salinity levels in the hinterland. It is therefore not desirable to make use of this function hence the ecosystem service is not further considered.

5. Climate regulation
The capacity of an ecosystem to regulate the climate is to a large extent determined by its capacity to store organic carbon. Based on Brion et al. (2004), Lancelot et al. (2005) and Thomas et al. (2005) we use a value for yearly carbon burial in sandbanks and foreshore without vegetation of 0.0012 to 0.0019 ton C/(ha.y).

In salt marshes values range between 0.55 and 2.46 ton C/(ha.y) (Middelburg et al., 1995, Böhnke-Henrichs and de Groot, 2010, Mcleod et al., 2011, Adams et al., 2012, Duarte et al., 2013, Tamis and Foekema, 2015), taking into account greenhouse gas emissions. For unvegetated mudflats, literature is scarce. Phang et al. (2015) found that unvegetated mudflats and sandbars in a habitat mosaic with mangrove forest and seagrass meadow have similar soil carbon stocks as seagrass meadow. We here apply the same values for the habitat tidal mudflats and sandbanks as for tidal marsh habitat.

Project Presentation

The Prins Hendrik Zanddijk project on the Dutch island of Texel is a multifunctional land reclamation project where flood defense is combined with nature development, public services and recreational appeal. Seaward of the existing dyke, a dune is landscaped to act as primary coastal protection. The existing dyke thereby loses its main function but remains in place as a scenic element.

Instead of using a classical engineering design approach with rule and compass, the inclusion and enhancement of public, recreational and ecosystem services are made the focal point of the design (Fordeyn et al. 2019). A unique and dynamic nature reserve with dunes, salt marsh and beach in front of the current dyke was designed, with the goal of upgrading some 200 hectares of the Wadden Sea area (UNESCO World Heritage Site). Central to the design are the interactions between ecology and sediment dynamics. In traditional hydraulic engineering, there is a trade-off between safety and ecological value, and between sediment stability and dynamics. Coarse sand resists erosion better, but provides a less suitable habitat for benthos, which makes the area less attractive to wading birds.

Therefore, the target species and habitats were analysed and sediment characteristics chosen accordingly. A specific strategy of including fine sands to stimulate benthos growth is applied. Other strategies for habitat creation include salt marsh recuperation and seashell patches. The design further deals with a trade-off between recreational opportunities and the natural habitat disturbance, and between the dynamics of soft coastal protection and the lifetime of public functions.

For the mudflat habitat in the lagoon, higher values for carbon storage may apply due to the high sedimentation rate: 2–5 cm/y (Hoogheemraadschap Hollands Kwartier and Witteveen+Bos Raadgevende Ingenieurs B.V. 2016).

On the beach, which is rich in shell fragments, strong oxygenation of the porous sediment in a highly dynamic environment causes rapid mineralisation of C and thus a release of C to the sea. Rauch and Denis (2008) calculated a release of 226 kg C/(ha.y) from the sandy beach to the sea based on measurements in the eastern English Channel. Charbonnier et al. (2013) found a value of 1041 kg C/(ha.y) along the coast of Aquitaine. The values for carbon sequestration in the different dune habitats are derived from

In traditional hydraulic engineering, there is a trade-off between safety and ecological value, and between sediment stability and dynamics.

literature references used in Van der Biest et al. (2017b).

The value for carbon sequestration in the polder area is derived from Boerema et al. (2016a) and is 0.95 ton C/(ha.y). This value is derived from a statistical model applied to Flemish polders using the ECOPLAN-SE toolbox for quantifying ecosystem services (Vrebos et al., 2017).

The economic value of climate regulation is calculated as the avoided reduction cost, i.e. the costs for emission reduction measures that can be avoided in other areas to reach the environmental targets (related to the worldwide maximum 2°C temperature increase relative to the pre-industrial level of 1780). Data is based on a meta-analysis of several climate model studies (Kuik et al., 2009). A monetary value of 220 €/ton C was used to calculate the economic value of carbon sequestration (Mint and Rebel, 2013).

6. Water quality regulation
Water quality regulation refers to the removal of excessive nutrients (nitrate and phosphate) from water (soil pore water, groundwater, surface water and sea). With the presence of an important agricultural area in the polder behind the Prins Hendrik sand dyke, the ecosystem service provided by the newly created tidal marshes in the lagoon in front of the dune can be of importance. These marshes are capable of storing nutrients that are discharged to the sea from the polders and by atmospheric deposition. The dunes can remove nutrients that are volatised during fertiliser application in the polder and from atmospheric deposition. Atmospheric deposition of nitrogen within the study area varies between 14–21 kg N/(ha.y) (RIVM 2017).

The values for denitrification, N retention and P retention in sediments in subtidal and intertidal habitats are based on Boerema et al. (2016b). For dunes, removal of N is estimated based on the N input through atmospheric deposition and N leaching to groundwater, where the amount of N that is not leached is the result of retention, mineralisation and denitrification processes. For dunes with herbaceous vegetation (grass and moss), N-leaching prevention is calculated based on leaching experiments in dunes near The Hague (70% leaching in calcium rich dunes (ten Harkel et al., 1998), and today's input through atmospheric deposition (RIVM 2017), resulting in a reduction of 4.2–6.3 kg N/(ha.y). The value for N-leaching in dune shrub with *Hippophae rhamnoides* (H2160) is derived from Stuyfzand 1984, who found that symbiotic N-fixing bacteria nearly triple the amount of leaching to groundwater compared to atmospheric deposition (-63– -42 kg N/ha.y). Similar results were obtained by Gerlach et al. (1994) on the Wadden island Spiekeroog. On the beach rich in shell fragments, denitrification is assumed to be negligible due to oxygenation of the porous sediment in a highly dynamic environment (Cockcroft en McLachlan, 1993, Charbonnier et al., 2013). The strong oxygenation of the beach on the other hand causes high rates of mineralisation of N, thus a release of N to the sea. For the coast of North France, Rauch and Denis (2008) found that N mineralisation in the beach sediments released on average 44.24 kg N/(ha.y) to the eastern English channel. Higher values were found along a beach in North Carolina (257.67 kg/(ha.y) (Avery et al., 2008) and for the coast of Aquitaine in France (181 kg N/(ha.y) by Charbonnier et al. (2013) and 191.68 kg N/(ha.y) by Anschutz et al. (2009). We here use the value of Rauch and Denis (2008) because of its proximity to the study area in comparison with the other studies. Like N, P is also quickly mineralised in highly dynamic intertidal areas. The sand used for the Prins Hendrik Zand dijk is dredged from two areas close to Texel (<15km). Due to the poor capacity of the

Ecological Pilots

Five ecological pilots were designed by Altenburg & Wymenga and included in the final design to kick start colonisation of fauna and flora (van der Zee, 2018).

- **Salt marsh transplantation:** 5,000 m² of existing salt marsh vegetation adjacent to the NIOZ port was relocated before construction of the sand dune and irrigated until it was transplanted in the sheltered zone at the corresponding isoline and slope.
- **Benthosplots:** fine sand including associated microfauna from the NIOZ salt marsh is deposited in 2,000 m² plots on the coarse-sand beach to form a biotope for macrofauna.
- **Seagrass:** The PHZD design provides promising conditions for reintroduction of seagrasses in the Waddenzee. A pilot experiment will be conducted at a suitable location when the morphology has stabilised.
- **Embryonic dunes, resting areas and nesting sites:** Both beach and sand spit are resculpted to create suitable habitats for dune vegetation, seals and birds.
- **Rock & Shell island:** Hard substrate is created near the outfall of the Prins Hendrik pumping station to split the outfall flow into meanders while creating a habitat for bivalves and shellfish.

soil to bind P in Fe- and $CaCO_3$-poor soils, it is more likely that P will be mineralised and the beach becomes a source of P to the open sea (Anschutz et al., 2009). Based on the consistent Redfield nutrient ratio of marine phytoplankton (ratio C:N:P = 106:16:1) and the value of N mineralisation on the beach (44.24 kg N(ha.y)), we assume a release of 2.77 kg P/(ha.y) from the sandy beach to the sea. Because atmospheric deposition of P is negligible (RIVM 2012) and because it is assumed that most of the P that comes in with sea water is mineralised on the beach (Anschutz et al., 2009), P retention in the dune is expected to be negligible and most of the available P is consumed by the vegetation. This is also confirmed by Kooijman et al. (2009).

Values for water quality regulation in cropland are derived from Boerema et al. (2016b). N and P storage in cropland is negligible (high consumption of N and P by crops). Denitrification is negative due to the usage of fertilizer and the leakage of N to the groundwater (-50 kg N/(ha.y)).

For the economic valuation, the shadow price for nitrogen removal (€/kg N) is used which is the cost for an equal removal of nitrogen using (other) technical investments (e.g. to reduce nutrient loads from the streams draining the agricultural area behind the dune). A monetary value of 40 €/kg(N) was used, this is the average from the range found in literature (5–74 €/kg(N) (Liekens et al., 2012). An important note has to be made on the value of P retention in coastal sediments. Due to the strong dominance of N over P in coastal waters in the North Sea, it has been suggested that further lowering the P content in the water should not be strived for until the N content diminishes, as this may induce changes nutritional quality of phytoplankton and disturbing Phaeocystis blooms in spring (Rousseau et al., 2002). In other words, P retention can only be considered for as a potential benefit for human well-being. The actual benefit can be accounted for under conditions of high P-loads or reduced N-load. With the proximity of an intensive agricultural area it can be assumed that there is a significant P-input to the coastal water in the project area, allowing to take into account the benefit. The economic value of P retention is based on the shadow price for P removal, which is 55 €/kg P (average of range found in literature: 8-103 €/kg P (Liekens et al., 2012).

7. Air quality regulation

Air quality regulation is the capacity of vegetation to remove fine dust particles (a.o. PM10) from the atmosphere by precipitation of the particles on the leaves, stems and branches and subsequent accumulation in the soil after rainfall events. Fine dust particles mostly come from emissions from cars, industry and households. In the study area, air quality may also be influenced by aeolian transport of very fine sand when spring tide low water and strong easterly and southerly winds co-occur. However, this phenomenon is expected to become negligible when the vegetation is full-grown and is capable of trapping the sand.

The benefit of fine dust removal by vegetation is reflected in reduced costs for health care. In the study area, fine dust concentrations are very low (< 15 μg pm10/m³), or of temporary nature. Air quality regulation is therefore not further considered.

8. Recreation

The design of the safety dune aimed to offer an appealing landscape to the visitor without disturbing the natural habitat. The safety dune is therefore overlain with an undulating layer that replicates the character of natural dunes. The dune reaches its maximum level near the southern and northern end both to increase the visual appeal to hikers and cyclists and to create a physical barrier between recreation on the dune and nature on the beach and in the tidal marsh.

The sandbody design increases the diversity of the landscape due to the creation of several habitats, both in the intertidal (beach, tidal flats and tidal marshes) and in the supratidal zone (dunes with *H. rahmnoides*, dunes with herbaceous vegetation and dunes with *A. arenaria*). Literature points out that structural complexity of landscapes is positively correlated with landscape aesthetics and number of visits (Harrison et al., 2014; De Nocker et al., 2015). Yet, it is a challenge to express in monetary terms its exact contribution in attracting people (Van der Biest et al., 2017).

The development of the project is expected to have positive impacts on recreation as a result of maintaining bicycle access, creation of an accessible beach, increased diversity of the landscape (different habitats) and increased opportunities for bird watching and seal spotting. Some of these elements were added to the final design as extras to the tender design (viewpoints and walking trail). Although the qualitative analysis provides arguments of added value for recreation, this is hard to substantiate in numbers. A comparison of numbers of visitors to the area before and after implementation of the project would allow for a quantification of the added recreational value.

9. Heritage

There are no objects of historical or archaeological value present in the project area.

10. Cognitive development

The economic benefits of cognitive development are created through application and export of knowledge and expertise by the companies and institutions involved in the project design and evaluation. The PHZD project design and evaluation (through model studies and monitoring) add to the know-how on the development of ecosystem- and nature-based solutions for coastal protection and the creation of additional benefits in terms of ecosystem services. However, these cognitive benefits are difficult to quantify and literature on this matter is nearly inexistent. The importance of the project for cognitive development can therefore only be qualitatively described.

The latter three services are categorised as cultural ecosystem services.

Biodiversity is not included in this study as an ecosystem service as such. However, benefits of biodiversity are taken into account through the creation of added value for several other ecosystem services (e.g. fish production, recreation). Detailed information on the impacts of the Prins

The ecosystem services provided by the sandbody alternatives are quantified to be at least triple of the benefits of the hard solution and at most seven times larger.

Hendrik Zanddijk on specific biodiversity aspects can be found in a.o. van der Zee et al. (2018) and Witteveen+Bos (2016).

Qualitative, quantitative and monetary assessment

The quantification of ecosystem services in this study is based on values of healthy and fully developed ecosystems. It is noted that in the first years after the construction of the project the habitats need to develop and that the realisation of the full potential of ecosystem services as presented below may require some years (Boerema et al., 2016a). Therefore, temporary effects associated with construction, both positive, e.g. the ecological pilots to accelerate the habitat development and negative, e.g. the extraction of sand from the North Sea, are not included in the final quantification of the ecosystem services given its longer-term outlook.

Temporary effects

The construction and maintenance of the PHZD require the extraction of a large amount of sand from the North Sea (5.5 mio m³ for construction + 1 mio m³ for maintenance). The extraction sites are located at about 10–15 km distance from the island of Texel. The extraction involves disruption of the soft sediment seabed and its habitats (NATURA2000 H1110 Sandbanks which are slightly covered by sea water all the time), and increased turbidity due to the overflow plume during dredging. However, the impact is temporary and benthic life restores after 1 to 4 years (Simonini et al., 2007; Essink, 2005). Especially in highly dynamic areas in the North Sea impacts are considered to be insignificant in comparison with the large natural dynamics of the system (Rozemeijer et al., 2013, Schellekens et al., 2014, Wijsman et al., 2014). The impact assessment of the sand extraction and transport (Kleijberg, 2016) also concludes

TABLE 1

Summary of potential effects of the 3 scenarios on the yearly provisioning of ecosystem services.

	Ecosystem Service	Indicator	Unit	Dyke restoration	Tender design	Final design
Provisioning	Agricultural production	expected agricultural production polders	k€/y	0	26.8	26.8
	Fish production	fish production supported by nursery function	k€/y	0.6	4.5	4.9
	Drinking water production	–	–	0	0	0
Regulating	Climate regulation	C sequestration/burial rate	k€/y	6–7	21.1–53	19.9–52.5
	Water quality regulation	N removal/retention/burial rate	k€/y	190.1–215.5	659.9–1255.8	743.2–1384.2
		P retention/burial rate	k€/y	0.3–5.9	7.5–154.8	9.2–167.2
	Salinisation prevention	–	–	0	0	0
	Air quality regulation	–	–	0	0	0
	Flood protection	avoided damage costs	mio €	60	60	60
		avoided casualties	# people	0–5	0–5	0–5
	Erosion prevention	reduced dyke maintenance costs by wave attenuation	k€/y	0	37.6	37.6
	Sedimentation regulation	–	–	0	0	0
Cultural	Recreation	landscape quality, infrastructure	score	+	++	+++
	Heritage	heritage values	score	+	–	–
	Cognitive development	expertise, know-how	score	0	+	+
	Sum Additional Monetary Benefits (excluding flood protection)		**mio €/y**	**0.2–0.23**	**0.75–1.53**	**0.84–1.67**

that the extraction has no significant effects on the habitat types and associated species.

The sandbody scenarios have a temporary effect on saltwater intrusion in the construction phase. Overpressure on the groundwater may cause instability of the dyke and the nearby buildings. In the polder, the saline seepage water may squeeze out the fresh rain water layer at the surface of the agricultural land, causing damage to growing crops. This phenomenon was observed in earlier projects such as Zandmotor and Zwakke Schakels Noord-Holland (Hondsbossche Pettemer Zeewering). At Prins Hendrik Zanddijk, these temporary effects are mitigated through an extensive real-time measurement system and extraction of seepage water by horizontal and vertical drainage.

Comparison of longer-term effects

The potential longer-term ecosystem services effects of the three scenarios (dyke restoration, tender design and final design) were compiled in monetary terms (see Table 1). This excludes the flood protection benefits. As was mentioned earlier, all three scenarios provide the same flood protection service. The effects of the three cultural ecosystem services can only be compared qualitatively.

The ecosystem services provided by the sandbody alternatives are quantified to be at least (minimum added value) triple of the benefits of the hard solution (dyke restoration) and at most (maximum calculated added value) seven times larger. Each year, the sandbody alternative creates an additional 0.55 to 1.47 million euro of ecosystem services benefits, mainly due to enhanced fish production, climate regulation, water quality regulation and erosion prevention.

The ecosystem service in this case study with the largest additional benefits is water quality regulation, which is explained by the high monetary value for nitrogen removal and the importance of the tidal flats and marshes for nutrient storage in sediments and denitrification. The creation of the sand dyke results in a loss of 132.5 ha (tender design) or 124.3 ha (final design) shallow sandbanks on the foreshore. The economic benefits in terms of ecosystem services of this habitat are however low in comparison with tidal flats

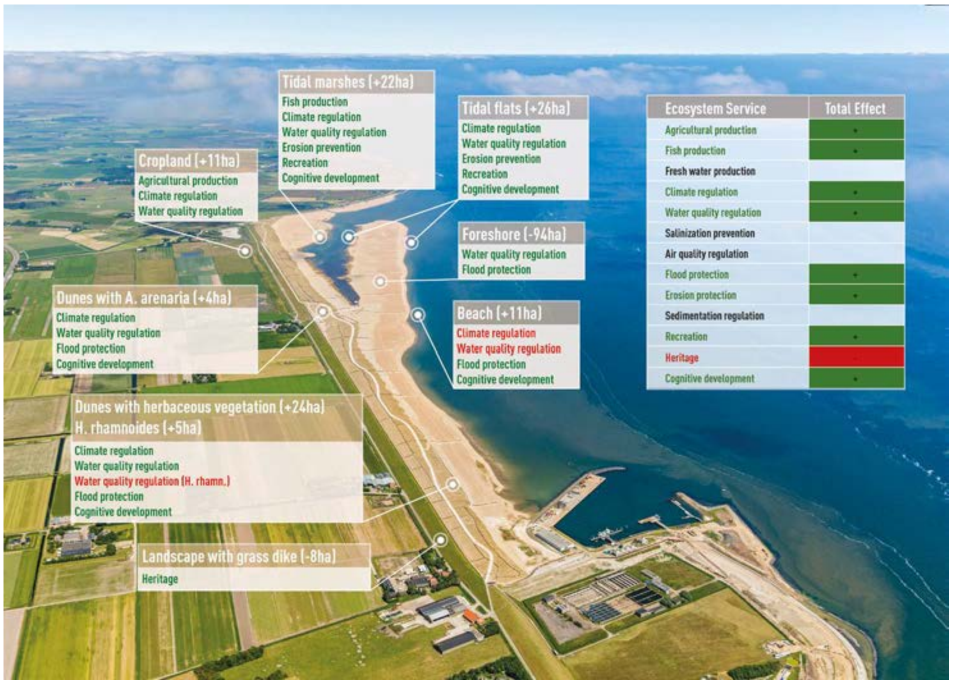

FIGURE 5

Overview of expected changes in habitats and ecosystem services within the boundaries of the Prins Hendrik Zanddijk (comparison of final sand dyke design with scenario restoration of asphalt dyke).

TABLE 2

Evaluation of the cost efficiency of the sand dyke

	Dyke restoration	Tender design	Final design
Construction cost	18.80 mio €	23.90 mio €	23.90 mio €
Management and maintenance costs per year	18.80 mio € x 0.2% per year = 0.04 mio €/y	20000 m³/y x 6 €/m³ = 0.12 mio €/y	20000 m³/y x 6 €/m³ = 0.12 mio €/y
Ecosystems services benefits per year (min–max estimate)	0.2–0.23 mio €/y	0.75–1.53 mio €/y	0.84–1.67 mio €/y
Total costs vs. benefits per year (min–max estimate)	***0.16–0.19 mio €/y***	***0.63–1.41 mio €/y***	***0.72–1.55 mio €/y***

FIGURE 6

The design of the PHZD focuses on nature development and recreational appeal in addition to its function as primary coastal protection. Planting of marram grass at the project site supports the NATURA2000 habitat type H2130A.

and dunes.

Some newly created habitats have negative impacts on ecosystem services, such as the emission of carbon and nutrients from the beach and leakage of nitrogen in shifting dunes with *Hippophea rahmnoides*. However, these losses are compensated for in other newly created habitats (e.g. tidal marshes). An important note is that the value of ecosystem services for the dyke restoration-scenario is actually not on account of the asphalted dyke itself, but results from the loss of foreshore habitat and associated ecosystem services due to the construction of the sand dyke.

Comparing the two sandbody alternatives, an added monetary benefit of 0.09–0.14 million euro/year is noted for the final design (PHZD). This is mainly attributed to the creation of a larger area of salt meadows (15 ha) and a smaller area of beach (5 ha). Again, the higher value is related to the importance of salt marshes for biochemical ecosystem services (C, N, P). Additionally, the reduction in beach area diminishes the emission of

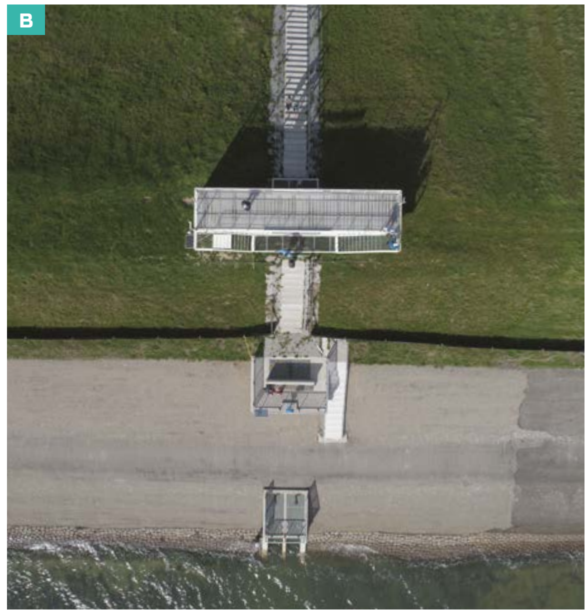

FIGURE 7

During the works, an experience centre on top of the dyke near the Prince Hendrik pumping station informed residents and tourists about the project.

Comparison with Other Projects

In a dedicated publication about ecosystem services for IADC, Ecobe has analysed the socio-ecological benefits of five marine construction projects (Boerema, 2016b).

- **C-power wind farm:** six wind turbines on a surface of 1.5 ha create a ESS benefit of 14 k€/year, mainly attributed to the hard substrate of the scour protection.
- **Botany Bay container terminal:** 16 ha of new salt marsh is created with a ESS benefit of 5.5k€/yr to partly compensate for the 63 ha container terminal which has a negative ESS impact of 126 k€/yr, the saltmarch a positive ESS impact of 15 k€/yr.
- **Zandmotor:** NID of coastal protection in Ter Heijde 815 k€/yr.
- **Western Scheldt Container Terminal:** 166 ha compensation area (ESS 642 k€/yr) created for the development of 133 ha container terminal (ESS -821 k€/yr).
- **Polders of Kruibeke:** insufficient data to perform cost-benefit analysis.

Who's Involved in the PHZD Project

The Prins Hendrik Zanddijk is part of the 'Hoogwater Beschermingsprogramma 2' the Dutch government programme to protect The Netherlands against floods from rivers, lakes and the sea. PHZD is one of 87 projects upgrading 362.4 km of dykes and 18 civil engineering works that are realised between 2015 and 2020. The programme is managed by an alliance of the responsible ministry (Ministerie van Infrastructuur en Waterstaat) and the waterboard (Hoogheemraadschap Hollands Noorderkwartier, HHNK). Lead Consultant to the HHNK is Witteveen+Bos Raadgevende Ingenieurs.

The tender was awarded in September 2017 to the Jan De Nul team: Altenburg & Wymenga was in charge of environmental management and came up with the ecological pilots, Feddes & Olthoff designed the cycling path and the dune landscape, John Körmeling designed the bird watchhouse, Waterproof B.V. ran hydrodynamic, morphological and aeolian models with the help of Leo Van Rijn Sediment, BT Geoconsult ensured integrity of the existing dyke and freshwater supplyline, Wiertsema & Partners analysed the geology and Artesia calculated the hydrological effect of the sand reclamation and drainage system.

The Ecosystem Management Research Group (ECOBE) at the University of Antwerp conducted the ecosystem assessment, Vito realised a remote sensing turbidity pilot, student D.D. Van Tol of Hogeschool Amsterdam investigated crop damage and students D. Clybouw and T. Vande Ryse of KULeuven campus Brugge measured and modelled aeolian transport.

nutrients and carbon to the sea. The total ecosystem services benefits of the final design are 9–12 % more than those of the tender design.

It is assumed that the results of the quantification of ecosystem services are representative for qualitative and fully developed habitats, which may not be the case in the first years after the construction. The usage of pilots in the final design, such as the transplantation of marsh vegetation, aims to accelerate the creation of additional benefits for nature and for ecosystem services. The final design will be faster in realising the full potential of ecosystem services in comparison with the tender design.

Taking into account the costs for construction and maintenance of the sand dyke and the restored dyke, a rough estimate can be made of the cost efficiency of the project (see Table 2).

A range of one to three years must be taken into account for the habitats to become sufficiently qualitative to provide the ecosystem services. Using the value for the maximum estimate of economic benefits (1.55 mio €/y – 0.19 mio €/y = MAX + 1.36 mio €/y total benefits), it requires five to seven years to entirely compensate the initially higher costs of the construction of the final design (23.9 mio € – 18.80 mio € = + 5.1 mio € investment costs) by the higher benefits it generates in terms of ecosystem services, in spite of the higher maintenance costs. Assuming that habitats are fully developed and qualitative only after three years and using the minimum estimate (0.72 mio €/y – 0.16 mio €/y = MIN + 0.56 mio €/y total benefits), the costs are compensated after maximum of nine years (5.1 / 0.56 mio €/y).

The final design will be faster in realising the full potential of ecosystem services in comparison with the tender design.

Conclusion

The creation of the PHZD generates both positive and negative effects on the ecosystem services. While replacing shallow sand bank area with beach increases emissions of carbon and nutrients and leakage of nitrogen, these negative effects are more than compensated by the creation of tidal marsh area and its associated beneficial ecosystem services, resulting in an overall positive result. It is estimated that the additional cost compared to the dyke refurbishment alternative is compensated within five to seven years.

The design of the PHZD focuses on nature development and recreational appeal in addition to its function as primary coastal protection. While the current ecosystem services methodology allows for a quantitative comparison of nature development, the differences in cultural ecosystem services between the designs (e.g. dune relief to create sea view from the bicycle path) could not be taken into account in the quantification. This leads to an underestimation of the benefits of the final design in comparison with the tender design and the dyke restoration alternative.

Summary

This article quantifies the benefits of the realised soft coastal protection design for the Prins Hendrik Zanddijk project (PHZD) and compares this result against the alternative of upgrading the existing dyke. The quantification in terms of ecosystem services is based on the assessment framework developed by Boerema et al. (2016). First, the type and size of habitats and associated ecosystem services are identified. and subsequently, the relevance of each ecosystem service is described and quantified.

The creation of the Prins Hendrik Zanddijk generates both positive and negative effects on the ecosystem services as the soft coastal protection project replaces shallow sand bank areas with both beach and tidal marsh area. The positive effects outweigh the negatives, with additional benefits created by the Prins Hendrik Zandijk quantified at 0.4 –1.07 million €/yr, mainly due to enhanced fish production, climate regulation, water quality regulation and erosion prevention.

The design of the PHZD focuses on nature development and recreational appeal in addition to its function as primary coastal protection.

Jan Fordeyn
Jan studied at the University of Ghent and graduated as a naval architect in 1994. Since 2007, he has helped develop projects around the world that fall outside the classic canon of marine construction and whose result relies on the symbiosis of different disciplines. As such he maintains close relations with experts, consultants, universities and manages several innovation projects. During the tender and realisation of the Prins Hendrik Zanddijk, he was technical manager and co-ordinated all design aspects.

Katrien Van der Biest
Katrien is a doctoral student 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.

Emile Lemey
Emile works as Project Development Engineer at Jan de Nul Group. His background is in Bioengineering and Marine conservation. At Jan De Nul he has focused on nature based solutions projects in which ecological considerations are an essential part of the design phase. He worked as Environmental Engineer on the Prins Hendrik sand dyke project during the realisation phase.

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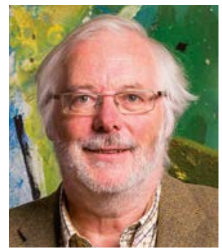
Annelies is a doctoral student in environmental science at the Research Group Ecosystem Management of the University of Antwerp, Belgium. Her research focuses on biophysical and economic evaluation of ecosystem services to assess the impact of ecosystem management, with an emphasis on estuaries. She obtained her Master's degree in commercial engineering and a Master's degree in environmental science at the University of Antwerp.



Patrick Meire
Patrick is professor in biology and head of the research group Ecosystem Management (ECOBE) 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.

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SHARE TO IMPROVE PRACTICES

Congress Hydraulic Engineering Structures and Dredging

26-27 February 2020
Russian Chamber of Commerce and Industry
Moscow, Russia

The congress includes the 7th International Forum of Dredging Companies and the 3rd technical conference 'Modern Solutions for Hydraulic Engineering'.

Infrastructure development is a key source of Russia's economic growth. The construction of port facilities and new hydraulic engineering structures on the country's inland waterways are essential infrastructure projects. It is necessary to account for international experience to implement these projects effectively.

The programme of the Congress will be devoted to the most modern technologies for dredging and hydro-technical works. Speakers and delegates will discuss real projects, the specifics of dredging works, the construction of specialised fleet and equipment.

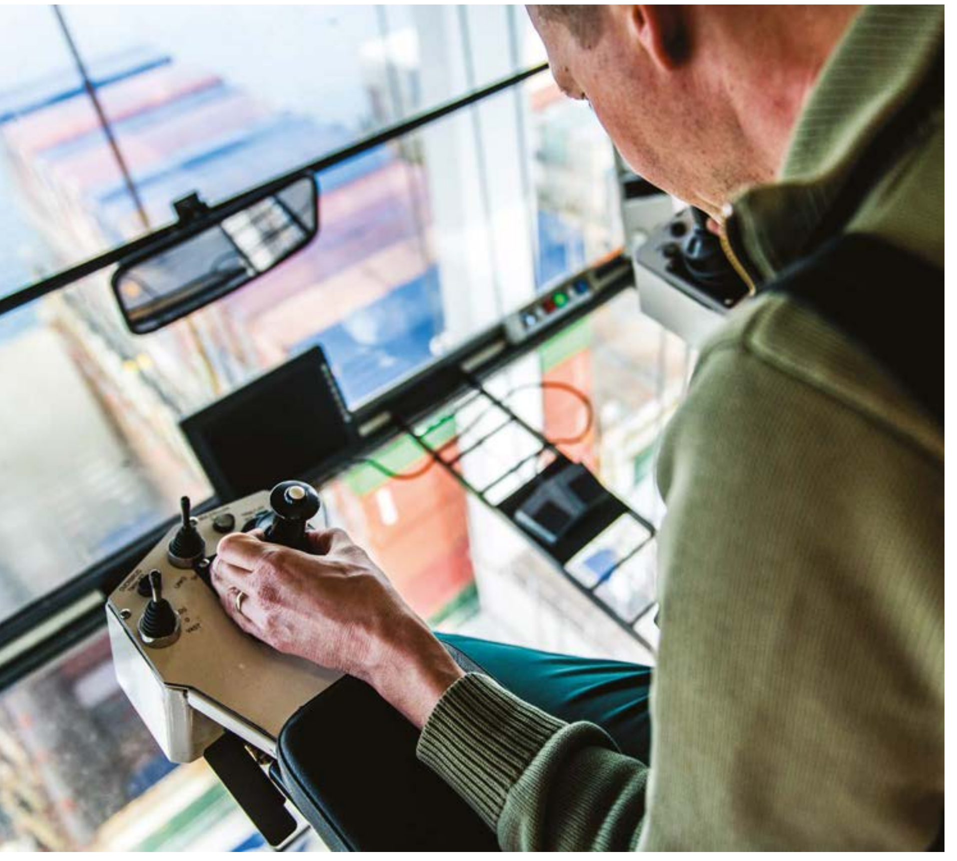
IAPH World Ports Conference

17-19 March 2020
Flanders Meeting and Convention Center
Antwerp, Belgium

The 2020 World Ports Conference is a world-class interactive event which brings together leading ports, their customers and stakeholders as well as regulators to imagine and deliver a future where ports lead in the areas of energy transition, data collaboration, reputation management and business innovation. The theme of this year's conference is to build transparency, predictability and trust, and elevate the industry to new demands of customers, communities, and stakeholders.

The three-day conference will feature a mix of panel discussions, one-to-one conversations, hands-on workshops and specialised working events to showcase unique, practical insights from business leaders who have engaged in successful and sustainable cross-industry collaboration. Attendees from various backgrounds will come away with an understanding of how to create genuine trust, boost transparency and increase reliability both internally and externally.

IADC's Secretary General René Kolman presented at the forum held in Moscow in 2018.



Conferences and seminars are intended for all stakeholders in the field of dredging: government officials, port authorities, offshore companies, researchers, scientists and dredging contractors.

WEDA Dredging Summit & Expo '20

9-12 June 2020
Marriott Marquis Houston
Houston, Texas, USA
https://dredging-expo.com

A technical conference organised by the Western Dredging Association (WEDA), the Dredging Summit & Expo '20 promotes the exchange of knowledge in fields related to dredging, navigation, marine engineering and construction. The theme for this year's conference is 'Dredging: The Impacts of Climate Change'.

Acting as a forum, the conference aims to improve communications, technology transfer, and cooperation among associations and societies while emphasising the importance of understanding and development of solutions for problems related to the protection and enhancement of the marine environment. Attendees include expert representatives of public authorities, suppliers, universities, research institutes, civil engineers and geotechnical engineers. Proceedings are relevant for contractors working in dredging, navigation, coastal and inland flood protection, deep-sea mining, offshore wind energy, oil and gas production fields, marine engineers, manufacturers, dredging technology providers, harbour and port representatives, consultants, port engineers, hydrographic surveyors, geologists, environmental managers, infrastructure managers, and public authorities.

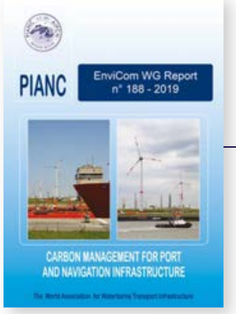
Attendees will witness high quality presentations, access the Expo of 90+ exhibitors and enjoy a social programme to properly facilitate interactions with more than 500 attendees from all segments of the dredging industry. Presentations of technical papers are for the advancement of the science and profession of dredging, navigation and marine engineering. To give a presentation, submit an abstract of a practical application or applied research before the deadline of 17 January 2020.

BOOK REVIEW

ENVICOM WG REPORT Nº 188 – 2019

CARBON MANAGEMENT FOR PORT AND NAVIGATION INFRASTRUCTURE

As environmental awareness grows, it becomes increasingly important for marine entities to investigate the carbon footprint of activities related to development, maintenance and operation of navigation channels and port infrastructure, including the management of dredged material.



There is an international scientific consensus that anthropogenic emissions of greenhouse gases have and will continue to affect the global climate. The central aim of the Paris Agreement adopted in December 2015, which is based on the assessment of the Intergovernmental Panel on Climate Change of 2013, is to maintain the global temperature rise in the 21st century just under 2 degrees Celsius above pre-industrial levels. This agreement addresses a range of areas necessary to combat climate change including a long-term temperature goal, global peaking of greenhouse gas emissions, mitigation and a global stocktake every five years.

While the International Maritime Organization reached an agreement on a global set of initial short-, medium- and long-term strategies to reduce international shipping emissions, there has been much less focus on the infrastructure that supports waterborne transport. PIANC and its partners in the Think Climate coalition are working to fill this gap and commissioned PIANC's Working Group (WG) 188 to help.

When considering developing a carbon management framework for ports and navigation infrastructure, taking proactive steps to effectively manage carbon will help an entity to:

- comply with emerging regulatory requirements;
- respond to general stakeholders and public pressure to reduce environmental burdens;
- take a leadership role in carbon management practices;
- address the UN Sustainable Development Goals;
- drive innovation and investment while influencing future practice and regulation; and
- benefit financially through efforts to reduce energy consumption and resources.

The WG 188 guidance document describes important considerations when developing a carbon management framework and gives an idea of how carbon can be managed, influenced and reported for a navigation infrastructure project or a port with both land-side and water-side considerations. The WG 188 guidance document covers aspects of the whole life cycle of the navigation infrastructure, from design to construction andoperations/maintenance to end-of-life reflections.

The included case studies help broaden the understanding of the carbon footprint and sequestration potential. Furthermore, they present best practices which can differ based on location and context-specific factors.

Apart from the general aspects and framing of the document in the first section, the second section sets out existing methods used to implement a carbon management framework

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https://www.pianc.org/publications/envicom/wg188

for navigation infrastructure and discusses management considerations, decisions and challenges in developing and implementing such a framework which should include:

- a reference to individuals or groups involved in the process and the framework scope and processes to achieve the desired outcome of managing and reducing carbon;
- the scope and goals of the framework should be defined within the context of the life cycle for ports and navigation infrastructure;
- roles and responsibilities through the supply chain should be established to allow collaborative working which will lead to progression and benefits for all;
- processes should be focused around establishing who to involve and when, timeframes, geographic and organisational boundaries and which greenhouse gases to include; and
- the methodology should allow targets to be set, on the basis of which plans for improvements can be developed.

The report advises authorities to choose the appropriate tug boat, considering the maximum power and operating profile needed. Photo Port of Antwerp

The third section discusses approaches for the quantification of carbon emissions of port and navigation infrastructure. The methodologies described allow for the calculation of emissions related to a proposed design both in terms of construction and in terms of operation. This section comprises a summary discussion with signposts to other reference documents containing more details on emissions calculation. However, it does not intend to reproduce existing guidance or to provide updates on carbon emission quantifications.

Best practices on carbon emission reduction are tackled in section four. Generally, the earlier on in the concept development, the greater the ability to select options that reduce carbon emissions from the siting, design, and implementation (construction and operation) of the project. The greatest opportunities to control carbon emissions lie in the decisions that are made in the early phases of the project life cycle. When a project alternative is selected and the plan enters the design phase, decisions regarding the physical layout of the infrastructure, the material components, and the installed equipment will restrict both the ability to reduce total emissions as well as the potential for reductions in the future during the long-term operational phase.

The fifth and last section focuses on the cost impact of the reduction program. Any carbon-emission-reduction-programme, either in construction or in operation, will be financially limited. It therefore needs to be financially optimised in order to obtain maximum reduction at a limited cost. This concept requires overall financial ranking of different technical options in a programme in which different parameters play a role. Appreciation for these parameters might differ between parties and include:

- reduction potential,
- capex intensity, and
- abatement cost.

With this guidance document, the WG 188 highlights exemplary case studies, identifies good practices in the management of navigation infrastructure, identifies opportunities to engage in carbon-sequestering activities, and summarises means to reduce the carbon footprint of the industry.

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