12 Safety against flooding

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Flooding along the coast can be driven by storm surges and sea level rise. In Europe, the coastal regions with the highest flooding risk are the North Sea coasts of Belgium, the Netherlands and Germany, as well as the Mediterranean coastal area of northern Italy (EEA Report 2017). The North Sea coast of Belgium, characterised by coastal dunes, sandy beaches and a naturally soft foreshore, may be vulnerable for violent storm surges (Quante and Colijn 2016). To date, no increased erosion could be demonstrated for the Belgian coast because the coastline is maintained by beach nourishments and in certain zones natural sediment accretion occurs (see also the CREST project).

Flooding of low-lying polders due to heavy rainfall may occur in the coastal region as well, but is not unique for this zone. It is important to also take into account a possible flooding of the hinterland, especially since the changes in precipitation by 2100 may be 10% higher along the coast than inland (Van Steertegem 2009). Due to the strong increase in extreme, short-period rainfall events, sewage and other drainage systems will face additional stress in the future (Brouwers et al. 2015). An additional challenge in the coastal zone concerns the integration of flood risks from inland waters (such as the Yser river) on the one hand and from the sea on the other (e.g. Willems 2013). As such, the decrease of the time window for discharges of excess water from the hinterland to the sea as a result of sea level rise requires additional attention. However, in this thematic chapter, flooding of the hinterland will not be further considered.

Climate influences: rising sea levels and storm surges

The Flemish Environment Agency (VMM), in collaboration with the Coastal Division among others, has developed the Climate Portal Flanders, which maps the climate situation with maps, key figures and graphs. In this portal, the current climate situation (temperature, precipitation, etc.), the effects (flooding, heat, drought, etc.) and the impact (casualties, costs, etc.) of climate change can be consulted. Furthermore, climate scenarios up to 2100 can be visualised.

Global long-term climate scenarios are published by the Intergovernmental Panel on Climate Change (IPCC). Brouwers et al. (2015) further provides an overview of the available scenarios with respect to sea level rise and storm surges for the Belgian coast. Within the context of the Coastal Vision project and the CREST project, climate projections were made for the IPCC climate scenarios RCP2.6[1], RCP4.5, RCP8.5 and one extreme scenario, with time horizon 2100 (CREST project and Flemish government 2018). Such assessments are important to provide sound underpinning of flood safety policies.

Between 1902 and 2015, the average sea level on earth increased by 0.16 m. The average annual increase has not remained the same during this period, but has accelerated. Today, the global average (calculated over 2006-2015) is 3.6 mm per year, corresponding to about 2.5 times the rate of the average increase of 1.4 mm per year between 1901 and 1990 (IPCC 2019). This exceeds the sustainability goal of maximum 2 cm rise per decade (Brouwers et al. 2015). Human activities are the main cause of sea level rise since 1970 (Slangen et al. 2016, IPCC 2019). The magnitude of sea level rise may vary locally. This can be explained in part by the non-uniform distribution of changing water density, a different impact of changes in ocean circulation, and local vertical (both upward and downward) movements of the earth's crust (website Milieurapport). The statistical analysis of the data is not easy because sea level is not only affected by climate change, but also by natural fluctuations. Nevertheless, it can be deduced from the series of measurements of the Belgian coast that the annual mean sea level[2] in 2019 is significantly higher than at the beginning of the measurements. In Ostend this is an increase of 134 mm between 1951 and 2019 (figure 1). In previous decades, significant increases in the annual average sea level were also recorded for Zeebrugge and Nieuwpoort (website Milieurapport). In addition to sea level, high and low tides can be analysed. In Ostend an approximate linear trend increase of high waters of 2 cm per decade is observed (Willems 2015). Since 2013, the annual mean high water heights are systematically higher than the trend line. Further research should reveal whether this is effectively an accelerated upward trend, or due to long-term oscillations (Willems 2019). From a data analysis of the extreme high waters at Ostend, the storm surge[3] shows a small additional increasing trend of 0.2 mm/year in addition to the yearly average increase of the astronomical component of 1.8 mm/year. However, this trend is not statistically significant taking into account the natural fluctuations in the occurrence of storms (Willems 2019).

[1] RCP (Representative Concentration Pathway) scenarios are scenarios that describe the evolution of greenhouse gases up to 2300 and are used in the fifth report of the Intergovernmental Panel on Climate Change (IPCC). The RCP8.5 scenario is the most extreme, pessimistic scenario and implies that nothing is done to combat climate warming. This is the so-called business-as-usual-scenario (Source: Royal Meteorological Institute of Belgium (RMI)).
[2] The sea level in Figure 1 is expressed in m RLR (Revised Local Reference). This means that the data of a local reference (for the Belgian coast this is the TAW or *Tweede Algemene Waterpassing*) to the international reference level.
[3] The storm surge heights can be calculated in two ways: the so-called straight surge or the skewed surge. For the skewed surge, the total flood elevation is reduced by the astronomical flood elevation during the same time cycle, with both often not occurring at the same time. For the straight surge, the total flood elevation is reduced by the astronomical water elevation at the same time (Willems 2019).

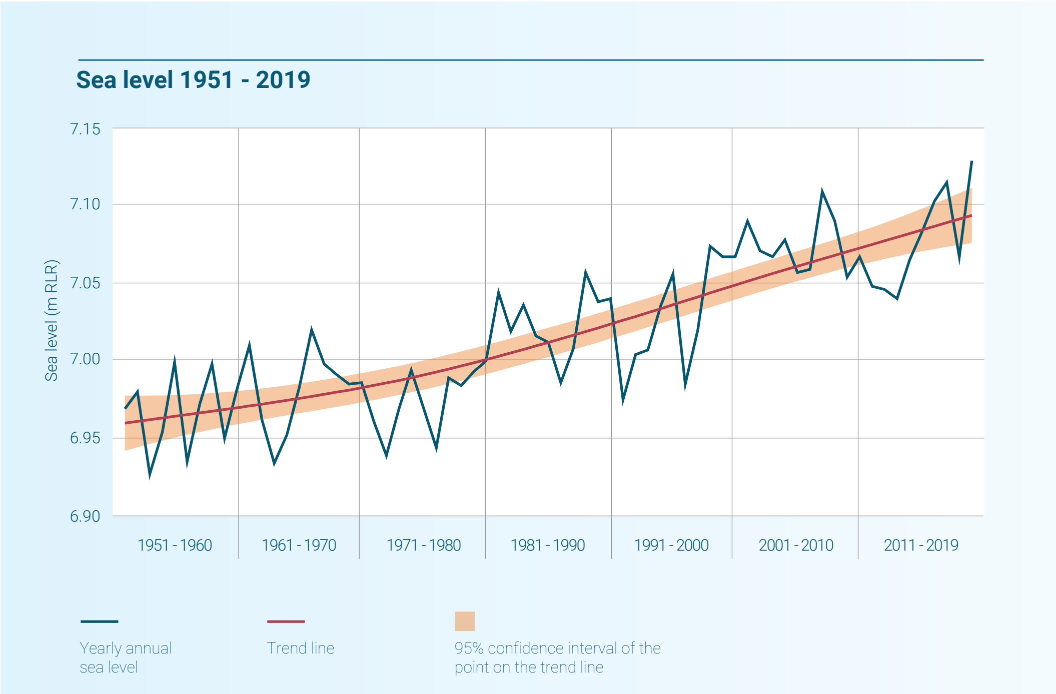

Figure 1. Evolution of the sea level on the Belgian coast (Ostend, 1951-2019) (Source: Milieurapport).

Events such as storms and floods are classified according to their return period. This return period represents the recurrence period of an event. A return period of 100 years means that a certain event occurs on average every 100 years, and thus there is 1 chance out of 100 that a particular event will occur in the next year. It is interesting to note here that with an (additional) sea level rise of about 50 cm, the current return period of a storm with a level of + 7.0 m TAW (Second General Water Supply) will shift from 1 chance out of 1,000 to 1 chance out of 100 per year (table 1). An increased storm frequency could not be demonstrated for the Belgian part of the North Sea (BNS) (Van den Eynde et al. 2011, CLIMAR project BELSPO, Hossen and Akhter 2015). Based on predictions with climate models, assuming an RCP8.5 scenario for the last thirty years of the 21st century, no significant increase in storm surge is expected, however an increase in extreme wind speeds is predicted (Van den Eynde et al. 2019).

Table 1. An overview of the flood risks in the Belgian coastal area in 2015 for different storm surge levels and return periods, including the associated casualties and the direct economic damage (Vanneste et al. 2018). (These numbers also include flood risks in the outskirts of Zeebrugge, albeit with simplified assumptions.)

Flood risks in the Belgian coastal zone			
Storm surge level	**Return period**	**Casualties**	**Direct economic damage**
+ 6.5 m TAW	~100 year	40	1.061 billion euro
+ 7.0 m TAW	~1,000 year	215	3.884 billion euro
+ 7.5 m TAW	~4,000 year	570	6.873 billion euro
+ 8.0 m TAW	~17,000 year	2147	10.491 billion euro

12.1 Policy context

At European level, the Floods Directive (Directive 2007/60/EC) was adopted in 2007 out of concern for the harmful effects of any flood on people, nature, heritage, economy etc. and the possible increase in the number of floods in the context of climate change. The directive applies to all European coastal and inland waters. Within the framework of this directive, the member states will analyse the river basins and associated coastal areas prone to flooding. In implementation of the aforementioned directive, flood hazard maps (physical properties of a flood such as the extent and depth of a flood) and flood risk maps (potential negative impacts on humans, the environment, heritage, etc.) must be drawn up by the member states. For Flanders, these maps can be consulted via the Waterinfo maps catalogue.

In Flanders, these flood risk management plans were integrated with the river basin management plans drawn up within the context of the European Water Framework Directive (WFD, Directive 2000/60/EC) (see thematic chapter **Nature and environment**). Since 1980, the water management policy has been the responsibility of the regions (special Law of 8 August 1980). The most important legislative instrument within this policy is the Decree Integral Water Policy of 18 July 2003 (coordinated on 15 June 2018 in the Water Code), which since 2010 provides for the Flemish implementation of the European Flood Directive. The flood risk management plans of the Flemish coastal area are included in the river basin management plan for the Scheldt (Programme of Measures for River Basin Management Plans for Scheldt and Meuse 2016-2021, River Basin Management Plans for Scheldt and Meuse 2016-2021)[4], and a river basin management plan for the Belgian coastal waters (Basin Management Plan for Belgian Coastal Waters 2016-2021) (see also thematic chapters **Nature and environment** and **Scheldt estuary**). The Coordination Committee for Integrated Water Policy organises consultation at the Flemish level between the various policy areas and administrative levels involved in water policy.

Building on the European adaptation strategy (COM (2013) 216) (website Climate-ADAPT), which was launched in 2013, the European Green Deal (COM (2019) 640) included an update to this adaptation strategy (COM (2021) 82). Within the framework of the Green Deal, a European Climate Law (Regulation (EU) 2021/1119) has been in force since 29 July 2021, that, among other things, legally anchors the European goal of climate neutrality by 2050.

In Belgium, coastal policy is mainly a Flemish competence. Although the federal government is competent for the area seaward from the baseline (i.e. low water line), the Flemish government also has some competences with impact beyond the baseline, mainly the coastal protection infrastructure (coastal safety) and the maintenance of navigation channels to the four Flemish seaports. Specifically, for floods from the sea, the Coastal division (part of the Agency for Maritime Services and Coast (MDK), which falls under the Flemish Mobility and Public Works (MOW) policy area) is responsible for protecting the Flemish coast against flooding.

An assessment of the Flemish coastal protection in 2007 and 2008 showed that at that time, about one third of the straight coast[5] and the coastal ports needed additional protection against the impact of heavy storm surges. The Masterplan for Coastal Safety (2011) describes the measures that need to be taken for an adequate protection of the coastline and the adjacent low-lying polders against a storm surge with a return period of 1,000 years, with 2050 set as the time horizon. The masterplan took into account a sea level rise of 30 cm[6]. The plan has been implemented in stages since its approval by the Flemish Government on 10 June 2011 and is now in an advanced phase. An update of the assessment in 2017 revealed that at the locations where measures have already been implemented as part of this Masterplan for Coastal Safety (2011), the level of protection has clearly increased. However, at some locations additional measures are needed to reach the proposed safety level. The intention is to use 'soft' measures (beach nourishment, dune nourishment, etc.) as much as possible complemented by 'hard' measures (storm walls, wave attenuating construction of the seawall, etc.) where necessary. An overview of the measures, including their status, is given in table 2. In addition to the measures within the framework of the Masterplan for Coastal Safety, beach nourishments are also carried out for maintenance purposes, or, as in the case of Nieuwpoort (2017), as nature compensation for the construction of the OW plan Ostend (Gysens 2009).

In parallel with the Masterplan for Coastal Safety (2011), and building on initiatives that have been taken since 2009 both from private initiatives (THV Noordzee Kust 2009) as from the government (Masterplan Vlaamse Baaien 2014), the starting decision of the Coastal Vision project was taken in 2017. This project aims to develop a long-term approach for the protection of the Flemish coast, assuming a sea level rise up to 3 m. The project was initiated within the Complex Projects framework. On June 25 2021, the Flemish Government decided to discontinue this procedure and to continue the development of the Coastal Vision project with a tailored approach.

In addition, the Sigmaplan of the Flemish government should also be mentioned. This plan elaborates the protection against flooding from the Scheldt and its tributaries, and runs until 2030, but wil not be further discussed in detail here (see also thematic chapter **Scheldt estuary**, ScheldeMonitor and the website of the Flemish-Dutch Scheldt Commission (VNSC)).

[4] The new River Basin Management Plans for Scheldt and Meuse 2022-2027 will take effect on 1 January 2022. See thematic chapter **Nature and environment**.

[5] Straight coast: the whole of the beaches, foreshores, dunes and sea dikes.

[6] The water level at sea during a 1,000-year storm is currently around +7 m TAW. Sea level rise will cause the water level to rise. The Masterplan for Coastal Safety (2011) uses the following assumptions regarding sea level rise: +30 cm by 2050, +80 cm by 2100 (compared to the year 2000); a constant acceleration of 0.08 mm/year, which is in line with the acceleration of global sea level rise as monitored by satellite since the 1990s (IPCC 2019).

Table 2. An overview of the protection measures and the status of implementation per focus area anno spring 2021. The planned quantities of sand for the nourishments were derived from the Masterplan for Coastal Safety (2011). The section numbers refer to the individual sections of coastline (with an average length of 250 m) which are used to devide the Belgian coast. The numbering runs from 2 (on the French border) to 255 (on the border with the Netherlands).

Zone of interest	Selected measures, incl. the planned nourishment quantities	State of implementation (anno 2021)
De Panne - section 8	• Dune nourishment; • Planned: 22,000 m³ sand.	• A detailed safety assessment shows that the standards for flood risk are not exceeded, making dune nourishment unnecessary.
De Panne-centrum (section 13 to 18)	• Beach nourishment with an elevated beach; • Planned: 85,000 m³ sand.	• 2011: beach nourishment; • 2017: maintenance; • 2020: maintenance.
St. Idesbald - Koksijde-centrum (section 21 to 31)	• Beach nourishment with an elevated beach; • Planned: 248,000 m³ sand.	• 2011: beach nourishment; • 2017: maintenance.
Koksijde - section 39	• Raising the road by the nourishment of the dune passage in combination with the reconstruction of the road; • Planned: 1,800 m³ sand.	• 2013: dune passage raised and rebuilt.
Haven Nieuwpoort	• Construction of a storm surge barrier.	• 2018: start of construction of the storm surge barrier; the construction works will take more than three years; • Completion of the abutment on the right bank is scheduled for 2022.
Middelkerke - Westende (section 74 to 88)	• Beach nourishment with a low-lying beach in combination with wave-absorbing expansions and a storm wall seawards of the casino; • Planned: 1,700,000 m³ sand.	• 2013-2015: phased nourishment for a beach lower than the seawall level; • 2017: maintenance; • 2021: start phased reconstruction of the seawall with wave-absorbing expansion grass dyke.
Raversijde - Ostend Wellington (section 97 to 108)	• Beach nourishment with a low-lying beach in combination with a high storm wall or adapted seawall ramp and wave-absorbing expansion or widening of the seawall at Raversijde; • Planned: 1,500,000 m³ sand.	• 2013-2014: widening and raising of the beaches; • 2014: beach nourishment; • 2018: maintenance; • 2020-2021: Construction of a storm wall of 40 cm on the dyke of Mariakerke; • 2021: Construction of a dune in front of the dyke as measure for the windblown sand on the N34 and the tram rails and the restoration of the dyke in Raversijde; • 2021: Maintenance beach nourishment.
Ostend centre (section 109 to 117) + Port of Ostend + Ostend-East (section 118 to 120)	• OW-Plan Ostend (storm walls in the port, beach nourishment and wave-absorbing expansion seawall, mobile storm walls on seawall Ostend centre)	• 2012: dyke Albert I promenade along the entire length, strengthened and equipped with a fully removable mobile storm wall; *Zeeheldenplein* near *Klein Strand* completely renovated and strengthened; • 2013: construction of nourishment; • 2018: maintenance; • Since 2014: construction of a storm wall on the quays in the *Vismijnlaan*, *Wandelaarskaai* and *Slijkense Steenweg*; • 2020-2021: construction of a mobile storm wall between *Zeeheldenplein* and *Visserskaai*; • 2021: The preferred alternative for the protection of the inner port of Ostend is being developed.
Ostend-East (section 121)	• Beach nourishment in line with OW-plan, subsection on integrated coastal zone management Oosteroever (sections 199 and 120); • Planned: 85,000 m³ sand.	• 2014: beach nourishment; • 2021: development of natural dunes in front of the Spinoladyke, planting of marram gras.
De Haan - Wenduine (section 172 to 176)	• Beach nourishment with low beach in combination storm walls on roundabout and seawall/widening seawall; • Planned: 700,000 m³ of sand.	• 2012: construction of a nourishment from west to east at the level of the entire seawall; • 2014, 2016, 2017, 2018, 2020: maintenance; • 2015: renovated widened seawall, equipped with water barriers and storm walls; • 2021-2023 [in addition to the Masterplan for Coastal Safety] phased construction of an optimised groyne field to combat erosion.

Zone of particular attention (continuation)	Selected measures, incl. the planned nourishment quantities	State of implementation (anno 2021)
Port of Blankenberge	• Construction of a storm wall on + 8 m TAW in combination with an erosion protection embankment around the harbour	• 2016-2018: construction of a storm wall (phase 1); • 2020: construction of new quay walls, mobile barriers and a pilot with a self-closing mobile barrier; • 2021 [in addition to the Masterplan for Coastal Safety] construction of a new breakwater for the harbour channel.
Blankenberge (section 185 to 195)	• Beach nourishment low beach; • Planned: 384,000 m³ sand.	• 2014-2015: phased nourishment; use of dredged sand from the port channel.
Port of Zeebrugge	• Construction of a storm wall at + 8.0 m TAW around Prince Albert I dock and connected to the locks in combination with an erosion barrier around the port.	• 2018: Construction of the storm walls in design phase; • 2020-2021: construction of storm walls between New Yorklaan and Visart Lock and between Zweedse Kaai and Vandamme Lock.
Knokke-Heist (section 225 to 243)	• Beach nourishment (profile between steep and low beach); • Planned: 3,620,000 m³ sand.	• 2012, 2013, 2014, 2015, 2017: planned nourishments; • phased nourishment of 2,000,000 m³ in total: started in 2020 with a foreshore nourishment, end expected in 2023-2024; • 2021: nourishment on the beach of Duinbergen.
Zwin (section 250 to 255)	• Zwin project.	• 2016-2019 construction of 4 km long Zwindijk, in combination with measures against salinisation.
Rehabilitation of locks and weirs	• Ports of Blankenberge, Ostend and Zeebrugge.	• These projects are carried out in several phases.

Belgium and Flanders are, each within the limits of their competences, committed to both mitigation of and adaptation to climate change. At the federal level, there is the National Climate Adaptation Strategy (National Climate Commission 2010). At the Flemish level, the Flemish Adaptation Plan 2013-2020 (Department of LNE 2013) ensures the structural integration of adaptation in the policy and in the operation of the various policy areas. From 2021 onwards, the Flemish Energy and Climate Plan (2019) and the Flemish Climate Strategy (Flemish Government, 2019) will apply as transversal policy plans.

In order to implement all of the coastal protection measures, environmental legislation must also be respected by the development of environmental impact reports. Furthermore, for the construction of hard structures, environmental permits must be granted.. This implies a close collaboration with, in particular, the Marine Environment division of FPS Public Health, the Royal Belgian Institute for Natural Sciences (RBINS), the Agency for Nature and Forest (ANB) (which falls under the Flemish policy domain Environment) and the Flemish Department of Environment and Spatial Development (OMG) with regard to the granting of environmental permits.

100% safety can never be guaranteed, which is why emergency plans remain necessary. All coastal municipalities are required to draw up a municipal emergency plan against flooding from the sea (special emergency and intervention plan for flooding, BNIP flooding). If the (expected) impact of a storm surge exceeds the municipal level, emergency planning is scaled up to provincial level (with a coordinating role for the provincial governor), or even to the national level if provincial emergency planning prove insufficient. The Province of West Flanders is responsible for the preparation and coordination of the provincial 'BNIP Flooding'. The Crisis Centre of the FPS Home Affairs can take over the coordination by the implementation of the National Emergency Plan for Floods and High Water.

12.2 Spatial use

The Masterplan for Coastal Safety (2011) describes the location of the zones of interest along the Flemish coast, as well as the measures to be taken for each of these zones (see table 2 for an overview of the measures). The status of the works in each zone can be followed on the Coastal division website. The spatial distribution of the flood hazard (the physical properties of a flood such as extent and depth) and the flood risks (potential negative consequences for people, the environment, heritage, etc.) can be consulted for Flanders via the map catalogue of waterinfo.be. For the Coastal Vision project the use of space is further elaborated in the integrated research project.

Coastal protection is also addressed in the marine spatial plan (MSP 2020-2026, RD of 22 May 2019, see also Verhalle and Van de Velde 2020). With regard to coastal safety, sufficient space has been foreseen by the long-term vision (FPS Public Health, Food Chain Safety and Environment 2020) to realise the objectives of the Masterplan for Coastal Safety (2011). In the MSP 2020-2026, a zone for the testing of new methods of coastal protection is included near the Broersbank (off the coast of De Panne) (see also **12.5.1 Nature-based solutions**). Furthermore, the MSP 2020-2026 assumes the most sustainable extraction of sand and gravel, *inter alia* in function of the protection of the coast against flooding. In principle, coastal protection measures are possible everywhere in the BNS. This is important since new forms of coastal protection are developing, some of which can be situated more offshore. For the construction of a test island, specific conditions have been formulated in the actions for the implementation of the MSP.

12.2.1 Types of coastal protection

Depending on the type of coastal protection deployed, the required space will vary. The publication of De Bruyn et al. (2020) gives an overview of the three different types of coastal profiles that occur along the Flemish coastline: dune landscape, touristic areas and ports, each with their own requirements and potential for coastal protection. Depending on the protection needs and the local preconditions, including the available space, the appropriate type of coastal protection will be applied. Traditionally, a distinction has been made between soft coastal protection (beach, foreshore or dune replenishment, etc.) and hard coastal protection (storm walls, dike elevations, dune foot reinforcements, etc.). Hybrid solutions are often chosen, e.g. a combination of beach nourishment and dike reinforcement. In recent years, there has been an increasing focus on so-called Nature Based Solutions. These are discussed further in **12.5 Sustainable use**.

12.3 Societal interest

12.3.1 Damage and casualties caused by floods

More than 85% of the Belgian and Dutch coastal zone (zone up to 10 km inland for floods from the sea) lies below +5.0 m TAW and thus below the level of an annual storm (+5.5 m TAW) (EEA 2006, Euroion project, EEA 2013, EEA 2017). Approximately 15% of the surface area in Flanders lies below 5.0 m above mean sea level. Moreover, the Belgian coastline is the most built-up coastal region in Europe. In 2000, more than 30% of the coastal zone (zone up to 10 km inland) was built up and so was almost 50% of the area up to 1 km from the coastline. In the province of West Flanders, 33% of the population lives in low-lying polder areas that are susceptible to flooding by the sea (Brouwers et al. 2015). In addition to habitation, the coastal zones of the Netherlands and Belgium are home to important economic activities, partly because of the presence of seaports. Hence, in case of a flood, the loss of human life and material damage may be very high (Publications office of the European Union 2010, Kellens 2011, Boelaert 2017, EEA 2017, Coppens et al. 2018). Without mitigation and adaptation measures, the annual damage from coastal flooding in the EU could increase to nearly 814 billion euro in 2100, with at least 3 million EU citizens affected by coastal flooding (European Commission 2020). In Belgium, the annual damage in 2100, assuming further development on fossil fuels and RCP8.5, can be estimated at 20 billion euro, with 31,700 people affected by floods (Vousdoukas et al. 2020).

The study carried out to determine the protection measures of the Masterplan for Coastal Safety (2011) includes flood risk calculations in addition to the safety assessment of the sea barrier. To this end, the Flanders Hydraulics Research (the Department of Mobility and Public Works of the Flemish government) in cooperation with the Coastal Division have drawn up flood maps with corresponding estimates of casualties and storm surge damage for the coastal area (see also: the Waterinfo map catalogue, where the information on potential economic damage and economic risks in the event of flooding can also be found). For the calculation of flood risks (in terms of casualties and damage), Flanders Hydraulics Research and the Ghent University developed the so-called LATIS software. LATIS version 4 will allow the mapping of the ecological, social and cultural impact of floods for Flanders (Beullens et al. 2017). These flood risk calculations are updated on a regular basis. The most up-to-date results are determined for the situation in 2015 (Ruiz Parrado et al. 2017, Vanneste et al. 2018).

Table 1 summarises the calculation results for a range of extreme storm surge levels. It is noteworthy that the direct economic damage in absolute value is higher than the figures from the previous calculation in 2006 (Meire et al. 2011). This is on the one hand the result of improvements in the LATIS software and on the other hand the result of an update of the monetary value of the buildings and infrastructure on the seawall and in the coastal zone. After all, the ongoing spatial developments in the coastal region mean that the economic and human losses are potentially increasing. Hence, in general it can be stated that the damage that a storm with a certain probability of occurrence can cause is usually increasing (Plan-MER voor het Geïntegreerd Kustveiligheidsplan: kennisgeving 2009, Kellens 2011). Compared to the previous calculation in 2006, a decrease in damage and number of casualties is observed for the state in 2015, when for both times the same (monetary) values are used as input for the calculations. This is due to the already implemented measures of the Masterplan for Coastal Safety (2011).

Furthermore, within the framework of the Masterplan for Coastal Safety (2011), a map was developed with the distribution of a flood in case of a 1,000-year storm surge, most recently under the conditions of the year 2020 (figure 2). The greatest material risks are located in the vicinity of the four harbours, which are also among the weakest points in terms of coastal safety. Prior to the implementation of the Masterplan for Coastal Safety (2011), the coastal towns that scored the lowest were: Oostende-Centre, Oostende-Raversijde Oostende-Mariakerke, Oostende-Wellington and De Haan-Wenduine. Also, in Middelkerke-Westende, the risk of damage and the risk of casualties was relatively high. In the meantime, these risk have been reduced by implementing the planned interventions of the Masterplan for Coastal Safety (2011) in the coastal municipalities.

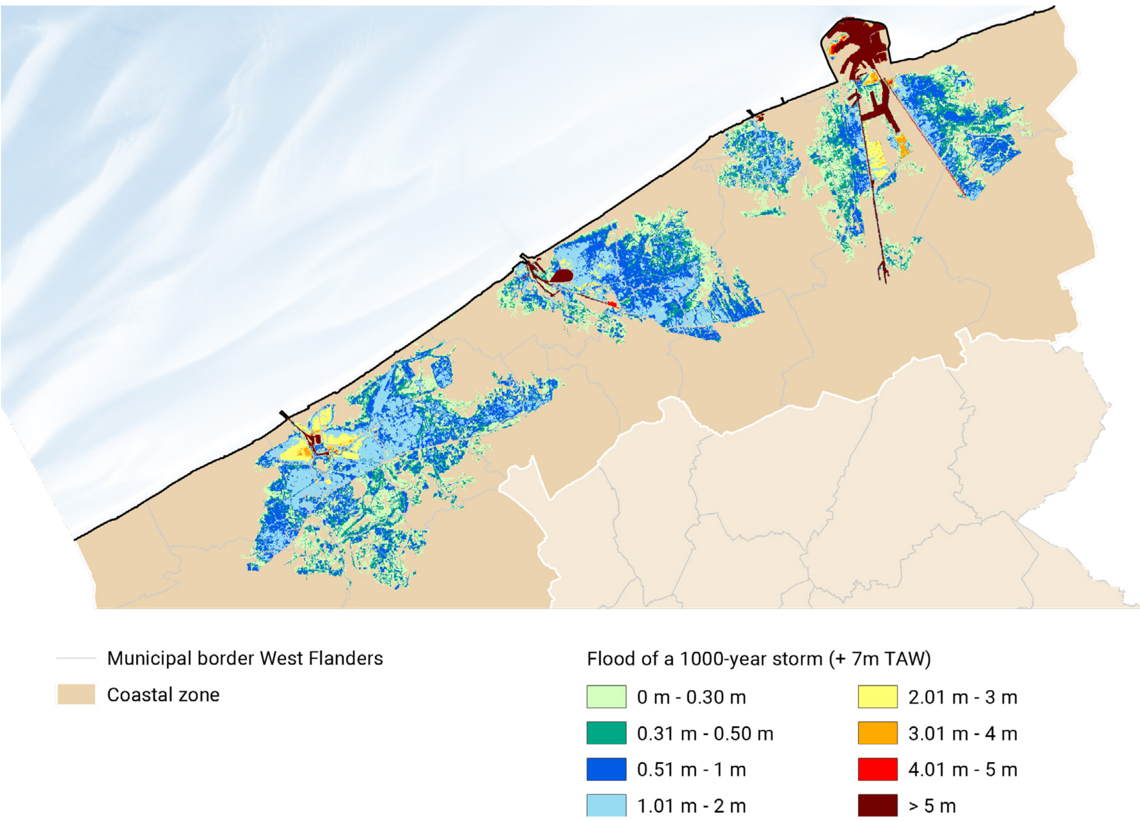

Figure 2. Simulation of the spread of flooding during a 1.000-year storm surge (+7,0 m TAW storm) under 2020 conditions (Masterplan Kustveiligheid 2011, Vanneste et al. 2021).

12.3.2 Investments in coastal protection

For the period 1998-2015, it is estimated that the total cost for coastal protection and climate adaptation (protecting coasts from flooding and erosion) for the EU amounted to 15.8 billion euro (DG Maritime Affairs and Fisheries 2009). In the ClimateCost project (2009-2011), these costs were also calculated for different future scenarios (Brown et al. 2011). Other European projects that have addressed this issue are COASTANCE (2007-2013), ANCORIM (2009-2012), Theseus (2009-2013), CoastAdapt (2009-2011), CLAMER (2010-2011), SCAPE (2016-2020) and LISCOAST (2018).

A recent report commissioned by the Blue Cluster (Bilsen et al. 2019) on the economic and societal relevance of the Blue Economy in Flanders, also addresses the economic and societal importance of coastal protection. The report states that in Belgium around 18 million euro are spent annually on coastal protection. This expenditure is made, among other things, in the context of the regular maintenance of the beaches and the implementation of the Masterplan for Coastal Safety (2011).

The total cost of the Masterplan for Coastal Safety (2011) was estimated at the time of conception at more than 300 million euro. An important cost included in this estimate concerns the renovation and reinforcement of locks, dams and drainage structures in the ports. In addition, it was estimated that an average of 600,000 to 700,000 m³ of sand per year would be required for the periodic maintenance of the new beaches. Prior to the start of the Masterplan for Coastal Safety (2011), an annual average of 550,000 m³ of sand was added to the Flemish beaches (pumped up with pressure pipes or brought in by trucks) (Maelfait and Belpaeme 2007, Vandewalle et al. 2008, Masterplan for Coastal Safety 2011). Figure 3 shows the annual volumes of sand for beach and foreshore nourishment. An important reason for the large volumes in 2014 and 2017 are the emergency nourishments after major storms (e.g. *Sinterklaas* storm in December 2013, *Dieter* storm in January 2017) (see also thematic chapter **Sand and gravel extraction**).

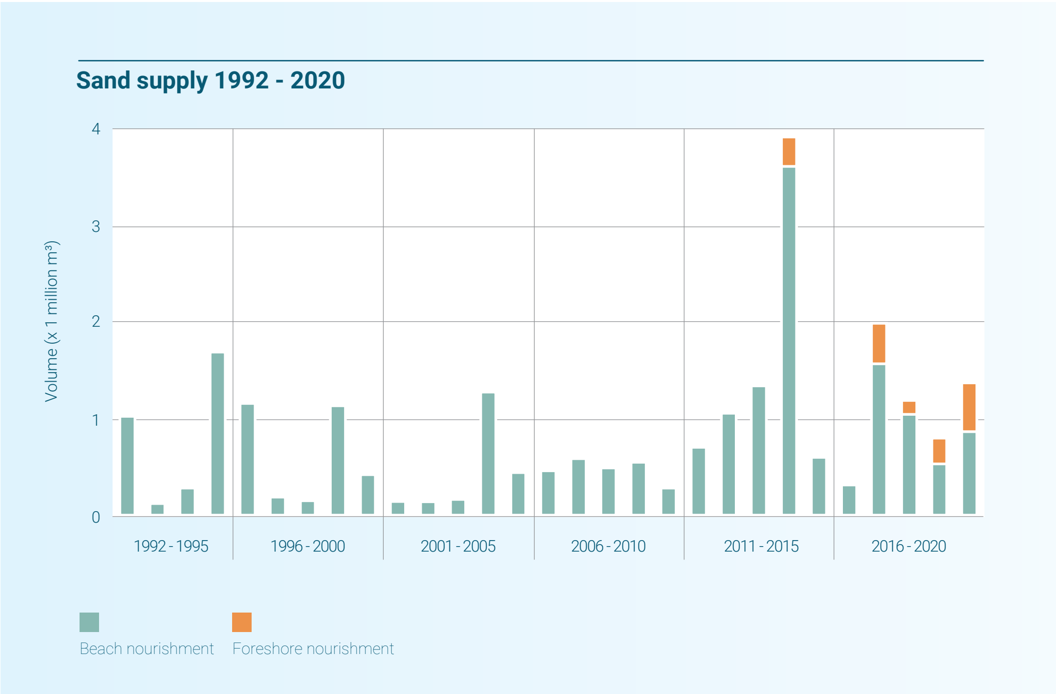

Figure 3. Evolution of the annual volumes of sand for beach and foreshore nourishment (Source: Coastal division). In the case of a beach nourishment, sea sand is applied via dredgers above the low-water line. For forshore nourishment, the sand is applied below the low-water line.

In addition, the Flemish government invests in research on how to integrate coastal safety sustainably and cost-effectively into the spatial development of the coastal zone. This happened, amongst others in the CREST project. The Living Lab Raversijde, which grew out of the CREST project, *inter alia* provides for a test dike that has been custom-built for research purposes. This research infrastructure should lead to more insight into the processes of wave overtopping and wave force on structures, and will result in long-term, detailed hydrographic monitoring of the soft coastal protection at Raversijde to facilitate research and innovation (incl. pilot tests).

12.4 Impact

Depending on the technique used, the protection works and infrastructure on the Flemish coast have an impact on a number of environmental aspects. Both the hard and soft coastal protection measures are therefore subject to the European EIA Directive (Directive 2014/52/EU), as a result of which an environmental impact assessment (EIA) must be carried out before the environmental permits are granted.

In general, the EIA studies in the context of the Masterplan for Coastal Safety (2011) estimated the environmental impact that may occur during and after construction and as a result of maintenance works. The effects must therefore be considered potential effects that are project-dependent. The effects stemming from the exploitation of the required resources (e.g. sand extraction at sea) were included in separate EIA reports. Table 3 provides an overview of the potential impacts to be considered in the assessment of coastal protection measures and the related literature that elaborates on these topics. For a more detailed description, reference is made to the following publications: Geïntegreerd Kustveiligheidsplan. Niet-technische samenvatting (2009), Plan-MER - Plan voor kustverdediging en maritieme toegankelijkheid van Oostende (2007).

In addition to a general plan-EIA which describes the environmental impact of the protection measures of the Masterplan for Coastal Safety (2011) in its entirety, a project-EIA is also drawn up (when necessary) to assess the local effects of individual projects. In 2016, for example, the project-EIA for the storm surge barrier in Nieuwpoort was approved (OMG, Nature and Energy 2016) and in 2021 the notification was made for the project-EIA for the measures against the sedimentation in the marina in Blankenberge (Darras 2021). In most cases, however, an exemption from a project-EIA can be requested.

Table 3. An overview of the potential effects that should be considered when evaluating coastal protection measures, accompanied by the relevant literature.

Discipline	Potential effects	Literature
Water	• Turbidity of the water column; • Changes in the flow pattern and currents of the sea water; • Hydrological effects – changing groundwater levels in the dunes and adjacent areas; • Changes in groundwater quality (depending on the quality of the supplied sand).	Plan-MER – Plan voor kustverdediging en maritieme toegankelijkheid van Oostende (2007), Geïntegreerd Kustveiligheidsplan. Niet-technische samenvatting (2009), Lebbe 2011
Seabed	• Impact on the seabed, beach, dune and polder soils (degree of soil disturbance) and the effect on soil morphology.	Plan-MER – Plan voor kustverdediging en maritieme toegankelijkheid van Oostende (2007), Geïntegreerd Kustveiligheidsplan. Niet-technische samenvatting (2009), Houthuys 2012, Van den Eynde et al. 2012, Janssens et al. 2013, Houthuys et al. 2014, Colson et al. 2016, INDI67 project BELSPO
Air	• Emissions into the air and their impact on human health.	Plan-MER – Plan voor kustverdediging en maritieme toegankelijkheid van Oostende (2007), Geïntegreerd Kustveiligheidsplan. Niet-technische samenvatting (2009)
Noise and vibrations	• Noise impact on humans and animals and the effects on human health.	Plan-MER – Plan voor kustverdediging en maritieme toegankelijkheid van Oostende (2007), Geïntegreerd Kustveiligheidsplan. Niet-technische samenvatting (2009)
Landscape, archaeology and architectural heritage	• Functional fragmentation of the spatial use; • Visual-spatial effects of adding or changing landscape elements; • Disappearance and disturbance of historical geographical elements and structures; • Effects on architectural heritage and archaeology.	Plan-MER – Plan voor kustverdediging en maritieme toegankelijkheid van Oostende (2007), Geïntegreerd Kustveiligheidsplan. Niet-technische samenvatting (2009)
Fauna and flora	• Effects on habitat, vegetation, benthos and avifauna; • Creation of habitats due to the expansion of dry beaches and dunes; • Barrier function for benthos.	Engledow et al. 2001, Speybroeck et al. 2004, Volckaert et al. 2004, Speybroeck et al. 2006a, Speybroeck et al. 2006b, Speybroeck et al. 2007, Plan-MER – Plan voor kustverdediging en maritieme toegankelijkheid van Oostende (2007), Van Ginderdeuren et al. 2007, Geïntegreerd Kustveiligheidsplan. Niet-technische samenvatting (2009), Janssen and Rozemeijer 2009, Braarup Cuykens et al. 2010, Vanden Eede and Vincx 2011, Vanden Eede 2013, Van Tomme 2013, Van Tomme et al. 2013, Vanden Eede et al. 2014, Colson et al. 2016, Staudt et al. 2021
Mobility	• Modifications in accessibility.	Plan-MER – Plan voor kustverdediging en maritieme toegankelijkheid van Oostende (2007), Geïntegreerd Kustveiligheidsplan. Niet-technische samenvatting (2009)
Spatial use (human-space)	• Modifications in access possibilities; • Modifications of recreational area; • Functional changes; • Nuisance.	Plan-MER – Plan voor kustverdediging en maritieme toegankelijkheid van Oostende (2007), Geïntegreerd Kustveiligheidsplan. Niet-technische samenvatting (2009)
Human, health and safety aspects	• Potential health effects, due to the exposure to polluted air, noise emissions and vibrations; • Changes in the safety of recreationists or inhabitants, due to changing sea currents, or due to the placement or removal of obstacles, or general modification of coastal safety.	Plan-MER – Plan voor kustverdediging en maritieme toegankelijkheid van Oostende (2007), Geïntegreerd Kustveiligheidsplan. Niet-technische samenvatting (2009)

Within the context of the ecosystem vision for the Flemish Coast, an impact assessment framework was developed that allows to provide scientifically founded information on the impact of an intervention on the ecosystem and to inform policy makers about the possible consequences of a decision (Van der Biest et al. 2017a, Van der Biest et al. 2017b, Van der Biest et al. 2020). The practical application of the ecosystem services concept to a number of marine infrastructure projects was elaborated in Boerema et al. (2016) and Boerema et al. (2021).

12.5 Sustainable use

A resilient coast can withstand influences or fluctuations in the environment and will not change significantly as a result of natural processes and sustainable use. A resilient coastal protection was defined as a key element for a sustainable Flemish coastal ecosystem in the ecosystem vision for the Flemish Coast (2017). This study provides a vision for the development of the coastal protection on the long-term, linked to an ecological assessment framework developed to assess the (long-term) impact of future developments in the context of coastal safety with respect to the feasibility of this vision (Van der Biest et al. 2017a, Van der Biest et al. 2017b).

In view of the many users which are active in the coastal zone, Europe formulated in 2002 a recommendation for an integrated coastal zone management (ICZM, 2002/413/EC). Within the framework of the Masterplan for Coastal Safety (2011) the principles of integrated coastal zone management were followed in the execution of the social cost-benefit analysis. The Coastal Vision project launched in 2017 focuses primarily on coastal safety but also looks at possible benefits on an economic, social and natural level (see also note Rondelez and Pirlet 2018 with focus area on the eastern part of the Flemish Coast).

Within this context, the quadruple helix approach (in which government, research, industry and the public are jointly involved) is gaining importance. An example of this is the Think Tank North Sea, a neutral and unbiased entity in which stakeholders from the quadruple helix discuss on themes such as: 'Living with Climate Change' (Mertens et al. 2020) or 'Working with Nature' (Degraer et al. 2020). The mutual cooperation between governments, knowledge institutions, companies and citizens plays an important role in the elaboration of innovative concepts, which are gaining interest in the field of coastal safety. The Blue Cluster, the Flemish maritime innovation cluster, supports companies in setting up partnerships with other companies, knowledge centres and government institutions for the development and promotion of economic activities at sea. A number of initiatives, demonstration and innovation projects for integrated coastal protection are included in table 4.

12.5.1 Nature-based Solutions

Although themes such as Low Impact Development or Best Management Practices have been in use since the 1970s, it is mainly since 2007 that the term Nature-based Solutions (NbS) has appeared in literature (Ruangpan et al. 2020). There are several definitions of NbS (a.o. Cohen-Schaham et al. 2016), each emphasising the need to balance social, economic, and environmental objectives, and the importance of its sustainability in the long term (Martin et al. 2020).

In 2020, the European Commission defined nature-based solutions as: '*Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions*'. At the same time, NbS is not the only term to describe natural solutions to climate challenges. Other terms that are used include Building with Nature (De Vriend et al. 2015), Ecological Engineering (Borsje et al. 2011), Nature-based infrastructure (Sutton-Grier et al. 2018), Natural and Nature-based features (Bridges et al. 2021), Ecosystem-based Coastal Defence (Temmerman et al. 2013), Working with Nature (Degraer et al. 2020), Ecosystem Approach (Adriana Gracia et al. 2018), where the emphasis may either more on problem solving or more on management approaches. NbS can therefore be seen as an umbrella term, encompassing a wide range of conservation and sustainability measures (Eggermont et al. 2015, Nesshöver et al. 2017, Gómez Martin et al. 2020, Vojinovic 2020). NbS are especially a subject where innovation from government, research and industry come together. Natural or nature-based protection measures include shallow sandbanks, foreshores and replenishments; underwater reefs; mudflats, salt marshes and intertidal sandflats and dunes (Van der Biest et al. 2017a, Van der Biest et al. 2017b, Bonte et al. 2021). Examples of NbS along the Flemish coast are the construction of an additional dike at Raversijde in 2021 (SARCC project), the construction of biogenic reefs with the purpose of (future) coastal protection, such as the pilot project near De Panne (Coastbusters 2.0 project), the facilitation of beach nourishment through sand transport over coastal sandbanks (Verwaest et al. 2020) or the development of dunes near Ostend Oosteroever (Strypsteen and Rauwoens 2021). An overview of the potential of NbS on our sandy coast is given in Boerema et al. (2021).

Table 4. An overview of studies, projects and initiatives in the context of coastal protection.

Studies, projects and initiatives	Timeframe	Short description
CLIMAR project (BELSPO) (Van der Biest et al. 2009, Van den Eynde et al. 2009, Van den Eynde et al. 2011)	2006-2011	This project developed a framework in which adaptation measures, to control the impacts of climate change, can be evaluated for the ecological as well as the social and economic aspects of the North Sea environment.
QUEST4D project (fase 1 and fase 2 BELSPO) (Van Lancker et al. 2012)	2007-2011	This project quantified erosion/ sedimentation patterns and distinguished the natural from anthropogenic induced sediment dynamics.
CcASPAR (Allaert et al. 2012)	2009-2012	This project conducts research on the spatial impact of climate change with the aim to develop spatial adaptation strategies and sustainable policies for Flanders on various spatial levels. The developed strategies have been tested for the coast and the Yser Valley.
Kappa-plan (Kustwerkgroep Natuurpunt 2010)	2010	Natuurpunt and the West Flanders Environmental Federation (WMF) advocate for an integrated climate adaptation plan for a sustainable coastal protection. In this Kappa plan, coastal protection is designed with natural climate buffers against climate change and flooding.
Coastal communities 2150 (Stratton 2012)	2011-2014	This project aims to inform stakeholders in coastal areas about climate change and its effects on the coast (erosion, floods, etc.).
Metropolitaan Kustlandschap 2100 (verkennende en methodologische analyse van de Belgische kust, ontwerpopgaven en exploratief ontwerpend onderzoek deel 1, 2 en 3) (Geldof and De Bock 2014)	2012-2014	This initiative from *LABO Ruimte (Ruimte Vlaanderen and Team Vlaamse Bouwmeester)* – in association with the Department of Mobility and Public Works (MOW) and the Agency for Maritime and Coastal services – explores various possible future scenarios for the Flemish coast from a metropolitan perspective.
4shore project (Colson et al. 2016)	2013-2016	Over a period of three years, this project has mapped ecological changes in foreshore and beach nourishments on a temporal and spatial scale for the beach and the shallow coastal zone (Mariakerke and Bredene). Within the 4shoreBis project, the macrobenthos and the physio-chemical characteristics of the bottom sediments were evaluated for the beach of Middelkerke after a beach nourishment.
Meetnet Vlaamse Kust – project Broersbank (Thoon 2016)	2013-2016	This study project has built up a unique data set and set of numerical models that will contribute to further research into a safe, robust coastline. In order to investigate the impact of sandbanks on the reduction of wave energy in detail, a monitoring network was started, consisting of seven buoys off the coast.
TILES project (BELSPO) (Van Lancker et al. 2019)	2013-2017	The TILES project (Transnational and Integrated Long-term marine Exploitation Strategies) is focused on forecasting and adaptive long-term management strategy for the exploitation of geological resources in the North Sea.
ARGONAUTS (Montreuil et al 2017)	2013-2018	*ARGus and in-situ mONitoring of beAch and shoreface NoUrishmenT for Sustainable coastal safety*. The aim of the project is to evaluate a foreshore nourishment in Ostend (Mariakerke) as an alternative measure to maintain extended/ nourished beaches.
Provoost et al. 2014	2014	In this ecosystem service report of the *Natuurrapport 2014*, the protection against floods from the sea by means of natural coastal protection elements is elaborated.
CORDEX.be project (BELSPO) (Termonia et al. 2018)	2014-2017	The aim of the CORDEX.be project is to combine the existing and new research activities of nine Belgian partners in the field of climate modelling in order to create a consistent scientific basis for climate services in Belgium. The valorisation of the CORDEX project is discussed in Van Schaeybroeck et al. (2021).
INDI67 project (BELSPO) (Fettweis et al. 2020)	2014-2019	Development of methods to improve the monitoring of MSFD indicators 6 (sea floor integrity) and 7 (hydrographical conditions).

Studies, projects and initiatives (continuation)	Timeframe	Short description
CREST project (Monbaliu et al. 2020)	2015-2019	The CREST-consortium (Climate Resilient Coast) studied the robustness of the Flemish coast under a changing climate regime. In particular, effects on coastal dynamics and impact for future safety strategies were investigated. This innovation project enabled a better insight into near coastal and inland physical processes, but also into the flood risks along the coast and the impact of the wave transfer. Furthermore, the project determined the resilience of the natural coastal system in relation to storms and wind; and developed climate scenarios for the Belgian coast. The CREST project is divided into three core activities: (1) integrated modelling of waves, currents and sediments on a multi-scale, (2) advanced modelling of wave overtopping risks in coastal municipalities and (3) improved knowledge of coastal processes.
Building With Nature	2015-2020	This project demonstrated 'Building With Nature' projects, which increase coastal safety solutions using natural processes to manage flood risks and coastal erosion while improving ecosystem services. To this end, 'Nature Based Solutions' were applied at 7 coastal locations in BE, NL, D, DK, SE (sand nourishments on the North Sea coast and Wadden Sea barrier islands) and at 6 locations in river basins in BE, NL, SE, SCO (e.g. river restoration). In Flanders, a beach nourishment in Ostend was investigated.
SCAPE project	2016-2020	The aim of this project was to protect coastal areas against the consequences of climate change, such as floods and extreme rainfall, on the basis of a landscape guided design. Water managers, planners and architects developed a joint approach deploying the landscape against the water-related consequences of climate change.
Territoriaal Ontwikkelingsprogramma (T.OP) Kustzone	2016-running	T.OP Coastal Zone was inititated by the Department of Environment and Spatial Development (OMG) in cooperation with the province of West Flanders to draw up an action-oriented programme for the spatial development of the coastal zone in the short and medium term.
Coastbusters (Coastbusters 2020)	2017-2020	In the innovation project Coastbusters the possibility to use biogenic reefs as coastal protection measure was investigated. The species tested to act as natural coastal protection were seaweed or sea grass, mussels and sand mason worms. Mussels seemed the most optimal species to act as a reefbuilder and therefore to serve as coastal protection measure.
RS4Mody project (BELSPO)	2017-2021	This project aimed to investigate the morphodynamics of a tidal beach from short (storm event) to long term (> 25 years). This allowed for a better understanding of the morphodynamics of the beach and the implications thereof for coastal management.
ENDURE	2018-2020	This project focused on dune management to make the 2 Seas area resilient to climate change. In order to visualise the advantages of different dune management approaches (hard engineering versus ecosystem-based approach), a call for tenders was launched for the development of new cartographic solutions. With a clear visualisation, coastal managers should be able to better understand how their measures are changing the coastal zone.
DataBeach	2019-2021	The DataBeach project developed groundbreaking new measurement technology, machine learning models and probabilistic calculation methods for disruptive advances in the design of soft coastal protection measures. The Coastsnap station in Ostend was also installed within the Databeach project.
SARCC	2019-2023	The project seeks solutions to sustainably protect coastal cities from the effects of rising sea levels. The focus of the project is on the use of Nature-based Solutions (NbS) within coastal defenses, both in policy and in the concrete construction of coastal protection projects. An important part of the project is the building up of knowledge about NbS, and the dissemination of knowledge to authorities and society.

Studies, projects and initiatives (continuation)	Timeframe	Short description
Coastbusters 2.0	2020-2022	Building on the research conducted in Coastbusters, Coastbusters 2.0 conducts further research into a sustainable design for the development of a self-sustaining mussel reef as coastal protection measure. Research will focus on sustainable and biodegradable materials, the design of a modular biogenic reef concept, innovative monitoring solutions and the ecosystem preconditions and services of coastal reefs.
Coastsnap Belgium	Running since 2020	CoastSnap is a global Citizen Science project that aims to engage citizens to participate in scientific research on the accretion and erosion of different beaches. The project provides specially designed holders at fixed "CoastSnap locations" where people can place their smartphone in order to take a standardised picture of the beach. These photos form a dataset on which scientific research is carried out. In Belgium, Coastsnap stations are currently installed in Ostend (Oosteroever, as part of the Databeach project) and Koksijde (as part of the RS4 Mody project).
Bankbusters	2021-2024	Bankbusters aims to strengthen the knowledge of ecosystem processes, associated boundary conditions and concepts for the reuse of dredged material in order to facilitate the restoration of eroded tidal flats and wetlands and improve local ecosystem services.

Legislation reference list

Overview of the relevant legislation on European, federal and Flemish level. For the consolidated European policy context see Eurlex. The national legislation can be consulted on the Belgian official journal and the Justel-database, the Flemish legislation is available on the Flemish Codex.

European legislation and policy context			
Document number	**Title**	**Year**	**Number**
Recommendations			
2002/413/EG	Recommendation concerning the implementation of Integrated Coastal Zone Management in Europe	2002	413
Communications			
COM (2013) 216	Communication from the Commission: An EU Strategy on adaptation to climate change	2013	216
COM (2019) 640	Communication from the Commission: The European Green Deal	2019	640
COM (2021) 82	Communication from the Commission: Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change	2021	82
Directives			
Directive 2000/60/EC	Directive establishing a framework for Community action in the field of water policy (Water Framework Directive)	2000	60
Directive 2007/60/EC	Directive on the assessment and management of flood risks (Floods Directive)	2007	60
Directive 2014/52/EU	Directive to amend Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment	2014	52
Directive 2014/89/EU	Directive establishing a framework for maritime spatial planning (MSP Directive)	2014	89
Regulations			
Regulation (EU) 2021/1119	Regulation to establish the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law')	2021	1119

Belgian and Flemish legislation		
Dates	**Title**	**File number**
Decrees		
Decree of 14 July 1993	Besluit van de Vlaamse regering betreffende de definitieve aanwijzing van de beschermde duingebieden en van de voor het duingebied belangrijke landbouwgebieden.	1994-11-16/33
Decree of 18 July 2003	Decreet betreffende het integraal waterbeleid	2003-07-18/72
Decree of 25 April 2014	Decreet betreffende de complexe projecten	2014-04-25/I8
Royal Decrees		
RD of 22 May 2019	Koninklijk besluit tot vaststelling van het marien ruimtelijk plan voor de periode 2020 tot 2026 in de Belgische Zeegebieden	2019-05-22/23
Law		
Special Law of 8 August 1980	Bijzondere wet tot hervorming der instellingen	1980-08-08/02