14 Scheldt estuary

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The North Sea region is home to a number of important estuaries. These include the estuaries of the Seine (France), the Elbe (Germany), the Weser (Germany), the Humber (United Kingdom), the Ems-Dollard (Germany and the Netherlands), the Thames-Essex (United Kingdom) and the Scheldt (the Netherlands and Belgium) (Debergh et al. 2009, TIDE-toolbox). These estuaries have a great ecological value and parts of them are designated as Natura 2000 areas (see also thematic chapter **Nature and environment**). On the other hand, these estuaries provide space for important economic activities such as harbour developments and tourism. Furthermore, these estuaries face common challenges such as increasing flood risks, upscaling of shipping, issues regarding sediment management and the preservation of ecosystem functions. Considering the common challenges of these areas, European collaboration projects concerning estuarine research and management have been conducted. Depending on the project and the project partners, these projects focus on one or several of these challenges (e.g. TIDE, SEDNET, SCALDWIN, EMOVE, HARBASINS, SMARTSEDIMENT, INTERTIDE, etc., see also list of projects in ScheldeMonitor).

The Scheldt estuary consists of the Sea Scheldt and its tidal tributaries (Durme, Rupel, Zenne, Dijle and Netes), the Western Scheldt and the mouth of the Scheldt with the *Vlakte van de Raan*. The preservation of the tidal regime along the entire salt - freshwater gradient, with the associated tidal habitats and communities, is a unique feature in North-West Europe (Directorate Zeeland and AWZ 2001). The strong interaction between the Scheldt estuary and the North Sea results in the exchange of water masses, dissolved matter, sediments, fauna and flora, etc.

Although that the Scheldt estuary is a Flemish-Dutch matter, this thematic chapter mainly focuses on the Flemish context. For the Dutch efforts in the Western Scheldt in the context of nature, safety and accessibility, reference is made to the website of Rijkswaterstaat and the Natuurpakket Westerschelde.

14.1 Policy context

14.1.1 Common policy and management

The policy and management of the Scheldt estuary is a cross-border affair that involves both Flanders and the Netherlands. Between both countries, several treaties and memoranda of understanding (MoU) on the Scheldt estuary have been concluded (Vlaams-Nederlandse Scheldecommissie (VNSC)). Furthermore, ministerial declarations and treaties have been adopted in the context of integrated water management in the Scheldt Basin, which not only involve Flanders and the Netherlands, but also the Walloon Region, the Brussels-Capital Region and France (International Scheldt Commission). An overview of historical treaties and agreements is available in van Langenhuysen and van Langenhuysen (1919) and Baekelandt (2002).

To ensure the alignment between the Flemish and Dutch authorities, a number of specific cross-border organisations for the Scheldt estuary have been created. In 1948, on the occasion of the foundation of the Benelux Customs Union, the Technical Scheldt Commission (TSC) was established. This commission consisted of Dutch and Belgian/Flemish officials and was responsible for studies on the Scheldt (e.g. the Delta Plan, the Scheldt-Rhine connection, the Long-term vision on the Scheldt estuary and the Development sketch 2010 Scheldt estuary). In 2008, the TSC was succeeded by the Flemish-Dutch Scheldt Commission (VNSC) as stated in the Treaty on Common policy and management of the Scheldt estuary (2005). The VNSC consists of a political college, an official college and an executive secretariat. This body promotes the cooperation between Flanders and the Netherlands at the policy and management level in the pursuit of a safe, accessible and natural Scheldt estuary. In order to create a strong support base for further development of the Scheldt estuary, the Scheldt Council was established in 2014. This official advisory board contributes to the future policy of the VNSC. In response to specific policy and management questions, the official college may set up working groups to carry out specific tasks. Seven working groups were established under the VNSC: 'Development sketch 2010', 'Long-term perspective on nature', 'Long-term perspective on accessibility', 'Research and monitoring (R&M)', 'Flexible dumping', 'Monitoring New Lock Terneuzen (NST)' and 'Decision supporting system NST'.

In 2013, the VNSC published a first evaluation report (Evaluation of the Treaty on policy and management of the Scheldt estuary) of the Flemish-Dutch cooperation based on the Scheldt Treaty on Common policy and management. In a second report, recommendations are made for the evaluation period 2019-2023 (Evaluation of the Treaty on policy and management of the Scheldt estuary 2014-2018). This report also identifies a number of priority themes towards a robust and sustainable Agenda for the Future of the Scheldt estuary. This agenda started in 2014 with a comprehensive policy and management support research programme. Meanwhile, the first research programme of the 'Agenda for the Future, 2014-2018' has been completed and, in collaboration with stakeholders (e.g. through the establishment of the Scheldt Council), initiatives have been launched to develop long-term perspectives for nature and accessibility. The first research programme resulted in substantive conclusions

relevant to the management as well as recommendations for new and additional research opportunities, which led to the Roadmap to Agenda for the Future 2019-2023 and the Research Programme 2020-2023. In addition to this research programme, the cooperation between Flanders and the Netherlands also consists of an integrated monitoring programme aimed at the functioning of the estuary (MONEOS), which is monitored by the permanent VNSC Working Group Research and monitoring (R&M).

In addition to the system monitoring included in the MONEOS programme, specific monitoring programmes are carried out with the aim of making the effects of certain interventions visible. The MONEOS-T implementation programme monitors the effects of the construction and maintenance strategy of the widening of the waterway based on the protocol for flexible dumping, and there are numerous monitoring efforts that make it possible to map the nature development projects in Zeeland. Using research and monitoring programmes such as OMES (*Onderzoeksprogramma Milieu Effecten Sigmaplan*), most of which is included in the cross-border monitoring programme MONEOS, Flemish water authorities and scientists can monitor the autonomous developments of the hydro-morpho-ecological system and the environmental impact of human activities on the Scheldt estuary (Maris et al. 2020a, Maris et al. 2020b).

The ScheldeMonitor was set up in 2003 on behalf of the VNSC with the aim of acting as a central information system on research and monitoring in the Scheldt estuary. Since 2010, in addition to providing access to information (expertise, literature, projects, etc.), the ScheldeMonitor also focuses on data (datasets, measurements, etc.) and data products (maps, graphs, indicators, etc.) related to the Scheldt estuary, with a focus on accessing and archiving data series from the MONEOS programme.

14.1.2 Joint nautical management

There is also cooperation between Flanders and the Netherlands on a sector level. Through the Joint Nautical Management (GNB), both countries ensure the organisation of smooth and safe shipping traffic to and from the Scheldt ports. The Permanent Commission for the Supervision of Scheldt Navigation, established by article 9 of the Convention of 19 April 1839 regulating the separation between the Netherlands and Belgium, is the highest body in the organisation of the GNB and is responsible for the safe and smooth handling of shipping traffic. The Joint Nautical Authority (GNA) is responsible for the daily nautical control of the traffic flow. Realtime monitoring of shipping traffic on the Scheldt is carried out by the Scheldt Radar Network (SRK), a shipping guidance system that is jointly managed by the Flemish and Dutch governments. The operational, functional and technical management of the systems of the SRK is carried out by the Management and Operation Team (BET-SRK).

14.1.3 International Scheldt Commission

The International Scheldt Commission (ISC) was initially established by the Treaty of Charleville-Mézières (1994) under the name 'International Commission for the Protection of the Scheldt' (ICBS). The commission is operating under its current name since 2002, following the coming into force of the Scheldt Convention. The aim of this entity is to strengthen cooperation between the riparian states (France, Belgium and the Netherlands) and Regions (Flanders, Brussels and Wallonia) of the international Scheldt river basin, for the benefit of sustainable and integrated water management. Since 2000, the commission has been responsible for making a single management plan for the international river basin district of the Scheldt and for coordinating the national programmes of measures (first elaboration in 2009) in the implementation of the Water Framework Directive (WFD, Directive 2000/60/EC). The current management plan (Scheldt, coast) and programme of measures apply for the period 2016-2021.

14.1.4 European guidelines

The management and policy of the Scheldt estuary are to a large extent guided by international and European legislations such as the Birds- (Directive 2009/147/EC) and Habitats Directives (Directive 92/43/EEC) (Natura 2000), the Waterframework Directive (WFD) (Directive 2000/60/EC) and the Floods Directive (Directive 2007/60/EC). This is done by setting specific targets for good ecological and chemical status (WFD) and conservation objectives (COs – N2000). The national and regional policy instruments then provide for the local implementation of these directives (see also thematic chapter **Nature and environment**). An overview of the policy framework for the Scheldt estuary is available in Debergh et al. (2009).

14.1.5 Long-term vision on the Scheldt estuary

The Long-term vision on the Scheldt estuary (LTV, Directorate of Zeeland and AWZ 2001) has been the starting point for a common integrated, cross-border policy. This vision was jointly adopted by the Netherlands and Flanders in 2001 and approved by the governments and parliaments of both countries. The objective of the LTV was to develop a healthy and multifunctional estuarine water system that is used sustainably for human needs. The vision mainly focused on the themes 'safety', 'accessibility' and 'nature', while keeping the development of the morphology of the estuary as a central focus. The LTV was made up of three components:

- Short-term situation sketch: starting situation (2005) based on the expected short-term effects as a result of the already planned measures and the established policy;
- Target 2030: description of the long-term situation to be pursued (2030);
- Development sketches 2010: description of alternative medium-term policy strategies to move from the short-term situation sketch to the long-term target.

The Development sketch 2010 Scheldt estuary (ProSes 2004) included project proposals (measures and policy efforts) that had to be started mainly in the period 2004-2010 in order to achieve the target set for 2030. Most of the projects have now been completed. A number of projects, such as the Natuurpakket Westerschelde (with the depoldering of the *Hedwige-Prosperpolder*) and the realisation of the Sigmaplan, are still in progress.

In Flanders, the LTV themes 'safety' and 'nature' are jointly implemented in the updated Sigmaplan (2005) approved by the Government of Flanders. The measures laid down therein serve both safety and nature, with a robust estuary at stake. The objectives for nature in the Sea Scheldt were refined and concretised as a result of the updated Sigmaplan (Adriaensen et al. 2005). A series of measures were proposed to achieve these objectives. Three types of measures can be distinguished:

- The development of mudflats and salt marshes by allowing controlled reduced tides (RT) in a flood control area (FCA);
- The renewal of dikes or depoldering;
- The development of wetlands in the valley, potentially as a FCA.

14.2 Spatial demarcation

By definition, an estuary contains the part of a river that is subject to tidal influences (Fairbridge 1980) and where salt seawater is mixed with fresh surface water. In the case of the Scheldt estuary, this is the area from the mouth of the river to the locks in Ghent (Merelbeke), including the Durme, Rupel, Zenne, Dijle and Netes up to where tidal influence can be recorded. The exact spatial boundary of the estuary is formed by the dikes (figure 1).

The Long-term vision of VNSC (Directorate Zeeland and AWZ 2001) applies to a specific geographic area. However, a trans-border perspective is used when this is required for certain aspects. The upstream border was set at the locks in Ghent (Merelbeke) and the upstream border of the tidal influence of the tributaries. The downstream border of the estuary contains the Scheldt and its river mouth, including *Vlakte van de Raan* and other shallow water areas. The channels are taken into account up to the limit of the nautical management (indicative border: the piloting intersections west of *het Scheur*). The Port of Zeebrugge and its fairway *Pas van het Zand* are not included in the area demarcated for the LTV. The LTV also covers the banks up to the main weirs.

The evaluation method (Maris et al. 2014a) uses the most detailed classification based on the OMES (research on the environmental effects of the Sigmaplan) compartments and a classification into macro/mesocells specific to the Western Scheldt. The OMES classification is initially based on variations in salt content. In the freshwater zones, residence times are also taken into account (figure 2). This scale level is aggregated into a chain of macrocells and mesocells. The macrocells are formed by the large curved ebb channels and straight flood channels, which are intertwined by shortcut channels (Depreiter et al. 2014). Depending on the desired spatial detail, the zones are taken together or the focus is put on a smaller spatial scale within a zone. For example, different scale levels can be distinguished (Maris et al. 2014a, Barneveld et al. 2018):

- Level 1: Estuary;
- Level 2: Western Scheldt – Sea Scheldt – Tributaries;
- Level 3: Strong polyhaline zone – Weak polyhaline zone – Mesohaline zone – Zone with strong salinity gradient – Oligohaline zone – Freshwater zone with long residence time – Freshwater zone with short residence time – Tributaries;
- Level 4: Scheldt-compartment (compromise between macro-/mesocells in the Western Scheldt and the OMES compartments in the Sea Scheldt).

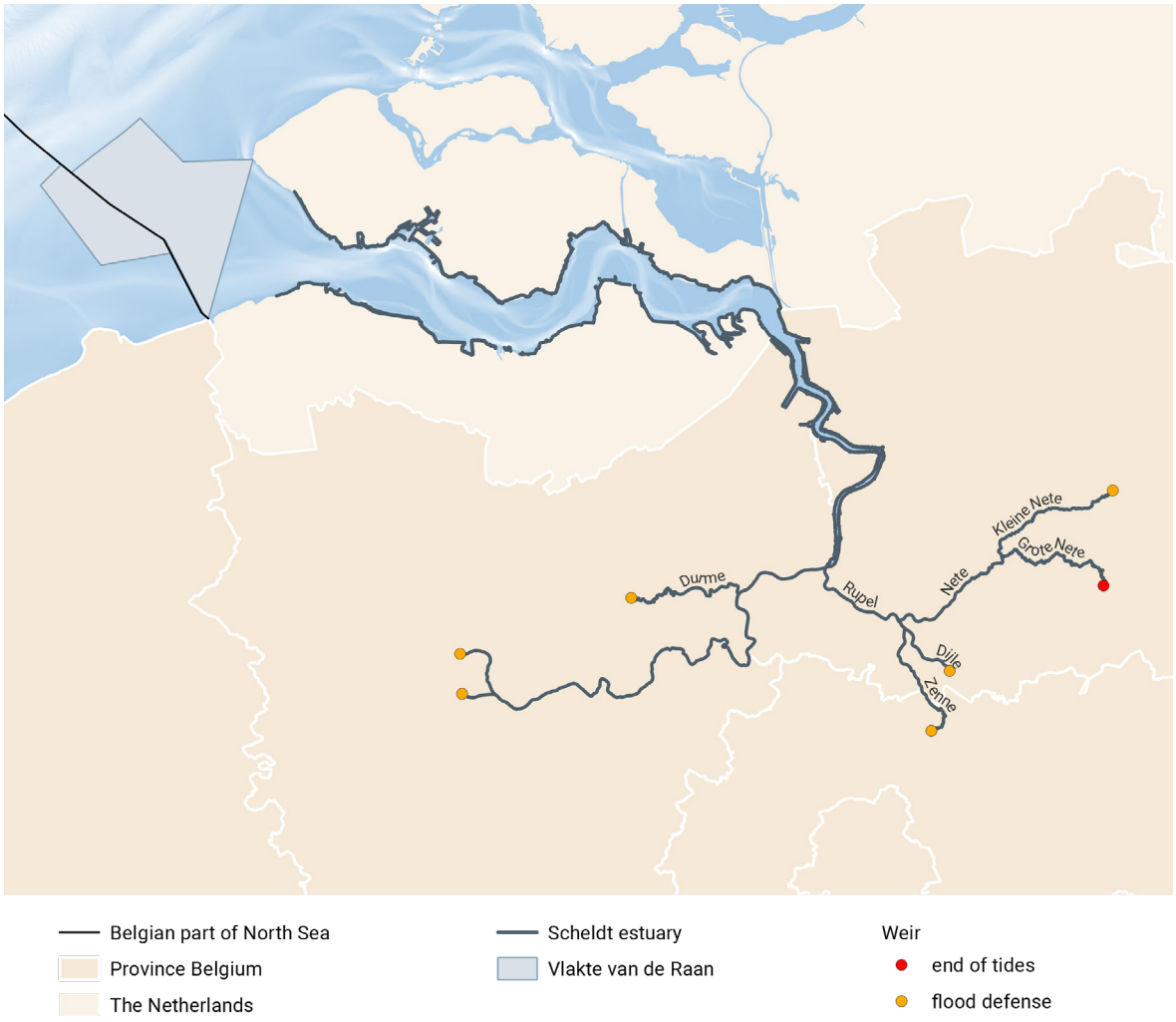

Figure 1. The area of the Scheldt estuary, with an indication of the estuary, the Western Scheldt, the Lower Sea Scheldt and the Upper Sea Scheldt (Source: Natura 2000, RBINS, MarineAtlas.be (based on RD of 22 May 2019 (MSP 2020-2026), ScheldeMonitor, Flemish Hydrography).

14.3 The hydro-morphological system of the Scheldt estuary

The Scheldt estuary is an estuary in which the tidal regime is retained along the entire salt - freshwater gradient (Directorate Zeeland and AWZ 2001). It is characterised by an ebb-dominated main channel and several flood-dominated side channels (Huisman et al. 2021). Over the past years, the hydro-morphological system of the Scheldt estuary has experienced a vast evolution that can largely be linked to human interventions. Sediment extraction and the widening of channels result in an increased trench depth and, as a consequence, an increased tidal range (Vandenbruwaene et al. 2020a). Since the end of the 19th century, an increase in annual mean high water levels has been observed throughout the estuary. Furthermore, low water levels decreased in areas with increased trench depths due to channel widening. The increase in trench depth also results in an increased celerity[1] of low water, leading to a reduction in tidal asymmetry (Vandenbruwaene et al. 2020b). On the other hand, historic land reclamations appear to increase high water celerity and tidal asymmetry. These hydro-morphological changes are mainly observed along the *Hansweert-Liefkenshoek* segment (Vandenbruwaene et al. 2020a, Vandenbruwaene et al. 2020b). Along the estuary, the flood volume and the difference between low and high tide show a clear relationship. Due to the relatively larger effect of top discharge, the slope of this relation increases upstream. A similar relation is found for the ebb volume, with the exception that for the highest flows no increase is observed at larger tidal differences (Plancke et al. 2021).

[1] Velocity.

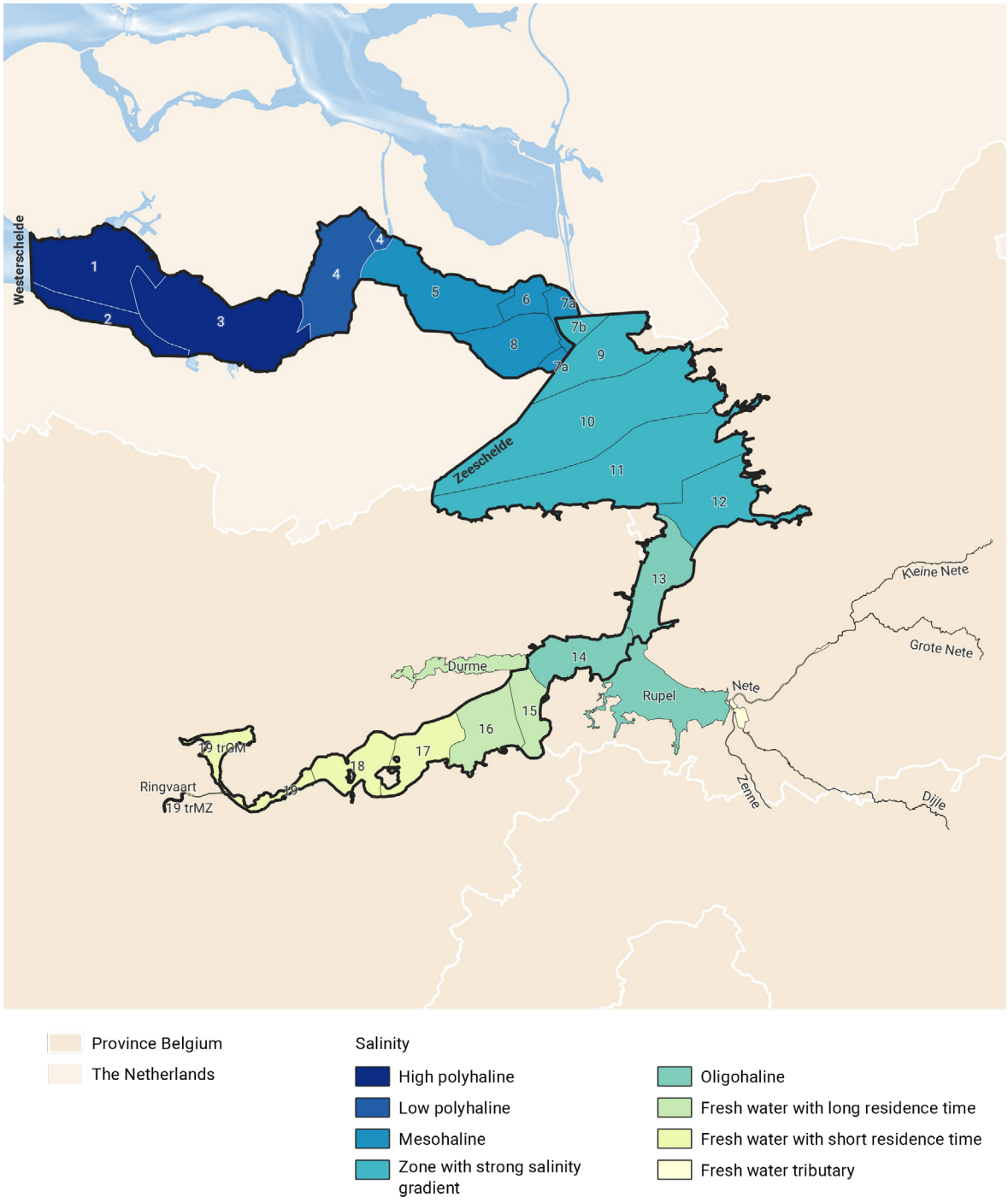

Figure 2. The spatial classification of the Scheldt estuary according to the evaluation methodology for the Scheldt compartments (level 4), Scheldt zones (level 3) and Western Scheldt – Sea Scheldt – Tributaries[2] (level 2) (Source: Maris et al. 2014a, Van Ryckegem et al. 2017, Barneveld et al. 2018).

Additionally, research was conducted on the importance of waves in the estuary, within the framework of the research programme 'Agenda for the Future'. Wave height in the estuary is rather limited due to the fetch length[3] of the waves, not exceeding a few decimetres (Huisman et al. 2021). As part of the project 'Waves in the estuary', various measurements (tidal, current, wind and wave measurements) were collected at four locations along the entire estuary (Meire et al. 2019a, Meire et al. 2020, Meire et al. 2021a, Meire et al. 2021b). Downstream, higher maximum wave heights were measured on every occasion. The wave data measured at the most downstream

[2] With trGM refering to the section Gentbrugge-Melle and trMZ to the section Melle-Zwijnaarde.
[3] The horizontal distance over which wave-generating winds blow.

location were also compared to wave data from measuring stations at the mouth of the Scheldt and on the North Sea. This showed an apparent decrease in wave height towards the Scheldt estuary (Meire et al. 2021b). In these studies, both waves produced by wind and ships were analysed.

The Western Scheldt comprises of three sediment types. The gullies generally consist of sand, whereas the intertidal areas are characterised by silt sediment. In addition, areas with erosion-resistant peat or clay are also present (McLaren 1993, Huisman et al. 2021). The sediment in the Scheldt is subject to the tides and consequently moves up- and downstream (Plancke et al. 2021). The sediment transport in the Scheldt estuary was extensively investigated as part of the 'Agenda for the Future' on different time scales (Plancke et al. 2020a) and areas of the estuary (e.g. see Hassan et al. 2017, Plancke et al. 2018, Plancke et al. 2019a, Plancke et al. 2019b, Plancke et al. 2020b, etc.). A sensitivity analysis of several parameters of the hydro- and sediment dynamics and morphological processes was also carried out at mesocell level (Meire et al. 2019b).

14.4 The ecosystem of the Scheldt estuary

Starting from Vlissingen-Breskens, the incoming tide penetrates 160 km inland, causing the Sea Scheldt to occupy an extensive freshwater tidal area with associated biotic communities (i.e. Maris et al. 2014). As a result, the Scheldt estuary has a special natural value and a rich array of ecosystem services (i.e. the benefits that society receives from nature (ecosystems) such as food production, flood protection, recreation, etc.). Due to its geographic location in an economically important and densely populated area, the Scheldt ecosystem is under constant pressure, such as habitat loss, anthropogenic disturbance and pollution (e.g. Maris et al. 2020a, Maris et al. 2020b). Over the past years, man has strongly influenced the Scheldt by means of reclamation and embankments, straightening and channel widening, sediment extraction, agriculture and urbanisation, with an impact on tidal amplitude (e.g. de Munter et al. 2010, Depreiter et al. 2014, Vandenbruwaene et al. 2016, Vandenbruwaene et al. 2020a, Vandenbruwaene et al. 2020b, Huisman et al. 2021) and a sharp decline in the area of mudflats and salt marshes as a result (e.g. Van Braeckel et al. 2012, Maris et al. 2014b). The quality of the remaining habitats was also under severe pressure due to changes in hydrodynamics (e.g. current velocities, waves, exposure rate) (e.g. see De Vet 2020) and poor water quality.

The Scheldt estuary is by nature a very dynamic system. Mudflats, salt marshes, sandbanks and gullies are constantly subject to changes in tides and salinity. The ecologically valuable habitats in the Scheldt estuary are mainly the low-dynamic (low current velocity) shallow water areas and the intertidal areas (mud flats, sandbanks and salt marshes). An overview of the different ecotopes as well as the trends in their spatial distribution is given in Barneveld et al. (2018). The low-dynamic shallow water areas are essential for the reproduction and growth (nursery function) of fish, crustaceans and molluscs. The intertidal areas are foraging, spawning, breeding or growing sites for many organisms and contribute to the biodiversity of the estuary (e.g. Van Ryckegem et al. 2020). In this way, they are an essential habitat for economically important species such as sole (*Solea solea*) (Maris et al. 2014b). The mudflats and sandbanks are usually rich in bottom-dwellers and provide an important source of food for waders and other birds (e.g. Vanoverbeke and Van Ryckegem 2015, Craeymeersch and Ysebaert 2020). The trophic relationships among species are evaluated by Van De Meutter et al. (2019) and De Neve et al. (2020). Particularly the areas with a moderate exposure rate (the percentage of time that the mudflat or sandbank is above water) are most attractive from an ecological point of view (Milieueffectrapport Verruiming vaargeul Beneden-Zeeschelde en Westerschelde 2007, Wetsteijn et al. 2007, Depreiter et al. 2014). Salt marshes, on the other hand, offer nesting possibilities for many bird species. Moreover, they serve as a refuge area for various species during high tide. Furthermore, the intertidal areas have an important regulating effect on water quality by removing nitrogen and acting as a source of dissolved silica, which is essential for the growth of diatoms (e.g. Gribsholt et al. 2005, Struyf et al. 2005, Struyf et al. 2006, Jacobs et al. 2008). They also provide oxygen enrichment and offer refuge for, *inter alia*, the plankton in case of unfavourable conditions in the gully itself.

Beside these ecosystem services and its ecologically attractive function, the Scheldt estuary provides a whole range of important ecosystem services (Schepers et al. 2018). For example, salt marshes play a role in the buffering of wave action (Heuner et al. 2015, Van Braeckel et al. 2019) and sea level rise (Broekx et al. 2011, Ntegeka et al. 2013, Temmerman et al. 2013, Temmerman and Kirwan 2015, Smolders et al. 2020, van der Werf et al. 2020), indirectly generating an economic value. The monetary valuation of (changes in) ecosystem services is already discussed in several publications (e.g. Liekens et al. 2013, Staes et al. 2017). Numerous reports on the economics of ecosystems and biodiversity have also been published at European level (TEEB website). The SMARTSEDIMENT project studies sediment management in function of ecosystem services provisioning throughout the entire Scheldt delta, including not only the Scheldt estuary but also the Eastern Scheldt. In addition to the known threats to ecosystem services in the Scheldt estuary (pollution, loss of habitat, etc.), the occurrence of invasive species can also be considered a potential threat to species diversity in recent decades (e.g. Van

Damme et al. 1992, Van Damme and Maes 1993, Ysebaert et al. 1997, Faasse and Van Moorsel 2003, Azémar et al. 2007, Soors et al. 2010, Kerckhof 2011, Soors et al. 2013, Adriaens et al. 2014, Boets et al. 2016, Verleye et al. 2020, SEFINS project).

International Directives and Agreements, such as the Ramsar Convention and the European Birds and Habitats Directives, in combination with national legislation, have ensured that mudflats, salt marshes and most parts of the Scheldt estuary and the adjacent valley/polders are (inter)nationally protected. This is because of the unique character and rarity of the entire estuarine salt - freshwater gradient on the one hand, and the importance as a wintering, migration and breeding area on the other hand. In the Western Scheldt, European fishing quotas led, among other things, to regulations for cockle fishing in order to preserve sufficient food for birds. With respect to water quality, an important step was taken with the publication of the European WFD (Maris et al. 2014b).

The ScheldeMonitor collects all available information (expertise, literature, projects, etc.), data (datasets, measurements, etc.) and data products (maps, graphs, indicators, etc.) relating to the various aspects of the Scheldt ecosystem. Important information is also available in the reports produced within the framework of the R&M working group (see the websites of the ScheldeMonitor and VNSC).

14.5 Human activities in the Scheldt estuary

The Scheldt estuary is not only an important ecosystem, but also hosts a number of human activities, such as shipping, dredging for nautical accessibility, recreation, flood protection with associated embankment and alternative measures (e.g. controlled flood plains), embankments, fisheries, etc. Some of these activities are described in more detail below.

14.5.1 Shipping and ports

The Scheldt estuary, particularly the area downstream of Antwerp, is characterised by a large number of shipping movements. In 2019, the number of seagoing vessels that entered the ports of Antwerp and Ghent (North Sea Port Flanders, via Terneuzen) amounted to 17,634, or approximately 48 a day, of which 82% was accounted for by the port of Antwerp. These seagoing vessels represented a total gross tonnage of 453.3 million GT (gigatonnes) (92% for Antwerp), representing a total cargo traffic of 270.7 million tonnes (88% for Antwerp). In addition, inland navigation of goods in the port of Antwerp and Ghent accounted for over 101.3 and 24.6 million tonnes, respectively (Merckx 2020). In 2018, the port of Antwerp also provided direct employment for 62,635 fulltime equivalents (FTEs) (59% of direct employment in Flemish seaports) and generated an added value of 11.1 billion euro (65% of Flemish seaports) (Merckx 2020) (see also thematic chapter **Maritime transport, shipping and ports**).

The location and operation of ports generate effects on the environment. These effects are listed, *inter alia*, in the (plan-)environmental impact assessments (EIAs) of the ports' strategic plans (see also EIA file database, Departement of Environment and Spatial Development).

Vlaamse Waterweg nv is working on an integrated plan for the Upper Sea Scheldt and wants to create a sustainable balance between all of the functions of the river: navigability, recreation and nature development. The EU is equipping its network of waterways for inland navigation, which is why, for example, the Seine and Scheldt will be better connected, allowing the direct transport of large cargoes over water between Paris, Antwerp and Rotterdam. In order to prevent excessive traffic on the Ghent-Terneuzen Canal and the Western Scheldt, the Upper Scheldt should also be easier to navigate for class Va cargo vessels (with a load capacity up to 2,250 tonnes). This new connection between the ports of Ghent and Antwerp will facilitate shipping between the Scheldt basin and the Albert Canal, and thus provide added value for the entire Flemish waterway network. In addition, the Coastal Vision project (previously *Complex project Kustvisie* and *Vlaamse Baaien*) is looking into possibilities for estuarine shipping at an advanced shoreline. The construction of islands could remove restrictions on inland navigation and have a direct impact on coastal safety and safer coastal navigation (Project Group Vlaamse Baaien 2012, Rondelez and Pirlet 2018).

14.5.2 Dredging and dumping

In 2019, the Government of Flanders (Maritime Access division) invested 219.9 million euro to ensure the accessibility of Flemish ports (including the Scheldt estuary, Merckx 2020) (see also thematic chapter **Dredging and dumping**). This investment includes maintenance dredging at sea, on the Western Scheldt and on the Lower Sea Scheldt, wreck salvage and sludge processing (see also the Decision of the Government of Flanders of 13 July 2001).

The aim of the Convention on the Implementation of the Development sketch 2010 Scheldt estuary (Verleye et al. 2018) was to ensure the implementation of a number of projects aimed at optimising the safety, accessibility and nature of the Scheldt estuary. In order to guarantee accessibility to the Scheldt harbours, the fairway was widened to a tidal independent navigation of up to 13.1 m wide that is continuously maintained. To this end, a new dumping strategy was developed in the Western Scheldt (Plancke et al. 2010), based on the principle of Flexible dumping. In addition to preserving the physical characteristics of the system, in accordance with the Scheldt treaties (2005) on the Development sketch 2010 Scheldt estuary and the Common policy and management of the Scheldt estuary, this dumping strategy created new ecologically valuable habitats near a number of sandbank edges by means of targeted dumping of dredged material. Furthermore, the relation between human interventions and water levels during windless periods was also investigated on behalf of the Maritime Access division (Van De Moortel et al. 2021). In recent years, alternative dumping sites have also been explored near deeper parts of the main channel by means of pilot dumping to re-dump the dredged material into the estuary. These new insights will be used in the optimisation of the dumping strategy. For the disposal of the dredged material from the maintenance of the Lower Sea Scheldt, the Maritime Access division obtained environmental permits from the provinces of East Flanders and Antwerp.

For the Sea Scheldt, sludge management is an important point of attention (e.g. increased sludge concentration in the water column, indications of an increased total quantity of sludge in the estuary) (Cox et al. 2019). The Agenda for the Future includes research on sludge management (Vandenbruwaene et al. 2016, Vandenbruwaene et al. 2017, Vandenbruwaene et al. 2020a, Plancke et al. 2021), with the aim of increasing system knowledge of the Scheldt estuary and investigating the extent to which numerical models can reproduce these processes (Evaluatie verdrag beleid en beheer Schelde-estuarium 2014-2018, Werkplan 2020-2023. Onderzoek en monitoring Schelde). Based on these models, research was carried out that led to an optimisation of the current permit for the dumping of dredged material from maintenance dredging in the Lower Sea Scheldt for both the sludge-rich and the sand-rich fractions (Plancke et al. 2016, Plancke et al. 2019c).

The sustainable management plan for the Upper Sea Scheldt includes dredging works that maintain the navigable profile of the river without damaging protected nature. A dredging programme has been developed for the next twenty years to keep the river navigable. The implementation of this sustainable management plan started in 2015.

14.5.3 Protection against flooding

The implementation of the Sigmaplan by the Government of Flanders provides protection against flooding from the Scheldt river and its tributaries, and runs until 2030 (see also **14.1 Policy context**; ScheldeMonitor and website VNSC). For example, the polders of Kruibeke now form a flood control area with reduced tides (FCA-RT) and the de-poldering of Lillo allows more space for flooding. In addition, several models have been developed to map the consequences of flooding and rising sea levels in the Scheldt estuary (Nnafie et al. 2018, Smolders et al. 2020, Vandenbruwaene et al. 2020c). Also, since 2015, under the WFD, EU member states are required to prepare flood risk management plans at river basin level with a special focus on protection against and prevention of floods. The flood risk management plan for the Scheldt was integrated into the River basin management plans for Scheldt and Maas 2016-2021 and the Programme of measures for the river basin management plans for Scheldt and Maas 2016-2021. Within Flanders, the Coordination Committee on Integrated Water Policy (CIW) coordinates the procedures for drawing up all mandatory documents for the WFD and the Floods Directive. Furthermore, the water assessment (watertoets), in which the government assesses the impact of a future project on the water system, also contributes to the prevention of flood damage. The water levels can also be consulted in realtime at www.waterinfo.be and flood-sensitive areas can be searched for on Flanders' Climate Portal (see also thematic chapter **Safety against flooding**).

14.6 Evaluation of the functioning of the Scheldt estuary

In addition to the mandatory assessments, Flanders and the Netherlands have decided to jointly carry out a six-yearly evaluation (under the umbrella of the VNSC working group on R&M) to assess the functioning of the Scheldt estuary and the activities that take place in the estuary. This evaluation makes use of the monitoring results of the integrated monitoring programme for the Scheldt estuary, which is being carried out by various institutions (e.g. Nederhoff 2016, Vandenbruwaene et al. 2020c, Van Ryckegem et al. 2020). The report focuses on the evaluation of the three main functions – 'nature', 'safety' and 'accessibility' – in the form of seven communication indicators for sustainable management (table 1).

Table 1. Overview of the indicators that are part of the evaluation methodology for the T2021 evaluation of the three principal functions of the Scheldt estuary (Source: SchkeldeMonitor).

Principle function	Indicator
Safety	Hydrodynamics
Accessibility	Hydrodynamics
Nature	Water quality
	Ecology
	Habitat
	Morphology

In 2011, an evaluation method was published that describes how each indicator should be evaluated (Holzhauer et al. 2011). This methodology is dynamic and was updated for the first time by Maris et al. (2014a). Within the methodology, each indicator is individually substantiated according to a pyramid structure in which the relevant key parameters, calculation parameters and explanatory parameters are included. In order to be able to evaluate the starting situation, the starting point has been defined unambiguously with 2009 being the reference year (Holzhauer et al. 2011, Maris et al. 2014a). Depreiter et al. (2014) describe the starting situation (T2009) and the trend developments until 2009 of the Scheldt estuary. Barneveld et al. (2018) (T2015) evaluate the situation in the Scheldt estuary between 2010 and 2015 and try to identify the causes for the observed trends. A new update of the evaluation methodology is expected by mid-2022, with which the next six-yearly evaluation (T2021) will be carried out. This update will focus on increasing the coherence between the various pyramids for 'nature', a broader interpretation based on narratives on ecology and the relevant human activities on the Scheldt estuary. Analysis scripts are additionally implemented on the data analysis platform of SchkeldeMonitor and, where possible, linked to the databases of this platform.

Prior to the evaluation method described above, a set of indicators had already been selected in the context of the LTV objectives and aligned with the entire cross-border Scheldt estuary, in consultation with scientists and policy makers (see Indicators for the Scheldt estuary 2011 and the website SchkeldeMonitor).

Finally, a system analysis of the Long-term perspectives on Accessibility and Nature was carried out to identify the current state, developments and bottlenecks. Furthermore, as part of the recovery measures taken in the Scheldt and Durme estuary, a PAN area analysis (Programme-based Approach to Nitrogen) was drawn up in 2018 (Mertens and Van Ryckegem 2018), followed by a climate adaptation plan for the estuarine nature in the Sea Scheldt in 2019 (Van Ryckegem 2019).

Legislation reference list

Overview of the relevant legislation on international ('Year A': adoption; 'Year EIF': entry into force), European 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.

International conventions and agreements			
Acronyms	**Title**	**Year A**	**Year EIF**
Canal Ghent-Terneuzen	Verdrag tussen België en Nederland betreffende de verbetering van het kanaal van Terneuzen naar Gent en de regeling van enige daarmede verband houdende aangelegenheden	1960	1961
Scheldte-Rhine connection	Verdrag tussen het Koninkrijk België en het Koninkrijk der Nederlanden betreffende de verbinding tussen de Schelde en de Rijn	1963	1965
Improvement of the waterway at Walsoorden	Overeenkomst tussen de Regering van België en de Regering van het Koninkrijk der Nederlanden betreffende de verbetering van de vaarweg door de Westerschelde nabij Walsoorden	1970	1972
RAMSAR	Convention on wetlands of international importance, especially as waterfowl habitat	1971	1986
Protocol Canal Ghent-Terneuzen	Protocol bij het verdrag tussen het Koninkrijk België en het Koninkrijk der Nederlanden betreffende de verbetering van het Kanaal van Terneuzen naar Gent en de regeling van enige daarmede verband houdende aangelegenheden	1985	1987
Treaty of Charleville-Mézières	Verdrag van Charleville-Mézières inzake de bescherming van de Schelde *(beëindigd in 2006)*	1994	1998
Widening channel 48/43/38 feet	Verdrag tussen het Vlaams Gewest en het Koninkrijk der Nederlanden inzake de verruiming van de vaarweg in de Westerschelde	1995	1996
Ministerial Conference in Middelburg	Verklaring ondertekend door de Regeringen van het Koninkrijk der Nederlanden, de Franse Republiek, het Vlaams Gewest, het Brussels Hoofdstedelijk Gewest en het Waals Gewest, betreffende het integrale beheer en de duurzame ontwikkeling van de Schelde, met de goedkeuring van het Schelde Actieprogramma	1998	1998
Ministerial Declaration of Liège	Ministeriële Verklaring van Luik	2001	2001
MoU Kallo (1th MoU)	Memorandum van overeenstemming tussen Nederland en Vlaanderen met betrekking tot. de onderlinge samenwerking ten aanzien van het Schelde-estuarium	2001	2001
MoU Vlissingen (2th MoU)	Tweede memorandum van overeenstemming tussen Vlaanderen en Nederland met betrekking tot de onderlinge samenwerking ten aanzien van het Schelde-estuarium	2002	2002
Scheldt Treaty	Scheldeverdrag	2002	2005
MoU Den Haag (3th MoU)	Derde memorandum van overeenstemming tussen Vlaanderen en Nederland met betrekking tot de onderlinge samenwerking ten aanzien van het Schelde-estuarium	2005	2005
Pilotage Rates	Verdrag tussen het Vlaams Gewest en het Koninkrijk der Nederlanden inzake de beëindiging van de onderlinge koppeling van de loodsgeldtarieven	2005	2008
Joint Nautical Management	Verdrag tussen het Vlaams Gewest en het Koninkrijk der Nederlanden inzake het gemeenschappelijk nautisch beheer in het Scheldegebied	2005	2008
Common Policy and Management	Verdrag tussen de Vlaamse Gemeenschap en het Vlaams Gewest, enerzijds, en het Koninkrijk der Nederlanden, anderzijds, inzake de samenwerking op het gebied van het beleid en het beheer in het Schelde-estuarium	2005	2008
Development sketch 2010 for the Scheldt Estuary	Verdrag tussen het Vlaams Gewest en het Koninkrijk der Nederlanden betreffende de uitvoering van de ontwikkelingsschets 2010 Schelde-estuarium	2005	2008
Scheldt Council Institution	Besluit van het Politiek College van de Vlaams-Nederlandse Scheldecommissie inzake de instelling en activering van de "Schelderaad"	2014	2014

European legislation and policy context			
Document number	**Title**	**Year**	**Number**
Directives			
Directive 92/43/EEC	Directive on the conservation of natural habitats and of wild fauna and flora (Habitats Directive)	1992	43
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 2009/147/EC	Directive on the conservation of wild birds (Birds Directive)	2009	147

Belgian and Flemish legislation		
Dates	**Title**	**File number**
Decisions of the Govt. of Flanders		
Decision of the Government of Flanders of 13 July 2001	Besluit van de Vlaamse Regering betreffende de aanduiding van de maritieme toegangswegen en de bestanddelen van de haveninfrastructuur	2001-07-13/90