HZ UNIVERSITY OF APPLIED SCIENCES

ENHANCING DELTA RESILIENCE

Inauguration of Joost Stronkhorst as
Lector in Building with Nature at Delta Academy,
HZ University of Applied Sciences,
8 September 2016

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WELCOME

Honourable Executive Board of HZ University of Applied Sciences, dear colleagues, students, family and friends,

thank you for attending to my inauguration as Lector in Building with Nature at Delta Academy – Applied Research Centre (DA-ARC).

The expanding populations and economy in low-lying deltas are facing the same challenges: flood risks, environmental degradation, loss of natural capital and a lack of resilience towards sea level rise and subsidence. The mission of Delta Academy is to educate the next generation of professionals which is capable of creating sustainable solutions to these complex problems. We try to achieve this through interdisciplinary education and applied research in the field of civil engineering, aquatic eco-technology and delta management.

In the next half an hour I will talk about delta resilience and ways to enhance resilience using Building with Nature solutions. I will give a short introduction on deltas, define delta resilience, go over different Building with Nature concepts, showcase some of the work that the research group Building with Nature is doing here in the Dutch SW delta and present new ideas for future work, here and abroad.

I build upon the work by Mindert de Vries, my appreciated predecessor and colleague at Deltares in Delft who did pioneering work and launched many Building with Nature projects in this region. Along with my fellow lector Professor Tjeerd Bouma, I have the pleasure of working with a wonderful team of dedicated researchers, a team capable of good science, teaching, tough fieldwork and teamwork. Our challenge is to understand how Building with Nature can enhance delta resilience to improve the level of flood safety and for the sake of natural capital and delta development at large.

Joost Stronkhorst

DELTAS & RESILIENCE

DYNAMICS IN DELTAS

Maybe you recognise this iconic photograph taken from the moon by the crew of Apollo 8 on Christmas day 1968. It is entitled 'Earth Rise'. At that time, it made mankind more aware that the blue planet we live on is precious and that we should treat our living environment with care.

For 4.5 billion years the earth and the moon have formed a couple. The gravitational effect of the moon is responsible for the tides on earth, one of the dynamic factors in deltas. The tidal cycle of flood and ebb pushes seawater in and out of an estuary, twice daily, every day of the year.

Deltas are formed where rivers supply abundant amounts of sediments into the sea. The shape of a delta mainly depends on three sediment transport processes: the flow of the river water, the powerful forces of waves and the tidal currents. According to the Galloway classification (Galloway, 1975) river-dominated deltas develop in front of very large rivers that enter a calm sea with minimal waves and tides: for example, the Mississippi delta. The Nile delta is an example of a wave-dominated delta, resulting in a more even distribution of river sediment along the coastline. If tides are dominant, it results in a shape like, for instance, the Ganges-Brahmaputra delta.

All kinds of dynamic geophysical processes are taking place: morphological changes, inundation of the tidal flats, nutrient cycles, salinity gradients, etc. These processes influence the ecology and results in high biodiversity in and productivity of the water, on land and the wetlands in between.

Earth rise

Man has become a serious factor in shaping deltas too, as we can see in the Dutch SW Delta. This delta of the rivers Rhine, Meuse and Scheldt has a sandy coast along the North Sea, islands with fertile but low-lying polders and estuaries with tidal flats and channels. Over the last century we have changed the delta dramatically by shortening the delta coastline and embanking and compartmentalising the branches. The most influenced are the stagnant lakes (Volkerak-Zoommeer and Haringvliet both freshwater, Grevelingen and Veere both salt water). The least modified areas are the tide-dominant Scheldt estuary and Oosterschelde tidal bay, but even here the human impact on the estuary development is very significant.

RESILIENCE OF DELTAS

Resilience can be defined as the ability of a system to withstand and recover from hazards (e.g. flooding). The term has been used since the 1990s in Dutch water policy plans (Ministry of Transport & Public Works, 1999), by the World Wildlife Fund in their vision on delta development (WWF, 2008). More recent it is used by, for example, the United Nations and World Bank in the context of disaster risk reduction (UNISDR, 2015), the City of New York as their vision behind restoring the damage caused by hurricane Sandy (NYC, 2013) and by research networks devoted to the governance and capacity building of communities (Post Carbon Institute, 2013).

Delta resilience in my view can be understood as *the amount of change each part of a delta can undergo while retaining essentially the same function and structure as well as the degree to which each part of a delta is capable of self-organisation and adaptation to the change.*
In practice this means, for instance, that:

- Flood defences are designed to dissipate storm and wave energy that may hit a coastline, with natural foreshores that rebuild and adapt themselves through sedimentation, vegetation growth, accretion etc.;
- Estuarine waterways are deepened in such a way that if dredging stops the natural conditions of the estuary return immediately, including the network of tidal channels and a good ecological status;
- Human communities living in deltas are aware of disaster risks and climate change and have self-organising coping capabilities;
- Aquaculture in delta areas take place within the ecosystem's carrying capacity;
- Industries and cities on the delta are independent of freshwater supply from outside their region in times of drought, by protecting and re-using their freshwater resources most effectively.

Resilience can evolve through cycles of growth, accumulation, crisis and renewal and often self-organises into unexpected new configurations. This way a delta can absorb stress and bounce back from a setback without suffering damage.

SINKING OF DELTAS

Ladies and gentlemen, many urbanized deltas are sinking (Syvitski et al., 2009). This is a result of different factors including: i) subsidence, a drop in surface level due to natural compaction of sediments or accelerated by extraction of groundwater, oil, or gas or draining of land; ii) low sediment input because sediments are being trapped upstream behind hydroelectric dams or sediment transport is interruption by coastal structures and iii) sea level rise. Let's zoom in on the last topic.

The effect of sea level rise on deltas is illustrated by the paleogeographic reconstruction of the Dutch SW delta made by De Vos (2015). The reconstruction covers the last 11,000 years (Holocene). In the first part of the Holocene, sea level rose rapidly and the coastline retreated because the supply of sediment was smaller than the demand for sediment to grow apace with rising sea level.

When sea level rise started to slow down, the sediment supply exceeded the sediment demand, and the shoreline moved seaward. Later on and protected by sandy coastal barriers marshland started to develop in the freshwater environment. Some 2500 year ago the sand barriers were breached and seawater flooded the area again. During the last thousand years, inhabitants of the Dutch SW Delta have reshaped the area by impoldering large parts of the delta for agriculture and protecting themselves from the sea by raising dikes, with the Delta works as the final masterpiece.

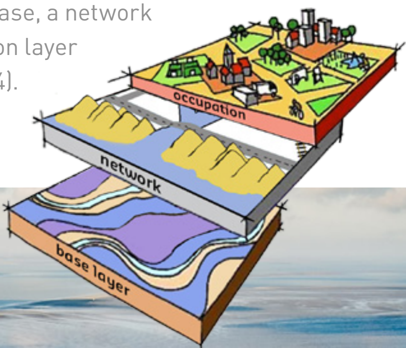
Here in Flushing, at the mouth of the Scheldt estuary, sea level has been recorded since 1862. The sea level is rising by an average of 2 mm per year (equal to 0.2 m in a century). But over the last few decades, the rise has accelerated to 3 mm per year. This is an effect of global warming as addressed by the International Panel on Climate Change (IPCC, 2014). However, high-end scenarios predict up to 1.8 m of sea level rise by the end of this century if CO2 emissions continue unabated (Jevrejeva et al., 2014). This may actually happen, considering the alarming rapid melting of Antarctic ice sheets reported in *Nature* this summer (DeConto & Pollard, 2016)!

Faster sea level rise, faster subsidence and low sediment inputs reduce delta resilience and jeopardise delta life for coming generations. So: "it is the sediment, stupid!"

We will have to find holistic solutions that simultaneously ensure flood safety, productivity and biodiversity. Given the complexity of our delta systems this will be extremely difficult. We need delta programmes to make it happen.

SPATIAL LAYERS OF A DELTA

A very useful way to analyse delta resilience is by imagining a delta as a three-layer model consisting of a base, a network and an occupation layer (Bucx et al., 2014).



The base layer is the bio-geophysical layout of a delta: geology, morphology, hydrology, ecology etc. The network layer encompasses the man-made infrastructure of dikes, waterways, ports and roads. The base layer sets the boundary conditions for the network layer and together they enable the occupation layer, which encompasses the built-up environment, economic activities and so forth. Changes in the base layer usually take place at larger scales of time and space (e.g. sea level rise and subsidence) than in the other two layers.

The bio-geophysical factors of the base layer determine coastal hazards like, for instance, erosion or salt water intrusion or flooding. We recently developed an internet application that allows the identification of erosion hazards at any given coast in the world (http://chw.openearth.eu/viewer). The application uses global open access data of physical factors and the classification method called Coastal Hazard Wheel (Rosendahl Appelquist L, Halsnæs K, 2015). Delta Academy student Alex Levering developed the CHW App at Deltares and received the HZ Stern Award for best BSc thesis of 2016.

A well know Dutch example of the consequences of lack of resilience is the 1953 storm surge. The poor condition of the sea defences (network layer) caused the disaster that hit the SW delta. The Delta Works were the firm and robust response to this great disaster; it took 40 years to complete (1958-1997).

Today the Dutch delta is indeed a wealthy place and regarded as the safest delta in the world. That doesn't mean that the job is done; the sea level is rising and sea defences need to be maintained. Can we equip ourselves to be resilient, bounce back and adapt to the turbulence ahead? According to the UN one of the essentials for making urbanized deltas resilient is protecting ecosystems and making or restoring other natural buffers for mitigating floods, storm surges, or other natural hazards.

BUILDING WITH NATURE

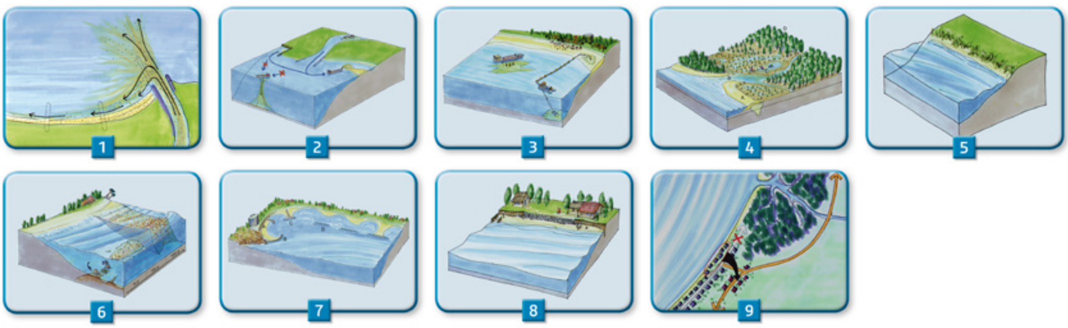
PRINCIPLES OF BUILDING WITH NATURE

Using natural materials and the constructive forces of nature to build and maintain flood defences or rehabilitate degraded ecosystems is referred to as Building with Nature (Waterman, 2011; Borsje et al., 2012; Temmerman et al., 2013; De Vriend et al, 2015). The idea is to make nature-based flood defences by using wind, waves, tides and currents, to use the stabilising effect of mussel and oyster beds or the wave-damping effect of mangrove forests and salt marshes, and to use sand, silt and clay as building material. A suite of eco-engineering options are available, including:

1. restoration of natural sediment transport
2. re-use of dredged material
3. sand nourishment
4. mangrove and saltmarsh restoration
5. re-shaping cliffs
6. development of living breakwaters (mussel, oyster and coral reefs)
7. smart use of hard structures
8. small-scale protection measures
9. managed realignment and spatial planning

(Stronkhorst et al., 2013).

Building with Nature solutions typically fulfil multiple functions besides the primary function they are designed for. For example, wetlands protect against floods but also function as nurseries for commercial fish species, as CO_2



sinks, as aesthetical landscape elements, or as tourist attractions. Building with Nature aims to balance traditional natural values with functionality and economic benefits.

In the Netherlands, Building with Nature is supported by the water sector through the public–private consortium Ecoshape and government institutions involved in coastal infrastructure and ecosystem development (van Slobbe et al., 2013). Building with Nature has already been applied in many hydraulic engineering projects, for example, the Dutch 'Room for the River' project, the Sigma plan for the Scheldt river in Belgium, the Dutch 'Coastal weak links' project, Flemish Bays, the program engineering-with-nature of the US Army Corps of Engineers and the Dutch programme 'Dynamic Preservation of the Coastline'.

SAND NOURISHMENTS TO PROTECT SANDY COASTS

When in 1990 a storm hit the dunes here close by on the island of Walcheren, the resilience of this coast was tested to the limit. Fortunately, Walcheren was not inundated, though the sand buffer was greatly reduced. The 1990 storm had an impact at a national level and initiated the sand nourishment schemes that Rijkswaterstaat has been implementing ever since, the 'Dynamic Preservation of the Coastline' programme (Hillen & Roelse, 1995). This is an excellent example of Building with Nature. The long-term goal is to allow the coast to grow apace with rising sea level and combat coastal erosion. Large dredging vessels collect sand from the deeper North Sea and place it on the foreshore or beach, from where tides and waves redistribute it naturally and wind brings the sand into the dunes. For the sand nourishments along the coast of Walcheren I estimated that the benefits exceed the costs because the sand nourishments save expensive sea defence re-enforcements on the landside; provide favourable conditions for beach recreation and tourism; create extra dune habitat and protect the fresh groundwater reserves in the dunes. From the perspective of asset management, the Dynamic Preservation of the Coastline programme is an economically sensible approach. Similar Building with Nature strategies are needed for many other delta coasts as well as for other basins in the SW Delta.

The sand volume of the dunes is a good indicator of resilience. To cope with the high-end sea level rise scenario mentioned earlier I believe that for at least the coming century we can create enough resilience to the Dutch coasts by applying sand nourishments. This is because we are very lucky in having vast reserves of sand in the North Sea (Stronkhorst et al., in prep). At a global level, however, sand is becoming a rare natural resource used above all for the construction of roads and buildings (see UNEP publication Sand, rarer than one thinks (Peduzzi et al. 2014). So many sandy coastlines will retreat or require very large investments in hard coastal engineering measures to prevent that from happening.

I began my career as an environmental researcher in the Delta Department (Deltadienst) in Middelburg during the construction of the Delta Works. In 1986 the Oosterschelde storm surge barrier was finished and is operational ever since. At that time we investigated the ecological effects of, among others, a temporal closure of the storm surge barrier. Today we are more concerned about its long-term side effect on the sand balance of the Oosterschelde. This is because the barrier is limiting the sand transport to the sand flats while the waves continue to erode the sand flats, depositing sand in the deep tidal channel. For wading birds these sand flats are crucial feeding grounds. Therefor sand nourishments have been executed at Galgeplaat and Oesterdam (Boersema et al., 2016a) to protect the sand flats. Rijkswaterstaat and NGO Natuurmonumenten have commissioned our research group and our research partners Deltares, Imares and NIOZ to make a sand nourishment design for the sand flat Roggenplaat that enables wading birds to visit the area for at least the next 25 years. So together with Rijkswaterstaat we are working on sustainable solutions for this type of coastal erosion (van de Werf et al., 2016). In the winter of 2018/19 a dredging company will execute the sand nourishment of 1.3 million cubic meters of sand. Our research consortium will monitor the developments that follow.

BUILDING LIVING BREAKWATERS

Reefs of oysters and mussels may have sediment stabilisation and erosion prevention capabilities. This is being tested in combination with a sand nourishment at the Oesterdam, Oosterschelde (Salvador de Paiva et al., 2016; Van den Brink, 2016). Building with Nature researchers and many students are working hard to collect and analyse data. The research consortium with Deltares, Imares and NIOZ will soon present its final findings and answer the

question on the morphological effectiveness and ecological benefits of the sand nourishment and added value of the oyster reefs.
Our group and partners are trying to build a durable littoral mussel bed in the Oosterschelde and develop a maintenance strategy for it. The aim is to achieve a number of seemingly conflicting goals, such as: create new, cost-effective production locations for the shellfish industry; develop nature-friendly methods to protect erosion of intertidal areas and increase the natural value of tidal wetlands in the context of the Natura 2000 objectives. Many partners share a great interest in this research and many students are and will be involved in this four-year project.

RESTORATION OF MUDFLATS AND SALT MARSHES

Crucial for delta resilience is the presence of wetlands, including mud flats, salt marshes and mangrove forests. In the last century half of these habitats on earth were lost due to all kinds of coastal developments: land reclamation, building of aquaculture ponds, erosion, etc. Mud is an essential substrate for salt marshes and mangrove forests. Wetland vegetation provides accelerated soil building with sea level rise (Kirwan et al., 2016) and protects coastlines from incoming waves. Additionally, wetlands are nurseries for fish regulate nutrient levels in the water and, very importantly, have a great capacity to store the greenhouse gas carbon dioxide in soil and biomass for centuries.

Beneficial use of dredged material may include the creation of wetlands in the Scheldt estuary to compensate the loss of salt marshes in the SW delta (Storm, 1999). A very large volume of approximately 10 million cubic meters of sediment is being dredged every year to maintain the estuarine waterway to Antwerp. I hope we can find partners to start a Living Lab on the development of more wetlands, for instance, along the south shore of Zuid-Beveland. This fits nicely in the research agenda of the Flemish Dutch Scheldt Commission (VNSC) that is coordinating the trans-boundary management of the Scheldt estuary.

This year lector Tjeerd Bouma, an internationally renowned scientist on the ecology of mud coasts, will start a new Building with Nature project on the Dutch south border of the Scheldt estuary. Here new groynes are being built by the water board; the research is and commissioned by the Province of Zeeland. The question is if these hard structures will enhance deposition of sand and mud from the Scheldt estuary and result in durable intertidal flats. Colleague Carla Pesch is working on a comparable issue in the Port of Rotterdam.

Lector Robert Trouwborst is currently working on a research proposal to apply new sensor technology to improve our monitoring capability to quantify the content of mud in the water and to link this to many practical questions related to mussel culturing, the design of a dike toe and water quality in, for instance, the port of Rotterdam together with Hogeschool Rotterdam.

MANGROVE RESTORATION

To better understand the conditions in Asia with regard to 'Enhancing delta resilience' the Delta

Academy has selected the coastal city of Surabaya as a research area because of the added value to our research agenda and reciprocity in the relationship with the Technical University of Surabaya (ITS). Surabaya will provide a living lab on topics like, for example: mangrove restoration (taking place near Wonorejo), sustainable port development (taking place in Teluk Lamong) and post-disaster management (for the Lumpur Lapindo case). The Delta Academy has already established a good network for collaboration with ITS, NUFFIC and the Indonesian Netherlands Association and partners Witteveen+Bos and Deltares. Our research group will focus on the mangrove restoration, using to our advantage recent BSc theses of Delta Academy students and the experiences of our partners with mangrove restoration at the central north coast of Java (Demak). This approach is in line with the Dutch international water ambition, which is to test delta solutions together with foreign parties and educate young professionals (http://www.waterinternationaal.nl/).

MANAGED REALIGNMENT OR 'DE-POLDERING'

Beaches and wetlands in front of a sea defence that are eroding eventually disappear because they cannot move landward due to the very presence of the sea wall or dike. This is called coastal squeeze. If space is available in the hinterland a new inland sea defence can replace the one close to the coastline. This 'managed realignment' creates accommodation space for sediments to settle and form tidal flats and salt marshes. It is a way of increasing resilience in an estuarine and coastal zone. This approach is frequently used in the UK, and some other European counties, however, in the SW Delta it

has been applied only a few times on a small scale because of public concern about 'de-poldering' (Stronkhorst & Mulder, 2014). Our research group, students, colleagues of Deltares, IMARES and NIOZ are working on this issue at Perkpolder (Scheldt estuary). The managed realignment at Perkpolder took place in 2015 and transformed 75 ha of farmland into a low-dynamic muddy habitat as nature compensation for the deepening of the shipping lane to Antwerp. Measurements show rapid deposition of mud and a fast colonisation by small macro benthos and wading birds (Boersema et al, 2016b). Salt is by Deltares and has been halted by an ingenious smart drainage system. Similar developments are taking place in: Rammegors, Hedwig polder, Zwin, Waterdunen and Haringvliet and are mainly triggered by nature restoration. These projects may contribute to delta resilience, but there is no concerted research agenda to learn from these cases for future projects.

ECO-FRIENDLY HARD STRUCTURES AND DIKES

Dikes protect polders from flooding. The dikes along the Oosterschelde require special attention since this is a National Park and Natura 2000 area. Here, dike re-enforcements require eco-friendly dike building material. In a project called Building-for-Nature various

companies produced building materials with uneven surface that may attract more flora and small fauna. The new materials are being tested by our team on dikes of the regional water board (waterschap Scheldestromen). Examples of substrates are: concrete blocks with holes; mastic asphalt mixed with lava stones or oyster shells (Van Oijen, 2016). Students are involved in the intensive monitoring. Final results will be published early 2017.

We expect to continue this type of research for two reasons: to come up with nature-based dike re-enforcement methods in the Oosterschelde to meet Natura 2000 regulations; and to enhance biodiversity on other hard substrate surfaces like wind turbine platforms in the North Sea etc.

APPLIED RESEARCH AT DELTA ACADEMY

Over the year a very large number of students have been involved in our work and improved their research skills. On Delta Academy website students can find portfolio of research assignments, including lector assignments, stages, minors, and thesis topics.

The Applied Research Centre covers four topics: Building with Nature, Aquaculture in Delta Areas, Water Technology and Resilient Deltas. We have a highly qualified staff (~20 FTEs) that combines research and teaching. Our research projects are funded by companies, the Centre of Expertise Delta Technology and funds for applied research provided by the Netherlands Organisation for Scientific Research/NWO.

This summer, an independent audit committee reviewed our achievements. There is great appreciation of our scientific impact, how we contribute to the innovation of professional practice in the region, of our contribution to the renewal of the curriculum and our function as a regional research hub. Following the audit we have come to the conclusion that *delta resilience* is an overarching theme in our work. This will be made more explicit in our new strategic research agenda 2017-2020 we are working on right now.

LIVING LAB SW DELTA

ON OUR WAY TO DELTA WORKS 2.0

What can society in the SW delta expect of Building with Nature in the long-term? Two interesting scenarios have been sketched by Wiersma et al (2011). The first scenario shows much wetland and natural estuarine gradients. The second scenario shows a dune massif that connects the islands protecting the delta while valuable freshwater from the rivers are and stored in the Grevelingen and Oosterschelde. Maybe these are ways of enhancing delta resilience. But how will we achieve this, is there a grand design for Delta Works version 2.0?

It appears that step-by-step we are on our way to a Delta Works 2.0! An inventory of on-going Building with Nature related projects in the SW delta shows that already more than 60 real-life cases are in progress or are planned (reference year 2015). Most projects contribute to delta resilience and serve flood safety and nature development at the same time. You can read all about it in the book The New Delta by Bianca de Vlieger and TU Delft professors Joost Schrijnen and Han Meyer (for sale in October of this year).

So there is a wealth of real-life cases that provide opportunities for learning-on-the-job. It's high time to declare the SW delta as living lab for enhancing delta resilience!

PLACE FOR JOINT-FACT-FINDING AND CO-CREATION

A living lab in my view is cooperation between universities, industry, governments and civil society for open innovation (scientific, social and technological) to solve a concrete

practical problem in a given region through co-creation. A living lab is also a showcase for a particular solution and a platform for joint-fact-finding.

Many research opportunities lie ahead. To mention a few: funding possibilities by the Centre of Expertise Delta Technology, Netherlands Organisation for Scientific Research, the national Delta Technology Knowledge and Innovation Agenda 2016-2019 of Top sector Water and the national Water and Climate Knowledge and Innovation Programme (NKWK), the national Science Agenda, the EU Horizon 2020 programme with Societal Challenge #5 on 'nature-based solutions'. In addition, there are several interesting new initiatives that are expanding the research opportunities even further, including Delta Platform, Centre of Expertise on Wind and Sea and the development of a MSc in Delta Development at Delta Academy.

To change these opportunities into new concrete innovation projects Delta Academy will continue and expand the collaboration with companies, governmental organisations, NGOs, consulting firms, other higher education and research institutes. Together we can establish a Living Lab Enhancing

Living Laboratory Enhancing Delta Resilience

Delta Resilience that includes new Building with Nature topics related to, for instance:

A. Smart use of dredged material to create new wetlands in the Scheldt estuary,
B. Coastal developments and sand nourishment along the Dutch delta coast,
C. Building-for-nature on hard substrates in the SW Delta region,
D. Business-innovation-through-nature in ports,
E. Managed realignment in the SW Delta,
F. and last but not least mangrove restoration for a resilient coast of Surabaya

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REFERENCES

- Boersema M, Bouma T, Ysebaert T, van den Brink A, van der Werf J, 2016a. Effectiveness of local sand nourishment at the Oesterdam for safety and ecosystem preservation. Poster presentation at the conference Adaptation Futures, Rotterdam, 10-13 May 2016.
- Boersema M, van der Werf J, Bouma J & Stronkhorst J, 2016b. Morphological developement of the Perkpolder basin. Poster presentation at ECSA, conference on estuarine restoration, Antwerp, 5-9 July 2016.
- Borsje BW, van Wesenbeeck BK, Dekker F, Paalvast P, Bouma TJ, van Katwijk MM, de Vries MB, 2011. How ecological engineering can serve in coastal protection. Ecological Engineering 37 (2), 113-122.
- Bucx T, et al., 2014. Comparative assessment of the vulnerability and resilience of deltas. Delta Alliance report#7. Delta Alliance International, Delft-Wageningen, The Netherlands.
- DeConto RM & Pollard D, 2016. Contribution of Antarctica to past and future sea-level rise. Nature 531, 591–597.
- De Vos P, 2015. Origin of the Dutch Coastal landscape. PhD thesis, University of Utrecht.
- De Vriend HJ, van Koningsveld M, Aarninkhof SGJ, de Vries MB, Baptist MJ, 2015. Sustainable hydraulic engineering through Building with Nature. J of Hydro-environment Research 9:159 - 171.
- Galloway, W. E. (1975) Process framework for describing the morphologic and stratigraphic evolution of deltaic depositional systems. In: Models for Exploration, Houston Geological Society, 87-98.
- Hillen R & Roelse P, 1995. Dynamic preservation of the coastline in the Netherlands. Journal of Coastal Conservation, 1, pp. 17-28.
- IPCC, 2014. Coastal systems and low-lying areas. Eds Wong PP et al. Chapter 5 in Fifth Assessment Report (AR5), pp. 361-409. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Jevrejeva S, Grinsted A & Moore JC, 2014. Upper limit for sea level projections by 2100. Environmental Research Letters, 9(10), 104008.
- Kirwan ML, Temmerman S, Skeehan EE, Guntenspergen GR & Fagherazzi S, 2016. Overestimation of marsh vulnerability to sea level rise. Nature Climate Change 6, 253–260.
- NYC, 2013. A stronger, more resilient New York. City of New York.
- Ministry of Transport & Public Works, 1999. Fourth national policy document on water management in the Netherlands.
- Peduzzi et al. 2014. Sand, rarer than one thinks. UNEP Global Environmental Alert Service (GEAS), March 2014.http://www.unep.org/pdf/UNEP_GEAS_March_2014.pdf
- Post Carbon Institute, 2013. Resilient against what?
- Rosendahl Appelquist L, Halsnæs K, 2015. The Coastal Hazard Wheel system for coastal multi-hazardassessment & management in a changing climate. Journal of Coastal Conservation 19, 2, 157-179.
- Salvador de Paiva J, Walles B, Ysebaert T & Bouma T, 2016. Using pacific oyster Crassostrea gigas for sediment stabilization: how their effectiveness depends on biological and environmental setting. Presentation at ECSA, conference on estuarine restoration, Antwerp, 5-9 July 2016.
- Storm, K, 1999. Slinkend Onland. Rijkswaterstaat, Middelburg, report AX-99.007 [in Dutch]
- Stronkhorst J, van der Spek A, van Maren B, 2013. A quick scan of Building-with-Nature

solutions to mitigate coastal erosion in Colombia. Commissioned by Ministry of the Environment, Colombia, Report 1207028, Deltares, Delft, The Netherlands
- Stronkhorst J, 2013. Economic rationale of sand nourishments along the North Sea coast of the island of Walcheren, Report 1207778, Deltares, Delft.
- Stronkhorst J & Mulder J, 2014. Considerations on managed realignment in the Netherlands, In: Esteves, LS (Ed). Managed realignment: A viable long-term coastal management strategy? Springer Briefs in Environmental Science. New York: Springer.
- Stronkhorst J, de Ronde J, Coastline management and flood safety - part
- Stronkhorst J, Giardino A, Huisman B, Santos FD, in prep. Long term sand nourishment strategies to mitigate shoreline retreat at the low-lying coasts of Holland (The Netherlands) and Aveiro (Portugal).
- Temmerman S, Meire P, Bouma TJ, Herman PMJ, Ysebaert T & de Vriend HJ, 2013. Ecosystem-based coastal defence in the face of global change. Nature 504 (7478), 79-83.
- UNISDR, 2015. Sendai Framework for Disaster Risk Reduction 2015-2030.
- Van den Brink, A, 2016. Biodiversity on Artificial Oyster Reefs. Poster presentation at ECSA, conference on estuarine restoration, Antwerp, 5-9 July 2016.
- Van der Werf J, Boersema M, Nolte A, Schrijvershof R, Stronkhorst J, de Vet L, Walles B & YsebaertT, 2016. Variantenstudie Roggenplaat suppletie. Centre of Expertise Delta Technology (Deltares, Delta Academy, Imares, NIOZ), commissioned by Rijkswaterstaat.
- Van Oijen T, Salvador de Paiva J, van Heuvel T, Boersema M, Bouma T, 2016. Building for Nature: Adjusting the surface structure of concrete revetments to stimulate biodiversity in the intertidal zone. Poster presentation at the conference Littoral Biarritz, 25-29 October 2016.
- Van Slobbe E, de Vriend HJ, Aarninkhof S, Lulofs K, de Vries M, Dircke P, 2013. Building with Nature: in search of resilient storm surge protection strategies. Nat Hazards 65:947–966.
- Waterman, RE, 2011. Integrated Coastal Policy via Building with Nature. ISBN/EAN 978-90-805222-3-7.
- Wiersma A, Tangelde M, Brouwer J, Abma, R, 2011. Sustainable scenarios for the Southwest Delta based on Building with Nature strategies. Deltares, Utrecht report 1202061-000.
- WWF, 2008. High tide for Low Netherlands [in Dutch].

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