Creating a Sustainable Waterway to Antwerp

An interdisciplinary research on the improvements of a flexible dredging strategy compared to conventional dredging, aiming for a sustainable estuary of the Scheldt.

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------ ABSTRACT---

This interdisciplinary study analyses the possibilities of improvements in dredging schemes in the Estuary of the Scheldt. Thereby the newly proposed dredging method of flexible dredging is compared to the conventional dredging which has been applied the past decades. In this comparison the alterations in influences on morphodynamics, ecosystem health and the feasibility are taken into account. Flexible dredging is in its experimental phase, only predictions of morphodynamic effects have small uncertainty; they show positive results on the morphodynamic stabillty in the estuary. Though when these improvements are translated to ecosystem health and feasibility, a positive outcome and very little influence may be expected respectively. Therefore flexible dredging seems to be a promising method for reducing the negative effects of dredging, but needs more thorough investigation, especially to be able to accurately assess long term ecological effects and its costs and benefits.

Keywords: Scheldt Estuary, flexible dredging, morphology, ecosystem health, feasibility

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1 Introduction

The Scheldt estuary is the debouchment of the Scheldt river, which is 160 km long and covers an extensive area of 21.000 km^2 in both Belgium and the Netherlands that connects the river the Scheldt to the North Sea (van den Bergh et al., 2005). An estuary is a coastal body that is either permanently or periodically open to the sea and which receives at least periodic discharges from rivers. This body of water thus receives sediment from both fluvial (from rivers) and marine (from sea) sources. Characteristic to estuaries, and what makes them different from ordinary deltas, is that the net sedimentation transport is landward so they are infilling their own valleys (Messelink, 2011). Because of these unique features estuaries are important contributors to the world's biodiversity by providing unique habitats alongside an uninterrupted salinity gradient from a marine to a freshwater system (van den Bergh et al., 2005). The Scheldt estuary is therefore an unique ecosystem in Europe. However, the estuarine environment is severely threatened, mostly because of human induced disturbances (Baden et al., 2010; Heck and Valentine, 2005).

Downstream the Scheldt estuary is one of the largest ports of Europe situated, Antwerp, with 15.240 sea vessels passing every year. The port provides an access from the North Sea though West Europe and is therefore a very important logistic route. For Belgium the estuary of the Scheldt generates 6% of its GDP (Anon, 2010). Navigation through this waterway requires a certain depth and width of the channel, which is achieved and maintained by dredging. The possible alleged loss in biodiversity and existing ecosystems due to dredging is the focus of stakeholder debate aiming for ecological conservation and economic gains respectively. The ecological issues result from the combined effect of land reclamation, land and water management, discharge manipulation, canalization, and channel deepening. This paper is aimed to reduce the impact of just one of those facets, namely the channel deepening , thereby contributing to an more sustainable waterway development.

Therefore it will investigate the influences of dredging in the Scheldt estuary in general and possible improvements in the current dredging strategy specifically. Thereby we will analyse the potential of a new dredging approach called 'flexible dredging'. This new approach of dredging is proposed by experts of the Port of Antwerp (Plancke et al, 2006) as an alternative to conventional dredging. It tries to solve the ecological threats, like decreased retention capacity, fragmented ecological structure, increased erosion rates and especially tidal current velocities (van den Bergh et al., 2005). Furthermore since vessels are getting bigger and because of competition among Western Europe the need for a dredged estuary intensifies (Nistal,2004). Integrating the benefits of dredging with preservation of the original functions of the estuary is the main purpose of flexible dredging.

Earlier research on dredging of the Scheldt, for instance a study done by van den Bergh et al. (2005), found a negative influence of dredging on nature. However Plancke et al. (2006) mentioned the first promising results of flexible dredging toward nature preservation. The main contribution of this paper lays in weighting the viability of applications of flexible dredging and its characteristics compared to conventional dredging, which is carried out up till now. It does so by answering the following research question:

Does the flexible dredging strategy compared to conventional dredging contribute to a more sustainable future of the estuary of the Scheldt?

This question is researched by answering the following more disciplinary sub questions regarding both dredging methods:

What are the effects of the dredging method to the morphological stability of the estuary system?

What is the influence of the dredging method towards the sustainability of ecosystem health?

What are costs and benefits of the dredging method in the Scheldt estuary?

To justify this interdisciplinary approach it is stated that the Scheldt problem is complex, relevant and at the interfaces of all three disciplines, namely ecology, geomorphology and economics, and that insights are offered by all three disciplines and that none of them has been able to address the problem comprehensively by itself (Repko, 2008). For preserving ecosystems, knowledge about the consequences of dredging regarding all sub disciplines need to be integrated to be able to create thoughtful incentives to sustainability and to make these incentives economically and geographically feasible . Each dredging method, and its interconnections to the many natural and economic features and processes within the estuarine system, need to be fully evaluated considering all disciplinary perspectives. Only then the evaluation would serve the greater whole that could eventually lead to a more dynamic and holistic governance of the estuary.

The next chapter will introduce the study area and will explain some basic disciplinary jargon and concepts. The third chapter contains the theoretical framework in which we work. Chapter 4 and 5 will provide general insights and basic knowledge of conventional dredging and the implications of flexible dredging respectively. Both conventional and flexible dredging is evaluated by its actual operation, its implications for biodiversity and ecosystem health and its feasibility. The paper concludes in Chapter 6 en 7 with a discussion and a conclusion.

2 Study Area

This section aims to give insights into the characteristics of the Scheldt estuary to provide the preconditions for understanding the influences of dredging. It thereby defines on which parts of the estuary the focus lays in the evaluations and which concepts and jargon are used to describe those research areas.

The estuary of the Scheldt has some local variations in water depth. A depth map of the whole estuary on which its morphological distinct entities is shown in figure 2.2 on the next page. The system is subdivided in different morphological entities that are all controlled by the energy gradients that exist within the system. Therefore the whole estuary could be subdivided in three main zones seen as vertical on the direction to the stream. That part of the channel situated below mean low water is the subtidal zone, this part is constantly submerged and draining water from upstream and it generally consists out of the main navigation channels. The part of the channel situated between mean low water and mean high water is the intertidal zone and the part that is only submerged at spring tide is the supratidal zone. In the last two zones water is shallower and the current velocities and energy levels are lower. This makes them ideal habitats for all kinds of flora and fauna. Figure 2.1 shows a diagram of one such margin of the estuary main channel.

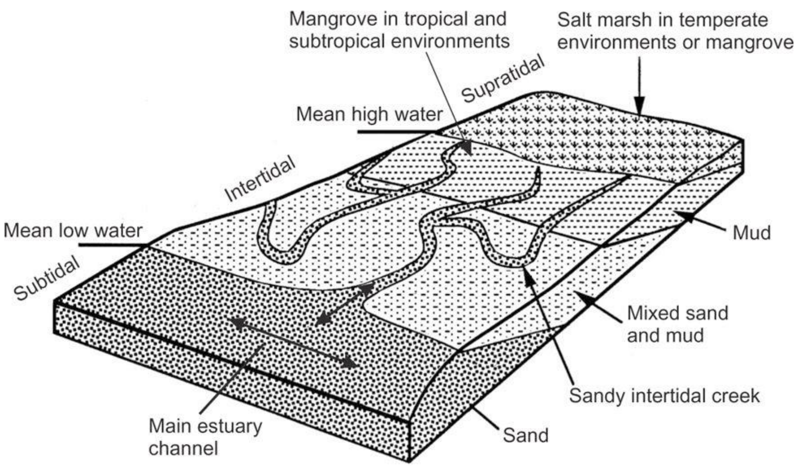

Figure 2.1. Diagram showing typical morphology and sediment distribution for the intertidal margin of an estuary channel. (Messelink, 2011).

Those higher situated areas thus consist on a variety of high value 'ecotopes'. An ecotope is an integration word for both 'morphology' and 'habitat'. They are defined as the smallest homogeneous landscape features that can be considered ecologically distinct (Bastian, 2003).

Within the Scheldt estuary there are a number of different ecotopes within the inter and supra tidal zones. In this paper the focus lays on four main ecotope types, namely the 'platen', which are big sandbars, the secondary channels and the shallow water and transition zones which all lay in the intertidal zone, and the tidal flats, large clayish flats sometimes with marches upon them, that lay in the supratidal zone.

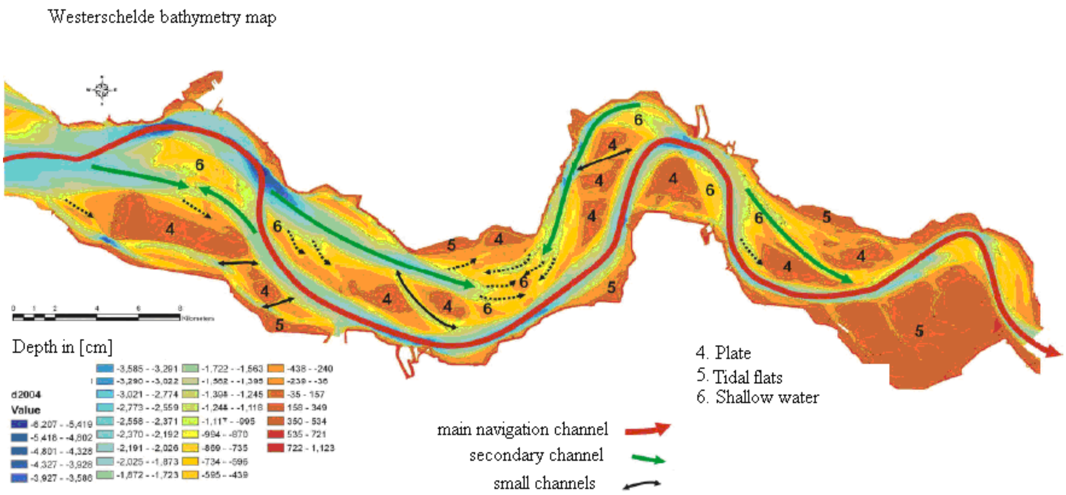

Figure 2.2. Schematic overview of the morphological elements in the Westerscheldt (Consortium Arcadis-Technum, 2007).

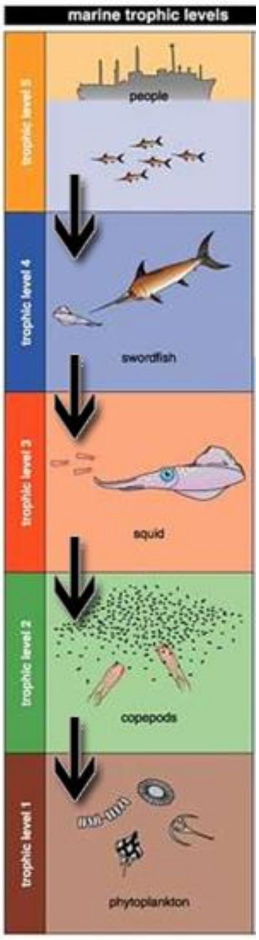

Figure 2.3. A marine ecosystem food web

Every ecosystem, consistant out of different ecotopes, has got its unique type of food web. A food web consists of different trophic levels; the first trophic level is occupied by the smallest life forms whereas the highest trophic levels contain top predators (fig. 2.3). The system is built in such a way that species can only feed on the trophic level below their own.

Within each ecosystem primary producers represent the lowest level of the food chain (Holzhauer et al., 2011). In the Scheldt estuary this trophic level is particularly occupied by the phytoplankton population of organisms called diatoms (Holzhauer et al., 2011). Thus, when diatom populations change, a shift in the whole energy transfer to higher trophic levels will find place (Holzhauer et al., 2011). This is it that makes diatoms have an important role in the estuary. The second trophic level is occupied by different 'primary consumers' which are the direct link between phytoplankton and higher trophic levels. Some species in the higher trophic levels are good indicators for the health of the ecosystem because they can only persist if the ecosystem is in a healthy state (Maris and Meire, 2008).

3 Theoretical framework

This section deals with theoretical foundation obtained from ecological, morphodynamic and economic perspectives involved in this research. And thereby provides insights that help with interpretation of the results. Furthermore this section seeks for tangent theories among the disciplines and if possible makes use of integration techniques provided by Repko (2008).

3.1 Stable States

Since dredging of the Scheldt estuary is concerned with sedimentation and erosion of the navigation channel, the concept of a morphodynamic stable state combined with awareness of multiple possible stable states play a key role. This concept is about a dynamic stable state in which input and output (in the case of a navigation channel typically sedimentation and erosion) have comparable rates providing a stable state. Negative feedback mechanisms maintain the stable state in case of a slight imbalance in input and output (Huggett, 2007). However this imbalance can reach a threshold in which the system moves to another stable state with different characteristics compared to the initial state. With regard to species dynamics in ecosystems, this mechanism of departures from stability that can reach certain thresholds holds too (Scheffer, 2001). This tangency among earth sciences and ecology, together with Repko's (2008) integration technique of reorganisation makes it possible to merge both theories and thereby it provides common ground. This common ground, in its core, is about the awareness of the existence of multiple stable states.

When situations arise in which states depart from their stable position by positive feedback mechanics, both in morphology and ecology, certain thresholds could be reached, that would cause drastic changes to the system. Possible losses and dangers from exceeding a threshold change costs and benefits of the action and thereby (in)directly alter its feasibility. Therefore economic estimations are highly depended on stable state and threshold awareness gained from ecology and earth sciences. When considering the equilibrium between costs and benefits in an environmental cost and benefits analysis (CBA) can only be feasible when ecological and morphological equilibria are taken into account (Söderbaum, 2008). In these insights therefore lies not only common ground among the involved disciplines, but also the essential knowledge to provide a sustainable solution for the Scheldt estuary.

3.2 Valuation of Ecosystems

In addition to the common ground in the previous paragraph, the concept of ecosystem services is about which goods and services provided by nature can have an economic value (Fisher et al. 2009); it therefore bridges the gap between ecology and economy. The human benefits retrieved from ecosystems, for example for production, education and recreation, are defined as ecosystem services by Helliwelll (1969). Chapin et al. (2000) defines ecosystem services as "…the processes and conditions of natural ecosystems that support human activity and sustain human life." A definition which additionally states that services can provide aesthetic and cultural values (Daily, 1997).

To determine feasibility of dredging, its costs and benefits should be elaborated. Since loss in ecosystem services needs to be considered as costs of dredging, the value of ecosystems needs to be determined to take them into account.

Generally spoken there are two types of operations that can be followed to perform an ecosystem valuation. 1) The first approach is about the market value of a good or service, in this way it is investigated what a certain good or service would have been worth when sold on a market. This practice is mainly executed through a comparison between an ecosystem service with an comparable good produced by men and found on an actual market (Goulder and Kennedy, 1997). As an example one can think of a fresh water plant found alongside a wetland with great filtering capacities. To cost of treatment to yield fresh water for such fresh water plant can be considerably lower compared with a similar fresh water plant in an urban area (Bade, 2006). 2) The second approach is as simple as it is subjective, and is based on the extent to which people are willing to save a certain aspect of nature at a certain cost (Goulder and Kennedy, 1997). This approach is useful when no market comparison is possible or when determining emotional value. (Hanley et al, 2001).

4 Conventional Dredging in the Scheldt

This chapter describes the implications of conventional dredging with regard to its requirements for a navigable waterway, its influence on surrounding areas and its feasibility. Hereby we consider conventional as the dredge methods that has been used up till now, opposite to the newly proposed flexible dredging which is described in the next chapter. As obtained from our common ground in the theoretical framework both this and the following chapter will make use of interdisciplinary knowledge on stable state equilibria and the economic value generated by nature.

4.1 Requirements for a Navigable Waterway

The port of Antwerp needs a water depth of 13.1 meter for tide-independent navigation (Graveland, 2005). However for safety reasons, for example, the uncertainty of water depths, waves, sudden sedimentation, irregularities of dredging and squad effect, there is a safety water depth standard of an extra 12,5% (Fig. 4.1).

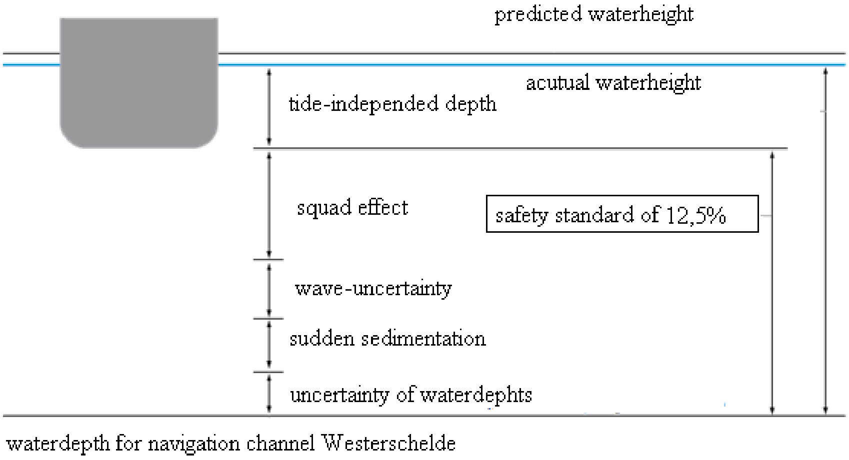

Figure 4.1: Minimum water depth for tide-independent navigation. (Modified from Project Verruiming vaargeul, 2006)

The squad effect is a hydrodynamic effect on the water height by which a boat that is navigating at higher velocities through shallow water is creating areas of low pressure that results in a ship coming closer to the river bed than would be expected. Because of this the waterway has to be dredged to an officially set water depth of 14,7 meters (Project Verruiming vaargeul, 2006, p15)

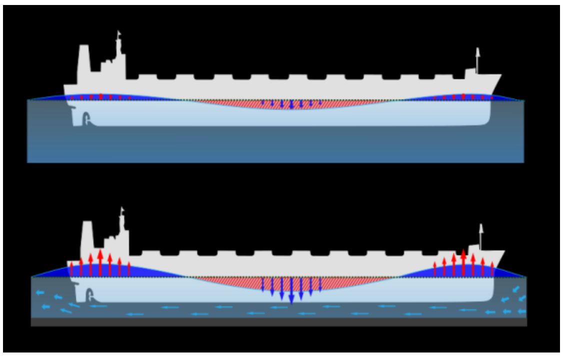

Figure 4.2: The squad effect. The lower ship is moving faster than the upper ship.

4.2 The influence of Dredging on Morphology and Ecosystems

4.2.1 Morphology

Conventional dredging has as primary goal keeping the main navigation channel at a minimum of 14.6 meter depth. The dredging activities already started in the end of the nineteen century but intensified in the fifties last century (Plancke, 2006). The dredged material was always disposed at fixed disposal sites or in the North Sea. Due to this loss of sediment within the estuary system and specifically the loss of it in the main navigation channels, the erosive-energy of the tidal wave increases, because of the reduction in friction due to loss in specific surface area. The higher tidal current speed and wavelength result that the intertidal and supratidal areas suffer increased erosion. With intensified tidal current speeds, the sea water wedge penetrates deeper into the estuary whereby the salinity in the estuary changes as well (Maris and Meire, 2011). Because species have certain salinity level boundaries where they can cope with, the changes in salinity could mean a loss of habitat for certain species (Maris and Meire, 2011). Furthermore, interferences in the east of the estuary near the river can cause fresh water to run up further into the estuary and thereby changing the salinity as well. Therefore, monitoring the salinity of the Scheldt is essential to know the habitat ranges of different species (Deltaris bijlagerapport, 2011). The general trends are area reduction and increased height of the plates and their prolonged drying-interval, decrease of area of shallow water and tidal flats, extension of area and deepening of the navigation channel and sedimentation in the secondary channels and small channels. Also the transitions to low dynamic shallow parts of the estuary turned more steep; also see figure 4.3 (Deltaris bijlagerepport, 2011). In other words, due to the human impacts of conventional dredging the high-dynamic surface area extended and deepened and the surface area of low-dynamic shallow water (intertidal-area and tidal flats) decreased dramatically. Those morphological changes have an inherent positive feedback mechanism. Because there is less low-dynamic shallow water area, friction is lower and tidal energy higher, resulting in even more erosion of the low-dynamic shallow water areas. Thus this 'runaway effect' is the departure from a morphodynamic stable state towards an alternative (stable) state. This erosion will take on and on till it could cross a threshold. After this point a negative feedback mechanism like deposition will no longer turn the system back in its old state and some new balance will form between erosion and deposition changing the morphology of the estuary completely.

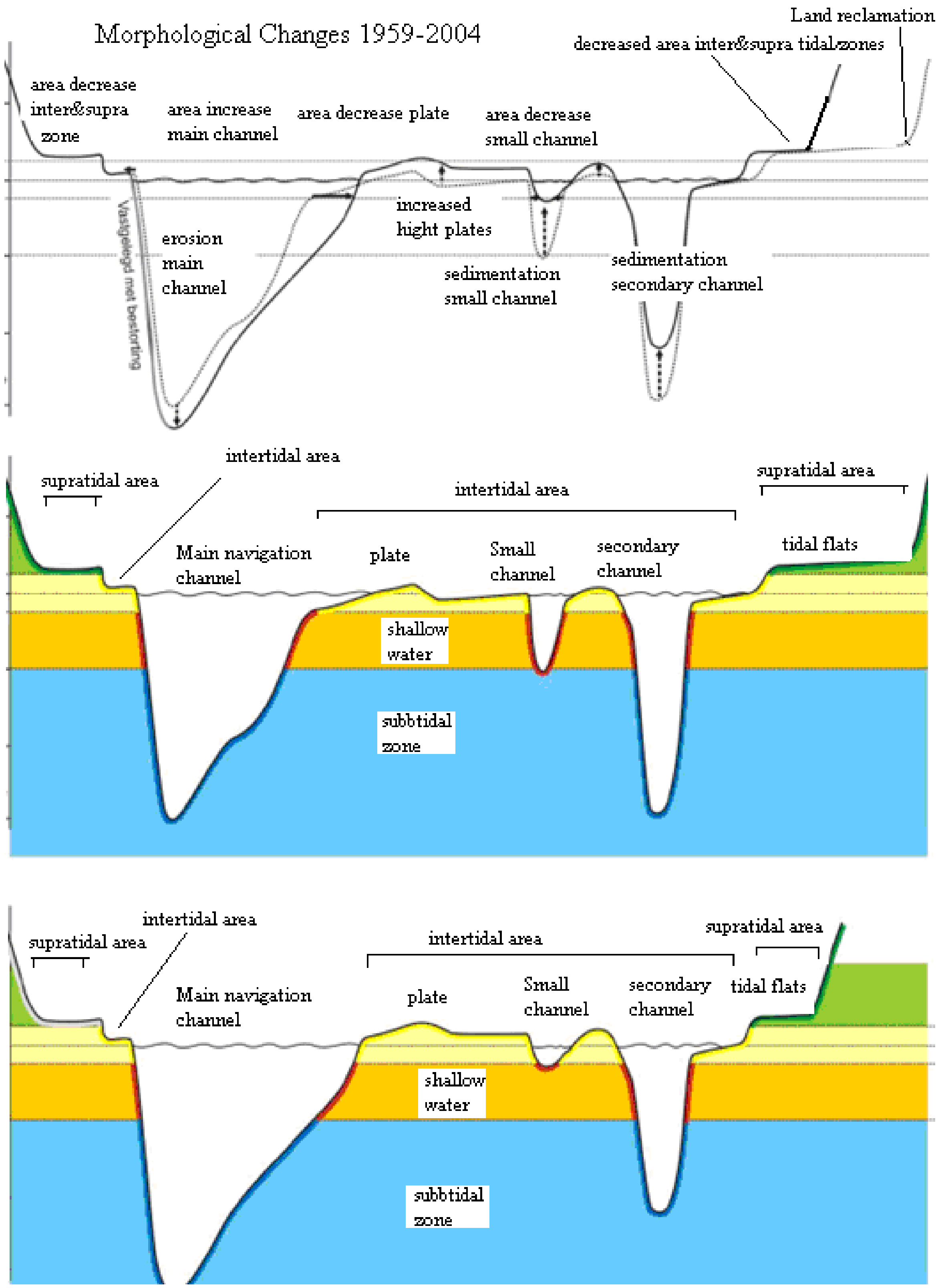

Figure 4.3: Summary schematic profiles of the morphological developments for the whole estuary of the Westerschelde in the periods of 1959-2004. The top graph shows the difference between1959 and 2004.The middle graph shows the situation in 2004, the lower graph shows the 1954 situation (Deltaris bijlagerapport, 2011)

4.2.2 Ecosystem health

With regard to the organisms living in the Scheldt estuary, dredging involves disturbances on different trophic levels of the food web. Two different types of disturbances are induced by dredging activities with regard to the first trophic level; first of all, the removal and the deposit of the soil itself causes phytoplankton populations to be harmed (Licursi and Gomez, 2008; Maris and Meire, 2011). This means that phytobenthos, primary producers living in or on the soil of an aquatic system, will be removed during dredging activities, and will be covered when the dredged soil is deposited (Maris and Meire, 2011). This means that by dredging the Scheldt, phytobenthos populations will be harmed badly. Secondly, solid particals and nutrient level concentration rise due to the destabilization of the soil (Holzhauer et al., 2011; Licursi and Gomez, 2008). Nitrogen (N) and Phosphorus (P) concentrations increase heavily, but do not have any influence on the growth rate of phytoplankton populations in the Scheldt because the estuary is a non nutrient limited ecosystem (Maris and Meire, 2008). On the other hand, due to dredging solid particles release from the estuary bed lead to increase of turbidity resulting in lower light penetration capability in the water (Licrusi and Gomez, 2008; Maris and Meire, 2008). Because diatoms are not the best competitor for light, other harmful phytoplanktonic blooms can arise (Maris and Meire, 2008). In addition, although the Scheldt estuary is not limited in nutrients, it is limited in Silicum (Si), which diatoms need for their skeleton (Holzhauer et al., 2011). These two factors mainly determine the species composition of phytoplankton in the Scheld estuary (Holzhauer et al., 2011; Maris and Meire, 2008). It implies that if dredging takes place too often, an actual overgrowth of harmful phytoplankton blooms (like cyanobacteria and dinoflagellata) is likely to arise whereby the health of the whole estuary will be decreased and human health is endangered. Moreover, if harmful phytoplankton blooms arise that cannot be eaten by the second trophic level, occupied by primary consumers like zoöplankton (Fig. 13), an energy transfer problem arises to higher levels in the food chain. Monitoring the turbidity of the water is therefore of extreme importance (Maris and Meire, 2008).

Because zooplankton forms the direct link between phytoplankton and the higher trophic levels like fish, it is of great importance that these populations remain healthy and stable (Maris and Meire, 2011). Zooplankton in the Scheldt estuary have a food preference for diatoms, therefore it is essential that diatom population persist. Because the zooplankton cannot feed on the harmful blooms, the phytoplankton populations simply die and sink to the ground where they will be decomposed by bacteria (Holzhauer et al., 2011). These bacteria use large amounts of oxygen when decomposing the phytoplankton (Holzhauer et al., 2011; Maris and Meire, 2008). This causes a phenomenon called hypoxia; because the bacteria use so much oxygen, a depletion of this molecule finds place within certain layers of the water column (Holzhauer et al., 2011). These anoxic conditions are an enormous threat for the ecosystem because all the organisms, from the lowest trophic levels up until the highest predators need oxygen to survive. A very short anoxic period will harm the ecosystem severely (Maris and Meire, 2008). In addition, submerged sea grass like *Zostera noltii* can suffocate if anoxic conditions arise (Nolte, 2011). Sea grass functions as an important nursery habitat for a variety of fish and other organisms and has thus an important ecological role in the estuary. It is thus the depletion of oxygen due to the effects of dredging that can cause the estuary to collapse.

Beside the fact that silicum, oxygen and salinity levels should be monitored as indication for the health of the ecosystem, certain species can serve as health indicator as well. This is a so called indicator species, which is situated in the highest trophic level. This is because all the influences from lower trophic levels induced by dredging, can be found in the highest (Fig. 4.4) (Maris and Meire, 2008). If the energy between all the trophic levels is transferred well, it means the highest trophic level will be healthy and persist (Maris and Meire, 2008). For the Scheldt estuary, breeding birds and several fish are seen as indicator species (Maris and Meire, 2008).

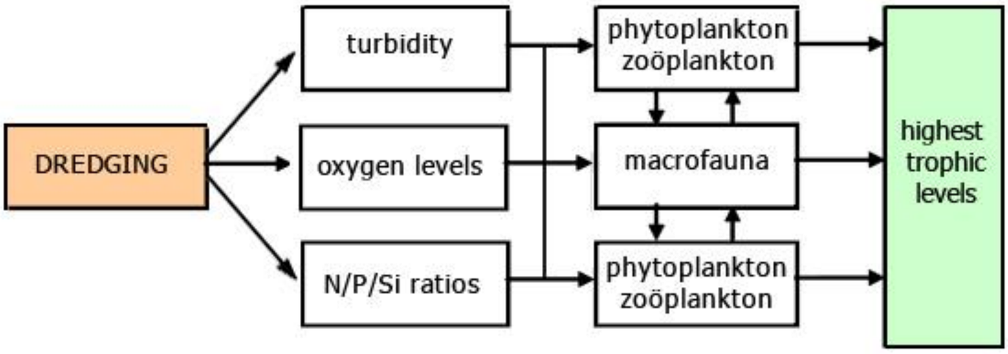

Figure 4.4: influence of dredging in in the trophic level pyramid (obtained from Maris and Meire, 2008)

Just like every ecosystem the estuary of the Scheldt is defined to be in a certain stable state with all its ecological components, and is thus in some kind of equilibrium (Scheffer, 2001). A shift in species diversity as described above could cause the ecosystem to shift into an alternative stable state, thereby the ecosystem is harmed in such a way that it cannot restore itself (Scheffer, 2001).

As described above, due to lower light penetration capability as a result of turbidity harmful algae blooms can arise whereby a shift in species composition is seen that will have a negative influence on the rest of the food web. Thus, if dredging will occurs too often, the ecosystem can be pushed out of equilibrium and thereby be harmed irreversibly.

As described above, the Scheldt estuary could be damaged irreversibly as well by the depletion of oxygen, which could shift the ecosystem into an alternative stable state if it reaches a certain threshold. This threshold can be found at a minimum of 9 mg/l as this is the natural demanded concentration of oxygen in the Scheldt (Holzhauer et al., 2011). Below this level organisms will encounter a shortage of oxygen and die. It is thus of great importance for the maintenance of the ecosystem's health that close monitoring will take place when dredging.

4.3 Feasibility

This section will provide insights in the cost and benefits of dredging the estuary of the Scheldt. These cost and benefits should be taken account when a cost benefit analysis (CBA) of dredging the estuary of the Scheldt is made. It is important to notice that these costs and benefits are only concerned with a situation in which the estuary is dredged compared to a situation in which the estuary is not dredged. In other words a CBA of dredging evaluates whether it is feasible to dredge the estuary or not. Cost and benefits of the estuary itself that are not altered when dredging is applied are not taken into account. Because of the scope of this interdisciplinary research this section contains non-numerical descriptions and predictions. This is for instance because some possible ecological effects of dredging are not economically assessed. Either because it is not done yet, or because it is simply too complex to attach a value on it. Furthermore as can be seen from the scheme below (Figure 4.5), the system of the Scheldt estuary is of such complex nature with a lot of internal feedback that in this relatively concise study aiming for numerical data is not realistic. Thereby, as obtained from Söderbaum (2008) economic feasibility and sustainability also very much relies on ecologic equilibria making indication of future costs hard.

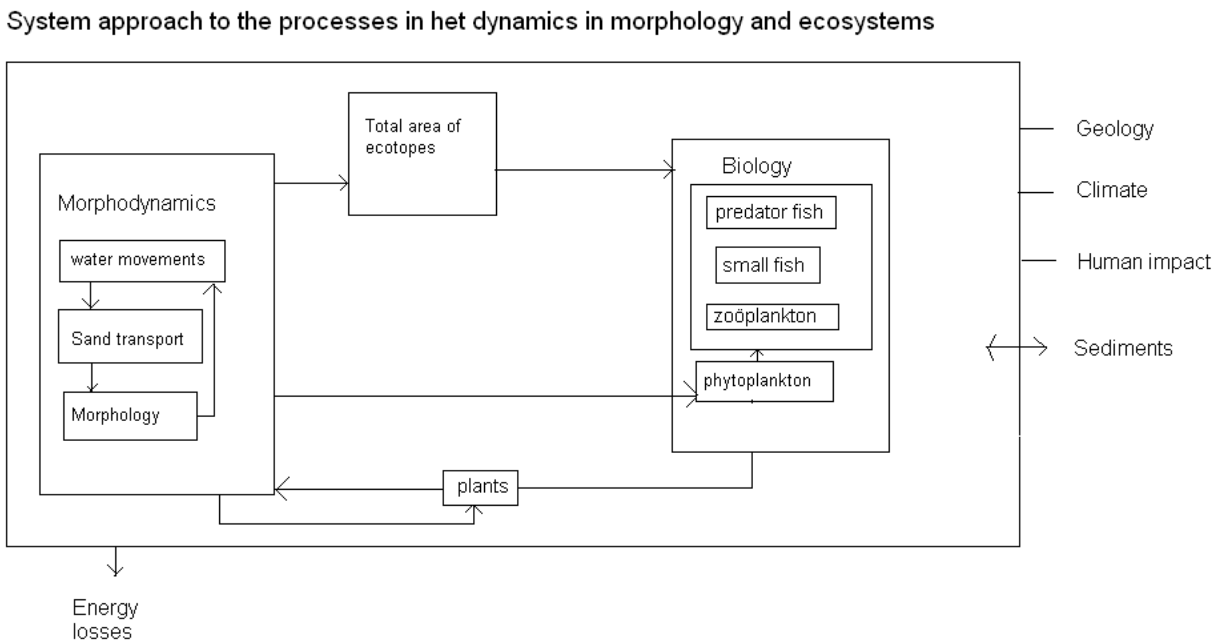

Figure 4.5: interconnections between morphology, Biology and human impact.

4.3.1 Benefits

The benefits of dredging in the estuary have several components and are manifested at different scales in time as well as in different spatial scales, as shown in the table below. Besides differentiating scales it is also useful to distinguish 1) direct benefits and 2) indirect benefits. Direct benefits end up by actors that are actually involved in a dredging program. Where involved is either financially (like brokers) or involved in the decision making process (habitants nearby living nearby). Indirect benefits are part of external effects and end up with actors that are not directly involved in any dredging project. The latter can be for example users of infrastructure surrounding Antwerp without having any connection with the port these users still might benefit (or suffer) from a change in the intensity of (water)transport to Antwerp. (Nistal, 2004)

	Local	**Regional**	**National**	**International**
Direct	Opportunities for dredging business Less waiting time for maritime cargo	Increased income through pilotage, towage and throughput	Increased Tax income Business for brokers and trade companies	
Indirect		Increased employment	Increased competitiveness	Reduced road transport

Table: 4.1 Indication of the benefits of dredging the estuary of the Scheldt

Direct Benefits

As can be seen in the table the direct benefits of dredging the Scheldt start on a small scale (in time and spatial) and consist of business and thereby employment for (local) dredging firms. Depending on the frequency and intensity of maintenance of the channel these benefits alter in duration and amount. Maritime cargo firms and their vessels are less dependent on tidal influence which lowers waiting time before crossing the estuary to a port. On a slightly bigger scale the port of Antwerp (strictly holds for all ports in the estuary) will benefit from its more attractive position with a dredged channel. These benefits are economically found in more business in pilotage, towage and throughput. The fact that Antwerp will become more attractive with a dredged channel is because marine cargo vessels vastly increased in size the last decades and thereby require more depth and width of the channel. (Nistal, 2004). This adds up since the Port of Antwerp has to compete with Rotterdam which has the same hinterland but has a significant shorter waterway to open sea and is therefore less depended on (controversial and costly) dredging programs (Van den Bergh et al, 2005).

Indirect benefits

Again starting from a relatively small scale the first indirect benefits are found within the regional scale through increased employment possibilities. The indirect character of this benefit is because of the effect graduates over time and because in this case only employment s indirectly related to the ports should be taken into account. One can think of grown market for housing etcetera (Anon, 2010).

Further along the spatial scale there are opportunities for national economic growth due to increased competitiveness in western Europe. This mainly deals with the competition among the ports of Antwerpen, Rotterdam and other ports in Western Europe that have a (partly) shared hinterland.

On a bigger scale also the differences in transport efficiency play a role. Water transport is the most energy efficient transport technique measured in unit of cargo weight per unit of distance (McKinnon, 1999). Therefore it is most favorable to use water transportation for as long as possible. For instance, when vessels swerve to Rotterdam because of a non-dredged Scheldt, but the cargos destination is in Belgium the distance of road km per unit of cargo increase. If instead the Scheldt is dredged this might cause for less road- and rail transport in (Western) Europe compared to a non-dredged Scheldt . Therefore this could be a benefit of dredging, though with an highly indirect character.

4.3.2 Costs

When considering costs the direct effects are very limited. This is because the direct costs contain the costs of executing a dredging project itself and are therefore only concerned with nautical infrastructure and labour cost for the initial dredging as well as for maintenance of the channel.

The indirect costs, being (internalised) negative external effects, have a considerably wider range in time and space. These scale with their main costs are presented in the table below. Even more than with benefits the distinction of cost ending up at different scales is not completely strict and depending on the case these costs and scales intertwine.

	Local	Regional	National	International
Indirect	Decreased sight quality Reduced fishing possibilities	Reduced flood control Eroded river banks (might reduce farm land) Reduced recreation around the estuary of the Scheldt	Reduced (recreational) value of the Scheldt Human health danger due to toxic algae blooms	Endangered species

Table: 4.2 Indication of the indirect costs of dredging the estuary of the Scheldt

Moving from a small to a bigger scale we first see that the estuary of the Scheldt provides a scenic sight which value for instance is represented in added value of real estate and in its attractiveness as touristic attraction (Bade, 2006). Dredging the estuary might lower these values because of intensification of navigation activities, because dredging itself and the maintenance of the channel, as well as because the expected growth in cargo transport on the estuary. This water traffic will likely decreases the value of estuary that is enjoyed by its surrounding habitants and recreational users. Less recreation might also cause for extra cost due to the economic possibilities it brings. (Erfurt-Cooper, 2009). This economic effect of decreasing recreational value of the scheldt might end up on a more regional or even national scale. Also, since the economic value of this service provided by the Scheldt estuary is of complex and unique character and has little options to compare with it would be very hard to numerically implement in this costs in a CBA.

Moving towards the more regional scale possible losses volumes and the diversity of species for fishing might add up to the costs of dredging through decreasing (employment in) fishery (Stevens et al., 2009) This costs could be more indirectly over time when dredging mainly harms primary producers causing the fish population to shrink only in the long run (Van Buuren et al, 2010). Finally since the ecosystems in the Scheldt estuary has a water retention capacity, the ecosystems estuary generates economic value by reducing flood chances. In the case this water retention capacity worseness this aspect too adds up to the costs since it increases the need for human flood control like embankments. (Van Buuren et al, 2010).

With regard to national and international scale the costs of the negative effects of dredging have a very indirect an uncertain character. Long term disturbances in the estuarine ecosystem of the Scheldt might speed up the threat of extinction for endangered species. Determining causal relations between ecosystem disturbance and threats for certain species is hard though, and is revealed on very large time scales (Chapin et al., 2000), making implementation into a CBA on dredging tough.

5. Flexible dredging

This chapter will describe the implications on flexible dredging with regard to its operation, feasibility and influence on morphology and biodiversity and especially the added value of its systematics in comparison to conventional dredging.

5.1 Implementation

Based on the '*Tracébesluit Verruiming Vaargeul Westerschelde* '(Proses, 2008) there is currently a legally implemented authorization for dredging and dumping activities in and around the navigation channel where the principle of flexible dredging is practiced. This strategy is flexible in the way that the dumping area is no longer a fixed location outside the estuary. The dredged material in this new strategy is used to renovate eroded areas inside the estuary. By this, sediments stay within the system, surface area will not decrease and tidal currents will not increase in erosive strength, therefore it would stop the positive feedback loop and provide a more stable state for the morphology of the estuary. Dredged material is to be transported directly from the sedimentation areas where the dredging took place to the erosion areas of the system. To point out these areas thoughtfully there is a continual need for monitoring how the morphodynamics operate within the system.

By eliminating the positive feedback loop with flexible dredging, it is less likely that a threshold will be reached that cause ecotopes and ecosystems to swap to alternative stable states than it is would be with conventional dredging. This implies for the state of ecological health that the estuary will be less nutrient enriched and less turbid as the dredging will find place less often and with reduced intensity (Holzhauer et al., 2011). Harmful phytoplanktonic blooms and hypoxia have a lower change of occuring with flexible dredging. Furthermore, close monitoring in the ecosystem is needed with flexible dredging in order to see where sedimentation and erosion finds place (Holzhauer et al., 2011). This monitoring includes the following: 1) height of plates, thereby ensuring that the habitat of benthic species will not fall dry; 2) velocity measurements, thereby ensuring erosion of soil and benthic species will not find place and in addition whether salinity levels might change; 3) the composition of the soil, important for different species as several mineral and metal concentrations could be found toxic for different species (Holzhauer et al., 2011). Monitoring turbidity, oxygen levels and nutrient concentrations could be easily implemented and thereby the thresholds of these criteria can be closely watched, however this will add up to the cost of flexible dredging compared to conventional dredging. Still flexible dredging will thus improve the health of the ecosystem in both a morphological way and an ecological way, though being more expensive. Table 5.2 on the next page summarizes the ecological and morphological benefits of this new approach.

	Ecology	Morphodynamics
Influence of flexible dredging	- Less turbidity - Less direct harm by the dredging - Less nutrient enrichment - Less change in salinity gradient - More light penetration - No toxic algae bloom - No hypoxia - Energy distribution to higher tropic levels intact	- No sediment loss of the system - No increase in tidal energy - No intensified erosion of inter and supratidal areas - No ecotope loss

Table 5.1: Overall ecological and morphological effect flexible dredging

5.2 The influence of Flexible Dredging on Morphology and Ecosystems

Currently there exists one test case example of flexible dredging in which the sides of eroding sandbar plates are renovated with dredged material. This test took place in the Scheldt at the 'plaat' of Walsoorden in 2006 (Plancke, 2006) and it showed that enough sediment stayed in place so the low-dynamic shallow water ecotope area would be regenerated.

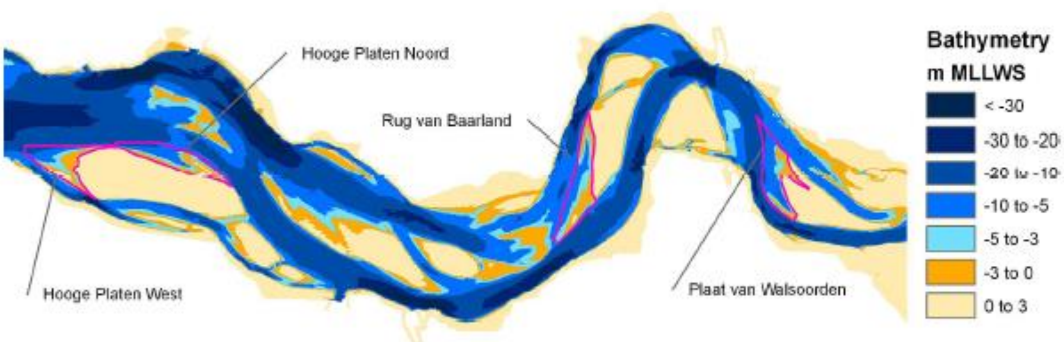

Figure 5.1: locations with authorization of dumping sites at sides of eroding sandbar plates.(Deltaris bijlagerapport, 2011)

In figure 5.1 the locations of eroding sandbar plates are shown where there is currently authorization for dumping dredged material. Those locations are chosen because of their relative high chance of changing into low-dynamic area within 5 years, therefore providing an important evaluative feature of the proposed flexible dredging model. Besides it will lead to a growth of this kind of ecotope of 114 hectares (Deltaris bijlagerapport, 2011).

This principle of flexible dredging of the case study in Walsoorden could be extended to the other ecotopes that exist within the estuary, that are as well currently under threat, like the tidal flats, navigation and secondary channel, transition zones, shallow water area, and other ecotopes in the inter and supratidal zones. An overview of the whole flexible dredging model is given in Figure 5.2 by Plancke (2011). The green hatched areas in this model would be excellent dumping places for dredged material from the red areas where dredging is needed. In darker green are shown the sandbar recovery areas, in light green the recovery possibilities in the secondary and inter tidal areas and in ultra-light green the possibilities in the main navigation channel.

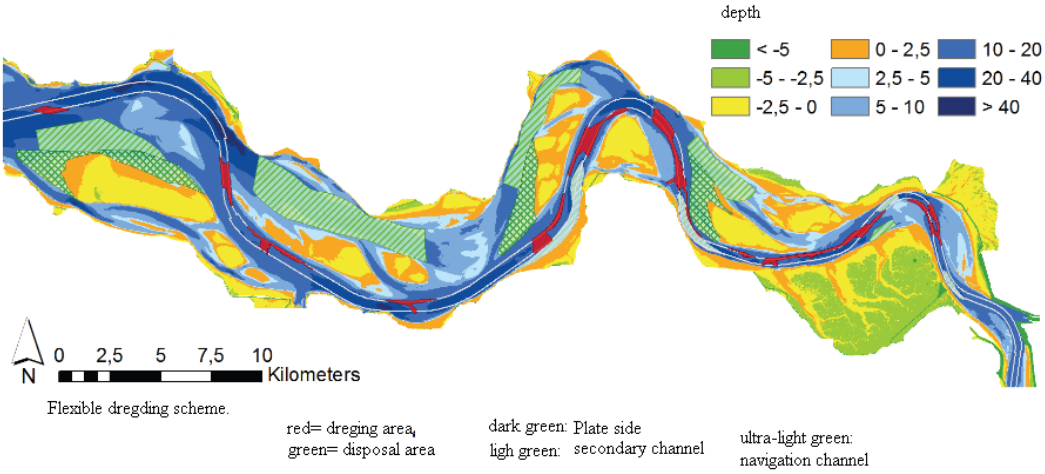

Figure 5.2: overall flexible dredging model by Plancke (2011)

To give the model some more quantitative meaning maximal dumping quantities are approximated in millions of meters quadrates (mm^3) for the first 5 years (Beirinckx, 2011), see table 5.1. For this approximation the Scheldt estuary system is subdivided in smaller subsystems called macrocels that all have their own morphodynamics. Figure 5.3 gives an scheme of this classification.

	max in secondary channel Mm^3	max in transition zone Mm^3	max in navigation zone Mm^3	Max in macrocel Mm^3
MC 1	**6,5 (max 3,0 Mm^3/j)**	**13,7**	**0,0**	**13,7**
MC 3	**8 (max 3,2 Mm^3/j)**	**8,0**	**0,0**	**8,0**
MC 4	**2,5 (max 2,4 Mm^3/j)**	**7,0**	**19,0**	**26,0**
MC 5	**11,5 (max 3,8 Mm^3/j)**	**13,5**	**4,5**	**18,0**
MC 6	**2,0 (max 1,0 Mm^3/j)**	**2,0**	**5,5**	**7,5**
MC 7	**0,0**	**0,0**	**2,5**	**2,5**

Table 5.2: Maximal dumping quantities for flexible disposal in the first 5 years in each macrocel. (Beirinckx, 2011)

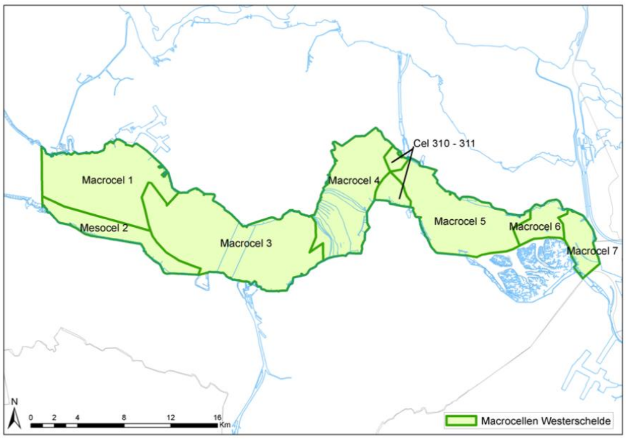

Figure 5.3: Macrocels in the Western Scheldt. (Beirinckx, 2011)

Those quantities are based on possible ecosystem harm when the dumping quantities are too intense, space possibilities and navigation requirements. The five years are proposed to again have an important evaluative feature, so the success of the new strategy can be assessed properly before the strategy is implemented at higher scales.

Other estimations within the first 5 years are that lowdynamic areas such as shallow and intertidalwaters will become much more stable (Holzhauer et al., 2011). These areas will grow as a result of soil deposits at the side of the estuary (Holzhauer et al., 2011). An ecological win is expected because the process goes more subtle with each human intervention, which is good for the survival of species living in these lowdynamic areas (Holzhauer et al., 2011).

One guess on the higher scale possibilities for dumping in the main navigation channel is already proposed by Deltaris. In table 2 is shown the quantities again in millions of meters quadrates (mm^3) (Deltaris bijlagerapport, 2011). Areas are subdivided by distance between towns and there are given two hypothetical possibilities: reducing the depth of the navigation channel to a depth of -17 meter NAP or reducing depth to -20 meter NAP. The second option is more realistic. However much more investigation is needed before those numbers could be fully incorporated into the model.

	< NAP-17 m	< NAP-20 m[13]
Vlissingen - Terneuzen	215 Mm3	140 Mm3
Terneuzen - Hansweert	95 Mm3	56 Mm3
Hansweert - Bath	10 Mm3	4 Mm3

Table 2: Theoretical possible space for disposal in the navigation channel. (Deltaris bijlagenrapport, 2011)

5.3 Feasibility

Because of the experimental phase of flexible dredging currently, the economics of an implementation remain speculative, especially with regard to indirect effects of this new strategy future research is very much needed in order to be able to give an elaborated assessment of flexible dredging (Proses, 2008). Though within this notion of uncertain predictions it might is useful to consider possible alterations of a CBA caused by the introduction of flexible dredging.

First, initial cost might be higher due to more sophisticated disposal strategies as shown by Plancke (2006). Secondly, maintenance cost will increase due to intensified monitoring, as mentioned in section 5.1. On the other hand Plancke (2006) shows that flexible dredging seems to reduce the frequency and intensity of dredging activities, and therefore could lower the costs. This cost reduction could be directly through an overall less expensive dredging scheme and/or indirectly through less frequent and less intense environmental disturbance. The balance between the extra cost and the benefits of less dredging seem arguable and uncertain currently. Finally, since flexible dredging aims for an navigable channel with the same with properties as within conventional dredging, a difference in navigation activity and its associated costs and benefits is not to be expected. Therefore, for all the elements in a CBA that are related to the navigation capacity it is not likely to change.

	Minor **(relatively small, short term)** **(few million, few years)**	**Medium** **(relatively small, cumulative over time)** **(millions, decades)**	**Major** **(Substantial, long run)** **(up to billions, future generations)**
New Costs	Additional infrastructure - precise disposal techniques	Monitoring program - Morphologic indicators - Ecologic indicators	
New Benefits		Lower intensity of dredging - Better morphodynamic stability requires less intervention	Less ecologic disturbance, preservation/return of: - Biodiversity and ecosystem health (also fishery) - Tourism for nature value - Safety for human health (less algae bloom) - Less EU legislated nature compensation

Table 5.3: different expected alterations on feasibility when dredging changes to a flexible approach.

6 Discussion

Since this paper investigates an alternative option for dredging in the future, our findings are based on results of small (experimental) cases that are executed. For a more in depth assessment, future research should give more insights in the reduced ecologic damage and the concrete alterations on feasibility. Ideally these information is generated by a case study based in the implementation of flexible dredging in a comparable estuary. Taken this into account, the main limitations of the results presented here are there mostly qualitative character, caused by the scope and timeframe as well as the limited available data. Furthermore, conclusions scientific research cannot decide whether the (economic) benefits exceed the (ecologic) downside of dredging. Studies like this one can provide preconditions for a balanced decision. Dredging is thereby only one of the numeral possibilities to get to a more sustainable system, combination with other approaches such as giving land back to the river, could have higher potential impacts.

7 Conclusion

Departed from common ground on the notion of possible multiple stable states in ecosystems and morphodynamics and the need for feasible management of the estuary of the Scheldt, this paper investigated the influences of dredging in general and possibilities of flexible dredging specifically. Thereby it investigated: *does the flexible dredging strategy compared to conventional dredging contribute to a more sustainable future of the estuary of the Scheldt?*
The principle idea of flexible dredging is to use the dredged material to renovate eroded areas, like plates, transition zones, tidal flats and certain deep parts of the navigation channel. For this there is a need for continually monitoring to see where the is sedimentation and where erosion takes place so that we can learn which morphologic approach would generate the most stable state. The case study of the disposal at the plate of Walsoorden in 2006 showed us that enough sediment stayed at the place of disposal so new or regenerated low-dynamic shallow water area could be created with the dredged material. This gives a indication that in the future this concept can be placed more and more into practice. Dredging causes buried nutrients to come up and causes the Scheldt estuary to become in a nutrient enriched state. Phytoplankton populations (small algae) are thereby supported to grow in abundance. Not only important phytoplankton populations can increase but harmful algae blooms may arise. Furthermore anoxic conditions can occur with an increase in algal blooms, causing a severe damage to the ecosystem. If those damages reach a certain threshold, the ecosystem might shift into an alternative stable state. Flexible dredging decreases the intensity of this ecological disturbance and therefore might contribute to more sustainable management of the estuary of the Scheldt and also might lower the (social) costs of dredging. Since dredging in general alters the estuarine system, a feasibility analysis not only should focus on direct cost and benefits of such a project but also requires knowledge on future implications for the estuary and its surroundings. Based on current knowledge flexible dredging seems promising, not only because its morphologic characteristics seem desirable and it reduces ecological disturbance, but also with regard to its feasibility, flexible dredging seems to adheres standing for future implementation in the estuary of the Scheldt.

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