

Deltares

Enabling Delta Life



Flood Risk Management





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Introduction:

What is Flood Risk Management?

1

Over the last few decades, the world has experienced an increasing number of devastating floods. Tragic events, such as the Asian Tsunami (2004) and Hurricane Katrina (2005), showed hundreds of thousands of people losing their lives or becoming homeless in a matter of hours. They also illustrate that flood risk is a worldwide phenomenon. Recent flood disasters in Europe, such as the Elbe flood of 2002 and the UK floods in 2007, were considered national crises, partly because of the huge amount of damage caused, at 15 and 6.5 billion Euro, respectively.

This trend in losses due to natural disasters is increasing worldwide. A significant proportion of these losses is caused by floods. For instance, floods and flash floods accounted for almost a quarter of all natural hazard events in 2004. Climate change may cause a further increase in the flood hazard probability and magnitude, whilst it is certain that demographic and economic development is causing a continuous increase in the vulnerability of many floodplain and coastal areas. Even a modest 2% economic growth in these flood-prone areas causes the economic damage of a given flood to double every 30-35 years.

Past disasters have triggered many governments to embark on disaster management, such as flood control, early warning systems and evacuation planning, with the ultimate aim of protecting their inhabitants from the vagaries of nature. International initiatives have also taken shape, such as the adoption of the EU Directive on Flood Risk Assessment and Management on 23 October 2007. A major worldwide contribution to disaster reduction is the Hyogo Framework for Action 2005-2015, which was adopted at the World Conference on Disaster Reduction in January 2005 in Kobe, Hyogo, Japan. The main message of this Framework is that disaster management should broaden its scope through the integration of disaster risk considerations into sustainable

development policies, planning and programmes at all levels, with special emphasis on disaster prevention, mitigation, preparedness and vulnerability reduction.

A widely used frame for flood risk management is the disaster management cycle (see figure below). This figure distinguishes three distinct phases in flood risk management: prevention, flood event management and post-flood measures. It clearly shows that flood risk management encompasses a wide range of activities and measures, ranging from the traditional flood defence measures, such as dikes and dams, to spatial planning, early warning, evacuation and reconstruction. This reflects the increasing awareness that solutions should be sought in a combination of measures to protect against flooding and to reduce vulnerability. At the same time this poses the question as to how the optimal combination of measures can be found. Costs and benefits need to be weighed while at the same time intangibles such as socio-cultural preferences, environmental consequences and practical applicability have to be accounted for too. Flood managers and policy makers are therefore in dire need of knowledge on each of these aspects. As a newly formed research institute, Deltares is a natural partner that can contribute the required knowledge. Each of the constituent former organisations was specialised in only a part of the flood risk knowledge domain. Together they now embody hundreds of years of experience, which makes Deltares unique in the field of flood risk management.

Flood Event Management

- early warning
- evacuation
- rescue
- first aid

Prevention

- spatial planning
- flood control
- preparedness
- insurances
- evacuation plans



Post-flood measures

- relief
- cleaning
- financial aid
- reconstruction



Repairing a dike breach in Bangladesh

Why this publication?

One of the key knowledge fields of Deltares is flood risk management. Since its formation, Deltares has incorporated experts, scientists and advisors in many of the knowledge domains for flood risk management. Deltares is a key player in this field, conducting applied research, developing knowledge and models and providing tailor-made advice. We assess flood risks by making integrated risk analyses covering the probability and impact of floods, analysing historical records of high water levels and floods. Computer simulations show the possible impacts of floods. We map out the vulnerability of an area in the event of a flood, and study the effect of climate change and spatial planning on the flood risk. We test the strength of flood protection systems, such as dikes and dams. In addition we design systems for early warning and evacuation planning. This brochure provides an overview of these activities and expertise, illustrated with past and present projects executed worldwide.



Flood risk management philosophy: how safe is safe enough?

2

People want to be safe, but how safe is safe enough? Should we invest in higher dikes, storm surge barriers and seawalls and if so, how much money is society willing to spend? Or is it better to make our societies more resilient and invest in flood proofing of buildings, improved early warning systems and so forth?

With the current state of the art in science, we are able to provide much more information to the decision maker than, say, a hundred years ago. Knowledge from hydrology and hydraulics enables us to better assess the probability of high waters and the flooding extent, depth and duration. Geotechnical knowledge provides information on the strength of the flood protection system and the probability of failure. Geographic information systems combined with economic and casualty prediction models can estimate the potential damage. This knowledge helps us to answer questions such as: How big an area can be flooded, at which depth and how fast? How many victims could it cost and how much damage must be reckoned with? What will the long-term economic and social costs be? These and other questions illustrate the multi-dimensional character of the concept of risk.

Risk assessment in three steps

Deltares applies a three-step approach in assessing flood risk:

1. The first step is the analysis of flooding probability (the flood hazard) and consists of a calculation of the physical stress on the flood defence system and the strength of this system to withstand the stress.
2. The second step is a calculation of the risk as a product of the probability of flood events and their consequences.
3. The third step is providing information for the evaluation of the flood risk: what level of risk is acceptable and how much effort and money are we willing to spend to reduce the risk?

STEP 1 | ASSESSMENT OF FLOODING PROBABILITY

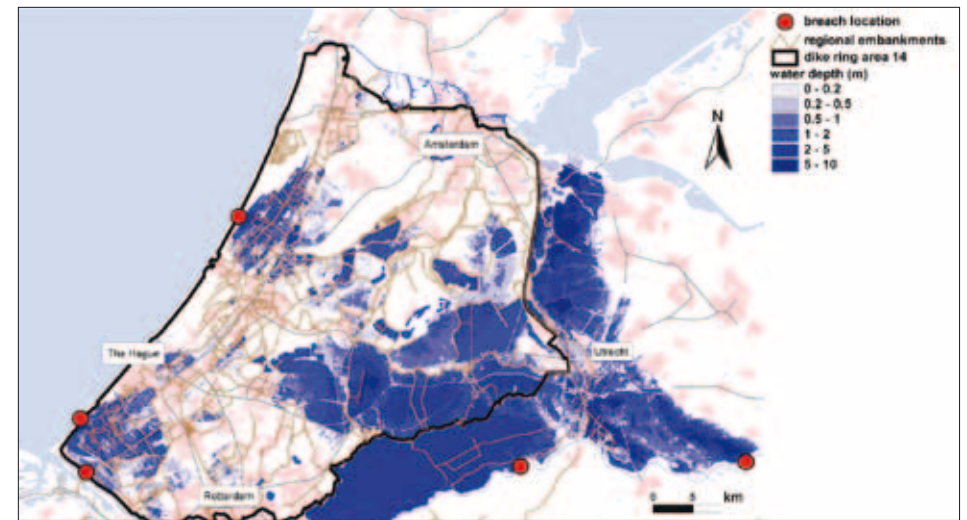
From exceedance frequency to flooding probability

In The Netherlands the design of a dike is based on a defined exceeding frequency. This is the probability that a dike will be unable to withstand water levels and waves. For example, an exceeding frequency of one in 1,000 per year means that the water defence must be able to withstand all combinations of water levels and waves that have an occurrence probability of one in 1,000 per year. Recent developments in flood risk management are moving towards a more complete flood risk approach. This goes beyond the traditional approach of building dikes that are high enough to withstand a certain predefined high water level. It includes methods to determine the probability of flooding, incorporating all of the various failure mechanisms, such as overtopping, piping and instability of the inner slope. Chapter 4 is entirely devoted to the reliability of flood defences. Also the likeliness of extreme water levels, including joint probabilities of events that lead to critical situations, such as high river discharge with a storm surge in a delta, are part of this approach. In Chapter 3 our prediction capabilities regarding both riverine and coastal extreme events are presented.

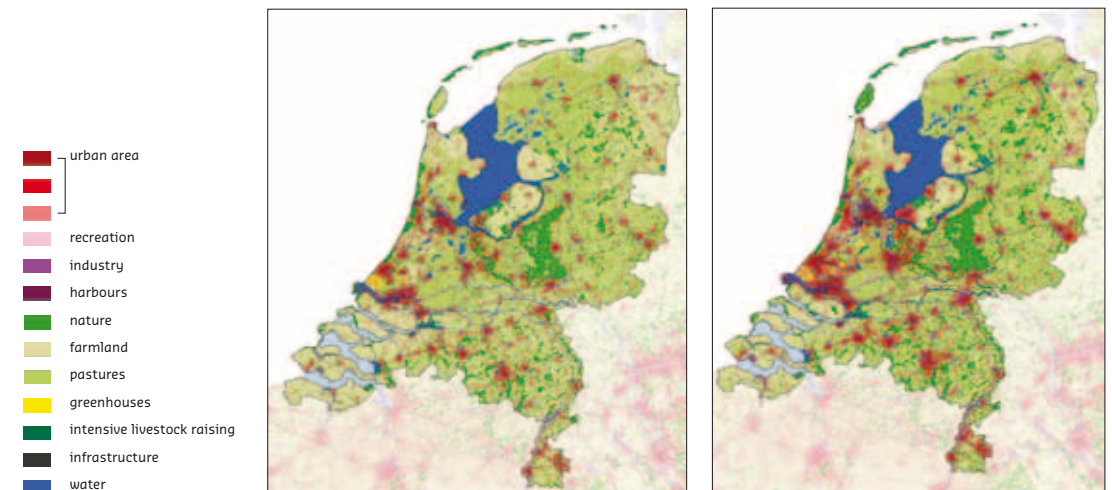
STEP 2 | FLOOD EVENTS AND THEIR CONSEQUENCES

Flood modelling is one of the key expertises of Deltares. We have developed and use a range of flood modelling software packages, such as *SOBEK 1D/2D* and *Delft3D*. With these models we can predict not only the maximum area that is flooded during an extreme event, such as a breach in a levee, but also the dynamics of inundation. Flood damages and losses also depend on hydraulic variables such as water depth, current velocities and the speed at which the water level rises. Our software is capable of dynamically simulating a flood event over time and space.

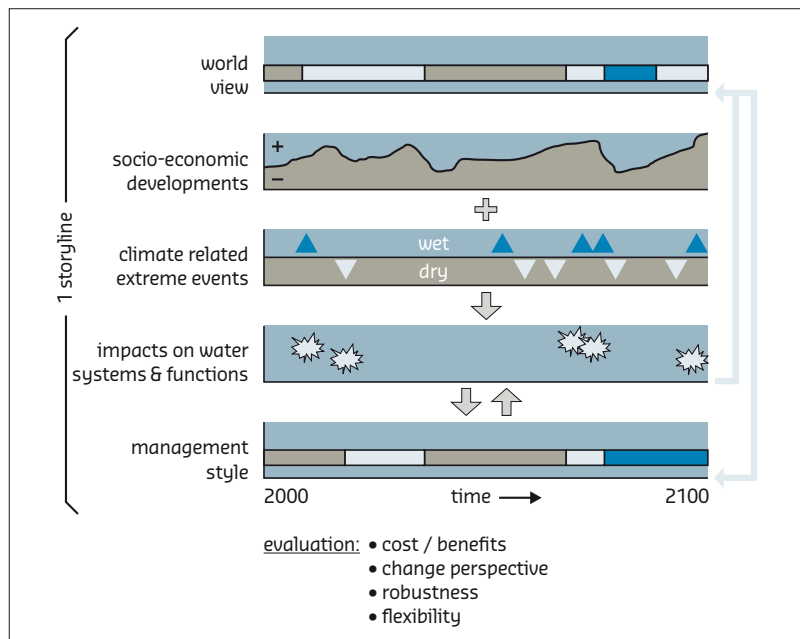
Deltares not only considers probabilities of a failure and subsequent flooding, but also the developments in land use in flood prone areas. Scenario building has become a true applied research field on its own, especially in view of climate change research. Deltares has been and is involved in several studies, both for the Dutch government and in EU RTD framework projects, such as FLOODsite and SCENES.



Simulation of a large flood scenario between Rotterdam and Amsterdam with SOBEK 1D/2D



A land use change scenario: increased urbanisation in 2040 (maps prepared by the Dutch Environmental Assessment Agency PBL)



Example of a storyline

Scenarios are used to determine the effect of autonomous developments on flood risks. Flood risks change when flood hazards change, when flood patterns change or when vulnerability changes. Scenarios must therefore describe developments which result in such changes. Hazards may change due to, for example, climate change, changes in the upper catchment which affect runoff, and land subsidence. Also flood patterns and vulnerability to flooding may be affected by land use change, economic growth and demographic changes.

The challenge in scenario studies is not merely in defining the scenarios, but in how to analyse them in relation to strategies. We use for instance storylines as a method to explore the future. Storylines are narratives in which various future developments, including the water system, societal responses and external developments, are interrelated in a consistent way and illustrate typical transition cases. Deltares collaborates with various other research organisations and universities in The Netherlands to develop this method in which the interrelations between the physical and social systems are described.

STEP 3 | EVALUATION OF RISKS

Risks cannot be evaluated simply by a model or method. A considerable amount of subjectivity is involved, for instance in the way people perceive risk (see below). However other aspects also play a role here, such as the impact that flood risk measures have on peoples' lives, the economy and the environment. Therefore, measures should be evaluated for all their implications for society and the environment, including their costs. This suits the overall goal of flood risk management planning which is contributing to sustainable development by balancing risk reduction with other societal goals. Deltares performs casualty risk and cost benefit analyses (CBAs) and develops tools to support decision making (DSSs). Examples of these analyses and DSSs designed by Deltares are described in Chapter 7.

Research into risk perception

A well known way of expressing risk is the following formula:

$$\text{risk} = \text{probability} \times \text{consequences}$$

Hence, a large risk may arise because there is a high probability of a flood with only modest consequences. Alternatively a large risk may arise because there is a very small probability of a flood – such as 1/1,000 per year – but with high consequences, for instance if central London were to be flooded by the North Sea. However although this seems very logical and rational, this is not the same as how people perceive risk. It is generally acknowledged that there is a discrepancy between how risks are formally quantified and how people perceive risk and whether they accept risk. Firstly, people distinguish between risks from natural hazards and hazards caused by human activities. Natural hazards are accepted more easily. Secondly, in the common perception, the consequences of events are not only easier to grasp, but are also more important than their probability. The consequences are therefore given more weight in the judgement of risk. This means that people judge one hundred fatalities with a 1/100 per year probability as being worse than 1 fatality every year. Furthermore, in their actual behaviour, people take into account the personal advantages of running a certain risk. This also explains why people accept comparatively high risks in traffic, and in smoking cigarettes, etc. In the context of flood risk management, personal gains are seldom obvious. Deltares has collaborated with other research institutes to gain more insight into the risk perception of people living in flood-prone areas (see Box on Flood Risk Perception and Communication below).



Flood Risk Perception and Communication (PROmO)

A four-year research project was executed by a consortium of universities, consultants and research institutes led by Deltares, with the objective to study the key factors that determined the perception of flood risks among citizens. Surveys were held among more than 3000 households and 200 business enterprises regarding risk perception and communication. A typical observation was that only a minority of respondents regards flooding as a likely event. The public has a great trust in the current flood defence system and in the authorities' ability to maintain this system. However when it comes to assigning regionally differentiated standards for flood protection, a different picture emerged. Round table

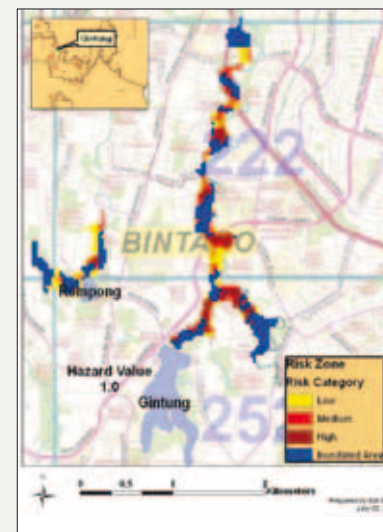


discussions held in various parts of the country showed a rather wide array of perceptions on differentiation: there were strong adversaries of differentiation in some dike rings, whereas in other dike rings differentiation was viewed as a logical consequence of differences in the values to be protected. In some dike rings regional sentiments played a major role in the perception of the differences in standards. The discussions about these dike rings showed considerable mistrust of the national government. The perception is that the national government wants to differentiate and that the region has nothing to gain in such a process. Although the study focused on The Netherlands, both the results and the methodology are of wider relevance. Understanding the factors influencing risk perception is very useful for decisions on adopting or implementing measures – such as safety standards, relocation issues and the introduction of insurance – and communication strategies for flood risk management.

Reservoir safety inspection, Jakarta: an example of a quick response in integrated flood risk management

In the early morning of Friday 27 March 2009, a large 'bang' signalled the start of a disaster at Situ Gintung, a small reservoir along the Pesanggrahan river just South of Jakarta, Indonesia. The saturated dike of the reservoir gave way and within 10 minutes the bank-full reservoir released about a million m³ of water into the downstream urban area. The resulting flash flood (or 'little-tsunami') came as a complete surprise. About 100 - 200 people could not escape. Especially in the first kilometre downstream of the reservoir the flash flood caused major damage. A wave as high as 5 meters rushed down destroying everything in its path. After reaching the Pesanggrahan most of the force was absorbed, but still major flooding occurred up to 5 km downstream of Situ Gintung, causing severe damage to the semi-permanent housing along the river.

Immediately after the disaster the Indonesian Government started preparations to avoid similar disasters. A specialist team from Deltares with the Indonesian water management agency *PusAir* and several consultants from The Netherlands and Indonesia were mobilised to assist Indonesia with a safety inspection of the smaller lakes in and around



Jakarta. This inspection team, representing the dam safety knowledge from Indonesia and The Netherlands, started within two months with a risk inventory of the most important and seemingly dangerous small reservoirs and related structures in Jakarta and surroundings. The inventory included a field inspection as well as dam break and overtopping analyses that formed the basis for recommendations on the urgent measures that should be immediately implemented.

How can we predict a flood hazard?



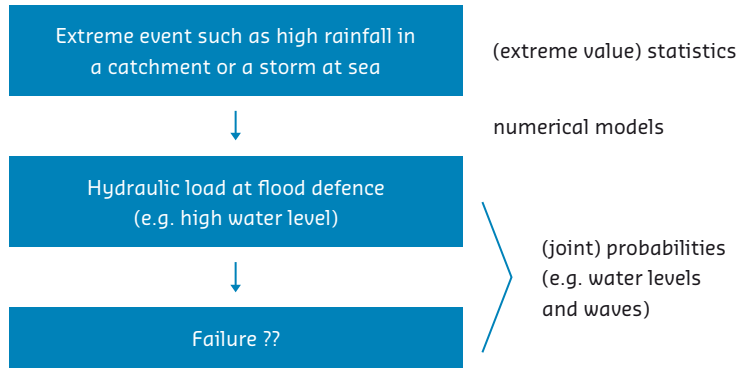
Flood prediction is at the core of flood risk management. Deltares develops knowledge and systems that map out risks and forecast threats in order to enable appropriate responses. Our products include real-time flood forecasting systems, which can be used to take imminent action, such as evacuations. However we also use this knowledge about flood risk to advise on flood protection schemes and spatial planning measures that can reduce the risk in the future. The prediction of flood hazards is our core business and our approaches are in the forefront of the international state of the art.

Hydrological predictions, statistics and probabilities

For the calculation of a risk it is crucial to have knowledge about the probability that an extreme event will happen. This could be a high river discharge caused by heavy rainfall in the catchment, a deadly storm surge generated by a combination of spring tide and strong winds, or a tsunami triggered by an earthquake. Essentially, many of these phenomena are stochastic, which means that their occurrence is difficult to predict. Luckily we have historical records of past events, and therefore we can use (extreme value) statistics to identify the threat. Models that simulate the extreme event, such as high rainfall in a river catchment or a storm at sea are used to calculate the hydraulic load, such as the water level. Probability methods are also used in assessing the chance of a failure.

Extreme value statistics

Flood disasters are uncommon. We therefore only have a few observations of the phenomena that cause them, for instance high rainfall or discharge events. However in order to assess the safety of a flood defence system we have to know the probability of such events. The challenge is therefore to extrapolate from a series of known values to determine the probability of an extreme value for rainfall or discharge. Various statistical techniques are available to

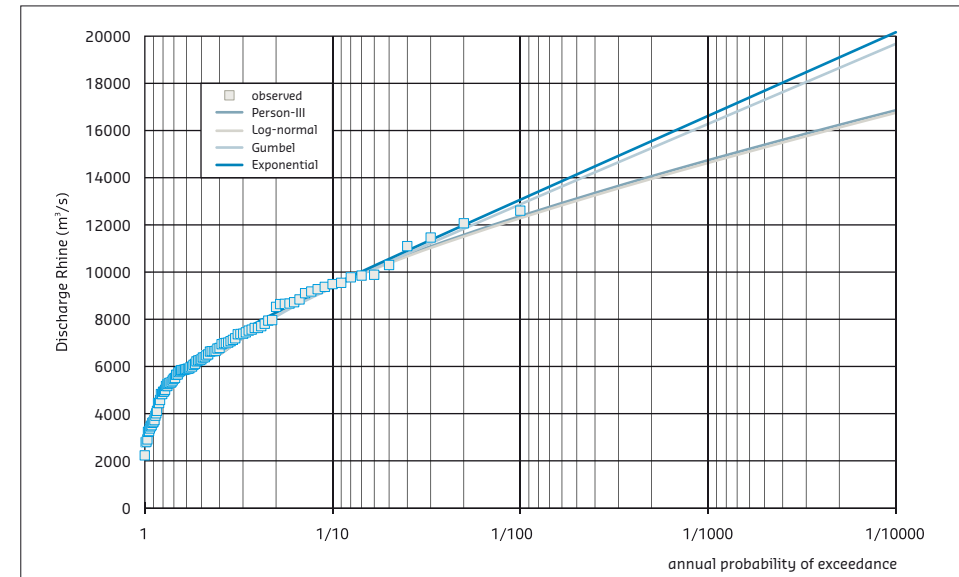


make this extrapolation. Our software package for hydrological data analysis *HYMOS* provides easy use of all the main distribution functions, such as Weibul, Gumbel, Lognormal and Pearson.

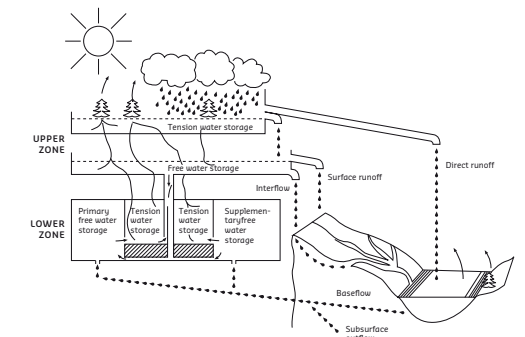
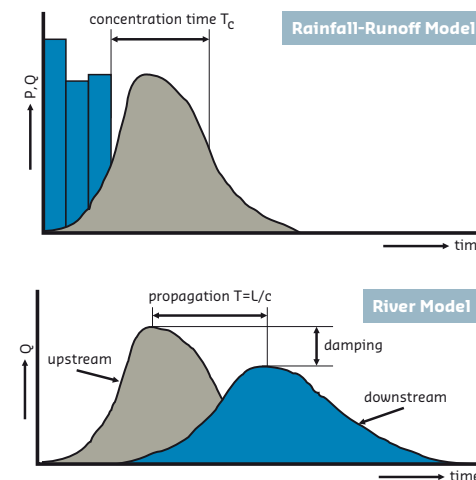
Whatever method is used, one must remain aware of the fact that uncertainty is involved. As can be seen in the graph below, the extrapolated extreme Rhine river discharge values for a recurrence time of a thousand years differ significantly, depending on the type of distribution one chooses. It is therefore important to use these techniques carefully: always ask oneself if the results are physically realistic and include the level of uncertainty as part of the result. Deltares has both the models and expertise to provide advice on what to choose as the most appropriate extrapolation. Moreover, Deltares has extended the record base by reconstructing past extreme events using geological analysis of flooding deposits.

Modelling of rainfall runoff and rivers

To translate an extreme event into a hydraulic load (a high water level) at the flood defence requires modelling of the runoff and of the river flow. The Sacramento rainfall-runoff model is part of our *HYMOS* software. For river flow, Deltares has developed the *SOBEK* software suite, which combines a 1-dimensional model for river channels with a 2-dimensional model for floodplains and other areas prone to flooding in a fully integrated manner. With these models, relevant information for the flood manager can be produced, such as bankfull water levels or inundation depths at any location along the river.



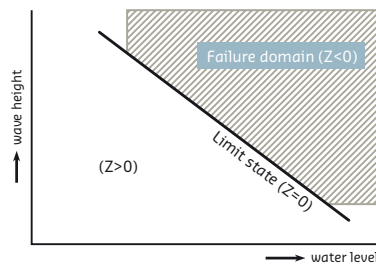
Observed and extrapolated extreme discharges for the River Rhine at Lobith, The Netherlands



Schematic representations of discharges for Rainfall-Runoff (Sacramento model) and River model

Probabilistic methods for failure determination

Failure of a flood defence system is a function of the hydraulic load and the resilience or resistance of the defence system. In the next chapter we will take a detailed look at major failure mechanisms of dikes, dams, dunes and other control systems. Here we concentrate on the hydraulic load. Usually this load is described in terms of a water level. When this reaches a critical level a dike may breach. Often the design height of the dike is determined by a water level corresponding to a certain probability, e.g. 1/200 per year. Flood control managers therefore need to know what this water level is. While it can be calculated relatively easily in the case of a river by using discharge rating curves, other factors are needed for a sea dike, such as tides, barometric pressure and wind speed and direction.



Illustrative schematic view of a reliability function

Nevertheless how can we combine the probabilities of, say, water level and wave height, into one probability of failure? Failure mechanisms are mathematically described by a so-called *reliability function*. The reliability function describes under which hydraulic conditions (in this case a combination of water level and wave height) the protection scheme will fail.

For the safety of the land to be protected we need to know the probability (or frequency) with which this will happen. Mathematically this means we need to know the accumulated probability of occurrence of all combinations of variables in the failure domain. We obtain this by running numerical models for both the water level and wave height under a large set of boundary conditions. Deltares uses and develops various probabilistic computation techniques to tackle this. Numerical integration and Monte Carlo techniques can be used if the computation time of the numerical simulation model is short. However when many hundreds or thousands of runs of a larger model are required,

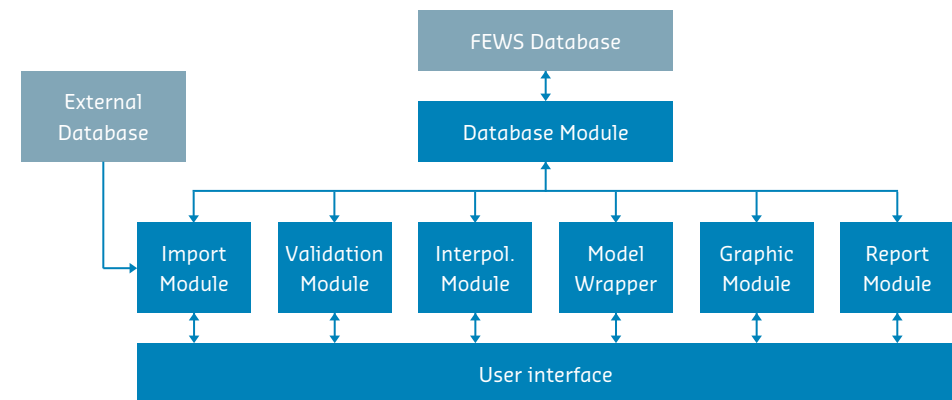
computation time becomes limiting. Optimisation techniques for Monte Carlo, such as Directional Sampling reduce the amount of model computations in comparison with the ordinary Monte Carlo. Also other techniques such as First Order Reliability Method (FORM) have the advantage that they require relatively little computation time.

Data assimilation

Notwithstanding large improvements in hydraulic modelling over the years, models will always retain a certain level of uncertainty. One way we use to reduce uncertainty in our prediction models is data assimilation: feedback of independent data into the models such that these models provide a good resemblance of the state of the water system. Several techniques are available and under development at Deltares, such as extended and ensemble Kalman filtering.

Delft-FEWS

Timely dissemination of information to authorities and inhabitants of flood-prone areas is key to an effective flood warning system. Our long experience in using and developing the techniques and models for data analysis and pathway simulation has enabled us to develop many flood forecasting systems. This has now been combined into our standard Flood Early Warning System (*Delft-FEWS*). Delft-FEWS is quickly becoming the world standard in Flood Forecasting Systems. The open interface allows you to plug in a wide range of simulation models, weather forecast feeds, grid data and observed hydrological data. In





Deltares predicts high water levels in Jakarta, Indonesia

With precise and timely predictions, Deltares contributed to the protection of large parts of Jakarta from flooding on Tuesday 3 June and Wednesday 4 June 2008. The government in Jakarta pulled out all the stops to get sandbags out in time and to start pumping operations. This flood was not the first that Deltares saw coming. On as many as three occasions – on 29 October, 26 November and 23 December 2007 – Deltares predicted the flood days exactly. The high water warnings were

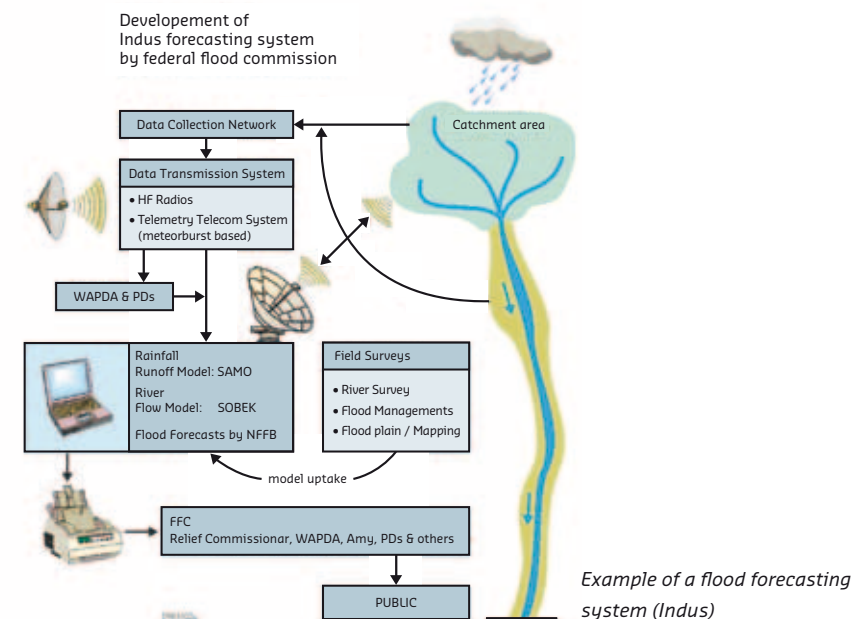
particularly valuable during the third flood, allowing provisional water defences to be built from sandbags and bamboo with all speed. The result was a dramatic limitation of the flood damage.

The flood predictions were based on an extensive analysis of the water levels near Jakarta. A number of phenomena had been identified that, in conjunction, resulted in exceptionally high water levels off the coast of Jakarta on 4 June. First of all, there is a spring-tide cycle of 18.6 years. This cycle is caused by the variations in the moon's orbit around the Earth, which result in variations in the distance between the moon and the earth. The cycle peaked that year, resulting in higher spring tides. Secondly, this peak in the 18.6-year cycle on 4 June coincided with a semi-annual peak in spring tide levels. The combination of these two phenomena ensured that the tide was exceptionally high on 4 June (and the days before and after).

A third phenomenon that plays a role in the water levels near Jakarta – the 'Sea Surface Anomaly' – is not, strictly speaking, tidal. These anomalies consist of variations in the water level of a seasonal nature. They are caused by large-scale seasonal variations in the (monsoonal) meteorological patterns above the Pacific and Indian Oceans. In Jakarta, on average, June is the month with the highest anomaly. Because the anomalies vary from year to year and depend on the weather (the presence of anticyclones, for example) the variations in water levels that they cause are difficult to predict. However, using a flow model developed by Deltares, linked to a meteorological model providing predictions a few days ahead, it was possible to make a better estimate of the expected water level on 4 June. Using this operational model, with daily updates of meteorological predictions, Deltares is currently producing daily predictions of water levels for Jakarta.

does not matter whether you have schematizations in Mike, Hec-Ras, HBV, Sobek, ISIS or other formats: Delft-FEWS will be able to communicate with them. Even your own data format or simulation model can be linked-up with Delft-FEWS. On top of this modular approach, the software comes with a user-friendly GIS interface, time series editor and a wide range of tools for visualization, analysis, validation and conversion of data. Every task can be fully customized and automated.

One of the first projects that used Delft-FEWS was the National Flood Forecasting System (NFFS) at the Environment Agency in the UK. It comprises the Agency's complete fluvial and coastal flood forecasting capability for England and Wales. The NFFS has been developed by Deltares with subcontractor Tessella Scientific Software Solutions (UK). NFFS has been fully operational for three regions since October 2005 and the countrywide operationalisation was completed in September 2006. Delft-FEWS is a living product which benefits continuously from user experiences and our own R&D efforts. The system is now being used in twenty countries all over the world including the United Kingdom, Austria, The Netherlands, Switzerland, the United States and Taiwan.





Flooding of the city of Roermond along the river Maas, The Netherlands in 1993

Flood modelling of rivers

Deltares is continuously developing and improving its modelling capabilities for flood prediction. For rivers we have developed *SOBEK 1D/2D* to simulate the hydrodynamics of one-dimensional river/channel network and two-dimensional overland flow. This model is suited to simulate the dynamics behaviour of overland flow over an initially dry land, as well as flooding and drying processes on every kind of geometry, including flat land or hilly terrain. The computer program allows the user to add one or more 2D domains to a 1D network. These domains can even be nested, providing a refining of the grid at desired locations. The 1D and 2D domains are automatically coupled at the 1D calculation points whenever they overlap each other. The 1D channel network and the 2D rectangular grid hydrodynamics are solved simultaneously using the robust Delft scheme which is able to tackle steep fronts, wetting and drying processes as well as subcritical and supercritical flow.

A systems approach to flood defence systems

Deltares is actively involved in estimating the flood risk for a system of river embankments through calculations of hydraulic responses to dike breaches. The response of a complete flood defence system to an imminent flood depends to a very large extent on the occurrence and location of a dike breach. Should a flood defence fail in one polder, the chances of flooding of a nearby polder are probably lower. By randomly drawing dike breach locations in a Monte Carlo simulation, Deltares analyses the system behaviour with the use of the *SOBEK 1D/2D* hydrodynamic model. Recent experiences of this modelling method demonstrated the true complex behaviour of river defence systems. In fact, both beneficial and adverse effects can occur simultaneously or in separate flood occurrences, that contribute to the overall flood risk. This underlines the need for determining the statistically-weighted contribution of both beneficial and adverse aspects on the flood risk of an entire river system.

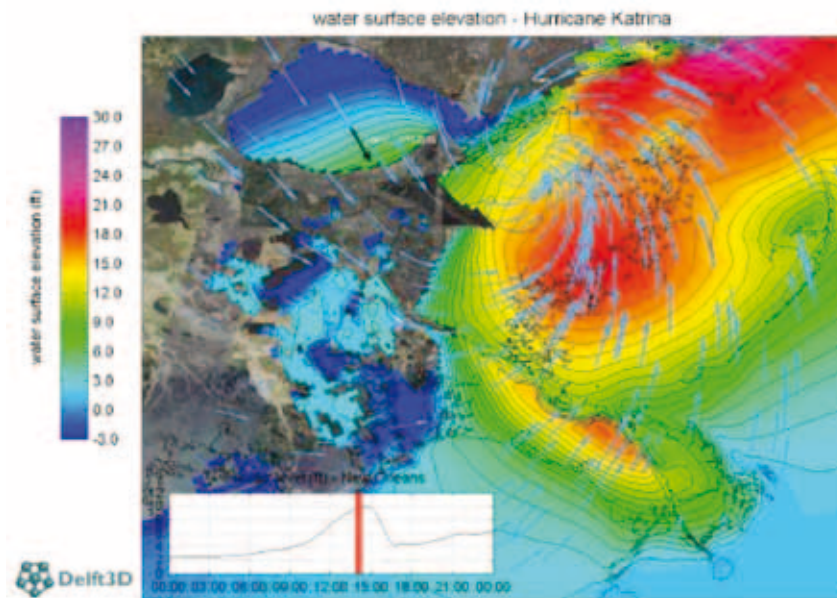
Storm surge modelling for hurricanes and cyclones

In many semi-tropical coastal regions of the world, storms can turn into disastrous hurricanes or cyclones. Especially the east coast of the USA, the islands in the Caribbean, the coasts along the Bay of Bengal and the South China Sea are vulnerable to such storms. For the last 10 years Deltares has been developing sophisticated storm surge modelling as part of early warning systems in various countries. For storm surge simulations with *Delft3D-FLOW*, a Wind Enhancement Scheme (WES) has been devised to generate a storm wind field. The program computes surface winds and pressure around the specified location of the moving eye of a cyclone taking into account the path or track of the storm. The WES model can use cyclone track data given by any Meteorological Agency. However, the Joint Typhoon Warning Centre, Hawaii, is the only agency that predicts sustained maximum winds at regular intervals. Improvements to the model, initially developed by the UK Met Office, have made the program more robust and enabled more reliable and consistent results. The program also calculates the radius of the maximum winds offering a possibility to compare the output with Radius of Maximum Winds derived from radar and satellite observations.

The wind friction coefficient applied in the models is a crucial factor to simulate the correct maximum surge level. Therefore, Deltares is cooperating with the Dutch meteorological institute KNMI to further improve the wind friction formulations, especially for severe wind conditions (wind speed > 35 m/sec).

Based on our project experiences, a *Hurricane Toolbox* has been developed, through which the generation of cyclone wind fields becomes much easier and faster than before. With the Toolbox it is possible to download the latest storm tracks from NOAA's National Hurricane Centre and directly convert these into 2D wind fields on a moving spider web. Setting up working cyclone models in Delft3D has now become a matter of minutes. An example of a simulation of the water surface elevation for Hurricane Katrina is shown in the figure below.

A recently completed project in Andhra Pradesh (India) focused on the development of a forecasting and warning system for storm surges and floods, and the implementation of the system at the State Disaster Management organisation. In this early warning system the Wind Enhancement Scheme was applied to a high spatial and temporal resolution Delft3D grid. Also included was a module to simulate the overland flooding of the coastal zone and river delta areas. The model application included the effect of tide-storm surge interaction.



Hurricane Katrina making landfall close to New Orleans on 29 August 2005

Historical evidence

Evidence of superstorm surges from our historical and pre-historical past provides important information for present day flood risk management. Because monitoring records of high water levels are usually limited to about one hundred years in most countries, we have to dig literally into the past to know what occurred many centuries ago. Sometimes, nature can help by exposing old flooding layers along the coast. This is what happened during a north-westerly storm on 9 November 2007, which eroded about 10 m of the frontal dunes along a 1 km long stretch near Heemskerck, the Netherlands. The resulting dune scarp provided a unique exposure of beach and aeolian sediments.



Geologists examining the deposit of a historic storm along the Dutch coast

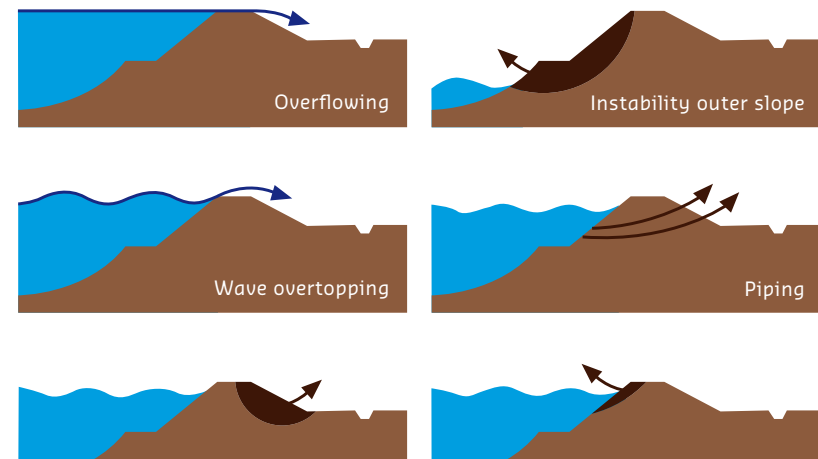
In the months following the storm, geologists from Deltares and TNO – *Geological Survey of The Netherlands* studied this exposure, with particular emphasis on shell-rich layers that were deposited by the historical storm waves. The timing of the storm was determined using optically stimulated luminescence, a new dating method that allows geologists to determine the time of deposition of sand layers, and historical documents. The resulting late-eighteenth-century age was coupled with the measured elevation of the storm layer, thus forming a vital data point in the existing, historically measured time-elevation series. This approach is seen as a breakthrough in storm-surge research, opening doors in the global analysis of ancient surge levels. A similar approach will be applied for the reconstruction of wave-height and wave-period combinations during extreme storms.

How strong are dikes, dunes and dams?

4



The Dutch have been building water defences for over a thousand years. No other country has such an enormous wealth of experience on this subject and Deltares is at the centre of this web of knowledge. We are specialised in literally every part of every type of dike, barrier, seawall, dam or dune. Designing and maintaining these flood control structures becomes more complex as flood risks increase. However societal demands are also increasing. Urbanisation and environmental concerns put stringent requirements on the design of water defences. Deltares is a key player in the design, testing and management of such infrastructure. We develop standards and guidelines, but also innovative techniques and computer models. We test and validate these innovations in our own modelling facilities and field laboratories. We team up with water managers, universities, knowledge institutes and companies in The Netherlands and abroad.



Failure mechanisms of a dike



Construction of the Smart Dike that was brought to failure in the Macrostability Experiment conducted in September 2008 (see also photo on page 28)

The Smart Dike ('IJKdijk')

Dike failure is a serious concern of the water manager because protection against flooding is not only determined by the height of the embankments (which can be easily measured), but also by their strength. Weak spots in the embankment can collapse because of instability or internal erosion rather than by overtopping. The key to safer embankments is therefore to find ways to determine the processes that undermine the strengths of the dike and to measure the weaknesses over its entire length.

Determining failure processes of embankments remains a research field in development. The strength of embankments depends on a large number of parameters which are difficult to measure. Calculation methods for embankment strengths are available, but there is significant uncertainty between the calculated and the actual strengths. Because of the huge investments involved

and the increasing costs of maintenance and management for the water manager this is an unsatisfactory situation. Systematic experiments to calibrate these models will improve the design of embankments. They will also enable the development of models that, when fed by real time data from sensors in dikes, calculate the short and long-term future of the embankment system. Most importantly they can report if immediate safety issues are at stake.

The Smart Dike ('IJKdijk') is a unique international test facility with the aim of conducting these systematic experiments and integrating and validating dike and sensor technology. The Smart Dike is an initiative of both the research institutes TNO ICT, Deltares, the Dutch national water board research foundation STOWA, IDL and the regional development agency N.V. NOM. However other companies have been invited to join the experiments as well and about 50 companies are enlisted already. The test facility allows to construct test embankments that can be brought to failure. So far, tests on slope stability during wave overtopping, macrostability and piping have been conducted.

Photos above show the execution of macrostability tests. The dike is fitted with sensor technology from different participants, ranging from acoustic measurements, optical detection, micro-electromechanical systems, thermo-graphic cameras and LIDAR combined in an innovative way for the measurement of pore pressures and humidity. To calibrate the new techniques and to accommodate the test in general, reference monitoring consisting of pore pressure meters, humidity meters and inclinometers is also installed. Besides testing sensor technology for early warning applications, the tests provide a wealth on data to improve our knowledge on failure mechanisms.

The Wave Overtopping Simulator

A Wave Overtopping Simulator is a device to perform destructive tests on inner slopes of real dikes in order to measure the erosion resistance against overtopping waves from severe storms. The Wave Overtopping Simulator was developed in 2006 by Van der Meer and tests were performed by Royal Haskoning/Infram in 2007. A consortium led by Deltares performed further tests for Rijkswaterstaat, the executive agency with responsibility for water that is part of the Dutch Ministry of Transport, Public Works and Water Management. These tests showed the behaviour of various inner slopes of dikes, embankments or levees under simulation of wave overtopping, up to a mean overtopping discharge of 125 litres per second per metre.



Experiment with the Wave Overtopping Simulator

The Simulator consists of a high-level mobile box to store water. The maximum capacity is 5.5 m³ per metre width (22 m³ for a 4 m wide Simulator). This box is continuously filled with a predefined discharge and emptied at specific times simulating the overtopping tongue of a wave at the crest and inner slope of a dike. The discharge of water is released in such a way that for each overtopping volume of water the flow velocity and thickness of the water tongue at the crest correspond with the characteristics that can be expected. Various overtopping volumes are released randomly over time.

Results of the testing show how strong the inner slope of a dike is for wave overtopping, what kind of failure mechanisms can be expected, what the weak points are during overtopping and where further research should be focussed. These observations provide important information for designing dikes. For instance, the results of the tests show that wave overtopping produces less erosion than previously thought.

The Delta Flume

The Delta Flume is a large-scale wave flume to measure wave loads on structures. This facility is also used in projects where scale effects can be expected, e.g. stability of placed block revetments and dune erosion. It measures 240 x 5 m and has a depth of 7 m. The wave board has a second-order wave steering system with active re-reflection compensation. It can generate waves up to 2.5 m high.



The Delta Flume in action: testing dune strength

Dune erosion experiments

New insights show that the wave conditions along the Dutch coast could be more severe than accounted for until now. Not necessarily the wave heights, but especially the wave periods, appear to be bigger than expected. The safety of dunes and dikes along the Dutch coast are therefore being reviewed to judge whether additional measures need to be taken to guarantee the required safety. To achieve this, it is necessary to know how the wave lengths and wave periods affect dune erosion during storms. There are indications that longer wave periods increase dune erosion.

Rijkswaterstaat asked Deltares to investigate the effects of the wave period on dune erosion and to extend the method presently used to assess the safety level of the Dutch dunes. A group of specialists from both Deltares and other institutes (the universities of Delft, Utrecht and Twente, and Alkyon) carried out these investigations. The research included large-scale dune erosion tests that were carried out in the large Delta flume of Deltares. A characteristic Dutch dune profile was placed in the flume for that purpose with approximately 3,000 m³ of sand. The results of these tests play an essential role in improving the method to determine dune erosion during storms with severe wave conditions.

Piping experiments

Piping, the development of erosion channels under dikes, is thought to be an important dike failure mechanism. Research in the past has produced several forecasting models, both empirical and analytical. As piping involves major risks, Deltares is performing a research programme in order to validate and



Small-scale piping experiment

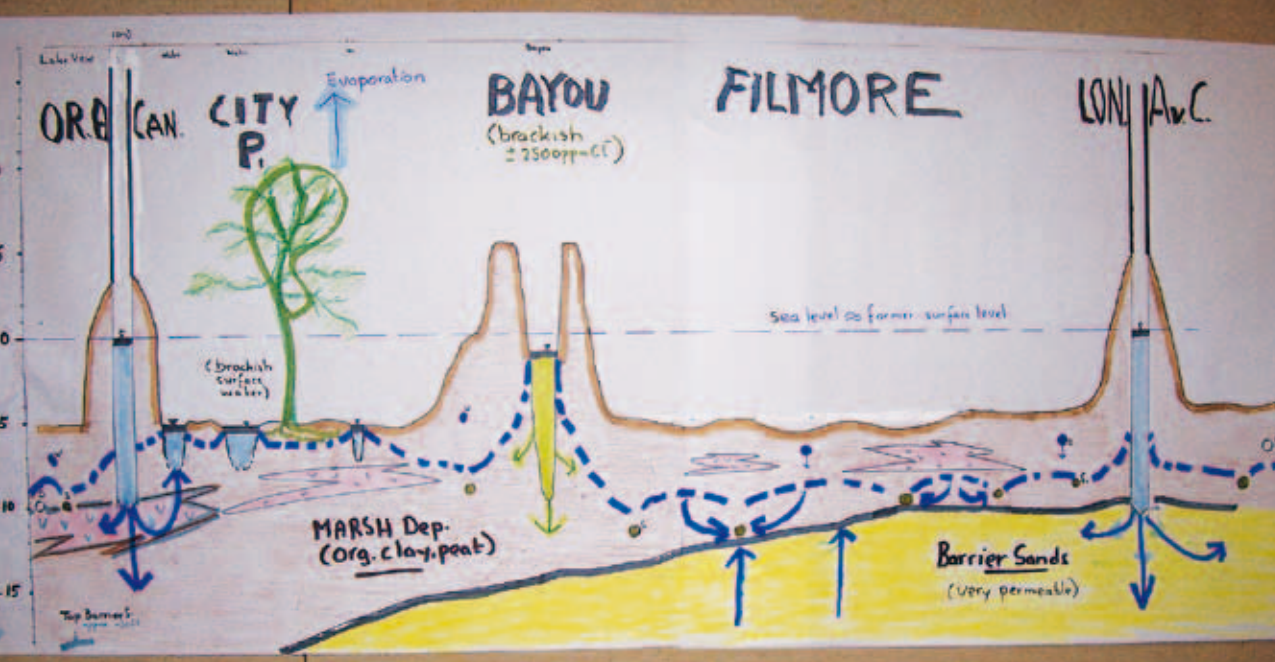


The Geo-Centrifuge

Soil behaviour is strongly stress dependant. Therefore, model tests on soil structures like dikes are not straightforward; a 5 cm high dike acts differently than a 5 m high dike. Centrifuge tests can be used to overcome this problem. After placing a model in the centrifuge while spinning around, the centrifugal force is used to model earth's gravity. For example when spinning around at such a speed that the centrifugal force acting on the model equals 100 g (hundred times the earth's gravity), a 5 cm high has the same 'weight' as a 5 m high dike. In this way relevant phenomena can be studied properly and (expensive) field tests can be well prepared.

The Deltares Geo-Centrifuge is unique in its dimensions, with an armlength of 6 m a model up to 2.5 tons, which can be accelerated up to maximum 300 g. The Geo-Centrifuge is a valuable tool in understanding failure mechanisms of dikes.

possibly improve our geo-engineering models. Experiments are being performed to investigate the influence of the properties of sand, such as grain size, grain size distribution, sphericity of the grains and permeability. The study involved small scale tests, as shown by the photo below as well as medium scale tests, tests in the geo-centrifuge and field tests. The field tests were part of the Smart Dike ('IJKdijk') project described earlier. The results of these experiments already revealed a wide range of erosion processes, thus deepening our understanding and guiding the improvement of current models. Based on the knowledge gained in this study handbooks for design of dikes and guidelines for stability assessment for existing dikes are rewritten at this moment.



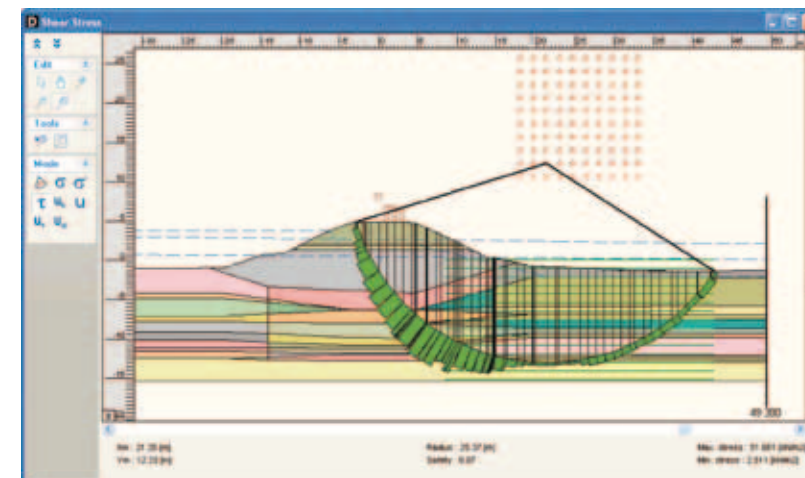
Sketch of the subsoil and groundwater situation leading to the collapse of the London Avenue Canal Levee in New Orleans (result Dutch Dialogues, III)

Hydrogeology mapping, groundwater and subsidence modeling

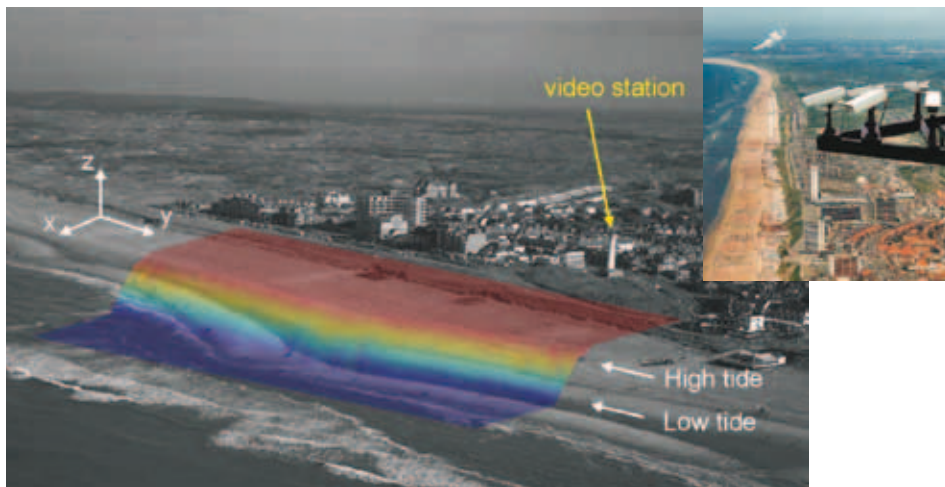
Flood risks can also be related to several subsoil processes such as uncertainties in geological knowledge or subsidence due to groundwater drainage, groundwater abstraction and gas/oil pumping. The collapse of the London Avenue Canal levee in New Orleans during Katrina, for example, was largely due to the hydrogeological properties of the subsurface. The levees and the canal bottom were founded into very permeable barrier sands. As a result of the high flood water levels, the thin layer of marsh deposits collapsed, undermining the levee. The size of the flooded area was related to man-made subsidence during the last century. Land subsidence in New Orleans is strongly related to the drainage of shallow groundwater. Managing the shallow groundwater level in soft soil areas can minimize subsidence. In cities such as Bangkok or Jakarta the main cause of subsidence is groundwater pumping from very vulnerable aquifers resulting in a decreasing subsurface level of several meters. Deltares is the specialist of soft soil processes: mapping (hydro-)geology around existing dikes, modeling groundwater and the relations with subsidence, mapping subsidence using satellite images, monitoring groundwater and subsidence. Online groundwater level monitoring can also be an informative tool to determine the soil storage capacity. In combination with rain forecasts, flooding risks due to saturated soils can be determined.

Slope stability and soil settlement prediction software

Based on our experimental research and experience, Deltares is developing geo-engineering software tools for the design and safety analysis of embankments. *D-Stability* is a slope stability package for soft soils. *D-Stability* offers several specific features for the design of river dikes and road embankments, including a reliability module allowing for the input of partial safety factors. A stochastic distribution of parameters enables semi-probabilistic analysis. Experts in probabilistic analysis can use the Bishop probabilistic random field module, allowing users to take into account spatial variation of parameters. The Uplift module makes it possible to undertake a safety analysis of river embankments under the influence of changing water levels in aquifers. *D-Stability* can easily be integrated with other Deltares geo-engineering software, such as *D-Settlement*, that predicts the transient settlement of peat and clay soils. *D-Settlement* offers accurate and robust models, capturing consolidation, creep, submerging, drains, and staged loading, unloading and reloading.



D-Stability screen shot: Bishop slip circle with shear stress



The ARGUS coastal monitoring system enables data-model integration for coastal safety

XBeach: an open-source programme for dune erosion, overwash and breaching

Together with the US Army Corps of Engineers, UNESCO-IHE, Delft University of Technology and the University of Miami, Deltares has developed *XBeach* (eXtreme Beach behaviour model), to simulate the nearshore response to storm and hurricane impact, including wave breaking, surf and swash zone processes, dune erosion, overwash and breaching. *XBeach* can be used to study complex situations such as alongshore conditions, a range of nearshore conditions, dune profiles and the presence of sea walls and revetments. The model is an innovation compared with previous process-based models because it can manage directionally-spread short wave groups, infra-gravity waves, unsteady currents, sediment transport and bed level changes in a single, compactly-coded model. External scientists have free access to the model and have contributed to the development of the code. The project therefore has contributed to Deltares' role as a knowledge exchange centre.

The *XBeach-wizard* links *XBeach* to the images of the Argus coastal monitoring system. This data-model integration tool makes it possible to predict the morphological behaviour of the coastline on a short to very short time scale without the need for expensive field measurements.



Maeslant storm surge barrier in closed position

Storm surge barriers: physical modelling and operational software

For decades Deltares has been active in the design and testing of storm surge barriers and closure dams. Major studies were executed during the implementation of the Delta Plan in The Netherlands after the 1953 flood disaster.



Oosterschelde storm surge barrier The Netherlands closed during heavy storm

Highlights of the Deltaplan included the construction of storm surge barriers in the Oosterschelde (1986) and the Nieuwe Waterweg (1997). Abroad we have been involved in several large storm surge protection projects, for instance St.Petersburg, Venice lagoon and New Orleans.

The Maeslant barrier in the Nieuwe Waterweg (The Netherlands) protects the harbour and city of Rotterdam from storm surges in the North Sea. Deltares carried out physical scale model tests to study the stability of the barrier especially during the closure of the gates. Deltares also participated in the development of the decision support software for the barrier. The *SOBEK 1D* model is part of this software, which predicts water levels that, when exceeding a specified threshold, will automatically trigger the barrier to close.



Ecobasin at the toe of a dike

The Rich Dike

Deltares is constantly exploring innovative ideas to optimise flood protection. An example is to combine the function of flood control with other functions, such as ecology or recreation. Take for instance the 'Rich Dike' concept, which centres around the idea that dikes act as an important habitat for species. They form a hard substrate that is colonised by all sorts of aquatic plants and animals. Such habitats can be promoted by marginal adaptations in dike construction, thus increasing biodiversity. The ideas are currently being worked out and tested in situ along several dike sections in The Netherlands.

What are the options for adaptation?

5



Reducing the vulnerability of an area usually requires changing the land use. Housing, industries and services can, obviously, be best located on higher ground. In particularly exposed situations entire villages have been relocated, as happened with the village of Röderau Süd on the Elbe River close to Dresden after the August 2002 flood. However one may also think of improving the discharge capacity of rivers that effectively lowers the high water levels. In addition in urban areas flood risks can be reduced by flood-proofing of buildings.

Resilience or resistance?

Resilience and resistance are two different responses of a system to external stress, for example a flood event. A *'resistant'* system defends against the event, whereas a *'resilient'* system will give in to the stress of flooding but allows immediate recovery. Both may yield a system which is robust in the sense that it can cope with external stress. Thus in flood risk management, resistance strategies are aimed at the prevention of flooding up until a certain threshold, primarily by flood defence, whereas resilience strategies principally allow flooding but try to control the flood area and flood depth as well as land use within the flood-prone area in an attempt to achieve proportionate impacts with increasing flood magnitude, to maximize recovery capacity, and thus to prevent catastrophes. resist

A typical example of a combination of a resistance and a resilience strategy is the Room for the River project: by lowering the floodplain, realigning the dikes and reconstructing secondary channels, the water regains more space and this leads to a reduction in high water levels. One of the important aspects in this approach is the consequences of the measures for the long-term river morphology. Deltares is continuously carrying out research into sediment transport, erosion and deposition processes, especially in relation to the vegetation development in the floodplains. The combined response of vegetation growth

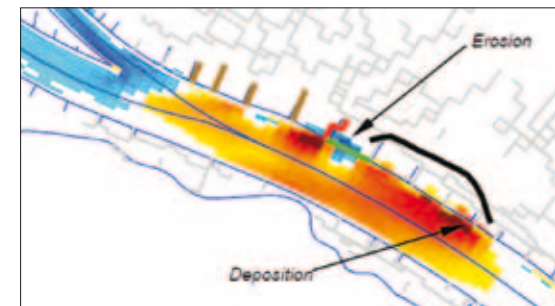
and morphological evolution in the floodplains may affect the durability and sustainability of the measures. Detailed knowledge of these processes allows optimisation of maintenance strategies such as cyclic rejuvenation.

River morphology

Floods affect not only the water but also the sediment in rivers. Banks may erode during floods with the risk of undermining flood defences. On the riverbed large dunes may develop that push up flood levels by increasing the hydraulic resistance. Erosion and sedimentation may change the distribution of discharges at river bifurcations in deltas, giving some branches higher flood discharges than accounted for. Moreover, flood management strategies based on giving more space to a river induce sedimentation. This requires maintenance, as sedimentation reduces the navigability of the main channel and gradually negates the flood level reduction gained by the strategies. River morphology thus affects both flooding risks and the sustainability of flood management strategies. Fortunately, adverse effects can be minimized if the design takes morphological processes into account. Deltares has been a leading centre in river morphology for decades. Short-term and long-term changes in river bed topography and bed sediment composition can be computed using Delft3D, which remains one of the world's leading modelling systems for morphodynamics.

Room for the River: from strategic flood risk research to implementation

In the 1990s Deltares explored in a strategic research project whether and how The Netherlands could accommodate a 30% increase in flood discharges in the Rhine River. We concluded that rivers would need more room and that careful planning could avoid losing land to the river by combining the discharge function with flood-proof land use functions. Deltares then quantified the loss of floodplain surface area since 1850 at approximately 65% and calculated that urban development has created several bottlenecks in the floodplain. Giving more room to rivers would substantially lower flood levels and sustain a more attractive environment, both urban and natural. This greatly influenced public and political opinions. Room for the Rivers was officially adopted by the Dutch government to achieve the required safety level for the river systems. Later it also became the guiding principle for climate change adaptation along the major Dutch rivers.



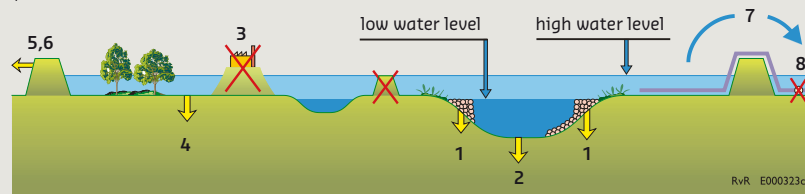
Impact of secondary channel – bed level changes

In 2005 specific targets were set at the national level and local authorities became responsible for the design and construction of individual measures along the Rhine, Scheldt and Meuse rivers. Deltares audits these designs and makes assessments of their combined large-scale effects on the river system. In addition to hydraulic effects, we also quantify geotechnical, groundwater and morphological effects. Furthermore, we provide advice on the landscape quality through the participation of our landscape architects and geographers in the 'Quality Team'.

The Planning Kit

The implementation of the new Room for the River policy requires difficult choices at the local level and it is thought essential to involve local stakeholders in finding optimal solutions. Both national and regional authorities, municipalities and individual citizens proposed around 700 local measures that could help in reducing the water levels. Each of these measures would have secondary impacts and different costs. In order to handle such a huge amount of information a special tool was developed, the planning kit 'Room for the River', which proved to be successful in supporting joint planning with stakeholders.

Underlying the tool are advanced scientific, cause-effect models. These remain hidden to the users of the tool. Users can add measures to the existing situation of a river area in an intuitive manner, directly relating to their normal perception. They can for instance lower a dam or remove an obstacle. The tool visualises the results of such interventions, again, in an intuitive way, e.g. showing the effects on natural quality and water levels. In this way, stakeholders – ranging from authorities to citizens – can jointly evaluate different strategies for adaptation in a river area, without being burdened with interpreting the results of the underlying models



- | | |
|--------------------------------|---------------------------------------|
| 1 lowering of groynes | 5 locally setting back dikes |
| 2 deepening low flow channel | 6 setting back dikes on a large scale |
| 3 removing hydraulic obstacles | 7 detention reservoir |
| 4 lowering flood plains | 8 reduction lateral inflow |

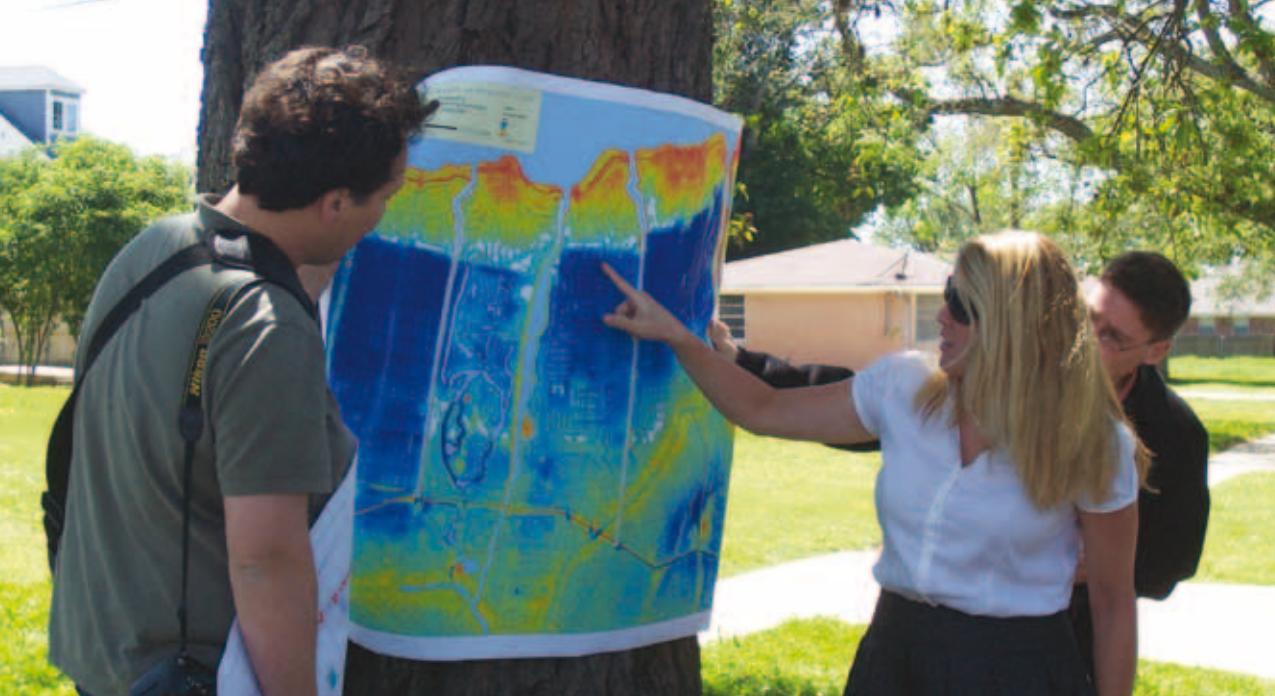
Overview of possible measures in the 'Room for the River' project, supported by the Planning Kit



New Orleans, Louisiana in the aftermath of Hurricane Katrina (29 August 2005), showing Interstate 10 at West End Boulevard, looking towards Lake Pontchartrain

Urban flood management and adaptations

Typically, many cities and towns are situated in locations that are prone to flooding, especially deltas and flood plains. Many of the world's famous metropolitan areas, such as New York, Sydney and Hong Kong are close to the sea and face serious flood risks, as the city of New Orleans has tragically shown a few years ago. Climate change may increase this risk, not only through rising sea water levels, but also because of more extreme weather conditions. Therefore there is a need for climate adaptation and mitigation measures, to make these urban areas more climate-robust. Flood-proofing of buildings is a well known measure in this respect.



Field visit during the Dutch Dialogues meeting in New Orleans. During the Dutch Dialogues meeting urban planners, architects and water specialists together with local politicians made plans for the reconstruction and water safety of the city of New Orleans



Floodplain near Schoonhoven, The Netherlands

Deltares has taken up this challenge in an integrated way. Urban water is still seen too much and too often as an independent component of the urban living environment. However, it should be developed as the carrier and driver of a more pleasant and sustainable living environment and of all sorts of activities. We are therefore conducting research into the effects of climate change on urban drainage, water management and treatment. We are developing processes and instruments for more climate robust urban planning, e.g. through the use of water gardens as ways of improving the micro-climate. We are also making analyses of the probability and the severity of urban water problems and flooding, producing flood risk maps, developing warning systems and assisting in crisis management.

Reducing flood risk by compartmentalisation

In flood risk management, compartmentalisation aims to reduce flood risks by reducing the consequences of a flood event. In a strict sense, compartmentalisation implies dividing large flood protected areas into smaller ones by dividing embankments which are equally high as the primary defence. Several variations are possible. For example, the flooding can be slowed down or the flood water can be guided to less vulnerable areas through embankments much

lower than the primary defences. Compartments can have different sizes, sometimes resulting in 'lines of secondary defence' which keep the larger part dry, or instead allowing large rural areas to be flooded whilst keeping small urban areas dry by 'city rings'.

Deltares performed a nationwide assessment of the feasibility of such a strategy. This was done for the major 53 existing dike-ring areas in The Netherlands, applying a land evaluation approach to assess the suitability for compartmentalisation. This assessment showed that significant reductions in economic damage and the number of affected people could be achieved with this strategy. However, implementation is not straightforward and should be tailor-made to the area in question. For instance, the pattern of existing embankments, roads and railroads is of paramount importance to the flooding process. Furthermore, new secondary embankments should be constructed with reference to the existing landscape and historical values. Therefore, landscape architects need to work side by side with engineers and sound procedures for involving stakeholders need to be in place. Deltares shares its experience both on the technical and governance issues with its partners and clients.

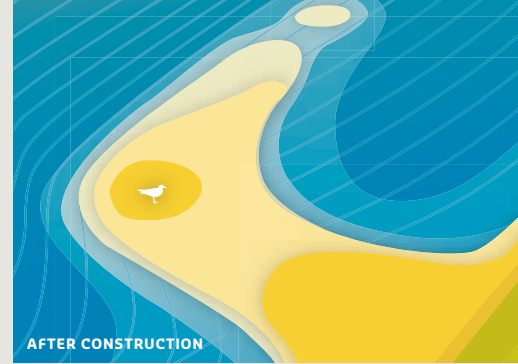


Beach nourishment

Building with nature: sand nourishments

Sand nourishment is the mechanical placement of sand in the nearshore zone to advance the shoreline or to maintain the volume of sand in the littoral system. It is a soft protective and remedial measure that leaves the coast in a more natural state than hard structures and preserves its recreational value. The method is relatively cheap if the source of sand is not too far away (<10 km) and the sediment is placed at the seaward flank of the outer bar where the navigational depth is sufficient for hopper dredgers. Three types of nourishments are distinguished: beach, shoreface and dune nourishments.

These kinds of measures need to be repeated every few years, because wave and current forces will gradually spread out these nourishments to the onshore and offshore direction. A typical lifetime of a normal shoreface nourishment is in the order of 5 years. Therefore, Deltares is also studying alternative nourishment techniques.



Artist impression of the Sand Engine developing through time

The Sand Engine

Deltares, together with other research institutes and government agencies, is investigating the potential and risks of a 'super-nourishment' called The Sand Engine in front of the Dutch coast (shoreface). Although the current beach nourishments are successful and effective for local coastline maintenance, such a super-nourishment could turn out to be more efficient in serving more functions than safety alone. The idea is to apply an extra amount of sand that would be redistributed by nature itself, thus stimulating natural dynamics of the coast, increasing a buffer zone for future sea level rise and enlarging the coastal intertidal zone which is beneficial for nature and recreational values alike.



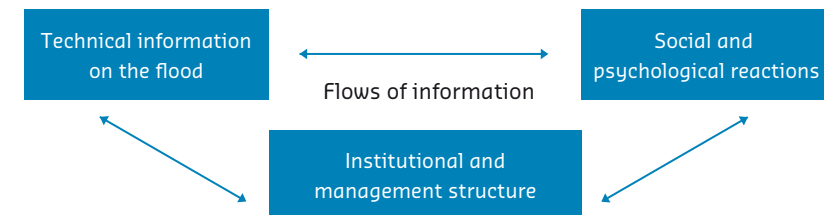
What can be done if things go wrong?

6

Because it is impossible to completely eradicate the risk of flooding, society has to be prepared when things go wrong. There are several ways in which Deltares supports Flood Event Management. An important component for this is a real time early warning system. This enables authorities to start implementing contingency plans, such as evacuations and mobilisation of rescue forces. We already discussed our Delft FEWS in Chapter 2. Now we turn to knowledge and tools that support the development of contingency plans and flood risk insurance products.

Crisis management for flood risks

Three interrelated components are important in crisis management: the technical aspects of a flood, the socio-psychological reaction of the vulnerable people and the organisational and managerial structure. An appropriate contingency plan should ensure an optimal information flow between these three components. Deltares is in a unique position to support the development of such a contingency plan because it has knowledge and experience on all three components. Communication is the key to a successful plan: bringing the



The three components of crisis management



New Orleans (August 30, 2005) – U.S. Coast Guard looks for survivors in the wake of Hurricane Katrina

information together to reach a ‘common operational picture’. This means that at any time during the crisis each and every participant active in the emergency team has the same up-to-date picture of the situation.

We face the challenge of linking the domain of water management with the domain of crisis management. In most countries these domains are partly separated. During normal situations the water managers are responsible for maintaining the flood control infrastructure, but when water rises to critical levels and people have to be evacuated this picture changes radically. A whole range of governmental agencies, departments and echelons come into action: the police, fire brigade, mayors and governors take their position. People have to be warned, traffic has to be regulated, transport arranged. Especially when a large area is critically at risk of becoming inundated this soon becomes a huge logistic operation. Sound information is then urgently needed and has to be communicated to those that need it. Deltares is working on concepts and tools to facilitate this information need. In The Netherlands we assist our government in implementing *FLIWAS*, the Flood Information Warning System at national, regional and local level. In addition together with partner institutes we are developing a National Evacuation Module.

Evacuation planning and modelling

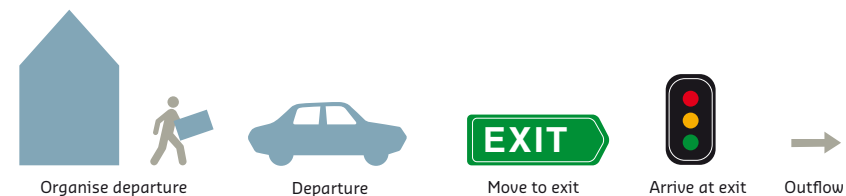


FLIWAS was originally developed under the EU co-financed INTERREG programme NOAH by a consortium of Dutch and German institutes. FLIWAS supports decision-makers, water managers and other people concerned to take the right decisions at imminent high water levels. With the system evacuation plans for various flooding scenarios and evacuation strategies can be developed with the Evacuation Calculator (EC) which is part of FLIWAS. Although we were not involved in the development of FLIWAS, Deltares is currently engaged in the discussions Rijkswaterstaat is leading on future applications.

National Evacuation Module

HKV - *Iijn in water* and Deltares are developing the National Evacuation Module version 2.0 as a component of FLIWAS. It is based on a prototype developed in 2008 which used experiences from earlier evacuation decision support systems. It contains three modules: the Planning Module, Exercise Module and Monitoring Module. The Planning module assists in the drafting of evacuation scenarios and the determination of potential casualties. The Exercise module is used in training sessions and aims at increasing the skills of crisis managers and their teams. The Monitoring Module supports the monitoring and evaluation of the evacuation process.

The Evacuation Module contains demographic data and road infrastructure data. Default settings are included for the traffic process and behaviour of people. Information regarding the threat, objects and distinctions between groups (e.g. especially vulnerable groups such as elderly or disabled persons) is input that should be provided by the user.



Evacuation models are simulating the flow of traffic



Rescue operation underway, United Kingdom

Deltares provides emergency advice

As part of an agreement with the Dutch Ministry of Transport, Public Works and Water Management, Deltares is on stand-by for any emergency related to flood risk. Should a critical situation in any part of the Dutch flood control system arise, experts from Deltares are available to provide technical advice to the Ministry. Within 24 hours a team will then be formed that consists of a mix of expertise suitable for the type of situation. Each year several mock exercises are conducted to train the Deltares staff and maintain a sense of vigilance. Crisis team members include experts on engineering, floods and droughts, environment and water quality, soil and groundwater.



Emergency repair during high water at Ochten, The Netherlands in 1995

Innovation in insurance for disasters

Flood insurance and compensation systems are important parts of strategies for dealing with flood risks. Increasingly insurers and reinsurers use sophisticated probabilistic catastrophe models to price flood risk. For instance the Parameter Trigger Concept is based on the principle of a payout mechanism based on a parameter that can be measured or modelled. The advantage is that funds can be made quickly available after the event because no laborious proof of damage has to be given. There is no explicit link to the loss suffered by the insured. The main challenge is to capture the majority of damaging events by the trigger definition. By using our sophisticated flood risk modeling software, Deltares can assist in analyzing long-term datasets relating to the underlying hazard, in determining the damage correlation function and in estimating real-time flooding conditions. Also our expertise on sophisticated monitoring systems, geotechnical analysis, stakeholder and economic analyses regarding flood risks certainly can contribute to the development of innovative flood insurance systems.



Temporary shelters after the 2004 tsunami, Aceh, Indonesia

Deltares coordinates the US-NL network on emergency management

After the US experience with flood issues during Hurricane Katrina it was thought that a number of lessons learned were applicable to Dutch risks. It was concluded that it would be desirable to establish a network of individuals and institutions that would generate and share relevant knowledge in support of Dutch disaster management issues and to identify areas where additional research is necessary. A further objective is to initiate original collaborative research. It is expected that these insights could help in the government's efforts to prepare for, respond to, and recover from water related crisis situations. In particular, we are focused on efforts that can reduce damage, casualties, and social disruption.

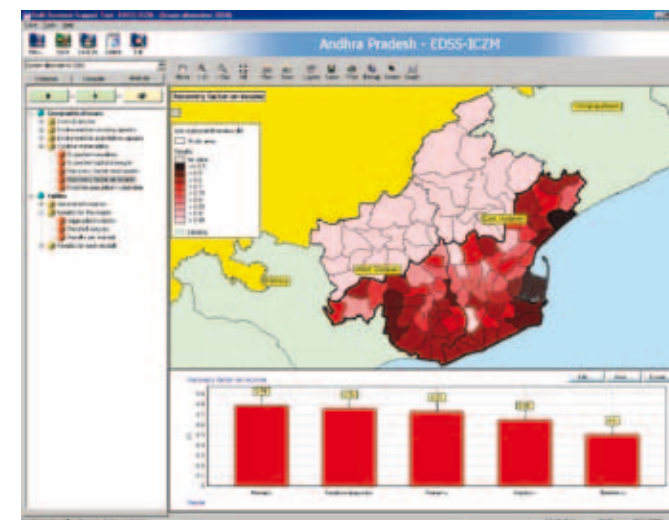
A network has been established of American and Dutch experts in the field of disaster management, called Netherlands/US Water Crisis Research Network (NUWCREN). It is linked to the Disaster Research Center of the University of Delaware (USA) and several partners from other US universities and to the COT (Institute for Safety and Crisis Management), Wageningen University, Deltares and TNO in The Netherlands. Deltares was contracted by the Dutch Ministry of Water and Transport to facilitate the management aspects of the network. Deltares' responsibilities are primarily to negotiate contracts and to facilitate reporting between NUWCREN and the Ministry. In essence, their primary role is to facilitate the transmission of network activities to the Ministry and ministry guidance to the network.

How can we support decisions and management?

7



The previous chapters presented a kaleidoscope of knowledge and information which enables us to better understand flood risks. But how can we integrate all the information in order to make better decisions on risk management? In this chapter we will focus our attention on improving the capabilities of decision makers and managers. Deltares and its partners are developing modern tools for decision support and training. We also advise on how to prepare a cost-benefit analysis or how to perform a policy analysis.



Screen from the Andhra Pradesh Expert DSS, showing the vulnerability of the Godavari Delta to storm surges



Gulfport, Mississippi, 6 September 2005 after Hurricane Katrina

Decision Support Systems for flood risk management

Over the years the use of decision support systems or DSSs has gained importance in flood risk management. DSSs may be developed and used to assist in the integral evaluation of large sets of possible measures. The basic idea behind such systems is to assist decision makers in their work by providing relevant information to base their decision on through a computer platform. A DSS can retrieve information from a variety of sources, such as databases and models. These tools are also valuable in communicating complex results and solutions to a wide audience of stakeholders. In cooperation with landscape architects, clear maps may be produced to visualize the major issues and to develop a decision framework for climate-proof spatial planning.

Deltares has been at the forefront of developing such systems. One of the successful examples in the field of flood risk management is the Room for the Rivers Planning Kit, which was introduced in Chapter 5. Another example of a tool that integrates flood risk with planning for sustainable development is the Expert DSS for integrated coastal zone management and vulnerability assessment, developed for Andhra Pradesh, India. It is unique in the fact that it enables the modelling of the entire impact chain from flood hazard to damage and recovery. The tool enables an explorative analysis of typical flood risk measures as well as land use planning and environmental management measures.

Economic effects of a flood disaster:

	Monetised	Not monetised
Direct effects	<ul style="list-style-type: none"> • Direct material damage: <ul style="list-style-type: none"> - houses and assets - vehicles - capital goods from enterprises - agricultural crops and livestock - infrastructure • Disruption of businesses • Costs of rescue, evacuation and relief 	<ul style="list-style-type: none"> • Casualties (deaths, injured, evacuees) • Damage to landscape, nature, environment and cultural heritage
Indirect effects	<ul style="list-style-type: none"> • Damage at suppliers and customers • Substitution by production outside the flooded area • Demand impulse through repair and reconstruction • Permanent impact on productivity and competitiveness 	<ul style="list-style-type: none"> • Cut-offs of infrastructure, telecom and power lines (lifelines)

Cost-benefit analysis for flood risk management

The benefits of a flood protection system can be expressed as the avoidance of casualties, damages and losses. By quantifying these benefits in terms of avoided annual expected loss it becomes possible to compare these benefits with the costs of the protection system. Although this principle is easy to understand, the use of a cost-benefit analysis (CBA) in flood risk management is far from straightforward and requires expert knowledge from both economists and engineers.

The use of cost-benefit analysis to determine the level of safety for a specific area or country is still relatively uncommon. One of the reasons is that the method for determining the economic impact of a flood is still developing. Deltares is actively contributing to this development through its engineers and

economists, who define the CBA as a quest for a long-term investment strategy that produces the lowest possible combination of costs for preventive measures and damage from flooding.

One of the issues in using a CBA is that over time the annual expected loss changes: in ten or twenty years' time this loss will probably increase due to economic development of an area. Another challenge is the calculation of indirect economic impacts of a flood. A straightforward method to measure these indirect damages is absent, because of the difficulty in identifying and measuring them, the limited data resources available and the fact that indirect damages are spread over a much wider area than the direct damages.

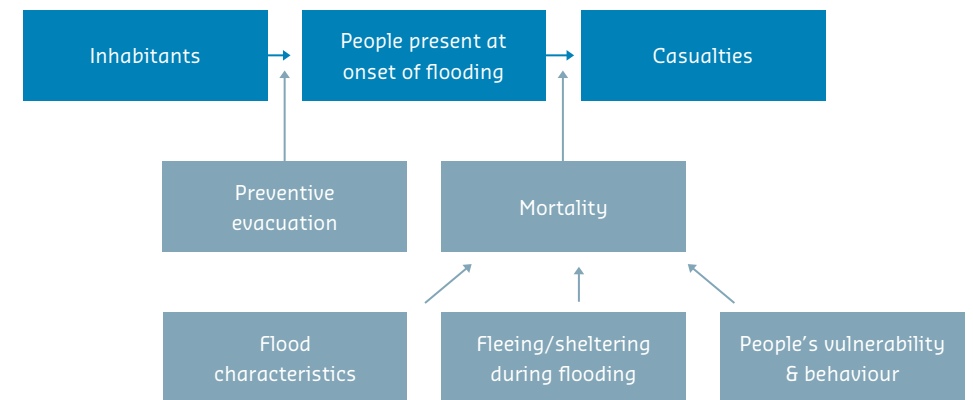
Compared to the direct impact, which is relatively easily assessed through the physical damages to buildings, infrastructure and production capital, the indirect effects consist of both positive and negative feedbacks. Indeed, in the longer term, due to an accelerated modernization of the economy after a disaster, the economy could even benefit from a natural disaster, however counterintuitive this may sound: economic development is shifted to a new starting point. Subsequently different scenarios – a further decline or even accelerated growth – are plausible.

Together with other research institutes and universities, Deltares is improving knowledge and tools that combine flood simulation models with damage functions and algorithms. Model results are being compared with empirical data from past disasters, such as Hurricane Katrina and the Elbe floods. The results are being used as input to a broad evaluation of the Dutch safety standards.

Casualty risk assessment

Casualty risk can be assessed from an individual point of view or from a societal perspective. Individual casualty risk is related to a person's probability to die in a flood. Societal casualty risk, or group risk, is related to the probability of many casualties caused by the same event. Both viewpoints are considered relevant for the discussion on future flood protection standards.

The individual risk criterion could be used as a minimum safety level for everyone. Societal casualty risk can be a useful criterion to avoid societal disruption. Deltares performs casualty risk assessments using and improving existing methods and models that combine the flood characteristics, such as water depth and flow velocity, evacuation efficiency and vulnerability of the inhabitants.



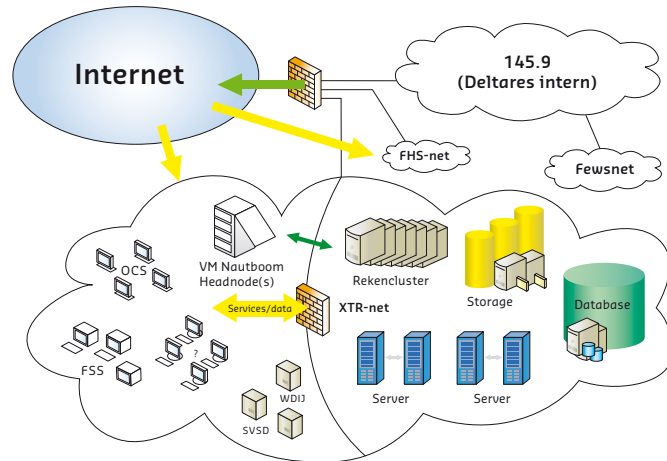
Schematic overview of the flood casualty analysis

Deltares supports the WMO HelpDesk on integrated flood management

This HelpDesk is a facility that provides guidance on flood management policy, strategy and institutional development to countries that want to adopt an integrated approach to flood management (IFM). The IFM approach, developed at the turn of the Millennium, aims at balancing development needs and flood risks in river basins within the overall context of Integrated Water Resources Management. It is based on close partnerships with the countries and tailored to their specific needs, with the aim of assisting in IFM implementation.

The HelpDesk is hosted by the World Meteorological Organization and is based on its philosophy of working together on weather, climate and water issues. Accordingly, the IFM HelpDesk operates through a decentralized network of technical and financial partner institutions that form the 'HelpDesk Support Base'.

The Letter of Engagement between WMO and Deltares was signed in March 2009.



Draft reference architecture for crisis management (Flood Control 2015)

Flood Control Room Simulator

The Flood Control Room Simulator is a training environment where decision makers can practise true-to-life calamities. The integrated philosophy of Flood Control 2015 with regard to flood protection is central in this. One of the uses of the control room is to train operators in the use of management systems, as well as in validating decision support systems. We also develop our own training programmes: how should information be provided so that it works best? Serious gaming methods are one of the ways we achieve this. Deltares cooperates with IBM and ARCADIS in this initiative under the Flood Control 2015 programme.

Deltares Academy: Understanding dike safety

Deltares Academy is Deltares' educational facility in the field of geo- and hydraulic engineering by means of international courses, masterclasses and ICT facilities. The international courses focus on knowledge development of professionals dealing with soil and water related projects. One of the courses provided by this facility deals with dike safety. This course has been developed for employees from national and regional agencies responsible for dike maintenance and dike safety. During this three-day course participants will see, learn and understand many different failure mechanisms. They will be able to predict, detect and monitor the mechanisms within a safety approach concept. The course focuses on four items:



Screen shot of the Levee Patroller: Game over!

- the state-of-the-art view on failure mechanisms; emphasis is on understanding the mechanisms rather than their mathematical descriptions;
- new developments in the field of inspection techniques for daily maintenance and for high water conditions;
- the know-how and experiences in application of reliability tools for different areas in Europe;
- case studies including a thorough analysis of the occurred events (New Orleans, Czech Republic).

The Levee Patroller: an example of serious gaming

Serious gaming is rapidly gaining recognition in training and education situations. Together with Delft University of Technology, Deltares has developed a training game for dike safety inspection, named the *Levee Patroller*. The game is used for educating levee patrollers in recognising dike failure mechanisms and to train them in the procedures they have to follow when such a failure mechanism is encountered. The virtual environment is an advantage because various situations that rarely occur but may have serious consequences, such as a dike breach, can be easily simulated. The trainees can learn by trial and error without serious consequences.

The option to make decisions about emergency measures in calamity situations requires trainees to think about the geotechnical aspects of the failure mechanisms and to choose a measure that controls the problem. It is also possible to practise each failure mechanism as a mini game in order to get used to the development of the different failure mechanisms and reporting.



Can we make flood risk management climate proof?

8

The design of robust flood management schemes should be based on a sound understanding of the impacts of climate change and should take into account the demographic and socio-political context. Climate change scenarios are therefore an essential part of flood risk analysis. In addition, the potential impacts of climate change on flood risks could be such that traditional measures and strategies do not suffice. The design of climate-proof adaptation strategies may therefore include new concepts for both flood defence (super dikes or climate dikes) and infrastructure (dry- and wetproof buildings).

Adaptation to impacts of climate change

Adaptation to the impacts of climate change is an important driver in flood risk management: how to deal with increasing sea levels and flood waves in rivers. The answer to this question includes the assessment of the vulnerability of areas to climate change, the design and evaluation of adaptation strategies and the advice to policy makers on how to cope with the uncertainties associated with climate change. Climate change and land use changes may have major impacts on the hydrological behaviour of water systems. With a variety of modelling techniques Deltares is able to quantify the effect of these changes.

Tipping points in flood risk management

Until recently, the general approach to developing strategies in response to climate change consisted of developing one or more possible climate scenarios and using them to calculate the effects of these strategies. An innovative approach uses tipping points to describe the extent to which the climate may change before current flood risk management is no longer adequate. A tipping point depends solely on the magnitude of change, and not on time. The results are therefore independent of the climate scenarios at a given time.



Stormy conditions at the harbour of Holwerd on December 2003

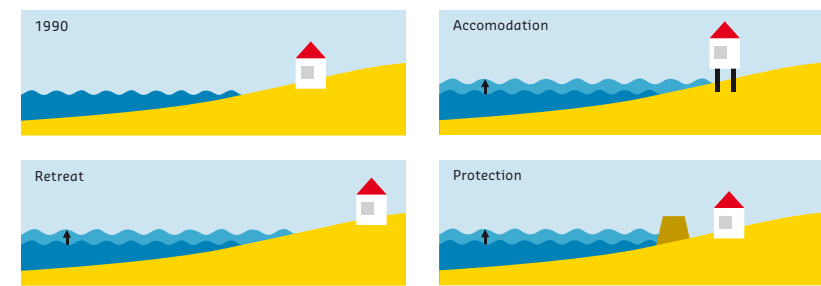
The reasons for abandoning the current management strategy could differ. For instance, it may have reached its physical, spatial and technical limits, or it may be considered to be too expensive. Maintenance of the current strategy could also become impossible when it involves socially unacceptable interventions or has reached its organisational or management limits.

Deltares has studied the tipping points for the Maeslant storm surge barrier. The barrier has been designed for a sea level rise of 50 cm at the most. Until this level has been reached, the rise in sea level can be dealt with by closing the barrier more often. However closing the Maeslant barrier more often is

recognised as a tipping point because the barrier was designed for a closing frequency of once in 10 years. A rise in the sea level of 50 cm implies an estimated closing frequency of approximately once in three years. More frequent closing means that the barrier will no longer fulfil its intended purpose because the entrance to the harbour will be seriously obstructed. For instance a sea level rise of 85 cm will push up closure frequency to once or twice a year and a rise of 1.5 m would mean that the barrier would have to be closed about 30 times a year (if no additional measures are taken in the tidal river area).

Coping with sea level rise

Of all potential impacts of a rising global temperature, accelerated sea level rise is probably the most important for deltas and other low lying coastal areas. Combined with the subsidence of delta soils, sea level rise can lead to a series of changes in the delta environment. It increases coastal erosion, thereby threatening human settlements and enlarging the risk of coastal flooding. Predictions for sea level rise range to 60 cm per century and more. Deltares has been a forerunner in global and national vulnerability assessment studies to sea level rise since the early 90s. Over the years a shift in attention has taken place from estimating the consequences of an accelerated rise in sea level to finding the optimal ways for coping and adaptation. In many cases the option of retreat is not very feasible, because of the many interests at stake and limited space in the coastal zone. Constructing or raising the dikes is often thought of as a traditional response, which in many cases are indeed appropriate. However how long can this strategy be maintained? Is it still feasible for a more than 1 metre sea level rise? Or should we go for alternatives, such as raising the land or making our houses flood resistant? Should we go for super dikes or – alternatively – go for building with nature?



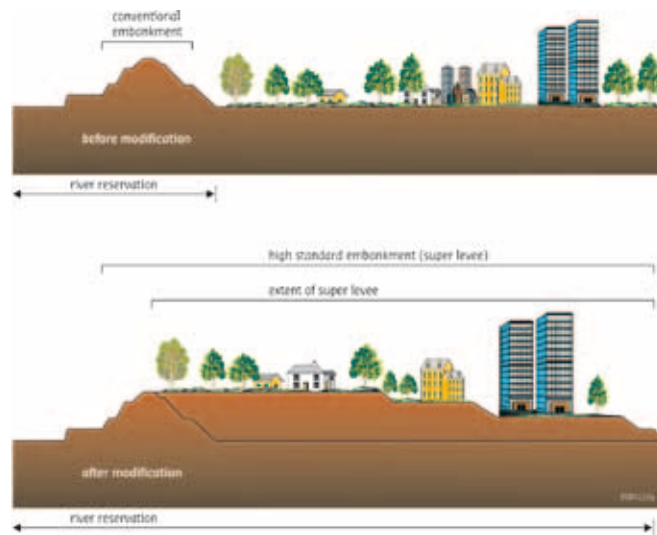
Response strategies for accelerated sea level rise

Climate dikes

The idea of dikes that cannot breach originates from Japan, where cities such as Tokyo, Osaka and Nagoya are protected with super levees 300 to 500 m wide. A super levee or dike is a broad river embankment which can withstand overflow. It prevents uncontrolled flooding due to a dike breach. The slope of the embankment is made very gentle. In the unlikely event that the river rises above the embankment, the water would spill 'gently' down the slope. The embankment is protected from destruction and serious damage to assets along the river is minimized.

The concept of super levees in Japan has inspired Dutch engineers and landscape architects to develop the concept of Climate dikes or Delta dikes. These Delta dikes, thanks to their height, width or structural reinforcements, should be sufficiently strong that uncontrolled flooding is practically excluded.

Studies and pilot projects are being executed through the water innovation programme of the Dutch government and Deltares. A growing number of organizations and networks are involved, including consultancy firms, landscape architecture companies, construction companies as well as regional and local authorities. An important goal of the programme is to gain experience with the climate dike concept.



Cross section of a conventional embankment design and a super levee design



To conclude



Floods can never be eliminated completely, despite our growing knowledge and experience. Many challenges still lie ahead. Global warming is an important, but not the only, driver of change. As economies grow, the potential damages of a flood increase too. Trade-offs between money spent on flood protection or on other societal demands constantly require difficult decisions. Decisions that have to be taken in a world of uncertainties. Providing the knowledge on risks and alternatives remains essential to reduce or deal with these uncertainties and to make informed choices. Deltares is striving to contribute to this endeavour as a partner together with other players in this field.

As we have shown in this publication, Deltares operates in nearly every part of the flood risk management domain. Many examples illustrate how we do this in collaboration with others. We collaborate with universities and research institutes all over the world. We work together with consultancy firms active in engineering, IT and management. We work with national governments as well as regional water authorities. We carry out our roles as knowledge developer, knowledge provider and knowledge broker. We do this in the conviction that only through a combination of knowledge and collaboration can we contribute to a better, more sustainable development of our flood prone areas: enabling delta life through managing flood risks.

We invite you to contact us and work together on these challenges for a safer world tomorrow.

Deltares Flood Risk Management Team

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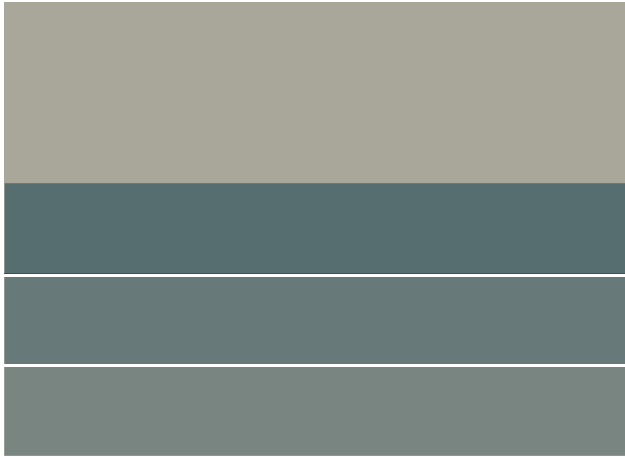
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