Deltares

Enabling Delta Life

Sustainable water management under climate change

how to develop strategies for an uncertain future

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how to develop strategies for an uncertain future

“The best way to predict the future is to design it” – Buckminster Fuller

All over the planet, the summer of 2010 has shown us the impacts of both ends of climate variability: floods, landslides and mudflows caused by extreme rainfall, as well as forest fires due to extremely dry and hot conditions. Whether these extremes are an indication of a changing climate or just part of climate variability is hard to say. It is clear, however, that the way we manage our land and water systems strongly determines whether or not climate extremes lead to disasters.

Uncertainty does not excuse us from taking action. Methods are needed to define strategies for sustainable water management in an uncertain future. Deltares helps to develop these methods, for coastal areas, deltas and river basins. In this publication, issued on the occasion of the conference *Deltas in Times of Climate Change, Rotterdam 2010*, we introduce several of these methods.

The succession of three methods in this publication is a stepwise approach to the design of an adaptive strategy. The first step is the determination of adaptation tipping points. The second step is exploring adaptation pathways of alternative strategies once a switch to a new strategy is needed. The third step is the design of a chosen, new strategy.

We hope you enjoy this issue and we look forward to assisting you in managing your water systems in a world full of uncertainties.

Prof. dr. Huib de Vriend
Director Science Deltares

A world of uncertainties

Sustainable water management involves dealing with uncertainties, both now and in the future. Uncertainties are a fact of life: the further ahead, the more difficult to address. Uncertainties for future water management manifest themselves in several ways.

Natural variability. Changes in time are not necessarily due to climate change or other external pressures, but may reflect irregular natural variability. It may be hard to distinguish the impact of climate change from natural variability in projected extremes, for example on precipitation and river runoff. Besides, the natural and social processes interfere and result in additional uncertainties; net sea level rise in densely populated deltas, for instance, is partly due to land subsidence caused by over-exploitation of ground water reserves.

Socio-economic uncertainties. In future projections we have to choose a time horizon and a scenario of socio-economic developments. Generally, a number of scenarios are chosen to account for various possible future developments that might unfold. Some of the uncertainties may be attributed to human values and risk perceptions, to society's learning capability, or to complex decision making processes with many different stakeholders.

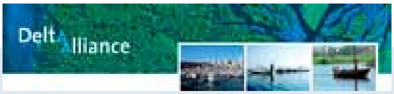
Model uncertainties. Uncertainties often arise from a lack of understanding of the natural system, leading to incomplete or over-simplified process formulations in climate models and in, for instance, hydrological models to calculate river runoff. Furthermore, input data and model parameters can be uncertain or incomplete.

In the Delta Alliance several countries share their knowledge on the contribution of these uncertainties to sustainable water management in their river deltas.

Adaptation to subsidence in Indonesia

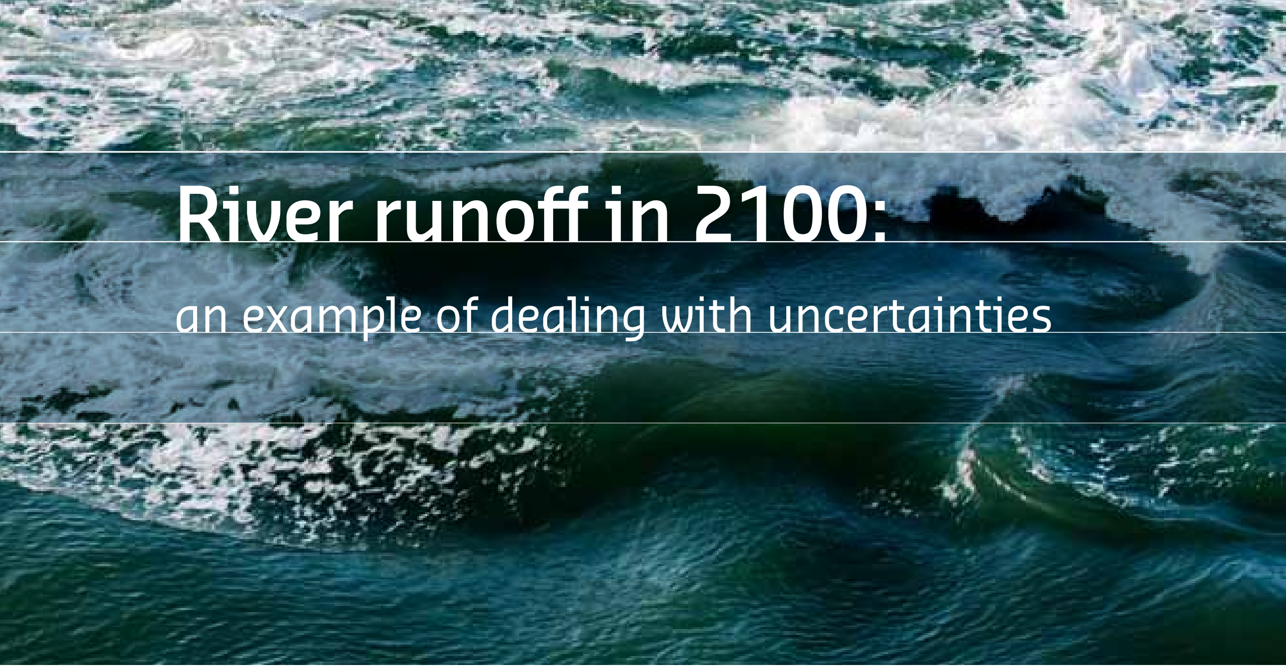
In Jakarta land subsides at a rate of 1 to 15 cm/year, with local maxima up to 25 cm/year[1]. This subsidence damages buildings and infrastructure and increases flood risk. Therefore, adaptation measures to reduce the impact of coastal subsidence and sea level rise should be developed as soon as possible.

Jakarta is an example where experience with a safe and sustainable development of the urbanized Dutch delta can be translated to other areas[9]. Not all Dutch best practices are applicable, but a lot of experience can be shared on topics such as improving resilience of deltas, upgrading infrastructure, coastal erosion management, disaster preparation, and climate adaptation plans.



The Delta Alliance

Deltares is a partner in the Delta Alliance, an emerging international network devoted to supporting the sharing, development and implementation of responses to the most critical problems facing river delta regions today. The mission of the Delta Alliance is to increase the efficiency and pace of responses to critical problems commonly experienced in river delta regions worldwide. The network supports integration of knowledge across disciplines, sectors, and regions, by providing information, supporting integrating activities, and creating a network of dedicated individuals and organizations. At present, the Delta Alliance is being formed with partners in USA (California), Indonesia, Vietnam, and The Netherlands (www.delta-alliance.org).



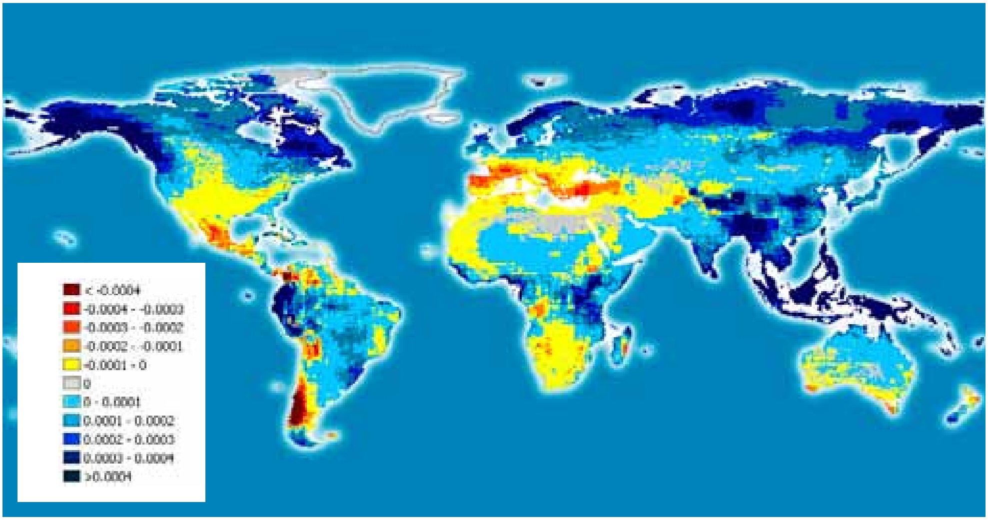
River runoff in 2100:

an example of dealing with uncertainties

Climate change will affect river runoff all over the planet. A thorough assessment has been made of these global hydrological effects. Change in river runoff in 2100 has been studied for 19 large catchments, covering a variety of climatic zones, latitudes and continents[18].

Daily river discharge has been calculated for the period 2081-2100 by using meteorological data from an ensemble of twelve General Circulation Models. Two emission scenarios in the upper range of possible CO_2-emissions have been taken from the IPCC. River discharge has been calculated with a globally distributed hydrological model. This model calculates river runoff for each individual cell by solving the daily water balance and thereafter routes this runoff along a river network. Thus, an ensemble of future runoff time series has been obtained. River discharge for the period 2081-2100 has been compared to river discharge for the period 1971-1990.

The change in river discharge has been calculated for: annual mean discharge, inter-annual discharge variability, discharge distribution over the year (river regime), and the spatial patterns of river regime. The direction of change is illustrated by showing the results on world maps and indicating in which regions the likelihood of hydrological changes is largest (see the map below).



Projected global change of annual mean discharge by 2100 in m^3 per m^2 per day, calculated from an ensemble of 12 circulation models for one of the emission scenarios.

The study revealed:

- a consistent decrease in runoff for southern Europe, southern Australia, the south and north of Africa, and southwestern South-America. Significant discharge decreases are projected for most African rivers, for the Murray and for the Danube;
- runoff increases and discharge peaks earlier in the year for sub-Arctic and Arctic regions;
- a slight discharge increase for monsoon influenced rivers;
- an increase of continental outflow to oceans for all oceans except for the Mediterranean Sea.

The spread in the ensemble of circulation models is larger than the spread between the two selected emission scenarios, indicating that the choice of emission scenario is of little importance given the uncertainty of the models. Furthermore, the spread between the circulation models shows that a large ensemble of models is needed to assess reliably the consequences of climate change on river regimes.

Adaptation tipping points for water management strategies

How much climate change can we cope with before we need to shift to a new water management strategy? Policy makers are looking for an answer to this question. The adaptation tipping points approach[16] helps them to determine at which point in time new strategies are needed.

We define adaptation tipping points as points where the magnitude of change due to climate change or sea level rise is such that the current strategy will no longer be able to meet the objectives. This gives information on whether or when a water management strategy may fail and alternative strategies are needed. The driver for taking action is not climate change, but being unable to meet objectives. Thus climate change is only one of the issues. Socio-economic developments, for instance, may also result in (earlier) adaptation tipping points.

The results of the adaptation tipping points approach can be easily adapted to new insights in climate change or socio-economic developments.

Sand nourishments at the Dutch coast.

Dealing with uncertainties: top-down or bottom-up

Usually climate change scenarios are taken as a starting point to assess the impact on functions and define strategies to adapt to the consequences of climate change. In subsequent steps a projection of climate change and sea level rise is made (**pressure**), the effect of these changes on water quantity and quality of a system is quantified (**state**), and the way the latter changes affect the objectives for functions such as safety, nature and agriculture is estimated (**impact**). Based on these impacts one decides whether policy objectives are (still) met or an alternative strategy is needed (**response**).

The adaptation tipping point approach starts where the classical top-down approach ends, and follows steps in reverse order: determine the objectives for the functions at stake (**impact**), quantify the relevant boundary conditions under which these objectives can still be met (**state**), quantify the corresponding climate characteristics and sea level (**pressure**) and compare these with climate change projections to estimate when these tipping points may be reached.

The classical top-down approach addresses the question: "What if the climate changes or sea level rises to a particular scenario?". The adaptation tipping point approach addresses the question: "How much climate change can we cope with?".

The adaptation tipping point approach has been tested for a number of functions:

- Flood protection of the sandy Dutch coast will most likely not reach a tipping point before 2100: there is plenty of sand available from the North Sea to continue the strategy of sand nourishments, even in the most extreme sea level rise scenario. Therefore, the current coastal flood defense strategy is robust at least until 2100.
- The functioning of the Maeslant storm surge barrier to protect Rotterdam harbour and its hinterland, however, may have a tipping point. Either in the second half of this century or after 2100, depending on the chosen sea level rise scenario: the maximum sea level rise for which the barrier has been designed, is an additional 50 cm.
- Fresh water supply in the western part of The Netherlands has a tipping point when surface water salinity, which increases due to sea level rise and low river discharge, exceeds a critical level for irrigation and potable water. This is estimated to be the case at 35 cm sea level rise relative to 1990, which may be the case either around 2030 at its earliest (worst case), or after 2100.

But not all adaptation tipping points are far into the future. Research has shown that the objective of preserving the present variety of plants and animals species in The Netherlands can no longer be met at this very moment.

In The Netherlands, the so-called Delta programme has been initiated in which strategies are explored for future flood risk management and fresh water supply. Within this programme the adaptation tipping points approach has been introduced, similar to the Thames Estuary approach.

Adaptation tipping points for the Thames Estuary

The adaptation tipping point approach is being used in the United Kingdom to find the best strategy for flood protection of the Thames Estuary[13]. It helps to address uncertainty over future climate change by incorporating flexibility, increasing resilience to tolerate a wider range of climate conditions, and identifying low-regret and win-win measures.

Learning and monitoring is essential to the adaptation tipping points approach. When monitoring reveals that water level rises more quickly than originally envisaged, the implementation of a new strategy can be brought forward in time. Likewise, under a slower water level rise decisions to raise upriver defenses can be put back in time.

The strategies are designed to implement small, incremental changes which are common to all the strategies first, leaving the major irreversible investment decisions as far as possible in the future.

The Thames Barrier was designed to protect London from a 1 in 1000 year combined tidal/fluvial event in the year 2030. The year 2030 is an adaptation tipping point for flood risk management of the Thames Estuary.

Adaptation tipping points for The Netherlands

The Delta programme focuses on climate-proofing the areas along the main water systems in The Netherlands. One of these areas is the ‘Rijnmond and Drechtsteden’ area that includes the port and city of Rotterdam and adjacent cities such as Dordrecht. In this area the impact of climate change on flood risk may be high because of the combined effect of sea level rise, land subsidence and increasing peak river discharges[2,8]. Besides, the economic value of the area is high and still rising. Studies are being carried out to establish the urgency of climate change adaptation measures and the options for future adaptation strategies.

Fresh water supply in the southwestern part of The Netherlands is being jeopardized by the effects of climate change and policy measures aimed at restoring estuarine dynamics. Furthermore, the demand for fresh water is still rising. A qualitative water balance analysis shows that most of the fresh water supply is used to combat salt intrusion whereas only a minor part is used for irrigation and potable water[4]. For future water management strategies a choice can be made between the continuation of the present strategy to combat salinisation or to switch to a strategy of adapting to salinisation.

Salinisation also jeopardizes fresh groundwater reserves in this area. Due to sea level rise and land subsidence the hydraulic head in the groundwater system will increase, leading to increased seepage of salt water and a doubling of the salt load in some parts of this area by 2100[10]. Consequently, agriculture depends more and more on shallow rainwater lenses. Advanced numerical modeling is being used to assess effective measures to make the water supply from these lenses climate proof[3,11].

Climate-proofing urban areas

Water underlies the delta city, both metaphorically and literally. To create a more sustainable, more climate-robust, healthy and pleasant living and working environment, water management should be improved in concert with soil, subsoil and land use[12].

In a sustainable strategy cities are less dependent on external resources and waste production is reduced. For this purpose we need to reduce the inputs of water, food and energy, and the imports of sand, ground and building material. We also need to recycle water. Furthermore, adaptations are required focusing on a more multifunctional use of water, providing space for water, and benefiting water as a source of energy, for food production, and for supporting the soil. Water can also contribute to a more healthy and pleasant urban living environment by supporting the quality of the urban landscape.

An adaptive, water-wise design, operation and management of cities reduces their vulnerability to floods, droughts, extreme heat and land subsidence. We call this the Water City.[12]

Exploring pathways for sustainable water management

Once an adaptation tipping point is in sight, a switch to a new strategy is needed. Each new strategy has its own future tipping point that, again, requires a switch to be made. In the long run water management is thus a succession of strategies. Several successions are possible. How can we find the succession of strategies that provides the sustainable water management that we need?

The successions of strategies into the future are adaptation pathways in a changing environment. These pathways can be explored from many possible transient scenarios of climate and socio-economic developments[5,14,15]. This approach shows the range of options from which policy makers can choose. The adaptation pathways approach thus supports decision making for sustainable water management in a changing environment.

Sustainable water management is about making the best choices at the right moments for a long period of time. These choices will be influenced by events, such as floods and droughts, and changing societal perspectives on preferred strategies, as well as by new insights and knowledge in the course of time. Adaptation thus follows pathways of strategies that are influenced by current and future climate, socio-economic developments and societal perspectives. A strategy is sustainable when it can cope with various possible futures while being flexible enough to be adapted in case the future unfolds differently than anticipated.

A new method explores the range of possible adaptation pathways by simulating the dynamics of these pathways in response to the variability and change of climate and socio-economic factors for the next 100 years. A model is used that represents realistic cause-effect relations between climate change and socio-economic pressures and their impacts on the water system and society. In each run of the model, a year-by-year set of calculations is made in which a climate realization with, for instance, corresponding precipitation results in a peak river discharge and associated impacts. Management measures may then be taken accordingly, either defined a-priori or derived from policy makers in a workshop setting through a multi-actor, interactive game[6].

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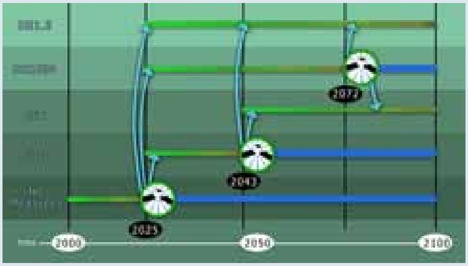
The pathways give information on the effectiveness and timing of measures. They also show dead-ends or the options left when a specific decision is made. Policy makers can benefit from this method by using it to develop roadmaps for sustainable water management. The method increases their knowledge of the system; water managers and other stakeholders can experience the effects of water and social events and how this influences the decision making. The method includes both natural and social uncertainties, and thus allows for finding both physically and socially robust pathways. The model that is used allows for a rapid assessment of many transient scenarios to explore many futures and responses to these futures. It appears, for instance, that climate variability may be at least as important for decision making as climate change, especially for the mid to long term.

Using pathways in river flood protection

In the figure below a selection of the results of a hypothetical case study is presented, which assesses the impact of different decisions on flood risk management, and of different climate change scenarios on river flood protection strategies[16]. In this case, the cause-effect relationships relate the consequences of climate change, such as a change in precipitation, to subsequent changes in river discharge, water level and flood risk. Story lines may include strategies such as raising dikes or making ‘room for the river’. This example focuses on the indicator flood risk; the critical value at which a tipping point is reached, is an a-priori defined amount of flood damage. A story line is completed when the river has been managed for 100 years.

The figure shows that a strategy without measures leads to a tipping point 15 years from now; at that time flood damage will have increased up to the critical value and a new strategy has to be chosen. The strategy of raising the dikes to cope with 1.5 times the second highest discharge in the past (DH1.5), fulfils the objectives throughout the 100-year period; for this strategy no tipping point is reached and a switch to an alternative strategy is not needed. Raising the dikes to a 1:1000 per year discharge (DH1000) results in a tipping point about 75 years ahead. After that time the alternative strategy ‘room for the river’ (RvR) reduces flood risk sufficiently until 2100. A choice for damage mitigation by building floating houses (Float) ´buys´ some 20 years, but a switch to, for example, the ‘room for the river’ strategy is necessary to reach 2100.

When socio-economic developments and social events are also taken into account, the story lines may include, for instance, a situation where spatial claims from other functions result in too little space left for ‘room for the river’ measures. A change in perspective towards living with water rather than fighting it, on the other hand, may lead to a preference for the ‘room for the river’ story line.



A selection of adaptation pathways for flood risk management.

Green Adaptation: strategies based on ecosystem services

Ecosystems offer services that we use when we, for instance, grow crops or store fresh water. Various new adaptation concepts have been developed in the past decade in which ecosystem services are at the base of sustainable climate adaptation strategies in view of flood protection, fresh water supply, water quality and food production. These concepts are called Green Adaptation.

Examples are the application of eco-engineering within the programmes Room for the River and Building with Nature. These concepts focus on benefiting ecosystem services and natural processes in flood protection measures, infrastructure design, and coastal nourishments. An example of eco-engineering is a project in which strong vegetation is planted in front of a dike to break incoming waves. This allows the dike to be one meter lower than a dike without vegetation, but gives the same flood protection level and reduces construction costs while increasing the natural value of the area. Several Green Adaptation concepts are being developed within the Building with Nature Programme, carried out by a consortium of Dutch commercial partners and research institutes, including Deltares (www.ecoshape.nl).

Dike with vegetation in front.

Delta governance:

designing adaptive strategies

The adaptation tipping points approach helps us to determine at which point new strategies are needed. The adaptation pathways approach helps us to explore the succession of strategies that provides the sustainable water management that we need. These strategies need to be designed. Deltares develops an approach to delta design that integrates two concepts: the concept of physical planning layers that is being used in spatial planning, and the concept of a four layer approach of governance[7,17].

In this approach we combine our knowledge of the subsurface and the water system, its land use and possible technical solutions, with our knowledge of socio-economic developments and governance.

The concept of physical planning layers is based on three layers: the base layer of water and soil, the network layer with the infrastructure, and the occupation layer with the zoning of land functions. The characteristics of these layers both enable and constrain land use in a hierarchical way: soil characteristics of the base layer, for instance, largely determine the type of agriculture in the occupation layer. These characteristics, and thus the interaction between these layers, can be influenced to favour specific land use functions. An extended network of canals, sluices and flood defenses in the network layer, for instance, enables a densely populated, prosperous society in the occupation layer in a delta that is abundant in water.

In our approach we integrate the characteristics of these layers with the roles and behaviour of the actors involved according to a four layer approach of governance: a top level of societal normative values, customs and culture (L4); and lower levels of formal institutional environment (bureaucracy of government, legislation, polity, judiciary) (L3); arrangements, agreements and contracts (L2); and individual actors making decisions on a day-to-day basis (L1). The higher levels influence the behaviour of the actors at the lower levels: private land ownership, for instance, is legitimized through property rights at the formal institutional level (L3) and often embedded in societal values of ownership at the top level (L4). This integration supports unraveling the problem and planning a governance strategy connected to the spatial problem involved.

	L1 measures and current land use	L2 arrangements, agreements and contracts	L3 formal institutional environment	L4 culture, customs and values
occupation layer	switch to salt tolerant crops			
network layer	↑			
base layer	adapt to higher salt concentration	←	switch strategy: no longer combat salt intrusion	

In the example of fresh water supply in the southwestern part of the Netherlands (p. 10) salt intrusion through surface and ground water increases due to sea level rise and lower river discharge. It may be decided to switch from a strategy of combating salt intrusion to a strategy of adapting land use to a higher salinity level in surface and ground water.

The decision to no longer combat salinisation is legitimized in governance level L3. As a result, salt concentration in the base layer (ground water, ditches) increases. This may induce farmers (L1) to start growing salt tolerant crops. Thus, an interaction between governance levels L3 and L1 results in an impact of changing characteristics of the base layer on agriculture in the occupation layer.

The interaction between governance and spatial planning may, however, turn out differently. Farmers may decide to keep on growing their fresh water crops, if switching to salt tolerant crops appears economically less attractive. Then farmers decide to buy fresh water; the increasing demand for fresh water will stimulate alternative fresh water supply through arrangements (contracts) being made at governance level L2. As a result, the land use in the occupation layer is disconnected from the characteristics of the base layer. Moreover, the price level of the fresh water is adjusting spontaneously in level L2 independent of the arrangements in level L3. This mechanism is an automatic driver for innovations in watersavings. So the L3 strategy of naturally moving along with the sea level rise leads to the paradoxical consequence of technologically more intensive agriculture.

Sustainable water management is about designing adaptive strategies for an uncertain future. With our methods to explore when new strategies are needed, what strategies we can choose from and how we can design them, we take a step ahead in our mission of 'Enabling Delta Life'.

	L1 measures and current land use	L2 arrangements, agreements and contracts	L3 formal institutional environment	L4 culture, customs and values
occupation layer	continue fresh water agriculture			
network layer	disconnection	alternative fresh water supply or water saving (innovation)		
base layer	neglect higher salt concentration		switch strategy: no longer combat salt intrusion	

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This publication is the first in a number of special issues that will be published by Deltares in the future. These special issues are a continuation of the books on the State and Future of the Delta (Staat en Toekomst van de Delta) that were published in 2008 and 2009. From now on we will update you on research results related to specific societal issues on a more regular basis than just one book per year. We will publish special issues on topics that from our point of view deserve extra attention.

With the State and Future of the Delta Deltares aims to make knowledge on the state, the trends and the developments in delta areas accessible to a wide audience. Challenges and opportunities are also presented. As an independent knowledge institute we try to give overviews based on the facts and established knowledge, to support decision makers. We strive to serve a wide audience: politicians, policy makers, interest groups, private companies, other researchers and all who are interested in the physical environment in which we live.

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