Deltares

R&D Highlights

Edition 2020

enabling delta life

Contents

Advisory Council

To advise the management about research and strategic positioning, Deltares has an external Advisory Council with representatives from the knowledge world and from the commercial sector. The issues addressed by the Council are long-term in nature, an example being the questions of where Deltares should invest to realise its ambitions, and of which research issues should be addressed to produce timely responses to problems expected in the future.

The members of the advisory council are:

- **Prof. dr. ir. Jacob Fokkema (chair)**, Delft University of Technology
- **Ir. Frank Goossensen**, Arcadis Nederland BV, Division Water
- **Prof. dr.ir. Wilco Hazeleger**, Utrecht University, Faculty Geosciences
- **Prof. ir. Aad van der Horst**, BAM Infraconsult, Delta Marine Consultants
- **Prof. dr. ir. Stefan Aarninkhof**, Delft University of Technology
- **Dr. Bram de Vos**, Wageningen UR, Environmental Sciences Group
- **Ir. Harold van Waveren**, Rijkswaterstaat; Water, Verkeer en Leefomgeving
- **Drs. Hans de Groene**, VEWIN
- **Dr. Ir. Anneke Hibma**, Van Oord

International Advisory Board

Deltares has an International Advisory Board since 2018. The International Advisory Board advises Deltares on the international context in which it operates and draws attention to new trends and developments.

The members of the international advisory board are:

- **Henk Ovink (chair)**, Special Envoy for International Water Affairs for the Kingdom of the Netherlands
- **Prof. Michael Berkowitz**, Rockefeller Foundation, Managing Director, 100 Resilient Cities, President
- **Prof. Dr. David N. Bresch**, Full Professor for Weather and Climate Risks at the Swiss Federal Institute of Technology, ETH Zürich and MeteoSwiss
- **Dr. Margaret Leinen**, Scripps Institution of Oceanography, Director; AGU Chair; USA
- **Dr. Claudia Sadoff**, International Water Management Institute (IWMI), Director-General
- **Bambang Susantono**, Asian Development Bank, Vice-President for Knowledge Management and Sustainable Development
- **Prof. Dr. Georg Teutsch**, Helmholz Leipzig, Scientific Managing Director, Germany

Scientific and Young Scientific Councils

Deltares established a Scientific Council in 2012. The council monitors the scientific quality of the activities at Deltares and provide the management with advice, solicited or unsolicited, about the research programme, strategic investments, scientific publications and the relationships with the universities. The Scientific Council consists of a number of Deltares staff members with international scientific reputations, most of whom are part-time university professors. Professor Jaap Kwadijk chairs the Scientific Council.

Introduction

Deltares is the independent applied research institute in the area of water and the subsurface in the Netherlands. We use our top-level knowledge to open up the way to innovative and sustainable solutions for global issues relating to the use, and the risks, of water and the subsurface. The Deltares mission is 'Enabling Delta Life'.

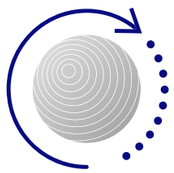
That mission is more urgent than ever and there will be no change in the coming decades: deltas are changing worldwide. As a result of migration and population growth, economic growth and geopolitical shifts, and certainly in response to climate change, rising sea levels and land subsidence. For us as a research institute, then, it is important to map out how the deltas may alter as a result of all these factors. It is only if we properly describe the possible changes in long-term scenarios that we can make the right decisions about how to respond in order to keep deltas liveable, safe and resilient.

Social agendas, both in the Netherlands and abroad, are increasingly being formulated in terms of missions. Deltares is allowing its own research agenda to reflect that approach. The social challenges and agendas have been formulated from the perspective of water and the subsurface, including infrastructure, as four 'mission areas': Future Deltas, Sustainable Deltas, Safe Deltas and Resilient Infrastructure. Those mission areas are not separate. The future studies in the Future Deltas mission area provide frameworks or direction for robust, future-proof solutions relating to current policy intentions, and measures to address issues facing society. Those solutions are elaborated in Sustainable Deltas, Safe Deltas or Resilient Infrastructure.

As an independent research institute we connect the worlds of science, applied research, government and business. This edition of the R&D Highlights provides a bird's-eye view of a number of research projects from the past year based on the four mission areas. We show how we establish connections by working with business and other research institutes and what knowledge we develop to deliver innovative and sustainable solutions to global social issues.

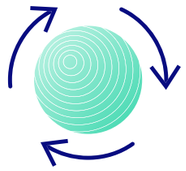
Mission areas

Future deltas



How do deltas change in response to sea level rise and land subsidence, population growth and economic growth?

Sustainable deltas



How do we ensure that ecosystems and natural resources will also be available for future generations?

Safe deltas

How do we protect the growing population and economy from extreme events linked to water and the subsurface?

Resilient infrastructure

How do we make our infrastructure resilient on land and water? Adaptive where necessary while preserving functionality.

Knowledge base

Knowledge facilities & key technologies

Key technologies, software and models, experimental facilities and data facilities

Long-term knowledge base

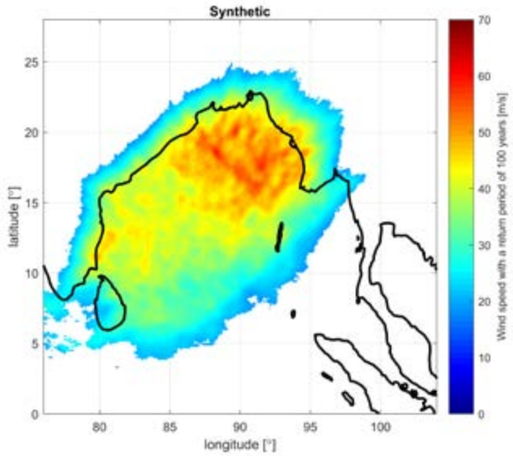
Active alliances with universities and matching for research projects

Future deltas

How do deltas change in response to sea level rise and land subsidence, population growth and economic growth? We use long-term scenarios to establish a picture of the possible consequences. By drawing on this knowledge and expertise, governments can make informed decisions, despite the uncertainties, about how to act now in order to keep deltas, as well as coastal areas and river basins, sustainable, safe and resilient. This knowledge is essential if the Netherlands is to remain the world's best protected delta in the long term and it is tremendously important for other low-lying areas worldwide.

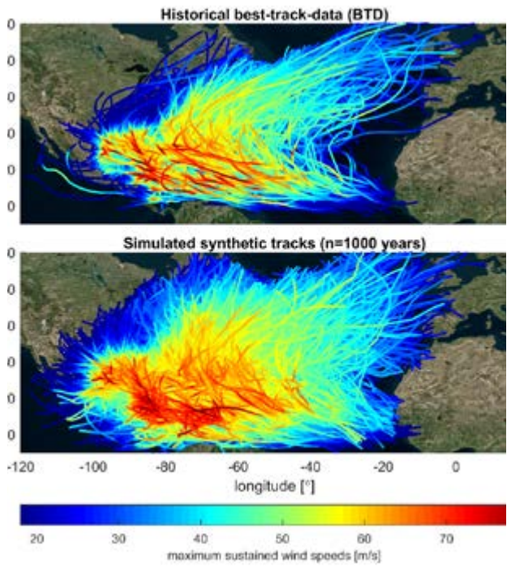
TCWiSE: generating synthetic tracks for tropical cyclones

Tropical cyclones are among the most destructive natural hazards worldwide. They cause billions of euros of damage around the globe. Tropical cyclones (also known as cyclones, typhoons or hurricanes) are low-pressure storm systems with strong winds that form mainly over warm tropical seas, which provide energy. Coastal regions are particularly vulnerable to the impact of tropical cyclones in the form of strong winds, rain, high waves (due to winds) and storm surges (due to wind and pressure). Traditionally, the derivation of design criteria for tropical cyclones has depended on the simulation of events in recent decades with numerical modelling software (such as Delft3D or SWAN). However, this approach may not deliver reliable estimates of the extremes, particularly in regions with low numbers of cyclonic events in the past.



Wind speeds with a return period of 100 years for the Bay of Bengal based on synthetic tracks

Deltares has developed a Tropical Cyclone Wind Statistical Estimation tool (TCWiSE) that can be used to provide more reliable estimates of extreme tropical cyclone wind speeds, as well as the associated hazards and risks. Reducing the uncertainty margins associated with extreme conditions allows for the derivation of more accurate design conditions and therefore more effective mitigation options and cost savings in the design.



Historical tracks and 1000 years of simulated synthetic tracks in the North Atlantic Ocean with corresponding maximum wind speeds

TCWiSE uses historical statistics for tropical cyclones to generate thousands of synthetic tracks representative for very long time scales. In other words, the tool can generate large numbers of artificial tropical cyclones and therefore help to determine the probability of a particular event. Moreover, TCWiSE can take future climate conditions into account by including the effects of climate change such as higher maximum wind speeds or cyclone frequency. With more reliable estimates of wind speeds, the tool can be used to provide more reliable forecasts of storm surge and wave heights.

The tool has been successfully applied in studies of different oceanic basins (such as the United States, Bangladesh, the Marshall Islands, Mozambique, Oman and Saint Martin). The tool and a practical application are currently being described in two journal papers: Nederhof et al. (2020, in preparation) and Leijnse et al. (2020, in preparation).

Further reading:
MSc thesis TU Delft Jasper Hoek:
http://resolver.tudelft.nl/uuid:2986959f-53ce-42a6-9299-c24833353616

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The impact of sea level rise and resilience potential in the Caribbean

Coastal erosion and beach protection on the island of Aruba

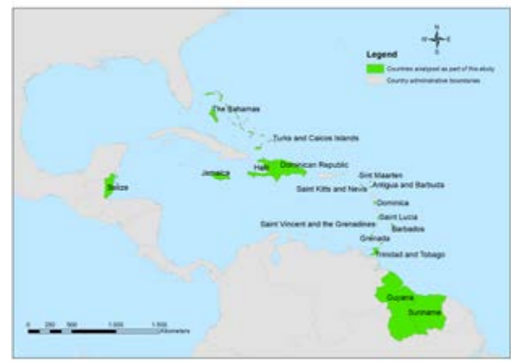
Natural hazards cause major economic damage in the Caribbean, in part because of the geophysical characteristics and location of the area: it is affected by significant natural hazards, including flooding due to storms, extreme waves and precipitation, winds, coastal erosion, earthquakes, tsunamis, tropical cyclones, volcanic eruptions and landslides.

In addition, a large part of the population, infrastructure and businesses are generally concentrated in the coastal areas. The people living here are therefore affected directly or indirectly when a disaster strikes. Economic growth can be wiped out at a stroke. For example, when Hurricane Maria struck Dominica in 2017, it caused damage and losses equivalent to 220% of the country's gross domestic product.

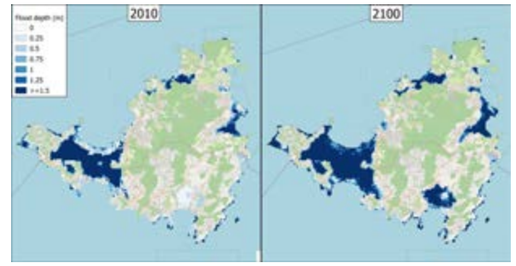
Climate change and sea level rise, in combination with socio-economic growth, are likely to exacerbate this situation, which is already critical for many of these countries. In particular, the effect of sea level rise will lead to more frequent and intense flooding and chronic coastal erosion, with a direct impact on the local economies.

In this study, Deltares and the World Bank, in collaboration with the Caribbean Disaster Emergency Management Agency (CDEMA), are assessing how coastal flooding and erosion associated with sea level rise affect seventeen countries in the region. The aim of the study is to derive proxies to estimate the resilience and adaptation potential of each country. The study will contribute to a World Bank flagship report to be published in 2021 that will focus on a holistic approach to resilience, and specifically on natural disasters and climate change in the Caribbean. The results of the study will also be presented at several global events such as the Understanding Risk Forum.

A regional modelling framework was set up for the purposes of the study that comprises a) a hazard module to estimate coastal flooding and erosion and b) an impact module to estimate expected annual damages and the affected population for each country. Information from



Overview of countries analysed as part of this study



Example of the simulated effects of sea level rise on one island (Saint Martin)

globally available models and datasets is used to derive the input conditions for this analysis (for example, Vafeidis et al., 2018; Muis et al, 2016; Vousdoukas et al., 2020). The Deltares models SFINCS (Super-Fast INundation of CoastS) and FIAT (Flood Impact Assessment Tool) are being used for the hazard assessment and they will be further developed for the purposes of upscaling the assessment worldwide.

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Safer flood: managing forecast uncertainty to improve decisions for flood control

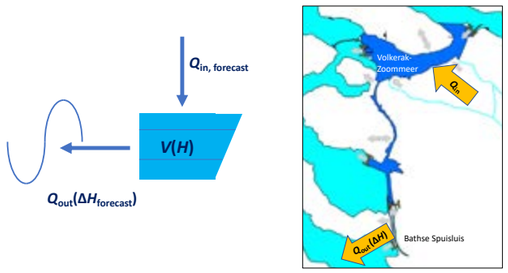
Weather forecasts are crucial for the management of water systems. For example, to prevent flooding, lake levels can be lowered when rain is predicted so that some of the water from upstream areas can be stored in the lake. However, weather forecasts are uncertain and so operational water managers often face challenging problems because they need to 'make decisions under uncertainty'.

This is particularly challenging in the case of extreme events, when water managers have little time to explore how the impact of different measures in the context of different forecasts. A software tool that can provide the basis for optimal control interventions would therefore be very useful. However, few existing tools take forecast uncertainty into account and this makes their implementation in real-time decision support systems difficult.

To overcome this decision-making problem, Deltares developed the RTC Tools software framework for model predictive control (MPC). MPC is a technique in which a model of the control system – such as a lake – uses the effects of control actions in response to a predicted future, or even a set of multiple futures (ensemble forecasts), to represent forecast uncertainty. The RTC Tools software makes it possible to set up models in which control can be rigorously optimised to inform the user of the best possible control action and the associated system response. A key benefit of the approach is that the optimal control action is computed transparently for predefined goals and priorities. Recent developments have reduced the calculation time needed for the optimal advice in relation to the combination of discrete decision variables and ensemble forecasts. The calculation time has now been reduced to the extent that the method can currently be used in operational practice.

Rijkswaterstaat's 2019 Corporate Innovation Programme financed our testing of improved ensemble-based MPC methods with a case study of flood control in the Volkerak-Zoommeer lake. A storm surge at sea can severely limit the spill capacity that is needed here to create in good time the capacity required to store a considerable proportion of the flood water the lake receives from rivers upstream. A combined assessment of the forecasts of storm surge and river floods is needed in the decision-making process. Using synthetic ensemble forecasts with scalable uncertainty bands, Deltares showed that the ensemble-based MPC methods are indeed technically ready for use in operations. Moreover, we were able to provide a nice demonstration of the fact that MPC with ensemble forecasts delivers better control than MPC with single forecasts only: the latter is prone to proposing control actions that are delayed too much if forecasts prove to be even mild underestimations. This study showed that this innovative technique is promising and that other decision-making problems under uncertainty can also benefit from it.

The Bathse Spuisluis spillway structure separating the Volkerak Zoommeer lake from the Western Scheldt estuary



Model scheme of the Volkerak-Zoommeer reservoir system with excessive water inputs and spill potential dependent on water levels at sea

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Remote sensing of river ice for flood early warning

River ice jams are a major source of flood risk in cold regions, especially during the autumn, when the river freezes, and spring, when ice breaks up. Ice jams and the associated flooding are very difficult to model and forecast accurately. Monitoring, therefore, plays a pivotal role in flood risk management. Satellite data offers flood forecasters a low-cost way to monitor river ice formation and dynamics over large areas and with high frequency.

The River Ice Teams for the Canadian provinces of Alberta and Quebec are working together with Deltares to set up operational access to Near Real-Time satellite data and develop methods to detect and classify river ice.

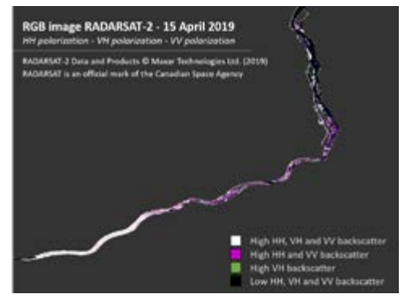
This study evaluates the potential of Synthetic Aperture Radar (SAR) data from Sentinel-1, RADARSAT-2, and RADARSAT Constellation Mission in monitoring river ice. Radar data is particularly useful since it penetrates clouds, which are often present during periods of freeze- and break-up. The radar beam of a SAR sensor can be transmitted and received horizontally and/or vertically. Most research and operational services for river ice classification are based on single- or dual-polarised data (Sentinel-1). When the radar transmits and receives data from multiple directions, it collects polarimetric data (e.g. RADARSAT-2), which increases the potential for classifying specific ice break-up features.

The Canadian RADARSAT Constellation Mission (RCM), which was launched in June 2019, offers new opportunities. RCM also acquires polarimetric data and this constellation of satellites can also cover a larger area than previous RADARSAT missions. Given that RCM was only launched last year, little is known about its potential in ice classification. This research aims to develop ice classification methods, with a focus on how the orientation of the radar influences the detection of different types of ice.

The project is supported by Deltares and supervised by experts from Natural Resources Canada (NRCan), TU-Delft, and Deltares. River ice classification methods from this initiative will be integrated into operational flood early warning systems designed by Deltares, providing a customised overview of satellite data over the rivers of interest.

This project not only provides great operational utility for flood forecasters and reservoir operators in cold regions but also demonstrates a real-time application of satellite data for decision-making. We expect that satellite-derived information can be used for advanced hydrological or hydraulic modelling of river ice.

River ice jam formation shown with optical (Sentinel-2) and (Sentinel-1) SAR data



Combinations of wave polarisations and backscatter for RADARSAT-2 data. The location of the ice jam is white due to high backscatter.

Example of plastic discharges from a river established with hydrological modelling

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Adaptative capacity of restored mangrove fringes under climate change

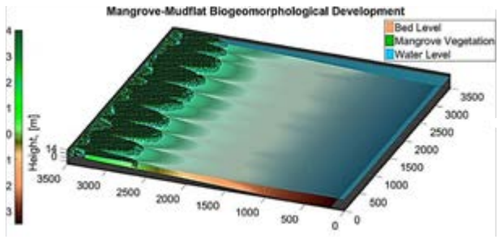
Field measurement campaign in Guyana

Uncertainties relating to the impact of sea level rise and storms, which threaten the coastal hinterland, heighten the need for design guidelines for mangrove adaptation and their use to protect coasts. The ICZM policies introduced in Guyana in 2004 pioneered a decade of restoring damaged or lost mangrove fringes to act as a buffer in front of the concrete dikes. However, to ensure the future safety of Guyana's hinterland, an understanding of the mechanisms governing the system's adaptation to sea level rise and storms is fundamental.

Üwe Best's PhD research is therefore using process-based modelling with the aim of quantifying the biophysical processes governing the geomorphological evolution of mangrove-mudflat systems with spatially explicit observations of mangrove population dynamics. For the purposes of calibration and in order to establish a clearer picture of the interactions between hydrodynamics, sediment dynamics and mangroves, field observations were collected along Guyana's coast. The fieldwork involved collaboration with, and institutional capacity strengthening at, the Ministry of Public Infrastructure and the Mangrove Restoration and Management Department.

The pilot area, which was 1km wide and 6km long, was established along the mangrove-mudflat coastline at Chateau Margot. The mud is transported in the form of mud banks from the Amazon. These banks dampen waves; in their absence, there is increased erosion, loss of mangroves, and full exposure of the dikes to waves. The modelling will improve our understanding of Guyana's complex ecosystem, create knowledge and awareness of climate change processes and help mitigate negative effects.

A two-dimensional, high-resolution, depth-averaged model of the field site was developed using Delft3D-Flexible Mesh. This model was coupled with a mangrove dynamics model capturing the development of the Avicennia germinans and Laguncularia racemosa species under suitable inundation and competition regimes. The coupled model simulates geomorphological development on the basis of the interaction between the intertidal flow, waves, sediment transport, and the temporal and spatial variation in the mangrove growth, drag and bio-accumulation over 100 years. Different climate scenarios (RCP 4.5 and 8.5 SLR) simulate the retreat and decay patterns, with modelled tipping points being found after water level increases of 1.5m. Results indicate that mangrove adaptability hinges on the long-term sedimentation responses and system conditions needed to promote the establishment of belt widths exceeding 300m.



Mangrove-mudflat bio-geomorphological development after 160 years

Üwe Best is working on her PhD from 2017 to 2021 at the IHE Delft Institute for Water Education and Delft University of Technology. She is supervised by Dano Roelvink, Mick van der Wegen, Jasper Dijkstra and Johan Reyns. Deltares and Lamminga Fund Foundation are funding the research.

Further reading:
https://www.un-ihe.org/uwe-sachelle-ntame-best

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Modelling plastic waste in rivers from source to sea

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Plastic marine pollution (plastic soup) is one of the significant environmental challenges of our times. It is estimated that 8 million tonnes of plastic enter our oceans every year, with severe impacts on both marine life and human livelihoods. Globally, most of the plastic waste comes from land because of the massive amounts of single-use plastics we use in our societies, litter dropped by people and, particularly in less developed countries, very poor waste management. Rivers are known to be key pathways for the transport of plastics from land into the oceans. However, we lack clear information about how plastic enters waterways and in what quantities, and how much plastic is discharged by rivers.

Deltares has developed a suite of tools to model the transport of plastic waste from land to the sea through rivers, integrating data on plastic waste leakages from different land sources with hydrology. Population and solid waste-management data (for example, the amounts of plastic waste generated, collected and treated) are used to estimate the amount of mismanaged plastic generated in a particular area. Any plastic waste that is not properly collected and treated can leak into the environment and be washed off into streams, rivers and lakes. From there, it can be transported downstream towards the sea unless is retained by natural or artificial obstacles, such as vegetation and dams, or removed by cleanup operations along the way.

Using hydrological models such as W-FLOW, we are simulating the hydrological flux for a specific catchment, considering the topography, elevation, soil type, land use, and spatially and temporally variable weather data such as rainfall data. The way water falls and flows on land is the main vector for the transport of plastic (and indeed , any other substance) from land into and through rivers.

As a result, we can construct a spatially and temporally variable representation of the transport and fate of plastic waste from source to sea as a reflection of specific performance levels in the areas of waste generation and management in the communities located in the catchment area. In turn, this can help governments and local authorities to tackle plastic pollution in several ways. For example, we can establish a baseline for input levels of plastic into the sea for any given year and from there track progress as waste management improves. Our approach can also help to pinpoint those communities where interventions are most needed and possibly the areas of the river where cleanup operations might be optimal.

Deltares suite of models used to simulate sources, pathways and fate of plastic pollution from land-based sources

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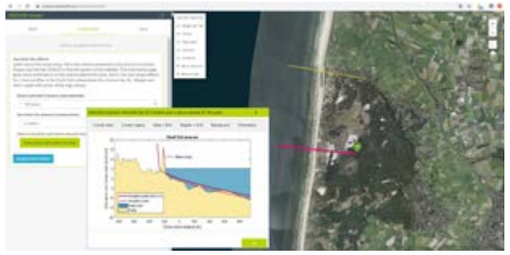
Exploring the effects of sea level rise on dunes with the ENDURE web mapping tool

Coastal dunes are found worldwide on shores where areas of coastal sand supply and onshore winds favour inland transport. Exploiting the resilience of coastal dunes to sea level rise is the new frontier in nature-based coastal defence and protection. The step from regional IPCC scenarios for sea level rise to future-resilient protection from storm surges is huge and a tool is needed for exploratory assessment.

Deltares therefore devised a mapping solution that enables stakeholders to assess their local situation in the broader context of the coastal zone on the Southern North Sea and the Channel coasts (the Two Seas region). We have also facilitated the discussion of possible future scenarios for morphological regime shifts in sandy dune coasts by delivering predictions based on a combination of morphodynamics (behaviour modelling) with wave and storm surge statistics (reanalysis data). This web mapping tool enhances sensitivity analyses of the impacts of coastal climate change and furthers the discussion of preparations for adaptation measures.

Deltares created this mapping solution *https://endure.openearth.eu/* to support the Interreg 2 Seas project ENDURE - Ensuring Dune Resilience against Climate Change, *http://www.endure.eu.com/*. The project aims to promote the role of dunes as adaptive, living sea defences: dunes naturally migrate, flex and evolve to create a self-replenishing barrier to the sea. The project partnership works collaboratively, using the best of cutting-edge science, design and innovation to develop a coastline with more natural resilience to erosion, flooding and rising sea levels.

What makes our ENDURE mapping tool special is that dune and coastline managers are using the tool to discuss the possibilities – and impossibilities – of working with natural processes to enhance the resilience of local coastal beach and dune areas. As a case study, we tested our approach on several UK, Dutch, Belgian and French coastal profiles. We found different regimes at short distances from one another, possibly as a result of coastal squeeze. The first line of defence is less critical: inner dune crest heights and dune volumes are adequate. The coastline and the dune foot remain essential in an assessment of the state of the coast but our results stress the need for dynamic dune management if we are to establish the resilient coasts needed to prepare for sea level rise and severe storms. The next step is to deploy coastline management measures to strengthen inner dunes. How to optimise the redistribution of sand is another fundamental problem on which Deltares is working in collaboration with the dune management authorities.



An example of the effects of sea level rise in the ENDURE web mapping tool

Further reading:
https://endure.openearth.eu/

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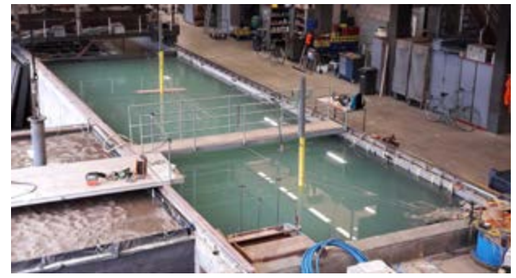
Clearing the beach after storm damage in Zandvoort (NL), 20 Jan 2018

Underwater acoustic fibre optics

Distributed Acoustic Sensing (DAS) with fibre optics is an emerging technique. It has been applied in the oil and gas industry for monitoring deep reservoirs but the technology has considerable potential for shallow applications because of its high spatial and temporal resolution. Two projects were defined for Rijkswaterstaat to investigate its potential use for several common problems. The first step was a signal test in a laboratory environment. A tank was set up in the Deltares facilities containing a sand bed with a clay cover. The tank was fitted with several fibre optic cables and filled with water.

Yellow fibre-optic cable embedded in the sand bed



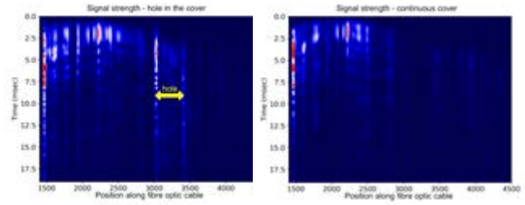
Yellow fibre-optic cables wrapped around two vertical poles

Leakage through water beds

One of the possible applications of DAS for Rijkswaterstaat is monitoring leakage in water beds. Generally, the water beds of channels are covered by a layer of clay that prevents either the infiltration of surface water or the seepage of groundwater. A possible benefit of DAS is that it could be used to monitor long stretches of water bed (100 m – 1 km) in one go with spatial resolution at the ~1 metre scale. We measured the acoustic signal in two situations: one with a continuous clay cover and one with a one-metre-long hole in the clay. Hot water was pumped through the hole in the clay layer to mimic leakage. The acoustic measurements showed a clear difference in energy between the hole and the situation with the cover.

Saltwater intrusion in freshwater bodies

Another possible application of DAS for Rijkswaterstaat is the detection and monitoring of saltwater intrusion in freshwater bodies. Knowledge about the spatial and temporal distribution of the salt is required to understand the process better and to take appropriate measures. DAS could provide spatial information in addition to the point observations of Rijkswaterstaat's monitoring network. In principle, the spatial variations in the speed of sound can be converted to spatial variations in salinity. As a first step, we measured the speed of sound with DAS in the tank under cold and hot water conditions (14°C and 35°C), which are analogues for varying salinity in real-life situations. A significant difference was found in the speeds of sound in the two conditions. The next step will be to test the technology in the field at a Rijkswaterstaat location where there is periodical salt intrusion. If this future test is successful, the technology can be applied at other problem locations as well.



Acoustic signal with and without a hole in the clay cover

Further reading:
http://publications.deltares.nl/11203677_003.pdf

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Recent advances towards consistent and automated satellite-derived bathymetry

Monitoring intertidal and subtidal bathymetry at large spatiotemporal scales using traditional surveying methods is a challenging and costly task. With the abundance of freely available satellite data in the last years and the availability of parallel processing platforms like Google Earth Engine, the automated derivation of bathymetry from satellite data appears to be a very appealing option.

There are several methods for extracting bathymetry from satellite data, including approaches for deriving bathymetry for the intertidal zone, by combining water/land boundary dynamics with the measurements of water levels. At the same time, light attenuation in a water column, as observed by optical satellite sensors, can be used to infer water depth from spectral reflectance, providing a way of estimating subtidal bathymetry.

In this study, we are developing algorithms and software tools to derive both intertidal and subtidal bathymetry from freely available satellite data. The final goal is to fuse the resulting products with in-situ measurements to generate a consistent dynamic bathymetry. Our algorithm is based on the use of spatiotemporal optical satellite data to estimate water occurrence for the intertidal zone and the use of inverse-depth methods to derive bathymetry for the subtidal zone.

Our method is implemented in the Google Earth Engine parallel processing platform and uses NASA/USGS Landsat 8 and ESA/Copernicus Sentinel-2 satellite imagery. We apply a two-step approach to remove cloudy pixels from the input data. The first step includes the filtering of cloudy images by computing the cloudiness of observed TOA reflectance over small image patches. This metric is combined with the cloud frequency estimated on the basis of MODIS data. The second step includes per-pixel cloud masking followed by algorithms for estimating intertidal and subtidal bathymetry. After the calibration of the subtidal bathymetry using in-situ measurements, the final product is a fusion of intertidal and subtidal bathymetry with high spatial and temporal resolution.

This research was partly funded by the Dutch Ministry of Infrastructure and Water Management.

It was also partly funded by the Executive Agency for Small and Medium-sized Enterprises (EASME), and the European Maritime and Fisheries Fund (EMFF), European Union, under the project EASME/EMFF/2017/1.3.1.2/01/SI2.791269 EMODnet High resolution seabed mapping.

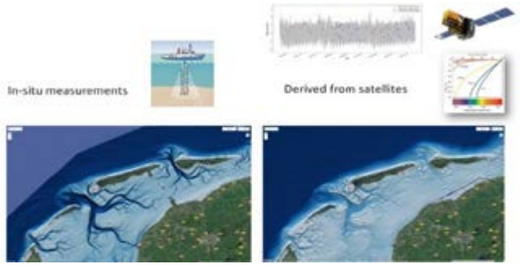
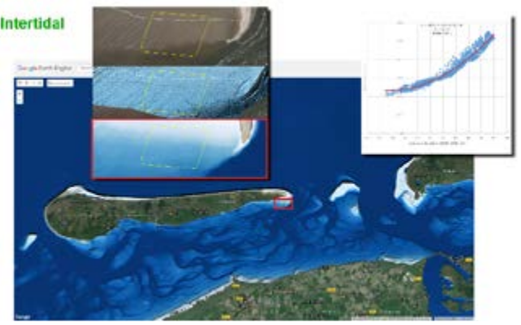


Figure 1: Vaklodingen bathymetry (in-situ data source for Dutch waters) on the left and satellite-derived bathymetry on the right. For more information: *https://gena.users.earthengine.app/view/bathymetry-from-space*



Validation of the intertidal bathymetry using AHN2 LiDAR measurements for the Wadden Sea, Netherlands

Further reading:
https://www.researchgate.net/publication/340715664_Automated_ extraction_and_fusion_of_the_intertidal_and_subtidal_bathymetry_from_the_Landsat_and_Sentinel_satellite_data-?channel=doi&linkId=5e99b66d4585150839e3ccf3&showFulltext=true

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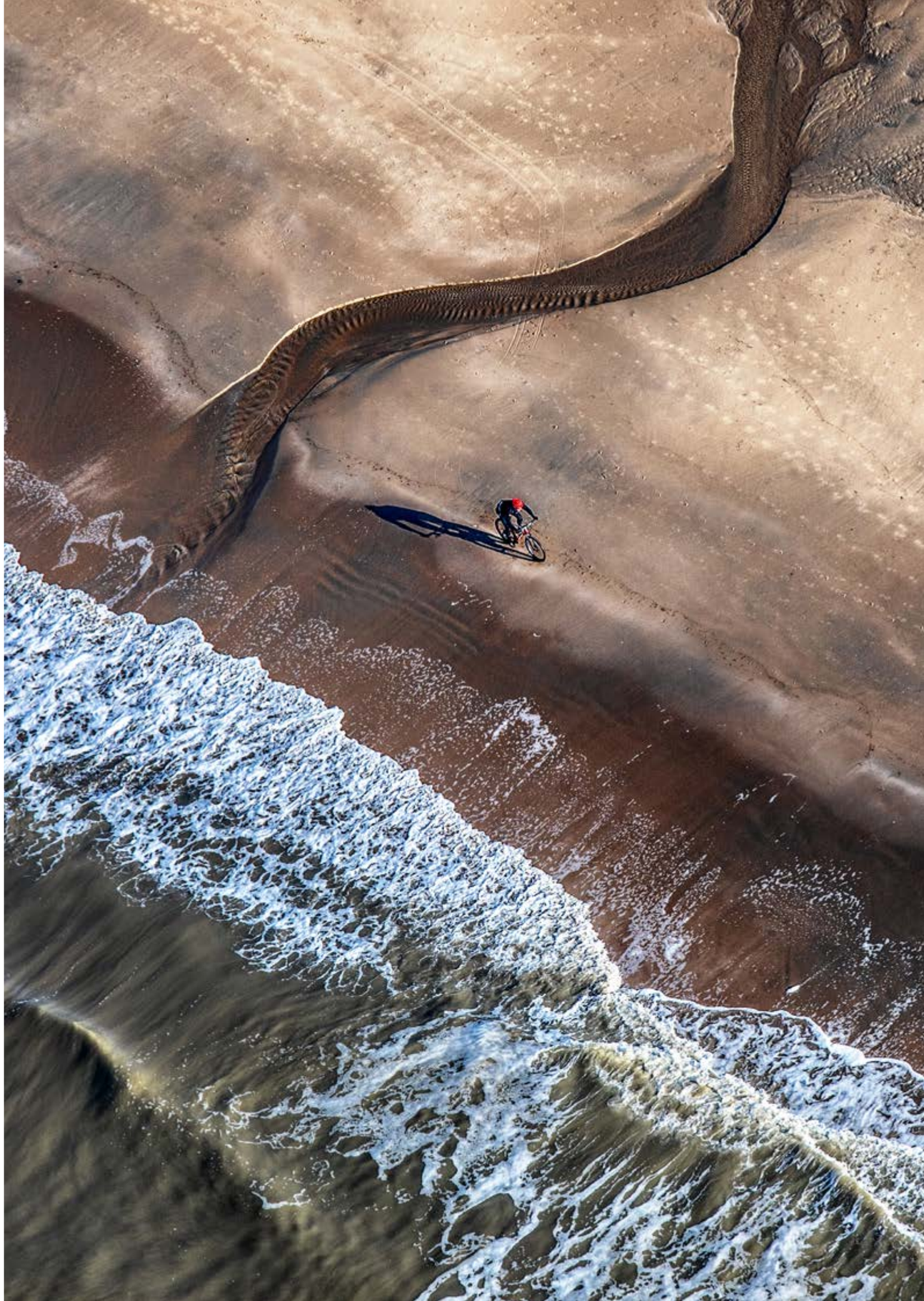


Sustainable deltas

How do we ensure that ecosystems and natural resources will also be available for future generations? Water and the subsurface play an important role in the missions for the energy transition and sustainable food production. We make our knowledge of the water, groundwater and subsurface system applicable to the design and management of regions in such a way that, for example, energy and food can be produced sustainably. How can we accommodate the challenges in the available space? When doing so, we look not only at technical, but also socio-economic, feasibility. We make it clear which decisions and dilemmas are involved and we link them to the impact on the area.

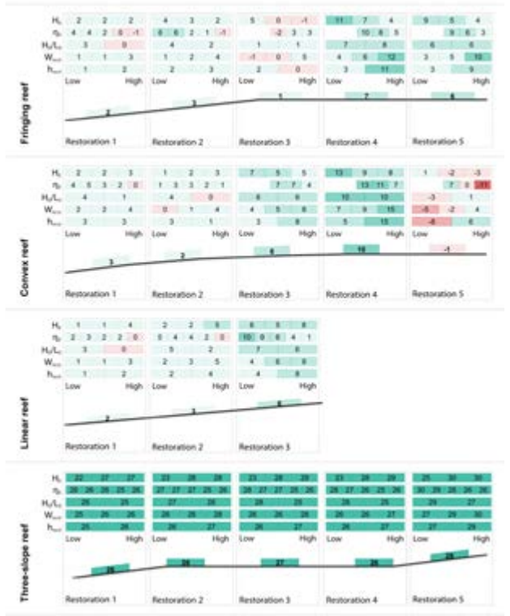
Restoring coral reefs to reduce coastal flooding

Coral reefs protect vulnerable coastal communities from flooding by damping waves. However, while reefs have been restored for ecological reasons, restoration projects to improve coastal protection have been relatively neglected. A clear understanding of efficient restoration measures could significantly improve the effectiveness of action taken by stakeholders ranging from governments, private institutes and engineering companies to individuals with the aim of improving the functioning and health of coral reefs and reducing the risk resulting from coastal hazards.

In collaboration with the US Geological Survey, Deltares investigated the restoration locations on a cross-shore reef profile that will mitigate the flood risk most effectively. A range of restoration configurations (varying in width and height) were imposed in different locations on four reef profiles. These representative reef profiles were deduced from the classification of 30,000 US reef profiles made available by the US Geological Survey, including Hawaii, Guam, the US Virgin Islands and American Samoa. The XBeach model was used to quantify the effectiveness of coral restoration approaches in terms of reducing flood risk for a range of reef profiles, restoration locations and restoration configurations in different wave and water level conditions.

The results are promising. For reef profiles with a relatively deep shelf, mean runup (a proxy for flooding) reductions of up to 30% were achieved, while for profiles that are already relatively sheltered from wave impact (such as the fringing reef profile), mean reductions of up to 10 % were accomplished. The results also showed the large fluctuation in runup reduction efficiency with different restoration parameters and local environmental conditions, highlighting the importance of well-designed reef restoration for coastal protection.

This research is the first step towards a better understanding of the effects that govern the efficiency of coral restoration and it serves as an example of how green infrastructure can be used to enhance coastal protection. The allocation of limited funds to well-designed coral restoration operations may make it possible to provide vulnerable coastal areas with the much-needed support to manage and restore their reefs.



The flood risk reduction efficiency (in % runup reduction) of different coral restorations for four reef profiles (seaward side on the left, beach on the right) in different conditions (offshore wave heights H_0, water levels η_0, wave steepness values H_0/L_0, restoration widths W_{rest} and restoration heights h_{rest}.)

Further reading:
https://repository.tudelft.nl/islandora/object/uuid:d202de1e-a1ac-4299-a36a-4747a8020da7

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Training a laptop to forecast the discharge at Lixhe

The weir at Lixhe in Belgium is used to control the water levels of the river Meuse between Lixhe and Monsin. During low flow periods, the water is released in pulses towards the Dutch part of the Meuse. The limited buffer there means that the excess water has to be diverted to the Grensmaas via the weir at Borgharen. Unfortunately, this has an adverse effect on the ecology there. As this is a Natura 2000 area, the water managers at Rijkswaterstaat urgently need operationally effective forecasts of these sudden peaks.

The current Rijkswaterstaat system for river flow forecasting uses advanced hydrological and hydraulic models to forecast discharges and water levels in the Meuse. These models forecast the day-to-day discharge at Lixhe fairly well but they do not capture the hour-to-hour discharge variations during low flow periods. The Belgian water managers do not have forecasts of the sudden peaks either.

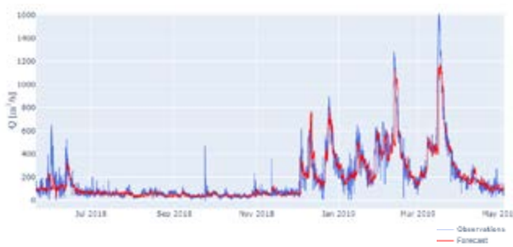
We used artificial intelligence to build alternative models for the discharge at Lixhe. The methods used were *random forest, boosting* and *artificial neural networks*. The models were trained with three years of hourly observations of the water level, discharge and rainfall in the Meuse basin upstream of Lixhe and the discharge at Lixhe itself. These models were used to produce forecasts looking one hour ahead based on a test data set covering one year. The model that performed best was the boosting method, which builds a set of rules to make predictions. During each iteration cycle, predictions are corrected on the basis of the errors in previous iteration cycles.

The boosting algorithm was used to train sub-models for 1 to 48 hours ahead that were used in turn to make forecasts up to 48 hours ahead in the test period. The selected method results in reasonably accurate forecasts of the overall tendency for the discharge at Lixhe up to 48 hours ahead. The prediction metrics are about as good as we would expect from traditional hydrological models, which is a good result. However, we were able to predict sudden discharge peaks only between 3 to 4 hours in advance. While promising, this result needs further improvement to make it more useful.

The results were discussed with Rijkswaterstaat, who find them promising as well. Further steps will follow to improve forecasting accuracy, hopefully to the extent that the method will be operationally effective.

Contributors: Carmen Martínez Barbosa, Olav van Duin, Matthijs den Toom

The Meuse and Grensmaas in the Netherlands, with the weirs at Lixhe and Borgharen



Discharge forecasts for Lixhe 48 hours ahead made with the boosting method, plotted in succession

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Marconi: studying salt marsh construction on a large scale

Established Salicornia vegetation on the seaward side of a section with a mud percentage of 20%, 10 September 2019

The Marconi pilot study is an EcoShape project. The aim is to determine the optimal conditions for salt marsh construction by varying the composition of the substrate (percentages of sand and mud) and sowing vegetation.

Salt marshes can help to improve flood risk management, nature development and biodiversity, water quality, sediment reuse and leisure facilities. EcoShape partners Deltares, Wageningen Marine Research, RoyalHaskoningDHV and Arcadis are involved in the project. Deltares and Wageningen are responsible for the fieldwork and data analysis. Other funding from the Wadden Fund is being channelled through the municipal authority of Delfzijl.

The pilot study is located on the seaward side of the embankment separating the navigation channel leading to the port of Delfzijl from the Ems estuary on the border between the Netherlands and Germany. The site consists of three experimental plots of 2.3 hectares and three of 1.8 hectares separated by permeable brushwood barriers. Clay and silt were mixed into the top metre of the sandy bed to produce areas with silt percentages of 5, 20 and 50%. Glasswort seedlings (Salicornia procumbens) were sown in a density of 50 m-2 in half of the 1.8-hectare plots

The dynamics of the salt marsh area have been monitored since November 2018 to determine the vegetation species, vegetation development, algae cover, bed level change and sediment characteristics. State-of-the-art measurement techniques were used to obtain continuous high-resolution (in minutes) measurements of the bed level using ASEDs: Acoustic Surface Elevation Dynamics and Echologgers. A LiDAR drone was used to measure the bed elevation of the entire area periodically.

A variety of salt marsh vegetation was observed as early as the first growing season. Preliminary results emphasised the importance of fine sediments. There is more vegetation growth in the test sections with higher mud concentrations. Preliminary results indicate that the ratio of 20% mud to sand may represent an optimal balance for practical construction and vegetation development. Indeed, mixing mud into sand turned out to be difficult for mud percentages above 20%.

To assess at least two growing seasons, monitoring will continue until September 2020. Knowledge collected in this project will be published on the EcoShape website by the end of 2020. Since salt marshes can adapt to changing environmental conditions such as sea level rise and changing storm conditions, the knowledge is globally relevant for the development of salt marshes and embedding them in the construction of hybrid flood defences.

Infographic describing the Marconi pilot project

An overhead drone overview of the pilot project, 8 July 2019

Further reading:
https://www.ecoshape.org/en/projects/saltmarsh-development-marconi-delfzijl/

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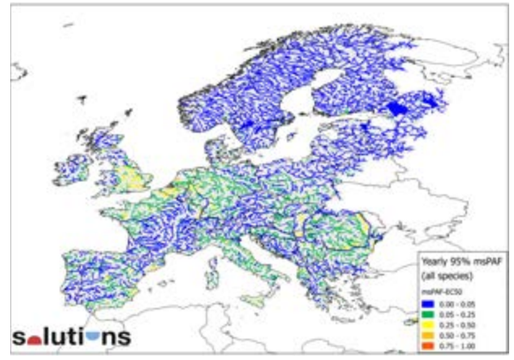
Getting to grips with emerging contaminants

A recent scientific publication reported that over 350,000 chemicals and mixtures of chemicals have been registered for production and use worldwide. Do these chemicals, or mixtures of them, represent a threat to human health or aquatic ecosystems? And if so, what can be done to prevent or mitigate those risks? Monitoring data are still lacking for most chemicals. Modelling may be a valuable additional tool for the initial screening of these substances.

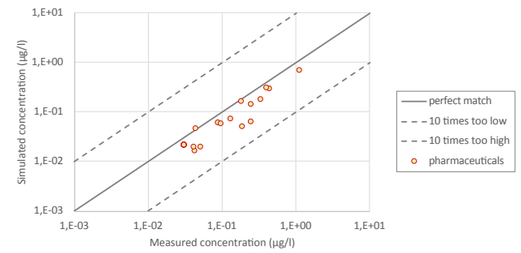
A recent scientific publication reported that over 350,000 chemicals and mixtures of chemicals have been registered for production and use worldwide. Do these chemicals, or mixtures of them, represent a threat to human health or aquatic ecosystems? And if so, what can be done to prevent or mitigate those risks? Monitoring data are still lacking for most chemicals. Modelling may be a valuable additional tool for the initial screening of these substances.

Deltares experts participated in the EU-funded R&D project SOLUTIONS (*https://www.solutions-project.eu/*) from 2013 to 2018. They coordinated an effort to model thousands of chemicals on a pan-European scale, and to estimate their effects on aquatic ecosystems. In 2019, we coupled these European models to the National Water Quality Model of the Netherlands (LWKM2.4) and the National Pollutant Release and Transfer Register (*http://www.emissieregistratie.nl/*). The aim was to determine the extent to which modelling could provide reliable quantitative information about the concentrations of a wide range of emerging chemicals in Dutch surface waters. This is essential information for national and regional water managers, not least because measured concentration data for many chemicals are still lacking. Modelling also reveals causal links between socio-economic drivers and impacts in water systems. Information of this kind is indispensable for cost-effective interventions. The Dutch water system is extremely complex due to multiple human interventions in the water cycle and the lack of gravity-driven constant flow directions. The challenge was therefore enormous.

We found that modelling can produce very useful and reliable results for pharmaceuticals provided that information about their use volume or the concentrations in waste water is available. At the same time, our findings resulted in increased confidence in the LWKM2.4 model: it apparently provides an adequate representation of the complex Dutch water system. Research into other substance groups is continuing. A better representation of hydrological processes at time scales of hours to days is required for pesticides. In the case of the broader group of industrial chemicals, quantitative information is needed about types of use. Deltares remains active in this field: we are involved in national projects, international projects and the NORMAN network for emerging contaminants (*https://www.norman-network.net/*).



Simulated mixture effect in 22,728 European water bodies of 1,785 chemicals (1,348 chemicals with various uses extracted from REACH registration dossiers, 105 pharmaceuticals and 332 pesticides), expressed as the 95%tile of the multi-species Potentially Affected Fraction of species (msPAF), based on the acute median effect concentration (EC50). This metric is expected to relate to the loss of aquatic species.



Comparison of simulated and measured averaged (in space and time) concentrations in surface waters for 16 pharmaceuticals. In this graph, every dot represents a single substance.

Further reading:
Scientific papers: DOI: 10.1002/etc.4373; DOI:xxxxpapervanGilsetal-expected to be accepted in Aprilxxxx
SOLUTIONS Policy Briefs:
https://www.springeropen.com/collections/solutions/
Report: link to KIWK report – will become available end of March

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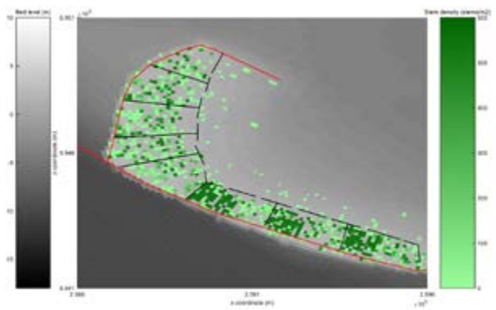
Dynamic vegetation modelling - riparian vegetation, seagrasses and salt marshes

Impression of the Biogeomorphological Modelling workshop at the Dutch Consulate in San Francisco in December 2019



The stem density (stems/m2) at the end of the growth season (October) in each cell in the Marconi marsh on the right colour bar, in line with the bed level (m) on the left colour bar. The black lines show the dikes separating the sections. The marsh was plotted using the x- and y-coordinates (m) of the domain (Van den Broek, 2020).

The rising interest in natural and nature-based solutions (NBS), as well as other ecosystem services, has created a demand for tools that can quantify the development and performance of natural or nature-based systems like salt marshes and mangroves. This quantification is used for the design and evaluation of nature-based flood defences under scenarios of climate change and therefore to establish more confidence in the long-term resilience and actual performance of such systems.

Over the last decade Deltares has worked with universities and other research institutes to develop and apply modelling tools and approaches that simulate the effects of biota in numerical models such as Delft3D and XBeach. Conversely, the impact of environmental conditions on the development of organisms has been incorporated in D-Water quality and other growth models.

In the past few years, we have developed Python-based tools for vegetation dynamics that are much faster and more user-friendly. The interface enables interaction with both relatively simple ecological models in Python scripts and more advanced models. This allows NBS to be assessed in ways that used to be too complicated and costly. In 2019 this modelling suite was applied in a wide variety of projects to widen applicability to cover several types of ecosystem.

We have worked in the EU Horizon 2020 project Hydralab+ on the development of specific vegetation species with the help of two students. Yoram Bosschenbroek simulated the dynamics of riparian vegetation in river floodplains and interactions with river bed dynamics for a river resembling the Allier (France). Leonie Akerboom studied climate-change-related feedback between seagrasses and suspended sediment in the Rødsand lagoon (Denmark). The development of the seagrass is simulated on the basis of the temperature and light environment, which depends on suspended sediment concentration.

Saltmarsh vegetation was simulated for a constructed and natural site (Zuidgors) using a process-based model including tides, waves and sediment. The vegetation development was simulated using the well-established Windows-of-Opportunity and Population Dynamics concepts.

Further reading:
Broek, J.F. van den (2020) Numerical modelling of the biophysical feedbacks of Salicornia at the constructed Marconi salt marsh.
http://essay.utwente.nl/80661/

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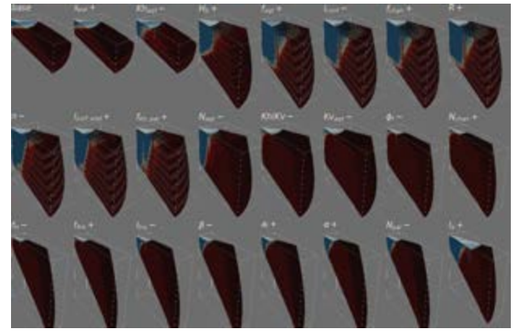
Fresh groundwater resources in coastal zones around the world

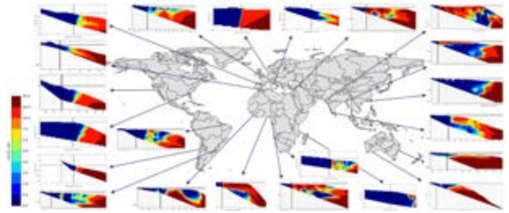
The growing population and the booming economy in deltas and coastal zones, which are often located in mega-cities, will increasingly tax existing fresh groundwater reserves. As deltas and coastal zones are already under threat from climate change (there is less precipitation in many areas) and sea level rise, the impacts of these stressors will most likely lead to the enhanced depletion and salinisation of fresh groundwater resources.

At the same time, groundwater reserves are crucial to solving the problem of future water scarcity in deltas and coastal zones in a context of increasing climate and socio-economic change. Until our technologies are advanced enough to increase supply (for instance, by using water of lesser quality) or reduce demand, fresh groundwater will be of vital importance for economic (in other words, agricultural and industrial) development in many countries. In this research, we applied state-of-the-art variable-density groundwater-flow computer code (iMOD-WQ) to estimate current and future fresh groundwater reserves and distributions in thirty major deltas and in some 30,000 coastal stretches around the world. This meant running 2D and 3D paleo-hydrogeological models in parallel computation modus in the Dutch supercomputer Cartesius. The last 100,000 to 200,000 years were simulated because the effects of very old salinisation processes can still be found in present-day fresh-salt groundwater distributions in deltas and coastal zones.

We also simulated the impacts of scenarios for sea level rise, assessed the main factors explaining these fresh-salt groundwater distributions and mapped these factors worldwide. This allowed us to increase our understanding of salinisation processes in deltas and coastal zones, and therefore to contribute to the more sustainable management of fresh groundwater in coastal areas. The knowledge gained in this project will be shared with local water authorities from countries (including Egypt, Myanmar, Spain and Vietnam) in scientific publications and in two upcoming PhD theses from Utrecht University (by Joeri van Engelen and Daniel Zamrsky). Furthermore, we expect the modelling tools and knowledge developed in these two PhD research projects to be used in future projects worldwide.



The effect of 23 hydrogeological factors determining the 3D fresh-salt groundwater distribution at a delta scale (PhD research Joeri van Engelen)



Profiles around the world with fresh-saline groundwater distribution (PhD research Daniel Zamrsky)

Nile Delta

Further reading:
https://www.deltares.nl/en/news/pioneering-research-on-global-fresh-groundwater-reserves-worldwide/
https://doi.org/10.3389/feart.2019.00339

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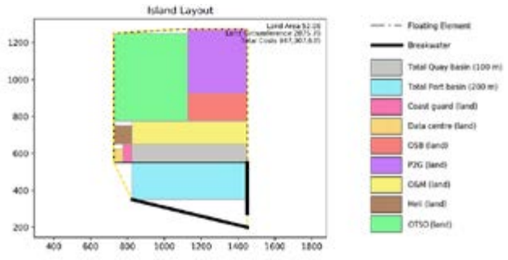
IJVERTECH: a first step towards technological feasibility for multi-functional energy hubs

Artist's impression of a multi-functional island concept (courtesy of RHDHV)

The Dutch government is currently upscaling offshore wind in the North Sea to accomplish the objectives set out in the Dutch Climate Agreement. The Dutch offshore wind roadmap until 2030 includes plans for the installation of 11.5 GW and another 35 – 75 GW in the decades to follow (RVO.nl).

At present, wind power is collected and transported to the mainland by separate offshore transformer stations. However, given the plans to upscale offshore wind, artificial islands are coming into the picture as a very serious and cost-effective option for collecting, transforming and transporting energy to the mainland. They can play a key role in this area: as hubs in a wider energy system, as locations in the infrastructure required for maintenance and operations, and as bases for other activities related to renewable energy. Using islands in this way represents a step forward in the multiple use of the available space in order to unlock the full potential of the largest Dutch source of sustainable energy in a cost-effective manner.

In a research consortium comprising Offshore Service Facilities, MARIN, RHDHV, Deltares, Boskalis and Van Oord, and with co-funding from the TKI Wind op Zee (Top consortium for Knowledge and Innovation Offshore Wind), a first exploratory study has been conducted looking at the technological feasibility of a multi-functional, small-scale pilot island. The study produced conceptual designs for three island alternatives – two with a climate-robust revetment and one with a climate-adaptive revetment – that also have a beneficial effect on the ecosystem around the structure. A rough layout of the facilities and activities that can be hosted on the island has also been developed on the basis of a series of workshops with the consortium partners, initial analyses and design



Schematic of the island layout. Colours represent different island functions

principles. The island will have to be approximately 25 hectares (500 x 500m) in size to facilitate a windfarm of 1GW. There will be space for electricity transformer stations, a power2gas plant, facilities for operations & maintenance, an offshore supply base, a heli platform, a coastguard station and a data centre.

The results of this study can be used to demonstrate the potential of an artificial island hub as an interesting alternative to facilitate the upscaling of offshore wind in conjunction with other North Sea functions and users. The results are preliminary but they establish the groundwork needed to consider this option and demonstrate the need to support further research.

Further reading:
https://offshoreservicefacilities.nl/

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Testing selective withdrawal at IJmuiden with advanced measurement techniques

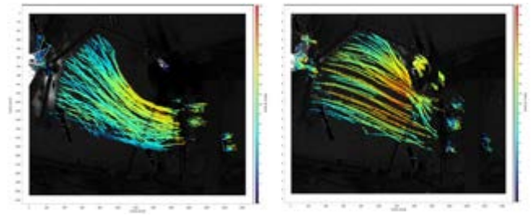
Rijkswaterstaat is building the world's largest sea lock at the entrance of the North Sea Canal in IJmuiden to allow the larger vessels of the future to sail to the Port of Amsterdam. As a consequence, a larger volume of salt water will enter the North Sea Canal after each lockage cycle, with adverse effects on agriculture and drinking water in the region.

Rijkswaterstaat aims to remove the extra salt from the larger lock by selectively withdrawing salt water using the pumping station and the discharge sluices in IJmuiden. A screen with an opening at the bottom will be built for this purpose at the entrance to the Binnenspuikanaal so that mainly salt water (which is heavier than fresh water) will end up at the discharge sluices and pumping station.

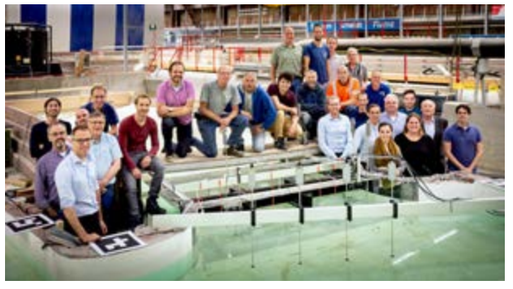
Earlier numerical simulations performed by Deltares (Delft3D and detailed CFD) have shown that selective withdrawal near IJmuiden is effective in terms of reducing the salt impact on the North Sea Canal. However, due to the complex nature of the flow patterns around the salt screen –a highly 3D flow and flow separation around the southern bend – physical scale model tests were necessary to validate the numerical CFD model. The validation of a numerical model for this complex flow behaviour is crucial in order to use the numerical models to assess the effectivity of the salt screen.

Physical scale model research was performed in the Lock Facility at Deltares. The reference design of the salt screen as created by Royal HaskoningDHV was tested at scale 1 to 40. The research focused on the flow patterns around the screen in the presence of a stratified density distribution (in other words, salt water at the bottom and fresh water on top).

◀ Location of the selective withdrawal screen in IJmuiden



Left: Particles trajectories and velocity at the interface between salt and fresh water. Right: Particles trajectories and velocity in the salt layer



Deltares project team

Advanced measurement techniques such as PIV and 3D PTV were used in this project. An optical technique, Particle Image Velocimetry (PIV) was used to characterise the flow through the screen by tracking small laser-illuminated particles added to the flow. The same technique was used by our experts at Deltares to track the flow patterns in a large area upstream of the salt screen and investigate the amount of flow separation at the southern bend. The concept behind both techniques is that the transportation of particles by the flow can be used to derive flow velocity and flow patterns.

The results of this research have shown that the CFD model is well able to provide an accurate representation the flow patterns around the salt screen as measured in the physical scale model.

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The Marker Wadden: Finance and procurement of innovative infrastructure

The Marker Wadden are an archipelago of nature islands that have been built to restore ecological quality and biodiversity in the Markermeer lake. The islands provide a diversity of habitats (above and below the waterline) and they help to solve the turbidity problems in the lake by trapping sediment and using it as a resource to build these and future islands.

The construction of the Marker Wadden started in 2015. The current project is nearing completion and with that, the first 500 hectares of islands will be in place. Preparations and plans for the second phase of the Marker Wadden – the intention is to double the area of the islands – are currently being developed.

The Markermeer lake, a Natura 2000 site and a valuable ecological and recreational asset, is located to the north of the Randstad, a region that includes Amsterdam and Almere. Nature in the region is under pressure and so there is a threat of restrictions in spatial development as a result of the enforcement of nature legislation. This means that improving natural values in the Markermeer lake is necessary for future socio-economic and spatial development in the region.

This study drew on the Financing Framework for Water Security approach, as well as serious gaming techniques, to anlayze this large-scale pilot project. The resulting insights can be used as a basis to advance a collaborative process for the drafting of a financing and implementation strategy for upscaling. The strategic goals of the public and private partners of the project were compared to the actual services delivered by the project. Different services delivered by this project where identified, valued (according to potential revenue streams) and matched to the beneficiaries. Additionaly, an indication of the reliability of the service delivery was assessed by using the technological readiness level metrics.

The study i) illustrates the importance of understanding in advance the desired and expected services delivered by the project, ii) confirms the need for a clear hierarchy in service delivery in order to understand trade-offs and prevent conflicting interests, and iii) emphasises the usefulness of understanding the uncertainties affecting the desired services for the proper allocation of risk to the public, private and operational partners. Government funding has been vital for Marker Wadden phase 1 but this type of project allows for a more blended finance approach in which scarce public sources can be used strategically to leverage private financing in parallel with the further development of public-private partnerships. These insights are useful for the upscaling of the Marker Wadden but they can also be valuable for other nature-based and innovative infrastructure projects.

Further reading:
Altamirano, M. A. (2019). Hybrid (green-gray) water security strategies: a blended finance approach for implementation at scale. Background paper Session 3. Roundtable on Financing Water, Regional Meeting Asia Manila, OECD
https://www.oecd.org/water/fifthmeetingoftheroundtableonfinancingwater.htm

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The Marker Wadden from above (Source: EcoShape 2019)

Assessing building damage from subsidence and groundwater lowering

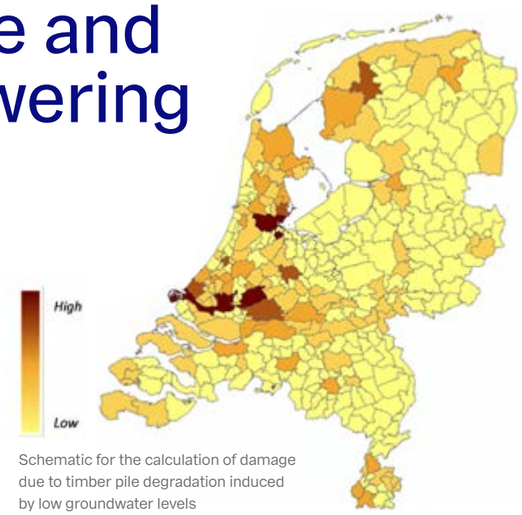
The subsidence of peat and clay soils due to the lowering of the groundwater table and the loading of soft soils is commonplace in the Netherlands. It causes extensive damage to exposed and vulnerable assets such as infrastructure and buildings. Awareness of subsidence-related damage to buildings has increased recently in the Netherlands, particularly after reports of damage attributable to the 2018 drought.

However, despite this being a major concern for homeowners and public authorities, there was no clear, systematic large-scale method on the regional or national scale to assess the spatial extent and potential magnitude of the risk. Nevertheless, this information is key to developing awareness and informing concrete and meaningful action. In this project, we developed an approach and implemented it in the Netherlands as part of the National Knowledge Programme Water & Climate – Climate Resilient Cities. The results of the drought risk analysis are available on the website *www.klimaatschadeschatter.nl*, which provides climate risk information for individual municipal authorities to support the development of climate risk strategies.

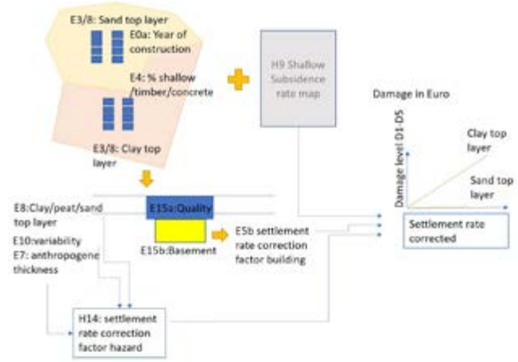
In this study, we addressed two subsidence-related damage mechanisms to buildings: the differential settlement of buildings on shallow foundations and timber pile degradation due to low groundwater levels. We built three modules for each damage mechanism based on the conceptual framework of Hazard – Exposure – Vulnerability, in which:

- Hazard describes the events causing damage: in this case subsidence and/or low groundwater levels;
- Exposure is an inventory of the building assets at risk: the probability of buildings on shallow foundations being exposed to differential settlement, or of buildings on timber piles being exposed to fungal pile degradation; and
- Vulnerability defines the level of physical damage (architectural, functional and/or structural) to the buildings at risk.

The underlying database allows for a plug-and-play type of application. Initially, it is based on expert judgement, and validation with the available local and detailed information, while allowing for future improvements. Changes in individual factors that contribute to damage can be seamlessly integrated for the systematic development of damage estimates.



Schematic for the calculation of damage due to timber pile degradation induced by low groundwater levels



Spatial distribution of expected damage due to timber pile degradation and the differential settlement of buildings on shallow foundations until 2050 (without climate change)

At this stage, the uncertainty associated with different contributory factors is still high and further research is ongoing to reduce knowledge gaps relating to the description of the hazards as well as the exposure and vulnerability of the buildings.

Further reading:
https://piahs.copernicus.org/articles/382/577/2020/
Costa, A.., Kok, S., Korff, M., 2020. Systematic assessment of damage to buildings due to groundwater lowering-induced subsidence: method

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Safe deltas

How do we protect the growing population and economy from extreme events linked to water and the subsurface? We describe the risks of extreme natural phenomena such as drought, flooding, extreme erosion and landslides. We provide tools for predicting and managing risks in the context of crisis and disaster management. This also includes the consequences of extreme geological events such as tsunamis and earthquakes due to land subsidence. Our work here includes an emphatic focus on the infrastructure we need for protection against extreme events.

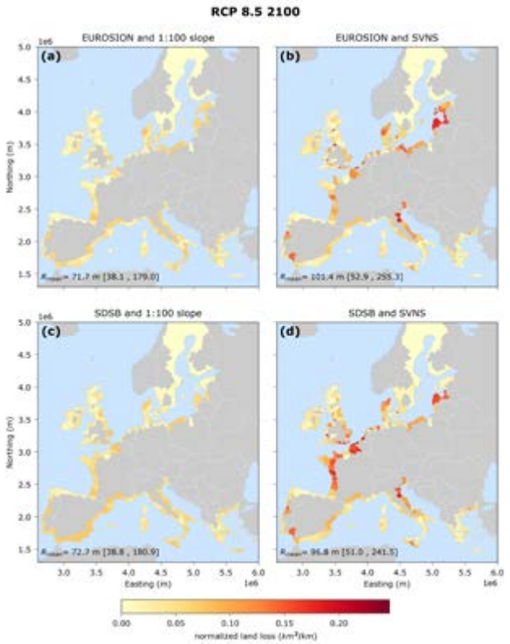
Coastal erosion due to sea level rise in Europe

Sea level rise is already happening, and it is projected to accelerate in the future. It will cause the erosion of sandy shorelines and the loss of valuable land on all our coasts. Until now, land loss estimates at the European scale have neglected both the spatial distribution of sandy coasts and the natural variability of the nearshore slope.

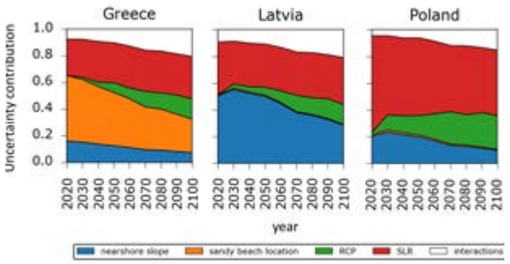
This study, which is part of the EUCP project financed by the European Commission, quantified the uncertainties relating to the selection of geophysical datasets. Two existing datasets (EUROSION and the Deltares Shoreline Monitor) were used to estimate the location of sandy beaches. A new dataset for the variation of the nearshore slope on the European coast was derived from global topobathymetric data and compared with the assumption of a constant slope of 1:100 that has been generally used until now. Projections of sea level rise during the present century and in two future scenarios (RCP 4.5 and RCP 8.5) were used to estimate shoreline retreat due to sea level rise. The land-loss estimates were then aggregated for each European region (at the NUTS3 level, which is roughly equivalent to the provincial/regional level) and Member State.

The analysis showed that the average potential shoreline retreat of sandy beaches on the European coastline between now and 2100 is expected to be about 100 m in the severe RCP 8.5 scenario, and half that in the moderate scenario. However, as can be seen in the maps, the spatial distribution of the land loss from region to region can vary considerably. The uncertainty relating to the selection of the geophysical data can account for almost 45% of the total uncertainty in the projection of shoreline retreat projections for 2050. This figure is 25% for 2100.

This role played by this uncertainty can vary from country to country, as can be seen in the examples of Poland, Greece and Latvia. In the case of Poland, uncertainties in the projections of sea level rise and the RCPs accounted for almost all uncertainty. In case of Greece, the data describing the sandy beach locations were the most important factor, while in the case of Latvia the definition of the nearshore slope was the most significant factor in the uncertainty of land-loss projection. This type of information can be useful for EU countries for the purposes of prioritising the datasets that require improvement in order to estimate future land loss more accurately, and therefore to help improve adaptation strategies.



Regional normalised land loss in EU for each data combination



Contribution to uncertainty by decade for Greece, Latvia and Poland

Further reading:
Athanasiou, P., van Dongeren, A., Giardino, A., Vousdoukas, M., Ranasinghe, R., and Kwadijk, J.: Projections and uncertainties of sandy beach loss due to sea level rise at the European scale, EGU General Assembly 2020, Online, 4–8 May 2020, *https://doi.org/10.5194/egusphere-egu2020-10149, 2020*

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The AlgaeRadar has come of age

Nuisance and health risks caused by toxic blue-green algae (aka cyanobacteria) are familiar to leisure visitors and bathers in natural pools or lakes. In addition to the disruptive effect on leisure activities, excessive blue-green algae concentrations in surface waters can cause many other severe water-quality problems such as oxygen depletion and fish mortality.

Early warning and mitigation based on accurate forecasts of algae concentrations are extremely useful for water authorities and managers of bathing waters. In the past, there have been various attempts to predict algal blooms using complex numerical process-based models. Despite the high temporal and spatial resolution, these models did not yield satisfactory results. Deltares developed the AlgaeRadar recently as an alternative and more successful approach.

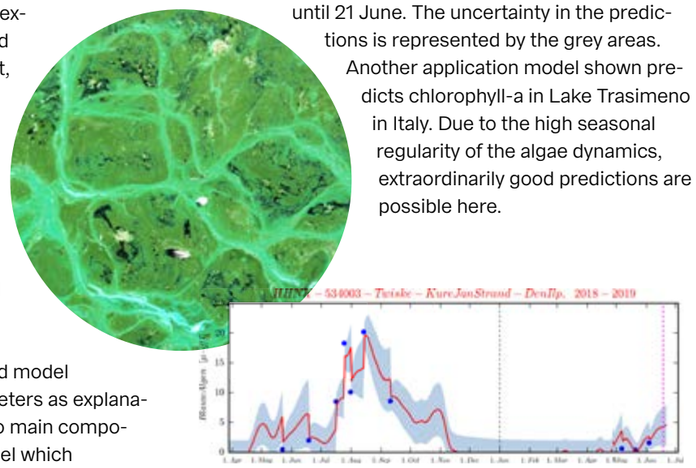
The AlgaeRadar is a fully data-oriented model with measured meteorological parameters as explanatory variables. The tool consists of two main components. The first is a deterministic model which addresses the temporal variability of blue-green algae during the season. The second is a stochastic model which, through a combination with on-site measurements, allows the AlgaeRadar to adapt to changing conditions, and therefore to improve short-term predictions.

An AlgaeRadar can be developed for virtually any water system where blue-green algae concentrations have been measured for at least five years. The frequency of these measurements should not be less than once every one or two weeks.

In 2019, the prototype was further validated and significantly improved in the context of the European project EOMORES. The improvements consisted of the addition of a “Blue-Green Algae Climate” time series as additional model input and the inclusion of uncertainties.

Applications used in the Netherlands and elsewhere have demonstrated the practical relevance of the AlgaeRadar. Moreover, a prototype version has been developed for the Dutch water management authority HHNK. It is being used quasi-operationally at various bathing locations in the ‘t Twiske leisure area.

The results from an AlgaeRadar application for blue-green algae predictions at Kure Jan Strand in ‘t Twiske (The Netherlands) are shown. The ‘actual time’ TA in this run is 18 June 2019. The blue dots denote the measured blue-green algae concentrations before TA. The solid red curve shows the AlgaeRadar predictions until 21 June. The uncertainty in the predictions is represented by the grey areas. Another application model shown predicts chlorophyll-a in Lake Trasimeno in Italy. Due to the high seasonal regularity of the algae dynamics, extraordinarily good predictions are possible here.



AlgaeRadar predictions of blue algae concentrations at Kure Jan Strand in leisure area ‘t Twiske in the Netherlands.

AlgaeRadar predictions of chlorophyll-a concentrations at measurement location TRS35 in Lake Trasimeno in Italy.

Further reading:
https://www.deltares.nl/app/uploads/2016/10/Flyer-AlgaeRadar-predicts-harmful-algal-blooms.pdf

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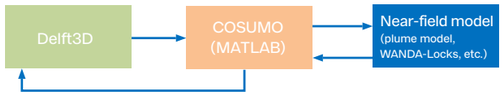
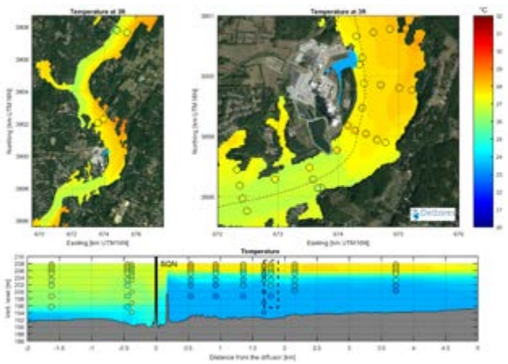
Solving multi-scale problems by coupling models with COSUMO

An integral assessment of the environmental impact is often required for the sustainable development of coastal infrastructure. Assessments of this kind are often complex and they depend on the interaction of land, water and man-made impacts on the system. However, these complex systems are typically assessed in multiple stand-alone assessments, even though interactions between these different assessments may be relevant.



COSUMO coupling framework



Comparison of coupled model results and measurements

To assess the impact of the cooling-water outfalls of large nuclear power plants in highly dynamic ambient conditions, Deltares developed a protype dynamic coupling method in 2012 in order to describe the interaction between plume models (which describe dispersion close to the outfall) and Delft3D4 (which can be used to simulate dispersion further away from the outfall). This study demonstrated the added value of dynamically coupling models for outfall dispersion since this approach allows for the correct assessment in a single simulation of the behaviour of the effluent under ambient hydrodynamic conditions with strong variations. This initial study resulted in the decision to set up a more generic interface: COSUMO.

COSUMO (Coupled Subgrid Modelling) is a generic interface that dynamically couples different numerical models for an integral and time-efficient modelling assessment. Applications vary from the modelling of cooling-water dispersion from power plants through to salt intrusion associated with lock operations and assessments of dredge plumes assessments. By comparison with multiple stand-alone individual models, an approach involving the dynamically coupling of models allows for a more integral assessment in which more physical relations are preserved. It also allows impact assessment studies to be more accurate and less conservative.

A key project was completed in 2019 that highlighted the capabilities of COSUMO in practice involved multiple nuclear power plants in the United States. Delft3D4, a plume model and a plant capacity model were coupled dynamically to set up a forecasting system for the environmental compliance of the cooling-water discharges. This allowed from the assessment in a single integrated modelling system of the potential impact of all processes on environmental compliance (such as hydrodynamics, meteorology and man-made impacts like hydro dam operations, and the use of cooling towers). As a result, mitigation measures can be triggered in good time to minimise the potential impact.

Since 2016, COSUMO has been successfully applied in over fifteen projects. They include various impact studies for other power and desalination projects, as well as salt intrusion assessments for the locks at Panama and IJmuiden. These successful, wide-ranging, applications of COSUMO underline the importance of software development, in this case the maturing of the software from initial proof-of-concept in 2012 to practical and stand-alone applications in environmental impact assessments.

Further reading:
https://www.deltares.nl/en/news/unique-first-world-3d-modelling-forecast-thermal-discharges-tennessee-river/

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Damaged containers floating in the North Sea (source: Kustwacht Nederland)

The MSC Zoe accident: assessment of North Sea conditions

In the night of 1 to 2 January 2019, the container vessel MSC Zoe lost a large number of containers in an area north of the Dutch Wadden Islands. The incident had a major ecological and social impact on the Wadden Islands, particularly Ameland and Schiermonnikoog. Following the incident, the Dutch Safety Board (Onderzoeksraad voor Veiligheid, OVV) initiated a technical investigation and asked the Dutch knowledge institutes Deltares and MARIN to contribute.

The objective of the investigation was to determine how exceptional the local conditions were during the incident and how those conditions, in combination with the main vessel specifications, may have contributed to the risk of losing containers in the area. Deltares studied the local conditions and MARIN the way the ship responded. The two research institutes worked closely together, sharing essential information related to their own specific areas of expertise.

The southern sailing route north of the Dutch Wadden Islands is known to mariners because it includes shallower sections where complex sea states can occur due to shallow water-wave interactions. Using state-of-the-art operational models and historical metocean databases, Deltares determined the metocean conditions that MSC Zoe encountered on its voyage: waves, winds, currents and water levels. These results have been validated on the basis of the available historical data, and there is therefore a high level of confidence in the model results.

Deltares provided MARIN and the OVV with the information about the metocean conditions during the storm of 1-2 January 2019 along the southern and northern sailing routes. Deltares and MARIN then discussed which combinations of conditions needed to be considered further

MSC Zoe after the incident (source: Kustwacht Nederland)

in a scale model study to assess the resulting vessel motions. This scale model study was conducted by MARIN considering a typical container vessel representative for the MSC Zoe class of container vessels.

In the light of the findings from both MARIN and Deltares, the OVV issued a warning for large container vessels using the southern sailing route above the Wadden Islands. The complete findings of the OVV are expected to be published in the spring of 2020. The outcomes of these studies will help to make container transport in the North Sea safer in the future.

Further reading:
https://www.onderzoeksraad.nl/en/page/13223/overboord-geslagen-containers-msc-zoe-1---2-januari-2019

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Should we regulate the Waal?

The drought of 2018 demonstrated the vulnerability of the Rhine's inland waterway network. Climate change is likely to affect river discharges given the increased probability of dry periods. To maintain reliable shipping traffic on the Waal river, control structures have been proposed in the past and they will now be proposed as a possible measure by some. However, a radical measure of this kind needs to be evaluated thoroughly given louder calls from society as a whole for the sustainable management of our natural resources taking all stakeholders into consideration.

The expert panel (during the closing remarks)

We worked with and for Rijkswaterstaat on the formulation of a careful approach to address this large and controversial topic. The first step was the development of a roadmap that describes the relevant questions that need to be answered in order to determine whether or not control structures are a viable option. After thorough consultations with the client, it was decided that a wide-ranging expert panel would provide the most valuable input at this stage of the research. Furthermore, it was thought that the discussion between the different experts would generate input that would be valuable for the identification of sensitive or unknown topics. We therefore organised a workshop for this purpose.

The workshop consisted of multiple discussion rounds to identify the maximum possible number of research questions and potential approaches from multiple backgrounds. This included an emphasis on "What" and "How" questions. The most important questions from the experts were, unanimously: what transport function should the Waal deliver now and in the future; and can the natural river deliver that? This apparently simple question requires a deep understanding of economic developments and the interaction between the natural system and logistical sector. On the basis of that understanding, it could be possible to determine whether the problem is significant enough to justify a feasibility study that takes all functions into consideration. It is not unlikely that the sheer size of the measures required to regulate the Waal could limit the potential solutions, as can be proved with a quick calculation. Finally, in their concluding remarks, the experts emphasised the need for careful assessment and for the early inclusion of all disciplines.

The results of the workshop were set out in a report with an overview of the relevant literature on the topic. The opinion of the expert panel was included in the formulation of follow-up research questions that will help Rijkswaterstaat in the assessment of the water-based infrastructure.

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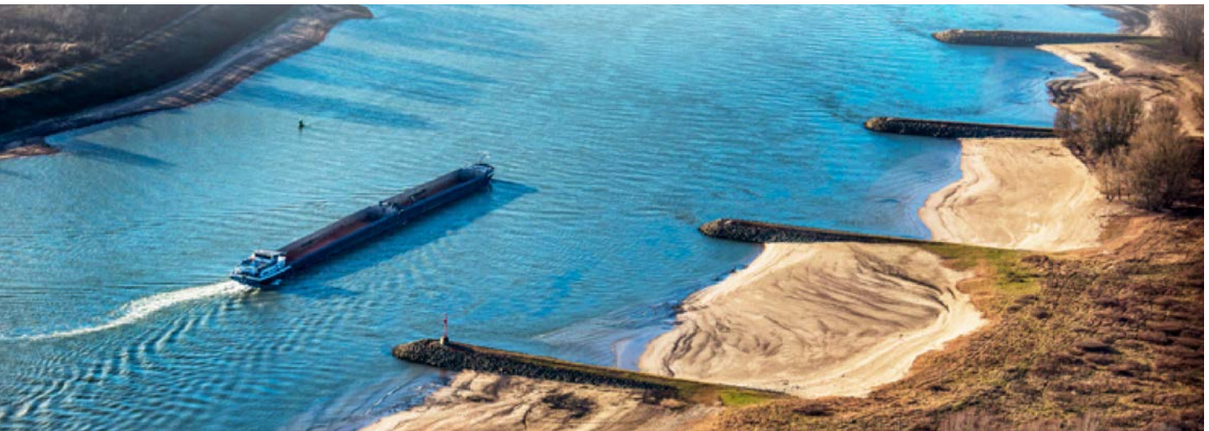


Scalable tools for assessing road disruption: direct and indirect impacts

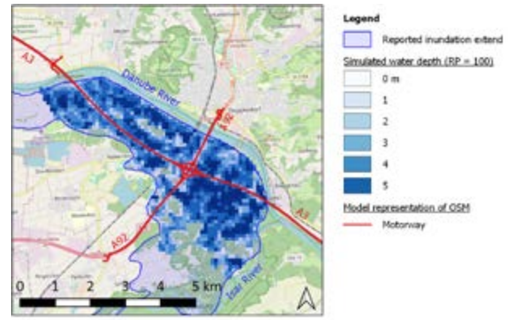
The road infrastructure in Europe provides essential services for European society and the economy, transporting freight and millions of people daily. The disruption of this vital network by river floods inflicts major damage and it will be more frequent given climate change.

Traditional grid-based models for flood risk cannot describe disruption accurately or account for the typical network characteristics of roads. On the contrary, reduced mobility can largely exceed the cost of physical damage. To address these issues, we developed a new object-based model for the European Union project COACCH (CO-designing the Assessment of Climate CHange costs) with the aim of assessing both physical damage and the disruption of road functionality.

From the tiny alley behind a house to Europe's largest ten-lane motorways: the new model calculates the current potential physical flood damage in different climate scenarios for each road in OpenStreetMap. We have also developed a new set of damage curves (linking water depth to damage) which makes optimal use of the available metadata in OpenStreetMap. For example, the metadata helps to distinguish between an inundated road and a bridge over a river. It can also predict that a motorway with expensive electronic signalling may suffer more damage than a simple road without these features. The model was successfully validated for a flood event that inundated a large cloverleaf junction in Deggendorf, Germany.

Furthermore, we developed a scalable approach for the assessment of the overall connectivity of the road network and how it changes as floods disrupt critical links. The method has been implemented in the Criticality Tool, the development of which began at Deltares in 2019 to assess the critical network behaviour of systems. Increased connectivity distance, time and/or costs can be assessed. The validity of the analysis has been demonstrated at the country level in Austria and used to identify potential tipping points when a combination of limited flood events leads to a disproportional disruption of the network. This supports different resilience perspectives, including those of the asset owner – *what are the vulnerable parts of my network?* – or the supply chain disruption – *what are the weakest links in my supply chain?* – to a specific economic sector or company.

The methods developed are scalable and flexible: they can be extended to include multiple hazards (including landslides, earthquakes or pluvial flooding), multiple countries, aggregation levels, other transport modalities (in other words, multimodal transport networks can be represented with the same methodology) and sources (OpenStreetMap or road data provided by end users).



Model validation for a historic flood event in Deggendorf, Germany

Identification of tipping points: floods simultaneously disrupting Austria's main corridor and 26% of the optimal routes for the country's NUTS-3 connectivity.

Further reading:
Paper: van Ginkel, K. C. H., Dottori, F., Alfieri, L., Feyen, L., and Koks, E. E.: Direct flood risk assessment of the European road network: an object-based approach, Nat. Hazards Earth Syst. Sci. Discuss., *https://doi.org/10.5194/nhess-2020-104, in review, 2020*

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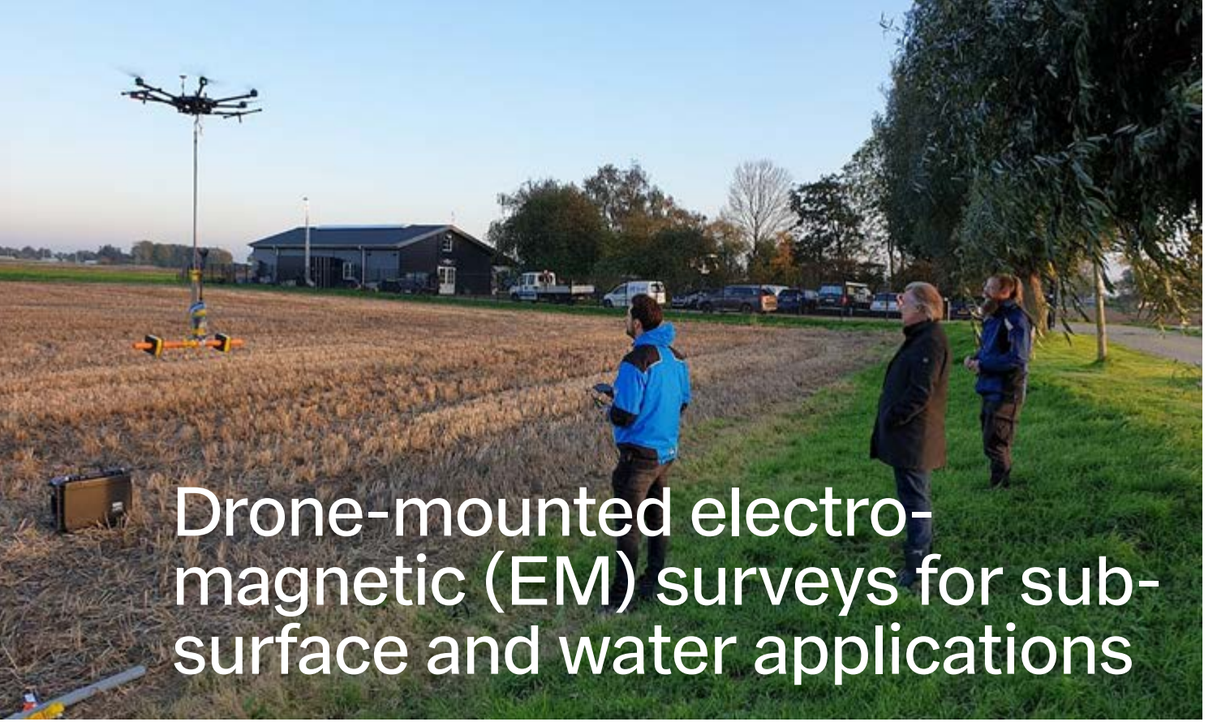


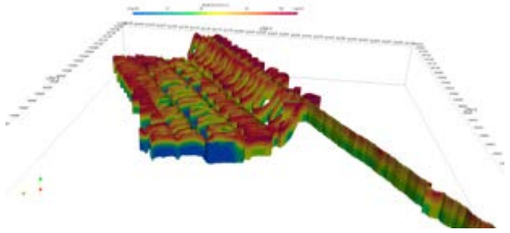
Drone-mounted electromagnetic (EM) surveys for subsurface and water applications

Test of a drone-mounted EM tool

Subsurface conditions play a significant role in many projects involving water management, infrastructure development and the construction or improvement of dikes. Traditionally, borings and CPTs are used to characterise the soil through sampling and descriptive modelling. Borings and CPTs are essentially point measurements and the accuracy of the subsurface characterisations depends on the density of measurements with respect to the scale of variation in the subsurface.

Geophysical surveys can give continuous 2D or 3D interpretations of the subsurface and support the interpolation of borings and CPTs. Deltares developed a drone-mounted electromagnetic (EM) surveying system given the niche for EM surveying and monitoring based on the following reasons:

- **Pro:** Drone-based EM surveying will be faster than land or water surveys and it can work better in less accessible terrain; Con: a drone cannot fly in some areas because of flight restrictions.
- **Pro:** the spatial (and temporal) resolution of drone data will be higher than airborne data (2 m^2 versus 100 m^2); Con: the coverage of data acquisition is higher with airborne systems (50 km^2 a day as opposed to 1 km^2 a day)
- **Pro:** regularly (weekly to monthly) repeat surveys/monitoring of small areas is affordable due to the acceptable mobilisation costs of drones by comparison with airborne surveys. Future developments in the area of autonomous drone flights could reduce the costs and mobilisation effort even further; Con: this is not true of larger areas; mobilisation costs can then be shared.



Results of a drone-mounted EM survey to map fresh/salt distribution in shallow groundwater in a polder area. Blue colours (low resistivity) show saline water, red colours (high resistivity) fresh water.

Tests were conducted in 2019 to determine the interference of the EM signal by the drone. A structure for mounting the EM device on the drone was designed on the basis of these tests, and flight stability and piloting were tested. It was found that the chosen design functioned as expected. The drone-mounted EM survey system was then tested further in two different areas for:

- salt-fresh groundwater resources mapping/dynamics
- surface water quality mapping/dynamics (measurements of rivers/canals)
- agriculture mapping/dynamics (soil condition, moisture)
- dike mapping/monitoring to assess internal structure and processes
- mapping geological/morphological resources (sediment/clay/sand/minerals/...)

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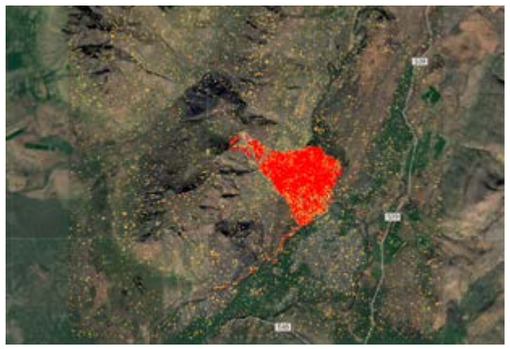
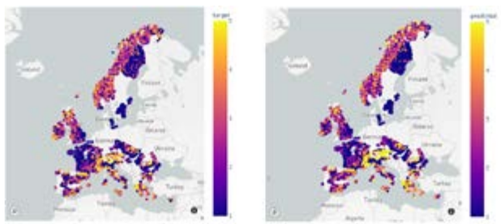
Spatio-temporal forecasting of landslides on regional to global scales

Where and when can landslides occur? This was the overarching question in our research into landslide forecasting. We adopted a data-driven framework that required high-quality/quantity landslide data. This proved to be the major challenge driving the research studies presented here.

A landslide inventory is the basis for any statistics-based landslide analysis. Given the difficulty of the manual delineation of past landslides, semi-automatic landslide detection is an appealing option. This was accomplished by building and training Machine Learning (ML) algorithms for optical bands of Sentinel 2 images to detect historical landslides with more than 80% recall and precision. More information can be found in the recent MSc thesis (by Meylin Herrera Herrera) from Delft University of Technology: "Landslide Detection using Random Forest Classifier". To address the limitations of optical images (such as the effect of atmospheric conditions), a follow-up study developed a SAR-based landslide detection algorithm using Sentinel 1 data. The framework developed in these projects will be used for generating landslide inventories for well-informed landslide hazard zonation in data-scarce areas.



SAR-based landslide detection: Iceland landslide in July 2018 (22.127 W, 64.791 N)



Deep Learning model for landslide susceptibility mapping

Landslide Susceptibility Mapping (LSM) is the spatial zonation of a region based on the likelihood of landslide occurrence. Reliable LSM requires a landslide inventory and a description of the associated controlling factors such as terrain features and land cover. A lack of accurate data leads to uncertainties in the zonation map. To overcome this challenge, we developed an AI framework in which a landslide susceptibility map of Europe was used as a reliable source of data to train a Deep Learning (DL) model for quick LSM. The trained DL model, which was tested on hold-out regions across Europe, can identify landslide-prone areas with more than 85% recall. In the future, we will evaluate the performance of the model for other regions in the world. It is expected that the accuracy of the DL model will increase over time as it is fed with more reliable susceptibility maps.

Knowing when a landslide may happen is equally important for decision-makers and residents of landslide-prone areas. To make this possible, we developed a global ML-based forecasting model for rainfall-induced landslides. A global spatio-temporal landslide inventory was established to this end at Deltares and augmented with data about controlling factors and with satellite-based rainfall data. The results showed that model performance was promising, delivering more than 70% accuracy. In the future, we will expand the dataset to include more accurate landslide data and improve the performance of the forecasting model.

The following researchers contributed to these research studies: Faraz S. Tehrani, Giorgio Santinelli, Carmen Martinez Barbosa and Amine Aboufirass.

Further reading:
Tehrani, F.S., Santinelli, G., Herrera, M., 2019, “A framework for predicting rainfall-induced landslides using machine learning methods”, ECSMGE 2019, Iceland:
https://www.ecsmge-2019.com/uploads/2/1/7/9/21790806/0521-ecsmge-2019_tehrani.pdf

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Fast reliability analysis for complex geotechnical models

Probabilistic models need to be made more efficient in order to keep up with time-consuming, state-of-the-art, geotechnical models including finite element models (FEM). Furthermore, probabilistic analysis is being used more and more to optimise designs or demonstrate compliance with safety standards.

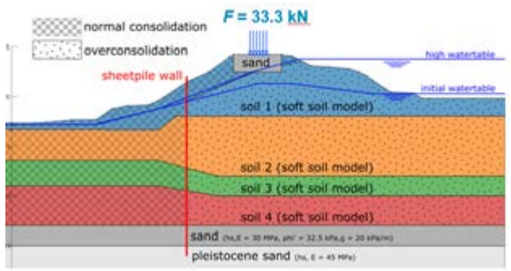
However, traditional methods for reliability analysis do not work well with state-of-the art geotechnical models because of excessive computing times (Monte Carlo) or inaccuracy (First-Order Reliability Method - FORM). Deltares and Delft University of Technology therefore developed the ERRAGA toolbox (Efficient Reliability Analysis for Geotechnical Applications).

The ERRAGA project involved the development of a Python toolkit specifically for the challenges typically encountered in geotechnical practice with FEM models for low failure probabilities. These geotechnical models have many variables and typically take minutes or hours to run for one model evaluation. Highly non-linear and noisy behaviour can also be expected.

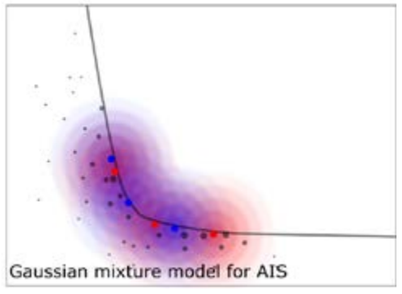
ERRAGA met these challenges by using meta-modelling in combination with machine learning techniques. A meta-model is a simpler, faster model that is trained to replace a more complex model in order to save computational time while maintaining reasonable accuracy. This is done by using a limited number of random model evaluations and smart interpolation between the computed points. An example is the use of a limited number of geotechnical model evaluations (represented by points and determined by varying the tangent of the friction angle) to construct two meta-models of the resulting bending moment in the sheet pile (represented by lines) that are used to predict when the limit state (maximum allowable bending moment Mmax) is exceeded.

Interpolation in ERRAGA draws on Gaussian Mixture Modelling and Kriging algorithms that incorporate machine learning and correlation patterns in the interpolation. The reliability analysis can be performed very quickly with the meta-model. The ERRAGA Python toolkit is used in combination with the Deltares Probabilistic ToolKit (PTK) for the probabilistic computations and to couple it efficiently with external geotechnical models. An example of the interpolation based on Gaussian Mixture Modelling for the AIS (Automatic Identification System) is also illustrated. The dots are the model evaluations that are used to determine the meta-model (line). The shaded blue and red areas show the zones of influence of individual points using this method. This approach reduces the number of model evaluations required to around 100, a lot lower than in traditional methods.

ERRAGA therefore brings the practical application of probabilistic analysis for challenging geotechnical models one step closer. More verification and application to cases will be needed to demonstrate its applicability further.



Example of a Finite Element Model, Plaxis, that is used to compute the probability of the maximum bending moment in a sheet pile in a dike being exceeded.



ERRAGA example of interpolation between samples using Gaussian Mixture Modelling for AIS

Further reading:
van den Eijnden, A.P. , T. Schweckendiek, M.A.Hicks (2020). Metamodelling for geotechnical reliability analysis with noisy and incomplete models. Revision submitted to Structural Safety

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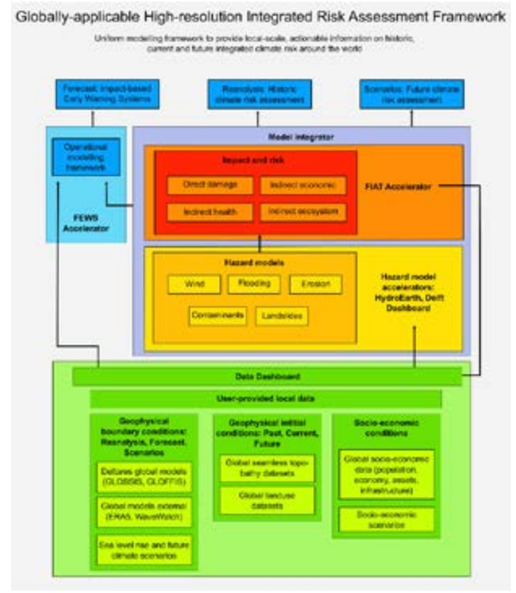
GHIRAF - rapid risk assessment anywhere in the world

The impact of extreme weather events on coastal areas around the world is set to increase in the future due to sea level rise, climate change (increasing storm intensity, rainfall and droughts), and continued development and investment in hazard-prone deltaic and coastal environments. Given the changing natural and socio-economic environment, accurate predictions of current and future flood risk are becoming increasingly important world-wide to mitigate risks.

Recent advances in computational power (as with cloud computing) and data availability (the increase in satellite-derived products, for example) are enabling, for the first time, the development of global-scale flood-risk models for application in areas where local models are less well developed or prohibitively expensive, or for applications where a global synoptic coverage is important. Despite the increasing granularity of these global models and datasets, they often still lack the resolution and accuracy to be "locally relevant", especially where inundation and impact assessments are considered. While a solution to this problem is to downscale global models and datasets to the local scale, setting up local models is hampered by inconsistency between underlying datasets and the required manual effort to generate downscaled integrated risk models inhibits their global application. To address these issues, we are developing a generalised risk assessment framework called GHIRAF (Globally-applicable High-resolution Integrated Risk Assessment Framework), which couples data and models to quickly provide locally-actionable information on the impact of historic, current and future world-wide extreme weather events (such as storms, extreme rainfall and drought). The framework is designed to support world-wide efforts to reduce and mitigate risks associated with extreme weather events by aiding prevention (scenario testing, design) and preparation (Early Warning) for extreme events, as well as support response (targeted relief efforts) and recovery (build-back-better) efforts.



Schematic view of the design of GHIRAF

Comparison of the global damage assessment model with NASA satellite image

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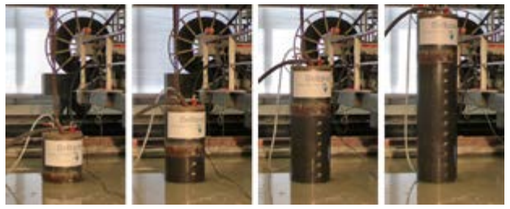
Resilient infrastructure

How do we make our infrastructure resilient on land and water? Adaptive where necessary while preserving functionality? Infrastructure on water and land, but also waterways, is affected by climate change. Deltares identifies the bottlenecks, making intervention possible. The cost-effective and sustainable integration of infrastructure is paramount here. We map out the effects of existing and new infrastructure on the area so that design, construction, management and maintenance can be optimised, while making use of natural processes as much as possible.

Sustainable decommissioning of offshore wind turbine foundations

Offshore wind farms are being built in large numbers to meet the ever-increasing demand for renewable energy. However, wind farms have a limited lifetime. The offshore turbines currently in place, for example, were designed with a lifetime of 25 years. The owners of wind farms, such as energy companies, are therefore required to remove wind turbines from offshore locations when the turbines reach the end of their operational life.

That requires the full or partial removal of foundation structures such as monopiles. Removing the piles in full is more sustainable, economical, and less hazardous in terms of Health & Safety than partial removal. It avoids, for example, underwater cutting and no steel is left behind in the seabed. The Hydraulic Pile Extraction Scale Tests (HyPE-ST) project – a one-year R&D Joint Industry Project executed as part of the GROW offshore wind research programme – looked at the sustainable removal of offshore wind turbine foundations (monopiles). It focused on both fundamental understanding and demonstrating the feasibility of hydraulically extracting monopiles for decommissioning .



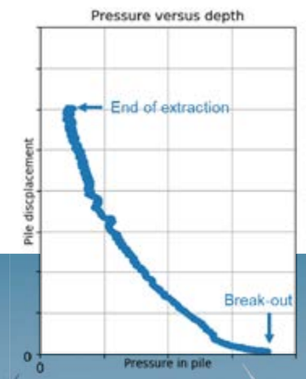
Test pile being hydraulically extracted

Pile removal by hydraulic extraction involves sealing the pile after removing the top structure (in other words, the wind turbine) and pumping water under pressure into the hollow structure, forcing the pile upwards. Before using this method in full-scale operations with expensive vessels and equipment, it was important to understand the pile-fluid-soil interaction in different soil types more clearly. A testing campaign was therefore conducted as part of the HyPE-ST project. A prototype monopile with a diameter of 8 m was tested at scales of 1:20 and 1:30 in the Deltares Water-Soil Flume facility. Four different soil conditions were used: medium dense sand, dense sand, medium stiff clay, and layered soil. The piles were installed by impact driving. During the extraction process, several parameters were monitored, including pressure, flow, pile displacement and plug displacement.

The HyPE-ST project demonstrated the feasibility of the hydraulic extraction method at the tested scales for a variety of soil configurations. The next step of this research will involve testing at a larger, more representative, scale and possibly offshore.

The HyPE-ST project is part of the GROW programme. It is a joint industry initiative involving Innogy, Deltares, DOT BV, IHC IQIP, Jan De Nul Group and the ECN part of TNO. The project received financial support from the Energy Top Sector of the the Dutch Ministry of Economic Affairs and Climate.

Contributors: Thomas Balder, Dirk de Lange, Dirk Luger, Etienne Alderlieste, Marcel Grootenboer, Marcel Busink and Ahmed Elkadi



Pressure and pile displacement

Offshore wind turbines, North Sea, UK (© Adobestock.com)

Further reading:
https://grow-offshorewind.nl/project/hype-st

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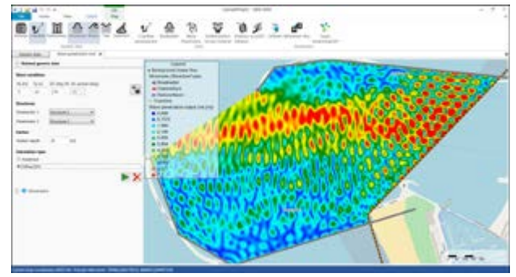
CoDeS: an interactive and integrated design platform for coastal infrastructure

The early design stages for coastal infrastructure typically involve the use of several basic tools to assess and optimise technical feasibility. However, as a rule, these tools are not developed in consistent and reproducible ways. Moreover, the proper validation and integration of various design aspects are often lacking, as is uniform and clear visualisation. Coastal Design and Support (CoDeS) aims to overcome these issues by providing an open-source platform for the consistent development of integrated, interactive and well-validated tools. It supports the early-phase design of coastal infrastructure, as well as interactive design sessions, education and communications with different stakeholders.

Deltares developed CoDeS in three Joint Industry Projects (JIPs) with Royal HaskoningDHV and Witteveen+Bos, with financial support from Dutch 'TKI Delta Technology' subsidies. CoDeS is unique because its generic platform allows tools to be easily embedded using Python code. This key feature has made it possible to jointly develop CoDeS with several coastal engineers from the consortium partners without the need for software development knowledge. The framework is connected to an automated test bench and it is subject to version control to make it robust, validated and reproducible.

The CoDeS platform comes with a graphical user interface (GUI) that allows users to interact easily with the tools. Users can manage, view and apply various types of data, while linking to global datasets. All data are consistently available in all CoDeS tools to guarantee consistent analyses and assessments. This means that, when a design is modified on the basis of tool results, all the other tools are updated immediately, enhancing interactivity. The current version of CoDeS (2.0) focuses on the development of new and existing ports and it implements the following tools:

- Coastline development
- Breakwater design
- Wave penetration
- Flow fields
- Access Channel Sedimentation
- Harbour Basin Siltation
- eCoDeS (ecological assessments)



Wave penetration tool showing wave patterns in a port

Breakwater design tool, cross-section of breakwater design and layers

The images found on this page (better referencing later based on page layout) show the wave penetration, breakwater design and flow fields tools. They visualise the penetration of waves into a port layout, the required dimensions of a breakwater and live interactive flow patterns during the design of port breakwaters. CoDeS provides this information in just seconds, and it has proven its value in various preliminary design assessments, interactive design sessions and tender documents of the consortium partners.

CoDeS 2.0 is fully open-source and it can be obtained by following the link below. The consortium partners invite anyone who is interested to download, use and possibly expand CoDeS, while joining our growing CoDeS community!

Further reading:
https://publicwiki.deltares.nl/display/CODES

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Optimising quay wall design by studying jets from propellers

Ship propellers generate high flow velocities near quay walls, jetties and locks. Generally, bed protection is installed to prevent instability as a result of scour. Although there are design guidelines, propeller-induced loads are far from fully understood and current design methods are often thought to be conservative. Given the limited validation of the design methods in place, a series of new field measurements were conducted in November 2018 and in June 2019 with the aim of establishing a clearer understanding of the near-bed flow field and verifying the applicability of the design methods currently in use. Improvements to design guidelines and the reduction in costs for bottom protection will generate large savings for many kilometres of infrastructure.

The field measurements were conducted at the Antarcticakade in the port of Rotterdam, a quay wall for inland vessels where the nautical water depth is approximately 7–9 m. The flow velocity induced by the main propeller of a tugboat was measured during the first measurement campaign. The aim was to determine whether it was possible to measure propeller-induced velocities accurately using a simple and flexible measurement setup that could be installed by a small crew. The measurements showed that the test setup used here was practical and feasible. However, the situation considered was not representative for the design loads on the bed protection.

During the second measurement campaign, a more normative situation was considered using the inland vessel Vorstenbosch (Length = 147.5 m, beam = 22.8 m and draught = 5.4 m), which is the largest inland vessel presently available in the Netherlands. The Vorstenbosch has two channel-type bow thrusters. This type of bow thruster was selected because no clear design guidelines are yet available for this type. Two situations were considered during the measurements: a bow-thruster-induced jet in the direction of the quay (reflection) and a jet in the direction of the port basin (free flow). In addition, different underkeel clearances were considered and the effects of using one and two bow thrusters were studied.

The field tests showed that near-bed flow velocities were much smaller than predicted by current design practice, indicating that there are possibilities to optimise bed protection designs in the future. This research project was a joint initiative by Rijkswaterstaat, the Port of Rotterdam Authority, Deltares, Delft University of Technology, the City of Rotterdam, Boskalis, Deme, and CROW. Research will continue in 2020 with the aim of making further improvements in design guidelines for bed protection.

Measuring the main propeller jet of a tugboat

Measuring the bow thruster jet of the largest inland vessel in the Netherlands

Installation of the measurement equipment

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Assessment of the residual service life of sheet piles

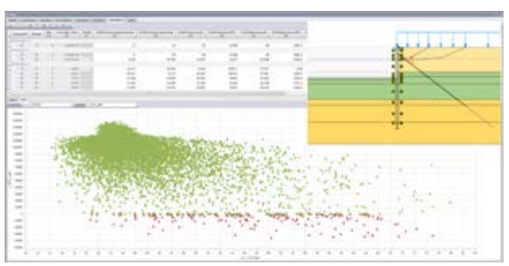
In the research programme “Hydraulic Structures” , Deltares, TNO, MARIN and Rijkswaterstaat are developing knowledge and tools that will allow the efficient and cost-effective replacement of over 200 large hydraulic structures (locks, weirs, etc.) in the Netherlands in the coming decades. The estimated costs for replacing these structures between now and 2030 are around 20 billion euros.

Steel sheet piles are profiled steel plates used for retaining soil and water. They are often key structural elements in hydraulic structures. The Dutch Ministry of Infrastructure (Rijkswaterstaat) is responsible for the asset management of over 800 kilometres of steel sheet pile structures on the banks of freshwater bodies. Optimising the assessment of the residual technical service life of these steel sheet pile structures could result in major savings.

The strength of steel sheet piles degrades over time as the thickness of the sheet material is reduced (due to corrosion). Corrosion involves high levels of uncertainty: exact corrosion values are hard to predict and there are large variations in time and place. However, the remaining wall thickness of the sheet piles is the dominant factor that determines the end of the technical service life.

Working with partners from industry, Deltares has focused the development of knowledge about steel sheet piles on the following areas:

1 Obtaining and analysing actual corrosion data from sheet piles exposed for a long period, such as steel sheet pile sections taken from the Eefde lock (in the Twentekanaal). The collected data and the resulting insights have been used as input for a Dutch code of good practice for corrosion and to produce a proposal for an updated safety philosophy.



Screenshot of the Deltares software ‘Probabilistic Toolkit’, which was used here for the reliability analysis of a sheet pile structure

Ultrasonic measurements of the remaining wall thickness of 80-year-old sheet piles by TNO and Deltares

2 Accurate (theoretical) predictions of thickness reduction are currently impossible. Inspections and thickness measurements are therefore essential for the asset manager. Deltares drafted an inspection protocol and an analysis tool for thickness measurements so that measuring and interpretation can be standardised and consistent.

3 Assessments of remaining technical service life are closely related to assessments of the reliability of the structure in relation to statutory requirements. To assess reliability in more detail, existing design and assessment tools have been coupled to the generic Deltares software ‘Probabilistic Toolkit’.

4 There has been further research (using finite element calculations) looking at the mechanical interaction between soil and slender, corroded, steel sheet piles to determine the extent to which soil can suppress local instability effects (buckling).

Further reading:
www.nattekunstwerkenvandetoekomst.nl (Dutch only)

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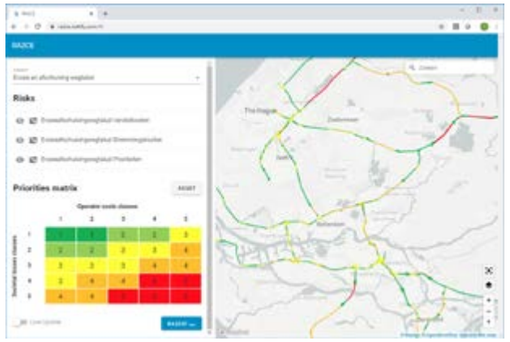
Stress testing the Dutch motorway network

The Dutch national road authority (Rijkswaterstaat) has stated its ambition to establish a climate-resilient road network by 2050. To attain that objective, Deltares developed and conducted a stress test with the aim of identifying the effect of future climate conditions and associated weather extremes on the Dutch motorway network.

Schematic view of elements of the stress test



Screen dump showing the RA2CE prioritisation module

In the first phase of this test, hazards were identified and the corresponding exposure of the motorways and vital elements like bridges and tunnels was assessed and mapped. In the second phase, we calculated the vulnerability of the motorways (assessing the damage and recovery costs) as well as the cascade effects on road users (losses due to delays incurred by road users due to the partial or full obstruction of the motorway).

The stress test looked at a total of thirteen hazards, including flooding due to intense rainfall, uplift of tunnels and light materials, dike breaches (river and coastal flooding), heat expansion of bridges, heat effects on road foundations, drought-, nature- and roadside-related fires and road deformation caused by soil subsidence.

There were no hazard maps for some of the hazards. We therefore used RI2DE (Risk Indicators for Infrastructure in Data-Scarce Environments), a tool we developed in-house. This tool identifies the susceptibility of infrastructure networks by combining several information layers relating to assets and infrastructure, and publicly available data about the environment. With RI2DE, we were able to map locations that are susceptible to the erosion of embankments and the effects of roadside fires.

By combining the maps that show the exposure of the road to the various hazards with the RA2CE tool (Risk Assessment and Adaptation for Critical InfrastructurE), we were able to determine the costs associated with the different hazards, now and in future scenarios. The RA2CE tool also makes it possible to combine repair costs (damage) with the road user losses (delays) interactively to prioritise hot spot locations for every road segment in the network.

The stress test was conducted in close collaboration with Rijkswaterstaat. The outcomes are being used by Rijkswaterstaat to evaluate the risks of disruptive events, identify effective measures and improve the climate resilience of future motorway network structures. This requires a dialogue with the Rijkswaterstaat districts, asset managers, governance and road specialists (in relation to the design standards that are used). Dedicated information packages have been produced for this purpose on the basis of the stress test results.

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Climate adaptation measures: modelling your own backyard

3D visualisation of the flooding caused by a rainfall event (source: ToekomstSterk)

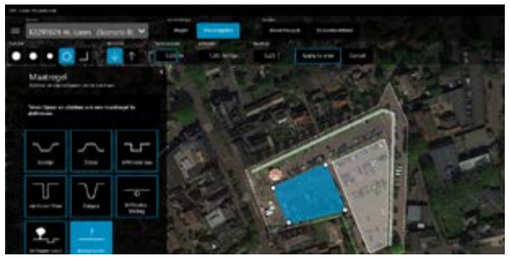
Heavy rains led to flooding in the town of Laren in the Netherlands. In response, the local authority announced the “Laren Rainproof” programme, which includes a wide range of measures to improve climate resilience.

Deltares is working with the ToekomstSterk engineering company, which has developed a technical master plan involving an array of infiltration, storage and sewerage measures using hydrological models from Deltares. A complicating factor is that a significant number of the rainwater infiltration and storage measures will have to be located on private land and the question is therefore how to mobilise the owners of the land to agree with interventions on their property. This requires a careful dialogue with the residents to ensure that they are involved each and every step of the way.

One of the steps taken to achieve this was the development of an interactive computer simulation model that visualises the effects of potential measures on people’s property. The tool is flexible in the sense that different measures can literally be drawn in and the effects can be calculated on the spot. The visualisations are in 3D, allowing people to see their own houses and land.

The project is technically challenging because it requires an innovative coupling between game engine software and the Deltares D-Hydro FM software.

Another challenging factor is the use of the approach in a participation process. Individuals, or groups of residents, are brought together to discuss the problem. The tool shows the inundation effects of rainfall events, indicating where the water accumulates, and where problems may occur. The second step is to discuss, draw in and calculate potential measures. Showing the


Potential measures can be drawn in and calculated on the spot (source: Deltares)

results triggers discussion and new ideas for different, additional and complementary measures. This procedure continues until there is a consensus about one or more designs. The resulting designs will be thoroughly checked and analysed afterwards by a group of experts and improved where necessary. If a design proves impractical, the residents are invited again to make changes. Once the design has been finalised, implementation of the plan follows. The municipality has agreed to pay for the measures, which is an important prerequisite for success.

Once this first round has been completed, the next group of residents will be invited, and that process will continue so that Laren can enhance its climate resilience step by step.

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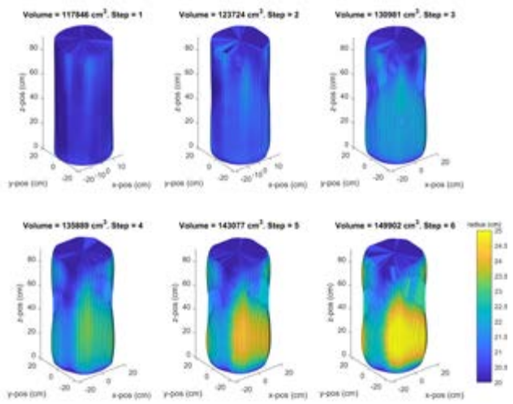
Novel technology for 3D deformation measurement in triaxial testing

The aim of the "Taaie dijken" (Ductile dikes) project is to improve the safety assessment of dikes by accounting for residual strength. The residual strength is the remaining resistance against flooding after the geotechnical failure of a dike. Improving the residual strength and therefore the creation of ductile dikes requires a sound understanding of the strength of the subsoil and dike body under large deformation.

Contour detection for one camera position for the artificial non-uniform sample

Typically, strength parameters for soil, including the dike body, are derived from laboratory tests and triaxial tests in particular. The analysis shows a considerable difference between the analysis of triaxial test data with a small strain approach, in which the stress and strain are linked to the original sample dimensions, and a large strain approach in which stress and strain are linked to the actual dimensions. In addition to the stress definition, the analysis of triaxial test data assumes homogeneous stress and strain distribution in a sample. This assumption is invalid at large strains. To improve the analysis of triaxial tests at large strains, a continuous recording of the sample dimensions is required.

This study elaborated techniques for measuring the contours of the samples during a triaxial test. A feasibility study in which different techniques were tested showed that a camera-based outline technique was promising and it was therefore elaborated further. Before the technique was applied to real soil samples, it was applied to an artificial sample. The artificial sample consisted of a steel frame surrounded by a membrane. Displacement was forced by introducing water between the steel frame and the lateral membrane. A comparison of the applied water volume and the measured displacements and corresponding volume changes demonstrated that the measurement technique was accurate.



Sample deformation during the test for the artificial non-uniform sample

Particular attention was paid to optical distortion in the elaboration of the measurement data. The method uses eight cameras and software that detect the outline of the sample on the basis of the photos taken. The differences found between the outlines in successive photos taken from the same position provide information about the lateral displacement, and the integration of the results from the eight different cameras provides the volume change.

The analysis of the data results in descriptions of the 3D shape of the sample at any relevant stage during the test. The results clearly show the non-uniform deformation of the sample. This will be useful in practical applications, for example to detect the development and position of shear planes. The test results show that contour detection is a valuable new tool in advanced laboratory testing.

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The Deltares R&D Highlights Edition 2020
Deltares wants its R&D results to be more accessible to the public and the private sector. This R&D Highlights Report for 2020 is one of the means to that end. The chapters of the report follow the structure of the five social issues that are central to the Deltares mission. To enhance interactivity, one or more contacts are listed for each project and readers interested in more details should not hesitate to contact them.

A PDF version of these R&D Highlights 2020 and the individual papers can be downloaded from *https://www.deltares.nl/en/publications/*. Re-use of the knowledge and information in this publication is encouraged on the understanding that due credit is given to the source. However, neither the publisher nor the authors can be held responsible for any consequences resulting from such use.

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