IMMERSE

Modelling study on sediment management of estuaries

Report 022-RES002

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Niels Van Putte, Tom Cox, Stefan Van Damme & Tom Maris

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Authors: Niels Van Putte, Tom Cox, Stefan Van Damme & Tom Maris
Contact: tom.maris@uantwerpen.be
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INTRODUCTION

Changing conditions

Over the past centuries, the tidal range has been increasing in the Schelde estuary. This trend still continues. The tide is also protruding more inland. At this moment, the largest tidal range is observed at the upper-Sea Scheldt. Even though the exact origin of this increase is not fully understood, it is most likely caused by a combination of human interventions (channel deepening, sand extraction, poldering, embankments and channel straightening) in combination with sea level rise.

The increase in tidal range can impact on safety (risk of flooding), accessibility (navigability of the fairway) and ecology, the latter by altering the physical and ecological processes in the estuary. Changes in suspended sediment concentration (and hence turbidity) in particular will influence the ability of water to transmit light, thus having an impact on algae growth, which forms the base of the food chain and local ecosystem.

It is observed that alongside the increase in tidal range, there is an increase in the suspended sediment concentration (SSC) over time. Especially in the more upstream regions, higher concentrations as well as higher salinity values are observed. Although freshwater discharge has a big influence on SSC in these regions, the increase in SSC cannot be attributed to discharge changes solely, but also to changes in bathymetry.

Immerse

The maintenance of the navigation channel near Antwerp is necessary in order to preserve the navigability for passing vessels. The required permit ensures that the dredged material needs to be disposed elsewhere in the estuary in a useful way. In the Interreg project IMMERSE's Work Package 3.2, alternative disposing strategies are investigated (IMDC, 2020). In 4 scenarios dredged material is used to modify the bathymetry of the estuary, and hence influence the tidal characteristics, the suspended sediment concentration and ecology of the estuary.

The 4 Immerse scenarios are summarised below, figures can be found in the appendix.

- Reference run: Existing bathymetry (2017).
- Scenario 1: Filling deeper parts of the navigation channel till -13,27 m TAW, for the part of the river included between Kallo and Rupelmonde (volume of disposed sand: 6.152.151 m^3).
- Scenario 2: Rising of the bed level of the river banks till -1 m TAW, for the part of the river included between Kallo and Rupelmonde (volume of disposed sand: 18.040.246 m^3).
- Scenario 3: Filling deeper parts of the navigation channel till -15 m LAT, for the part of the river included between Bath and Kallo (volume of disposed sand: 15.403.128 m^3).
- Scenario 4: Rising of the bed level of the river banks till -1 m TAW, for the part of the river included between Burcht and Rupelmonde (volume of disposed sand: 2.670.057 m^3).

In a first step, the impact of the different scenarios on tidal characteristics was investigated. Secondly, these results are used to quantify the changes in SSC. The modifications in the bathymetry and the consequent changes in the tidal range and SSC are finally implemented in an ecosystem model to investigate the impact on ecology: changes in primary production (= algal growth), chlorophyl a (= algal concentrations), oxygen and nutrients are modelled.

Because discharge can have a huge impact on water levels, SSC and ecology, the influence of low (10 percentile), medium (50 percentile) and high (90 percentile) discharge conditions are also investigated within this study (see further in the description of the used model, Table 1).

This report briefly resumes the results of previous studies on the influence on tidal characteristics and SSC, to further focus on the impact on ecology.

INFLUENCE ON TIDES

In the framework of this Immerse project, IMDC has investigated the 4 different scenarios mentioned above, varying the amount of deposited sand and the area of deposition. To estimate the tidal reduction induced by the different bathymetries, the difference in tidal amplitude and the percentual difference in tidal flood volume along the Scheldt estuary between the different scenarios and the reference run were analyzed. IMDC concluded that the effect is minimum for scenario 1 and 3 and maximum for scenario 2. Scenario 4 had the most impact on reduction in tidal amplitude per m^3 disposed sand. Therefore, scenario 4 was selected for further analysis.

Based on the Delft3D-NeVla simulations, FHR computed that the bathymetric changes of scenario 4 lead to a tidal range reduction of up to -0,13 m at Temse (Stark et al., 2021). In addition, the shape of the tidal wave becomes slightly more flood dominant upstream of the bathymetric changes and a bit less flood-dominant along and downstream of the altered section. These findings correspond qualitatively to the conclusions in IMDC (2020).

From safety point of view, conclusions for scenario 4 are positive: a reduced tidal range and reduced high water level decrease the safety risk.

Beside an influence on water levels, there was also a computed effect on hydrodynamics. This might also impact ecology, by e.g. changing current velocities and hence ecotopes. This was however not the scope of this study.

INFLUENCE ON SUSPENDED SEDIMENT CONCENTRATION

In addition to this positive impact on safety, the changed hydrodynamics in Scenario 4 may also influence suspended sediment dynamics in the Scheldt estuary. In particular, suspended sediment concentrations in the Upper Sea Scheldt have been increasing gradually over the past decades (e.g. Maris & Meire, 2017). Therefore, the impact of morphological measures of scenario 4 on SSC values in the estuary was assessed by FHR (Stark, 2021).

Methodology and model setup

In IMMERSE WP3.2 Scenario 4, developed by IMDC (2020), the bed level on both river banks is raised until an elevation of -1,0 m TAW over a section between Burcht and Rupelmonde (Figure 1). This bathymetric adaptation corresponds to a volume of 2,67 Mm^3 of disposed sand (IMDC, 2020).

The Delft3D-NeVla model was applied to analyze the impact of scenario 4. This model is able to represent the formation of a natural estuarine turbidity maximum (ETM) with a realistic distribution of sediment concentrations in the Upper Sea Scheldt. This modelled ETM remains present and fairly stable for simulation periods of several weeks to months, depending on the applied model settings and sediment characteristics.

In this study, the sand disposal of scenario 4 is implemented by a bathymetric adaptation of the bottom level (Stark et al., 2021). Bathymetry was changed in the model, without 'adding sand': the bathymetry is fixed, no additional suspended sediments are available in the model. Applying a fixed bed does assure a representative morphology throughout the simulation. This methodology assumes that the disposed sediment remains stable over time and therefore does not account for morphological changes that could be initiated by the intervention.

All details about the model and its setup can be found in Stark et al. (2021).

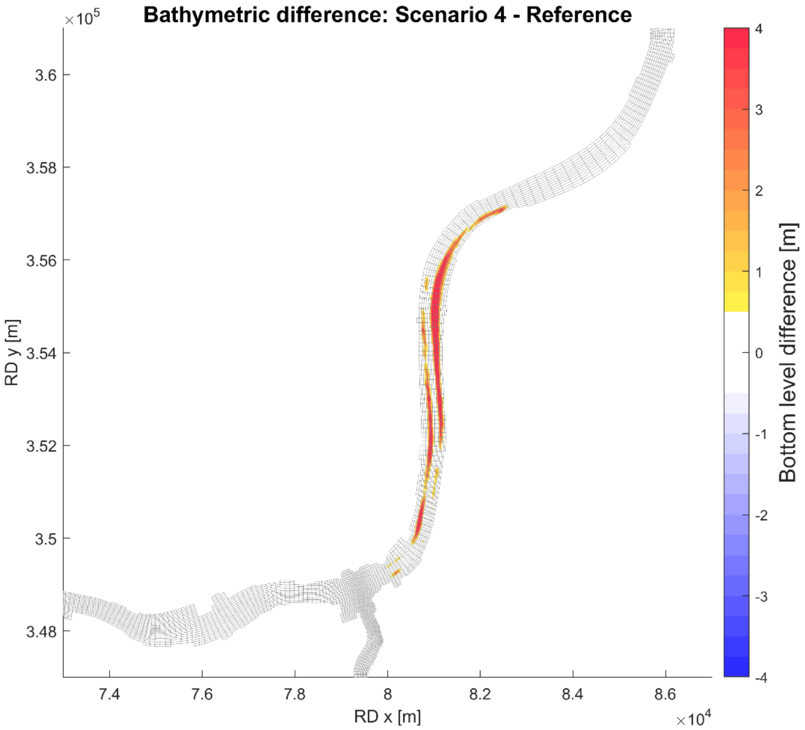

Figure 1 Bathymetric difference between Scenario 4 and the reference scenario (Stark et al., 2021).

Impact on SSC

Low discharge has a big impact on SSC in the freshwater reaches of the estuary, leading to high SSC (Cox et al., 2019). Impact on SSC by the Immerse scenario 4 might therefore be more pronounced or attenuated in a low or high discharge scenario. Figure 2 shows therefore the SSC distribution (spring neap averaged) for the reference scenario and scenario 4 with low discharge conditions (see further for low discharge definitions). The bathymetrical changes in scenario 4 lead to a small SSC decrease in the Lower Sea Scheldt, in the zone where the bathymetrical changes are implemented, and a SSC increase from KM-110 onwards in the Upper Sea Scheldt. The maximum spring-neap-averaged SSC values at the ETM increase from a maximum of about 420 mg/L to 480 mg/L in Scenario 4 (Stark et al., 2021). This implies an increase of 15% of the maximum sediment concentrations in the estuary. Locally, stronger SSC increases of up to +40% at KM-130 are modelled due to a shift of the ETM location. The relative SSC decrease in the Lower Sea Scheldt is much less (i.e., up to -10%), while the impact on SSC in the Western Scheldt is negligible.

To gain insight in the discharge dependency, Figure 3 shows the SSC distribution (spring-neap averaged) for the low, median and high discharge runs in the reference situation. Low discharge conditions clearly lead to a strong SSC increase between KM-110 and the upward estuarine boundary, corresponding with an upward shift of the ETM (Stark et al., 2021). High discharges on the other hand lead to a SSC reduction in the zone in which the ETM is situated (between KM-100 and 130) and hence a downstream shift of the ETM. Downstream of this ETM, from the Lower Sea Scheldt down to the mouth in the Western Scheldt, an increase in SSC is modelled at high discharges, as sediment from the ETM is probably washed away in a downstream direction. Besides, the high discharge condition also leads to a slight increase in SSC near the upstream boundary, potentially related to a higher sediment input from upstream.

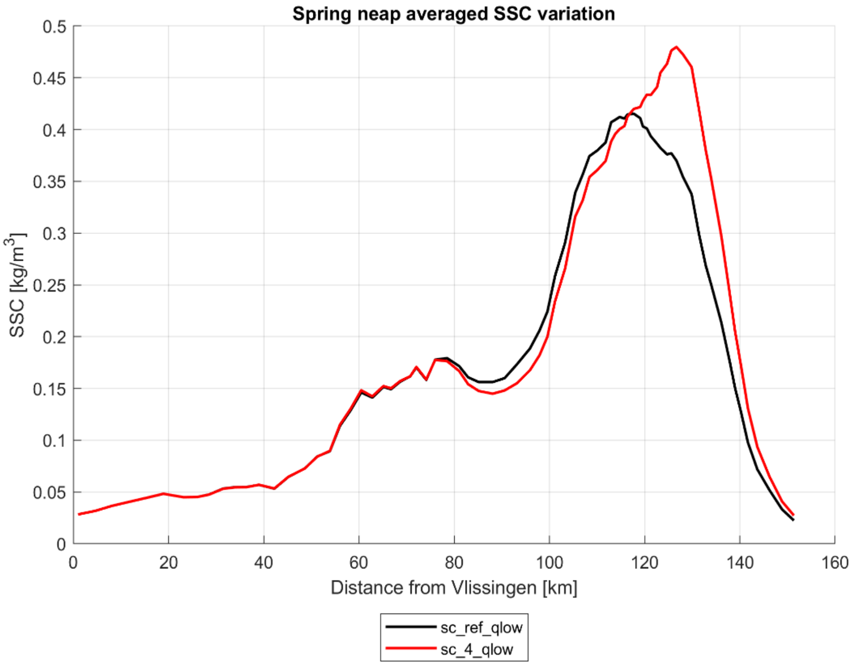

Figure 2 Along estuary SSC-variation averaged over one spring-neap cycle for the low discharge run for Scenario 4 and the reference situation (Stark et al., 2021).

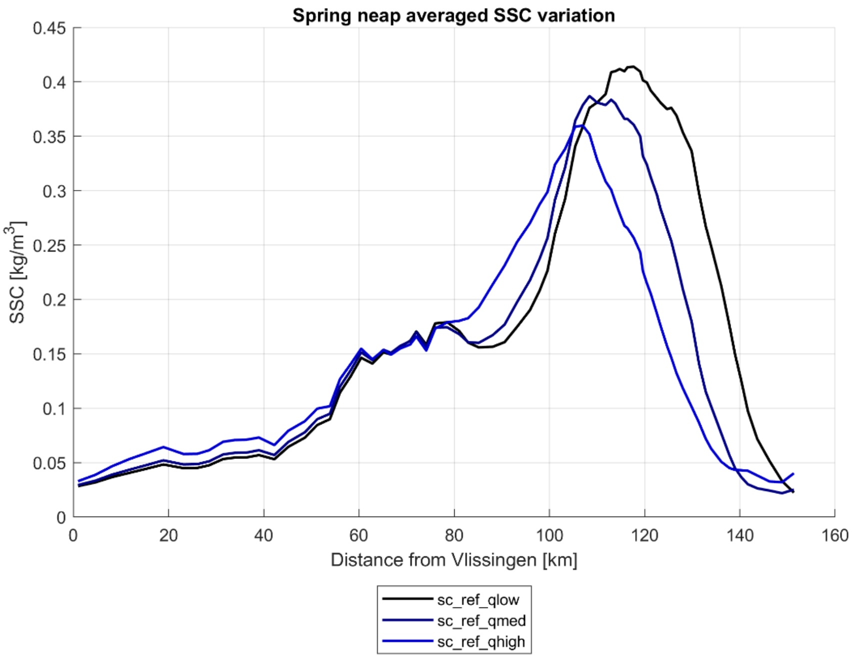

Figure 3 Along estuary SSC variation for low, medium and high discharge runs for the reference situation (Stark et al., 2021).

Figure 4 shows the SSC distribution (spring neap averaged) for the high – and low discharge runs of the reference scenario and scenario 4. During high discharge conditions, the variation in SSC along the estuary is fairly similar for scenario 4 and the reference run, except for the zone between Burcht and Rupelmonde (km 85 – 95 from Vlissingen) where the Immerse measures are implemented. Here a small decrease in SSC can be observed, up to – 6%. At low discharge, a similar decrease in SSC can be observed in this zone (up to minus 10%). However, in the upstream zone between KM-120 and 140 from Vlissingen, a stronger increase of 10 to 40% in SSC is modeled at low discharge in scenario 4 compared to the reference. This implies an upward movement of the ETM of about 10-15 km. The estuarine stretches over which SSC increases or decreases in Scenario 4 correspond fairly well with the zones in which the tidal asymmetry becomes more or less flood-dominant (Stark et al., 2021).

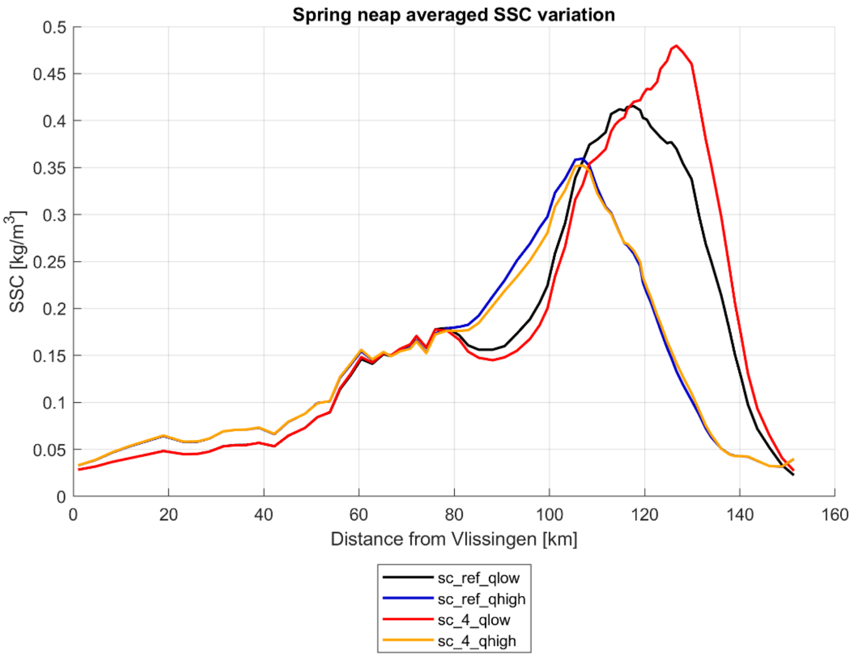

Figure 4 Along estuary SSC variation for low and high discharge runs in Scenario 4 and the reference situation (Stark et al., 2021).

Remarks

Stark et al. (2021) stress that there assessment was carried out based on the assumption that the implemented bathymetric changes remain stable. In reality, large scale disposal of sand and the consequent changes in tidal hydrodynamics may on its turn induce morphological changes in the estuary. Such morphodynamic feedback mechanisms may reduce the initial impact on tidal hydrodynamics and hence alter the impact on along-estuary SSC distribution. Moreover, the model assessment by IMDC (2020) indicates that bed shear stresses on the river banks increase significantly at the sites where sand is disposed and that the disposed sand on the banks would be rather unstable.

INFLUENCE ON ECOLOGY

Introduction

Primary production

This study focusses on the pelagic primary production: the growth of phytoplankton (algae) in the water column. Primary production forms the basis of the food chain; other trophic levels (zooplankton, fish, birds) depend on this primary production. Primary production also brings oxygen into the water. In an eutrophic system such as the Scheldt that still receives high loads of organic waste, oxygen consumption can be very high in summer due to bacterial respiration. This can lead to low oxygen levels, impacting higher life. Primary production can lift up the oxygen level and prevent oxygen shortage. Last but not least, algae impact the cycling of nitrogen, phosphorus and silica. The nutrients nitrogen and phosphorus are usually abundantly available in the Scheldt estuary and never limiting algal growth. Primary production in the Scheldt estuary is after all largely limited by light availability.

Changes in nutrient levels will therefore not have a big impact in the estuary itself, but might impact the nutrient export to coastal zone, and the occurrence of (harmful) algal blooms over there.

Light climate

Since light is the limiting factor for primary production in the estuary, any deterioration in the light climate will mean a decline in algal blooms. The Scheldt estuary is assumed to be well mixed. In this case, the actual amount of available light to phytoplankton depends on the ratio of the light penetration depth (euphotic depth) and the mixing depth, which determines the fraction of their time that algae can spent on photosynthesis. If e.g. the euphotic depth is 1 meter, and the mixing depth is 10 meter, algae will be 1/10th of the time in the light zone doing photosynthesis and 9/10th of the time in the dark. A euphotic depth / mixing depth ratio of 1/10 is considered to be the limit for algae. At lower ratios, algal blooms will not occur.

Light penetration in the water column is in a turbid estuary largely determined by the suspended matter concentration and its mud content on the one hand, and depending on the phytoplankton concentration itself on the other hand. High concentrations of algae can namely cause 'self-shading'. Mixing depth is largely determined by the hydrodynamic and morphological properties of the system. Considering the complete mixing over a large part of the Scheldt estuary, this mixing depth corresponds largely with the water column depth.

It is therefore expected that changes in bathymetry, particularly changes in the relative contribution of shallow regions that influence the mixing depth or changes that alter the suspended sediment concentration and influence the euphotic depth, could have a strong impact on the attained primary production.

Immerse

In the different scenarios of the Interreg project IMMERSE such bathymetric changes with impact on light climate and gross primary production (GPP) are expected. As described before, the focus in this report is on scenario 4: raising the river banks between Burcht and Rupelmonde to a maximum of -1.0 m TAW. Model results of FHR hypothesize that, compared to a reference scenario, the induced geomorphic changes will result in reduced suspended sediment concentrations in the affected zones of the estuary (and also changes upstream), hence resulting in increased light transmission. Combined with the creation of shallow zones (reduced mixing depth), this could result in an increased primary production in the affected zone. However, the model results of FHR also indicate an increase in suspended sediment concentration more upstream from the altered section.

The impact of the mentioned bathymetric changes on primary production will be investigated using a dynamic ecosystem model. Because of feedback mechanisms, a limited reduction of the light availability will result in a much stronger reduction of primary production. In a static approach, less light correlates linearly with less primary production. But less primary production results in less biomass build-up, and therefore less algae to do primary production. A static approach thus strongly underestimates the impact of a decreasing light availability. Therefore, within this Immerse project, a dynamic ecosystem model will be used to assess the impact of scenario 4.

Ecosystem model

The developed model is a 1-dimensional model and is tide-averaged. It resolves downstream volumetric transport of water and dissolved substances, but does not account for tidal variability. Its spatial configuration is based on the MOSES model by Soetaert et al. (1994) , but extends further upstream and has a higher spatial resolution (75 serial segments or boxes of variable length (ca. 5 km in the Western Scheldt, ca. 1,5 km in the Sea Scheldt) along the longitudinal axis (Merelbeke – Vlissingen; 155 km).

Each of the 75 model boxes (Figure 5) contains the bathymetry of the respective box relative to the mean water level in that box. The bathymetry of the reference scenario is based on measurements from 2011, and on the bathymetry of the SCALDIS model (Smolders et al., 2016) by interpolating the data on the calculation grid (Figure 6) (IMDC, 2020). Upstream from Baalhoek till Driegoten, the bathymetry has been renewed locally with measurements from 2017 (IMDC, 2020). In scenario 4, the same bathymetry was used, but alterations were made to boxes between Burcht and Rupelmonde, to incorporate the induced bathymetric changes. For both scenarios, model results were simulated for a period from 2009 – 2013, for which measured discharge data for every model box are readily available.

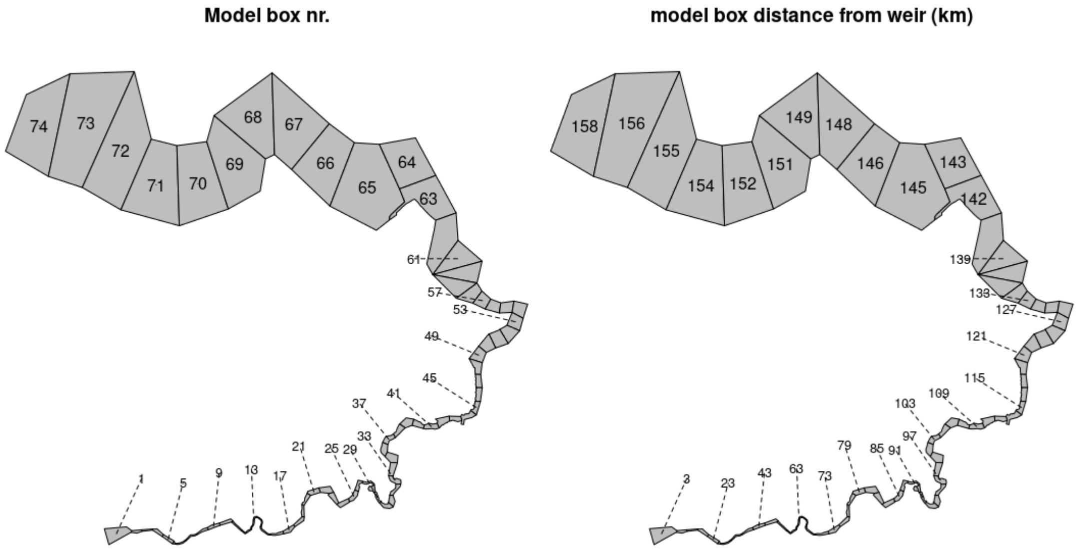

Figure 5 left: overview of the model boxes within the Scheldt Estuary. Right: indication of the mean distance from the weir for every model box.

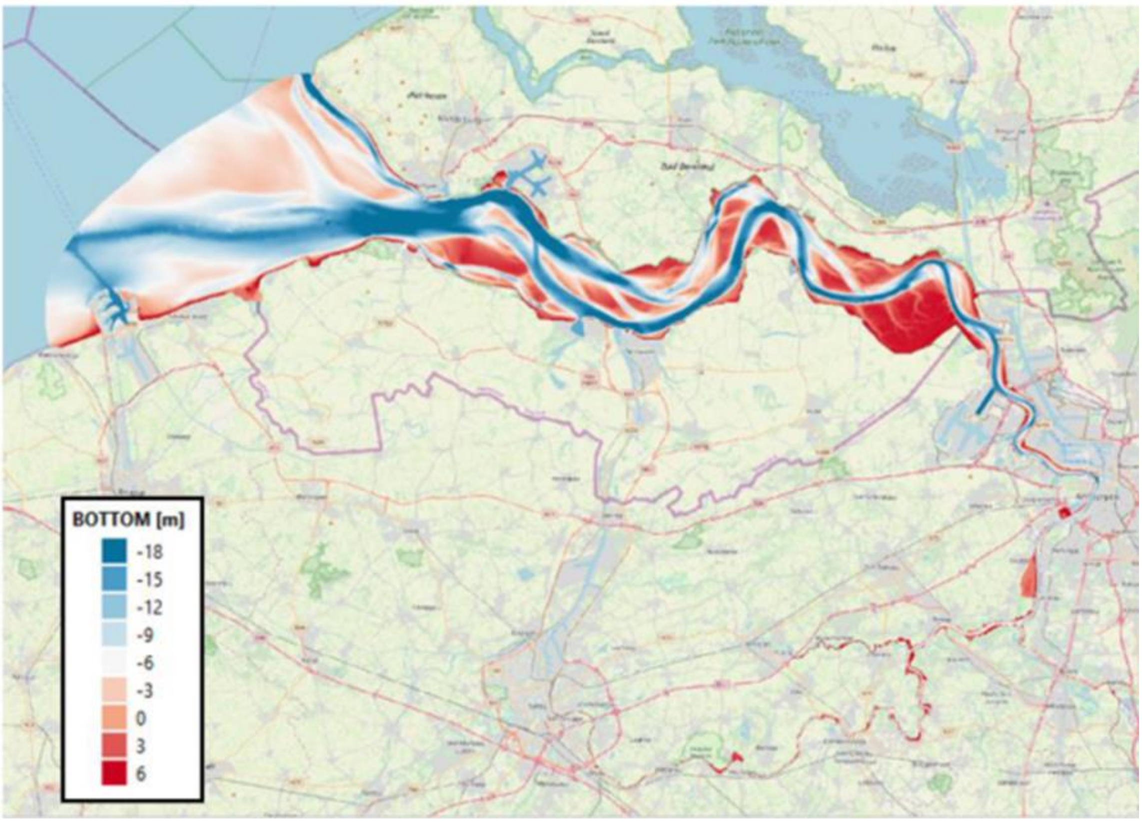

Figure 6 Bathymetry of the Scheldt estuary dated 2017 as used in the study (IMDC, 2020)

The ecosystem model itself does not simulate the effect of bathymetric changes on suspended sediment dynamics. However, these changes are crucial to incorporate into the model as it is the most prominent driver for algal growth and primary production. To include these effects in the model, it relies on the output from the cohesive transport model in Delft3D-NeVla, provided by FHR. For every model box, a difference in SSC relative to the reference situation is provided. These relative differences are then applied to the default SSC forcings in the ecosystem model.

In addition to the two main scenarios (reference and scenario 4, further referred to as REF and sc4), SSC forcings and mean water levels for three discharge regimes (LOW, MED and HIGH) were implemented (Figure 7). The discharge scenarios (LOW, MED and HIGH) were the same as in Stark et al. (2021). LOW, MED and HIGH were defined as 10, 50 and 90 percentile discharges over the period 1989-2018. The attributed values are listed in (Table 1).

Table 1: Upstream boundary conditions for low and high discharge simulations (Stark et al., 2021)

Boundary	Low discharge [m^3/s]	Median Discharge [m^3/s]	High Discharge [m^3/s]	SSC [kg/m^3]
Zeeschelde	4,79	22,46	88,45	0,05
Dender	1,12	3,2	13,69	0,05
Zenne	5,12	7,26	15,81	0,05
Dijle	6,15	11,18	28,12	0,05
Grote Nete	2,27	3,82	8,41	0,02
Kleine Nete	2,26	4,8	12,35	0,02
Spuikanaal Bath	10,2	10,2	10,2	0
Kanaal Gent-Terneuzen	31,1	31,1	31,1	0

A model run 'sc4 LOW' thus means that a period of 4 years (2009-2013) is simulated, using the observed discharges of that period as boundary conditions, but with SPM forcings and water levels typical for low discharge conditions, as shown in Figure 7. This is a heuristic approach to combine the short term FHR simulations with the long term ecosystem model simulations: SPM forcings typical for dry or wet conditions, modeled by FHR during one spring-neap cycle, are now implemented year-round, although they only occur during limited dry or wet periods.

For the MED discharge regime, actual, measured SSC data are used for the REF MED scenario; for SC4 MED these data are increased with a deltaSSC, computed by FHR. Model output for these MED scenarios gives realistic data, that is shown in surface plots with absolute values.

For the LOW and HIGH discharge regimes, a LOW and HIGH SSC reference was created, by increasing or decreasing the measured SSC used for REF MED with a delta SSC based on the SSC output of the FHR simulations for REF HIGH and REF LOW. This gives an altered REF, with SSC conditions typical for low or high discharges, but now implemented year-round. To be able to see the impact of SC4 during low or high discharge conditions and compare SC4 LOW or SC4 HIGH with REF LOW or REF HIGH, the modeled deltaSSC for SC4 LOW and HIGH are now implemented on this altered REF LOW and REF HIGH. The intention of the simulation is to get grip on the order of magnitude, the direction (increase or decrease) and the location of changes in ecological variables and rates under the proposed morphology in scenario 4. In reality, low or high discharge conditions do not prevail year-round. This is an important caveat when interpreting the simulation results. The absolute values and yearly averages of these model runs are therefore not relevant: it is the relative difference between REF en SC4 for a given discharge regime that can indicate changes in discharge dependency of the estuarine functioning when SC4 is implemented.

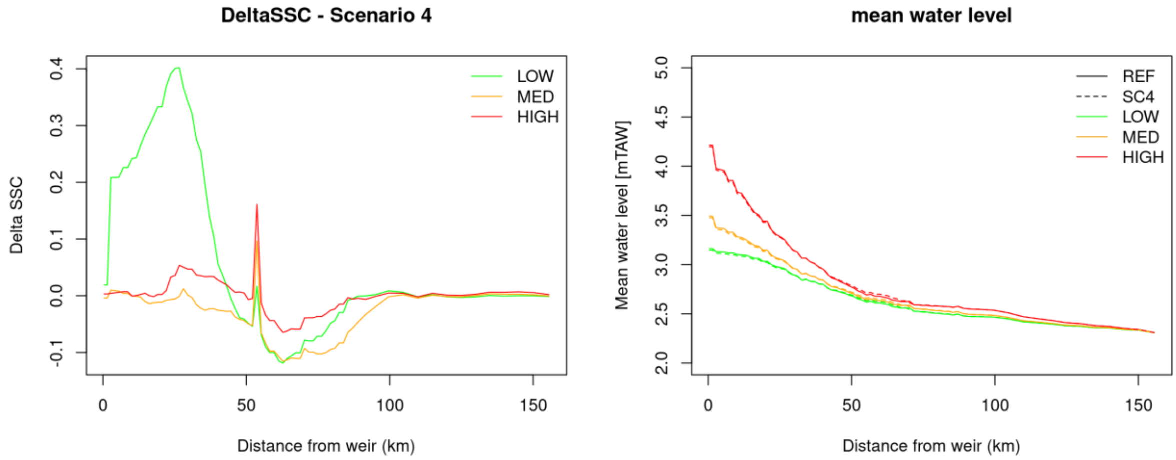

Figure 7 Results from the Delft3D-NeVla study that are used as input parameters in the ecosystem model. left: delta SSC (relative difference in suspended sediment concentration relative to the reference situation). right: mean high water level in the river for the different scenarios. Note the peak in SSC around km 55, modeled by FHR. In the ecosystem model, this peak is smoothened.

Gross primary production

Introduction

As mentioned before, primary production forms the basis of the pelagic ecology. In this study, the ecosystem model computes gross primary production (GPP): the total amount of carbon compounds produced by photosynthesis in an ecosystem in a given period of time, in this case expressed as mol C/m^3/day.

Primary production in the pelagic (water column) occurs by phytoplankton. These are free drifting single cell algae. Their survival depends on light availability in the aquatic system. Light availability is determined by the turbidity of the water, but also by the depth that the plankton cells can reach. If they linger too long in dark depths they will perish. Primary production is hence affected by bathymetry (mixing depth) and SPM concentration (euphotic depth). Bathymetry affects primary production in a direct way through changes in surface and volume. More specific, depth integrated GPP is directly affected by hypsometry, volume and free water surface.

There is also an indirect effect of bathymetry, namely the impact on longitudinal transport of biomass. Water volumes and cross sections feature in the advection-dispersion equations of transport; bulk dispersion depends on cross section. Changes in this longitudinal transport imply changes (increase or decrease) in local buildup of biomass. This will consequently influence GPP.

Results

Figure 8 shows the gross primary production for reference and scenario 4 for the MED discharge regime. A clear seasonal pattern is visible, with highest production in summer months, especially in the Upper Sea Scheldt. In absolute values, no big difference can be observed between the scenarios in Figure 8. Only in the project zone (marked with black dotted lines) a slightly higher GPP can be observed. The difference is however small, and therefore not clearly visible in Figure 8. This does not mean it is of no importance: the slight increase is observed in the zone where GPP, chl a en oxygen levels are low (see further).

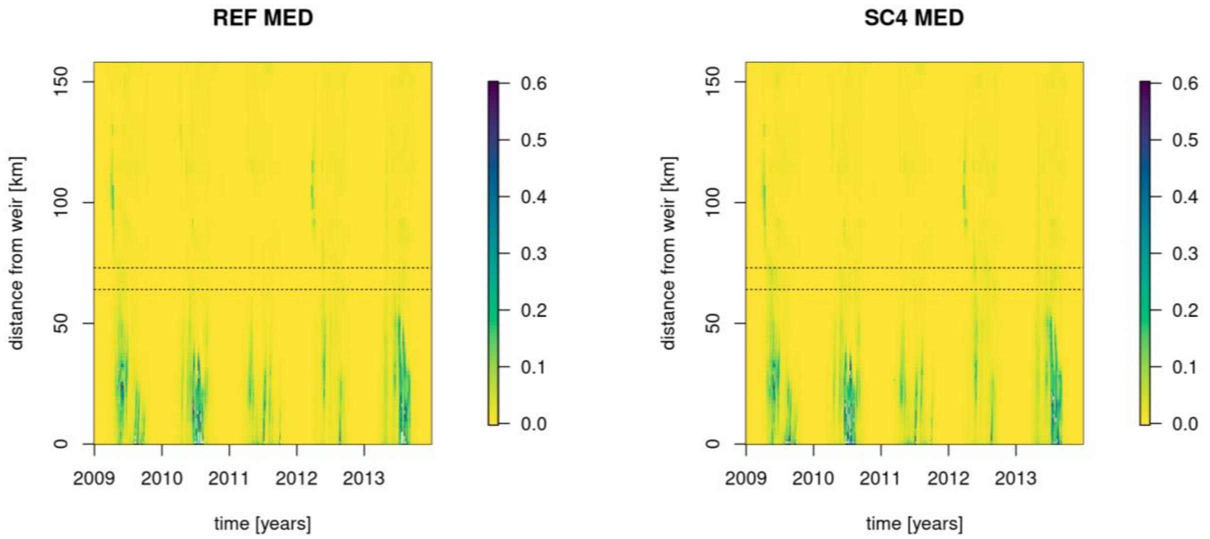

Figure 8 GPP (mol C/m³/day) in function of time and distance from the weir (Gent). The area in between the black dotted lines corresponds to the zone in which alterations are made to the bathymetry.

When looking at the relative difference between SC4 scenario and the REF scenario, the small increase in absolute value in the project zone seems to be an important relative increase in GPP, up to 100% (Figure 9). The relative increase in the project zone is strong in all discharge regimes.

At MED discharge conditions, SC4 has nearly no impact upstream the project zone. At low discharges however, SC4 leads to higher turbidity upstream, causing a decrease in GPP. Also at HIGH discharge conditions, GPP decreases upstream, but less pronounced. Downstream the project zone, a zone with usually lower GPP, the increase in GPP in the project zone has a positive effect: a relative increase in GPP can be observed. However, the relative increase is mainly observed in winter, and thus of little ecological significance. Especially for the LOW scenario, when LOW discharge conditions are implemented year-round, this relative increase of GPP in winter can be ignored. The slight relative decrease of GPP in summer during LOW discharge conditions however indicates a negative effect of the project on the downstream GPP.

Although the average GPP is higher in the most upstream parts of the Scheldt estuary, the Western Scheldt is by far the largest contributor to the total primary production and carbon sequestration, due to its large surface area and volume, compared to the other compartments. It is apparent that in summer both the changes to bathymetry and the discharge regimes only have a marginal effect on GPP in the Western Scheldt, and hence the effect on the total production of the estuary is also limited (Figure 10). Only when HIGH discharge conditions are applied year-round, a small decrease in GPP is observed.

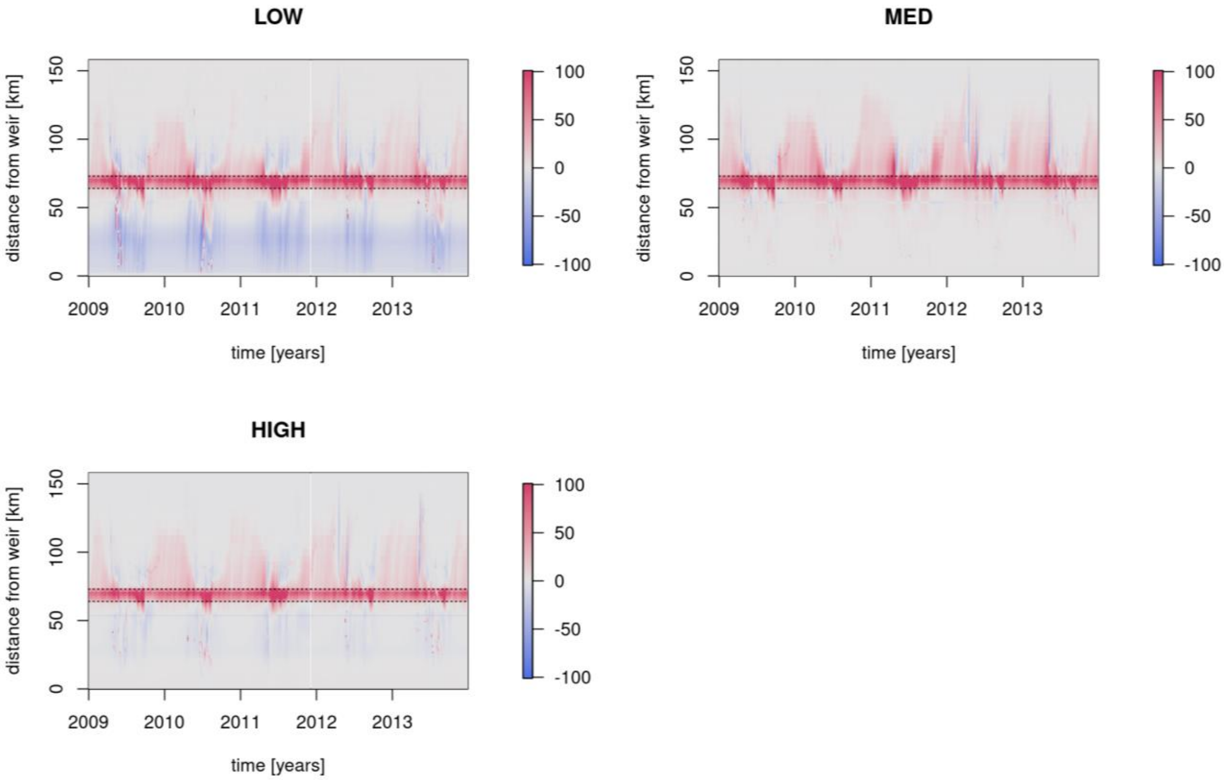

Figure 9 Relative difference in GPP (%) between SC4 and REF for the 3 discharge regimes. Positive values indicate a relative increase in GPP in the SC4 scenario compared to the REF scenario. Black dotted lines indicate the zone in which alterations are made to the bathymetry. For clarity, the color scale is limited to 100. Dark red or blue thus indicate +100 or -100.

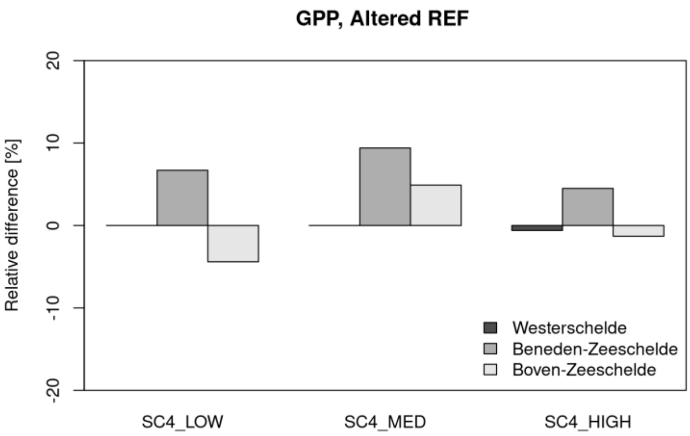

Figure 10 Relative difference (%) in GPP between REF en SC4 for LOW, MED and HIGH discharge conditions, averaged for Western Scheldt (Westerschelde), Lower Sea Scheldt (Beneden-Zeeschelde) and Upper Sea Scheldt (Boven-Zeeschelde).

Chlorophyll a

Introduction

Chlorophyll a is the major pigment in algae, and thus a good indicator for them. Although GPP and the concentration of Chlorophyll a are strongly interrelated, they are not equal. While GPP is a measure for the intensity of the photosynthesis process, the concentration of Chl a is an estimate for the biomass. For example, a large amount of phytoplankton that is on the brink of dying in dark conditions will be characterized by a high concentration of Chl a and a low GPP. A smaller population of phytoplankton (e.g. because of grazing) that is very active will show lower concentrations of Chl a but a higher GPP. So a shift in SPM through the estuary, for instance a decrease, can induce a shift in GPP, in this case an increase due to an improved light climate, although the total mass of chl a can remain constant when grazing also increases. The latter is certainly possible: high turbidity can hamper grazing activity of zooplankton. In less turbid water with higher chl a concentrations, grazing is likely to improve.

Results

In the reference, Chlorophyll a concentrations are higher in the Upper Sea Scheldt (Figure 11). This is more pronounced in the summer months. However, in years with a low discharge (2009 and 2011) an increase of the chlorophyll a concentration is apparent in the spring months. When MED conditions are applied, SC4 shows a slight increase in chl a in absolute value in the Upper Sea Scheldt and the project zone.

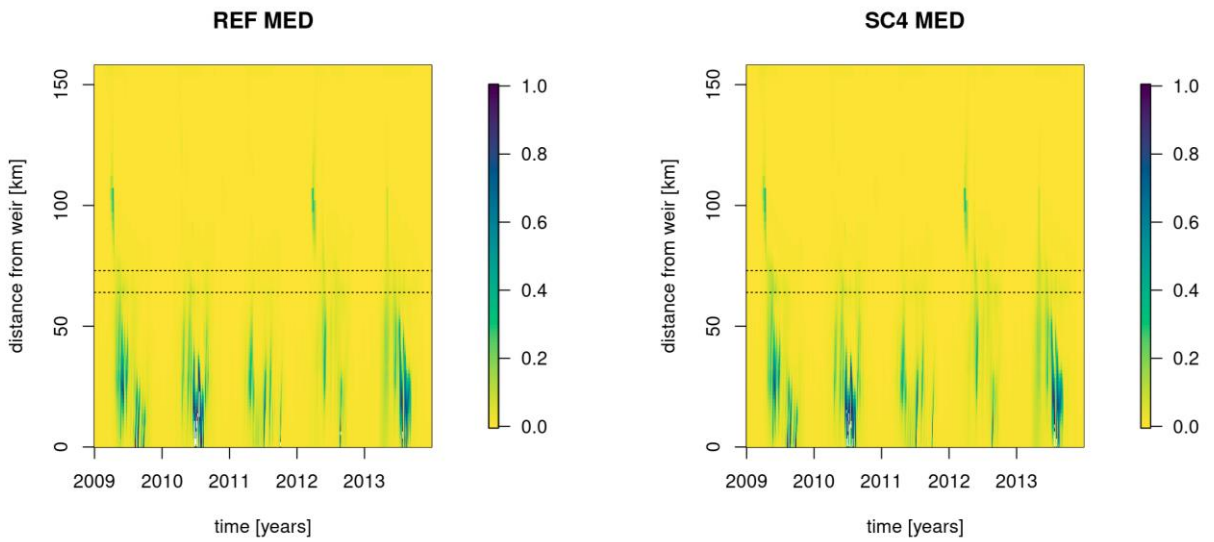

Figure 11 Chlorophyll a (mg/L) in function of time and distance from the weir. The area in between the black dotted lines corresponds to the zone in which alterations are made to the bathymetry

When the relative difference in chlorophyll a concentration between the MED REF and the MED SC4 scenarios are compared, a strong increase in the project zone during summer months is visible (Figure 12). The GPP and chl a pattern are very similar, indicating that the production per unit of biomass (P:B ratio) is also similar. This suggests no major differences in grazing or mortality of algae between scenarios REF en SC4.

In the project zone, where chl a was usually low, SC4 measures clearly have a positive impact. Immediately downstream the project zone, a decrease in chl a in summer, and an increase in winter is noted, but averaged over the entire model period, the balance remains positive for the Lower Sea Scheldt (Figure 13) under MED discharge conditions. Also in the Upper Sea Scheldt, on average an increase in chl a is modeled. In the Western Scheldt nearly no impact can be seen.

When implementing year-round LOW discharge conditions for SSC, the image changes (Figure 12, Figure 13). Especially in the Upper Sea Scheldt, the ecosystem seems to be more impacted by low discharge conditions under SC4 than in the reference. A decrease in chl a is modeled. In the Lower Sea Scheldt, LOW discharge conditions have lower chl a compared to MED, but the balance is still positive. In the Western Scheldt, the difference is negligible.

At HIGH discharge conditions, the positive effect of SC4 on chl a that was modeled under MED discharge conditions, diminished in the Lower Sea Scheldt and even becomes slightly negative in the Upper Sea Scheldt. Impact on the Western Scheldt remains very small under the different discharge regimes.

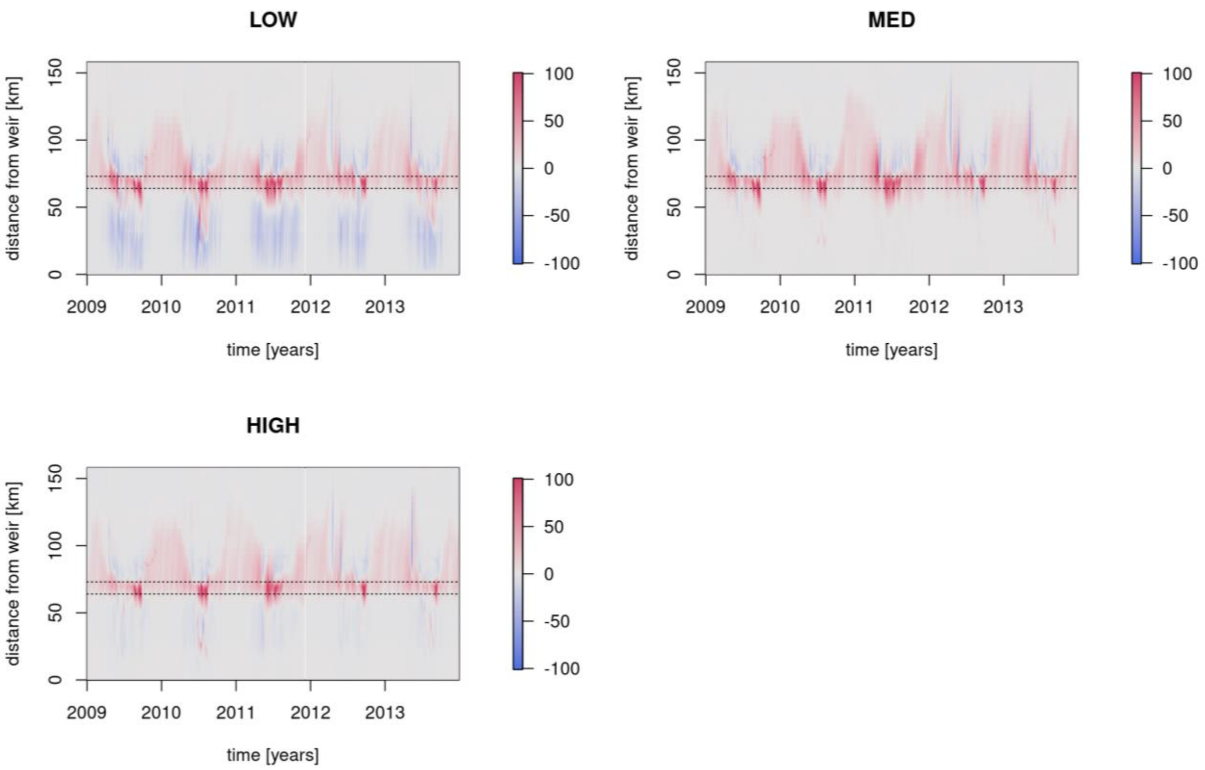

Figure 12 Relative difference in chl a (%) between SC4 and REF for the 3 discharge regimes. Positive values indicate a relative increase in chl a in the SC4 scenario compared to the REF scenario. Black dotted lines indicate the zone in which alterations are made to the bathymetry. For clarity, the color scale is limited to 100. Dark red or blue thus indicate +100 or -100.

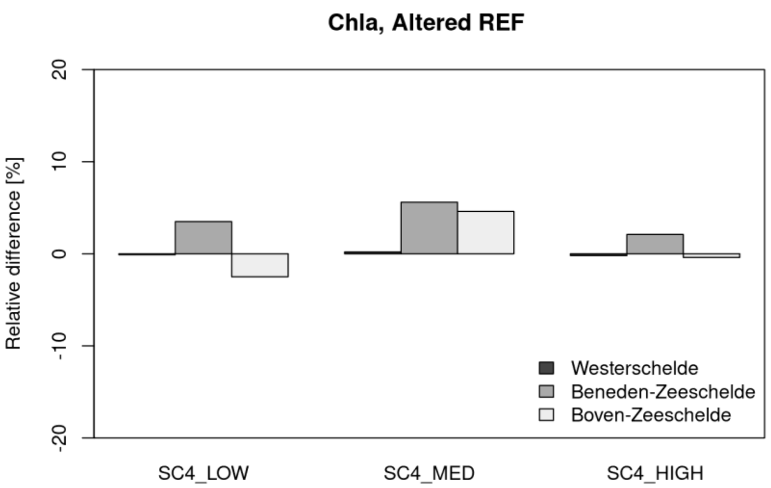

Figure 13 Relative difference (%) in chl a between REF en SC4 for LOW, MED and HIGH discharge conditions, averaged for Western Scheldt (Westerschelde), Lower Sea Scheldt (Beneden-Zeeschelde) and Upper Sea Scheldt (Boven-Zeeschelde).

Oxygen

Introduction

The oxygen concentration in the estuary is result of atmospheric uptake of oxygen or production by algae on the one hand, and consumption on the other hand. Although the oxygen concentration in the estuary is thus linked to the photosynthetic activity, summer concentrations of dissolved oxygen are usually lower compared to the winter. In summer, the solubility of oxygen is less, due to higher water temperatures. Also oxygen consumption by bacterial respiration is higher at higher temperatures.

Results

The zone in which the bathymetric changes of SC4 are applied, corresponds to the zone where oxygen concentrations are nowadays lowest in summer (Figure 14, REF MED). In this zone, GPP is limited due to a bad light climate and the stress that fresh water algae face when they approach the brackish reaches of the estuary. The dying off of algae and decomposition of this organic material causes an increased oxygen consumption, leading to the observed oxygen sag.

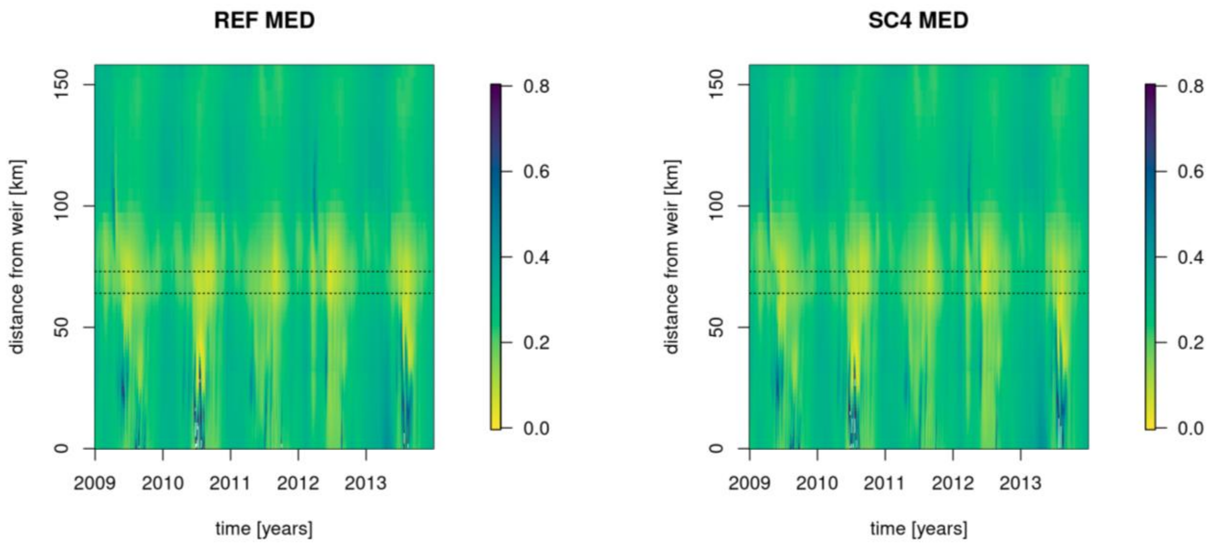

Figure 14 Dissolved oxygen concentration (mmol/L) in function of time and distance from the weir. The area in between the black dotted lines corresponds to the zone in which alterations are made to the bathymetry.

At first sight, not much difference can be observed between REF and SC4 MED in Figure 14. However, when looking at the relative difference in Figure 15, the bathymetric changes in SC4 do have a positive effect on dissolved oxygen concentrations for all discharge regimes, especially in summer, compared to the reference scenario. This positive effect is mostly limited to the affected zone. At LOW discharge conditions, a succession of increases and decreases can occur, but the net balance for oxygen remains positive in the Sea Scheldt (Figure 16). In the Western Scheldt, no difference can be observed.

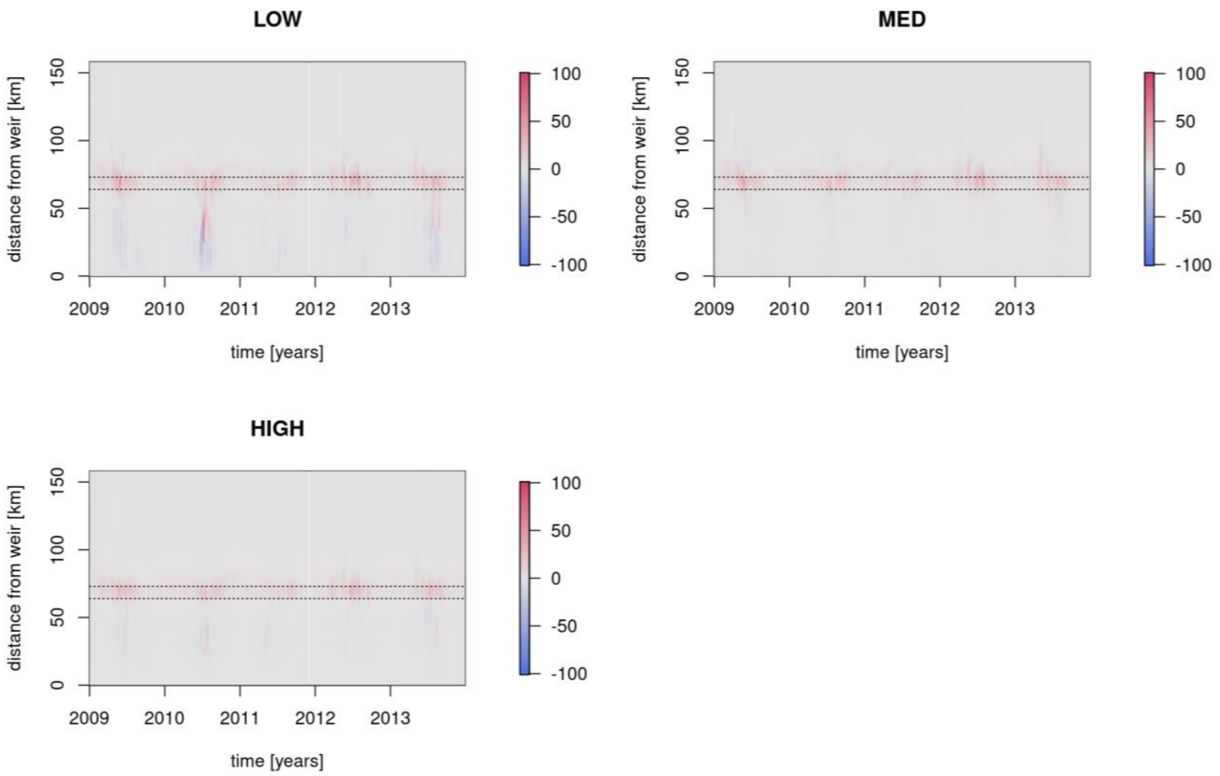

Figure 15 Relative difference (%) in oxygen concentration between SC4 and REF for the 3 discharge regimes. Positive values indicate a relative increase in chl a in the SC4 scenario compared to the REF scenario. Black dotted lines indicate the zone in which alterations are made to the bathymetry. For clarity, the color scale is limited to 100. Dark red or blue thus indicate +100 or -100.

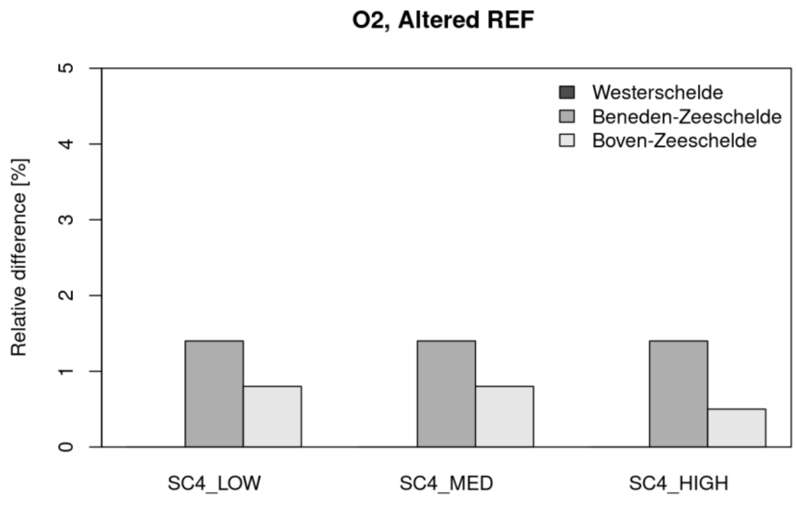

Figure 16 Relative difference (%) in oxygen concentration between REF en SC4 for LOW, MED and HIGH discharge conditions, averaged for Western Scheldt (Westerschelde), Lower Sea Scheldt (Beneden-Zeeschelde) and Upper Sea Scheldt (Boven-Zeeschelde).

Influence of discharge scenarios on oxygen

While the MED scenario SC4 (Figure 17) is representative for SPM forcings and water levels that occur at average discharge, MED is not representative for the year round SPM and water level conditions that will occur and hence not representative for year round activity of phytoplankton. During the 4 year modeled period, periods of higher and lower discharge occur, that would require discharge dependent deltaSSC values. To get insight in the discharge dependency FHR has modeled one high and one low discharge regime: HIGH and LOW. These are now implemented in the ecosystem model runs HIGH and LOW.

In the model run HIGH, phytoplankton is, over the entire modeled period, faced with reduced residence times, and, as high discharges result in lower SSC, better light conditions. In reality, HIGH will occur mostly in winter. In summertime LOW conditions prevail more frequently, and these must be considered as well. Therefore a comparison between REF and SC4 was performed for MED (Figure 17), LOW (Figure 18) and HIGH (Figure 19).

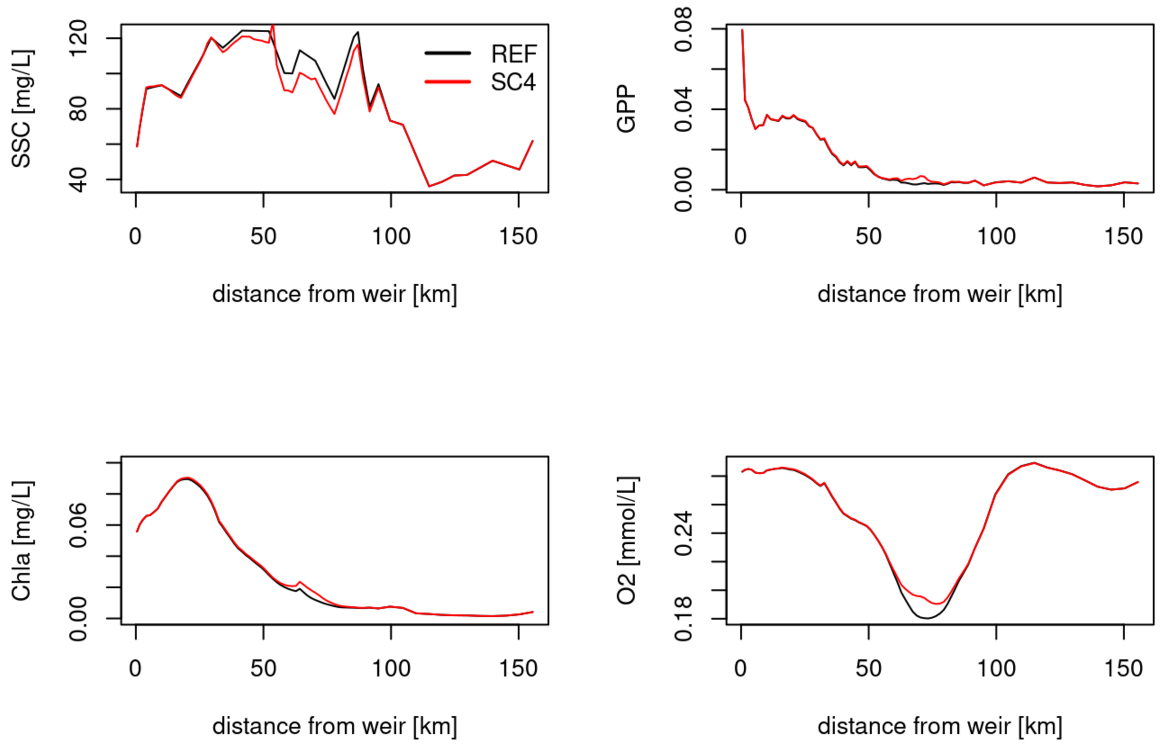

Figure 17 SSC, GPP, Chl a and O2 for MED REF vs. MED SC4 scenarios

The LOW scenario (Figure 18), that will typically occur in summertime, clearly results in larger differences between REF and sc4, especially in the upstream part of the estuary. In SC4, the Upper Sea Scheldt seems more affected by low discharges, leading to higher SSC, compared to REF under LOW conditions. This will cause lower GPP, lower chl a and lower oxygen in this upstream zone. Although oxygen levels decrease, oxygen problems do not occur. In the project zone on the contrary, SC4 still causes a reduction of SSC under LOW discharge conditions. The increase in GPP, chl a and oxygen is not affected by LOW discharge. The oxygen sag that typically occurred in the project zone, diminishes with SC4, even at LOW discharge.

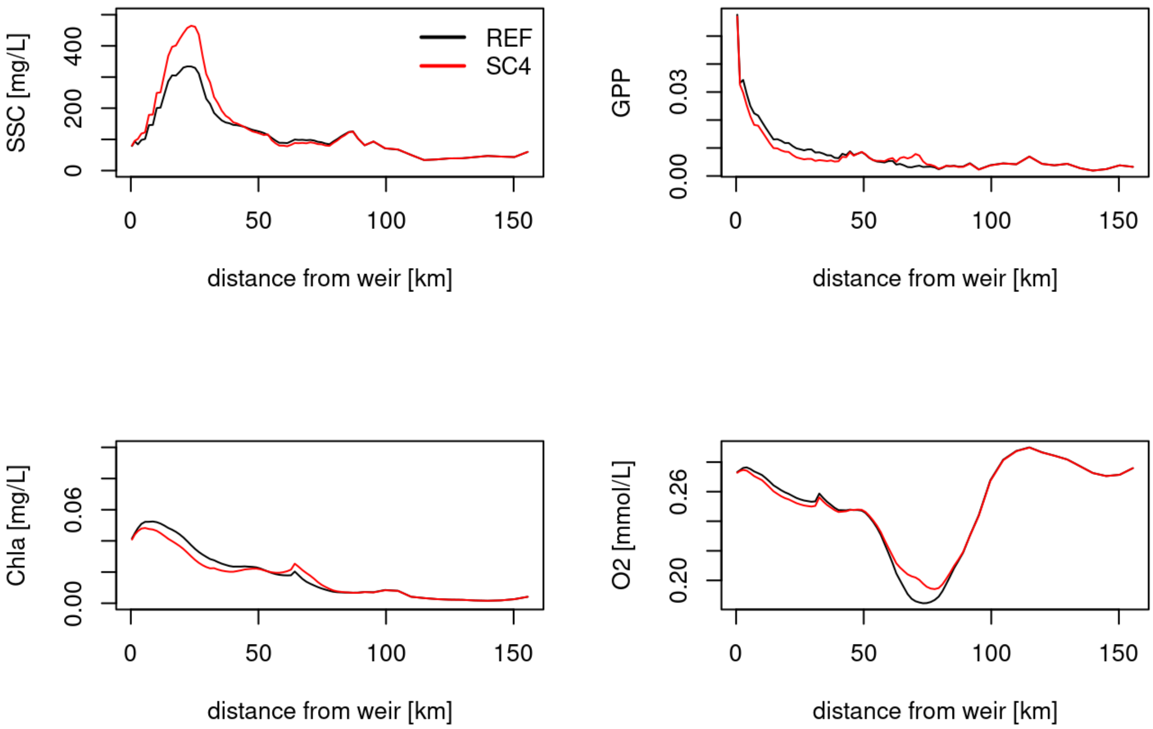

Figure 18 SSC, GPP, Chl a and O2 for LOW REF vs. LOW SC4 scenarios

The HIGH discharge regime will typically occur in autumn, winter or spring. Impact of SC4 under HIGH discharge regime seems to be very limited. Only in the project zone, a slight reduction in SSC is observed. Nevertheless, this can lead to an increase in GPP, chl a and especially oxygen, thus preventing an oxygen sag.

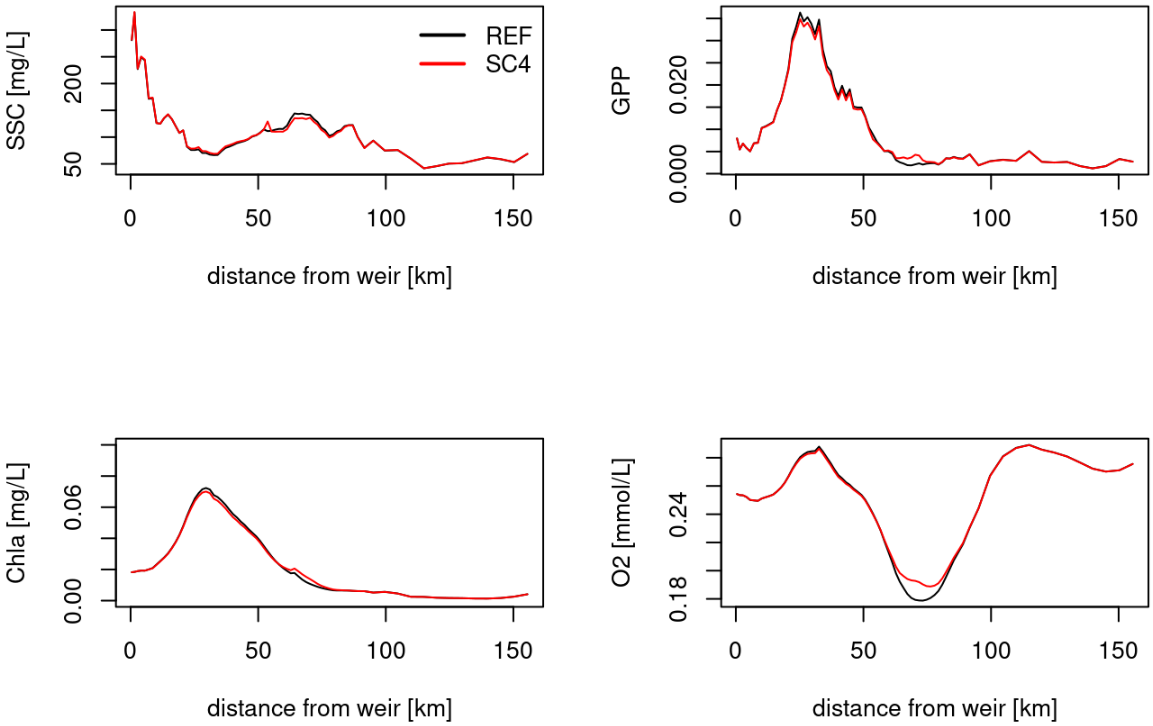

Figure 19 SSC, GPP, Chl a and O2 for HIGH REF vs. HIGH SC4 scenarios

These results indicate that the alterations made to the bathymetry between Burcht and Rupelmonde in scenario 4 have a positive effect on the oxygen concentration in the project zone, a zone in which the oxygen concentration is always the lowest. This effect is apparent in all discharge regimes.

Nitrogen

Introduction

Nitrogen is an important nutrient for algal growth. When it is abundantly available, it can lead to excessive algal growth, causing typical eutrophication problems such as foam on the shore and oxygen deficiency. In the Scheldt, where nitrogen concentrations are always high, light availability limits algal growth. In the coastal zone however, nitrogen export from the Scheldt estuary can cause eutrophication. Influence on nitrogen fluxes towards the North Sea is therefore an important parameter to check.

Results

The concentration of nitrogen in the estuary is not significantly affected by the bathymetric changes made to the estuary (Figure 20). Export of nitrogen to the North Sea seems therefore not to be influenced.

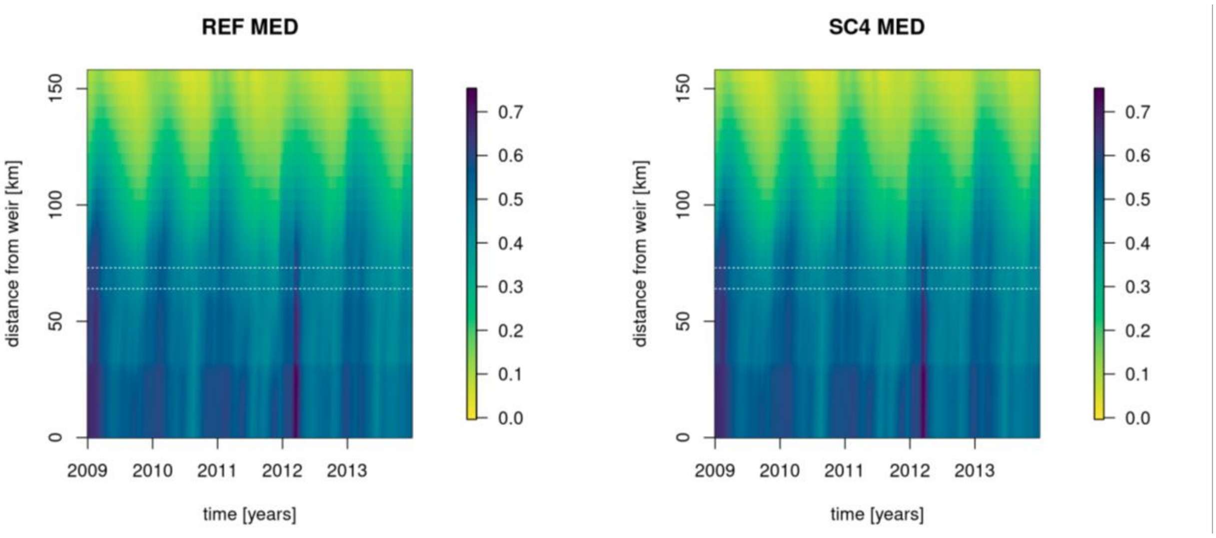

Figure 20 Total dissolved nitrogen concentration (mmol/L) in function of time and distance from the weir. The area in between the dotted lines corresponds to the zone in which alterations are made to the bathymetry.

Silica

Introduction

Silica is a nutrient essential for diatom growth. Diatoms are a group of algae that are most wanted as a food source. In fact, it is the diatoms that form the basis of the food chain. When the positive effects of algal growth for higher trophic levels are mentioned, this refers to the growth of diatoms.

Diatoms need silica in their diet to build up their silica skeleton. Without silica, they can’t grow. Green algae on the contrary don’t have this silica skeleton, can grow without silica, but are less appreciated as a food source. As long as silica is available, diatoms are dominating the algal blooms in the estuary.

When silica becomes limiting, green algae can take over. As they are less grazed by other trophic levels, they build up biomass that can give rise to eutrophication problems, in the estuary or the coastal zone.

Results

The bathymetric changes to the estuary have a small negative effect on the concentration of dissolved silica (DSi) in the sc4 affected zone during spring and summer: Figure 21 shows a small decrease between REF MED en sc4 MED. This is most likely due to increased diatom growth as diatoms take up DSi in their frustules. However, the impact seems little and is not leading to silica depletion. Changes in the phytoplankton species composition are not expected in the Sea Scheldt.

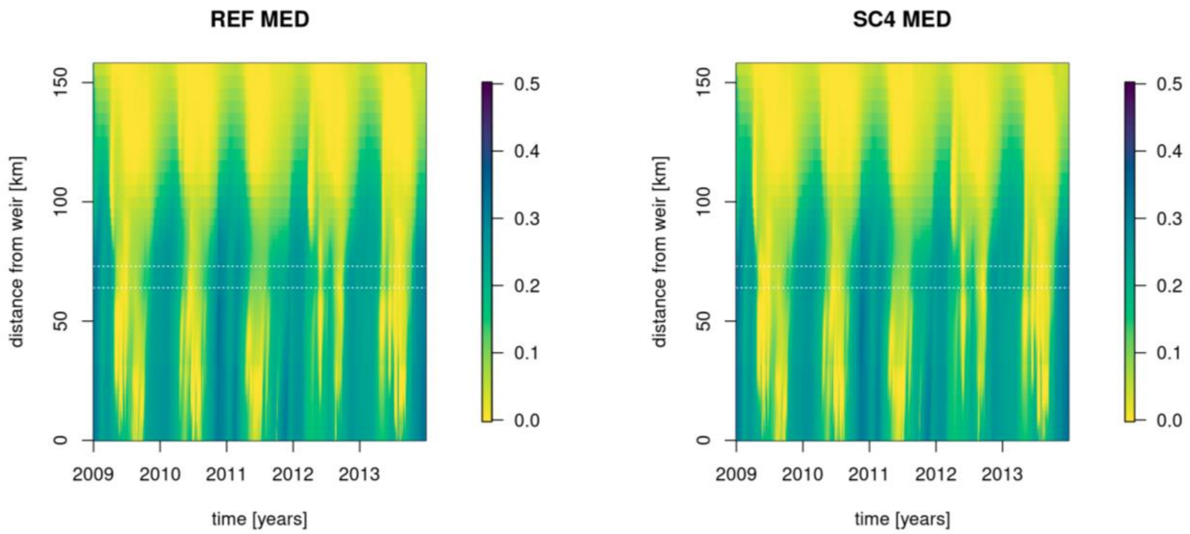

Figure 21 Dissolved silica concentration (mmol/L) in function of time and distance from the weir. The area in between the dotted lines corresponds to the zone in which alterations are made to the bathymetry.

At MED discharge conditions, DSi decreases both in Upper and Lower Sea Scheldt. In the Western Scheldt, the decrease is limited. The effect of discharge regime (LOW – MED – HIGH) is mainly apparent in the Upper Sea Scheldt, where the concentration of DSi increases with LOW forcings. This can be explained by the higher SSC in the LOW scenario, and hence lower primary production and silica uptake. With HIGH forcings, the opposite effect is observed.

Influence on the silica export towards the North Sea, and thus on coastal eutrophication, seems negligible.

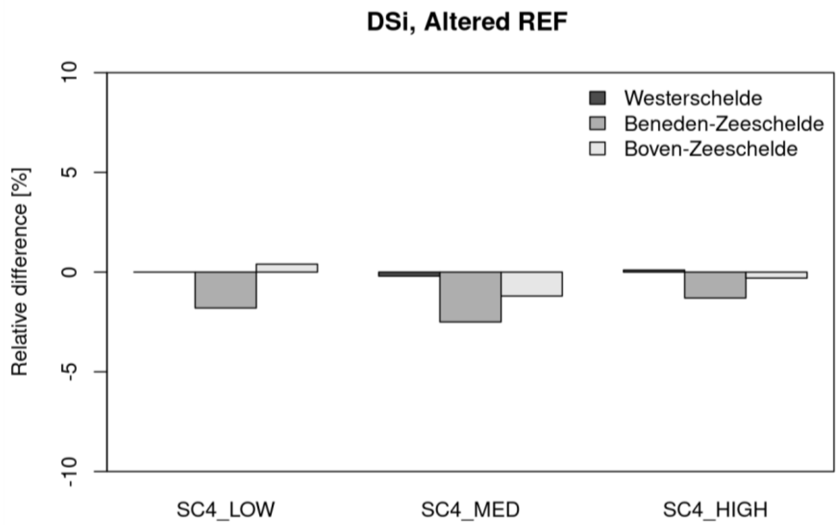

Figure 22 Relative difference (%) in dissolved silica concentration between REF en SC4 for LOW, MED and HIGH discharge conditions, averaged for Western Scheldt (Westerschelde), Lower Sea Scheldt (Beneden-Zeeschelde) and Upper Sea Scheldt (Boven-Zeeschelde).

CONCLUSION

In 4 scenarios studied by IMDC as part of the Interreg project IMMERSE's Work Package 3.2, dredged material is used to modify the bathymetry of the estuary, and hence influence the tidal characteristics, the suspended sediment concentration and ecology of the estuary. Scenario 4 had the most impact on reduction in tidal amplitude per m^3 disposed sand, and was therefore selected for further analysis.

In scenario 4 the bathymetry of the river banks in between Burcht and Rupelmonde are raised to a maximum elevation of -1,0 m TAW, resulting in a SSC reduction of up to 10% in the Lower Sea Scheldt and a SSC increase of 10-40% in the Upper Sea Scheldt for a low discharge situation.

The impact of the scenario 4 on primary production and water quality seems mainly to be limited to the project zone, between Burcht and Rupelmonde, where oxygen levels clearly increase. This occurs in all 3 discharge regimes, so a year-round improvement of the oxygen conditions can be expected. Although the direct effect is local, it can have an influence on the entire ecosystem, because the improvement is biggest in the zone where nowadays the lowest oxygen concentrations occur. Thus, with SC4, oxygen poor conditions that might hamper migration, will be less.

On the scale of the estuary, the impact is probably very small. At MED discharge regime, an increase in GPP is expected in the Upper Sea Scheldt, where normally the strongest algal blooms occur. But at LOW discharge conditions, GPP will decrease. However, LOW, MED or HIGH conditions don't prevail year-round. In a realistic year, there will be an alternation of HIGH, MED and LOW discharge conditions, during with algal populations will grow or decrease. Of course more LOW discharge conditions will occur in summer, but not all summer long. It is likely that in the Upper Sea Scheldt, increases at MED discharge will balance out with decreases during LOW discharge periods. However, a more accurate estimate of the net result of SC4 in the Upper Sea Scheldt is not possible.

Impact on nitrogen and silica fluxes to the North Sea are limited, so influence on coastal eutrophication seems negligible.

APPENDIX

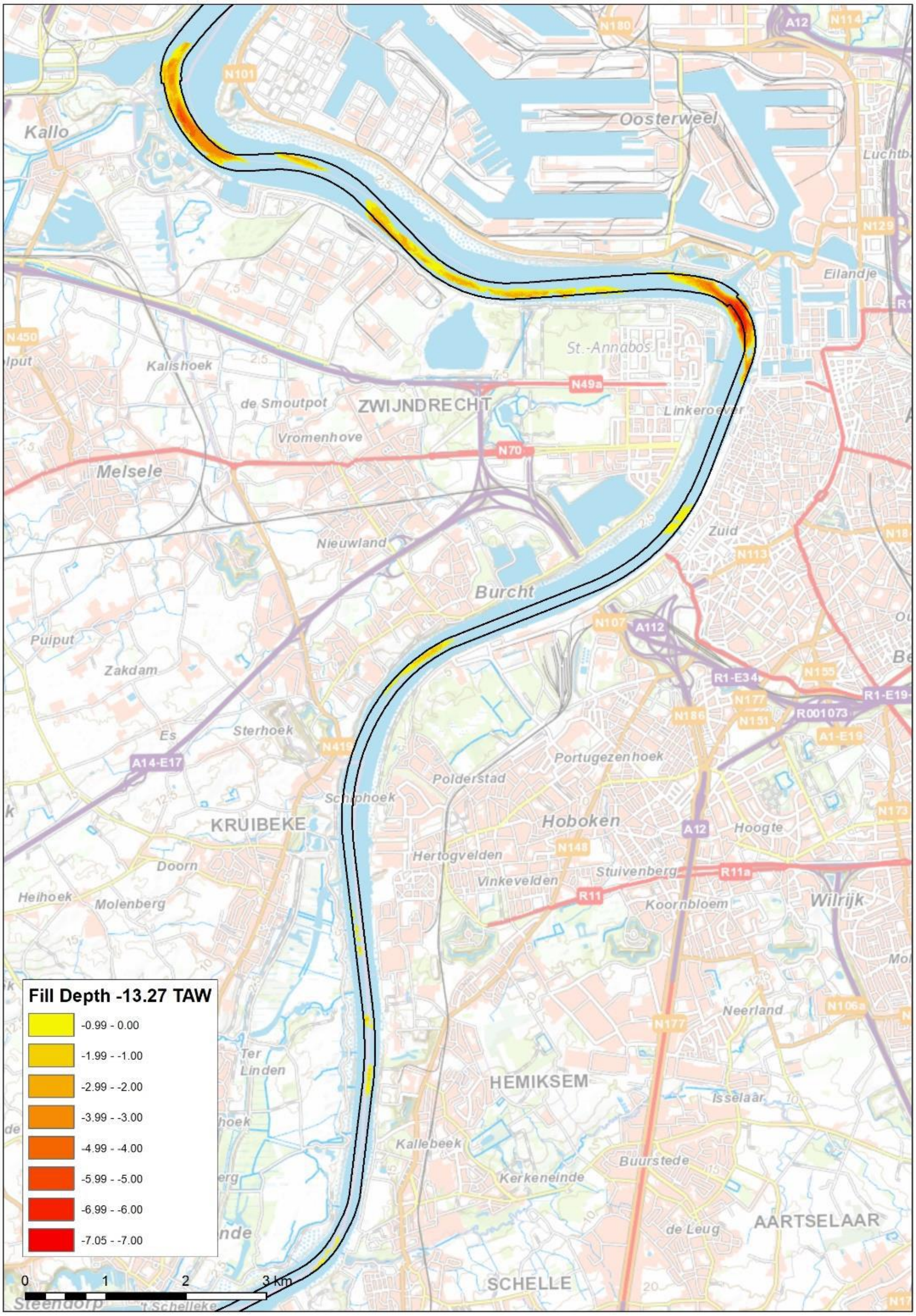

Figure 23 Elevation change [m] to reach the proposed fill depth for scenario 1 (IMDC, 2020).

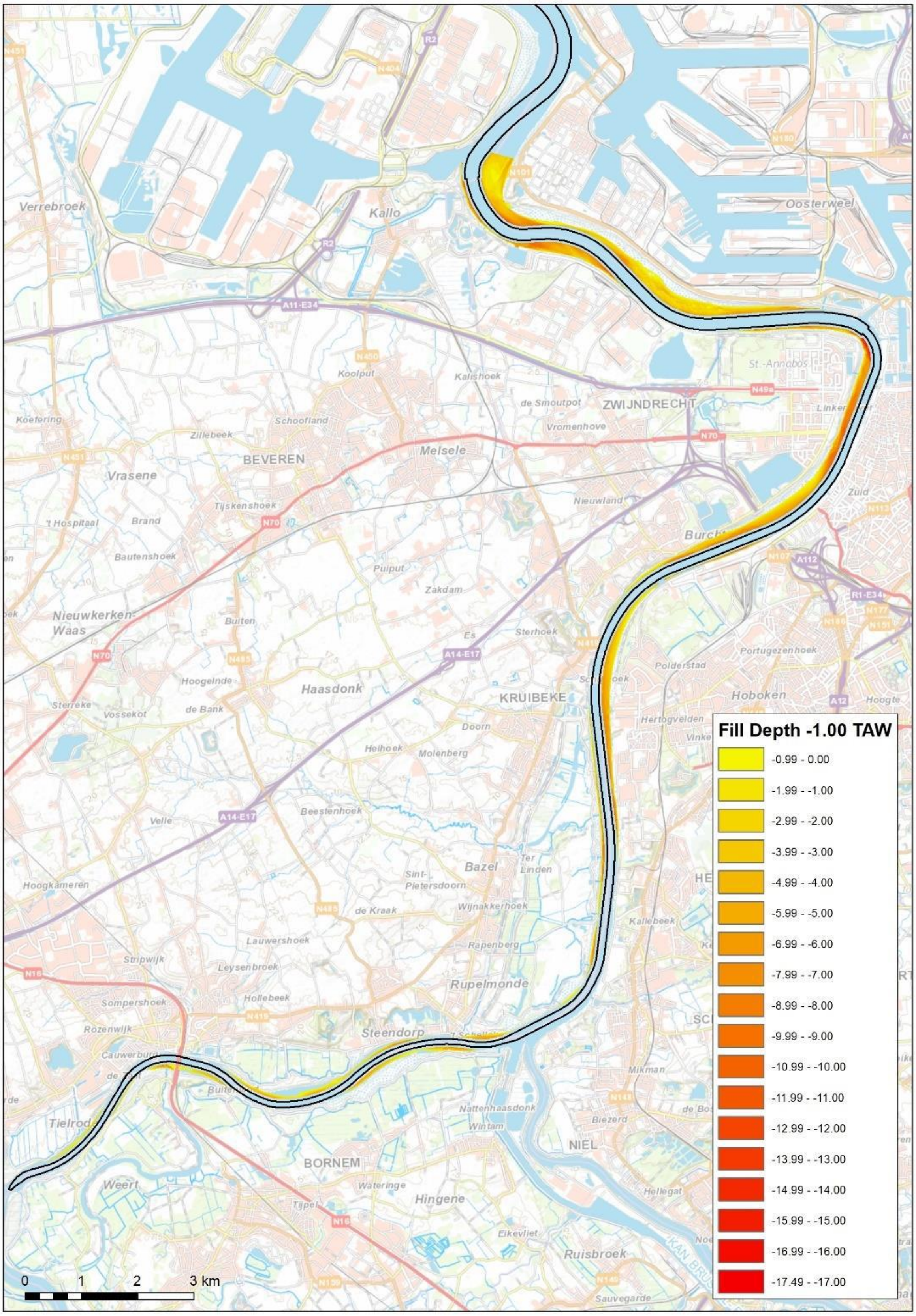

Figure 24 Elevation change [m] to reach the proposed fill depth for scenario 2.

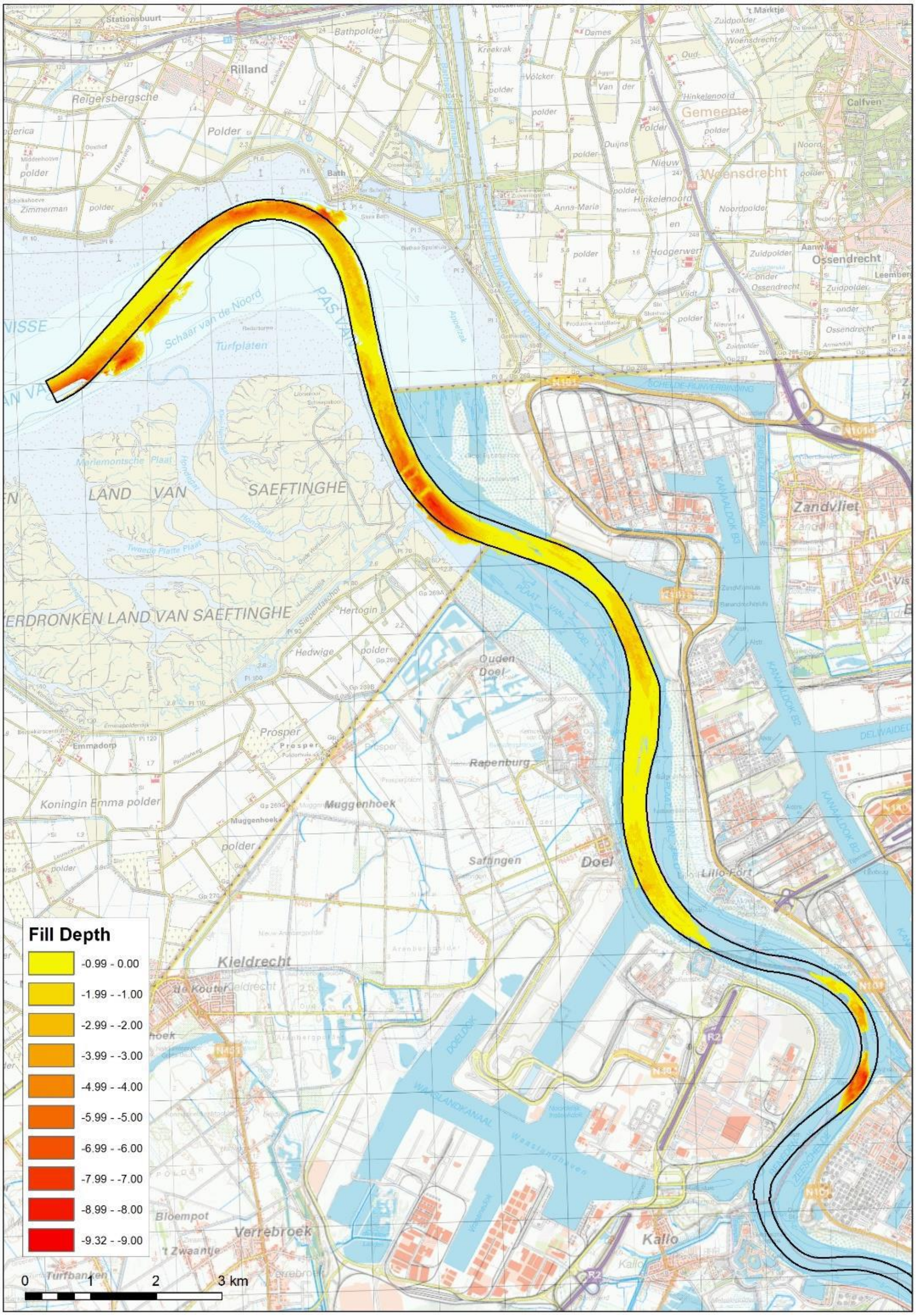

Figure 25 Elevation change [m] to reach the proposed fill depth for scenario 3 (IMDC, 2020).

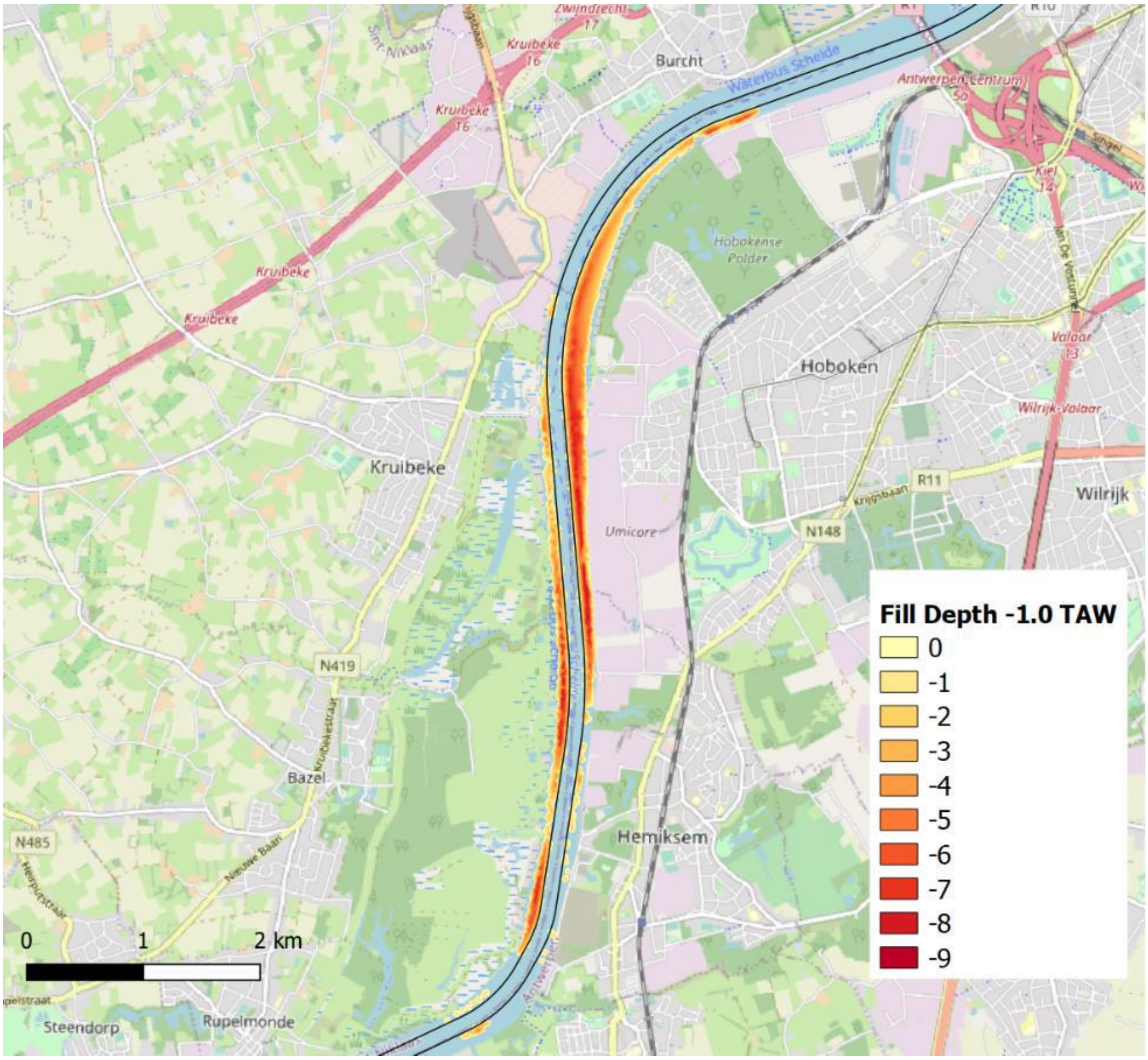

Figure 26 Elevation change [m] to reach the proposed fill depth for scenario 4 (IMDC, 2020).

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