POTATOES THAT CAN COPE WITH SALT

LOUISE FRESCO ON AGRICULTURE AND WATER

RESILIENT CITIES: READY FOR EMERGENCIES

DOSSIER FLOOD RISK: RISKS AND OPPORTUNITIES ON THE MAP

LEUR LE

NO.5 FEBR









A series of floods battered Brisbane, Australia, in January 2011. The result: 35 dead and damage amounting to between 3.5 and 4.5 billion Australian dollars. Although it is very tempting to take action immediately, the state of Queensland decided to draw up a sound plan first. How probable is extreme weather of this kind? How high will the water be, and where? Where we can build, and where not? Science is helping to identify priorities in a citu under threat. More on page 9.

### → 6 'AGRICULTURE AND WATER: A CHALLENGING COMBINATION'

Food security and flood risk management: today's priorities. Louise Fresco explains what two worlds can learn from one another. 'Even the Netherlands has no central delta authority yet.'

# → 9 FLOOD DOSSIER

It is precisely where the flood risk is high and large numbers of people live and work that the best solutions emerge. A new approach with great promise.

## → 24 THIS POTATO CAN COPE WITH SALT

Our groundwater is getting saltier all the time. Dry summers and sea-level rise are accelerating the process and that is having an impact on our approaches to food production and water management. One solution is to develop vegetables that are more resistant to salt.

And also:

3. Deltares in brief

- 16. Infographic: extreme flood events
- 18. Serious game with fertilisers
- 19. loane Teitiota's atoll will become uninhabitable within decades.
- 22. Testing ground: invisible threat below the dike
- 23. Knowledge at work: space-saving transportation of waste water
- 26. Resilient cities
- 28. Deltares software
- 29. Deltares organisation









#### CREDITS

Delta Life is published by Deltares, an independent institute for applied research in the field of water, subsurface and infrastructure. Throughout the world, we work on smart solutions, innovations and applications for people, environment and society. Our main focus is on deltas, coastal regions and river basins.

For more information: www.deltares.nl

Editing desk: P.O. Box 177, 2600 MH Delft, The Netherlands tel. (+31)088 335 8273, communicatie@deltares.nl A subscription is free and can be requested or cancelled by sending an e-mail to info@deltares.nl. Text: Deltares and Maters & Hermsen Journalistiek Design and layout: Deltares en Maters & Hermsen Vormgeving Print: Koninklijke BDU Grafisch Bedrijf bv ISSN: 2351-972X

# DELTARES



## **'SCREEN' TO STOP SALT WATER**

seepage screen has been installed in the Perk Polder in Zeeland to protect the freshwater lens in Kloosterzande. It contains pipes that capture salt water seeping underneath the dike. Since June 2015, the salt water from the Western Scheldt has been flowing in and out of the new tidal nature area. That is a concern for local farmers, who use the groundwater from this area to irrigate their fields. After years of exploratory research by Deltares, extensive calculations, the accumulation of specific information about the groundwater system and six

months of intensive testing in practice, the facility is working just as it should. Indeed, the freshwater stocks are actually growing naturally and so this would seem to be a promising approach for small islands throughout the world that will help to prevent the negative consequences of sea-level rise such as salinisation. Deltares will be conducting further research.

#### For more information:



www.deltares.nl/en/projects/ seepage-system-protectsfreshwater-lens-in-perkpolder/

#### IMPROVING THE FLOW OF THE HIGHWOOD RIVER

After the major floods caused by the Highwood River in June 2013, the province of Alberta in Canada now has to take steps to improve its flood defences. Deltares reviewed the sustainability, cost-effectiveness and social acceptance for two proposals, and found some areas for improvement. We advised the authorities not to use large-scale infrastructure but to enhance the discharae capacity of the Highwood River. Our recommendations mean that changes can now be made to the river that will be both safe and costeffective.

#### RESTORING THE SEDIMENT BALANCE

Some places in the Netherlands are affected by sediment shortages, while others have too much. The natural balance between incomina and outaoina sediment such as sand, clay and aravel has been severely disrupted. Both sediment excesses and shortfalls have dramatic consequences for public safety, the economy and ecology. This problem is seen not only in the Netherlands but throughout the world. Deltares wants to combine sediment supply and demand with the aim of exploring how to restore the disturbed sediment balance.



## DELTARES IN BRIEF

2011/01/01 to 2012/0 = 2012/01/01 to 2012/0 = 2012/01/01 to 2012/0 = 2012/01/01 to 2012/0 = 2012/12/31 to 201 = 2013/12/31 to 201

## FASTER PICTURE OF COASTAL CHANGES WITH SATELLITE IMAGES

Deltares can use satellite images to analyse morphological trends such as changing coastlines, sandbanks and salt marshes almost anywhere in the world. Tools that detect these trends automatically help to quickly establish a picture of the dynamics in a project area. With the ever-sharper resolutions of satellite images, more and more details are expected to become visible in the future, improving the quality of studies and consultancy, even in areas where few data are available.

### MAJOR URBAN CHALLENGES REQUIRE INTERDISCIPLINARY APPROACH

ed by Deltares, the Adaptive Circular Cities project has brought together several leading Dutch research institutes (TNO, DLO) and ECN). The aim was to come up with innovative solutions to major urban challenges by identifying technologies and planning concepts that contribute to climate change mitigation, climate adaptation and the sustainable use of resources. During the preparations for the project, it immediately became clear that the objectives could only be achieved by establishing interdisciplinary teams. That is why experiments with far-reaching cross-sectoral collaboration between investigators and with stakeholders were an important element in the project. The final results can be found on www.adaptivecircularcities.com.

## TACKLING KOREAN COASTAL EROSION

Deltares is working with the Korean Institute of Ocean and Technology to tackle coastal erosion. The work is needed because increasingly fundamental problems with erosion have been emerging since the 1970s, among other things due to the extension of ports without integrated plans for coastal management. South Korea does not have the right resources and knowledge to manage these problems adequately. Deltares will therefore be helping to improve software and to establish a standard model so the coast can be studied properly in the future. Deltares is working closely with Korean specialists so that they can use with the software independently.



RETA

More reports on www.deltares.nl

## CULTIVATING MUSSELS AND SEAWEED IN WIND FARMS

ultivating mussels and seaweed is the best way to combine wind farms in the North Sea with other sources of income, according to an analysis conducted by Deltares. Researchers looked at the most promising approaches to the multiple use of space in the North Sea, Baltic Sea, Atlantic Ocean and the Mediterranean Sea. The energy costs of offshore wind farms will have to be reduced in the years to come, and space will have to be found in the seas for both aquaculture and sustainable raw materials. At the same time, the negative impact on the local area needs to be limited. The study combined offshore technology, marine spatial planning, regulations, water quality and economic feasibility. A pilot project is now needed to test and apply the results in practice. The study was conducted on behalf of the EU by a consortium of 30 parties.

For more information:

www.mermaidproject.eu.

### DIKE FAILS, TRIAL SUCCESSFUL

How strong is a dike on a peat subsurface exactly? With the completion of a trial in the Dutch Leendert de Boer Polder, where researchers from Deltares and Delft University of Technology allowed a centuries-old dike to fail in controlled conditions, we now know more. The trial should allow water authorities to improve the robustness of dikes of this kind and to cut unnecessary costs at the same time. Researchers are analysing the data and they will decide in the spring of 2016 whether the acquired knowledge results in the correct safety assessments for this type of polder dike.



## WORLDWIDE STUDY OF FRESH GROUNDWATER RESERVES IN COASTAL AREAS

A better understanding of salinisation in groundwater systems and, at the same time, the advancement of solutions to prevent the further depletion of fresh groundwater reserves in coastal areas worldwide, and perhaps even to increase the size of those reserves. These are the aims of a joint study by Deltares and Utrecht University. Researchers will be drawing up precise maps showing the status of aroundwater resources in the forty most important deltas in the world. The data will also show how the reserves respond to the climate, sea-level rise and a growing population that is increasingly drawn to cities and is pumping up more and more fresh water. Researchers are also looking for solutions, such as smarter ways of extracting groundwater and ways to increase the infiltration capacity of the subsurface. Deltares and Utrecht University are combining specific knowledge with freely available databases from throughout the world. That makes it possible for the first time to estimate the size of fresh groundwater reserves, even for areas where data is scarce like the coastal zones of Bangladesh and Myanmar.





# 'EVEN THE NETHERLANDS STILL HAS NO CENTRAL DELTA AUTHORITY'

Agricultural engineers and water technicians: it's not always an easy relationship. Professor Louise Fresco, the President of the Executive Board of Wageningen University, has seen this for herself. 'But: we need each other and we can achieve a lot together.'

BY PJOTR VAN LENTEREN / PHOTOS SAM RENTMEESTER

ood safety and flood risk management are two priorities that are becoming increasingly related. So one of the first things that Professor Louise Fresco did when she became President of Wageningen University was to establish a group that brought agriculture and water experts together. The views of an agricultural engineer, director and writer who likes to look beyond the established boundaries between disciplines.

#### Food and water: logical, right?

'You would think so. But there was hardly any collaboration, even though all these people work for the same university in an area of one square kilometre. Fortunately, the ecological approach to thinking about the challenges of our time is gaining the upper hand. Engineers, physiologists and biologists are, of course, increasingly involved with one another.'

## What do water and agricultural engineers overlook in each other's fields?

'It is possible to combine food production, nature, safety and the economy in deltas. The growth of mangrove forests matches rising sea levels and they are breeding grounds for fish. Dikes built in particular ways can be used for mussel cultivation. But that's just the beginning. We have to learn to speak each other's language. For agricultural engineers, water engineers are people who create difficulties: they want to submerge precious land or use it for infrastructure. And the opposite is also true because farming is a sector that is highly unpredictable. Water simply moves to the lowest point: farmers have to deal with weather, pests, expected and unexpected interactions between plants, people and animals. Such a lot can go wrong, and then you lose your harvest, and your income.'

## To what extent can agriculture contribute to flood risk management?

'Agriculture isn't just part of the problem; it's also part of the solution. Farmers and biologists are good at the sophisticated management of complex systems. For example, with the right grasses and proper management, we can make sure that soil absorbs more  $CO_2$  and contributes to reducing global warming. The difference looks marginal, but don't forget how many thousands of square metres of grass we have. There is still a world to be won.'







## There are surely many other ways forward, such as saline agriculture?

There isn't a single solution; we have to tackle the problems in an integrated way. The salinisation of coastal areas is a major concern and saline agriculture is a good example of the complexity of our work. It sounds so promising but, in reality, the approach isn't producing much in terms of calories as yet. We may make progress by crossing salt-tolerant vegetables with potatoes or rice, but conventional breeding takes time, and the world isn't yet ready for the fast approach: genetic modification. On top of all that, the saline vegetables we have now are not very salt-tolerant at all. I think plants that remove salt from the soil have more promise. Everything is possible, but it takes time.'

#### How do you manage, despite all the complex problems in the world, to stay optimistic about the future?

'Pessimism is a luxury we can't afford. Three quarters of the world's population live and work within a hundred kilometres from a coastline and we will have two billion extra mouths to feed in the next thirty years, on top of the two billion we already have who can't get a balanced diet or even enough food. We must engage in a dialogue with one another, and that is what we are doing. We have accomplished such an incredible amount in recent decades. So we can ask each other a very concrete question: what can we actually do together?'

## What would you like to see at the top of the international agenda?

The world needs models. The Netherlands has made a lot of progress: farming isn't this closely controlled anywhere else, and water management is nowhere as sound. They aren't

this thorough even in California. But things have to be done quickly as well. Deltas are fertile and appealing but they are also vulnerable. Solutions cost a tremendous amount of money and so we can't manage without investors. I believe that large deltas like those of Nigeria, Brazil and South-East Asia need delta authorities that bring together public and private bodies to tackle the problems. Even the Netherlands hasn't got that far yet.'

#### Does it help that the most vulnerable areas often happen to be the most densely populated and economically strongest?

There are certainly areas where we have a good chance of achieving quick results, and setting an example for the rest of the world if we get to work now. In those areas, there are serious reasons for taking action, and there is a lot of investment potential. But we have to get started quickly. We are used to working in boxes. As a result, ministries and universities in the West may be very professional but they may also be too slow. We need a lot more ad hoc partnerships. It could be that the countries that have only had central governments for a short time will be able to move faster in the future. For example, Eastern Africa was the first place to introduce payment with cell phones. Things like this also make me optimistic.'

## Have the challenges in your profession changed a lot in recent decades?

'We know more and we can do more. What worries me is the enormous lack of trust in science that has emerged on this side of the world. There are highly educated people who say: "I only eat things that come from nature" or "I've stopped eating bread". Westerners take good, cheap food for granted, but they shouldn't. They dream about solutions that are completely impossible scientifically. There has been a rise in magical thinking that has been totally unexpected for me and that will certainly not help us to save the world. It's going to take a major effort to roll that back. It stands in the way of progress and it is negating what we have achieved with decades of systematic research.'

## What can the Netherlands learn from the rest of the world?

'Flexibility. We are often still talking when the problems elsewhere have already been sorted out. Entrepreneurship: there's another thing. Silicon Valley has obviously been a huge catalyst for ICT. We want to go down that road as well, but it takes much too long to set up something like that here. Diversity: we still have way too many white, grey-haired men at the top. That is probably one reason why we still think and work in disciplines, even though we actually should be looking at problems in all sorts of different ways at once. That's the way to succeed.'

# DOSSIER FLOOD RISKS

It is precisely in the locations where large numbers of people live and work that floods have a major impact. But there is also more room to invest in solutions. A positive perspective on the global response to the effects of climate change. 9

# WE SHOULDN'T BE STOPPING AT NATIONAL BORDERS. WATER DOESN'T.

Where do investments in flood risk management produce most returns? Water envoy Henk Ovink and Professor of Climate and Water Management Jaap Kwadijk about smart approaches to global partnerships for tackling the effects of climate change.

BY PJOTR VAN LENTEREN / PHOTOS SAM RENTMEESTER

ater envoy Henk Ovink and Jaap Kwadijk, Professor of Climate and Water Management, are two familiar faces in the water world. Both think we should be looking at the impact of floods, and not be trying to prevent them whatever it takes. But how? A governance answer from Henk Ovink and a scientific view from Jaap Kwadijk.



Administrator Henk Ovink: 'If you manage water properly, you can create prosperity and equality.'

Top civil servant Henk Ovink advised President Obama during the recovery of New York after Hurricane Sandy.

## How can scientific knowledge help the world to set priorities?

'The global water crisis is about more than just flooding.









The three countries with the highest numbers of people threatened by floods are India, Bangladesh and China. There are 10 Asian countries in the top 15.

## **†**220.000

Between 1980 and 2013, the direct economic damage caused by flooding exceeded 1 billion dollars worldwide. More than 220,000 people lost their lives.



If no action is taken, the level of damage will increase by a factor of twenty before the end of this century.

52bn Stéphane Hallegatte of the

World Bank has calculated that the level of damage in the 136 largest coastal cities (6 billion dollars in 2013) will increase to an annual 52 billion by 2050.

Water scarcity, excess water and polluted water all come and go, and the effects of the changes vary from place to place. No water means: no food, no energy, no economy and no life. The relationship with social issues and urbanisation is complex and so good scientific research is needed, as well as clear application in practice. Deltas are the areas where that complexity is often multiplied: they are hardest hit by climate change. But they are also the places with most capacity for change because it is precisely here that there is most dynamism. The majority of the world's population live in deltas. The right knowledge helps to identify priorities, and to establish frameworks for action.'

#### What do you see as the right knowledge?

We are working under the leadership of the Dutch Environmental Assessment Agency with Deltares and a large number of national and international parties on a new analysis. It focuses on the vulnerabilities and opportunities in the system and on places where there is most potential for change. This is possible due to the integration of existing knowledge, data and research. The online database Aqueduct was established in a major coalition with the World Resources Institute and it provides a clear picture of the vulnerabilities and dependencies relating to water. In addition, the studies by Professor Stéphane Hallegatte from the World Bank looking at the economic risks of water crises and poverty have strengthened our understanding and they are a direct source of substantive action.'

#### The Dutch Delta Plan is seen as the best approach. Should everyone have a Delta Plan now?

'No. I think it is important for us to export and connect our knowledge and expertise, but not necessarily our solutions. The principles are the same everywhere but they will lead to different approaches in each region or country.'

#### Which principles do you mean?

'The first of the four principles I have in mind is the development of an integrated long-term approach in conjunction with short-term projects, which should preferably be innovative. This is a motor that you should always keep running to achieve a genuinely sustainable resilient impact. Then there is collaboration in the field of financing. Using the right processes and tools, we can conduct sound social cost-benefit analyses of those integrated plans and projects, and produce clear evaluations. That results in transparency and proper accountability. And that helps public and private partners to work together and to invest together. The third principle is an inclusive process involving all the stakeholders, large and small, institutional parties and activists. All this backs up the fourth principle: the social and institutional capacity that is vitally needed to achieve a genuine, ongoing impact. In the end, it's all about cultural change.'

#### Dutch administrators and scientists are keen to play a leading role in flood risk management. Are you saying we don't do this already?

'In terms of flood prevention, we are a shining example to the world: everyone knows the way to our door. But nobody is really taking the lead worldwide, even though that is urgently needed. Of course, this always means working together but the Netherlands could establish an innovative, international, preventive strategy based on the four principles I have explained. We have the knowledge, the experience and the acknowledged position, and no-one disputes the urgency. As a country, we must show the courage needed to adopt that role and to get behind it together. That hasn't happened yet.'



#### lsn't that a bit odd?

'It is unfortunate and it could, given the magnitude of the problem, turn out to be disastrous. We have to join forces worldwide now. We can do it. And I believe we want to do it, too. Even so, when the World Economic Forum identified water as the leading global problem, not a single newspaper here covered the story. With our clean water, our dikes and our stormsurge barriers, we are well organised. But there is not much awareness of the problem, even though we can be so proud of our history and our current knowledge, and even though we can and should use it to help people throughout the world.'

## Despite the daunting nature of the challenge, what gives you hope?

Water brings together the main themes facing the planet: ecology and economics. If we manage water well, we create prosperity and equality. The wonderful thing is that water also demonstrates how vulnerable we are: it transcends national borders and politics. We should also be paying less attention to borders and thinking about more than just our individual interests. New ways of working together and innovative solutions where different interests meet: that is where the real power is and that is how we can change the world.'



Scientist Jaap Kwadijk: 'We should be taking a close look at what gives us most safety for our dollar.'

Scientist Jaap Kwadijk (University of Twente and Deltares) assesses flood risks throughout the world.

#### The Netherlands is about to tackle flood risk management differently. Why change something that the whole world agrees on?

'Even though we have the safest delta in the world, we need to think about how much we want to spend on safety. Maintaining 3,500 kilometres of dike costs a lot of money. In the new approach, we look at the impact of flooding on a society and an economy, and what it costs to prevent negative effects. Doing this shows that major investments can be needed in some locations that pay for themselves many times over. Elsewhere, they can be a waste of money. Clarifying the costs and benefits makes for a better debate and smarter choices.'

## Fantastic! Are you doing that for the rest of the world, too?

'Certainly! It's not enough to just identify the problem. Okay, we know where things go wrong and how badly. But what's next? What are we actually going to do about it? Deltares is involved in developing tools that clarify risks, consequences, costs and solutions. How can we get most safety for our dollar? Where do you get a return on your investment? We also combine knowledge about rising water levels and the weather with the rising population and economic growth. That makes sense, but analyses of this kind have been challenging until now, and this is an area we are working on.'

## What can water scientists themselves do better to help the world?

'Worldwide, more collaboration is still needed, but the same applies to our own institutions. Some people are working on clean water, others on the seas, and still others on rivers. If we can break down those divides and combine all that information, which is still very difficult in practice, we could achieve some interesting results. This type of collaboration should be the top priority, followed immediately by moving beyond scientific research and looking for solutions. We shouldn't be telling horror stories; we should be quantifying, and concentrating on, solutions. Otherwise, you just get bogged down in the analyses with which everybody is familiar by now.'

#### What can the world learn from the Netherlands?

'The Netherlands is very good at working with others. In the Netherlands, information gets exchanged between public and private bodies and the scientific world without having to surmount all that many hierarchical obstacles. I can pick up the phone and call a company or a ministry, and people will take me seriously. My own personal experience is that things can be very different in other countries. People don't listen enough to scientific institutes even though they are the suppliers of knowledge and innovation. We are a small country but, when we work together, we are unbeatable.'

#### And the other way round?

'The Netherlands has it easy compared to other places: we don't have extreme weather here, there is a solid subsurface of sand and the delta is small compared with the huge deltas in other parts of the world. Our Rhine is a stream by comparison with the Mekong River. And there is no opposition to flood risk management in the Netherlands: there isn't a single politician arguing against it, or claiming it's too expensive. There are parts of Asia and Africa where the population is growing rapidly, but where there is hardly any money is to protect the population from the rising water. This is where we see the real challenges. Dutch scientists should study these regions to think in ways that are less Dutch. We need to think much more in terms of the local situation. We shouldn't be telling people what to do; we should be telling them what will happen when they make particular decisions, and leave the politics to the locals.'

#### Every day, the numbers tell us what will happen in the decades to come, and it's quite a challenge. Why do you think we're going to make it?

'I cling on to one idea: you will never be able to prevent flooding entirely, but you can make it manageable. If we get to work now, there is still time. Learning from one another is easy now that information can be circulated so quickly. So no, I'm not pessimistic. Definitely not. It's going to be tough but, if we do the job properly now, we will be able to manage the problems.'





## FLOOD-SENSITIVE BRISBANE MAPS OUT THE FUTURE

After the floods of 2011, the authorities of Queensland in Australia need measures that have been thoroughly researched. People had to be sure the right steps will be taken. Ferdinand Diermanse of Deltares did the calculations.

BY PJOTR VAN LENTEREN

risbane, January 2011: the two reservoirs in the largest river in South-East Queensland, Australia, can no longer accommodate the rain that has fallen. A series of floods batter the capital and ninety other cities in Queensland. The result: 35 dead and damage amounting to between 3.5 and 4.5 billion Australian dollars. 'And,' predicts risk researcher Ferdinand Diermanse, 'it could happen again tomorrow.'.'

#### **Critical population**

Although it was very tempting to take action immediately, the state of Queensland decided to draw up a sound plan first. How probable is extreme weather of this kind? How high will the water be, and where? Where we can build, and where not? 'A thoroughly researched and costed plan can not only save a lot of money, it can also reassure a critical population that wants the authorities to consider all the options.' At the request of the Queensland authorities, Ferdinand Diermanse ran the calculations for a range of scenarios, looking at 309 kilometres of river in an area abounding in farmland and urban regions. The work involved taking all possible variations in natural processes into account, as in more traditional approaches. 'The difference between a lot of rain and too much rain, for example, is highly dependent on the wind direction, where the rain falls exactly, and rainfall in the previous days. That makes risk assessment particularly complex.'

#### Skype

A unique feature of this research is the close partnership with Australian experts. 'Quite often, a job comes in and you make a report. In this case, we delivered all our calculations to the Australians as open-source data, together with the models. If they decide, for example, to build a third reservoir, they can make adjustments to the model and see how the level of risk is affected.

In addition, independent experts evaluated all the results and Ferdinand Diermanse explained the numbers in person during local meetings with the press and residents of Brisbane. 'I regularly spent nights sitting at our kitchen table to attend meetings on Skype.'

#### Saving money

The calculations for the Brisbane River in Queensland were done in Delft FEWS, flood warning software that is also used by the Environment Agency (UK), the National Weather Service (US) and the Bureau of Meteorology (Australia). The modular system can be easily tailored to local conditions and requirements.

'It's an investment. But you can use the system to decide whether to intervene and where you won't be doing any building at all. That can produce enormous savings in the long term.'



#### **OPPORTUNITIES AND RISKS ON THE MAP**

To decide on the best strategy to combat climate change, we need accurate figures. That hasn't been easy until now because most studies focus only on flood risks, and not on the question of where floods have the most impact, which requires information about local socio-economic development. A major study led by hydrologist Hessel Winsemius that appeared late last year in Nature Climate Change includes all these catchment data in a single map.

#### At risk

But what do the maps show exactly? That is best explained by looking at the differences between, say, the Mekong and the Rhine. It is clear that socio-economic growth has most impact near the Mekong. Because the population and the economy are growing fastest here, the risks associated with flooding are on the increase.

The good news is that economic growth also produces the resources that make it possible to tackle the impact of floods. For example by looking closely at where people settle and at where action is needed. In Europe, a lot has already been done around the Rhine and socio-economic growth



2080 climate change margin of uncertainty in current prognoses Sphere size The size of the spheres shows the expected damage by comparison with the gross national product of the countries in the river catchment. The larger the sphere, the higher the level of relative damage Left and right halves The left half shows the situation in 2015, the right half the calculated damage in 2080. Orange and blue wedges The orange wedge shows

how much damage is the result of economic growth and the blue wedge shows the role of climate change.

--% The number underneath The percentage below the sphere shows the extent to which damage will increase by comparison with the current situation.

is much slower. Here, climate change is the main motivation for government authorities to make improvements.

#### **Rivers** only

This is the first time all these data have been brought together in a single model. The backbone of these results is the Global Flood Risk with IMAGE Scenarios (GLOFRIS) model. This software was developed by, among others, Hessel Winsemius and it is used throughout the world. The study was conducted in collaboration with the VU University Amsterdam, Utrecht University, the University of Twente and the Netherlands Environmental Assessment Agency.

Hessel Winsemius was involved in the past with the development of

the Global Flood Aqueduct Analyzer, which also helps countries to establish a picture of increasing flood risks and to make investment decisions. At this time, this information covers rivers only. The next step will be a world map that shows the risks associated with sea-level rise in the same way.

#### For more information:

hessel.winsemius@deltares.nl

15

## Extreme flood events

Flood disasters account for about a third of all natural disasters, by number and economic losses. Climate change will make extreme events more likely, whereas population growth and economic development, especially in delta areas, will increase the potential impact of flooding. This illustration gives an overview of four major flood disasters and their impact.

#### **Hurricane Sandy**

2012 – One of the costliest storms ever to hit the East Coast of the United States, flooding critical infrastructure, destroying homes and leaving more than 8 million people without power. The total death toll reached 201. Total damage was about \$70 billion.

#### UK river floods

A series of heavy rainfall events led to flooding during the winter of late 2015 and early 2016. Parts of Northern England suffered their worst floods in more than 70 years. Thousands of people were evacuated.

#### Hurricane Katrina

2005 - The costliest natural disaster and one of the five deadliest hurricanes in the history of the United States. 1,833 people died. Total damage was \$ 125 billion.

#### Asian Tsunami

2004 - The world's deadliest tsunami, with over 220,000 people killed and half a million injured by the waves that battered the low-lying coast. Waves of up to 10m hit the coastlines of Sumatra, Thailand, India and Sri Lanka. The tsunami reached up to 30m elevation in some areas.

# Building with Nature solutions

Building with nature solutions can contribute to flood risk mitigation while enhancing ecological and recreational qualities. They can complement or replace traditional solutions like hard embankments.

#### Mangrove forest

Mangroves reduce wind and swell waves effectively. However, extensive and wide mangrove forests are needed to mitigate the impact of tsunamis.



#### Willow forests

Willow forests reduce waves and fixate the subsoil. In combination with a grass-covered dike, they provide effective flood protection.



TTI TERE

111

#### Salt marsh

IT A MILLA III ALLAMBUDIA

Both the elevated ground and the vegetation of salt marshes contribute to wave reduction. In addition, vegetation retains the sediment, effectively combatting erosion.



#### Sand nourishment

Large-scale sand nourishment brings more sediment to natural beaches in dune systems, keeping them in position and making them more robust so they can withstand major storms.



Frédérik Ruys, Vizualism



## A SERIOUS GAME TO MANAGE NUTRIENT LOSSES

Farmers and industry are working towards restoring Waituna Lagoon in Southland New Zealand. They can now turn to the DeltaDataViewer serious game to help them achieve this. BY MEINTE BLAAS

Data and models are daily fare for researchers but most other people find them tough going. Presenting the research results in the DeltaDataViewer makes selecting and understanding scenarios a lot easier.

#### The problem

Farming has been expanding in the Waituna catchment since the 1960s. Today, more than two-thirds of the land area is used by agriculture. Lagoon health has declined over recent years due to increases in nutrient loading. Water quality may worsen due to turbidity and algal blooms if nothing is done. Making changes in how the agricultural land is being managed is part of the solution.

#### The challenge

It's difficult to gain insight in to the most effective management solutions at the catchment scale. Not only do discharges from individual farms differ, the types of soil and surrounding land use activities also affect the amount of nutrients that will ultimately enter the lagoon.

#### The solution

The DeltaDataViewer. An interactive serious game based on hydrological and water-quality models that takes the seasons into account. This serious game allows stakeholders to work

together on a tablet, changing input data with a click on the map to test different scenarios. For example by treating run-off water with a biofilter or by varying the amount of nutrients that enters the water from a farm. The overall effect on loading to the Lagoon then becomes visible in a few seconds.

#### **User findings**

The DeltaDataViewer is a powerful instrument for water managers and farmers. The industry organisation DairyNZ, which commissioned its development, is supporting farmers in finding a solution to improve water quality to meet environmental targets while still remaining profitable. This tool is not only about the science but also the way in which it's presented, together with stakeholders.

For more information: erwin.meijers@deltares.nl

# ATOLLS DISAPPEARING FASTER THAN EXPECTED

Most of the 500,000 people living on atolls in the Pacific and Indian Oceans will have to move to the mainland, not at the end of this century but within a few decades. Only the richer atolls can afford measures to deal with the rising waters, but even these are not permanent solutions.

#### **BY JANNEKE IJMKER**

loane Teitiota could be the first person on earth to officially apply for asylum on the grounds of climate change. He believes that his birthplace, the Kiribati atoll midway between Hawaii and Australia in the Pacific Ocean, has become uninhabitable. Floods are increasingly frequent, the quality of the scarce drinking water is declining rapidly, and the infant mortality rate is higher than in Bangladesh. So he decided to flee to New Zealand.

Boane is now back on his island but his story on the BBC has gone the world over, and his questions have struck a chord. What is going on with loane's atoll? What impact is climate change having? What knowledge do we need to address the problems? And are there any solutions at all?



loane's concerns are supported by scientific research. A partnership between the United States Geological Survey (UGSG), the University of Hawaii and Deltares has shown that many atolls will become uninhabitable in the coming decades due to climate change, much sooner than indicated by previous calculations.

#### Wave run-up

The new results are based on information about waves. Sea-level rise due to climate change is a problem in itself but waves are also getting bigger and that exacerbates the effect. Wave height is determined by the depth of the sea, the seabed and storms. If we also take 'wave run-up' into account, we find that atolls will be flooded twice as often as when we just look at sea-level rise.

These results are based on years of research. USGS and Deltares - which already has extensive experience with wave models for the Dutch coast - have been studying wave run-up in the Pacific Ocean since 2001 for the U.S. Army because of the military bases located there. Roi Namur, an atoll in the Marshall Islands, was one of the locations studied. The study there looked at the factors that make an atoll vulnerable to the impact of floods. The available models for sandy coasts were adapted for use on coasts made up of gravel and coral. The results are widely applicable.

#### Vegetable gardens

Floods are not the biggest threat. Because they are isolated, the islands are largely self-sufficient. The drinking water stocks consist of a thin lens of fresh water just above the sea level and food is grown in small vegetable gardens.

Cleaning up the mess after a flood takes weeks and rebuilding damaged infrastructure several months, but restoring the drinking water supply takes six to eighteen months. In many places, the floods return before the drinking water stocks have recovered. The inevitable result: less fresh water, and less food.

An additional problem is the destruction of coral. A healthy atoll can keep up with the rising sea level for a while: the living coral grows and the floods deposit debris from the coral on the atoll.

But the growth of coral reefs worldwide is being affected by pollution and climate change. Furthermore, coral is used locally to produce limestone and cement for housing, and fishermen use dynamite, causing further destruction. Another factor is that dying coral is less rough and so it reduces the height of waves less. Finally, when coral is lost, the sea gets deeper and so the waves get even higher.

#### Checklist

Not all scientists are predicting the imminent end of the human habitation of the atolls. Paul Kench of the University of Auckland studied historical maps, aerial photos and satellite images and found that 18 of the 29 islands have actually got larger in recent decades. However, the question is whether this is enough: the increase in the surface area is usually not associated with increasing height and so it probably has no effect on wave run-up.

What now? The study of the USGS, the University of



Hawaii and Deltares is focusing on the development of a checklist to identify the most vulnerable and threatened atolls. That information can be used to decide where the need is greatest.

#### **Concrete seawall**

But it is still unclear whether anything will actually be done with the information. The low-lying atolls rise up steeply and so they are difficult to protect using dikes or sand nourishment: the large amounts of sand that the Netherlands has in the near offshore are not available here. Some rich atolls can build homes on stilts. In some locations, people are building concrete seawalls that actually result in the erosion of the coastline elsewhere. Drinking water can be obtained with a desalination plant.

#### **Desperate poverty**

More than 500,000 people live scattered across atolls in the Pacific and Indian Oceans and most of them are desperately poor. But they have no choice: they must stop the destruction of the coral for housing and fishing, and stop discharging untreated sewage. Even then, these islands will probably become uninhabitable within a few decades. Animal species are endangered, habitats are disappearing and people will be forced to move out. Centuries of island culture will be lost. We do not know whether we can stop that process. (3)

22 DELTALife

#### **TESTING GROUND**

Ferry Schenkeveld is studying the effect of channels in the sand layers below dikes in the Geohal.



## **PIPING: INVISIBLE THREAT BELOW THE DIKES**

f there is one thing a dike manager doesn't want, it's a dike failure caused by *backward erosion piping*: water flowing through channels in the sand layers below a dike. It is an insidious threat that washes away sand to low spots behind the dike.

The latest assessment of Dutch dikes showed that there are many kilometres of dike that need to be strengthened to prevent failure as a result of backward erosion piping.

 $\overset{\space}{\mathbb{R}}$  These are very costly operations, so it is important to

 $\overline{\exists}$  thoroughly test the numerical models.

🚊 Initially, Deltares does this in small-scale experiments

 ${\mathbb H}$  of the kind shown in this photograph. Obviously, larger-

scale tests follow. In this way, the effects of backward erosion piping can be studied in different types of sand and it is possible to identify the types of sand that are more resistant.

Deltares also uses these experiments to look at new factors in the models such as the role of natural variations in the sand, and the effect of new countermeasures such as vertical sand-tight geotextile or a barrier for coarse sand. This improves our understanding of how safe dikes are, and how they can be strengthened in ways that minimise disruption and costs.

#### KNOWLEDGE IN OPERATION

Alliance between Deltares and industry produces innovative techniques and creates new market opportunities for business.

# SPACE-SAVING TRANSPORTATION OF WASTE WATER

msterdam is a densely-populated city. So every square centimetre of space saved is welcome. An opportunity arose in 2005 when the sewage-treatment plants in the east and south of the city were closed and a new plant was built on the other side of the city in the western port area.

Water company Waternet was faced with a few problems related to the transportation of dirty water from homes and companies to the new location: How do you move waste water through a fortykilometre-long mains system? How can you stop the spread of unpleasant smells and minimise costs? The answer to those questions was to install four booster pumping stations that pump 300,000 cubic metres of water to the western port area every day. That saves space - and cuts costs - because no underground cellars are needed to store the waste water. The closed system of pressure pipelines also stops unpleasant odours.

Waternet called in Deltares, Witteveen+Bos and Berenschot Osborne to develop this solution. The idea of the booster pumping stations was worked out in detail and the pump configurations were thoroughly tested in simulations. Nothing had to go wrong. The intensive preparation paid off: the transition from the old to the new transport system in 2005 went off without a hitch. And now, ten years later, the boosters are still doing a great job. 23

# THIS POTATO CAN TAKE A PINCH OF SALT

Our groundwater is getting saltier all the time. Dry summers and sea-level rise are accelerating the process and that is having an impact on our approaches to food production and water management. One solution is to develop vegetables that are more resistant to salt.

BY SEBASTIAAN VAN DER LUBBEN

One litre of sea water contains 35 grams of salt on average. Drinking water contains much less. In the Netherlands, water is allowed to contain less than one hundredth of that amount: 0.30 grams. By comparison: one litre of water from the Dead Sea contains an impressive 280 grams of salt.



Thirty per cent of the global population live less than seventy kilometres from a coastline. Groundwater in coastal areas is generally much saltier than inland. That is the result of a natural process that is accelerated as residents in denselypopulated coastal areas pump up large amounts of drinking water, which is then replaced by saltier water.



Climate change also exacerbates salinisation: sea-level rise means that seawater moves further inland and, where there is less rainfall and drought leads to the evaporation of rainfall, reserves of fresh groundwater are replenished less. A quick calculation shows that, in Africa alone, salinisation is affecting 70 million hectares of agricultural land.

Pl. 234. Morelle tubér Solanum t



fresh water much more difficult to grow. Land is subsiding in many coastal areas throughout the world, such as the Mekong, Mississippi and Ganges-Brahmaputra deltas. This will eventually lead to more salinisation of the groundwater system, and the Netherlands is no exception.

> In two places in the Netherlands - Zeeland and the island of Texel - potatoes are being developed that can cope with more salt water than usual. Meijer Potato, an international supplier of seed potatoes from Zeeland, is producing potatoes can manage water that is quite brackish. This is important because the amount of brackish ground around the world is on the increase. And so is the market for these 'salt-tolerant' potatoes.

If we let salinisation continue, more than 200 thousand hectares of farmland will be lost for freshwater farming in the Netherlands alone in the next hundred years. Particularly in the northern part of North Holland, the Haarlemmermeer polder and the Southwest Delta, the soil will get saltier rapidly if no action is taken, making traditional crops that need

As well as studying potatoes, scientists from Wageningen are also investigating other salt-tolerant crops such as sea kale, barley, common scurvygrass, wild rocket and scentless mayweed. The most successful of these crops is sea kale (*crambe maritima*), and it is already on the menus of a number of top restaurants.

> Deltares is mapping out groundwater resources in large deltas such as those of the Netherlands, the Mekong and the Nile, and we are working on ways of protecting water resources better from salinisation.

euse (Pomme de terre). cuberosum L. MAGE: SCIENCEPHOTO.COM

For more information: gualbert.oudeessink@deltares.nl

26 RELTALIFE

# RESILIENT CITIES YOU SHOULDN'T MISS

Many global cities are facing the challenges of a changing future. They are adapting their structures so they can, for example, recover quickly from floods.

BY KARIN STONE

Floods, economic decline, rapid population growth, climate change: cities have a lot to endure. Resilient cities go with the flow, adapt and use the latest technological developments and partnership forms. Smart water management, for example.

## Singapore: using water sparingly

Sources of water are scarce on the denselypopulated island of Singapore. To safeguard water supplies for its people in the future, the city has introduced a range of measures. For example, the city's waste water is recycled and extra parks have been built to retain and treat rainwater, and to cool off the tropical city. The most striking project is the construction of the Marina Barrage. The dam protects the city from flooding and creates a freshwater reservoir in the middle of the city.

## Hamburg Hafencity: flooding allowed

Hamburg Hafencity has been transformed from the old docks into a new residential area. There is an open connection to the sea and so floods are inevitable. Even so, it was decided not to build any dikes. The new homes have been built



RELTALIE 27

in higher locations, and the lower floors of renovated warehouses have been fitted out with steel doors that close at high tide. Roads and bridges have also been built so that traffic won't be affected by floods.

**Second Second S** 

**Rio de Janeiro: protecting favela residents from the rain** Rio will be in the spotlights during the Olympic Games in 2016. The preparations include a cleanup of Guanabara Bay, better drains and the recycling of waste. And the city is also looking at the favelas. These areas cannot manage the increasing levels of rainfall caused by climate change. The densely-populated, often poor, neighbourhoods are built on steep slopes and so they are exposed to landslides. The city is developing a warning system and housing for the vulnerable Melbourne: smart urban design Melbourne is very sensitive to climate change. It has to cope with problems ranging from heat waves, droughts and forest fires to heavy rain. To curb the summer heat, more green areas have been created and experiments have been launched with cool-roof technology. All the changes in the city take water into consideration, for example by using paving stones that let water through, and by building green roofs and wadis, features that allow excess rainwater to drain away into the ground slowly. The inhabitants of the city will also use water sparingly during droughts, for example by rinsing off their cars on the lawn and by using rain barrels.

**Dakar: raising awareness first** Rainfall and its low-lying location on the coast mean that the capital of Senegal is increasingly at risk from flooding. Drought and environmental problems are also on the rise. Annual floods particularly affect the poorest people living in the city's low-lying slums, which lack basic facilities such as drains and waste collection. Improvements to the drainage of water represent an important step. But it will be equally important for the people to become aware of the climate problem so that they can team up with the authorities to devise solutions for the long term.

#### **Rockefeller's 100 Resilient Cities**

With the exception of Hamburg, all the cities mentioned here are participants in the Rockefeller's 100 Resilient Cities Initiative. Deltares recently joined the network as a Platform Partner. By contributing our expertise, we will help cities to become more resilient.



areas.



28 RESTALIÉ



## Online tool to explore water availability

Climate change and socioeconomic developments mean that investors are uncertain about where and what has to be invested in the water sector. The Water2Invest tool gives them the opportunity to explore the future of water supplies, demand for water and water shortages in different regions, and to establish a clearer picture of the most effective measures and investments required. To help with the development of this tool, Deltares supplies information about the impact of water shortages in the economy, society and ecosystems, and about measures to tackle those shortages on the basis of hydrological and water allocation models developed by Utrecht University, FutureWater and partners. We are continuing to extend functionality and to improve visualisation. A first prototype has now been completed and it is available online at www.water2invest.envisim.com.

## Keeping an eye on our software

How do people look at Deltares software? We are finding out using eye-tracking. Researchers from Deltares and the Department of Neurosciences at the Erasmus Medical Centre in Rotterdam have been conducting experiments with this technology, that shows which components of the software users look at, and for how long. We use the results to make our software, manuals and user experiences clearer.



# Serious game: Port of the Future



The serious game *Port of the Future* allows partners in ports to work together on the development of climate-resilient, sustainable ports where economic growth is in harmony with the ecosystem. The game consists of a fictitious but realistic setting. The participants experiment with various measures in response to a range of scenarios. The game uses indicators that can be

manipulated to minimise the negative impact on the natural environment. Dutch and Colombian participants recently tried out *Port* of the Future in Cartagena during the economic mission to Colombia. The game allowed them to see the impact of interventions based on strategic decision-making by multidisciplinary teams.

### \*

## Next Generation Hydro Software



The new software package Delft3D Flexible Mesh Suite 2016 was launched at the Next-Generation Hydro Software conference during the Delft Software Days. The package is the result of five years of research by Deltares, the Ministry of Infrastructure and the Environment, the Ministry of Economic Affairs, STOWA and Dutch engineering firms. Deltares designs, develops, manages and maintains several software products for the modelling of water systems. Five of these products were meraed step by step in the last few years to produce this new, more user-friendly hydro software package. The strengths of each product have been kept and combined with innovations, resulting in a more powerful new product.

#### For more information:

www.deltares.nl/software/ d-hydro-suite

# KNOWLEDGE TASTING FOR WATER AUTHORITIES

ALLATAN OL



What is happening in the world of water? To share knowledge and identify the needs of water managers, Deltares organises a Knowledge Tasting for water authorities every two years. More than a hundred participants met in November at the Knowledge Tasting in Media Plaza in Utrecht, where they had the opportunity to discuss how new knowledge should be applied. It was an innovative networking day, providing a rich menu of knowledge tasting and co-creation. As well as visiting the knowledge market, water authorities had a large number of workshops to choose from.

#### RESEARCH INSTITUTES COMBINE FORCES IN ENVIRONMENTAL LABORATORY

Helping public and private bodies to make the right decisions and introduce the right measures to maintain a safe and clean living environment. That is the mission of Utrecht Castel, which Deltares established in collaboration with TNO and Utrecht University. The Utrecht Centre for Aligned Studies for Environment and Life, the environmental laboratory's full name, is a facility for research into developments relating to climate change and the environment that are essential for a healthy habitat.

**For more information:** jasperien.deweert@deltares.nl





#### MAKING DECISIONS **UNDER DEEP** UNCERTAINTY

Climate adaptation, energy supplies, communications, transportation and defence have at least one thing in common: decisions are taken in extremely uncertain conditions. This emerged during the third international workshop Decision Making under Deep Uncertainty, which brought together more than ninety scientists and experts from around the world. Because it has been applied in several domains, the discipline of decision-making in deep uncertainty has developed rapidly. To keep each other informed about developments in the interim, it was decided to establish a societu.

#### For more information:

www.deepuncertainty.org

## YOUNG DELTARES EXPERTS WRITE BEST PAPER



Pepin van der Ven, Greta van Velzen, Tom O'Mahoney and Alexander de Loor won the PIANC Young Professional Best Paper Award with their paper Comparison of Scale Model Measurements and 3D CFD Simulations of Loss Coefficients

and Flow Patterns for Lock Levellina

Systems. Their study showed that

the computational fluid dynamics method can be used to determine the discharge coefficient for a new lock design. The jury was impressed by the practical applicability of the study, which makes the use of expensive scale models redundant. or allows them to be used more effectivelu.

THE HIGHEST ARTIFICIAL WAVES IN THE WORLD IN THE DELTA FLUME



Two Dutch ministers - Henk Kamp (Economic Affairs) and Melanie Schultz van Haegen (Infrastructure and Environment) - officially opened the new Delta Flume, quite literally with a splash. They experienced first-hand that the Delta Flume does indeed produce the highest man-made waves in the world. The Delta Flume is used to study coastal protection, natural flood defences and block revetments in infrastructure. The research results will help to develop solutions to complex climate challenges in delta areas throughout the world. See the simulated wave by clicking on this link:





#### LAURENS BOUWER JOINS EDITING BOARD OF CLIMATE SERVICES

Senior researcher Laurens Bouwer has joined the editorial board of the new Elsevier magazine Climate Services. The international journal focuses on linking research with the practical use of information such as climate scenarios and adaptation methods. In addition to scientific research, the articles also cover practical applications. Laurens will be working on the fields of water and flood risks.

#### More information:

www.journals.elsevier.com/ climate-services.

#### CHANGES ON SUPERVISORY BOARD

There have been some changes in recent years on the Deltares Supervisory Board. Karla Peijs, Koos van Oord and Luc Kohsiek have welcomed Suzanne Jungjohann (Delta Lloyd), Henk Nieboer (Witteveen+ Bos) and Frank Verhoeven (Boskalis) to the team.



Deltares has a wide range of courses on offer. We can also organise them to cater to your specific requirements and on location. During the course of the year and specifically during large conferences, courses are arranged in clusters. For a full overview, see the Deltares Academy web page. A selection of our courses in 2016:

D-Geo Pipeline | Horizontal directional drillina J **D**-Foundations | Foundation design and testing D-Sheet Piling | Designing sheet piling Dynamic Behaviour | Hydrodynamics of Pipeline Systems J D-Settlement | Settlement calculations Delft3D Flexible Mesh | Hydrodynamic Modellina Delft3D 4 | Environmental Modelling Delft3D 4 | Modelling Sediment **Transport and Bed Dynamics** J/ D-Pile Group | 3D Modelling of pile groups Capacity and energy losses in wastewater pipelines due to gas bubbles WANDA | Pumps and Pump Cellars J D-Geo Stability | Calculating the

stability of earth bodies

WANDA | Control valves and valves

More information: www.deltares.nl/academy/ academy@deltares.nl

RECTALIFE 31

## DOCTORATES

#### **ROBERT MCCALL**

Received his doctorate in July 2015 at the University of Plymouth, United Kingdom Subject: Process-based modelling of storm impacts on gravel coasts Supervisor: Professor Gerd Masselink

#### **STEPHANIE JANSSEN**

Received her doctorate on 1 September 2015 at Wageningen University Subject: Greening flood protection in the Netherlands. A knowledge arrangement approach Supervisors: Professor A.P.J. (Arthur) Mol and Professor J.P.M. (Jan) van Tatenhove

#### **ANOUK BLAUW**

Received her doctorate on 18 September 2015 at the University of Amsterdam Subject: Monitoring and Prediction of Phytoplankton Dynamics in the North Sea. Supervisors: Professor J. Huisman and Professor R.W.P.M. Laane

#### **RIANNE VAN DUINEN**

Received her doctorate 9 October 2015 at the University of Twente Subject: Exploring farmers' drought adaptation behaviour. The role of risk perceptions, coping factors and social interactions Supervisor: Professor A. van der Veen

#### **LEO SEMBIRING**

Received his doctorate on 30 October 2015 at Delft University of Technology. Subject: Rip Current Prediction System for Swimmer Safety. Towards operational forecasting using a process based model and nearshore bathymetry from video Supervisor: Professor J.A. Roelvink

#### **VERA VAN BEEK**

Received her doctorate on 26 November 2015 at Delft University of Technology. *Subject: Backward erosion piping. Initiation and Progression* 

Supervisors: Professor M.A. Hicks (CiTG) and Professor A. Bezuijen (University of Ghent)

# GANGES

The densely populated basin of the 2510-kilometre-long Ganges River in India is home to 330 million people, almost a quarter of the country's population. The main river passes through five states, each of which are responsible for water management.

To show how complex this can be: the state of Uttar Pradesh alone could be one of the largest countries in the world, with an irrigation system larger than China's. After each monsoon, there is almost no rain for the rest of the year and some tributaries of the Ganges are reduced to little more than flows of waste water. Due to the intensive pumping of groundwater, which is often the only source of water for cities, agriculture and industry in the dry season, even less water reaches the river and the problem is getting steadily worse. An important non-economic factor is that the river is sacred to Hindus. A clean Ganges alone could save India 53.8 billion dollars in health costs and other losses. So it is hardly surprising that successive governments are working on a Ganges Action Plan. Deltares is supporting those plans with a system that shows the impact of any proposed intervention on the river and the many stakeholders involved.

For more information: kees.bons@deltares.nl