R&D Highlights 2016
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Dear reader,

It is my pleasure and honour to present the Deltares research highlights for 2016. More than 800 Deltares employees are involved in high-grade research and consultancy in the field of delta technology, the technology needed for sustainable living, work and recreation in low-lying, densely populated areas at the interface of the land and the sea, enabling delta life. It requires technical skills, as well as a thorough knowledge of the natural system and its response to human activities and environmental change. It also requires a broad interdisciplinary view of the functions of the natural system and how they can be integrated to the benefit of society, now and in the future. All of our activities, whether applied research or specialised consultancy, are intended to contribute to this body of knowledge. I hope this report shows that Deltares and its partners have made significant progress in adding to this treasury of interdisciplinary knowledge.

I am proud to present this collection of highlights, which were produced in both subsidised research programmes and commissioned contract work. If a project description stirs your interest, please don’t hesitate to get in touch.

Jaap Kwadijk
Deltares Science Director
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Deltanes is an international institute located in the Netherlands that engages in applied research in the field of water, subsurface and infrastructure. The institute’s motto is “Enabling Delta Life”, and it strives to implement that motto by developing and applying top-level expertise to help people live safely and sustainably in delta areas, coastal zones and river basins. Managing these densely populated and vulnerable areas is complex, which is why Deltanes works closely with governments, businesses, other research institutes and universities.

Our ability to carry out innovative research to support the Dutch government and private sector requires the long-term maintenance of a knowledge base with high scientific standards. We accomplish this in part with financing from the Ministry of Economic Affairs. Their subsidy amounts to about 10% of our annual turnover and it is used to support strategic research at Deltanes so that we have, for example, the opportunity to launch new joint-industry projects or to co-fund EU projects.

Not only does Deltanes work in the Netherlands, we are also active internationally. The international dimension is imperative: the Dutch market is limited and subsidies have been decreasing, which means we need to focus on problems facing the international community. Knowledge about sustainable delta living is becoming more critical worldwide. The growth of the world’s population is leading to an increased demand for water and natural resources, and putting increasing pressure on ecosystems. Climate change and sea-level rise, together with the increasing population and economic development, will exacerbate flood risks, a development that will be accompanied by a decline in the willingness of the public and business to accept these risks. In this context, Deltanes will have opportunities to make more of an impact on the international stage.
Introduction

To achieve the long-term goals of each programme, it is essential to have a project portfolio that is appropriately divided between strategic research, applied research, product development, knowledge transfer, and specialist consultancy. We therefore make strategic decisions about our research and marketing activities. Specifically, we redirect about 15% of our strategic research budget each year. Accordingly, we assess research requirements and current status in each programme and decide where that money can best be allocated to achieve the programme goals.

In 2016, the Dutch Ministry of Economic Affairs commissioned an evaluation of the TO2 institutions, including Deltares. The evaluation was conducted in late 2016 in line with the EMTO protocol, which is based on three main criteria: quality, impact and vitality.

In addition to the five themes described above, we also focus on Software Innovation. Our software, which covers the full spectrum of Deltares expertise, is by far the most important vehicle for the distribution of knowledge, which we support with an Open Source software policy. We also actively pursue and initiate new developments like serious gaming, map table applications and Open Earth.

Financial resources

The revenue sources of a programme are intended to evolve through the lifetime of the programme. Initially, strategic research subsidy and co-funding from European and national research funds will dominate but applied research funds and market contributions will become more prominent over the course of time. However, Deltares strives to enhance market commitment in all phases of
research and development so that the valorisation of the research will receive more attention from the outset.

The strategic research subsidy granted by the Ministry of Economic Affairs plays a crucial role in the programmes. It is used as seed money to start up new research and stir enthusiasm among other parties. Moreover, it is mobilised to co-finance concerted research actions in Joint Industry Projects (JIPs), in governmental subsidy programmes (such as TKI) and in European research programmes.

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:
- Professor Jacob Fokkema (chair), Delft University of Technology
- Ir. Frank Goossensen, Arcadis Nederland BV, division Water
- Professor Piet Hoekstra, Utrecht University, Faculty Geosciences
- Professor Aad van der Horst, BAM Infraconsult, Delta Marine Consultants
- Professor Marcel Stive, Delft University of Technology
- Dr. Bram de Vos, Wageningen UR, Environmental Sciences Group
- Ir. Harold van Waveren, Rijkswaterstaat; Water, Verkeer en Leefomgeving

Scientific Council
In order to monitor the quality of the knowledge activities at Deltares and to provide the management with advice, solicited or unsolicited, about the research programme, strategic investments, the disciplines and the relationships with the universities, Deltares has an internal Scientific Council. This council consists of a number of Deltares staff members with international reputations, most of whom are part-time university professors.

The members of the Scientific Council are:
- Professor Dick Vethaak
- Professor François Clemens – Meyer
- Dr. Ap van Dongeren
- Professor Marc Bierkens
- Professor Frans Klijn
- Professor Jaap Kwadijk (chair)
- Professor Han Winterwerp
- Professor Adam Bezuijen
- Dr. Peter van de Berg

Deltares established the Young Scientific Council in 2012. The Young Scientific Council gives solicited or unsolicited advice to the Scientific Council about Deltares knowledge development, especially in the long term. The Scientific Council proposed the establishment of a Young Scientific Council in order to bring in the knowledge and networks of these young professionals and therefore to keep abreast of the latest scientific developments and safeguard the high knowledge standards at Deltares. Moreover, the Scientific Council hopes to promote mutual collaboration and interdisciplinary research through this new council. A new Young Scientific Council was appointed in 2016.

The current members of the Young Scientific Council are:
- Dr. Marc Hijma
- Dr. Niels Jacobsen
- Dr. Jonathan Nuttall
- Dr. Chris Seijger (chair)
- Dr. ir. Frederiek Sperna Weiland
- Dr. ir. Heleen Vreugdenhil
Facts and figures
The figure below shows the distribution of revenue across the themes, and the geographical origin of the revenue.

The annual turnover of Deltares is about € 109 million, half of which is generated by R&D. This turnover is generated by about 800 employees, 538 of whom have scientific positions.

Deltares is also a breeding ground for master and doctorate students. Some are Deltares employees, others are co-supervised and supported (some financially) by Deltares. About 80 bachelor and master students were co-supervised by Deltares staff. Between 10 and 15 colleagues obtain doctorates every year. About 15% of the Strategic Research subsidy is allocated to doctorate studies.

Thirteen doctorates supported by Deltares were completed in 2016, five by Deltares employees:
- **Miranda van Wijngaarden** (Delft University of Technology) Mathematical Modelling and Simulation of Biogrout
- **Yasmijn van der Knaap** (VU-University Amsterdam) Stream valley catchments in times of climate change: an ecohydrological approach
- **Dirk-Jan Walstra** (Delft University of Technology) On the anatomy of nearshore sandbars: a systematic exposition of inter-annual sandbar dynamics
- **Arjen Markus** (University of Amsterdam) Release, transport and fate of engineered nanoparticles in the aquatic environment
- **Rik Noorlandt** (Delft University of Technology) A seismic vibrator driven by linear synchronous motors: Developing a prototype vibrator, investigating the vibrator-ground contact and exploring robust signal design

The Deltares staff include 21 part-time university professors. Other staff are involved on a part-time basis as assistant or associate professors, or as senior researchers. Deltares values these links highly, not only because they help to define and supervise research and disseminate knowledge, but also to recruit young talent. The academics at Deltares are alumni from a variety of universities, including universities abroad. About 15% of the Deltares academic staff are from countries outside the Netherlands.

Deltares works with universities to invest in knowledge centres at the universities of Delft, Utrecht, Twente and Wageningen. Current examples are the Geo-Engineering Knowledge Centre at Delft University of Technology, the Risk Management Knowledge Centre in conjunction with the University of Twente, and UCAD, the Utrecht Sustainable Earth Research Centre, a collaboration involving Utrecht University, TNO, Deltares, KNMI, KWR, PBL and RIVM. Deltares also has alliances with universities abroad such as the National University of Singapore (NUS).
Social and economic impact
Delta areas are becoming increasingly urbanised, leading to challenges in the areas of sustainable planning and pressures on natural resources. Climate change is affecting flood risks and the distribution of water, and therefore land use and spatial planning. Demand for integrated solutions is constantly increasing.

That is why the adaptive delta planning theme develops integrated methods and instruments to accelerate design, improve quality and reduce the costs of spatial planning. The costs and benefits of climate adaptation strategies need to be assessed over time and for different possible pathways. Integrated instruments will help to develop integrated solutions and apply them to urbanisation issues in deltas.

Government organisations involved in water management, subsurface and spatial planning are already integrating and applying Deltares knowledge to address adaptive planning issues.

Businesses also advise governments by using Deltares tools for consulting services. Doctorate and master students from universities worldwide are developing their talents through direct access to Deltares knowledge.

R&D Highlights
The Adaptation Support Tool is a planning support system that has been developed and used in various projects. It was applied in New Orleans in the aftermath of the hurricane Katrina. Changes in the Earth’s surface water over the past thirty years have been visualised at the global scale using freely available satellite data. Two highlights describe adaptive planning for coastal zones: one example looks at coastal protection strategies for mangroves and another focuses on the adaptive pathways for vulnerable coastal zones in the European funded RISES-AM project. Adaptive pathways have also been explored to address changes in demand for drinking water.

scope
The main aim of the Adaptive Delta Planning theme is to integrate our technical knowledge about water, subsurface and infrastructure with governance and policy-making to solve problems in highly complex systems in dynamic deltas. The primary focus is therefore on developing and testing concepts, methods and instruments to achieve this goal. The theme naturally requires strong ties with all the other Deltares themes.
Changes in the Earth’s surface water over the past thirty years

The Deltares Aqua Monitor is the first global-scale tool that shows where water has been transformed into land and vice-versa with a 30-metre resolution. The Aqua Monitor uses freely available satellite data and Google Earth Engine, a platform for the planetary-scale scientific analysis of geospatial datasets that is open to the general public. The Aqua Monitor can be used to detect both documented and undocumented surface water changes. The changes due to man-made interventions, natural variability, and climate change have now been revealed.

The heat map of global changes in surface water and land shows the conversion from water to land and from land to water over the period 1985 – 2015. The intensity of the colours reflects the spatial magnitude of the change. This map shows that surface water has been changing constantly on almost every continent, with the most extensive changes in Asia. The major areas include the Tibetan Plateau, where hundreds of new lakes have appeared and existing lakes have been extended, and the Aral Sea, which has almost entirely dried up during the last few decades.

While many countries report on dam construction, information about more remote or isolated areas has been lacking. In Myanmar, the Global Reservoir and Dams database shows an increase in the water surface between 1985 and 2010 of about 400 km². Using the Aqua Monitor, we found 1,180 km² of new surface water during the same period. The damming of the Rimjin River in North Korea close to the border with South Korea resulted in a storage surface of 12.4 km² that was actually due to the Hwanggang Dam, which was thought to be located 35 km to the east. These unknown reservoirs may have had a severe impact on the displacement of people and on the ecology. These issues still have to be investigated.

The results of the Aqua Monitor show the compound impact of natural and human change or variability. It is often hard to tell what has caused a change without determining the details of the local water and sediment budget. An example is the changes in meanders in the Brahmaputra delta, which are clearly natural, while the Mondrian-like shapes near Taiji Na’ier lakes in China are clearly man-made.

Universally-available analytics for big satellite data may have major implications for monitoring capacity and the associated actions. At the very local scale, members of the general public can now assess without expert assistance whether their houses are threatened by coastal erosion. At the regional scale, a downstream state can conduct year-to-year monitoring to see whether upstream neighbours are establishing new impoundments. Finally, at the planetary scale, global agencies such as the United Nations International Strategy for Disaster Reduction can monitor the appearance of new reservoir storage capacity that may reduce flood hazards.

Jaap Kwadijk, the Deltares scientific director: “This has never been done before. The tool has enormous potential. It can be used by everybody with an internet connection. People have already proposed applications that we had never thought of. I am pretty sure that numerous applications will emerge in the next few years.”
Adapting to changes in demand for drinking water

A rise in demand for drinking water requires extra investment, while a fall results in invested capital being underused. So uncertainty about trends in demand make investment decisions difficult for Dutch provincial authorities. Deltares helps the authorities during the process of decision-making under uncertainty by training officials in Adaptive Planning.

Most drinking water in the Netherlands comes from groundwater: more than 60% overall and up to 95% in some regions. The provincial authorities are responsible for safeguarding supplies in the long term. Uncertainties about socio-economic developments and climate change make it hard to predict how demand will fluctuate exactly and what resources will be available in a specific region. Adaptive planning is required. Deltares trained civil servants in the use of Dynamic Adaptive Policy Pathways. This approach was originally developed for freshwater supplies and flood risk management. This project adapted it for use in the drinking water sector.

The three basic components of the approach were discussed extensively in a series of workshops with civil servants from the various provincial authorities. The first component is the identification of tipping points. The tipping point in this case was defined as the point at which supplies dropped below 120% of the demand. The authority will then need to invest in additional capacity. The Province of Overijssel served as an example. The tipping point was determined for three different socio-economic scenarios. The moment at which the tipping point was reached varied between one year, eleven years and “never” in the three scenarios. This indicates the bandwidth of uncertainty that the authority needs to address.

The second component is the identification of measures and the assessment of the degree to which they result in the postponement of the tipping point. These measures may include increasing efficiency, issuing new permits, extra supplies from outside the province, or shifting extraction to surface water. When measures have little effect, follow-up measures were introduced, building towards pathways extending beyond 2050. Comparing the pros and cons of pathways established a clearer picture of the best and most flexible strategies. The third component is the design of a monitoring system for critical developments. Monitoring provides crucial information about whether the tipping point is approaching and whether the expected pathways are still feasible.

This project showed that the adaptive approach is a valuable tool for the drinking water sector. The provincial authorities are adopting this approach and they will be able to use it to develop long-term drinking water policy.
Adaptation pathways for vulnerable coastal zones

Global sea levels have risen almost twenty centimetres over the past century and they will continue to rise even if the Paris Agreement is fully implemented. Only a limited number of the coastal zones at risk (examples being the Thames Estuary, UK and the Rhine delta, Netherlands) are planning ahead and devising measures to respond to possible sea-level-rise scenarios. Measures of this kind are known as adaptation pathways. Since sea-level rise could have severe effects, adaptation is essential and may require extensive transformative action.

The speed and magnitude of sea-level rise are uncertain, and some adaptation measures require major investments. The exploration of different adaptation pathways is therefore needed to support decision-making and to ensure that the right investment is made in a timely, cost-effective manner. Every coastal zone at risk should therefore have an adaptation plan. Pathways can support awareness and link short-term decisions to long-term adaptation options, providing support for decision-making in coastal zones at risk.

The RISES-AM project has assessed the impacts of future sea-level rise and the effectiveness of adaptation strategies and options. It has also considered the barriers to the implementation of adaptation at the local, regional and global scales in a range of representative concentration pathways (RCPs) and shared socio-economic pathways (SSPs). Furthermore, the project has explored high-end scenarios not included in IPCC reports. The analysis is centred around scenario RCP 4.5 and extends to 2100 but it also looks at a new high-end sea-level-rise scenario developed as part of RISES-AM. High-end scenarios are particularly important for the management of situations involving high exposure and risk aversion which are found in many densely-populated coastal zones.

Six archetypical coastal zones were identified that are at particular risk as a result of high-end climate change and the possible adaptation pathways were mapped out for each of them. These types are Open, Urbanised coast with beach and/or sand dunes, Open rural coast, Urban delta, Rural delta, Urban estuary, and Rural estuary. The effects of sea-level rise in these zones are flooding, erosion, saltwater intrusion and rising groundwater levels. Generic pathways consisting of current and future adaptation measures were developed for these six archetypes. Local, regional and national governments should be encouraged to develop adaptive planning methods as a way of reducing the uncertainties in impacts associated with sea-level rise. Exploring adaptation pathways supports planning and decision-making by evaluating tipping points, alternatives and long-term uncertainties in terms of the decisions that need to be made today. Managers of coastal zones at risk should consider customising adaptation pathways as the main component in adaptive plans for coping with the impacts and uncertainties associated with sea-level rise.

Further reading: http://www.risesam.eu/
Coastal protection strategies from a social perspective

Around the world, the risk of flooding is higher in low-lying coastal areas and cities like Jakarta, Miami and Ho Chi Minh city. Although the need for coastal protection may be evident, the actual implementation of effective flood risk management strategies is quite a different story. Plans for these strategies may look wonderful on paper but they are difficult to implement due to financial, political and social constraints. In Italy, for instance, corruption undermined the construction of Venice’s storm surge barrier and flood risk management plans for Ho Chi Minh city in Vietnam were developed beyond the financial and technical capacities of the Vietnamese government to implement them.

This project addresses the plan/implementation gap by estimating the feasibility of seven different coastal protection strategies worldwide. The strategies range from the construction of hard, permanent structures such as sea walls and storm surge barriers to the preservation of existing natural structures like dunes, coral reefs, nourishment, and the restoration of salt marshes and mangroves.

We assessed the countries’ capacities to implement flood risk management strategies on the basis of five dimensions that represent factors which may result in implementation failure. The dimensions are political will, local participation, financial capacity, construction capacity and maintenance & enforcement. A question with respect to political will, for example, is whether politicians are prepared to take action to manage flood risks.

Implementation feasibility curves were developed for each dimension based on the analysis of literature for coastal projects. The curves indicate how important the dimension is for the successful implementation of a strategy. A strategy like mangrove restoration requires local participation and strict enforcement. Otherwise, young mangrove trees may be planted in the wrong way or cut down illegally later. Similarly, a complicated and expensive strategy such as a closable storm surge barrier requires high levels of financial and construction capacity. Databases with global indicators were used to determine country scores for the five dimensions. The database information was combined with the feasibility curves to explore the implementation feasibility of specific strategies in specific countries.

The results of the project are global maps showing implementation feasibility for the various strategies. These analyses help to inform discussions about which protection strategies are most feasible in a given country and whether a strategy is easier to implement in, for instance, New Zealand or China. Furthermore, the analyses help to focus attention on the social factors that enable or constrain implementation, and therefore to raise awareness about the risks for implementation.

This project provides direct input for the Aqueduct Global Flood Analyser, an online tool that shows maps of potential flooding around the world. The tool will integrate the analyses of coastal flood risks, the technical feasibility of strategies, and social implementation feasibility. The maps can be used in two ways. The first is to select those measures with a higher implementation feasibility. The second is to identify the additional efforts required to implement a measure in a specific country.

Further reading: http://floods.wri.org/
Adaptation Support Tool to reduce flooding in New Orleans

Hurricane Katrina had a devastating impact on New Orleans more than ten years ago. A large part of the city has now been rebuilt, directions for future water management have been laid out in the Greater New Orleans Urban Water plan (2013) and the coastal defence and pumping stations are largely in place. The major water challenge that remains is pluvial flooding. The Adaptation Support Tool has been implemented in New Orleans to facilitate the design of green infrastructure in collaboration with multiple stakeholders.

The traditional approach of increasing drainage capacity would seem to be less cost-effective and less sustainable than green-infrastructure solutions. New Orleans therefore wants to design and implement green-infrastructure solutions in collaboration with local stakeholders to reduce pluvial flooding. To facilitate the design process for green-infrastructure, Deltares developed the Adaptation Support Tool that was improved and customised for New Orleans.

Many stakeholders are involved in the creation of a climate-resilient New Orleans. Stakeholders include urban planners, landscape architects, water managers, civil engineers, local residents and other experts. The touch-table-based system AST was used in collaborative design workshops to create conceptual designs with, and with support from, the stakeholders. The AST facilitates planning support, the selection of adaptation interventions, interactive placement in the project area and the immediate assessment of effectiveness and costs.

The AST touch table consists of three panels. The left panel is for the input of local conditions and the selection of measures from a ranked list based on these conditions. The AST now includes 71 blue, green and grey measures for ecosystem-based adaptation. Typical examples of “blue-green” solutions are green roofs, bioswales, porous pavements and water squares. New measures added specifically for New Orleans included French drains, dry ponds, tree cells and bio-retention cells.

The centre panel shows a map of the project area with base layers such as Google maps and Openstreetmap.org and thematic layers (such as a digital elevation model and a flood map). The participants can draw the suggested measures on the map. The right panel then shows an assessment of the effects of the measures using a number of key metrics that include storage capacity, heat stress, flood reduction, the effects on water quality, the cost and additional benefits. In the case of New Orleans, groundwater recharge and evapotranspiration were added as key metrics because they are relevant for land subsidence and heat stress reduction.

The advantage of the AST is that participants immediately see the effects of the interventions they propose. The estimated effectiveness is shown, for example, as a percentage of the desired retention capacity, flood reduction and groundwater recharge. The AST is part of the Adaptation Planning Support Toolbox to support the complete collaborative design process in both the initiative phase and the planning phase.

Further reading:
van de Ven et al. (2016) http://dx.doi.org/10.1016/j.envsci.2016.06.010.
Social and economic impact
Deltares helps governments, businesses, civil society and knowledge institutions with innovative and effective solutions in flood risk management. For example, the world benefits from experiments in our high-quality wave facilities, such as the Delta Flume, where we simulate wave attacks and loads on flood defences.

Using our expertise and practical tools and models, governments throughout the world can respond better to flood risks. For example, 41 countries are currently using ‘FEWS’, the Deltares flood forecasting and warning system. Dutch consultants in the private sector are strengthening their international competitive position by drawing on our knowledge and international recognition. In society as a whole, the public trusts Deltares’ expertise and judgement as an independent top research institute. And finally, we have an impact in the scientific world through our combined research initiatives with universities, the support of professors and the supervision of doctorate and master students. In addition, scientists can use our open-source software.

R&D Highlights
The flood risk was assessed for Cork after the severe flooding of the city in 2009. This was one of the case studies in the European FP7 project INTACT. Other European FP7 projects include RISK-KIT, which provides a toolkit to reduce coastal vulnerability, and RASOR, which developed a platform for flood, seismic and other geohazard risk assessments. An example of the collaboration between the market, governmental organisations and research institutes is the Risk- and Opportunity-Based Asset Management for Critical Infrastructures programme.

Dutch examples of projects for flood risk management are the new risk-based dike assessment instrument and the use of past dike performance to update the reliability assessment. An international example is the multi-hazard risk assessment for Afghanistan, in which flooding is included as one of the natural hazards for the country.

Other highlights include the cost-effectiveness of widening rivers and a Bayesian approach for assessing wave attack in reef environments and numerical modelling.

scope
Rising sea levels, population growth and economic activity are driving an increase in demand for flood risk forecasting and possible protective measures. The research conducted by Deltares improves the precision of our assessments of dike strength, water-level predictions, wave heights and erosion, and allows for better risk assessments. Our expertise covers the full scope of flood risk management: from risk calculations to practical support for policy decisions. The result is seen in flood prevention measures that are more effective, more cost-efficient and socially acceptable.

Flood Risk
After an intensive period of five years of research and development, Deltares has completed an entirely new assessment instrument for dikes. The instrument will help to implement the recently adopted safety standards which provide a basic level of protection for every Dutch citizen, and includes the latest scientific insights about the strength of flood defences and hydraulic boundary conditions.

Primary flood defences protect 60% of the Netherlands from flooding. They are designed according to extremely strict standards and are tested regularly. Flood defence managers conduct these assessments using an assessment instrument provided by the national government. A complete update of the assessment instrument was required in response to two major changes. Firstly, new legislation has been introduced with up-to-date protection standards, providing every Dutch citizen with a basic level of protection. Secondly, more has been learnt about dike strength, climate change and the behaviour of water systems and these advances had to be included in the assessment instrument.

The new legislation is risk-based and it has resulted in minimum protection levels for dike sections in terms of maximum failure probabilities. An instrument was needed to test whether a dike meets the standard. It had to include our knowledge about a range of failure mechanisms, water-system behaviour and risk assessment. It also needed to deliver reliable, consistent and reproducible answers in a cost-effective way in order to help government with decisions about upgrading dikes and setting the associated priorities. The assessments are supported with software, schematisation guidelines and instruction fact sheets, as well as a set of reports, including reports on technical matters and the water system.

The success of the instrument depends on trained staff, adequate data and the deliverables described above. Knowledge, experience and data relating to the technical status of the flood defences are just as important as the instrument itself. Deltares and Rijkswaterstaat therefore organised training and final drills during which the flood defence managers had the opportunity to get acquainted with the modules of the instrument. They were able to see the value of the instrument and learn about the data requirements for their own region so that they could plan for the next assessment cycle.
Numerical modelling of water pressures in dikes

Dikes and dams prevent flooding. However, water penetrating the dike and the subsoil during high water periods reduces the strength of the structure due to the increase in pore pressure. Moreover, the rise in the hydraulic head in deeper layers may lead to the uplift of the top layer on the polder side of the dike. Finally, an increase in the potential head gradient can result in an internal erosion process known as backward erosion piping. To assess these effects it is important to have an adequate knowledge of the pore water pressure field, which can be obtained by solving the groundwater flow problem.

The coupled use of the finite volume code iMODFLOW, which is an accelerated Deltares version of MODFLOW, and the finite element code DgFlow solve the groundwater flow problem more efficiently by addressing the problem using multiple resolutions. iMODFLOW captures saturated flow at a regional scale (2x2km) by assuming that groundwater flows in a horizontal direction through highly permeable aquifers and vertically through low permeable aquitards. DgFlow simulates saturated and unsaturated flows at a local scale (100x100m) using a three-dimensional domain in combination with deformations in the subsoil.

The two programs are coupled by exchanging hydraulic heads (iMODFLOW to DgFlow) and fluxes (DgFlow to iMODFLOW) for each stress period at the boundary shared by the two model domains. As DgFlow addresses the physical processes in more detail, more time steps are needed in a stress period for a DgFlow computation than for an iMODFLOW computation. Furthermore, higher spatial resolution is needed for a DgFlow computation than for an iMODFLOW simulation. The simulated pore water field for a high water situation is imported in the geotechnical finite element code Plaxis, where the stability of the dike is analysed.

A simplified version of this approach, which is based on one-way coupling between iMODFLOW and DgFlow, has already been used in a research project funded by Rijkswaterstaat. The aim of this project was to assess the effect of a three-dimensional time-dependent groundwater flow on the stability of the dike in three locations alongside the river Waal. The hydraulic head distribution in a region measuring 1.5 x 1.5 km near Herwijnen was obtained from an iMODFLOW computation. The picture on the left shows the distribution for the low permeable cover layer and the picture on the right shows the hydraulic head in the sandy layer underneath. This model provides the boundary conditions for the DgFlow model, which captures a domain of 500 x 500 metres and includes a section of the Waaldijk. The groundwater model was calibrated on the basis of piezometer readings and the calibrated model was then used to predict the water pressures in the dike and the subsoil, which supports the dike during periods of high river-water runoff. A Plaxis computation based on the simulated water pressure distribution was used to assess the safety of the dike.

Further reading:
Flood Risk

Recent floods in Cork (Ireland) have disrupted health services and the water supply, affecting the lives of many citizens. These events clearly demonstrated the vulnerability of this critical infrastructure to flooding. To make Cork more resilient, Deltares and partners analysed the flood vulnerability of critical infrastructure and adaptation measures. The research was part of the EU FP7 project INTACT which looks at the vulnerability of critical infrastructure to extreme weather events. The project included five case studies, one of which was Cork.

Cork is the largest city in the southwest of Ireland. It suffered severe flooding in 2009. The flood lasted less than 24 hours but there was substantial damage: the closure of main transportation routes, the temporary closure of the roads to and from the hospital, severe damage to the university and a two-week interruption in the supply of fresh water to residents. Approximately 87,000 persons were affected by a lack of drinking water in their homes, the majority in the north of the city. Some urgent flood protection measures have already been implemented to prevent a repeat of similar events. Additional measures have been proposed for the areas in and around Cork.

Information about flood risks is crucial to evaluate the past, current and future vulnerability of critical infrastructure (CI) to flooding. Whereas general flood impact and risk analysis methods focus on direct damage due to the force of water on objects, damage related to critical infrastructure is generally associated with interruptions in services. The impact depends mainly on the network structure and the dependence of society and other networks on the services, and less on the nature of the actual flood.

Deltares and its partners used the storyline approach and the CIrcle tool to obtain information about the vulnerability of critical infrastructure and to study cascade effects. This approach does not require data transfer; it structures the input of key stakeholders and experts from workshops and interviews to obtain a picture of what may happen during a flood event, of the responsibilities of actors and of interrelations between different critical infrastructure networks. These insights contribute to the development of shared, consistent and comprehensive strategies, and adaptation measures.

The outcomes of this research help Irish stakeholders and others to arrange flood defence and mitigation measures, including emergency management plans. In Cork a comprehensive set of measures was proposed and it has already been partly implemented: flood forecasting, the management of reservoirs, and emergency management have been improved to respond more effectively. Additionally, quays and embankments have been strengthened to make flooding less likely. The potential impact of flooding has been reduced by protecting transformer stations from flood depths of one metre. Furthermore, the drinking water production plant is now protected better and is better prepared for floods.

Further reading:
De Bruijn et al. (2016). Flood vulnerability of critical infrastructure in Cork, Ireland. E3S Web Conf., 7 07005. DOI: http://dx.doi.org/10.1051/e3sconf/20160707005
The Rivers Delta Programme was completed in 2014. The aim of this programme was to develop a flood risk management strategy that reduces flood risks along the major rivers in the Netherlands and that also ensures that the new standards for flood risk management are met by the year 2050. The preferred strategy consists of a combination of strengthening dikes and widening rivers. However, as widening rivers is more expensive than strengthening dikes, questions arose about the cost effectiveness of the first. Deltares developed methods to compute two benefits of widening rivers: 1) a reduction in the costs of strengthening dikes and 2) additional risk reduction resulting from lower water levels. The ministry uses this information in a cost-benefit analysis to support their decision-making procedures about widening rivers in the next few decades.

In the Netherlands, dike reinforcements are needed to meet the new standards for flood risk management. The extent of the reinforcement can be reduced by widening rivers since this lowers water levels. Deltares first developed a method that calculates the reduction in dike-reinforcement costs obtained by widening rivers. The method combines information about dike-failure probabilities at different water levels with the probability that these water levels may occur. This procedure is followed for different failure mechanisms. If the total failure probability exceeds the statutory standard, the method computes the required dike reinforcement and the associated costs. The cost reduction obtained by widening a river is then computed by comparing the costs for different dike reinforcement options (in other words, with and without a wider river). The method provided, for the first time, an impression of the reinforcements currently required for all embankments on the major rivers in the Netherlands.

Lower water levels reduce not only the reinforcement required but also the impact of flooding. Lower water levels reduce the flow of water through the breach and therefore the depth, and sometimes the extent, of flooding. A large number of flood simulations were used to quantify the reduction of the impact and the results were combined with the computed flood probability to determine the reduction in the flood risk. The work was undertaken for the Ministry of Infrastructure and the Environment (WVL/DGRW). A consortium led by Deltares and including HKV, Arcadis and Royal HaskoningDHV developed the method for computing the reduction in costs for dike reinforcements. The collaboration between these organisations ensured that the latest knowledge about failure mechanisms was combined with knowledge about the local dike systems.

Until now, no adequate tools were available to compute the costs for dike reinforcements and the benefits (in other words, the reduction of flood impact) that are essential for risk-based decision-making. The new methods provide essential information that will not only be used to assess the benefits of widening rivers but also, for example, to assess the cost effectiveness of changes in discharge distribution over the three branches of the Rhine in the Netherlands.

Multi-hazard risk assessment in Afghanistan

The geographical location of Afghanistan and years of environmental degradation in the country have made Afghanistan highly prone to intense and recurring natural hazards such as flooding, earthquakes, snow avalanches, landslides and droughts. Since 1980, disasters caused by natural hazards have affected 9 million people and caused over 20,000 fatalities in Afghanistan.

The understanding and accessibility of hazard, exposure, vulnerability and risk information is key to the effective management of disaster risk. Currently, the government of Afghanistan possesses limited information about current and future disaster risks and the effectiveness of policy options as a basis for decisions about reconstruction and risk reduction.

The World Bank and Global Facility for Disaster Reduction and Recovery (GFDRR) initiated a project to develop new risk information for Afghanistan about fluvial floods, flash floods, droughts, landslides, snow avalanches and seismic hazards. The project was carried out by a consortium of five institutes: Deltares (Netherlands), ENEA (Italy), GRF-Davos (Switzerland), KIT-Karlsruhe (Germany) and OMRAN (Afghanistan). Deltares was responsible for the overall project lead and risk assessments for fluvial floods, flash floods and droughts.

Risk is computed as the product of hazard, exposure and vulnerability. The hazard component is the combination of probability and magnitude of hazardous events. Hazard analyses were carried out separately for each threat. Several models were implemented to simulate the relevant processes involved. These models were fed by climate data and geological data like elevation, slope, land use, soil characteristics and so on.

Exposure is a measure of the assets and population at risk. An extensive data collection and processing effort was carried out to derive nation-wide exposure data. This includes data about the population, residential buildings, household inventory, commercial buildings, schools, hospitals, mosques, capital stock and livestock. The derived exposure data were applied uniformly to all threats to ensure mutual consistency.

Vulnerability is a measure of potential exposure losses if a hazardous event occurs. Vulnerability analyses were carried out separately for each threat because of differences in the impact characteristics. For example, the vulnerability of agriculture to floods is high, whereas the vulnerability of agriculture to earthquakes is low.

The main project output consists of tables and maps (GIS) showing hazard, exposure and risk. The tables present results at the nationwide, province and district levels. An example of a flood hazard map and a risk map for the Nangarhar province can be found in the illustration. It shows the clear similarities between the hazard and risk contours. Areas of high risk (>500/y/ha) are found in municipality districts that are located in the floodplain as these are the areas where both hazard and exposure are significant. All maps are stored in an open access Web-based GIS platform (http://disasterrisk.af.geonode.org/), which can be consulted by the government of Afghanistan, the World Bank, NGOs or anyone else interested in risks due to natural hazards in Afghanistan.

Further reading:

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“POV Macrostability” is a 24-million-euro research project that is being managed for the High-Water Protection Programme (HWBP) by the Riverenland Water Authority. It consists of 60 subprojects looking at how to reduce the risk of macrostability using new reinforcement techniques. Macrostability is the phenomenon in which large parts of a dike slide when water levels are extremely high. Deltares is responsible for the technical vision and the quality of the research output and we are also involved in large full-scale trials.

One of the subprojects developed new design rules for stability walls in dikes that have been accepted by the ENW expertise network and that result in a 20% more cost-effective approach to dike upgrades. Another subproject is a study of the actual strength of dikes. The strength of the dike and the subsoil is tested using large and undisturbed samples from the Hollandsche IJssel dike taken with a large-diameter sampler developed by Deltares in collaboration with Wiertsema and Partners.

One full-scale field trial looked at “vacuum consolidation”, a method used to reduce settlement and horizontal deformation due to construction works. Applying a 60% vacuum under a geotextile on top of the soil has the same effect (higher shear strength) as preloading with a 3.5-metre-high sand berm. The durability of the higher shear strength is being assessed in three full-scale experiments. Pilot locations were selected near Bleskensgraaf and Schardam, which is where the conventional and new Beaudrain S vacuum techniques were applied. Field measurements, monitoring and laboratory tests were conducted before, and at different times after, four months of vacuum. Ball penetration tests showed an increase in strength by a factor of 3 due to the vacuum. At 100 days after the removal of the vacuum, there was a minor decline in ball resistance due to consolidation effects and the reduction of vertical stresses. Designers will be provided with a guideline for the expected increase in strength with vacuum consolidation.

Another field trial looked at the “JLD Dike Stabiliser”, a ground nailing technique. The JLD Dike Stabiliser is a long anchor rod with a spade-shaped anchor that is placed in the dike at an angle of approximately 45 degrees. A load displacement element is placed over the anchor rod to reduce cutting through the soil. A plate attached to the anchor rod is placed on the surface of the dike and the anchor rod is pre-loaded.

A consortium consisting of Deltares, JLD Contracting, Wiertsema and Partners, and the Antea group conducted two full-scale failure trials in Purmerend. One test used nails and the other did not. The analyses of the data from the tests showed how the technique works, how it should be modelled and what dike safety approach can be used as part of the new flood risk approach. The acceptance of the results by ENW facilitates the application of the technique in real dike-upgrade projects. A pilot project with the JLD Dike Stabiliser will be implemented in a secondary dike in Amsterdam in 2017.
Flood Risk

The Rapid Analysis and Spatialisation Of Risk (RASOR) FP7 project has developed a platform for performing flood, seismic and other geohazard risk assessments. The platform allows risk managers to simulate and analyse disaster scenarios using an intuitive web interface.

RASOR uses a scenario-driven query system that allows users to simulate disaster scenarios based on existing and assumed conditions, to make comparisons with historical scenarios, and to model multi-hazard risk both before and during an event. Managers can, for example, determine the extent of flooding in a given area and assess risks for Critical Infrastructure Systems in terms of the residual functionality of a given system (such as energy, transport or health). Public authorities can determine the potential impact of sea-surge scenarios based on actual, accurate subsidence data and the impact on flood defence infrastructure. RASOR allows managers to use real scenarios when determining new mitigation or prevention measures, and to integrate new, real-time data in their operational systems during response activities.

The RASOR platform has the functionality required to superimpose archived and near-real time optical and radar satellite data, and to combine them with in-situ and model data for both global and local applications. A new 12m-resolution Digital Elevation Model (DEM) TanDEM-X was used as a base layer for flood models that simulate disaster scenarios. Several case studies are available covering a variety of flood hazards in Indonesia, Greece, Italy, the Netherlands and Haiti. An additional case study in Malawi was developed in 2016 as part of a project for GFDRR/the World Bank. Ultimately, the RASOR Consortium will offer global services to support in-depth risk assessment and full-cycle risk management.

After thirty months of development and improvements, the RASOR project was terminated at the Understanding Risk event organised by the World Bank in Venice on 16-20 May 2016. However, as RASOR Coordinator Roberto Rudari said, “This is not the end, but the true beginning of what we have built up in the last two years”. RASOR is an open platform with open data and models that enables communities to perform multi-risk analysis. “Thanks to the RASOR Project, we now can identify risks better and make better decisions,” said Sinta Kaniawati, the General Manager of the Unilever Indonesia Foundation and a member of the National Platform for Disaster Risk Reduction in Indonesia. “We want the RASOR Project to help stakeholders all over world. Not just national governments, but also local agencies down to the community level. We hope work on RASOR will continue without interruption so that it can be a powerful tool that will help many of us to arrive at better solutions and build a safer world”.

Further reading:
www.rasor-project.eu

Map showing damage by flooding in Gonaives, Haiti
A toolkit to reduce coastal vulnerability

Every few years Europe is hit by a high-impact storm event that may cause damage amounting to millions of euros. Levels of damage are likely to increase due to higher sea levels and more intense storms as a result of climate change. Ongoing coastal development is also making coasts more vulnerable to storms and so coastal authorities need to take steps to prevent or mitigate damage in the future. They need information about where the coastal areas exposed to most risk are situated, what measures are possible, how effective these solutions are, and how to communicate with stakeholders.

The RISC-KIT (Resilience-increasing Strategies for Coasts) Toolkit was developed by a consortium of eighteen partners led by Deltares. It includes five tools. The storm impact database contains the impacts of recent and historical storms in Europe. One of the discoveries resulting from the archive data mining was that a large number of storms in the past had simply been “forgotten” and that storms are more frequent than previously thought. The Coastal Risk Assessment Framework (CRAF) tool pinpoints the highest-risk areas along the coast in a two-step approach. In the first step, potential hotspots are selected using simple rules, for instance by linking wave heights to coastal erosion. The second step uses the more detailed XBeach and vulnerability models to identify the area of highest risk.

The web-based management guide provides coastal managers with an overview of possible ways of reducing risk levels in the hotspots such as dune restoration or marsh creation. After a measure has been selected, effectiveness in terms of damage reduction can be assessed with the hotspot tool for Disaster Risk Reduction (DRR) assessment. This tool is based on the FEWS platform and allows the incorporation of the coastal managers’ own surge, wave and morphodynamical software. The results of the analysis are stored in a Bayesian network, which is a probabilistic model that connects waves, water levels, properties of the coast, measures and resulting damages. The results are shown in a web viewer. The multi-criteria analysis (MCA) guide helps coastal managers to conduct discussions with end users and stakeholders about the feasibility and acceptability of DRR measures.

All the tools have been tested at ten case-study sites in Europe, at least one on every regional sea in Europe. The characteristics of these sites vary in terms of coastal type (barrier islands in Portugal, salt marshes in the UK), land use (urbanised coast in Belgium), tidal range and dominant hazard (coastal erosion, flooding). The tools were found to be applicable to all these different coastal locations.

Further reading: www.risckit.eu
Reliability updates for dikes involve including observations of past performance in estimates of a dike’s present reliability. In this project, reliability updates were made operational by developing the method, applying it to specific cases, building software and drafting manuals. As Dutch dikes have already typically endured significant load conditions, the reliability updating method is expected to have a major impact.

Dike-slope stability is a relatively important failure mechanism in the Dutch assessment framework for primary flood defences. The last round of assessments in 2011 identified many dikes that failed to meet the safety requirements for slopes.

In a dike assessment, the estimated probability of failure based on a slope stability analysis can be compared directly with the target probability of failure for a specific dike section as defined in the statutory assessment of Dutch primary flood defences (the Statutory Assessment Instrument, WBI-2017). The assessment involves a semi-probabilistic approach or a fully probabilistic approach (in Dutch: gedetailleerde toets).

As in most geotechnical problems, the assessment of slope stability is typically dominated by major uncertainties relating to soil properties, often resulting in rather high estimated probabilities of failure by comparison with the actual failure rates observed in the field. If a dike section does not comply with the target failure probability using semi-probabilistic and fully probabilistic approaches, observations of past performance, such as non-failure after significant loading, can be incorporated to improve the probability estimates. The analyses for reliability updates are advanced assessments (in Dutch: toets op maat).

The R&D projects for reliability updating in 2016 included both the development and documentation of the method, the accompanying software (Probabilistic Toolkit) and the demonstration of applicability in realistic test cases. A secondary objective was to generate insights that can help to assess the potential effect on the updated reliability estimates for typical conditions. The test cases included dike sections along the Markermeer dike and the Krachtige IJssel dikes Krimpenerwaard (KIJK), and they used a level of detail and complexity which was representative for real-life conditions. A simplified approach with fragility curves (reliability as a function of outside water level) was introduced so that practitioners can match slope failure probabilities to field observations. All the cases confirmed that the results obtained with the simplified approach are a reasonable match with the results obtained using conventional reliability methods such as Monte Carlo simulation.

The method was developed and applied in test cases in 2016. Its success and positive international peer-review comments mean that it is on the verge of being applied in real projects with water authorities in the Netherlands in 2017.

Further reading:
Low-lying tropical islands are highly vulnerable to the effects of sea-level rise and climate change. Most pressing is the threat posed to their freshwater supplies by flooding linked to extreme swell waves. These “blue sky” events originate from distant storms and they are completely independent of local weather conditions. There can therefore be very little warning and time to organise a response.

The impacts of extreme swell wave events can be reduced with effective prediction tools. However, one of the problems is that the flood risk is difficult to quantify because it is dependent on the geometry of the islands and on the variability in wave and sea level conditions to which they are exposed.

Deltares collaborated with the U.S. Geological Survey to generalise previous site-specific studies of flooding on coral atolls and to develop a new approach to estimating flood risk on low-lying tropical islands. Using the wave model XBeach (which is open source), we developed a large synthetic database of numerical simulations representing a large range of realistic reef geometries, and wave and sea-level conditions.

We then entered the model results in the Bayesian BEWARE (Bayesian Estimator of Wave Attack in Reef Environments) network, a probabilistic model which estimates a range and distribution of likely outputs for a given set of inputs. The resulting tool allows us to make real-time flood predictions based on predicted offshore wave or sea-level conditions, and the unique characteristics of a given island.

We found that islands with narrow, smooth reefs with steep fore-reef slopes are the most vulnerable to runup and flooding. Furthermore, analysis of the results revealed that offshore wave conditions, water levels, and reef width are the most essential variables for predicting runup. Future research efforts should therefore focus on collecting those data from wave and surge prediction models and earth observation sources.

In addition to its potential for use in early warning systems, BEWARE also serves as a useful tool for assessments of the impacts of climate change such as sea-level rise or coral bleaching. This model can be used to answer questions such as ‘which islands will be most severely affected by rising sea levels?’, or ‘can we increase flood resilience for a given island by restoring its coral reefs?’ It is therefore also potentially useful as a guide for decisions about the allocation of limited funding to, and plan adaptations in, the places where they will have the most impact.
Risk- and Opportunity-Based Asset Management for Critical Infrastructure

Asset management is defined as ‘realising value from assets’ with the aim of finding an optimal balance between costs, performance and risk. The Risk- and Opportunity-Based Asset Management for Critical Infrastructure (ROBAMCI) programme (2015-2018) uses a risk-based and system-oriented approach to improve the management and maintenance of public infrastructures. The programme shows that an efficiency gain of more than 10% (€ 1-2 billion a year in the Netherlands) can be achieved by using risk-based and system-oriented asset management for decisions in life-cycle management. The ROBAMCI programme is a collaboration between government, private companies and research institutes which provides a wide-ranging and complete base of relevant knowledge and data.

A framework for Life-Cycle Analysis is being developed that can be used for calculating performance, cost and risk over time for the life cycle of systems of assets delivering functions in the public environment. As part of the framework, a tool is being developed that can be used to compare different strategic, tactical and operational plans for any type of asset. The tool is being developed and applied in various case studies, with applications throughout the domain of public infrastructure, such as underground infrastructure, dikes, sluices and pumping stations, and the coastal zone.

Many of the hydraulic structures in the Netherlands are aging and will have to be replaced within the next thirty years. The smart replacement of these structures will maintain the functional service level of the water system as a whole at the required level. In the case study looking at the pumping station and lock in IJmuiden, the future capacity requirement of the pumping station was studied from a system perspective. Various strategies (for example drainage through the Markermeer lake) for adapting the system in the light of a range of future scenarios were studied. This analysis showed that the range of solutions increases when a system approach is adopted, resulting in more perspectives for optimal long-term management.

Another case study is the LiveDike XL situated in the area managed by the Noorderzijlvest water authority. Structural health monitoring can be an important way of accurately assessing performance, a pivotal aspect of asset management. A tool for assessing the costs and benefits of dike monitoring was developed on the basis of experience at the LiveDike XL in the FloodControl IJkdijk research programme. A large monitoring campaign has been conducted in recent years on this dike. During the case study, the costs and benefits of the monitoring campaign were determined and a method was developed for forecasting those costs and benefits, while taking the uncertain return on investments into account. The savings from information obtained in the monitoring programme were in the order of 30% in terms of life-cycle costs for this particular case.
Social and economic impact
Demand for natural resources will continue to increase as the world’s population grows to nine billion people in 2050, in the case of fresh water by 55%. Conflicts over water scarcity may increase as well.

That is why the water and subsoil resources theme aims to find solutions to reduce uncertainties in the estimates of natural resources such as water, energy and raw materials. It also wants to improve water and groundwater management to minimise risks and optimise economic returns and sustainability. The availability of data about the earth’s surface and subsurface is growing rapidly, as is the capacity of computers to process them. In addition, innovative solutions, such as the storage of fresh water in the substrate during periods of surplus water for use in dry periods, are being developed to tackle freshwater scarcity on the local and regional scales. This theme enhances our insight into relationships between water scarcity and risks of conflicts in combination with the increasing numbers of refugees.

National governments currently formulate national water and delta plans with support from Deltares. Businesses optimise their products and services using Deltares’ evaluations of new methods and techniques for data gathering, data handling and visualisations. Governments worldwide learn more about water risks such as scarcity or lack of quality using analyses conducted by Deltares.

R&D Highlights
The use of satellite data is illustrated in the European FP7 project for the integrated assessment of water resources, ‘eartH2Observe’. Another example of support for water managers and decision-makers is the development of a Water Information System that was developed and applied for several international projects in countries including Azerbaijan, Kenya and India.

A new type of seismic vibrator was developed in a doctorate study. This instrument can be used to generate images of the structure of the shallow subsurface. In another example, fibre optics are used to visualise properties of the subsurface.

Other highlights include a pilot project involving the sustainable development goals for water, and improvements to the numerical efficiency of groundwater models at the national or global scales using parallel computing.
In September 2015, heads of state from all around the world adopted the 2030 Agenda for Sustainable Development consisting of 17 Sustainable Development Goals (SDGs) and 169 targets. The 2030 Agenda includes a dedicated goal on water and sanitation (SDG 6) that sets out to ‘ensure availability and sustainable management of water and sanitation for all’. Indicators include changes in the efficiency of water use over time and the level of water stress, which relates water withdrawal (‘abstraction’) to available freshwater resources. Six Proof of Concept countries (Bangladesh, Peru, Jordan, Uganda, Senegal and the Netherlands) were invited to test the methodologies developed by UN organisations and to collect data for these indicators.

As a result of the Proof of Concept process, Statistics Netherlands (CBS), Deltares and eLEAF conducted a demonstration project aiming to show how indicators can be compiled for the Netherlands, and what data can be acquired to support other countries in the process of evaluating indicators. The project received support from the Dutch Ministry of Infrastructure and the Environment and Ministry of Foreign Affairs.

A ladder approach was used in the demonstration project for the Netherlands. Each step includes more detailed or advanced data. The first step was to establish the indicators on the basis of statistical data. An example is the indicator for water stress, which states higher values as water shortages increase. Data from remote sensing and hydrological models were added in the second step. The third step has not been tested yet but it will consist of integrating the three sources in a fully consistent way before the indicator is computed. Finally, the indicator will be computed using the outcome of the integrated approach.

During the project, we looked at how existing statistical datasets could be extended and how modelling could provide additional detail for the purposes of calculating the indicators. The datasets were extended by, for example, improving geographical coverage, making time series longer and adding extra parameters. Some water balance terms had been simplified or neglected in the statistical data. Modelling can specifically add more details in space and time, and fill gaps in the data, for instance for fresh groundwater inflow and environmental flow. The indicator for water stress was calculated with and without additional data. The indicator for water stress for the Netherlands almost doubles if more detailed satellite and modelled data are added to the statistical data: 27% when using all three data types by comparison with 16% using statistical data only. The analysis also showed that there is a range of uncertainty in the indicator for water stress.

Combining the statistical data, the satellite-based data, and the model-based data has proven to be a useful exercise. Additional combinations of this data are expected to improve indicator compilation in the future for both the Netherlands and other countries. This will benefit the procedures that countries use to monitor and report on the targets relating to their Sustainable Development Goals for water.
Global earth observation for integrated water resource assessment

Global water resources are under pressure due to increasing demand from industry, agriculture, energy, tourism and households. At the same time, climate change may shift the balance in many regions of the world. It is still difficult to assess the quality of water resources, and access to those resources, in many regions of the world which lack basic observation and monitoring systems.

Deltares is coordinating eartH2Observe, an EU FP7 project that aims to use global water data from models and satellites at the local level in order to support decisions about the management of water resources. This involves combining the results of ten global hydrological and land surface models with large amounts of remote-sensing data. In addition, the results are being verified and refined in a number of case studies around the world (including Bangladesh, Colombia, Australia and Ethiopia) in which local water managers use the data in their region.

A key feature of the project is the free and open data policy. All products are available on a data portal (wci.eartH2Observe.eu) that supports a graphical user interface but also direct downloads using a number of protocols. The application of these global datasets has major potential in many regions of the world. Studies of water resources in many countries could not have been performed without the global models and satellite data including river discharges, precipitation, evaporation, reservoir surfaces and so on.

In recent Deltares projects in Azerbaijan, Myanmar, Afghanistan, Colombia and Morocco, global data from the eartH2Observe project have been invaluable in determining local hazards such as drought and flood risk, or in calibrating local models. Furthermore, the quality of the combined remote-sensing and model datasets is constantly improving and these improved datasets are also becoming relevant for regions with dense in situ measurements, where they can be used to enhance the existing datasets.

Further reading:
www.earth2observe.eu
and wci.eartH2Observe.eu
It is necessary to obtain images of the subsurface in a non-destructive way for a wide range of applications such as investigations of aquifer geometry. One of the options is the seismic method, which uses the propagation of mechanical waves, one type being sound waves. The structure of the earth can be inferred by analysing how the earth affects the propagation of these waves. Seismic waves can be generated in different ways. The source can be as simple as a heavy hammer or a weight dropped on the ground, but more advanced sources allow for more control and better quality data.

The seismic vibrator is an advanced seismic source of this kind. It can repeat a dedicated signal with predefined signal properties. A vibrator generates a sweep of several seconds of sinusoidal signals with varying frequencies and relatively low instantaneous power. A hammer produces a very short signal (lasting milliseconds) with much higher instantaneous energy, which is possibly more destructive for its surroundings. However, the vibrators that are generally used suffer from the distortion of the signal in the low-frequency band that contains an important part of the data.

To overcome this problem, a new type of vibrator was developed by Deltares and Delft University of Technology as part of a doctorate research project. The paper in Geophysics describing this vibrator received the best paper award in 2016.

The new vibrator is driven by linear synchronous motors (LSM) and it can produce very repeatable signals in the low-frequency band.

LSMs are electric motors that can generate linear forces and they are found in numerous applications. They are used in factories to move objects quickly and precisely, and in the propulsion system of some magnetic-levitation trains and roller coasters. The current design of the LSM vibrator allows the generation of seismic waves with frequencies between 2 and 200 Hz in continuous operation. The source can be used to investigate the subsurface down to a depth of approximately a kilometre with a maximum driving force of 7 kN.

Experiments with the newly developed LSM-driven vibrator showed that using sweeps of different duration leads to the uniform scaling of the spectrum, while using signals with different force levels alters the relative shape of the spectrum. This implies that this type of seismic vibrator can be used for the in-situ measurement of non-linear soil behaviour as well as the standard imaging of the subsurface. The ability to produce undistorted low-frequency signals makes this new source suitable for the analysis of surface waves to extract shear wave velocities down to considerable depths and to investigate the response of buildings to earthquakes. It also opens up possibilities for the automatic processing of the seismic data through full waveform fitting.

Further reading:
Water Information Systems to support water managers and decision-makers

Deltares is developing Water Information Systems in projects in several parts of the world. The aim of the systems is generally to validate, store and retrieve all kinds of water-related data and to provide easy access to the information. Furthermore, some of the systems are used to facilitate working with mathematical simulation models. They are configured for different users, draw on common open source and freeware components, such as PostgreSQL, PostGIS, Geoserver and FEWS, and they work with custom services like WPS. The components and services are loosely coupled and bundled as OpenEarth Water Information Systems. The systems also use common standards for data exchange like WCS, WFS and OPeNDAP.

An example of a Water Information System is the MajiSys system for water management in the Basin of Lake Naivasha, Kenya. It was developed with the University of Twente for the Water Resources Management Authority as part of the Integrated Water Resources Action Programme (IWRAP) executed under the lead of WWF Kenya and sponsored by the Royal Netherlands Embassy in Nairobi. MajiSys focuses on the validation, storage and retrieval of data about lake, river and groundwater levels, river discharges, and the abstraction of surface and groundwater. Combining these validated data in one system is a prerequisite for the sustainable management of the water resource in the basin of Lake Naivasha. The same components of the WIS are being used in Azerbaijan to create AzerWIS for the Azerbaijan Ministry of Emergency Situations. This system focuses on the availability of surface and groundwater resources.

The most ambitious application so far of the components of a Water Information System is now being implemented for the Indian Ministry of Water Resources, River Development & Ganga Rejuvenation and the Indian state-level Departments of Water Resources funded by the World Bank. The aim of the GangaWIS is to support strategic basin planning for the Ganga Basin. It is being used for the validation, storage, analysis, presentation and retrieval of data about surface and groundwater resources, water use, emission of pollutants, water quality and ecology. A complex linked modelling system is being used here that combines hydrology, geohydrology, water allocation, water quality and ecology. The FEWS component in GangaWIS prepares the input time series for these models and stores the output, with model linkage being facilitated by the GangaWIS. Finally, the dashboard of the GangaWIS enables decision-makers and stakeholders to evaluate the impacts of different scenarios and strategies on selected indicators. The dashboard and a map viewer can be used to disseminate information to target groups through the internet. The development of the mathematical models and the dashboard is a collaborative modelling exercise with the main governmental stakeholders at the central and state levels. The final version of the GangaWIS will be ready at the end of 2017.

Water Information Systems are essential support tools for the management of water resources. The modular setup with reusable components is an integral part of the Deltares approach for information systems, enabling tailor-made solutions that integrate measurements with model input and output to support water managers and decision-makers.

Further reading: http://openearth.eu
Fibre optics are widely used for communication technology such as internet networks. There are numerous other applications in the geosciences, one example being measurements of parameters like temperature and strain. There are multiple advantages. Fibre-optic cables are cheap and do not wear over time. Moreover, measurements are accurate and they are not affected by electromagnetic radiation, corrosion, moisture or water. Typically, accuracies are within 0.1°C, spatial resolution ranges between 0.002 m and 2.0 m, and measurement frequencies are up to 1 Hz.

Temperature is a useful parameter for monitoring the performance of aquifer thermal energy systems (ATES), which store warm or cold water in underground aquifers for use later. For example, warm water is collected in summer and stored in an aquifer for retrieval in the winter. The monitoring system around the ATES of one of the Deltares offices in Delft consists of six observation wells around the warm storage well and another six around the cold water storage well. The temperature is measured eight times a day using Distributed Temperature Sensing (DTS). Light is sent into the fibre and scattered along it. The amount of scattering is a function of temperature, while the travel time of the reflected light pulse depends on the distance along the cable. Temperature data are interpolated between the monitoring wells to obtain the spatial and temporal temperature distribution for the ATES. The monitoring showed that the warm well was not depleted at the end of the winter of 2015-16. The results have taught us more about how the systems work and this knowledge can be used in future set-ups to make the system more efficient.

Other applications of temperature fibre optics include the monitoring of flow rates, the detection of seepage zones and the detection of artefacts in diaphragm walls. In addition, coated fibre-optic cables and specialised measurement units can be used to monitor parameters other than temperature. For example, contaminants can be detected using a special coating and strain can be measured. Recent developments are the use of fibre-optic cables to detect vibrations in seismic surveys.

Further reading:
Operational decision support for water systems

Conventional decision-making processes often revolve around established guidelines, sometimes supported with computer simulations or black box optimisation models. RTC-Tools helps decision-makers find operational strategies that maximise financial profits and minimise expenditure.

In the first step, decision-makers state and prioritise their operational objectives. Using a computer model of the water system, RTC-Tools then computes the best possible schedules in terms of those priorities for controlling pumps and turbines, sluices and weirs. The computed schedules are presented to the decision-maker in a graphical user interface such as Delft-FEWS.

Version 2.0 of RTC-Tools was released as open source software in October 2016. This followed more than a year of intense development by a growing team. RTC-Tools 2.0 focuses on the transparent treatment of the competing goals and objectives that are typical of water systems. It also introduces a generic modelling framework, opening the door to decision support for interdisciplinary systems such as hydropower-transmission grid interaction. RTC-Tools 2.0 puts operator confidence first: the mathematical framework underlying the software was designed from the ground up for accurate and predictable decision support.

RTC-Tools has been used as the engine for a series of Quick Scan Tools that allow policymakers to rapidly evaluate different water allocation strategies. One of these was a prototype developed for Rijkswaterstaat (part of the Dutch Ministry of Infrastructure & Environment) to support the Landelijke Coördinatiecommissie Waterverdeling (national coordination committee for water allocation) in its operational decision-making processes. The second Quick Scan Tool application was developed to support the bottleneck analysis (knelpunten analyse 2.0) of the Freshwater Delta Programme. Furthermore, given the need to replace the legacy surface water models Distribution Model and MOZART in the National Hydrological Instrument, Deltares has proposed that RTC-Tools should be used for this purpose. Rijkswaterstaat and the water authorities have agreed and a project has been launched to complete this replacement by April 2018.

The new RTC-Tools is now being used in a variety of projects. Deltares is, in the context of the projects JIP Slim Malen (a joint industry project on smart polder drainage) and Rekenen aan Slim Water Management in de praktijk (computational smart water management in practice), working with a wide range of water authorities and energy suppliers. We are also collaborating with consultancy firms to develop control models for water systems and save pumping costs by means of smart scheduling that takes into account precipitation forecasts, surge and tidal forecasts, storage capacity at hand, and variations in the energy spot price. In this way, water authorities will contribute to the clearing of the energy market and therefore support the growing share of intermittent renewables such as wind and solar. RWSOS-IWP, which is used daily by Rijkswaterstaat for the day-to-day operation of many of its structures, will also use the new RTC-Tools to advise on short-term operations in the (North Sea/Amsterdam-RhineCanal).
Parallel Krylov Solver
for groundwater at the
national and global scales

Integrated high-resolution hydrological models are increasingly being used for the evaluation of water management in the field. Unfortunately, they require large amounts of memory and long run times. An efficient way of obtaining realistic run times and memory requirements is parallel computing, where the problem is divided between multiple processor cores. The new Parallel Krylov Solver (PKS) for the groundwater simulation code MODFLOW has been applied to the national Netherlands Hydrological Instrument (NHI) model and the global PCRaster Global Water Balance (PCR-GLOBWB) model. The Parallel Krylov Solver was developed in cooperation with the USGS, Utrecht University, Alterra and Delft University of Technology.

Numerical experiments for both the NHI and PCR-GLOBWB model were carried out on the Cartesius Dutch National supercomputer. The Cartesius has approximately 40,000 computational cores and a fast InfiniBand interconnect. Experiments were conducted on supercomputer nodes consisting of 2 Haswell 12-core CPUs with 64 GB RAM. Experiments for the NHI model were also carried out on a Windows server consisting of 2 Haswell 16-core CPUs with 128 GB RAM. The scaling results show that the new Parallel Krylov Solver results in significantly faster computing.

The NHI is a state-of-the-art coupling of several models: a 7-layer confined groundwater IMODFLOW model (structured grid of 10 million cells), a MetaSWAP groundwater model for the unsaturated zone (0.5 million cells), and the surface water model MOZART-DM. Our tests simulated the transient groundwater flow for the year 2006 with daily time steps. On the Cartesius, a serial run for the groundwater-only NHI model takes 2 hours and 45 minutes and requires 7.1 GB RAM. Using 48 cores, wall-clock time can be reduced to 6 minutes and 46 seconds, resulting in a speedup of ~24. On the Windows machine, a serial run for the fully-coupled NHI model takes 9 hours and 29 minutes and requires 44.5 GB RAM. Using 24 cores, wall-clock time can be reduced to 2 hours, resulting in a speed-up of ~5.

The global model PCR-GLOBWB provides a grid-based representation of global terrestrial hydrology. In our test we used the 2-layer confined MODFLOW groundwater model (unstructured grid of 4.5 million cells) and simulated groundwater flow for January 1992 with daily time steps. The first test used a Structured Input/Out (SIO), in which the model input and output is set up in a structured way for 53 global catchments and each partition contains one or more catchments. A speedup of ~17 was obtained using 48 cores, reducing the wall-clock time from 4 minutes and 48 seconds to 17.9 seconds. In the second test (no SIO) METIS was used for the partitioning. In this case, a speedup of ~45 was obtained using 48 cores, reducing the wall-clock time from 4 minutes and 43 seconds to 6.7 seconds.
Ecosystems and Environmental Quality

Scope
Aquatic ecosystems are vital natural resources that provide habitats for numerous species as well as drinking water and resources for industry and society. Pressures on ecosystems and the environment are increasing as the population and the economy grow. At the same time, governments are becoming more ambitious about protecting natural resources and the environment, and the sustainable use of resources, and there is increasing demand for ecosystem services. Deltares is developing knowledge about hydrodynamic, morphological, chemical and biological processes, and making that knowledge available through model and information systems for policy-makers, managers and users.

Social and economic impact
There is increasing demand for nature-based solutions in order to combine the protection of natural resources with the provision of goods and services for economic sectors and society. The theme focuses on the dynamics, services and use of general systems and ecosystems for safety, health and a green economy. Key questions covered by the theme are the following: Can social and economic developments be harmonised with environmental legislation, and vice-versa? Is it possible to replace expensive rigid flood defences or to combine them with adaptive nature-based alternatives? Can the better planning and/or use of ecosystem services and functions reduce the risks for human health, and how? And how can the need for policy-relevant information about ecosystems be translated into monitoring strategies?

Our research allows governments to implement water and environmental policies more effectively.

Dutch consulting and dredging companies are opening up new markets worldwide and non-governmental organisations can substantiate their visions and strategies by using our expertise. Doctorate and master students from universities worldwide can develop their talents through direct access to Deltares’ knowledge and research facilities.

R&D Highlights
Two highlights were funded with the FP7 subsidy from the European Union. The NUTPRINT project visualised the impact of eutrophication in the European coastal zone in order to inform the public, water managers and stakeholders. The REFORM project provides a framework for improving hydromorphological restoration measures with the aim of achieving target ecological status or fulfilling the potential of rivers in cost-effective ways.

The effect of human interventions is demonstrated in two highlights: one looks at the ports on West African sediment transport in the “sand river” and the other quantifies the sediment concentrations in an estuary.

Other highlights include the effect of dam gates on sediment flushing, the recovery of seagrass meadows near Adelaide, using drone technology to monitor vegetation in watercourses and the passive sampling of organic pollutants.
Nutrient footprint tool for coastal waters

Increased amounts of nutrients (nitrogen, phosphorus) are released into surface waters due to human activities on land. This has two negative effects. Firstly, higher levels of nutrients contribute to environmental problems due to the over-enrichment of water and sediments, especially in coastal zones. Secondly, nutrients leaching from arable land to surface water are no longer available as fertiliser for crops. Eutrophication is noticeable when it causes smells due to oxygen depletion or excessive algal blooms (of blue-green algae, for example). However, this is generally not noticed by the general public. The NUTPRINT project was established with the aim of visualising the impact of eutrophication in the European coastal zone in a simple way and of informing the public, water managers and stakeholders, creating support for mitigation measures.

NUTPRINT visualises the contribution of different sources of nutrients for any location in Europe. The most important sources contributing to eutrophication are diffuse loads associated with land use (agriculture, hard surfaces) and point sources such as industry, wastewater treatment and individual households.

The relative contributions of nutrient sources have been visualised for the region of interest and a comparison has been made with other regions in Europe. In addition, the project shows the retention of nutrients originating from a specific area on land in river systems and lakes. Generally, high levels of retention reduce the impact that an area has on eutrophication in coastal waters.

An example of a NUTPRINT visualisation covers an area in Spain. The nutrients in this example come mainly from agricultural land and to a lesser extent from forest and urban areas. The screen dump from the portal shows that 65% of areas in Europe release more nutrients. On its way to the sea, some of the nitrogen is retained in the river system and lakes, as shown by the grey bar.

The visualisations in NUTPRINT are based on model calculations. The Swedish Meteorological and Hydrological Institute (SMHI) developed a Europe-wide hydrological and water quality model (EHYPE) that runs on open data only. Normal and background runs were used in NUTPRINT to calculate the anthropogenic component of nutrient flows leaching from land to water. All point sources were removed for background runs and land use was defined as grass land in order to visualise the contribution of alterations in land use and point sources.

NUTPRINT is one of fourteen products developed as part of the EU project SWITCH-ON (Sharing Water-related Information to Tackle Changes in the Hydrosphere - for Operational Needs). The SWITCH-ON project brought together a consortium of partners to convert open, hydrology-related, data into marketable products for the general public, water managers and other stakeholders.

Further reading:
http://www.nutrientfootprint.eu
http://www.water-switch-on.eu/
A new approach has been developed to investigate different approaches to operating dam gates in the Funagira dam in Japan. This approach consists of quasi-3D-modelling coupled with the real-time control toolbox (RTC), resulting in more efficient reservoir flushing and more sediment transport to the downstream reach.

We applied the approach to the Funagira reservoir, which is located in the Tenryuu river in central Honshu, Japan. This research project is part of a long-term collaboration between Deltares and J-Power, one of the largest power companies in Japan. J-Power is actively seeking to jointly develop knowledge and techniques with the aim of improving gate operation and therefore the management of the sediment trapped in the reservoirs and the spread of sediment downstream. The river downstream of the Funagira dam suffers from bank erosion and point-bar formation due to the present pyramid-shape opening pattern of the gates.

Hydropower dams are major assets for society. Their number continues to increase because of growing demand for water and electricity. However, their presence disturbs river morphology and ecology. The reservoirs behind the dams suffer from a loss of storage capacity and contamination due to sedimentation. The reduction of storage capacity is a challenge for dam operators. The need to maximise storage capacity and preserve the ecosystem downstream at the same time requires the optimisation of operating rules. Sediment management practices for this purpose, such as sluicing and flushing, may generate undesirable morphological changes in the reach downstream of the dam. Gate operation is expected to be a factor in this area.

We developed a modelling approach to simulate flow regulation through a dam in order to establish a picture of how different gate-opening patterns affect morphodynamics. The aim of the approach is to identify possible improvements in the flushing process and to understand how this process affects morphological changes downstream of the dam. We built a quasi-3D morphodynamic model using the Delft3D4 software, which can simulate temporal and spatial variations in hydrodynamics and morphological changes in the reservoir and the river reaches. The Delft3D software was coupled with the real-time control toolbox (RTC) to control different gate openings over time. It should be pointed out here that both Delft3D4 and RTC are open-source software.

Equal-shape openings were introduced as a new pattern. We analysed and compared both patterns in terms of flushing efficiency and sediment distribution downstream of the dam. The coupling of the quasi 3D-morphological model with RTC was successfully used to establish in detail the differences between different patterns for gate operation. Equal gate operation minimises the formation of eddies downstream of the dam and reduces the erosion of the bed and banks. Equal gate operation is also more efficient in term of sediment flushing than the pyramid approach. Bed shear-stress distribution upstream and downstream of the dam was identified and analysed to determine the expected bed behaviour.

We propose the adoption of the new gate-operation pattern. The ongoing development of Delft3D was addressed in order to use the PID controller. This has been included in the new research questions for 2017. In addition, the reservoir conditions (sediment supply, reservoir bed level, reservoir water level, and dam operation) will be studied with a view to maximising sediment releases to the reach downstream during the low-flood seasons. The results of sediment-flushing will be evaluated on the basis of the downstream ecosystem.
Human interventions and climate change on the West African sand river

The West African coast consists of a narrow low-lying coastal strip maintained by sediment from rivers that is transported along the coast by waves and currents: a “sand river”. Today, however, much of the fluvial sand is retained behind river dams and the flow is interrupted at several locations by jetties. The sandy coastal barrier is therefore eroding almost everywhere. The situation is already critical and it is likely to worsen in the future due to climate change. The coastal zone is home to about 31% of West Africa’s population. This figure is expected to rise as urban population growth is increasing at an annual rate of 4% according to the World Bank. In addition, the coastal zone is the source of 56% of West Africa’s Gross Domestic Product.

Several studies have been carried out in the past in order to assess the problem of coastal erosion in different countries in West Africa. Although this information is extremely valuable as a first-step assessment of the ongoing erosion problems, those studies are mainly qualitative and they are based on different data sources in the different countries.

This study set up a quantitative and consistent large-scale sediment budget study using a unique numerical modelling framework for the Ivory Coast, Ghana, Togo and Benin. The numerical modelling framework was based on Delft3D and UNIBEST-CL+. The study has provided quantitative information about the sand moving along the coastline in the “sand river”. The study has also investigated and quantified the possible effects of major human interventions and climate change (that is to say, sea-level rise, increasing storm intensity and changes in the wave direction) on sediment transport along the coast and on shoreline changes.

The model output indicated, for example, that the effects (such as leeside erosion) of some of the major ports may extend up to nearly 50 kilometres along the coast. Moreover, land loss due to sea-level rise may become the largest source of erosion by the end of the century in the most extreme scenarios for sea-level rise. A key to the success of the project was “sharing information” and “creating awareness”. The main results of the project were discussed and shared in a number of consultation and validation workshops. Furthermore, a public on-line viewer is now available to facilitate communications with local stakeholders.

The project is part of the World Bank’s West Africa Coastal Areas Program (WACA), a convening platform that aims to help countries obtain financing and expertise to sustainably manage their coastal areas. WACA was established in 2015 in response to requests from West African countries to manage coastal erosion and flooding, promote climate-resilient coastal management and improve livelihoods in West Africa’s coastal communities.
Drones monitoring vegetation in watercourses

The seasonal development of vegetation in streams and rivers has two contrasting effects. On the one hand, this is a natural feature of flowing waters and it is valuable because it delivers ecological services and provides habitats for organisms. On the other hand, vegetation obstructs water flows, and dense vegetation patches exacerbate the flood risk upstream. Regional water authorities usually have limited information and knowledge about the vegetation present in their watercourses. An innovative monitoring technique was developed that uses a full-spectrum camera on a drone. The technique was tested in the River Experiment Center of the South Korean Institute for Civil Engineering and Building Technology (KICT) in Andong and in two Dutch streams.

Flow obstruction by vegetation can be reduced by mowing or dredging the vegetation. Currently, decisions about where and how much vegetation must be removed are often based on expert judgement during field assessments by individual persons, and there are no objective quantifying methods. In theory, methods are required to determine thresholds for acceptable levels of biomass in streams. Discharge and water levels need to be taken into account: when water levels upstream increase beyond a given point with a given discharge, overall roughness in the channel will increase too much as a result of vegetation development.

The aim of this project is to develop new techniques for determining where the true obstacles are located in a stream and which types of vegetation cause obstructions. The techniques should also identify the ecological value of the vegetation, and all the results should be obtained in a uniform and quantified way. The true obstructions in the stream are defined by a hydraulic roughness coefficient that is derived from spatial data on vegetation, biovolume and species characteristics. The ecological values of the stream vegetation can be retained as much as possible by removing the true obstructions only and leaving the other vegetation intact.

New Unmanned Aerial Vehicles (UAVs), better known as ‘drones’, and new cameras capable of capturing the full spectrum between 450-950 nm can be used to automatically monitor large stretches of brooks, channels, and rivers. The full-spectrum images are converted into maps of vegetation cover, biomass and species composition. The information can be obtained quickly using the full-spectrum camera and automated flight paths. Automatic processing ensures that the data are interpreted objectively.

The first tests in the Korean outdoor, unscaled test river channel with patchy vegetation showed that the full-spectrum camera detects the patches very well. The patches can be recognised by eye in the pseudo-real colour images and the black and white images. The measured spectrum is converted to parameters such as the NDVI index for vegetation biomass. The red patches in this image are the vegetation patches. The next step will be to upscale the method and establish a practical approach for the reliable mapping of vegetation for the purposes of both flood risk management and the assessment of ecological values in line with the EU Water Framework Directive (WFD) objectives for entire stream stretches.

This project was funded by the TKI subsidy fund and conducted in cooperation with the Korean Institute of Civil Engineering and Building Technology (KICT), the KICT-Joint Venture, the Rivierenland Water Authority, the Aa and Maas Water Authority, Twente University and KnowH2O.

Further reading:
Recovery of Adelaide’s seagrass meadows

Seagrass has been disappearing from Adelaide’s coastal waters in the Gulf St Vincent, South Australia since the 1950s. The Adelaide Coastal Waters Study concluded in 2007 that the seagrass decline was caused by discharges of treated sewage, rivers and storm water, which reduce water transparency and further the excessive growth of “epiphytes” on the seagrass leaves. Both phenomena reduce the amount of sunlight penetrating to the seagrass leaves and subsequently kill the seagrass. At that time, however, it was not clear when, where, and by how much these discharges would need to be reduced to create the conditions required for recovery of the seagrass meadows..

The South Australian Water Corporation (SA Water) provides drinking water and manages wastewater in the Adelaide Metropolitan area. SA Water commissioned Deltares to jointly develop coastal modelling capabilities that would help to answer these questions. With Delft3D as the main “engine”, SA Water, Deltares and DAMCO Consulting (Perth, West Australia) built the Adelaide Receiving Environment Model (AREM). The AREM combines information and knowledge embedded in Delft3D about coastal discharges, physical and biogeochemical processes in the coastal waters and the sensitivity of nine different seagrass species occurring in the Adelaide coastal waters to produce suitability maps for seagrasses. SA Water uses AREM to investigate how the condition of seagrasses responds to changes in coastal discharges in terms of timing, location and composition.

The development of AREM was only possible thanks to a substantial effort by SA Water to collect additional data about not only discharge but also the coastal waters. In particular, data quantifying the effect of different substances upon water transparency were important because those substances inhibit the penetration of sunlight to the seagrass leaves. SA Water measured the quantities and concentrations in the coastal waters. This allowed us to validate this part of AREM, which is needed to simulate water quality in the Gulf St Vincent.

Along the way, we learned that it is not just coastal discharges that affect the water quality. There is a very significant “natural” background level of substances that reduce water transparency. Most of the “Coloured Dissolved Organic Matter” in the water enters the coastal zone from the open sea, or it is released directly from seagrass meadows, sediments and mangroves. Likewise, most of the silt particles in the water are released from the seabed by wave stirring. The data and the AREM showed how the “seagrass-sediment-light feedback loop” works: when seagrass disappears, the seafloor is no longer protected from waves and releases silt particles which reduce water transparency and may prevent the seagrass from growing back.

The AREM does not solve the problem but it gives SA Water the best possible understanding of the degree to which proposed interventions can restore seagrass habitat.
Quantifying the long-term effects of human interventions on estuarine sediment concentrations

Many estuaries worldwide have been modified in recent decades and centuries, for example through land reclamation or to allow ever larger ships to access inland waterways. These human interventions often lead to higher suspended sediment concentrations (SSC), which reduce visibility and lead to a decline in primary production at the base of the ecological food chain. One estuary affected in this way is the Ems Estuary on the Dutch-German border. Deltares has quantified historical changes in SSC associated with human interventions and advised on mitigating measures.

Historical data are available for four observation stations in the estuary. The statistical analysis of these data revealed that SSC has increased by 0.5% to 3% annually. In order to explain these changes, a numerical model was constructed to systematically test the impact of human interventions in the past. The implementation of ports in combination with a dredging and dumping tool was essential in the model set-up. A bed module was also used to model the buffering of fines in the seabed.

Detailed model analyses produced a surprising result. It was previously thought that the deepening of access channels and the disposal of sediment dredged from ports and waterways would have most impact on SSC. However, the largest human impact resulted from changes in sediment sinks. Over the course of several decades, large amounts of fine-grained sediment were dredged and deposited on land. When this practice ended in the 1990s, SSC increased substantially. Similarly, large amounts of sediment were deposited naturally on intertidal areas for centuries. This process of accumulation accelerated during land reclamation. Without land reclamation, there were few net sediment sinks in the estuary, with increasing SSC as a result.

During several decades, this effect was obscured by large-scale sediment extraction from ports and waterways.

The results of this study of the role of sediment sinks are the basis for restoration measures implemented by local and national governments with the aim of reducing SSC by extracting sediment. The extraction strategies target the beneficial use of sediment in an environmental-friendly and cost-neutral way. Several pilot projects have been conducted in which suspended sediments are converted into building material for dike upgrades. This process involves the on-land ripening of clay and the creation of new intertidal areas where fine sediment accumulates.

A fresh look at effective river restoration

The assessment of the First River Basin Management Plans conducted in the context of the Water Framework Directive indicated that 40% of European rivers are affected by hydromorphological pressures that are caused predominantly by hydropower, navigation, agriculture, flood protection and urban development. A consortium of 26 partners coordinated by Deltares was therefore established to generate substantial output as part of the REFORM project (REstoring rivers FOR effective catchment Management) to support the implementation of the Water Framework Directive (WFD). The relevant results for application in river management have been summarised in a user-friendly way in the REFORM wiki. Furthermore, the outcomes of REFORM have been discussed and disseminated through stakeholder workshops, an international scientific conference, a summer school, numerous presentations, newsletters, policy briefs and eighty scientific publications.

Hydromorphological assessment should consider physical processes and appropriate temporal and spatial aspects beyond the boundaries of river restoration projects and the lifespan of projects. REFORM therefore developed an open-ended hydromorphology framework incorporating multi-scale spatial and temporal aspects that helps users to develop our understanding of the morphology and dynamics of river reaches and their causes. Vegetation and plants can play a cost-effective and significant role as physical ecosystem engineers in river restoration. Riparian and floodplain ecosystems are not subject to extensive monitoring but they are crucial to river morphodynamics and ecology. Direct measurements of hydromorphological processes and riparian vegetation are much more suitable for the assessment of hydromorphological degradation than measurements of in-stream biota.

Current biological sampling methods are not appropriate for capturing hydromorphological impacts and they underestimate the influence of hydromorphology on biota. There is a need to develop new biota sampling methods that are more sensitive to impacts of this kind. By contrast with the present situation, this should include sampling habitats (such as riparian habitats) that are particularly affected by hydromorphological degradation and assessing hydromorphology in ways that cover the entire range from excellent to bad status. This outcome of REFORM led to the establishment of a task group on hydromorphology as part of the European Common Implementation Strategy for Ecological Status (CIS ECOSTAT).

Restoration projects should adopt a synergistic approach with other resource users to secure win-win scenarios and draw up well-defined quantitative success criteria ranging from, for example, hydromorphological improvements to the expected beneficial impact on biota and ecosystem services. REFORM delivered a restoration planning framework which has the potential to substantially enhance the efficiency and effectiveness of restoration.

Hydromorphological restoration had positive effects on biota, even in small restoration projects. Restoration pays off because it improves ecosystem services such as landscape appreciation and flood risk attenuation. River restoration benefits not only aquatic biota but also terrestrial and semi-aquatic species. The key to success is to select measures that restore specific limiting habitats at relevant scales. To optimise the overall positive effect on biota, it is therefore essential to monitor and – if necessary – adjust restoration projects.
The added value of passive sampling in the monitoring of organic pollutants

Good and effective monitoring of water quality is key to determining whether, and where, measures should be taken to improve water quality. Monitoring normally involves the grab sampling of several litres of water, which are then sent to the lab for immediate extraction and analysis. This provides a snapshot of the water quality but compounds with an irregular emission pattern such as pesticides can easily be missed. Furthermore, concentrations are often below detection limits because of the small volumes sampled. The information obtained about the water quality is therefore limited.

Water-quality monitoring for organic pollutants can also be performed with passive sampling. A sampler with sorption material is exposed to water for several weeks or months. During the exposure, organic pollutants are sampled by diffusion from the water, resulting in a time-integrated average concentration based on large sampled volumes. This monitoring technique provides more valuable information about the substances in the water. A further benefit is that the passive samplers do not need to be extracted immediately after sampling; they can be stored in a freezer and sent easily to a laboratory later. As a result, they can be used worldwide, including remote areas with limited analytical infrastructure. In recent years, Deltares has further developed the technique and applications in a range of water types such as sewage water, surface water and groundwater, as described below.

Passive sampling was used at two hospitals in the Netherlands to monitor pharmaceuticals in the sewage water. The aim was to establish a picture of the main sources of these compounds reaching the sewage treatment plant. The samplers were used at several locations in the sewage system and analysed for a range of pharmaceuticals. It emerged that hospitals were the main source of only a small number of pharmaceuticals. Most of the load of these compounds came from other sources, often domestic waste water. Passive sampling detected more compounds than grab sampling.

Clients outside the Netherlands are also increasingly interested in passive sampling. Deltares was asked by the Nature Conservancy in California to use the technology to determine the levels of pesticides in an area used as a sanctuary for cranes. The results showed that a number of pesticides come from the crops grown on Staten Island and so the Nature Conservancy is rethinking their crop programme.

Detecting pesticides and antibiotics in groundwater can also result in better water protection. The detection of lower concentrations is beneficial and so passive samplers were developed for monitoring groundwater. The samplers were tested in two agricultural areas in the province of Noord-Brabant: application was straightforward, no additional pumping was required and it was possible to install the samplers for several months. Many more compounds were detected in low concentrations that had been missed by conventional monitoring.

Further reading:
www.stowa.nl/publicaties/publicaties/overzicht_toepassingsmogelijkheden_van_passive_sampling
Social and economic impact
The world’s population will increase to nine billion by 2050 and they are concentrated more and more in delta areas. These areas are increasingly threatened by climate change, rising sea levels and land subsidence. Not only the growing population but also rising prosperity are leading to more mobility and a greater interest in sustainability, including the use of natural processes. These trends will intensify demand for natural resources and renewable energy.

Our main goal is therefore to facilitate the efficient, safe and sustainable design, construction and maintenance of infrastructure in deltas. We develop innovative, reliable and cost-effective solutions for delta infrastructure that have an acceptable environmental impact.

The national and international oil and gas industry, contractors and consultants can draw on our knowledge, software and facilities in order to improve their competitiveness. Knowledge institutions and companies are able to link their research to the demands of society by exchanging facilities, software and experts with Deltares. Governments also benefit from risk reduction and increasing cost-effectiveness in the construction and maintenance of infrastructure. And public authorities can develop sustainable solutions that minimise the environmental impact, such as Green Ports. Universities strengthen their position in national and European research programmes and doctorate and master students are hosted and supervised by Deltares.

R&D Highlights
Projects for Delta Infrastructure are diverse in terms of location (offshore, onshore, rivers), kind of research (numerical models, physical models, guidelines, apps, laboratory tests) and financiers (strategic research budget, TKI and various market parties). Joint Industry Projects (JIP) are well represented in the Delta Infrastructure theme. An example of a JIP is the Coastal Foam project for the optimisation of coastal structures in harbours using numerical modelling. Some projects address the collaboration with market parties, such as the collaboration between the Port of Rotterdam Authority and Deltares for the design of the new Porto Central in Brazil.

Projects that focus on onshore applications included the Smart Thermal Grid at the Delft University campus to improve the sustainability of the university. Another example is the monitoring of railway track quality using satellite data. The aging of pipes and cone penetration tests in layered soils were investigated in the laboratory.

Other projects include the bather safety app, guidelines for inland waterways and the use of expert judgment and process parameters in the assessment of pile foundations.
Deltares hosts a mobile phone application that displays forecasts of sea currents and beach widths around the Sand Motor (Delfland Coast, the Netherlands). The information is consulted by the lifeguards responsible for monitoring bather safety at the Sand Motor. It allows them to anticipate potentially dangerous situations on the beach and in the shallow waters such as rip currents. Precautionary measures can be taken to reduce the risks for visitors to the beach.

The Sand Motor is a pilot project established to generate knowledge about the sustainable and economical maintenance of our coastlines that integrates different coastal functions: flood risk management, nature and leisure activities. The forces of nature redistribute the sand along the coast, making the Sand Motor a dynamic and unpredictable environment. At the outset, there was public concern about bather safety at the Sand Motor. In response, Rijkswaterstaat, the provincial authority of South Holland, the Haaglanden Security Region and the local lifeguard organisations decided to look for ways to manage bather safety.

An operational model predicts the currents and beach width in the Sand Motor area using global predictions of the tide, waves and weather. The hour-by-hour forecasts look 48 hours ahead and are updated every six hours to incorporate the most recent global predictions. The automatic retrieval of a range of (open-source) information flows to run the model and the periodical updating of the forecasts are implemented in the forecasting framework FEWS. In addition to the model-based predictions, the mobile phone application also shows near-real-time images from two video stations. This information helps the life guards to keep an eye on beach-user density and the trajectory of the water line.

The success of this project was largely a result of the frequent interaction with end users and the stakeholders. The continuous feedback from the lifeguards about the practicality of the application, the quality of the model predictions and the type of information required allowed us to iterate to a fit-for-purpose product that is tailored to the needs of the end users. In the annual evaluations of the bathing season, which are attended by all the relevant stakeholders, the application is still evaluated as ‘easy to use and very accessible’ and ‘our field observations confirm the model-based predictions’.

Deltares is now exploring other ways of using this service in the Netherlands and abroad. Safe bathing is a topic of global interest. The technical framework of the application is transferrable and information resources such as models and video images are widely available. This means that only minimal efforts will be needed to develop a very powerful tool.
Subsidence can play a key role in the performance, serviceability and safety of engineering works such as railway embankments. Research by Deltares in 2007 indicated that 40% of the maintenance costs for railways in the Netherlands are linked to preserving the geometry of the railway track. Deltares developed a predictive settlement model for railway embankments built on soft soils. The main achievement of this project is the stochastic prediction of secondary settlement using satellite data and subsoil data. This prediction will improve the assessment of the quality of railway tracks in the long term and help to rationalise existing monitoring campaigns.

The procedure for predicting secondary settlement consists of three steps. In the first step, the results of geotechnical investigations (CPT measurements, laboratory tests and borehole data), the detailed geological GeoTop model and satellite data (DInSAR) are all used to build a subsoil model of selected sections in homogeneous sub-areas. In the second step, the subsoil model is used to predict settlement using a deterministic approach with the Isotache model in Deltares D-Settlement. In the third step, the subsoil model is used as the basis for a stochastic approach. This approach uses variational data assimilation to calibrate soil parameters (thickness and secondary compression index). The variational data assimilation minimises the difference between the predicted and measured (from DInSAR satellite data) settlement trends for the railway track. Finally, the calibrated subsoil model allows for the prediction of secondary settlement during different time intervals. These predictions are accompanied by an uncertainty estimate based on a Monte Carlo probabilistic approach to the variability of geotechnical parameters.

The predictive settlement model is being applied to a railway embankment on the Hoekse Line connecting the towns of Schiedam and Hook of Holland in the west of the Netherlands. Secondary settlement is being predicted for each section of 25 m in a 550-m-long stretch over periods of 6, 10 and 20 years. The assumption is that there is no additional loading on the subsoil during these periods. The stochastic approach provides confidence bounds (average and standard deviation) for settlement predictions, whereas the deterministic approach supplies just one set of settlement predictions. The results show that the deterministic predictions are within the confidence bounds of the stochastic predictions. The stochastic approach results in settlement varying between 50 and 120 mm over 20 years. The deterministic approach indicates average settlement over the length of the stretch of 80 mm in 20 years. The approach highlights the potential of DInSAR satellite techniques for predicting track settlement using settlement models, probabilistic techniques and additional geotechnical data.

The project was supported by Deltares, the University of Salerno and SkyGeo through the Climate-KIC programme and the EU ERASMUS+ programme. The City of Rotterdam and Ed. Züblin AG made important contributions to this project.
Optimising coastal structures with numerical modelling

Coastal structures are an essential part of the design of ports: they provide shelter from storms and allow for safe operations. Coastal structures are often made from permeable material that may include everything from sand and gravel to large boulders and concrete blocks. The traditional approach to design is based on empirical formulations and experience from past works. Designs are then tested in physical laboratory settings. Alongside physical model testing, numerical models can be used to analyse different conditions and configurations. This allows for a more flexible and cost-efficient optimisation of the structure geometry.

The joint industry project (JIP) Coastal Foam focuses on the development of numerical tools to predict the stability of various components of coastal structures, and particularly on the open source CFD-toolbox OpenFoam. One of the studies looks at open filters in which rock material is placed on top of a sand core. Traditional guidelines state that the sand should not be allowed to move. Nevertheless, the combination of laboratory experiments and newly developed numerical methods has indicated that less strict design rules can be used while ensuring structural integrity.

Another area studied in the Coastal Foam JIP was slamming loads from breaking waves on crest wall elements. Crest wall elements are concrete structures on top of a breakwater and only a small number of empirical relationships are available to design these structures. This limited experimental evidence leads to huge uncertainties in the required weight of the crest wall and therefore uncertainty about the material required. The numerical model was validated on the basis of new laboratory experiments and its predictive power was found to be excellent. The model was then applied to a design exercise in which the weight of the crest wall element was optimised with either an existing empirical formulation from the Rock Manual or with the validated numerical model. This comparison showed that the methods can produce results that can easily vary by a factor of two. More worrying, however, was the fact that the empirical formulations did not necessarily produce conservative results.

This project shows that detailed numerical modelling is an accurate design tool that is also easy to apply early in the design process. The tool is likely to replace the existing empirical formulations for forces on crest walls since the predictive power of the latter is limited.

Further reading:
Collaboration between Port of Rotterdam and Deltares continues on Porto Central

Porto Central (PoC) is a new private industrial port complex located midway along the Brazilian coast in the south of the state of Espírito Santo. This port is being developed in a joint venture involving TPK Logística S.A (TPK, Brazil) and the Port of Rotterdam Authority (PoR, Netherlands). The project will allow PoR to continue with the establishment of its World Port Network, which also includes Sohar Port and Freezone in Oman. Deltares is contributing its expertise on sediment transport and wave modelling to these developments.

In the past, Deltares was involved in the PoR World Port Network by producing a number of advisory studies for Sohar Port on coastal impact and on the assessment of local wave and current conditions for basin berths and exposed jetty berths. That successful international collaboration between PoR and Deltares has now been continued for Porto Central.

Porto Central is a ‘greenfield’ port development. It is a completely new port that will be built at a previously unoccupied coastal site. This involves different and more extensive considerations than when expanding existing ports in ‘brownfield’ developments. As part of several ongoing investigations and preparatory studies commissioned by Porto Central, Deltares performed detailed wave computations for this port, applying offshore wave information to the planned port site and its surroundings. The resulting wave patterns were used by Deltares to calculate the expected coastal impact of the new port, that is to say the effect of the port on sediment transport patterns in the area, including sedimentation and erosion patterns.

The new port is planned at a site with fairly limited net sand transport along the coast. Close to the port location, large-scale coastal sediment transport changes direction from northbound to southbound. As a result, the potential impact of the port on the coastal morphological system is expected to be limited. To check the impact, it is crucial to establish an accurate picture of the transport directions and particularly the location of this reversal point. In addition, the local wave conditions are dominated by two wave systems from different directions, which, when averaged for a full year, largely offset each other. Subtle differences in the net annual effect of these wave systems should therefore be taken into account as well.

The reliable and accurate information on the wave conditions and sediment transport were provided to Porto Central as requested on the basis of the expertise and experience of Deltares and using detailed modelling with our Delft3D and Unibest software packages. The figure shows an example of the model results in terms of relative erosion and the accumulation of sediment. The outcome of the computations has confirmed the limited impact of the port on the environment in terms of the coastal morphology. Porto Central is using the results of the study to design the port.
OCP, a global leader in the phosphate and phosphate derivatives markets, is planning a new dry bulk facility off the western coast of Morocco at Laayoune. As part of this project, Royal HaskoningDHV prepared the preliminary design of an offshore breakwater to protect the dry bulk facility. Deltares then verified stability and overtopping performance using 2D and 3D physical models which allowed the optimisation of the design of the offshore breakwater.

The offshore breakwater is located in relatively deep water, which implies that waves coming from the Atlantic Ocean may be very large. The breakwater should be able to withstand significant wave heights of just over seven metres. These high waves will break on the armour slope of the breakwater and overtop the breakwater, particularly when water levels are high. The height of the waves needs to be reduced in order to limit wave forces below the jetty deck located behind the breakwater.

During the 2D physical model study the design of the breakwater was optimised by raising the crest level in order to limit wave conditions to the rear. In addition, a more economical solution for the rear armour was tested: a single instead of a double layer of protecting armour. Limited damage is permissible in the single layer of regularly-placed cube units. The integrity of the slope as a whole will not be endangered if a unit is pushed out of this kind of protection layer.

During the 3D physical model study, the optimised breakwater trunk section was installed using sixty-tonne Tetrapod units placed on the roundhead section. However, the stability of these units was unsatisfactory because of the large wave forces exerted on the units, resulting in many units being pushed out of the armour layer. A solution with regularly-placed cubes was therefore proposed and tested, but this time in a double layer with sixty-tonne cube units. Although the second layer may not be required in terms of stability, it provides an additional level of safety for this part of the breakwater, which is the most vulnerable. This change resulted in a very stable roundhead in which the incoming waves could not grab the protruding legs of the armour units as they did with the Tetrapod units. Another advantage of cubes is that the casting of the units and the construction of the armour layer are easier and quicker than with Tetrapods.

The Laayoune 2D and 3D scale model tests have proven that a very stable solution for a roundhead and the rear slope can be achieved by using cubes placed regularly in a layer. The solution guides the wave energy better without blocking it and therefore results in higher stability without the negative effects of rocking and high concrete stresses. It is therefore more durable and provides end clients with an ideal solution.

Further reading:
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Innovations in breakwater design
New guidelines for inland waterways in the Netherlands

Waterway guidelines are key to safe, reliable, and efficient navigation in the Dutch waterways network. The present waterway guidelines are restricted to canals. In recent years, Deltares, MARIN and Rijkswaterstaat have been developing a set of rules that will allow the guidelines to be applied to the complete waterway network, including the river systems. These rules are based on the in-depth analysis of the hydrodynamic and morphological conditions, and the manoeuvrability of inland vessels. A unique combination of numerical simulations and statistical data analysis models that use heterogeneous sources of information (about factors such as ship manoeuvring, experience from the field or physical models) ensures the best possible assessment of waterway guidelines (which include factors such as the cross-sectional profile of navigation channels, bend radius and port entrances).

The present waterway guidelines were published in 2011 and they are used for the design of waterways for inland commercial and recreational navigation (CEMT classes I to VIb). In particular, they are applicable to canals and channels without natural flow or with a low flow velocity of less than 0.5 m/s. The large majority of Dutch rivers exceed this flow velocity and Rijkswaterstaat therefore initiated a research programme to develop a comprehensive set of guidelines that can be used for waterways with a natural flow velocity greater than 0.5 m/s.

Fluctuating discharge levels in rivers lead to fluctuations over time in the navigation depth. In tidal rivers, the combination of alternating flow directions and varying water levels makes clear guidelines for the available navigable profile particularly necessary.

The continuous adaptation of river bends to flowing waters is another critical aspect of river navigation. In canals, the bends are designed for standard vessels and they have a stable, flat bottom. River beds are not flat and they are also not stable due to fluctuating discharge levels. River bends are therefore much more complex. In order to ensure safe and quick navigation, the new guidelines need to take into account the existing bend widths of the rivers and bend radius. In addition, locks and inland ports in flowing waters should also meet the requirements for navigation.

New waterway guidelines for rivers are key to safe, reliable, and efficient navigation on the Dutch waterway corridors to Germany and Belgium. These guidelines will apply not only to shipping channels but also to the structures in the waterways such as locks, bridges and ports. The new river guidelines will be published after the successful completion of the research conducted by Deltares and Marin in collaboration with Rijkswaterstaat and other field experts.

Further reading:
Improving the navigability of the Lower Old Danube in Romania

At 2783 kilometres, of which 2414 kilometres are navigable, the Danube is the second longest river in Europe. It is one of Europe’s most important inland waterways and has been designated a Priority Axis, a pan-European inland transport link from the port of Rotterdam on the North Sea to the port of Constanța on the Black Sea. In Romania, the Danube covers 1075 kilometres from its point of entry at Baziaș to the mouth at Sulina.

The section between Călărași and Brăila (km 375 – km 175) connects the Danube to the Danube - Black Sea navigation channel and the maritime Danube. The Danube Commission recommends a minimum depth of 2.5 m for the navigable channel and a width of between 150 and 180 m for this section.

Currently, the main arm of the Danube (km 347 – km 300) does not meet the minimum depth and width criteria on approximately 150-160 days each year. On these days, traffic is diverted through the Bala – Borcea branch, where the conditions are sometimes difficult due to the limited width of the fairway and sharp bends at some locations. Furthermore, this detour increases the distance travelled between Călărași and Cernavodă by some 110 km. Dredging is routinely carried out to comply with the recommendations of the Danube Commission. The morphodynamics of the river mean that this dredging is inadequate and only effective in the short term.

Several studies have been conducted in recent years and recommendations have been made to improve the navigation conditions on the Danube between Călărași and Brăila. The aim of the present project is to evaluate alternatives for improving navigability. In order to provide sound recommendations, we developed two different models: a detailed 3D hydrodynamic model for the Bala bifurcation, and a large-scale quasi-3D morphodynamic model for the Danube branches. The models were used to simulate and analyse two scenarios for improving navigability by comparison with the benchmark condition.

A challenging task in this analysis was the simulation of the large-scale autonomous morphological behaviour of the Danube. We were able to successfully reproduce the long-term trend of discharge reduction into the Lower Old Danube. After both models were validated, they were used jointly to analyse the proposed alternatives. Finally, we presented our client Egis Eau with a complete overview of the effect of the alternatives on water levels, discharge distribution and velocities, as well as the large-scale morphological impact. These results can now be used to select the best alternative from a hydraulic point of view. In conjunction with other factors such as costs, maintenance and environmental considerations, they will be used to produce recommendations about a solution to improve navigability.

Further reading:
Delft University of Technology wishes to be a prime example of an academic campus with energy efficiency measures and sustainably sourced power. The campus aims to reduce energy use by up to 30% by 2020 relative to 2009, to source 50% of all energy from sustainable sources by 2020, and to become 100% CO2 neutral by 2020.

One of the areas being investigated is the district heating system (DHS) at the campus. Facility Management and Real Estate (FMVG) has started a range of projects to support a transition from a conventional DHS (120 – 80°C) to a medium temperature DHS (80 – 40°C). This project includes the investigation and implementation of a smart district heating control system that allows the system to run at a low temperature. One reason for the switch to a lower temperature regime is the possibility of raising the number of full-load hours for the two combined heat and power (CHP) units. Another is the possibility of drawing on a geothermal source which supplies heat at approximately 70°C.

A model predictive control (MPC) system will be required that determines the minimum supply temperature and optimal use of the different sources. This MPC system is based on two simulation packages. The first is Low Energy Architecture (developed by Deerns), which can be used to minimise the supply temperature while providing a comfortable climate inside the building. The second is the Deltares Wanda package, which can be used to simulate hydraulic and thermal transients in pipeline systems like a DHS. Wanda is used to determine the source usage and required supply temperature on the basis of the results of the Low Energy Architecture simulation for optimal source usage with minimal carbon dioxide output.

Simulations for a standard climate year show that the supply temperature of the buildings can be reduced with minor modifications to the building envelopes. This leads to a lower return temperature at the CHP units, allowing for an increase in the number of full-load hours for these two units. In the optimal scenario, an increase of 20% in the full-load hours can be achieved. This cuts CO2 production by approximately 10%.

The MPC system has been implemented on the basis of these results for one sub-system supplying heat to three buildings. This system has been in operation since September 2016 and it will be validated during the winter. The system will be extended to include the other buildings if the results are favourable.
Aging pipes in underground networks

Underground networks for wastewater and drinking water are aging and effective asset management is required. This means quantifying the actual functionality and structural condition of the pipes, preferably using non-destructive methods. With this goal in mind, a group of companies, water authorities, municipalities, Deltares, Delft University of Technology, STOWA and RIONED joined forces in the Urban Drainage Knowledge Programme and set up an STW-funded research programme TISCA: Technology Innovation for Sewer Condition Assessment. A major aim of TISCA is to obtain information about hydraulic capacity and structural strength using non-invasive methods for existing infrastructure.

Before the development of the TISCA programme, 3D laser scanning technology was introduced for a new tool that accurately scans the interior geometry of old pipes. The resulting data are essential for the assessment of the structural strength of pipes and hydraulic roughness. For example, old pipes can contain irregularities such as small cracks and accretions of material that affect pipe strength and the flows of water and other fluids. Corrosion results in more hydraulic roughness (reducing the hydraulic capacity) and also reduces the thickness of the wall and makes the pipe weaker. A laser scan shows that material is lost at the top of the pipe (red dots) and this is seen as increased roughness on the inner wall at the top relative to the bottom.

The assessment of the condition and behaviour of aging pipes can be determined not only with measurements but also with models. One TISCA project is the Condition Assessment of Sewer Pipes by means of Finite Element Modelling (CASPFE). The aim is to quantify the interaction between the pipe and the surrounding soil. This is a step forwards since it allows for a more realistic representation of the soil mechanics. In the CASPFE model, the laser scan measurements serve as input for advanced structural modelling. Delft University of Technology is involved on the modelling side in the mixed-mode FEM analysis of concrete. The results of the modelling show that, counter-intuitively, egg-shaped pipes tend to crack first at the bottom (the thin end). This is difficult to observe in practice. Deltares will conduct experiments in the GeoCentrifuge to study the interaction of pipes with the soil. The GeoCentrifuge experiments are planned for the near future.

The intermediate results are already being used in further research by the Universities of Technology in Delft and Eindhoven, and by Deltares. Ultimately, the project will result in a method that will allow practitioners to make accurate assessments of the actual strength of aging underground pipes.
Cone penetration tests in layered soils

Cone penetration testing (CPT) is used widely to determine the geotechnical engineering properties of soils and to analyse the stratigraphy. However, it is hard to estimate a representative value for cone resistance when thin layers of sand and clay or peat alternate because the surrounding layers affect the measured cone resistance and result in an average value. The effect of multiple thin alternating layers is being studied in the laboratory in Delft.

The soil deposits of interest are “flaser beds”: a sedimentary bedding pattern created in an environment with intermittent flows that result in alternating sand and clay layers. This type of bedding is mainly found in marine environments. The thicknesses of the sand layers are typically between 5 millimetres and several centimetres. The aim of this study is to determine the correction factor needed for individual layers to obtain representative values from the measured ones.

Unique laboratory tests were conducted to determine cone resistance in layered deposits. Two CPTs were performed in artificially formed sequences of sand and clay layers. The thickness of the layer was 20 mm in the first test and 80 mm in the second. The thin sand layers and clay layers always had the same thickness in this experiment. In addition, separate reference tests were performed on sand only and on clay only. The preparation of these soil set-ups in a cylindrical steel tank in the laboratory was a tedious and meticulous job. The cylindrical steel tank was approximately 0.6 m in diameter and the diameter of the measured cone was 25 mm. A cross-section of the soil body was inspected visually after the completion of CPT.

The experiments showed that tests on artificial, thin-layered deposits produce reliable results. The results of the tests were used to validate a range of correction factors for cone resistance based on analytical models. The correction factors mainly depend on the ratio of the characteristic resistances of the individual sand and clay layers, as well as the ratio of layer thickness to cone diameter.

Representative cone resistance values are essential for liquefaction potential studies, which are conducted to assess the liquefaction potential of sands in response to earthquakes. This is important knowledge in many places in the world. As a first step in the analysis, CPT soundings were converted to liquefaction potential on the basis of measured values. In practice, the liquefaction potential of multi-layered soils is often overestimated because of the low values of measured cone resistances. The new correction factors help to determine liquefaction potential reliably for multi-layered soils during an earthquake.

The research was performed in collaboration with Fugro and Delft University of Technology. Additional laboratory tests and research are planned for 2017 to extend the work to higher stress levels corresponding to deeper soil layers.

Further reading:
During the installation of piles, data are gathered which allow the machine operator to make decisions. These data about the process parameters for screw displacement piles can be used by other people and in different phases of the project, reducing the discrepancy between the levels of attention devoted to the design and the installation phases of pile foundations. In this project, pile installation databases and expert knowledge were combined in a Bayesian belief network approach to take all the information into account in a systematic way and to infer the quality of the installed piles.

In the case of screw displacement piles, quite a lot of machine data, such as torque, pull-down and velocity, are collected during installation. Moreover, the machine operator works with implicit assumptions and decisions but there is no systematic way of processing this knowledge during or after installation.

The study was set up jointly with the piling companies in the Netherlands (BAM, Fundex, Hektex, VSF, and Bauer) and with GeoConsult. A contribution was received by the former GeoImpuls programme. The main focus of this study was the delivery of a proof of concept in which machine data, process parameters and expert knowledge can be used to assess geotechnical and structural pile quality.

The Bayesian belief networks (BBN) technique is suitable for this proof of concept, because it is a ‘machine and human/expert learning approach’ and practice in this field is often based on experience and expert judgement. The BBNs are based on the probability theory and readily combine available statistics with expert judgement. The discussions and the expert knowledge of the different partners were important for the definition of the model structure and parameters. In addition, the outcomes of statistical analyses of their databases have improved the performance of the BBN.

At first, a geotechnical review of the boring process revealed a relationship between the diameter of the pile and the pile head, the pitch of the screw and forward velocity. In addition, relationships were established between cone resistance, torque and pull-down. In the next step, these relations, the statistical outcomes and geotechnical parameters relating to soil conditions were included in a BBN describing both the boring process and the production of the pile as the casing was being pulled up. The BBN was used to determine whether pile quality will be adequate in certain conditions.

The project showed that the BBN can help the piling companies to monitor and control the pile installation process in real time. The BBN can be improved by using more pile testing data and by extending the expert knowledge included in the system. Furthermore, the approach could be extended to other types of displacement piles.
Colofon

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