INAUGURAL ADDRESS DANO ROELVINK

LIVING ON THE EDGE

UNESCO-IHE
Institute for Water Education

LIVING ON THE EDGE

Inaugural Address of J.A. (Dano) Roelvink,
Professor of Coastal Engineering and Port Development
at UNESCO-IHE Institute for Water Education
in Delft, The Netherlands

October 12, 2007

ISBN: 978-90-73445-17-8

Available also on: www.unesco-ihe.org

CONTENTS

Dear chairman, rector of UNESCO-IHE, professor Meganck, dear members of the governing board, colleagues from the academic board, professors from other universities, colleagues from UNESCO-IHE, WL | Delft Hydraulics, Delft University of Technology and other institutions, students, friends and family,
Ladies and gentlemen,

Playing with sand

When we are young we all like to play with sand. Even better, with sand and water. We love to watch little streams meander, we watch our dams break through or be eaten up by waves, we are fascinated by the power of the water and sometimes we manage to harness it for a while. Most of us then drift away, catching fish and crabs, becoming firemen or lawyers. The few of us who persist grow up to be coastal morphologists. In the following I hope to convey why this is a good thing, both for us and for society.

Living on the edge: a mixed blessing

A large percentage of the world population lives in coastal areas. There are good reasons for this. It is where things happen, where inland and maritime trade routes meet, industry is abundant, lowlands are fertile and beaches attract us like magnets. Because of this, there is an ever-increasing pressure on space and resources in these areas, while at the same time there is an increasing threat of coastal erosion and flooding, aggravated by sea level rise and climate change leading to increased frequency and/or intensity of extreme conditions.

The pressure on space and resources leads to a strong growth in infrastructure, especially in developing countries but also in developed countries. This in turn means that there is a strong need for research on the design of ports, breakwaters and land reclamations in increasingly challenging environments. Apart from the 'hard' engineering that is needed, the call for more sustainable development leads to a need for better prediction of the impacts on hydrodynamics, coastal morphology, water quality and ecology. More and more, engineers have to function within legislative frameworks such as the EU Bird and Habitat Directive and the Water Framework Directive, which pose high demands on the quality of impact prediction. This is a tendency that is already quite apparent in the developed world but is likely to expand rapidly to other coastal communities.

According to some estimates, 70% of the world's coastlines are eroding. In many cases this erosion is caused by human intervention on a range of scales, from reduction of fluvial inputs by upstream dams, direct sand mining from beach, dune and coastal systems to local effects of coastal structures, impeding natural sediment pathways. Sea level rise has direct effects on beach erosion, but a generally much larger effect through infilling of tidal basins and estuaries, where the tidal flats tend to follow the sea level. The sediment required by this process is delivered by erosion of adjacent coasts. Under accelerated sea level rise, there are many uncertainties as to the behaviour of the system as a whole, with important consequences for ecologically vital tidal systems worldwide and for coastal erosion.

The Coastal Engineer's habitat

The coastal engineer is a species that has evolved considerably over the past decades, from a person likely to prefer rocks, concrete blocks and other hard structures that harness the elements, to a person with probably a civil engineering background, but who is equally likely to meet physical geographers, ecologists, marine geologists, oceanographers, coastal managers and even lawyers and whose job is a mixture of analysing problems, designing solutions, predicting impacts and coping with legislation. Let us first look at some of his favourite spots.

Protection against flooding

Of course, living in a country that is half below sea level and that has historically suffered from flooding, both from rivers and from the sea, protection against flooding is a very obvious motivation for being in coastal engineering. As long as storms find us unprepared now and then and large losses are suffered both in terms of human lives and economic damage, coastal engineers will be working on large, eye-catching projects such as the Delta works, Thames barrier, storm surge barriers for Venice and Petersburg, but at the same time on more low-profile but just as important work like improving dike design, heightening and strengthening them, figuring out what possible forces may hit them and what their chance of failure is. Recent events like Katrina have stimulated more rigorous application of risk analysis and risk-based design methods [1] and have reintroduced a discussion on safety against flooding in the US, but also in the Netherlands. There are staggering differences between countries in how people deal with the risk of flooding, from accepting a once in thirty years chance that your house is washed away to worrying whether the dikes will withstand a once in 10,000 year storm. Coastal engineers should deliver the data, models and methods to develop a sensible strategy, which may range from designing evacuation plans and safe havens to ensuring that this is (almost) never necessary. Local differences in geography, economy, culture and politics may still lead to widely varying outcomes.

Erosion prevention

Eroding beaches, houses and hotels falling into the water are pictures that are largely fading into memory in the Netherlands, thanks to a consistent policy of nourishment, in place since 1990. In most other places these situations are still very real for a variety of reasons. Some of the reasons are natural, such as long-term erosion due to sea level rise, but many are caused by man: reduction of sediment supply by rivers due to damming, interruption of the longshore flow of sand by coastal structures, coastal development within the zone of natural short-term fluctuations. Solving these problems cannot be done by individuals; it requires 'thinking big' for which you need to work together within a coastal community and need strong institutions focused on the coastal area. Where larger-scale approaches are missing individuals trying to protect their properties often exacerbate the problem.

Increasing wealth and leisure time and cheap tickets have led to an enormous demand for square metres of beach. Because hotels, villas and resorts tend to be built too close to the waterline, this demand actually leads to a reduction in beach area in many cases. A fundamental principle of coastline management is conservation of sediment mass: if you get construction sand from the beach, you lose beach area; if you interrupt the flow of sand

Figure 1. Ad-hoc erosion protection in front of expensive resort, Playa del Carmen, Mexico.

along the coast, by building jetties, ports or groynes, you lose beach area downstream. Such principles have been well established since the 1950's but unfortunately are not put into practice in many places. Especially when beaches are at the core of a local tourism industry, it is astonishing how little attention is paid to the maintenance of healthy beaches. This does not just happen in poor and underdeveloped areas but just as well in expensive resort areas where every shrub and lawn is manicured but the main asset, the beach, is allowed to disappear amidst heaps of sand bags.

Of course, even when the organizational framework to solve these problems is there it is not always easy to solve erosion problems. Sometimes the sand just is not there, as in some small island states, or it is hard to find without disturbing valuable ecosystems. This is where coastal engineering has to come in and find innovative solutions, sometimes fixing the coastline by offshore breakwaters and tombolo-shaped beaches, sometimes using carefully designed low-crested structures, but maybe in the future by converting supertankers to carry sand over large distances and creating an open world market for sand.

Design of ports and navigation channels

Cargo transport by sea and inland waterways is the dominant mode and shows rapid growth. The containerization leads to higher efficiencies, but many ports in the world can not cope with the rapid increase of capacity demand and technological changes. The resulting congestion has severe economic consequences for the countries concerned, as well as undesirable environmental and societal impacts. Hence there is a need for methods to alleviate the immediate pressures of congested ports and to divert cargo transport from the road to inland waterways, wherever that is possible. My colleague Prof. Ligteringen covers the wide area of port design, rehabilitation and management, whereas our fields overlap where the outer layout and impact of ports such as the Rotterdam Maasvlakte-2 (pictured here) are concerned.

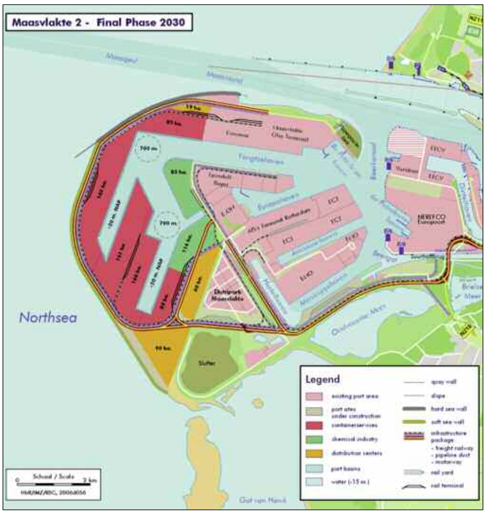

Figure 2. Projected Maasvlakte-2 extension of port of Rotterdam.

Land reclamations
Reclaiming land from the sea has been a booming business over the last decades, from Japan to Singapore, the Gulf States and China. Though these developments are often brought with statements about 'working with nature', in fact considerations about impacts on water quality, ecology and adjacent coastlines do not always play a dominant role. Compared to the time spent on optimizing and permitting the second Maasvlakte harbour (roughly fifteen years), these developments are conceived and carried out with a staggering speed. Probably an optimum should be found in between these situations, where impacts are minimised and mitigated and yet such big decisions are made, say, within less than a decade.

An interesting phenomenon in the Netherlands is that consultants, contractors and dredging companies, having built large islands in various shapes, now propose big islands or reefs in front of the Dutch coast. This is eagerly picked up by politicians and the media, often with the argument that this is necessary for the future safety of the coast as it reduces the impact of the waves. In my opinion, there may be many reasons for building such structures, but safety of our coast is not one of them. We can easily defend the coast against sea level rise by slightly increasing the rate at which we nourish our beaches and 'coastal foundation'. The more difficult problem facing the Netherlands is the combination of bottom subsidence, increasing water level and increasing river discharges; this problem manifests itself more inland, and islands or reefs do not help there, What would help, as was recently suggested [2], is to systematically increase the amount of sand that is shipped into the Netherlands and gradually lift up the country. This 'preventive land reclamation' is entirely feasible, given our dredging capacity and enormous marine reserves of sand.

Morphology of the coast

Outline
Morphology is the study of forms, whether of animals, plants or words; coastal morphology is the study of coastal forms. Some of these forms are hard (like rock) and do not move much. Others, such as beaches, dunes, channels, sandbars, shoals, are made of sand or mud and move all the time. Understanding and predicting these motions is what coastal morphologists try to do.

The approach we take depends on the scale of the problem or process we are interested in. This scale ranges from small-scale ripples to entire tidal inlets or coast lines. The larger the length scale, the larger the time scale; the upper beach profile can adapt to a storm in hours; the coastline around a port can take decades to adapt, and the effects of closing a tidal inlet can be felt for many centuries.

In coastal engineering, morphology is a core discipline. It is needed to assess damage to beaches, dunes and barrier islands during extreme events; it is needed to understand and mitigate coastal erosion; it is important in the design of ports, to assess impact on the coast and estimate dredging requirements for the navigation channel and basins; it is needed in the design and impact studies of land reclamations and finally, it is providing scenarios to use in coastal zone management.

Scale models
We generally approach these problems with models, of which we have a variety at our disposal or under development. To start with, there are the scale models, which appear to be starting a new life, after a period in which all the focus was on numerical models. The Dutch design rules for dune erosion are almost entirely based on large-scale flume tests and just recently have been adapted for changed design wave conditions based on such tests [3]. Scour around structures is another example where physical models are still much in use, in this case because of the complexity of the 3D currents and turbulence around them. However, in many cases such a direct application of physical modelling to a problem is difficult, and such models are then used to look into the details of processes and to validate numerical models that can be used at larger scales. Having no physical model facilities of our own, we hope to continue working together with Delft University, which often makes its lab available to our students, Delft Hydraulics, Leichtweiss Institute and other laboratories around the world.

Large-scale physical models of tidal systems, rivers and estuaries have become too expensive in Europe to compete with ever-improving numerical models, but are still widely used in countries like China, where labour cost is relatively cheap and there is considerable expertise in dealing with inevitable scale effects. Combining such models with numerical modelling can lead to interesting results, and is a direction we'd like to look into more. Already, together with colleagues from Hydraulic Engineering and River Basin Management, we have done interesting comparisons between physical and numerical modelling of reservoirs and stilling basins [4].

When waves are important and we have to look at large systems at the same time, physical modelling is no option anymore. The modelled waves would be too small to be represented properly, so we'll have to look at other methods.

Analytical models
First we turn to analytical models. They can be simple and elegant and provide almost instant insight. The coastline theory of Pelnard-Considère [5] has shaped our thinking about large-scale coastal evolution, and analytical and numerical successors of the theory are still abundantly used [6]. Other, more complex, analytical models explain point bars in rivers and estuaries [7], sand waves and tidal sandbanks [8], and though they use strong approximations of the physics, they tell us which processes are responsible for certain phenomena we see, so we can make sure that more complex numerical models reproduce these processes, which in theory they should, but in practice often fail to do.

(Semi-)Empirical models
The next type of models is heavily based on data and therefore called 'empirical models'. The equilibrium profile model for dune erosion, which has made it into Dutch law, is a good example [9,10]. Based on the observation that beach profiles always have the same shape after a storm, the method consists of shifting that profile back and forth until the eroded area equals the accreted area. For tidal inlets and estuaries there is a host of equilibrium equations [11], relating the tidal volume to channel cross-section, to total channel volume, to ebb delta volume, etcetera. If you divide a tidal inlet or estuary up into a number of units (ebb delta, channels, tidal flats) you can define equilibrium situations for each of them. However, that

does not tell you how they get to their equilibrium. To solve this, 'semi-empirical' models were developed, where the units all try to get to their equilibrium but sediment has to be transported between them. The rate of sediment exchange depends on how far each unit is from equilibrium. Marcel Stive and Zheng Wang use this concept to model long-term, large-scale effects of sea level rise and gas extraction, inlet closure, dredging and other scenarios [12].

Such models have shown a lot of value for specific situations, where there is a lot of historical data and nice testcases from the recent past (e.g. closure of inlets, channel deepening for navigation) to calibrate the coefficients in such models. In many places around the world this is not the case; also, more complex situations or more detailed questions need to be addressed than can be represented by the semi-empirical models we just discussed.

Process-based numerical models

Let us then turn to the type of modelling that I have devoted most of my efforts to, the 'process-based' or 'bottom-up' approach. Here we simulate on a numerical grid the complex patterns of currents and waves that together transport the sediment. We then apply the mass balance (change of bed sediment mass per time unit is equal to the sum of incoming minus sum of outgoing sediment transport) to change the sea bed level in each grid cell. This in turn affects the currents, the waves and the sediment transport so we loop back and repeat the process. In the meantime, the boundary conditions change, due to tide, offshore waves, wind and river discharges. If we know these boundary conditions we could in principle run for any given time period and let all the processes evolve, including the morphology. We can actually do this if we use a simple model that is not too computationally intensive or if we just have to model a single event (usually a storm) in detail. We'll come back to this case later when we talk about modelling hurricane impacts.

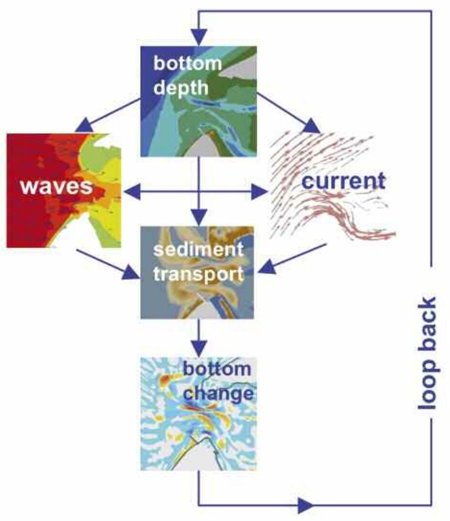

Figure 3. Scheme of morphological model.

In most practical situations where we apply morphological models, the time-scales of interest are much longer: years for effects of beach and shoreface nourishments, decades for effects of harbour extensions and land reclamations, decades to centuries for effects of bottom subsidence and sea level rise. At the same time, the geometry of such problems dictates a rather fine spatial resolution (small grid cells), which makes simulating a single tidal cycle time-consuming, let alone 700 tidal cycles per year.

Much of the research over the last decade has gone into two problems: a) how to make such simulations fast and robust enough to reach these time-scales at all, and b) how much sense do the results make? Of course we started with the first problem, with the optimistic feeling that if everything runs smoothly, results will come. Indeed, through the efforts of scores of MSc and PhD students (several of which from UNESCO-IHE) and some large EU and national projects, we have made much progress in modelling morphological changes over longer timescales. This was done by:

- improving morphological updating schemes, making use of the fact that the bottom changes much more slowly than the processes shaping it. A range of 'tricks' was explored, of which some have proved to be quite simple and effective, leading to a reduction in run time of two orders of magnitude. See [13] for an overview.
- reducing the variation in boundary conditions to a small set of representative conditions ('input reduction'), for which increasingly refined techniques have been developed [14, 15];
- testing the model (usually some version of Delft3D, a model system developed at Delft Hydraulics, [16]) for a host of hypothetical and especially field cases in the Netherlands (e.g. [17]), Venice (see figure), the Humber, the US west coast [18] and many other places, each time learning from obvious model or schematization errors.

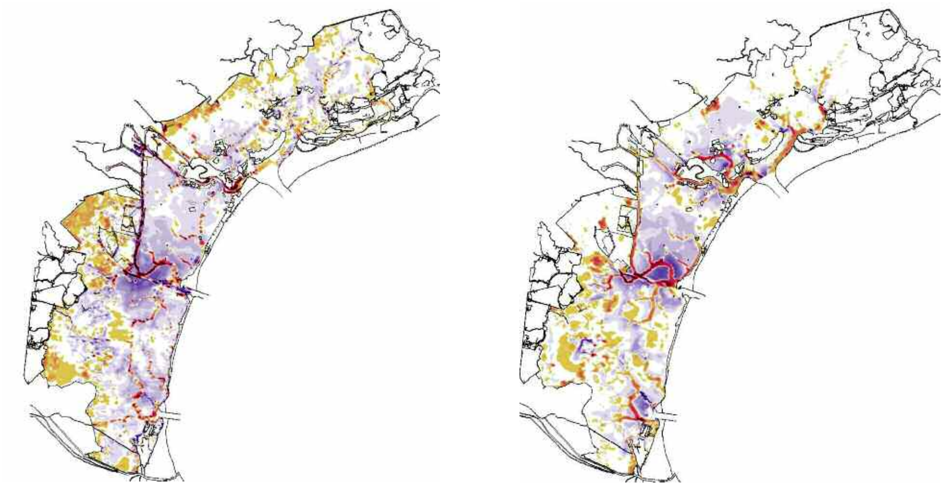

Figure 4. Observed (left) and modelled with Delft3D-RAM (right) bottom changes (blue=erosion, red=accretion) of Venice Lagoon over 1970-2000.

Testing against past developments

Most of these test cases concerned 'hindcasting' morphological evolution over a number of years; typically, the model-data comparisons show some (but not overwhelming) skill in predicting natural developments and similar skill in predicting impacts of human interference.

Conventional wisdom has it that this type of morphological models cannot predict natural development, but that they can predict the relative effect of structures, land reclamations, dredging etcetera. I believe this is wrong on two counts. First, sometimes we see surprisingly good skill in predicting natural or 'autonomous' behaviour and second, if we cannot reproduce what is happening in an area (and this is still often the case), the relative impacts are just as unreliable. Therefore, an overriding priority is still to improve our models and our understanding of their behaviour.

Improvement can be achieved firstly by refining physical formulations, especially in the description of sediment transport processes: predicting the ever-changing bed roughness, taking into account multiple sediment fractions and their interactions, refining models for wave-driven transport. Leo van Rijn is the unchallenged master of this subject, with new and improved formulations every couple of years (see [19], [20], [21] for the latest). In applying this to morphological modelling we're treading a fine line: by implementing these refinements we add complexity and extra tuning parameters, which males the next important point more difficult. Understanding model behaviour and building up real predictive skill is best achieved with models that have few free parameters and do not change much over time, allowing experience to build up. This was illustrated recently by Gerben Ruessink and co-workers [22], who showed that a slimmed-down version of a process-based coastal profile model could be calibrated by a single free parameter and still shows considerable skill in predicting the behaviour of breaker bars on beaches as far apart as Holland, Japan and the US.

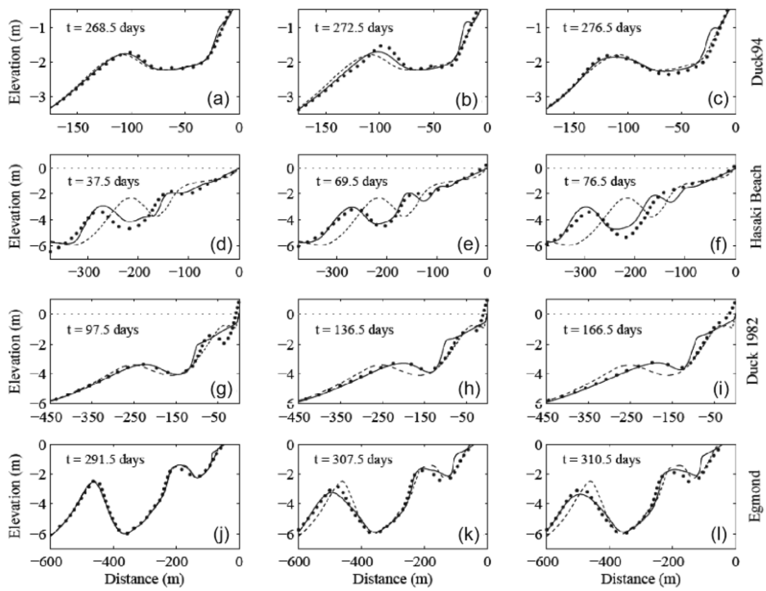

Figure 5. Measured (dots) and modeled (solid line) bed elevation at (a)-(c) Duck94, (d)-(f) Hasaki, (g)-(i) Duck 1982, and (j)-(l) Egmond versus cross-shore distance. The initial profile is shown with the dashed line. From Ruessink et al., 2007.

Undoubtedly we will see this time-scale of months extended to years or decades. We can expect absolute predictive skill to run against a prediction horizon, but likely such a model will still be able to predict general properties of sand bars, such as their length, amplitude and celerity.

Beyond our lifetime

In the early '90s, the general belief was that upscaling of small-scale processes to large space- and time-scales could only be done over a short period, after which everything would diverge and collapse; indeed, we have seen this behaviour in many cases, when we have simply taken a model that was calibrated over a period of some years and continued it for a much longer period.

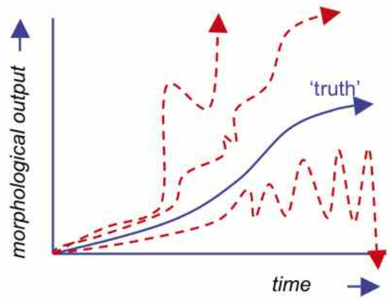

Figure 6. Morphosceptics' view of bottom-up models.

On the other hand, many natural systems tend towards some kind of equilibrium, and if we have some idea of the counteracting forces leading to this equilibrium, why should we not be able to make process-based models with similar behaviour? After groundbreaking work by Anneke Hibma [23], who produced beautiful and realistic-looking patterns by running a Delft3D model for schematic cases resembling the Western Scheldt, our group has taken up this kind of modelling with much enthusiasm.

A first example is from Mick van der Wegen's PhD work on the equilibrium of tidal embayments such as the Western Scheldt [24]. One of the questions is: given the outline of an estuary as seen from Google Earth, and given the tidal amplitudes outside it, can you guess the channel pattern and characteristic cross-sections? This would be very handy in areas where data is scarce (as in many parts of the world). In trying to answer this question, we come across many other questions, such as: how well are empirical relations reproduced by the model, what physical description is essential, or can we find a stable equilibrium? With present-day techniques we are able to run simulations much longer than the Western Scheldt has even existed and we are finding patterns that look quite convincing and

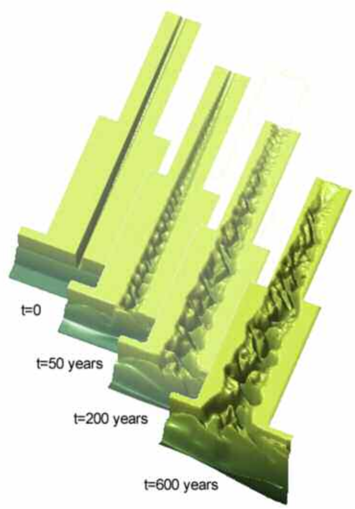

Figure 7. Simulated development of a sandy estuary.

agree with several empirical relations from literature, even though the physical processes included in these simulations are the simplest possible: just depth-averaged shallow water equations combined with a simple transport formula.

Tidal inlets in many parts of the world are valuable natural resources, which are threatened by human interference, bed level subsidence and sea level rise. Based on a wealth of empirical data, we know that intra-tidal flats and supra-tidal marshes tend to follow the relative mean sea level or mean high water level, by trapping part of the large amounts of sediment that enter and leave the inlets every tidal cycle. This means that inlets facing relative sea level rise act as sinks of sediment, often at the cost of adjacent coasts. Over large timescales this may lead to a shoreward transgression of barrier islands or, in case of insufficient sediment supply, to loss of valuable intertidal areas and marshes. Both types of behaviour pose serious coastal management problems: houses and villages are threatened and governments are often committed to preserving valuable habitat areas.

We've seen that the overall behaviour of tidal inlets facing sea level rise can be modelled using semi-empirical models, but detailed measures and effects are difficult to represent in that approach. Ali Dastgheib and Pushpa Dissanayake are now doing their PhD studies looking into the past and future behaviour of the Wadden Sea using the process-based approach. The Wadden Sea represents a fine collection of well-documented tidal inlet

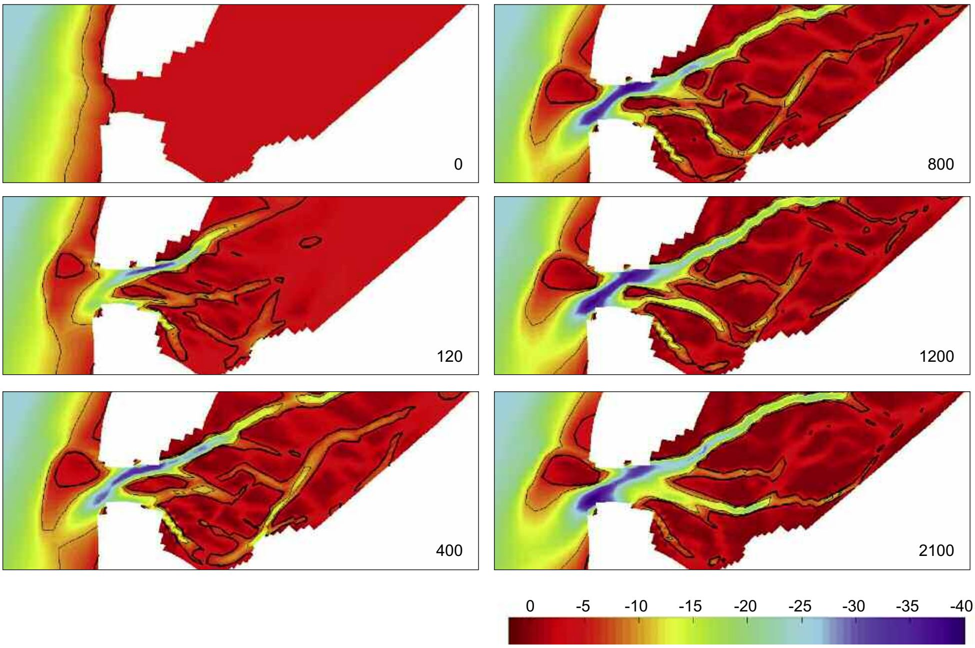

Figure 8. Simulated Evolution of Marsdiep Basin
bathymetry and its ebb-tidal delta using Delft3D model from a flat bathymetry inside the basin, in morphological years of 0 (initial condition), 120, 400, 800, 1200, and 2100.

behaviour, some near equilibrium (e.g. Ameland Inlet), some very much out of equilibrium (e.g. Texel Inlet, which is still adjusting to the closure of the Zuider Zee). We're finding that, again with relatively simple physics, much of the existing channel and shoal patterns are reproduced by running the model from flat bathymetries; moreover, we can investigate the interaction between different tidal inlets, showing that if one inlet (i.c. Marsdiep) starts as a relatively deep basin, it becomes more important and stays that way, at least for the 2000 years we've looked at it. Again, some equilibrium relations are reproduced beautifully, while others are followed in a qualitative sense. This means that process-based modelling is starting to become a viable alternative in long-term modelling. However, passing this entrance exam is only a beginning. We're now embarking on long-term (centuries) hindcasting of these systems and are likely to run into serious challenges as we will have to add more processes and complexity to obtain quantitative agreement.

We expect to gain much by collaborating with geologists in using the models to unravel principles of long-term coastal behaviour and to test hypotheses. The models we developed are finding their way into geology and provide a new direction in geological research, allowing more testing of hypotheses and a more physical underpinning of behaviour models. The delta formation simulations by Joep Storms [25] at TUD are a fine example of what this tool can do in the right hands.

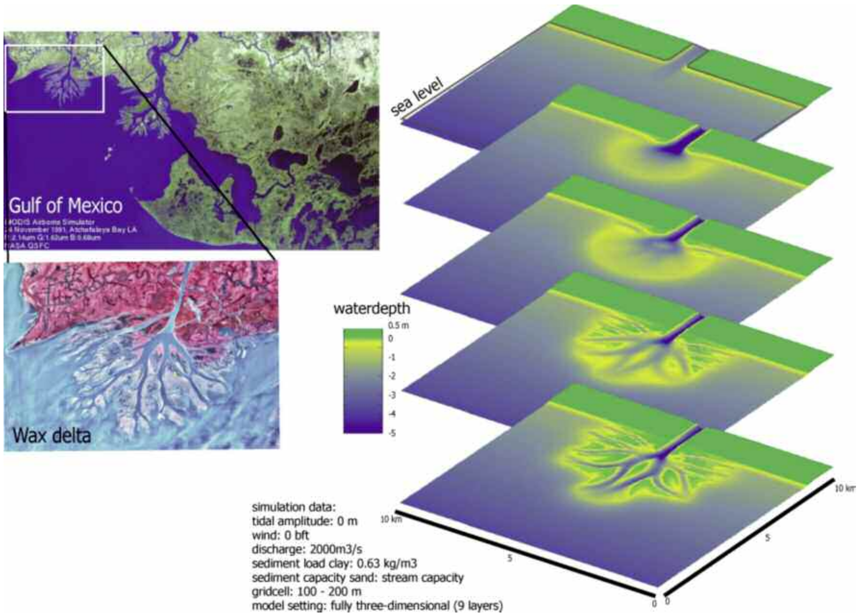

Figure 9. Simulated development of a river delta under conditions similar to the Wax delta (lower left panel.)

Once in a lifetime?

The devastating effects of hurricanes on low-lying sandy coasts, especially during the 2004 and 2005 seasons in the USA, have pointed at an urgent need to be able to assess the vulnerability of coastal areas and (re-)design coastal protection for future events, but also to evaluate the performance of existing coastal protection projects compared to 'do-nothing' scenarios.

Figure 10. Post-Katrina aerial photograph of Dauphin Island, Alabama (USA). Source: USGS/NASA.

In order to address such questions the Morphos-3D project was initiated by the US Army Corps of Engineers. This project brings together models, modelers and data on hurricane winds, storm surges, wave generation and nearshore processes (wave breaking, surf and swash zone processes, dune erosion, overwashing and breaching). Together with colleagues from Delft Hydraulics, Delft University and the University of Miami we were asked to contribute by developing a new public domain model, 'XBeach', that can predict nearshore waves and currents, dune erosion (scarping), overwashing and eventually breaching of barrier islands. Based on our long experience with modelling such processes in physical models and in computer models such as Delft3D, we have developed a prototype model and validated it against a number of large-scale flume tests in the first year of the project, which will continue for two more years.

The XBeach model can be used as stand-alone model for small-scale (project-scale) coastal applications, but will also be used within the Morphos model system, where it will be driven by boundary conditions provided by the wind, wave and surge models and its main output to be transferred back will be the time-varying bathymetry and possibly discharges over breached barrier island sections. The model solves coupled 2D horizontal equations for wave propagation, flow, sediment transport and bottom changes, for varying (spectral) wave and flow boundary conditions. Because the model takes into account the variation in wave height in time (long known to surfers) it resolves the special long wave motions created by this variation. This so-called 'surf beat' is responsible for most of the swash waves that actually hit the dune front or overtop it. Because of this innovation the XBeach model is better able to model the development of the dune erosion profile and to predict when a dune or barrier island will start overwashing and breaching.

The model has already been validated against extensive large-scale flume data sets including short and long wave distributions, return flow, orbital velocities, concentrations and profile change during dune erosion events. An essential part is an avalanching mechanism which allows a surprisingly accurate description of the evolution of the upper profile and dune face. Figure 11 shows a comparison between measured and computed current velocities and dune profile development for large-scale tests carried out at Delft Hydraulics' Delta Flume in 2005.

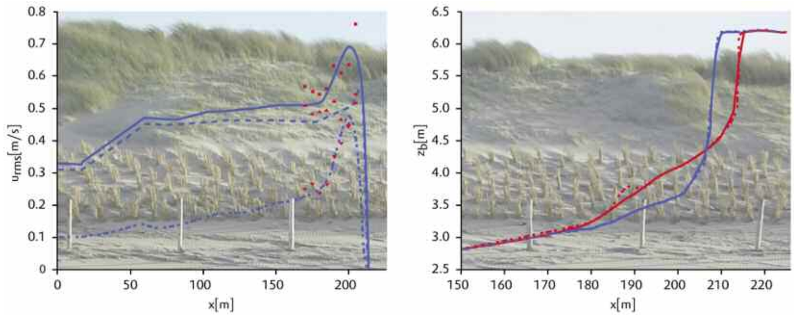

Figure 11. Left: measured and computed low-frequency, wind-wave frequency and total rms orbital velocities ; Right: Initial (blue), measured (red dashed) and computed (red drawn) profile evolution for large-scale dune erosion test.

Working on the development of such public-domain models fits very well within the mission of UNESCO-IHE, as it helps to spread modelling skill that was so far largely contained within complex model systems such as Delft3D or the Mike suite. The setup of the present model is much simpler and accessible, it is open-source and it is available for free. Of course, its scope is much more limited and, as with all public-domain tools, its reliability must be proven and improved by a hopefully fast-growing user community. By linking up with projects like the US Community Sediment Transport Model (CSTM) project, in which we participate we are on the one hand learning from other public-domain developments, such as the ROMS-SED model, and on the other hand bringing in what we think we know about storm impacts. With the USGS in St Petersburg, Florida we exchange our modelling skill with their fantastic data on hurricane impacts on barrier coasts.

The knowledge we gain by looking at the low-lying US barrier coasts is becoming very relevant in the Netherlands, where dune erosion during extreme events is again high on the agenda and where in the Wadden Sea barrier islands there are serious plans to re-introduce more dynamic behaviour by lowering the dunes in some areas where they have been artificially raised in the 19th century.

At least as important from UNESCO-IHE's perspective is the application and further development of such know-how for barrier systems throughout the world, notably in Vietnam, Sri Lanka, Australia, to name a few. Seasonal closure of tidal inlets and river mouths is a fact of life in many such places, but it poses serious problems to fishing communities often cut off from the sea, as well as flooding problems in the rainy season, because of the blocking of river discharge.

A further broadening of the applications of the model is encouraged by bringing the model into an EU 7th Framework project on coastal storm erosion, and by encouraging MSc students to do their research on problems in their home countries using this tool.

What kind of data is needed to use such models? Boundary conditions from coupled ocean-atmosphere models are more and more accurate and available, but local directional wave data and water level data are indispensable to check them. A major obstacle in many places so far is the lack of nearshore bathymetric data. Usually after a storm has hit a coast expert teams go out and measure the post-storm profiles, but meaningful analysis can only be done if the pre-storm condition is known. Likewise, to assess the vulnerability of a stretch of coast, the same data is needed.

What we hope to achieve in the longer run is to be able to provide advice and modelling tools to our partner institutes around the world, enabling them to accurately model the impacts of storms on the many low-lying, often heavily populated and used sandy coasts. This modelling can then be used to design proper dune profiles, to delineate zones where building houses should be discouraged, or at least to determine insurance premiums.

How about the effects of climate change and sea level rise? Given that the storm surge level is the single most important factor in determining dune erosion, any sea level rise will increase the probability of damage occurring (for example, in the Netherlands the probability of reaching a certain surge level increases tenfold for each 70 cm of sea level rise). This indicates that even the moderate sea level rise predicted by IPCC in the order of 50 cm/century can increase risks by a significant factor. A more sneaky effect of sea level rise is that it increases coastal erosion, especially near tidal inlets, which 'suck up' sediment in order to follow the sea level. This makes the adjacent beaches

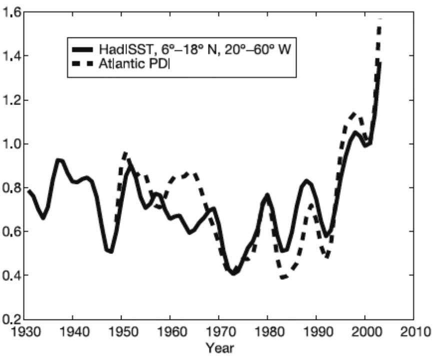

Figure 12. Atlantic Hurricane Power Dissipation Index (PDI), a measure of the total power dissipated over a year, vs. July-November averaged Sea Surface Temperature (SST). Source : Emmanuel, 2005.

and dune systems much more vulnerable. Additionally there is a clear correlation between the sea surface temperature and the intensity of hurricanes, (see picture, from [26]), which will undoubtedly lead to critical conditions being exceeded more often. We have to realise, however, that much of the increase in storm damage of the last decade is due to the fact that so many people have moved to the coast. Managing both this trend and the effects of climate change will be a tough challenge. Hopefully the tools we develop will help to base decisions on realistic scenarios.

Keeping our finger on the pulse

It is clear from the cases above that we need to pay much more attention to the state of the coast, to the trends in this state and to the way we use it and encroach on it. Setting up monitoring programmes to regularly survey beaches, channels and tidal inlets and estuaries, if they are not already in place, should be an overriding priority. It is astonishing with how little data coastal managers or dike departments in some areas have to devise strategies. The concept that storm damage is much worse when there has been an ongoing erosion process in front of a dike or dune does not get attention when there is no data to show it. Part of the lack of information at the right place is often an unwillingness to share data between institutions. It frequently occurs that several institutes do research and collect data in an area but that nobody gets the complete picture because of administrative walls. One way out of this, which has proven very successful in the oceanographic community and is rapidly expanding to coastal and nearshore areas, is the concept of (Coastal) Ocean Observing Systems, or Coastal Observatories, where various groups and institutes, providers and users share data and models, adding value to all contributions because integral data sets, connected and supported by models, have much more value than individual time series of single points in a big sea. Funding agencies, both national and international, should seriously consider to fund research through such observatories or at least to insist that research is brought under the umbrella of some coastal observatory.

Modelling is a key element and beneficiary of coastal observatories. It is essential in connecting the isolated data points to provide a synoptic view and relevant colour-coded pictures to put on the Web. Just as importantly, the continuous confrontation between models and data greatly improves the model skill. This is not just true for the generic model skill, where process representation in a model system may be improved by testing against data, but especially for the local model skill, which is improved by bringing in more and more local knowledge and experience.

Satellite-based remote sensing has long played an important role in ocean observing systems, providing data on sea surface temperature, chlorophyll, suspended sediment, wave heights, water levels and surface currents, but is much less readily applicable in nearshore areas. On the other hand, land-based video and radar systems can provide more and more information that, together with models and some in-situ data, can be used to quantify the bathymetry, waves and current patterns.

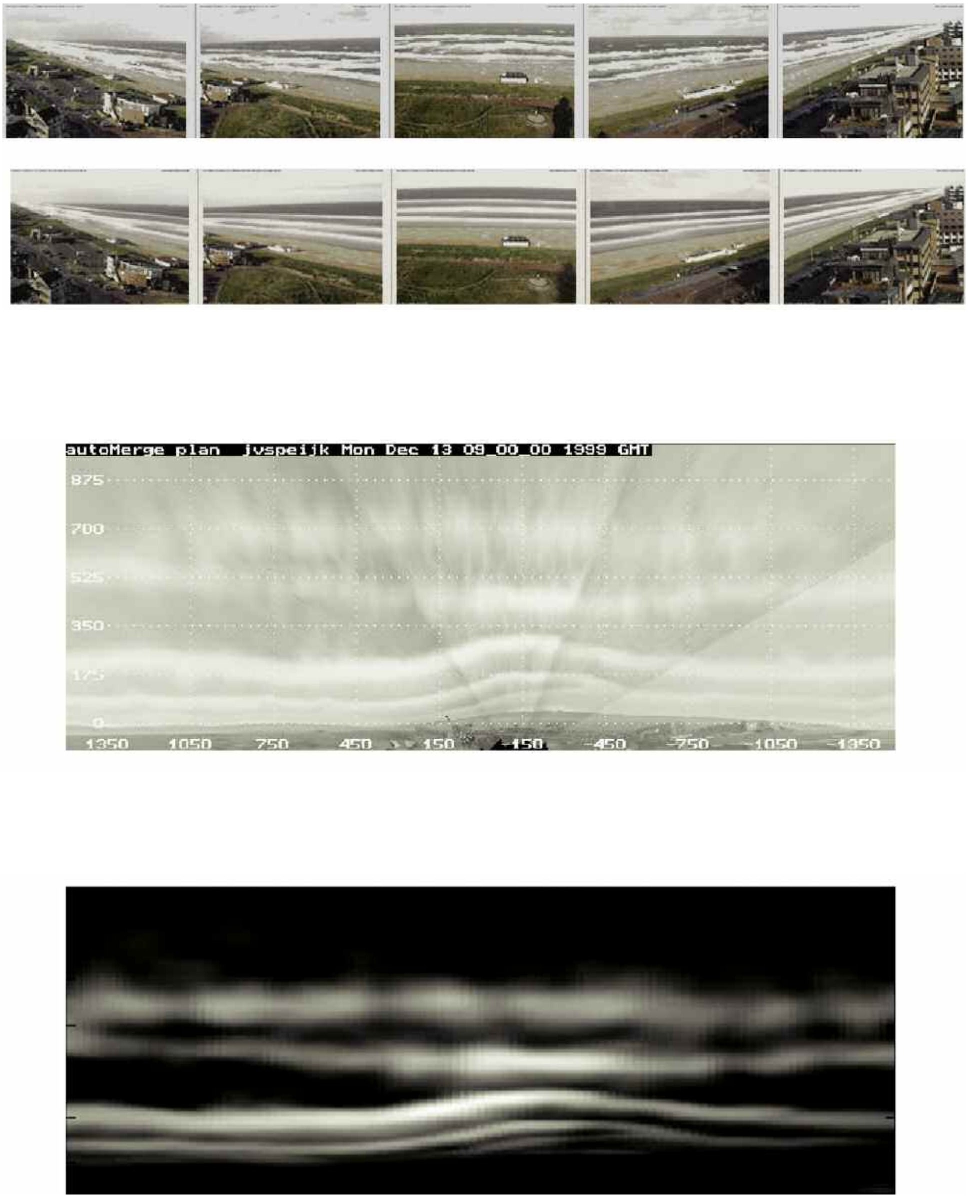

Figure 13. Obtaining data from video-images: from top to bottom: snapshots from individual cameras; time-average pictures per camera; merged and rectified image; detrended and scaled to wave dissipation. The bottom image can be compared to output from a wave model and by combining model and data we can obtain the bottom depth.

The Beach Wizard project in which we participate with Delft Hydraulics, Delft University and several US institutes, is a system that successfully assimilates different kinds of information from video and radar, such as average breaking wave patterns, position of the shoreline and wave celerity with a forward model of wave propagation and decay, currents and morphology change [27]. We have shown that we can measure the actual bottom depth of a barred beach in an area of some kilometres alongshore with an accuracy of 30-50 cm 'just by looking at it'. This technique, while it can be still further refined, is ready to be made operational and could provide beach resorts with daily updates of the bar and trough patterns (good for sailors) and the associated wave patterns (surfers) and dangerous currents (lifeguards). When it is run in conjunction with a morphological model, this can be validated continuously and the model skill can be improved dramatically, making it much more fit to design beach nourishments and shoreface nourishments or other coastal structures. Coupled with water quality models it could tell where and when not to swim or what to do to improve the situation. Such a system can be run and installed at relatively low cost and could be applied in many places around the world. It would raise public awareness of the coast and produce vital statistics necessary for evaluating coastal defences. A recent application for the Dutch coast revealed, for instance, that winter beach profiles (which are seldom measured because of the severe wave conditions) are significantly lower than summer profiles. This could have important ramifications for the evaluation of dune or dike safety.

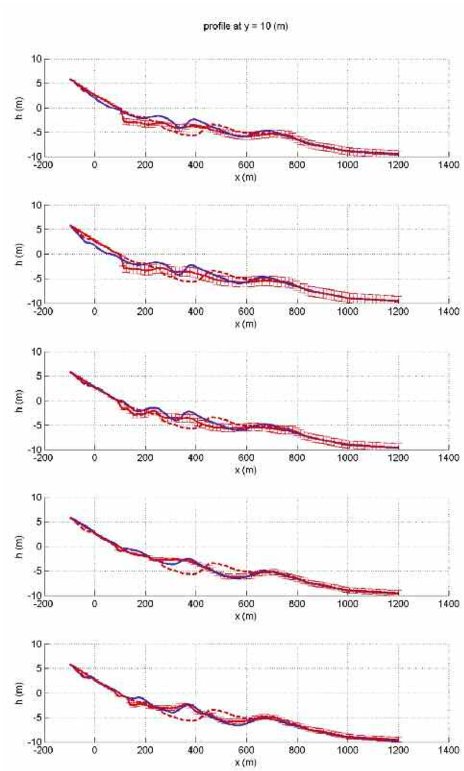

Figure 14. Results of the Egmond application of Beach Wizard at a cross-shore array (y = 10 m) at five points in time during the model period when the bathymetry was measured (from top to bottom: 05/04/2000, 17/05/2000, 17/09/2000, 18/04/2001 and 18/06/2001). The blue line indicates the measured bathymetry, the red line indicates the computed bathymetry. Dashed lines indicate the initial situation of both. The model predicted errors are shown in red bars.

Living safely on the edge

I would finally like to discuss some general ideas about how research in coastal engineering can make 'living on the edge' safer in the many places in the world where this is very unsafe. Let us focus, as for instance formulated in the Hashimoto Action Plan [28], on actions that could reduce the loss of lives due to water-related disasters. In my view there are three important types of action we must take, wherever we are:

a) Given the existing (lack of) flood protection, improve contingency plans.
b) Reduce the risk of flooding
c) Plan for future land use and climate change

The first type is the quickest to implement and can already reduce loss of lives drasticallt. This can start by educating people about the risks and how to cope with them (think of the English girl who saved 27 lives during the Indian Ocean tsunami because she had learned how to recognise one coming in school). It can be done at personal, local and national levels and must be supported by good data and insight into physical processes. It is important to map risks so that people know what could happen and can prepare. Early warning systems must be made reliable enough that people believe them and effective enough that they reach all people in time. Emergency and evacuation plans must be set up, communicated and practiced. Safe havens can be easily created and must be clearly indicated. In areas with little flood protection, it is vital that the awareness and resilience of people is improved. Our group can contribute by helping develop models of what happens in extreme events, not just in terms of hydrodynamics but also morphologically, and by connecting these models to global databases and models, in such a way that this technology becomes applicable anywhere in the world. Just as importantly, we're teaching the teachers who will spread this know-how and apply it locally. To reduce the risk of flooding, comprehensive risk assessment must be carried out for threatened areas, considering

- joint probability of extreme water levels and waves;
- strength of individual dikes, levees and other structures or natural defences;
- risk of flooding ofneighbourhoods, dike rings, polders;
- damages and lives lost as a function of frequency of occurrence.

We can then establish a sensible safety level per area. Based on that, authorities can prioritize and plan comprehensive and consistent defence systems accordingly, including buffer zones, retention areas where needed. Obviously, such defence systems must then be continuously monitored and maintained. Many lessons can be learned, both good and bad, from the extensive forensic studies carried out after hurricane Katrina. On the subject of risk reduction, our group can specifically contribute to the improvement of dike design (my colleague Randa Hassan's field) and to the analysis of the strength of dunes and barrier coasts, as I discussed before.

Finally, we need to plan for change. A high priority should be to combat coastal erosion as it slowly erodes safety against flooding. We must adapt to population and economic pressure on coastal resources leading to more people living in vulnerable areas, and often increased coastal erosion. And yes, we must adapt to effects of climate change, such as changed rainfall patterns, increased storm intensity and sea level rise. I hope that the models we develop and the insight we gain through them will contribute to making the right choices for the right reasons.

Words of thanks

There are many people who made it possible for me to stand here in front of you. I'll try to mention them in a chronological order.

First, there are my parents, brother and sisters who have raised me to be confident and optimistic in general and to think independently and critically. I'm very happy to have them all around and in good health.

Eco Bijker is still an example to me in how to teach, with a practical approach and a great sense of humour. Jan van de Graaff took the risk of hiring me as a research student assistant and guided me with much patience and tolerance. Pier Vellinga hired me at Delft Hydraulics, in the old De Voorst office, and bought a piano so we could start a band; beside this, he showed much confidence in me and set me on the track to get a PhD. Marcel Stive got me into morphological modelling and, in his friendly way, forced me to write things up; he has been a great colleague ever since. Huib de Vriend introduced me to the EU projects that I have enjoyed very much and that gave me the opportunity to get a PhD. Jurjen Battjes was a wonderful promotor; once his blue pen finally stopped scratching you knew it was ok. My colleagues at TU Delft have been and still are great to work with, both under Kees d'Angremond and Marcel Stive; talks with my roommate Ad van der Spek taught me a lot about geology that now comes in handy; Ad Reniers has been a good friend and co-worker and still is, even at some distance in Miami.

I'm happy that Dirk-Jan Walstra and Ap van Dongeren are taking over many, but not all of my tasks at Delft Hydraulics and TUD, and that we still get to work together a lot. Also it's good to have Maarten van Ormondt back, whose Muppet program is starting to get just as out of hand as Mark van Koningsveld's McTools; it is initiatives like this that make Delft Hydraulics such a fun place to be. Both in de Voorst and in Delft, Delft Hydraulics has been a very inspiring environment. I'm happy to keep the connection alive, even for one day per week and wish my colleagues a smooth transition into Deltares. I have much enjoyed collaborations within the Netherlands Centre for Coastal Research (NCK), especially at the summerschools organised by Han Winterwerp and Herman Ridderinkhof, and I have much to thank many international colleagues for, at the US Geological Survey, the Office of Naval Research and the US Army Corps of Engineers.

Of course I am very grateful for the confidence the search committee led by Arthur Mynett has put in me. I have come to feel at home at UNESCO-IHE and enjoy a very pleasant relationship with my roommate, Mick van der Wegen, Joop de Schutter, the head of the Water Engineering department and with my colleagues within the core, the department, the Academic Board and many others within the institute.

Finally, I have had an incredibly good time with Hesseltje and my great kids Floortje, Joris and Marijn. There is nothing more important than that.

Thank you for your attention,
Ik heb gezegd.

REFERENCES

[1] US Army Corps of Engineers, 2007. Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System. Final Report of the Interagency Performance Evaluation (IPET) Task Force. Available online at ttps://ipet.wes.army.mil/

[2] van der Meulen, M.J., A.J.F. van der Spek, G. De Lange, S.H.L.L. Gruijters, S. Van Gessel, B.L. Nguyen, D. Maljers, J.Schokker, J.P.M. Mulder and B.A.A. van der Krogt (2006). Regional sediment deficits in the Dutch Lowlands: implications for long-term land-use options. J. Soils Sediments 7(1)9-16 (2007).

[3] van Gent, M.R.A., E.M. Coeveld,D.J.R. Walstra, J. Van de Graaff, H.J. Steetzel and M. Boers (2006). Dune erosion tests to study the influence of wave periods. Proc. 30th Int. Conf. on Coastal Engineering, Jane McKee Smith (ed.), pp. 2779-2791, World Scientific.

[4] Khedayyer, A.T., J.A . Roelvink and P. Boeriu. Considerations on hydraulic designof the settling basins of the water supply intakes for hydropower plants. Proc. Int. Conf. HYDRO 2006, Sept. 2006, Porto Carras, Greece.

[5] Pelnard-Considere, R. 1956. Essai de theorie de l'Evolution des Formes de Rivages en Plage de Sable et de Galets. 4emes Journées de l'Hydraulique, les Énergies de la Mer, Question III, Rapport No. 1, pp 289-298.

[6] Andrew Ashton, A. Brad Murray, Olivier Arnoult. Formation of coastline features by large-scale instabilities induced by high-angle waves. Nature Letters 414, 296 - 300 (15 Nov 2001)

[7] Schuttelaars, H.M. and H.E. De Swart. Initial formation of channels and shoals in a short tidal embayment. J. Fluid Mech. , 386:15-42, 1999.

[8] Hulscher, S.J.M.H. and G.M. van den Brink. Comparison between predicted and observed sand waves and sand banks in the North Sea. J. of Geophysical Research, Vol. 106, No. C5, pp. 9327–9338, 2001

[9] van de Graaff, J. (1977) Dune erosion during a storm surge. Coastal Eng., 1(2) pp. 99-134.

[10] Vellinga, P. (1982) Beach and dune erosion during storm surges. Coastal Eng., Vol. 6., pp. 361-387.

[11] Eysink, W.D. and Biegel, E.J. (1992). ISOS*2 Project : Impact of sea level rise on the morphology of the Wadden Sea in the scope of its ecological function, phase 2. Delft Hydraulics report H1300, Delft, The Netherlands.

[12] Stive, M.J.F. and Z.B. Wang (2003). Morphodynamic modelling of tidal basins and coastal inlets. In: advances in Coastal Modelling, Chapter 13, V.C. Lakhan (ed.), Elsevier Science.

[13] Roelvink, J.A. Coastal morphodynamic evolution techniques. Coastal Engineering Volume 53, Issues 2-3 , February 2006, Pages 277-287.

[14] Latteux, B., 1995. Techniques for long-term morphological simulation under tidal action. Marine Geology 126, 129– 141.

[15] Cayocca, F., 2001. Long-term morphological modeling of a tidal inlet: the Arcachon Basin, France. Coastal Engineering 42 (2), pp. 115– 142.

[16] Lesser, G.R., Roelvink, J.A., van Kester, J.A.T.M., Stelling, G.S., 2004. Development and validation of a three-dimensional morphological model. Coastal Engineering 51 (8–9), 883– 915.

[17] Elias, J.P.L., M.J.F. Stive and J.A. Roelvink. Impact of back-barrier changes on ebb-tidal delta evolution. Journal of Coastal Research, Special Issue no. 42, pp. 460-476.

[18] Gelfenbaum, G., J.A. Roelvink, M. Meijs, M. Buijsman, and P. Ruggiero. Process-based morphological modeling of grays harbor inlet at decadal timescales. In: Proc. Coastal Sediments '03.

[19] van Rijn, L.C. Unified View of Sediment Transport by Currents and Waves. I: Initiation of Motion, Bed Roughness, and Bed-Load Transport. J. Hydr. Engrg., Volume 133, Issue 6, pp. 649-667 (June 2007)

[20] van Rijn, L.C. Unified View of Sediment Transport by Currents and Waves. II: Suspended Transport. J. Hydr. Engrg. 133, 668 (2007)

[21] van Rijn, L.C. Unified View of Sediment Transport by Currents and Waves. III: Graded Beds. Journal of Hydraulic Engineering, Vol. 133, No. 7, July 2007, pp. 761-775 , (doi 10.1061/(ASCE)0733-9429(2007)133:7(761))

[22] Ruessink, B. G.; Kuriyama, Y.; Reniers, A. J. H. M.; Roelvink, J. A., Walstra, D. J. R. Modeling cross-shore sandbar behavior on the timescale of weeks. J. Geophys. Res., Vol. 112, No. F3, F03010 DOI:10.1029/2006JF000730.

[23] Hibma, A., de Vriend, H.J. & Stive, M.J.F., 2003. Numerical modeling of shoal pattern formation in well-mixed elon-gated estuaries. Estuarine, Coastal and Shelf Science. Vol. 57, 5-6, pp. 981-991.

[24] Van der Wegen, M. and J.A. Roelvink (2007). Long-term morphodynamic evolution of a tidal embayment using a 2 dimensional process based model. In rev. Journal of Geophys. Res.

[25] Storms, J.E.A., M.J.F. Stive, J.A. Roelvink and D.J.R. Walstra. (2007). Initial morphologic and stratigraphic delta evolution related to buoyant river plumes. Proc. Coastal Sediments 2007, New Orleans, ASCE.

[26] Emanuel, K. (2005). Increasing destructiveness of tropical cyclones over the past 30 years. Nature Letters Vol 436, 4 August 2005, doi:10.1038/nature03906.

[27] van Dongeren, A. , N. Plant, A. Cohen, J.A. Roelvink, M. Haller and P. Catalan (2007). Beach wizard: nearshore bathymetry estimation through assimilation of model computations and remote observations. Subm. Coastal Engineering.

[28] Hashimoto Action Plan. Compendium of Actions, United Nations Secretary-General's Advisory Board on Water and Sanitation, March, 2006.

UNESCO-IHE
Westvest 7
2611 AX Delft
The Netherlands

PO Box 3015
2601 DA Delft

T +31 15 215 17 15
F +31 15 212 29 21
E info@unesco-ihe.org
I www.unesco-ihe.org

UNESCO-IHE
Institute for Water Education