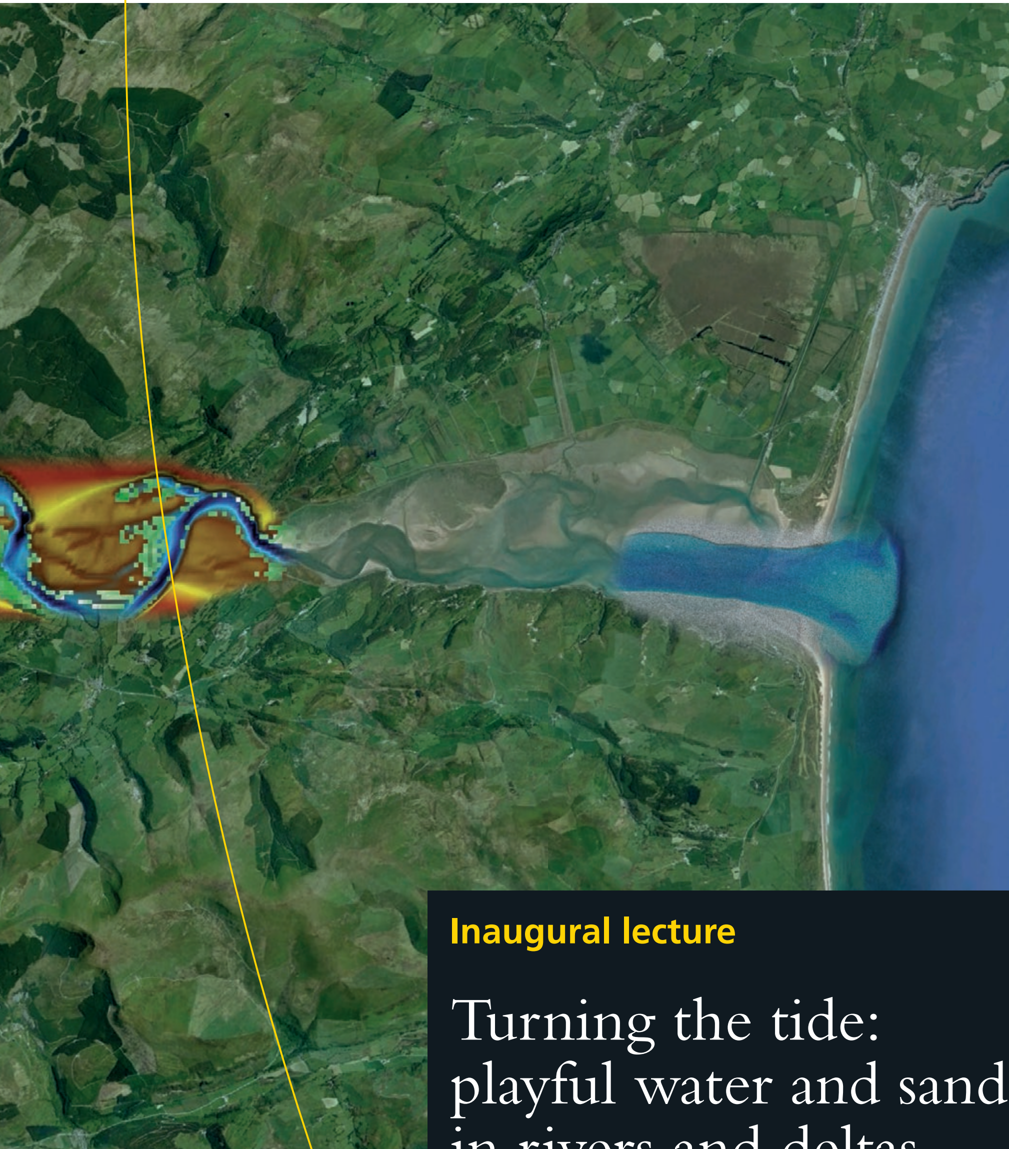
Universiteit Utrecht

Faculty of Geosciences



Inaugural lecture

Turning the tide: playful water and sand in rivers and deltas

Maarten Kleinhans

Universiteit Utrecht

Turning the tide: playful water and sand in rivers and deltas

Inaugural lecture, delivered upon acceptance of the Chair in Physical Geography,

specifically the process sedimentology of river-dominated systems, at Utrecht University's

Faculty of Geosciences of Utrecht University, on 26 September 2014

by Maarten Kleinhans.

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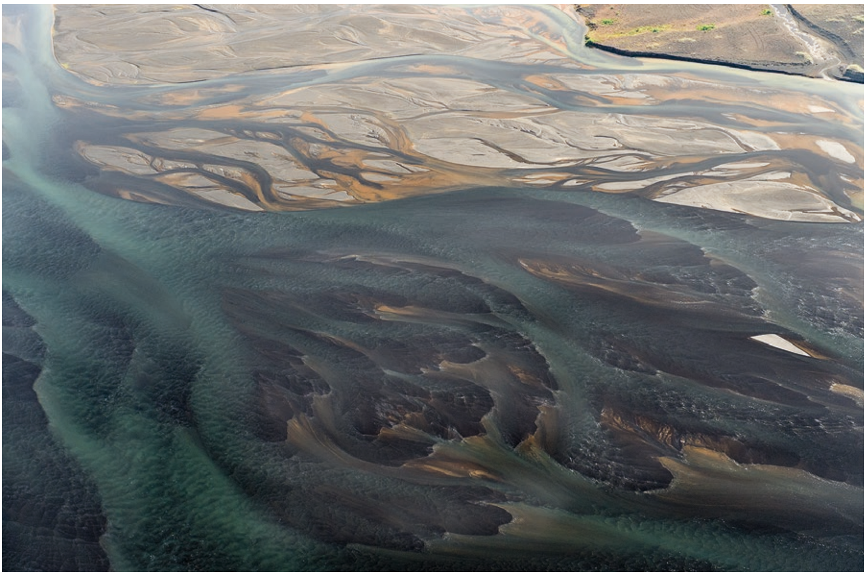
The Portmanteau Estuary flowing into the Boojum Sea
(Source: author and Margot Stoete).

Dear Chancellor of the University, dear colleagues, students, family, friends, and children,

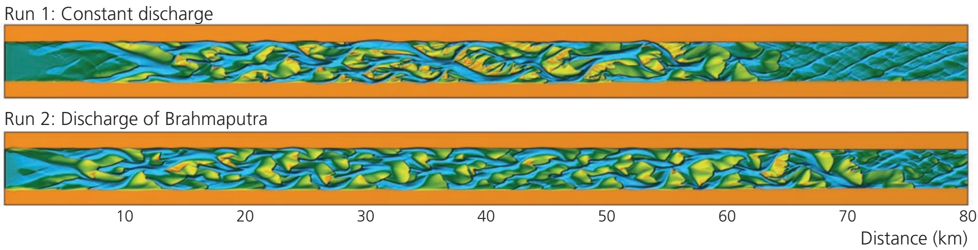
Big questions

Water and sand create fascinating patterns on the surfaces of planet Earth and Mars. These patterns emerge where rivers form fans, fluvial plains and deltas, and plant life often contributes to their formation. They show regularities, but also many imperfections and changes over time, and these make me rather curious. What creates these patterns? Why are they not simply wiped out by wind, rain and flowing water? Do they form as a whole, or bit by bit? How dynamic are the patterns? How are they affected by plant and animal life, and how, in turn, do they affect life? Which aspects of these patterns emerge because of inherited landscapes, and what patterns would emerge on a clean slate?

The task of the chair in process sedimentology of river-dominated systems is to investigate morphodynamics and deposits along the continuum from source to sink, including the subsystems of alluvial fans, rivers and their floodplains, deltas and the



Sand bars in a braided river, south coast of Iceland (André Ermolaev).



Numerical model of a braided river(Filip Schuurman).

downstream tidal rivers and estuaries. In layman's terms this means that I, as a professor of water and sand, study how flowing water creates landscapes of sand and mud, from the mountains to the sea. I do this primarily because of my appreciation of their beauty and curiosity about their formative processes. But we also need to understand these systems better, because a considerable share of the world's population lives and works in their vicinity, and because they are important for species richness and food chains in nature. How can we study these systems to gain a better understanding of them and predict their future behaviour?

In this lecture I will discuss ongoing and new research, as well as academic education and its importance for society. One of the three fundamental tasks of Utrecht University is to prepare students for their role in society. One of the ways we do this is by having them participate in our research, which is one way how science has been demonstrating its value society for centuries, long before myopic politicians invented terms such as 'applied science' and 'impact'. How can we make the exchange of questions and insights between science and society as effective as possible?

The present motto of Utrecht University, 'Bright minds, better future', is not only about students, but also about a million Dutch children living near rivers in the Rhine delta. We need science for their better future, which is why we need to share our insights and their potential application in clear, layman's terms. But are we currently doing this well enough? For many children and other people alike, science is a bit like magic, and the ceremony of the inaugural lecture – with togas – reminds one of the image of Harry Potter and Professor Dumbledore. This image is at least partly appropriate: education at Hogwarts is formative, societally relevant (excluding Divination, of course) and often very exciting. Does our academic education actually offer all that?

Patterns in the sand

Flowing water creates patterns in the sand that we can all observe on the beach, in the playground sandbox, and on satellite imagery of Earth and Mars. Understanding how these patterns form requires basic knowledge of flowing water and sediment transport. Currents are driven by gravity and wind, and slowed down by friction. Friction arises from the surface of the rough sand bed where turbulence forms. This slows down the flow, and increasingly so for shallower water, relative to the rugosity of the bed. Ripples and dunes formed as part of the process of sediment movement enhance the turbulence. Sediment is transported by the turbulent flow, but only above a certain threshold. This is because sand is heavier than water and the particles in the bed are interlocked. This particle friction is illustrated when avalanches are created in dry sand or gravel that only starts flowing at a rather steep slope. Slow currents consequently transport no sediment at all and faster currents transport little sediment, while doubling the flow velocity causes a disproportionally larger amount of sediment transport.

Now imagine a uniform layer of flowing water over an entirely flat sand bed. A single shallow depression, or perturbation, in the bed results in a slightly larger depth, with less friction and therefore faster flow. This causes much more sediment transport than just upstream of the depression. Consequently, more sand is removed from the depression than enters it, and so the depression scours. This run-away process leads to further deepening, whilst a sand bar forms and grows downstream of the depression because of all the sediment removed. The flow then converges again downstream of the sand bar to create a new scour, and so on. In that way, a pattern of channels and bars progressively forms from the initial depression, or, in the words of Ralph Bagnold, famous for his work on sediment transport, they 'spread like a disease'.

An example from daily life illustrates this process. Public lawns often tempt pedestrians in a rush to cut corners. Once a small path forms in the grass, more people will use it and the grass on the path may ultimately disappear entirely. The play of water and sand results in a similar positive feedback that creates a pattern. This morphodynamic process forms the basis for advanced computer models that can simulate such patterns from a clean slate with a perturbation.

Sand bars and vibrating strings

Rivers can have various patterns, depending on the channel's width-to-depth ratio. The bar pattern in a braided river is visually and mathematically similar to the vibrations of a string on musical instruments. The string's length determines the length of the standing wave and

Meandering river (Allier near Bressoles, Inventaire Forestier National, Lyon, France, 1997).

the pitch, while the overtones caused by shorter waves determine the quality of the sound. It is possible, for example, to simulate the sound of a church bell on the treble side of a piano by a set of intervals: a sixth, fifth, fourth and fourth. In a river, the number of sand bars and parallel channels depends on the ratio of channel width and depth. On average this ratio is similar to the ratio of diameter and thickness of a Dutch pancake. Relatively narrow and deep rivers have only one channel that can develop into a meandering river, whereas wider and shallower rivers form a braided pattern with multiple parallel bars and channels. Here the overtones are smaller-scale bars superimposed on the fundamental tone.

The overall pattern of a river may persist for decades, but individual bars, bends and channels migrate. How this works is still not entirely clear, but effective forecasting models would be quite useful for the people living on eroding river banks and bars. The development of such models is hampered, however, by the lack of objective methods for characterising a river pattern and its dynamics. We are continuing to work with mathematicians and physicists to seek methods for characterising these dynamic and complex patterns.

Whilst bars build up and migrate, layers in the sediment form a geological record of the system. Every time the bed erodes and then aggrades again, a layer forms that is recognisable from the size-sorting of the sediment within each layer and at the layer boundaries. Ripples and dunes lead to similar layers on a smaller scale, while displacement of entire rivers forms layers on the large scale of entire deltas. After a century of experimentation with flowing water and sand we have catalogues that allow us to infer the formative conditions from the layered patterns found in outcrops and cores. To further unravel the geological past of planet Earth and for more efficient mining of resources we need predictive models that create the layers from the dynamic forms at the surface. I am therefore working with researchers from Utrecht University, Delft University of Technology and Deltares on the relevant interactions between sand and gravel, and mud and vegetation on the scales of bars to entire river plains and deltas.

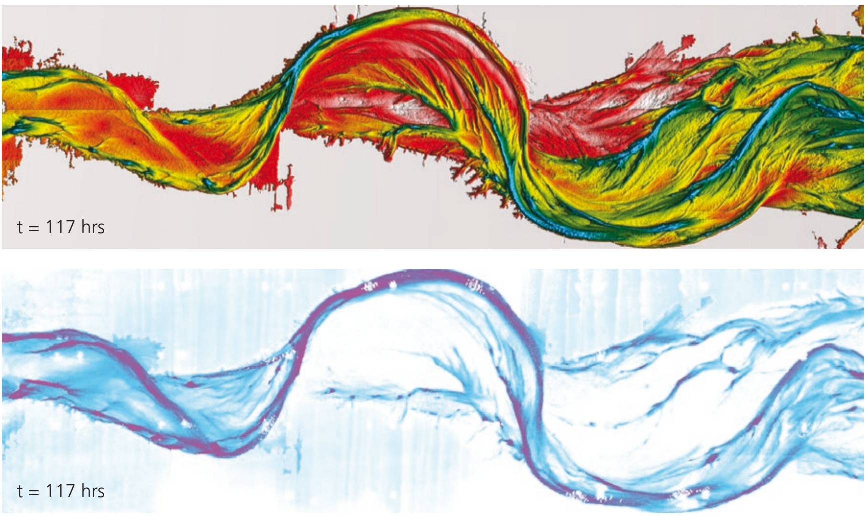
Self-forming riverland

What determines the width and depth of a river? The size of a river roughly scales with the amount of water discharged over a period of many years. Regardless of their size, rivers may have very different ratios of channel width to depth. These ratios are related to the balance of bank erosion and floodplain build-up. Banks with clayey soil and rooted vegetation form naturally on the river floodplains. Here mud deposits during every flood and plant life thrives on the fertile soil, while peat forms in wetter floodbasins. As bank material, this resists erosion much more than the sand or gravel found on the river bed.

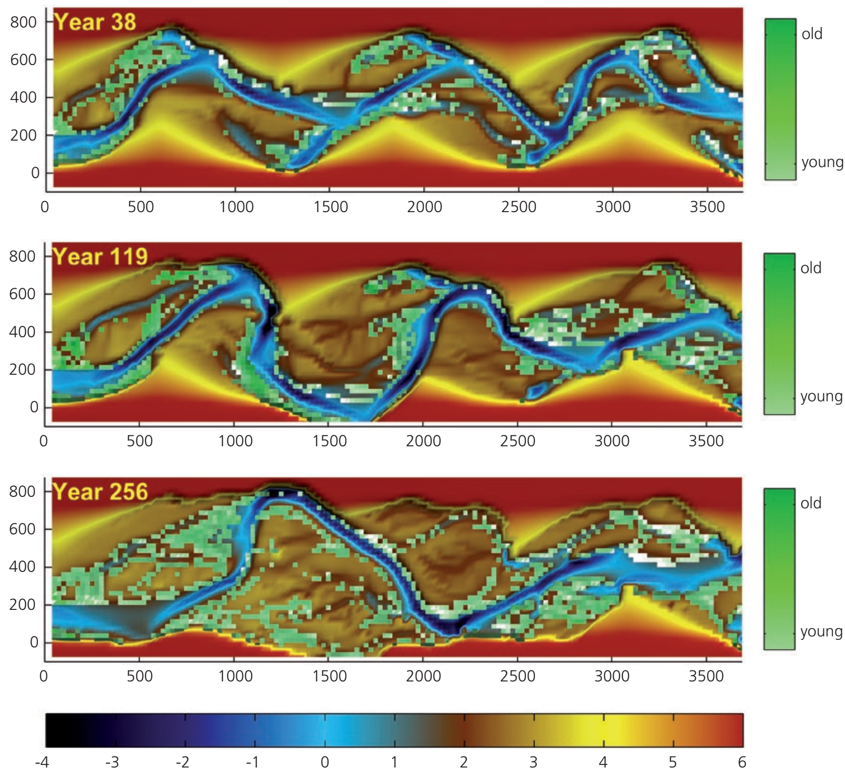
Hence rivers that receive little mud from upstream are generally wider and shallower, with a more braided pattern, than muddier rivers that are narrower and deeper and tend to meander.

This idea of a self-forming, meandering river that builds its own constraining deposit of mud and vegetation has been discussed in the literature for over a century. But until recently we were unable to prove it by simulation in experiments and computer models. Simulating a braided river in a sandbox or model is child's play, but a meandering river requires a self-forming floodplain, and this poses challenges. Several laboratories have recently used sprouts of alfalfa sprouts (Medicago sativa) for vegetation. River clay is much too strong relative to the miniscule laboratory river, but ground rock (, silica flour) seems to work well when supplied upstream. In our experiments, rivers without silica flour developed braided patterns, whereas rivers with silica flour developed spectacular meanders.

The experiments completely surprised us in another aspect of meandering. The dynamics at the upstream inflow point were found appeared to have an unexpectedly large effect. Meanders remained small and rather static when we supplied water from a single upstream position, but became very large and remained dynamic when we slowly moved the inflow point laterally. This finding, later confirmed in our computer models, showed



Experimental meandering river (Wietse van de Lageweg, Wout van Dijk and Anne Baar).



Numerical model of a meandering river with vegetation (Mijke van Oorschot).

that rivers not only convey water and sand downstream, but also convey information on planform geometry and curvature. This raises new questions about how fast and how far the planform disturbances migrate downstream, and how this works in the tidal environments with reversing currents of ebb and flood.

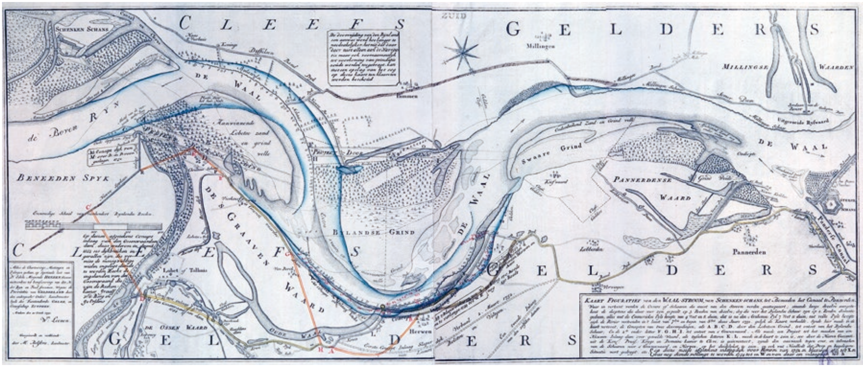
River bifurcations and avulsion

Bifurcations, the junctions where rivers split, are important as they distribute water, sediment, dynamics and problems for society over the downstream river plain and delta. It is only in the past two decades that river bifurcations have only been studied intensively, and it has often been assumed that they are stable in the sense that the partitioning of water and sediment is constant over time. However, we are now seeing many indications that bifurcations are in fact unstable, even under theoretically ideal conditions. This is due to the same run-away process that causes bars and channels, to the balance of bank erosion and floodplain formation, and to the migration of upstream disturbances.

Indeed, the river Rhine has displaced itself on the delta plain about 90 times over the past 8000 years. Such avulsion attests to unstable bifurcations. A temporary bifurcation exists during each avulsion, with one downstream branch that silts up and receives less and less flow, and another branch that enlarges. In small and steep rivers such avulsions may occur entirely within a single wet season, but they may take millennia in large lowland rivers. The avulsion of the Rhine from Leiden to Rotterdam, for instance, took place over a period of about 2000 years. The location, timing and duration of avulsions are determined by upstream and downstream factors, including the development of vegetation and of river mouths at the sea. The Department of Physical Geography is investigating all these factors.

The present-day Rhine has three major bifurcations, the banks of which were fixed about 150 years ago. But I worry that these bifurcations are unstable. The largest, most upstream bifurcation is that of the Waal and the Pannerden Canal, which was dug in 1707 AD to mitigate the problems caused by the natural abandonment of the Rhine branch towards Leiden. Routine bed level soundings done over the past few decades show that the bifurcation at the Pannerden Canal is continuing to change slowly but steadily. The well-known historical developments that led to the digging of this canal show that a changing bifurcation leads to serious problems of flooding and navigation for much of the country. Perhaps, if we are in time, it will be possible to take a relatively small measure to counteract the unwanted change. By this I mean to argue that Rijkswaterstaat should pay more attention to the long-term partitioning of sediment at the Rhine bifurcations lest they enter a stage of run-away avulsion.

Four centuries ago the famous natural philosopher Christiaan Huygens sought the explanation and mitigation of the problems in the division of water at the bifurcation. As did Christiaan Bruning, the engineer and first director of Rijkswaterstaat, two centuries later. (It was when I discovered in high school that such people are referred to as 'Homo Universalis' that my over-large ambition got a name.) But the division of water is largely the consequence of the division of transported sediment through which the bifurcations



River bifurcation in the Rhine at Schenkenschanz (left) and at Pannerden (right) (W. Leenen 1751, Map Conservatory, Marco van Egmond, Utrecht University Library).

develop. The branch that silts up has an increasingly higher bed elevation relative to the deepening branch. This means that the sediment entering the declining branch moves onto an increasingly steeper side slope. Under the direct effect of gravity this sediment increasingly avoids the declining branch, which slows down the final phase of channel abandonment. The gravitational steering of the sediment transport is affected by the dunes migrating over the bed, by bars and bends in the river, and by the associated sorting patterns of sand and gravel. In the coming years I will be investigating the process of sediment transport on sloping beds together with colleagues from Delft University of Technology and Deltares so as to help improve the forecasting models for river bifurcations.

River mouths

Estuaries, or river mouths at the sea, attracted my attention back in 2010. By then I had discovered that the process of sediment transport causes the patterns and dynamics of bars, bends and bifurcations, and found out how self-forming floodplains with mud and vegetation set the tone and overtones of river patterns, as well as how various forms of information propagate upstream and downstream through rivers. In estuaries all these processes are further complicated by the tides and the mixing of fresh river water and saline sea water. For example, estuaries often have surprisingly large meander bends, such as the one in the centre of London. All these factors prompt even more interesting questions than in the case of rivers.

River mouth: the Aberdovey estuary, Wales, UK (Google Earth).

A fascinating phenomenon, for instance, is that of the mutually evasive ebb- and flood-dominated channels, first described in 1950 by Johan van Veen, the designer of the Delta Works in the Netherlands. In such paired channels, one channel attracts mostly flood currents, whereas the other attracts mostly ebb currents. In view of the instability of river bifurcations this raises the question as to why two channels, rather than one, are stable in the tidal situation. In the Western Scheldt, large bends would appear to determine the preferential flow direction in the tidal phases because of the flowing water's inertia. But the mutually evasive, ebb and flood-dominated channels also appear spontaneously in our straight experiments and in a straight computer model. This phenomenon demands an explanation. An immediate area of application of this fundamental science project is in maintenance dredging for navigation, which is required in the shallow junctions of the ebb and flood channels. My lack of experience in the tidal environment means that I will be asking the necessary naïve questions, and maybe these will produce new insight.

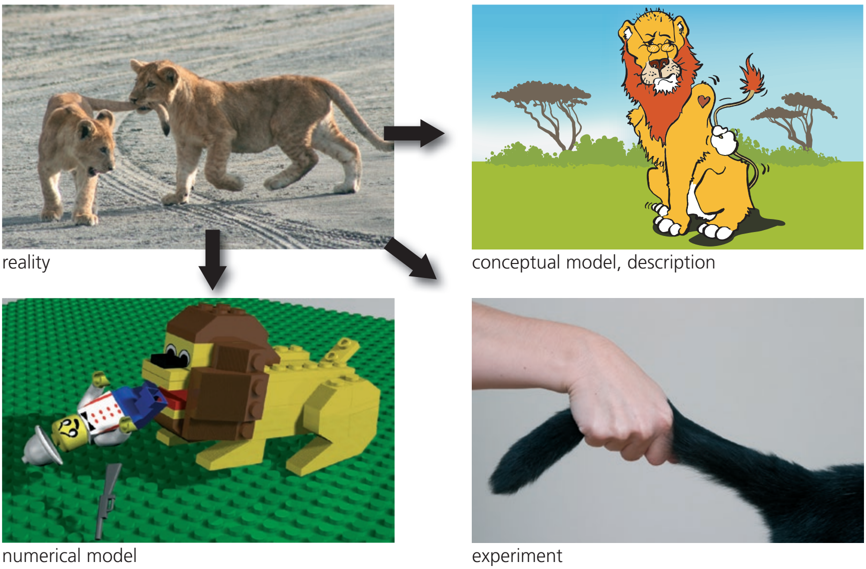
Most major ports are in fact situated in estuaries, and a lot of land has been reclaimed for agriculture around estuaries. Estuaries are also nature reserves that play an important role in food chains in nature. Heavy exploitation puts high pressure on the natural system, and the short-term economic functions are currently being given priority over the long-term importance of nature and ecosystem functions that will benefit today's children.

And so, ladies and gentlemen, came about my new line of research into estuaries, rising up like a cathedral out of the mist, composed from my earlier investigations of rivers and coasts on Earth and Mars. The themes of sediment transport, bifurcating channels, migration of disturbances, patterns of bars and bends, and the tone set by mud and plant life are continuing to resonate. I will be conducting the first bar with my team this year, using all the instruments available: field observations and satellite data, geological reconstructions, analytical and numerical models, and, of course, experiments.

To twist the lion's tail

The methods of observation in nature, computer modelling and experimentation are complementary in a number of ways. Nature is of course the focus of the work, but connecting cause and effect with observations made in nature is usually difficult, and often impossible, because of multiple processes being at work simultaneously. A major human interference in nature can produce clearer signals, but this is expensive and dangerous. As Lord Bacon reputedly said, we would like to twist the sleeping lion's tail to observe more interesting behaviour, but that is rather dangerous.

Although computer models can be manipulated without personal danger, these models are simplified representations of reality, bound by behavioural rules and the laws of nature. A computer model will never, therefore, produce a phenomenon that is not the result of these imposed rules, which foregoes the surprises that nature and experiments may give us.



Twisting the lion's tail (Fred Trappenburg).

Experimental estuary formed from a straight channel in a periodically tilting flume. Length 3 m (Jasper Leuven).

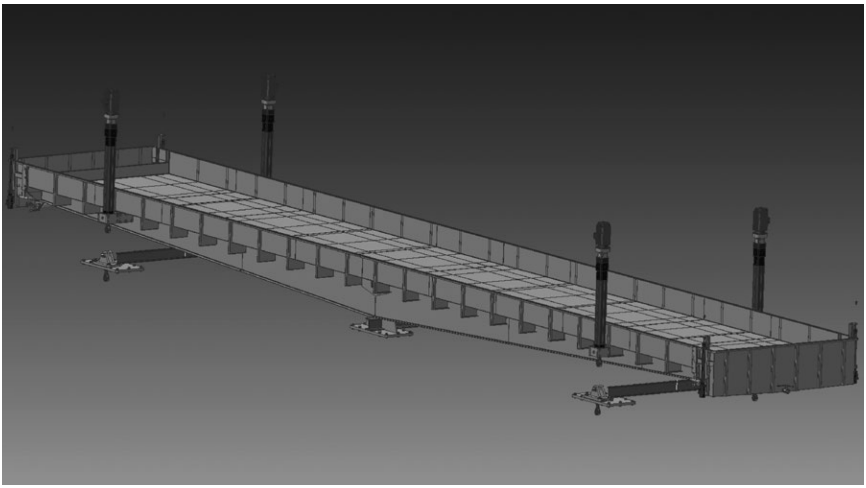
Yet natural morphodynamic systems are so complicated that we need to do modelling to gain an understanding of the effects of the imposed laws and conditions.

We can also safely manipulate experiments by using natural materials – water and sand. Most conditions can be effectively controlled and measured well, and processes proceed much faster than in nature because of the small size of the system. Thus I see entire miniature landscapes emerging and changing before my eyes, like a timelapse movie in a nature documentary by David Attenborough. However, experiments have their own peculiar problems: on this scale, materials behave somewhat differently from the same materials in full-scale natural systems. Although this scaling problem can be mitigated by applying certain techniques and approaches, it cannot be removed entirely. Nevertheless, we have managed to simulate rivers and deltas in form and behaviour. And, even better, our experiments have often surprised us greatly, just like nature, too, often does. I am, therefore, counting on further surprises in my future research on estuaries.

The Metronome: the new tidal machine

Simulating tidal-dominated systems in experiments has proved to be a major challenge for the past 120 years. As far as I know, fewer than ten laboratories attempted to create tidal systems, and all of them came up against considerable problems of scale. These included experimental estuaries that would not reach a dynamic equilibrium condition, but instead became static, or the forming of ripples and scours that were disproportionally large for the given water depth compared to nature. The most comprehensive set of experiments was done 120 years ago by Osborne Reynolds. Reynolds is best known for his work on turbulence. He worked on fundamental science and applied engineering alike, which shows that the distinction frequently drawn between fundamental and applied science has nothing to do with the real proceedings and impact of science. Reynolds' assistants manually raised and dropped the water level in their sandbox millions of times to create miniature tidal cycles. In these experiments, however, the sediment moved mostly downslope during the ebb phase, but hardly upslope during the flood phase, whereas sediment in natural estuaries the sediment is equally mobile in both tidal phases.

During my research I discovered another principle for simulating flow, and specifically sediment transport, by ebb and flood. By periodically tilting an entire flume, the slope is alternatingly directed landwards and seawards. This drives equal amounts of flow and sediment transport in both directions. I tested this idea for the first time on a tray and then, with the help of our technicians, further tested the idea on a table with one leg cut off so that it could tilt. At present we have a 3.5 m long tilting flume in use. I have seen fantastic miniature estuaries form in this simple but innovative tidal machine. As in nature, they remained dynamic, with perpetually moving channels and bars, unlike the old experiments and many current computer models that predict static systems. I am now building a new tidal machine measuring 20 m by 3 m that will tilt with a period of several tens of seconds for a single experiment lasting several months. I call this instrument the 'Metronome' and it will become operational in 2015.



A new tidal machine: design of the Metronome (ConSmeMa, Hattem, the Netherlands).

Formative academic education

Experiments are wonderful and insightful to watch because nearly everyone has some experience of water and sand. An experiment combined with a control experiment is also a fundamental scientific method that has been successfully applied in many disciplines. Yet many laymen, students and even scientists do not understand the purpose of a control. Fortunately it can be explained with an example from daily life. A real Dutch pancake is baked from a batter of wheat flour, milk and eggs. The flour and milk alone already form a bakeable substance, which raises the question of why the eggs are added. Most people answer this question using a hypothesis, based on their experience, that an egg hardens when heated, which could cause the pancake to bind. Clearly, most people have never actually tested this. The experimental method used for a fair test of the effect that an egg has on the strength of a pancake is to bake one pancake without an egg and one with an egg – the control experiment – and then to compare the two results. Both are otherwise treated in exactly the same way. With this appetising idea in mind we experimentally created rivers with and without floodplain-forming 'clay' and proved that this accounts for the difference between braided and meandering rivers. I believe that our students will learn much faster if we teach them how to ask their own research questions because it helps them to take conscious control of their learning.

On a more general point, the quintessence of science is curiosity and a critical attitude. These are academic attitudes that are dearly needed in governmental institutes, industry and other sectors in society. How can we make our academic teaching more formative, more societally relevant and more exciting for our students? Perhaps professors would benefit from a refresher course every five years, with the latest didactic insights. I recently heard a colleague make a well-meant remark that because our science is excellent, so, too, is our teaching. But this is like the reasoning that when car mechanics who supply excellent cars, they are also excellent driving instructors. This is a fallacy, because the fact that we do world-class research does not exclude the possibility that, didactically speaking, we are still living in the Stone Age. We are doing a lot of things well in our teaching programme, but there is still plenty of scope for further improvements.

Could we perhaps apply our scientific mechanisms for quality control and improvement to our teaching? In the Netherlands, the quality control at the level of individual courses is now primarily based on evaluation questionnaires by students, taken immediately after each exam on their course. This merely results in the short-term 'sales figures' rather than a long-term quality evaluation of the entire teaching programme and a measure of how this matches the roles of our alumni in society. Every bit of science, in contrast, is subjected to international peer review, as well as discussions in scientific literature and at specialist conferences. Would it not be a good idea to formally allocate time for intervision so that we can share of successes and failures in teaching and benefit from each other's experience? And would it not benefit our teaching if we, the lecturers, were exposed to constructive criticism by colleagues in related disciplines and from the science of didactics? This is something I hope to experiment with.

The attention we devote to the academic development of each and every student's academic development, particularly curiosity, a critical attitude and reflection on fundamental scientific skills, is, in my opinion, relatively informal and casual. Many students consequently do not become the owners of their own academic learning process until only rather late, and perhaps too late, in their programme. As a result, this causes many students to scrape through with low grades. Yet, according to their evaluations, they spend only a mere 25 hours a week on their studies rather than twice this amount, even though Dutch society pays half the costs of each student's education. Solving this problem does not mean agreeing to 'performance rates' set by the Ministry of Education, which I see as a perverse requirement of a minimum success rate that lowers overall standards. Instead it demands sensible carrots and sticks for both students and lecturers alike. As a contribution I am working developing together with colleagues and students to develop a first- year course on 'Time and causality in earth science'. The story line underlying this course is the development of planet Earth, and our main purpose is to consciously develop academic attitudes, skills and the prospect of perspectives on future jobs at an early stage of the students' educational programme.

From pre-schooler to postdoc

Scientific literacy benefits everyone, not just the Huygens', Brunings', Reynolds' and van Veens of this world, and those that pursue a career in science. All children will need 21st century skills to be able to use and select the new scientific knowledge and technology that affect their personal lives and the society they live in. In the past, universities used to reach out to children at the end of their high school careers to try and interest them in science and technology. But that is too late: there is a large body of evidence showing that children make important choices at a very young age: as early as primary school. At this stage, however, they all too often loose their interest in science and technology in particular, and their curiosity in general. Even though children have usually not yet chosen a career by the end of primary school, they already exclude careers in science and technology that they have not been exposed to. In addition more than three-quarters of highly gifted children ('bright minds' for that 'better future') fail to achieve their potential early in their school career. The key problem is that the teaching system currently discourages curiosity and inquiry-based learning, and so children loose their motivation to learn.

Madieke Kleinhans measures the steepness of a delta formed in the sandbox at the primary school De Ontdekkingsreis in Doorn, the Netherlands (author).

The teachers often get the blame, but this is like blaming the cleaners being on strike for the fact that the railway stations are dirty. The responsibility for education lies with politicians, with the commercial publishers that develop teaching methods, with higher education for teacher training institutions, with school governing boards and directors of schools, and with parents. It also lies with us, the scientists, because who is better placed to explain how science and technology work?

This is why we have set up Science Hubs at most Dutch universities. School pupils come to the Utrecht Science Hub to do their own scientific research, for example in a sandbox where they play with water and sand to create rivers and deltas. We also play Expedition Mundus, a classroom game that simulates science in the widest possible sense on a fictitious planet that I helped develop. More importantly, we teach the teachers how to teach science and technology education. This also benefits the universities: learning how to explain my science in clear language to primary school pupils has greatly improved my science, interdisciplinary collaboration and academic teaching. We therefore encourage and train scientists to do occasional teaching at primary schools.

And we should not underestimate children and their intelligent remarks, surprising questions and enormous enthousiasm to discover the world. During a river experiment at the primary school 'De Ontdekkingsreis', for example, someone asked: "So if lots of trees grow along the river there will be more floodings?". If they are given the opportunity, children show they have a clear vision on teaching: "Learning in this project is fun because there aren't any answers yet. We're looking for possible answers. In other lessons at school there is always only one answer that is right." This shows that inquiry-based learning and the empirical cycle are efficient methods of teaching, while information in science magazines and websites reaches a relatively low number of people, many of whom will have forgotten it a few days later. If a million school children are given the freedom to ask their own questions and do their own research, their lives may be changed forever. And it creates a positive image of the university among a large and eager audience – and their parents.

A future in the lowlands?

The land surrounding estuaries may flood from the sea during storms and from the land after rain storms, while the tides may be swept up many meters above sealevel, depending on the estuary's geometry. Sealevels are further predicted to rise between 25 and 123 cm by the end of this century, whilst the land is sinking because of natural subsidence. Because of the dikes, however, this subsidence is no longer being counteracted by natural sedimentation. Dredging done for navigation purposes may indirectly increase flood water levels. It is not inconceivable that lowlands all over the world will have to be evacuated this century. Higher coastal dikes are no solution where rivers have to debouch into the sea. Dikes also truncate natural ecological functions of former floodplains and dikes do not prevent landward intrusion of saline groundwater.

Many people are hoping for technological solutions to these threats. An inaugural lecture would be a fantastic opportunity to announce some great plan that will resolve all our problems, such as a large hydropower barrage in the Severn estuary or the Hooghly river. But this is about as useful as proposing planet Mars as a spare planet for humanity when we have made a complete mess of our own planet. So what do we really need to do then?

As I see it, what we need for a sustainable exploitation of the lowlands is an evidence-based, integral vision on coastal defences, ecologies and economies for the coming century, from the upper rivers to the shallow sea. This requires at least knowledge and ideas from universities and research institutes, as well as public understanding of how science works, daring and responsible politicians, and full governance in a national, non-profit organisation with the necessary knowledge of and insight into all these matters. This may well turn out to be less utopian than an inhabitable planet Mars.

Perhaps we can learn from the successes and failures of the 'Room for the River' project in the Netherlands. More than forty large engineering structures are being put in place along the river Rhine to reduce the risk of flooding and provide a bit more room for nature. This has been expensive for the state and, even though they received financial compensation, annoying for those people who have had to move. There is ample evidence, however, that the project is necessary to reduce flooding risk and so we have to continue to explaining this to the tax payer. An important factor in determining whether the overall project will succeed is the fact that the various subprojects are interconnected and their combined effects have been forecast. Many river scientists in the Netherlands, including myself, will in due course be evaluating the extent to which the project has been a success.

Perhaps the idea behind 'Room for the River' could also be applied further downstream: 'Room for Estuaries'. This room is needed not only to dampen the tidal flood wave, but also to allow silting-up of a zone of tidal marshes along the coast for protection and to buffer storm wave attacks on the dikes and other coastal defence structures. A zonated landscape such as this will provide much more room for nature. This approach would require the land reclamation skills of past centuries, but also new scientific knowledge for design and forecasting. How, for instance, do the dimensions and dynamics of channels and bars affect water levels? Are mud concentrations high enough for salt marshes to keep up with the expected sealevel rise? How is mud concentration in the rivers affected by upstream floodplain lowering if more room is created for flood mitigation and nature? How fast do natural banks erode, and how far can channels migrate into such banks? How wide do the natural zones have to be for an acceptable level of safety? And how can saline groundwater intrusion be stopped? I hope to contribute to some of these questions over the coming years.

Begin at the beginning

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I have said.

References

van der Ham, W. (2003), Meester van de zee. Johan van Veen, waterstaatsingenieur, 1893-1959. Balans, Amsterdam, 286 pp.

Cohen K.M., E. Stouthamer, H.J. Pierik & A.H. Geurts (2012), Digitaal Basisbestand Paleogeografie van de Rijn-Maas Delta/Rhine-Meuse Delta Studies' Digital Basemap for Delta Evolution and Palaeogeography. Department of Physical Geography. Utrecht University. Persistent identifier: urn:nbn:nl:ui:13-nqjn-zl. https://easy.dans.knaw.nl/ui/datasets/id/easy-dataset:52125.

Dalrymple, R. & Rhodes, R. (1995). Estuarine dunes and bars, in: Geomorphology and sedimentology of estuaries, edited by: Perillo, G. 359 – 422, Elsevier Science, New York.

de Haas, T., D. Ventra, P.E. Carbonneau & M.G. Kleinhans (2014), Debris-flow dominance of alluvial fans masked by runoff reworking and weathering. Geomorphology 217, 165-181, http://dx.doi.org/10.1016/j.geomorph.2014.04.028.

Frings, R.M., & Kleinhans, M.G. (2008) Complex variations in sediment transport at three large river bifurcations during discharge waves in the river Rhine. Sedimentology 55, 1145-1171, http://dx.doi.org/10.1111/j.1365-3091.2007.00940.x.

Hesselink, A.W., Kleinhans, M.G. & Boreel, G.L. (2006) Historic Discharge Measurements in Three Rhine Branches. Journal of Hydraulic Engineering 132, 140-145, http://dx.doi.org/10.1061/(ASCE)0733-9429(2006)132:2(140).

Kleinhans, M.G., W.M. van Dijk, W.I. van de Lageweg, D.C.J.D. Hoyal, H. Markies, M. van Maarseveen, C. Roosendaal, W. van Weesep, D. van Breemen, R. Hoendervoogt & N. Cheshier (2014), Quantifiable effectiveness of experimental scaling of river- and delta morphodynamics and stratigraphy, Earth-Science Reviews 133, 43-61, http://dx.doi.org/10.1016/j.earscirev.2014.03.001.

Kleinhans, M.G., M. van der Vegt, R. Terwisscha van Scheltinga, A.W. Baar & H. Markies (2012), Turning the tide: experimental creation of tidal channel networks and ebb deltas, Netherlands J. of Geoscience 91(3), 311-323, http://www.waddenacademie.nl/fileadmin/inhoud/pdf/03-Thema_s/Geowetenschap/NJG_special/NJG-91-3-Kleinhans.pdf.

Kleinhans, M.G., K.M. Cohen, J. Hoekstra & J.M. IJmker (2012a), Evolution of a bifurcation in a meandering river with adjustable channel widths, Rhine delta apex, The Netherlands, Earth Surf. Process. Landforms 36, 2011-2027, http://dx.doi.org/10.1002/esp.2222.

Kleinhans, M.G., H. Markies, S.J. de Vet, A.C. in 't Veld & F.N. Postema (2011), Static and dynamic angles of repose in loose granular materials under reduced gravity, J. Geophys. Res. Planets 116, E11004, http://dx.doi.org/10.1029/2011JE003865.

Kleinhans, M.G. & J.H. van den Berg (2011), River channel and bar patterns explained and predicted by an empirical and a physics-based method, Earth Surf. Process. Landforms 36, 721-738, http://dx.doi.org/10.1002/esp.2090.

Kleinhans, M.G., H.E. van de Kasteele & E. Hauber (2010a), Palaeoflow reconstruction from fan delta morphology on Mars, Earth and Planetary Science Letters 294, 378-392, http://dx.doi.org/10.1016/j.epsl.2009.11.025.

Kleinhans, M.G., M. F. P. Bierkens, & M. van der Perk (2010), On the use of laboratory experimentation: "Hydrologists, bring out shovels and garden hoses and hit the dirt", Hydrol. Earth Syst. Sci. 14, 369-382, http://www.hydrol-earth-syst-sci.net/14/369/2010/.

Kleinhans, M.G. Buskes, C.J.J. & De Regt, H.W. (2005). Terra Incognita: Explanation and Reductionism in Earth Science. International Studies in the Philosophy of Science, 19, 3, 289-317, http://dx.doi.org/10.1080/02698590500462356.

PISA, 2006. Science competencies for tomorrow's world, volume 1: Analysis. OECD, 383 pp., http://www.oecd.org/pisa/.

Reynolds, O. (1889), Report of the committee appointed to investigate the action of waves and currents on the beds and foreshores of estuaries by means of working models. British Association Report. Reprinted in: Papers on mechanical and physical subjects, Vol. II 1881-1900, Cambridge University Press, 1901, Chapter 57: 380-409, https://archive.org/details/papersonmechanic02reynrich.

Schramkowski, G. P., Schuttelaars, H. M., & de Swart, H. E. (2002). The effect of geometry and bottom friction on local bed forms in a tidal embayment, Cont. Shelf Res., 22, 1821-1833.

Schuurman, F., W.A. Marra & M.G. Kleinhans (2013), Physics-based modeling of large braided sand-bed rivers: bar pattern formation, dynamics and sensitivity, J. Geophys. Res. Earth Surf. 118, 2509-2527, http://dx.doi.org/10.1002/2013JF002896.

Struiksma, N., K. Olesen, C. Flokstra & H. De Vriend (1985). Bed deformation in curved alluvial channels. Journal of Hydraulic Research 23: 57-79.

van de Lageweg, W.M. van Dijk, A.W. Baar, J. Rutten & M.G. Kleinhans (2014). Bank pull or bar push: what drives scroll-bar formation in meandering rivers? Geology 42(4), 319-322, http://dx.doi.org/10.1130/G35192.1.

Van de Ven G. 1976. Aan de wieg van Rijkswaterstaat – wordingsgeschiedenis van het Pannerdens Kanaal. Walburg Pers: Zutphen.

van Dijk, W.M., W.I. van de Lageweg & M.G. Kleinhans (2013). Formation of a cohesive floodplain in a dynamic experimental meandering river. Earth Surf. Proc. and Landforms 38, 1550-1565, http://dx.doi.org/10.1002/esp.3400.

Van Oorschot, M., M.G. Kleinhans, G. Geerling, H. Middelkoop, E. Mosselman & T. Buijse (2014), Distinct patterns of interactions between vegetation and river morphology. 10th ISE 2014, Trondheim, Norway.

van Veen, J. (1950), Ebb and flood channel systems in the Netherlands tidal waters, Journal of the Royal Dutch Geographical Society, 67, 303-325, http://www.jstor.org/stable/4299518.

van Wessel, T., M.G. Kleinhans, A.W. Baar & J. Van Keulen (2014). Wetenschapper in de klas: Wetenschappelijk onderzoek en technologie vertalen naar onderzoekend en ontwerpend leren in het basisonderwijs, Utrecht University, Centrum voor Onderwijs en Leren, 70 pp., LINK.

Wang, Z., R. Fokkink, M. de Vries & A. Langerak (1995). Stability of river bifurcations in 1D morphodynamic models. Journal of Hydraulic Research 33(6), 739-750.

Web sites

www.uu.nl/geo: Faculty of Geosciences of Utrecht University

www.youtube.com/user/UniversiteitUtrecht: movie channel of Utrecht University

www.geo.uu.nl/fg/mkleinhans: research, teaching and science communication of the author

www.deltares.nl/en/: institute for applied research in the fields of water, subsurface and infrastructure

www.ruimtevoorderivier.nl/: programme led by Rijkswaterstaat to reduce river flooding risk

http://ahn.geodan.nl/ahn/: interactive map of the Actualised Elevation Database of the Netherlands

http://andreabe.fishup.ru/: work by landscape photographer André Ermolaev

www.expeditionmundus.org: classroom game simulating science

www.wetenschapsknooppunten.nl: science hubs for Dutch primary and early secondary school education

www.deontdekkingsreis.nl: leading primary school for inquiry-based learning

Prof. dr. Maarten G. Kleinhans (1972) has been a full professor in Physical Geography at the Faculty of Geosciences of Utrecht University since 1 June 2014, where he holds the chair in process sedimentology of river-dominated systems. He graduated in Physical Geography from at Utrecht University and was awarded his PhD (with honours) in 2002 by the same institute for his research into sediment transport and sorting in sand-gravel bed rivers.

His curiosity about water, sand and life has taken him into many different environments: from the beach to the river, back to the sea floor, upstream to the foot of the mountains and to planet Mars, from ships of Rijkswaterstaat to the laboratory, and into the virtual world of computer models, and now, with the Vici personal fellowship, downstream to river mouths. He is currently researching how the perpetually changing pattern of channels, sand bars and floodplains are formed by river flow and tides, while land is being created and destroyed. For this purpose he is building a unique facility, the Metronome, to conduct experiments involving the creation of self-forming estuaries. He is also seeking to improve forecasting models so as to strike a more sustainable balance between economically important shipping and ports on the one hand, and healthy ecosystems and safety against flooding defences on the other hand.