THESEUS

COASTAL PROTECTION

SMART IDEAS, SUSTAINABLE SOLUTIONS

THESEUS

INNOVATIVE TECHNOLOGIES FOR SAFER EUROPEAN COASTS IN A CHANGING CLIMATE

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http://www.theseusproject.eu

COOPERATION

A RISK AFFECTING US ALL

Are we truly aware that catastrophic storm events can also come our way? We all hear about floods. They mostly seem to happen in faraway places and perception is that they do not affect us directly.

Most flood events are associated with rivers, but recent storms have demonstrated significant impact on European coastlines. In November 2010 storm Becky caused considerable damage in about twenty ports along the Galician coast of Northern Spain. Earlier that year, at the end of February, the storm Xynthia had claimed 47 lives along the Atlantic coast of France.

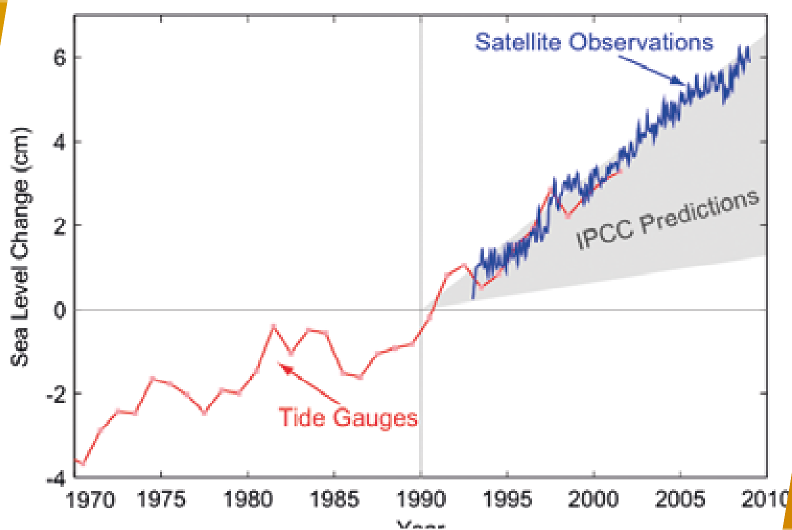
In fact, between 1998 and 2009, Europe suffered over 213 major floods causing 1126 deaths and at least €50 billion in insured economic losses.

SEA LEVEL RISE

Sea level rise due to climate change is one of the key parameters influencing the probability that flooding will occur. Sea level rise boosts the effect of storm surges and increases the likelihood of flooding, coastal erosion and the loss of flat and low-lying coastal regions. An additional 1.6 million people living in Europe's coastal zones could experience coastal flooding by 2080.

Global average sea level rose by 1.7 mm/year during the 20th century. Recent results from satellites and tide gauges in Europe indicate a higher average rate of global sea level rise in the past 15 years of about 3.1 mm/year. Projections by the Intergovernmental Panel on Climate Change (IPCC) for the end of the 21st century suggest a sea level rise between 18-59 cm above the average 1980-2000 level, with indications it might be even higher.

Therefore an expected rise in sea water level of some 50 centimeter should be taken into account during the design and management plans of coastal defense systems. However the potential impact of more extreme scenarios should also be taken in consideration.



Observations of change in sea level in the world in the last 40 years made by tide gauges (red line) and satellites (blue line). IPCC projections are shown in the grey zone. Until now satellite observations have confirmed the most pessimistic scenario. **Source: Trends in sea level rise since 1970. Copenhagen Diagnosis, 2009**

ASSESSING THE RISK OF FLOODING

The first step is to qualify and quantify risk in an objective way. Risk is defined as the probability of an event or hazard, multiplied by its consequences.

Risk = probability of occurrence x consequence

The probability and the consequences of a flood event can be assessed through the creation of a risk matrix. Risks can be prioritised according to their magnitude. Events with low probability and low consequences can be ignored, whilst events that are very likely to occur with severe consequences will be considered unacceptable.

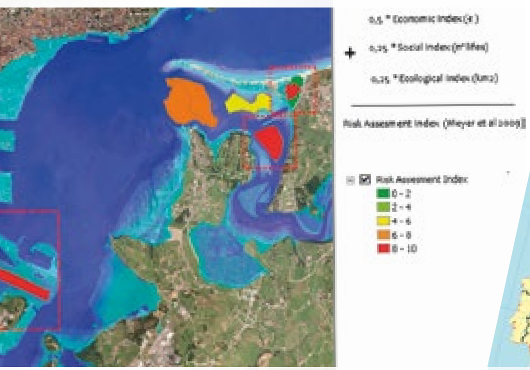
CONSEQUENCES			
Severe			Unacceptable
Considerable			
Minor	Acceptable		
	Unlikely	Likely	Very likely

PROBABILITY

The risk matrix is usually based on a combination of data (water level, wave height, wind speed and rainfall depth) obtained through observations, simulations using mathematical models and statistical analyses. With this data the probability that a coastal protection structure or river dike will fail given a certain load can be determined.

The consequences of flooding or erosion can then be assessed by calculating the damage to private and public properties, the natural environment and to people on the basis of topographic, socio-economic, land-use and demographic data. Loss of economic value, as a consequence, can be readily quantified, and hence so can the economic risk. However less tangible values related to, for instance, habitat loss or quality of life, require informed judgments to be made.

Technical tools such as the DSS (Decision Support System) developed during the THESEUS project can offer considerable support in evaluating alternatives and in the decision making process.



Coastal lowlands (indicated in red) are particularly vulnerable to Sea Level Rise. Map EEA

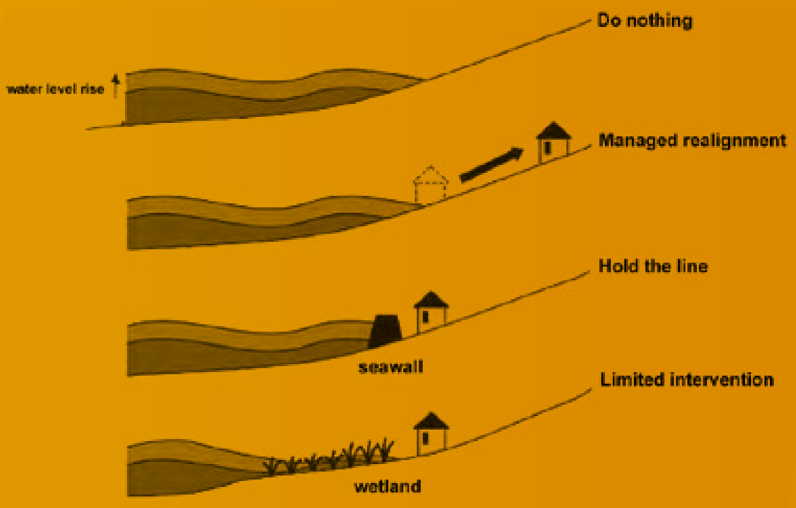
The THESEUS Decision support system (DSS), plots the high risk area's based on predefined scenario's. Here applied to Santander Bay.

MANAGING THE RISK

Once the risk has been assessed it can be mitigated. Risk Mitigation is the process of reducing the damages to services, goods and people, by **reducing the intensity or the patterns of the hazard** *(e.g. by placing barriers, by attenuating waves or through beach nourishment projects)* by **reducing the hazard exposure** *(e.g. by early warning and evacuation plans)*, and/or by **increasing social and economic resilience** *(e.g. by using insurance premiums, spatial planning and risk communication*).

As sea levels rise, many of the current structures will need to be upgraded or replaced to cope with the reduced safety levels. In many cases very innovative alternatives will need to be worked out. Increasingly popular ideas include restoring and supporting the natural development of salt marches and sand dunes, the creation of flood plains which can be opened in the event of exceptional high sea water levels, and artificial damping of wave energy in the coastal region.

Risk mitigation is nowadays multidisciplinary. It is recognized that a comprehensive cost benefit analysis with room for the integration of all **engineering, ecosystem** and **socio-economic** based options is needed as part of an integral decision process.



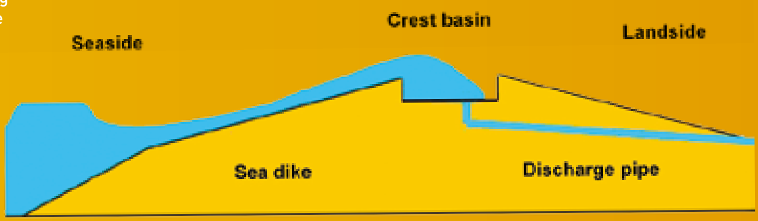
Different policy options for coastal management. Adapted from 'A guide to coastal erosion management' Heurtefeux *et al.* 2004, also on http://www.coastalwiki.org/

HIGHER DYKES?

A temporary rise in sea water level (up to meters) above the normal water levels is known as surge. During these surge events, caused by strong storm winds, the water gets piled up against the coastal protection structures. When it occurs during spring tide, a surge can lead to very dangerous situations.

Flooding of coastal areas is usually caused by wave overtopping or even breaching of the protection structures. Continuous overtopping damages the landward slope of the dyke, and can eventually cause to breach it. This might in the worst-case lead to a complete failure of the dyke due to soil instability.

›A Schematic presentation of a crest drainage dike in operation. The incoming water is captured in the basin and then drained either inland or back to the ocean (Jørgen Harck Nørgaard, *et al.* 2011. THESEUS ID 2.2, Part H. Upgrade of rubble mound structures.)



If some overtopping is acceptable the dyke's resilience against it can be improved by decreasing the angle of the landward slope and by providing an erosion resistant cover layer on the dyke. The amount of overtopping water can be limited by decreasing the angle of the outer slope, by increasing its roughness, by applying a berm or by increasing the height of the dyke's crest.

Stilling wave basins provide a quite innovative solution. Such basins are made up of an open seaward wall, a basin and a 2nd landward wall. In the basin the energy of the incoming waves is forced to dissipate so that over-topping of the landward wall is no longer possible. The open seaward wall allows the water to flow back to the sea.

A **Crest Drainage Dyke** is a similar construction and a possible option when overtopping of the dyke as such cannot be avoided. The basin is build on top of the dyke crest to "catch" the overtopping water. The water is then returned through drains either back to the sea or to a drainage basin on the landward site.

^The Zeeheldenplein in Ostendt is a nice example of a stilling wave basin
Picture: VLIZ (Decleer)

DID YOU MENTION BREAKWATER?

Attenuating the energy of the waves before they reach the dykes is a hot topic. While traditionally coastal engineers relied solely on groynes and breakwaters to carry out this task, alternative options are gaining popularity. **Natural barriers**, foreshore, beach and dune **sand suppletions, artificial reefs** and innovative **floating breakwaters**, all find their way into coastal protection strategies.

Artificial reefs consist of man-made hard substrates put onto the sea floor. They alter local hydrodynamics on purpose. Like breakwaters, artificial reefs can be used for breaking or attenuating waves, possibly even enhancing biodiversity and therefore keeping environmental impact to a minimum.

› "Reef balls" are installed on the ocean to form artificial reefs
Picture: VLIZ

The Belgian **action plan "Zeehond"** is experimenting with artificial reefs to increase local biodiversity. Installing artificial reefs is hoped to affect currents, leading to the establishment of biogenic reefs formed by tube-building polychaete worms in areas with slower currents. The artificial reefs themselves might provide a suitable substrate for the development of oyster banks.

Floating breakwaters are a possible alternative to traditional breakwaters for reducing wave intensity. Floating breakwaters work by attenuating and reflecting part of the wave energy and can decrease erosion rates and therefore also reduce flooding risks in coastal areas.

The main advantages of floating breakwaters is that they keep their efficiency with increasing sea water levels, their position can be rearranged and they are easier and cheaper to install. Especially at locations with a high depth are floating breakwaters an interesting solution. Important disadvantages are they need to be anchored and aren't esthetically attractive.

^A floating breakwater was installed within 24 hours in Holy Loch, Scotland
Picture: Intermarine Limited

A CASE STUDY

SCHELDT ESTUARY

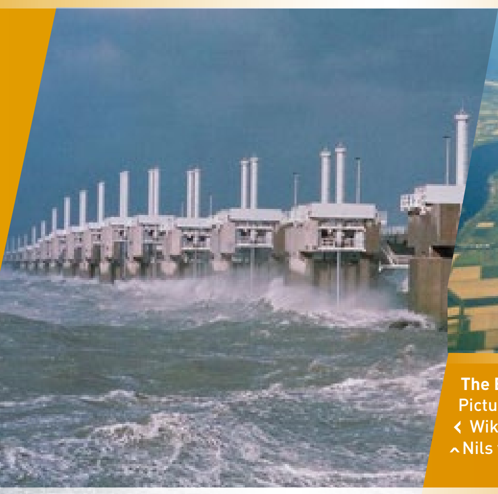
Like in many other European estuaries the management of the Scheldt River has to deal with opposing interests. Economic interests demand that large commercial cargo ships can reach the ports of Antwerp and Ghent as fast as possible. However the necessary modifications of the channel can affect the safety and the nature value of the estuarine ecosystem. The deepening of the channel contributed to the significant increase of the mean tidal range during the last century. This means that during each tidal cycle a higher volume of water enters and leaves the channel, which affects the currents and may impede the tidal ecosystem. Higher tidal ranges include a decrease in minimum and an increase in maximum water levels, the later one affecting the probability of flooding.

Several important floods have hit the Scheldt estuary area. Still in recent memory are the flood of 1953 mainly in the Netherlands and the flood of 1976, which mainly hit Flanders. These disasters led to the start of the Delta Works in the Netherlands and to the implementation of the Sigma Plan in Flanders.

Execution of such major coastal protection plans takes decades, and these plans have been revised along the way.

For example the original plan was to dam the Eastern Scheldt entirely instead of using the gated storm surge barrier, which was finally installed. The huge doors normally remain open, but can be closed during storm surges. Also the Sigma Plan has been altered recently to include the construction of flood areas; a solution which favours shipping, safety and nature.

In order to deal with the complex management of this estuarine system, the international Flemish-Dutch Scheldt Commission has been established. A long-term vision (2030) has been worked out in order to help managers make balanced decisions considering safety, socio economic development and nature values.



The Eastern Scheldt Storm surge
Pictures:
‹ Wikimedia, Rens Jacobs
^ Nils van der Burg, adapted by VLIZ

THE VALUE OF THE SCHELDT ECOSYSTEM

Erosion of salt marshes can reduce coastal protection levels.
Picture: Jim Van Belzen

Sensor used to measure wave attenuation above an oyster bed
Picture: Jim Van Belzen

The Scheldt ecosystem is characterised by dunes and salt marshes although one can also encounter sea grass patches and biogenic reefs such as mussel banks and oyster reefs.

The **dunes** are mainly found at the river mouth. They can reach heights up to 20 meters and therefore act as a natural barrier against flooding during storms.

Besides being ecologically important, **salt marshes** contribute to coastal protection because the vegetation attenuates wave energy and therefore reduces the pressure on the dykes. Research showed that also mussel banks, oyster reefs and sea grass can attenuate wave energy and thus contribute to coastal protection.

A patchwork of mussels and mud. Picture: Jim Van Belzen

Integrating these natural ecosystems in coastal protection plans has important benefits. Ecosystems can naturally adapt and regenerate after storms, as opposed to dykes, which will always need to be maintained and repaired. If the water contains enough clay and silt particles, it's even possible for the sea floor to keep track with sea level rise.

As dykes will not need to be as high to reach the same level of protection, integrating these ecosystems in the coastal protection plan can reduce the costs for improving or maintaining protection levels. Moreover these ecosystems provide beautiful landscapes with high ecological and recreational values!

THE DENDERMONDE AREA

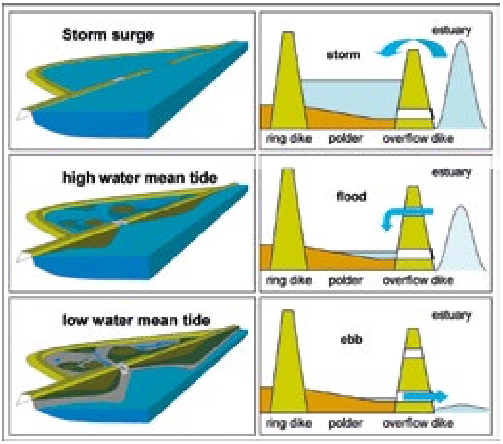
The Dendermonde area is a flood prone area at the confluence of the Scheldt river and its main tributary river, the Dender.

During high tide, the weir at Dendermonde and the ones more upstream along the river Dender are closed. The upstream flow volumes of the river are then temporarily stored in the river stretches between the weirs. During periods with extremely high tidal levels in the Scheldt and/or extremely high upstream Dender flows, floods can occur due to: Scheldt levels exceeding the Scheldt dike crests or water stored along the Dender exceeding the river's storage capacity. The latter can be due to prolonged high tidal levels (hence long closure of the downstream Dender weirs), or high upstream Dender flows, or to both effects combined.

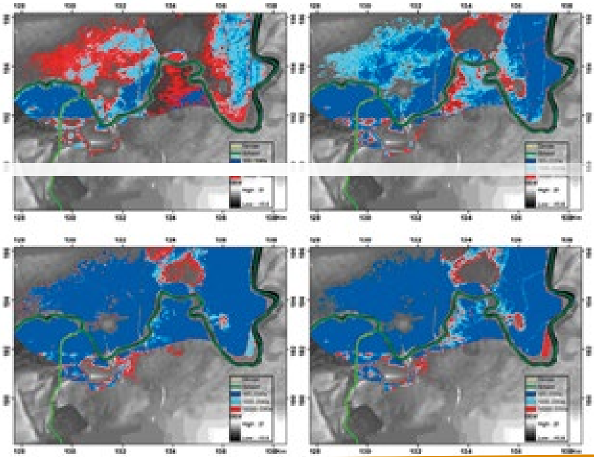
›Flood control area (Lippenbroek) along the Scheldt river. Water gets stored in during high tide and storm surges. During low tide a weir is opened to allow the water to flow back to the river.

During the THESEUS project an innovative approach was used to study possible effects of climate change. Based on a detailed sensitivity and correlation study, three future climate scenarios were selected for impact studies for the Dendermonde region in the 2080's: i) an extreme scenario combining an extreme sea level rise (SLR) of 2m with increased surge levels (21%) and increased (30%) upstream flow discharges; ii) a high scenario only differing from the extreme in the assumption on SLR (now set at 0.6m); and a mean scenario where a SLR of 0.6m is combined with a more moderate estimate for the surge levels (6%) and upstream flow discharges (16%). This method is innovative as it takes into account the correlation between surge levels and upstream flow discharges.

On the resulting Dendermonde flood maps, the impact of climate change is clearly visible. What was considered a very rare 1/10000yr event in 1990 will be a 1/100yr event in 2080!I



^Figure: Ecobe UA adapted by VLIZ



^Dendermonde flood maps (high scenario); upper right 1990 and then clockwise 2020, 2050 and 2080. Return periods: dark blue =1/100; light blue = 1/1000; red=1/10000.

MORE INFORMATION

Theseus Project
http://www.theseusproject.eu

European Flood Directive
http://ec.europa.eu/environment/water/flood_risk/index.htm

Permanent Service for Mean Sea Level
http://www.psmsl.org/

Sigmaplan
http://www.sigmaplan.be/en

Delta Works Online
http://www.deltawerken.com/English/10.html?setlanguage=en