THESEUS

COASTAL FLOODING

INNOVATIVE WAYS TO MITIGATE THE RISKS

RISK MITIGATION

Our coasts are increasingly threatened by flooding and erosion. As sea levels keep rising due to climate change, finding appropriate measures to protect our coastal environments and ensure the safety of the population and their various assets is one of the key challenges facing us today.

Mitigation is the process of reducing the damages to services, goods and people in the exposed areas, by reducing the intensity or the patterns of the hazard (e.g. by placing barriers, by installing wave energy farms, or through 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).

Traditionally coastal engineers chose for hard measures for protecting the hinterland by building structures such as groynes, breakwaters and dykes. Many of the current structures will need to be upgraded or replaced to cope with the reduced safety levels. This is not a trivial task at all. In many cases very innovative alternatives will need to be worked out.

Risk mitigation nowadays is multidisciplinary. THESEUS scientists from the very different fields of engineering, ecology and socio-economy have committed themselves to come up with innovative cross-boundary scientifically sound mitigation options for efficient coastal defence strategies. This booklet highlights some illustrative examples.

Mitigation measures require a multidisciplinary approach, including engineering, ecology and socio-economy (Picture copyright Danish Coastal Authority)

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INNOVATIVE TECHNOLOGIES FOR SAFER EUROPEAN COASTS IN A CHANGING CLIMATE

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HOLD THE LINE?

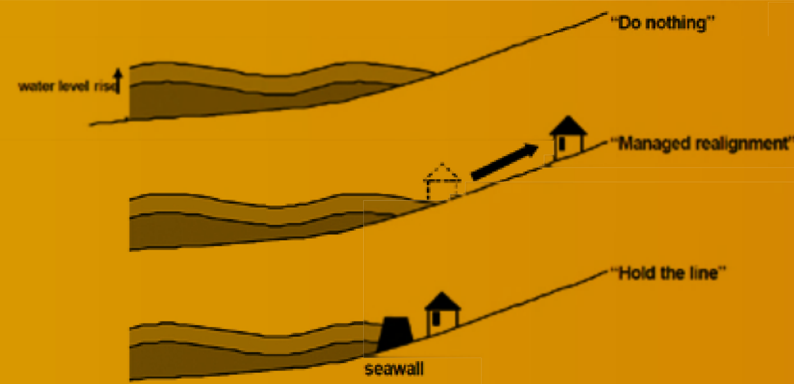
The traditional approach towards coastal mitigation was building hard defence structures to limit the probability of flooding. Building higher, longer and more barrier structures such as dykes, breakwaters and groynes to counter the increased flooding risks associated with climate change and sea level rise, was typical for the **"hold the line"** approach towards mitigation.

However, the costs of upgrading or replacing a coastal defence structure might become prohibitive and far outweigh the value of the assets in endangered zones. Discouraging or even prohibiting development in these high risk areas might be an option.

Alternative ideas deserve some more attention. 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 damping of the coastal wave energy.

Also **"managed realignment"** has gained in popularity in recent years among coastal managers, developers and engineers. One of the main features of this approach is the creation of natural buffer zones between the sea and the high assets areas.

Clear cut solutions usually do not exist and a comprehensive cost benefit analysis with room for the integration of engineering, ecosystem and socio economic based options needs to form an integral part of the decision process.



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

HIGHER DYKES?

A temporary rise in sea water level (up to meters) above the normal water levels induced by astronomic tide is known as surge. During these surge events caused by strong storm winds, the water gets piled up against the coastal defence structures. The possible increase in intensity and frequency of storm events in certain coastal regions combined with the undeniable rise in sea water level, both connected to climate change, poses a threat to coastal low lands.

Flooding of coastal areas is usually caused by wave overtopping or even breaching of the defence structures (usually dykes). A well known mechanism for dyke breaching is continuous overtopping damaging the rear or landward slope of the dyke. This might in the worst case lead to a complete failure of the dyke due to soil instability. A well known example of dyke breaching due to wave overtopping, is the 1953 North Sea flood claiming more than 1800 lives in the Netherlands.

There are 2 ways to deal with this problem:

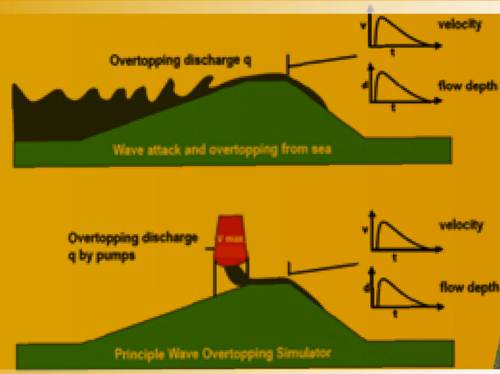
1) Allow for some overtopping by improving the **dyke's resilience to wave overtopping.** This can be done by decreasing the angle of the landward slope and thus also making the dyke wider and/or by providing an erosion resistant cover layer on the dyke. Full scale experiments (see picture) are used to create models for the design of overtopping resistant dykes. The presence of a second landward dyke can ensure additional safety.

2) When no overtopping is allowed, the amount of overtopping water can be limited by decreasing the gradient of the outer slope, by increasing its roughness, by applying a berm or by increasing the height of the dyke's crest.

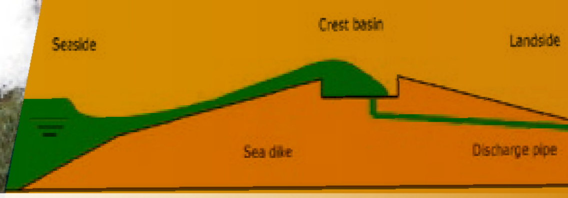
Stilling Wave Basins provide a quite innovative solution. Such basins are made up of an open seaward wall, a basin and a 2nd landward wall. In the basin the energy of the incoming waves is forced to dissipate such that overtopping of the landward wall is no longer possible. The open seaward wall allows 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 safe place on the landward site.

Architectural design can integrate such structures beautifully into the coastal landscape.



Through experiments with the wave overtopping simulator, THESEUS project scientists determine the resistance of dykes to wave overtopping. The figures illustrate the working principle and show an overtopping simulator in operation (Van der Meer Consulting b.v.; INFRAM b.v.).



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. (Adapted from Nørgaard, J. H., Andersen, T. L., Burcharth, H. F., Sergent, P., & Prevot, G. (2011). THESEUS Deliverable ID2.2: Part H - Upgrade of rubble mound structures)

DID YOU MENTION BREAK-WATER?

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 in protecting our coasts.

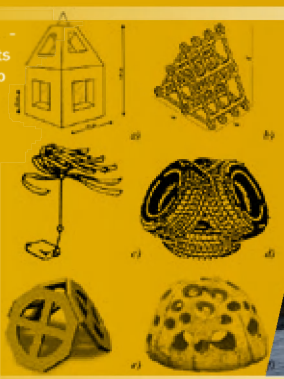
Artificial reefs consist of man-made hard substrates put onto the sea floor. They alter local hydrodynamics on purpose. Like breakwaters, artificial reefs can be used for breaking or attenuating waves, possibly even enhancing biodiversity and therefore keeping environmental impact to a minimum.

Artificial reefs for coastal protection can be constructed from a wide range of materials such as stones, geotubes and the smaller geobags (both are geotextile bags filled with sand or gravel) and pre-constructed reef units which are often designed to provide shelter and serve as nursery areas for fishes.

Floating breakwaters are a possible alternative to traditional breakwaters for reducing wave intensity. Box type floating breakwaters, probably the most frequently used type of floating breakwaters, consist of reinforced concrete boxes with empty interiors (or with a core made from light materials) that are moored to the sea bed with chains, piles or cables. 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.

Floating breakwaters have advantages compared to traditional breakwaters: they keep their efficiency with increasing sea water levels; their position can be rearranged and they are cheaper and easier to install, to move or even to remove. Floating breakwaters will never completely replace the traditional breakwaters. To effectively attenuate incoming waves, the width of a floating breakwater needs to be half as large as the incoming wave length. Such widths are often not feasible. Therefore unlike traditional breakwaters, floating breakwaters are not well suited to create completely sheltered areas in coastal waters.

S
constructed reef units (Courtesy Mirko Castagnetti and Barbara Zanuttigh. More info at http://www.theseusproject.eu/wiki/Artificial_reefs)



Bioblocks can be incorporated into traditional coastal protection structures to increase biodiversity. (Courtesy David Thomas, Bangor University)

Floating breakwater made from plastic pipes can be used to protect against waves from recreational vessels (Copyright Kuznetsov).

BLUE ENERGY MEETS COASTAL MITIGATION?

A **wave energy converter** (WEC) is a device that captures wave energy. Waves that have passed through a WEC farm have reduced energy levels and this is beneficial for coastal protection. WEC's have the potential to produce blue energy while at the same time protecting our coasts from wave attacks.

There is a wide diversity in wave energy converter types. WEC's can consist of floaters moving up and down with the waves thereby powering a generator. Such floaters can be deployed off shore or near the coastline.

Alternatively WEC's can be integrated into coastal defence structures such as breakwaters. Such WEC's can either function by harvesting the impact energy of the waves or by guiding water rolling in with incoming waves into a hydro turbine.

Wave Energy Converters could be integrated in Coastal Defence structures (Copyright Pelamis)

For WEC's to be useable as a coastal mitigation technique they should be able to reflect and/or absorb a significant part of the wave energy even during extreme storms, when protection is most needed. On the other hand to produce energy, they should work well in normal operating conditions. It remains an enormous challenge to combine both functions in one device.

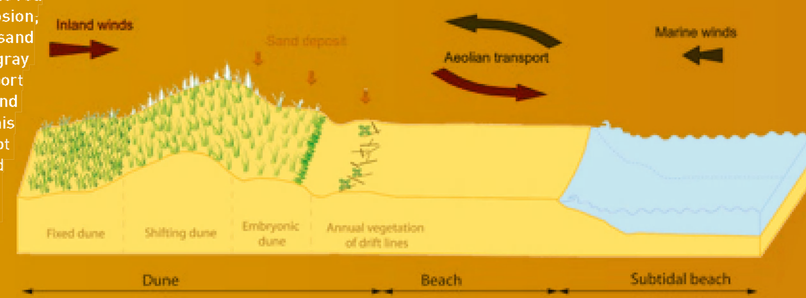
WORKING
HAND IN HAND WITH NATURE

Natural habitats such as **coastal dunes, salt marches, bottom vegetation** and **biogenic reefs** offer natural protection against coastal risks. It is very important to understand the natural dynamics of these systems, how to conserve them and how they can be used in coastal mitigation plans.

Coastal dunes are widely distributed across Europe and cover more than 13,000 km of the European coastlines. Dunes are formed on beaches. Plants trap and stabilize sand, which would otherwise be blown away by the wind. Dunes are a natural barrier against flooding during storms. Dune, beach and subtidal beach form one system. During storms, the dune serves as sand stock for the eroding beach. In calm weather conditions dune and beach are rebuild. In structurally eroding coasts, regular nourishment can be a safe and cost effective coastal protection measure.

A **salt marsh** is a salt or brackish water environment on the land-water edge of the coastal zone. Salt marshes can usually be found in sheltered areas, in estuaries and in protected bays with shallow water. The landscape is dominated by dense stands of salt-tolerant plants (herbs, grasses or low shrubs). They can provide coastal protection in several ways: In wave exposed areas, the marsh vegetation not only dampens the waves, but their roots also prevent sediment erosion due to wave impact. Salt marshes slow water down and stimulate sedimentation allowing many salt marshes to keep pace with sea level rise. Upstream in estuaries, salt marshes can store excess water during spring tides or during periods of high river discharge and thus provide an important buffer against river flooding.

A schematic cross section of a dune beach system. The red arrows indicate sand erosion; the yellow arrows indicate sand deposits; the blue and gray arrows indicate sand transport which may lead to sand deposits or erosion. Often this system is not in balance and sand nourishments are necessary (Copyright EID)



Bottom vegetation, such as **seagrasses** and **macroalgae** have dampening effects on wave intensity. Denser vegetation with a higher canopy will have a bigger impact. Vegetation can therefore contribute to coastal defence by reducing wave height and thus the probability of wave overtopping and flooding. In the same way as it does in salt marshes, bottom vegetation protects against erosion by decreasing the current flow, retaining suspended sediments and therefore enhancing sedimentation and by preventing re-suspension by the stabilising effect of the roots.

A reef can be defined as any structure in the marine environment that arises from the seabed and covers an extensive area. In European waters several organisms can form **biogenic reefs.** These can range from enormous structures formed by cold-water **corals,** large **mussel** and **oyster beds** to smaller aggregations of **tube-building polychaete worms.**

Although there is no doubt that biogenic reefs contribute to coastal protection by reducing wave intensities and by retaining sediments, the possible contributions of most types of temperate reefs around Europe remain largely unexplored. Of large **mussel beds,** it has been shown that their irregular structure (with mussels being partly incorporated in the sediment and partly in the water column), causes the water flow to slow down and enhance sedimentation. Mussel beds can also attenuate or even break waves, and so reduce the risks of wave related erosion and of overtopping (and flooding) of coastal defence structures during storms.

A biogenic reef of *Sabellaria alveolata* at Dubmill Point, Scotland (Courtesy Louise Firth)

WHAT ABOUT THE SOCIO-ECONOMY?

Flood risk involves both the probability of flood and the potential damage it can inflict. Potential damage and therefore also mitigation has a socio-economic dimension.

During rare extreme events the **primary focus** goes to safeguarding lives. In such events evacuation might be the one and only option. A reliable **flood forecasting system** and **emergency and evacuation plans** are a must, but in order for the population to cooperate, it needs to be (made) **aware** and needs to accept that a "100% no flood guarantee" does not exist.

The main mitigation options to reduce the vulnerability of **economic assets** (mainly people's houses and businesses) are insurance policies and government compensations (disaster funds). The insurance market plays a critical multidimensional role in flood risk management: transfer of risk, enhancement of risk awareness, promotion of resilience in the aftermath of a disaster, reduction of flood vulnerability and sensitivity by affecting "perceived risk", and support for the rebound of the socio-economic system in case of a disaster. As a simple example, insurers can lower the premiums of properties that invest in reducing their exposure to flooding or only offer payouts if measures are taken to make the property more flood resilient.

Socio-economic impact on Coastal flooding in the South of France, Vias, 2003 (Copyright EID)

A CASE STUDY THE GIRONDE ESTUARY

The estuary of the Gironde, with an area of 450 km² the largest estuary in Europe, is regularly subject to flooding caused equally often by storm surge as by high fresh water discharges from the two upstream rivers, the Garonne and the Dordogne. Flood risk is of major concern for local authorities. This risk is well known and historical documents go back to the thirteenth century. In response to an exceptional flood in 1770 that covered 24.000 ha of land along the banks of the estuary, measures were taken to reduce the impact of flooding. These and also more recent measures however, did not prevent new floods in recent years, as in 1981, 1999 and very recently in 2010 due to the storm Xynthia.

Protection measures now cover both land use and urban planning taking into account the exposure (flooding risk prevention plans) and the realization of structural elements to protect local areas. Special attention is paid to the rehabilitation and homogenization of the system through the existing national coastal and flash flood prevention plan adopted in 2011.

At the more local level, national authorities and local communities are involved in focus groups to discuss on a coherent strategy on the scale of the estuary. This is the action plan for flood prevention. A first phase of this plan was launched in 2012.

Organize a controlled flood to avoid this type of repair after Xynthia: dyke Dauzac (CETE SO - DLB)

Illustration of the existing protection for identified problem areas: Blanquefort Marsh

Spill fuse weir near completion in November 2007, Allan River (Hydro Plus)

The in depth discussions made it possible to define adequate protection adapted to the local hydrodynamics and based on identified challenges (protection of dense urban centers, local towns, industrial sites). The 1999 storm event augmented by twenty centimeters was used as a reference for the Verdon region.
It was realized that the hydraulic impact could be compensated better by increased mobilization of storage areas with little or no impact on humans. The work was started using the following principles:

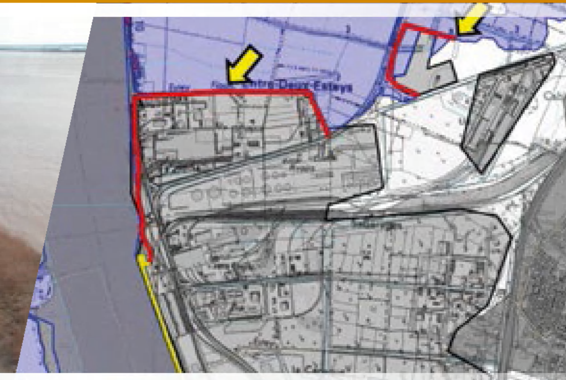
- no increased risk compared to the current situation for non-protected items
- no change in the frequency of overtopping
- control of the flooded areas by limiting them to areas without human occupation

Working principle of fuse plug dykes to inundate extra zones of floodable marshland.

Together with other connected measures, dykes with controlled overflow are being considered in order to flood the marshes and other areas for temporary water retention. La Jalle de L'Olive must be recalibrated to a width of 25 m and a bottom level of one meter, and a regulating structure of 5 m high and 10 m wide needs to be realized. Two road crossings of 50 m wide should be made. In addition, a fuse plug dyke must be created along the Garonne river bed over a length of 685 m and along the northern part of Jalle de la Bécassine. Innovative uses of the principle of fuse plug dykes is not exhausted, different concepts exist such as lower crest levels and spill fuse weirs.

Protection of industrial areas by raising the level of dykes along river summer bed

The industrial zone of Bassens is protected from flooding by creating lateral (earthen) dykes along the 'estey' (local word for creek) and local protection is added by the construction of small earthen dams. Along quays, mobile barriers and low concrete walls provide additional protection.



A fuse spill weir can be installed along the dyke (CETE SO - DLB)

Protection Industrial Zone Bassens / Lormont (Artelia)

MORE INFORMATION

Theseus Project
http://www.theseusproject.eu

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

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

Schéma d'Aménagement et de Gestion des Eaux de l'estuaire de la Gironde et des milieux associés
http://www.sage-estuaire-gironde.org/site/index.php

Direction Départementale des Territoires et de la Mer de la Gironde
http://www.gironde.developpement-durable.gouv.fr/