IMDC

Plume modelling MER MOG2

Elia Asset NV

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1 Introduction

1.1 The assignment

The Elia group (hereafter referred to as 'the client') is currently investigating layout options for the Modular Offshore Grid 2 (MOG 2) project. The project encompasses the development of a power grid infrastructure in the Belgian part of the North Sea with the option of building a high voltage offshore platform. That is according to the current state of design an island with dimensions of 260 by 500 meters, for which three locations have been identified for the placement of it (i.e. locations West 1, West 2 and Noord, shown in the overview of Figure 1-1). Impact of maritime works related to construction of such an island and the impact of the island itself on the benthic communities must be studied thoroughly. Special care must be taken of the gravel beds, where sedimentation of fine sediment must be limited to 0.01 m in order to prevent irreversible loss of these beds. To this end, IMDC is provided with the task to perform numerical plume simulations to assess the potential impact of the MOG2 project on the background turbidity and sedimentation of fine sediment. For the construction phase, realistic fine sediment spill scenarios are defined, whereas for the operational phase, results of the morphological impact of the MOG 2 island, studied by Svašek (Svašek Hydraulics, 2022), are used as input for the long-term fine sediment release (scour) scenario's.

The results of the currently presented study will serve as input for an environmental impact study which addresses the implications of the MOG2 project.

Temporary disposal sites

For the purpose of the plume modeling study, two temporary disposal sites are taken into consideration: site 1 for island related works and site 3 for cable related works (Figure 1-1). These are two out of the four sites proposed by Elia, but also still other locations could be appointed by the permit authority.

1.2 Scope of the report

In this report, a three-dimensional TELEMAC model is set up in order to study the impact of dredging works, as well as the risk of siltation of the gravel beds after the construction of the island and installation of export cables. In order to do so, various scenarios are simulated, each of them for conservative conditions, for which the maximum sediment concentrations and sediment deposition are determined.

1.3 Reading guidance

This report represents the analysis of the plumes that are generated during dredging and disposal activities when constructing the island and cable laying, as well as from the scour after the construction of the island. Thereto, first the model setup of the hydrodynamic and the sediment transport model are discussed in chapter 2. In chapter 3 the different scenarios are presented. The impact on the sediment concentrations and the deposition are discussed for each of these scenario in chapter 4. Finally conclusions are given in chapter 5.

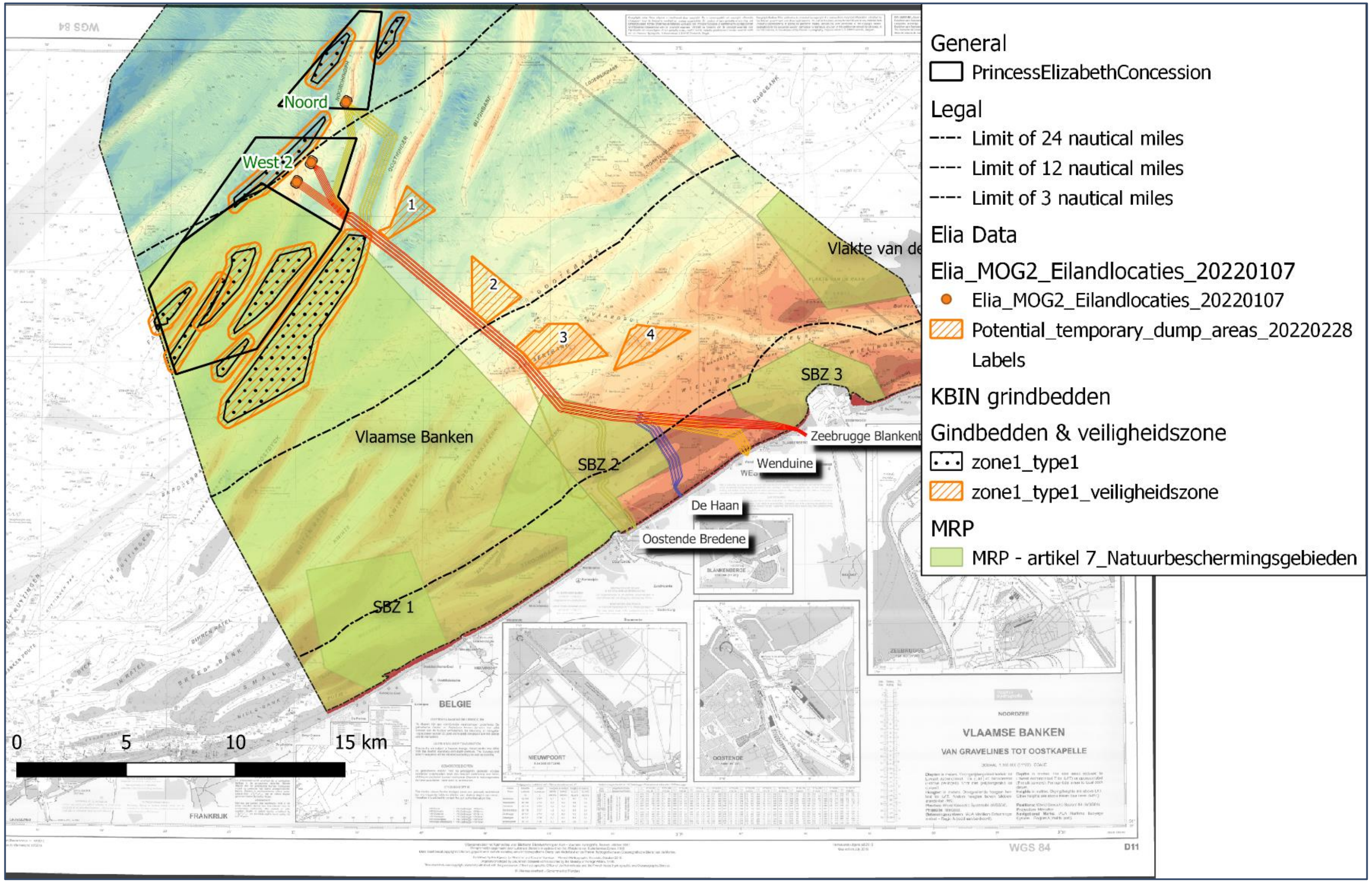


Figure 1-1 Overview of Belgian part of the North Sea with information relevant for this study.

2 Description of numerical model

2.1 Hydrodynamic model

2.1.1 Model software

The TELEMAC-3D software (v8p1 goblinshark) is applied for the suspended sediment transport calculations, and it solves the three dimensional equations such as the free surface flow equations (with or without the hydrostatic pressure hypothesis) and the transport diffusion equations of intrinsic quantities (sediment concentration). TELEMAC-3D makes use of the shallow water equations as first derived by Barré de Saint-Venant using a finite element method in the nodes of a mesh consisting of prisms with a triangular base. The main results are, for each point in the 3D mesh, the velocity in all three directions and the concentrations of the transported quantities. On the surface mesh, the main result is the water level. The bed level update and sediment dynamics (i.e. hindered settling) are simulated using GAIA, which is the latest sediment transport code of the TELEMAC modelling suite.

2.1.2 Numerical grid and bathymetry

The study area consists of the entire Belgian part of the North Sea, though the model extends as far as Normandie in France and North-Holland in the Netherlands (Figure 2-1). The number of triangular elements in the model mesh varies per scenario, but has in general more than 150,000 elements, with a dimension ranging from 20 m to 10,000 m (Figure 2-2). Mesh refinements up to 20 m were applied around points of interest for this study, such as proposed MOG2 island locations, temporary disposal zones and cable sections.

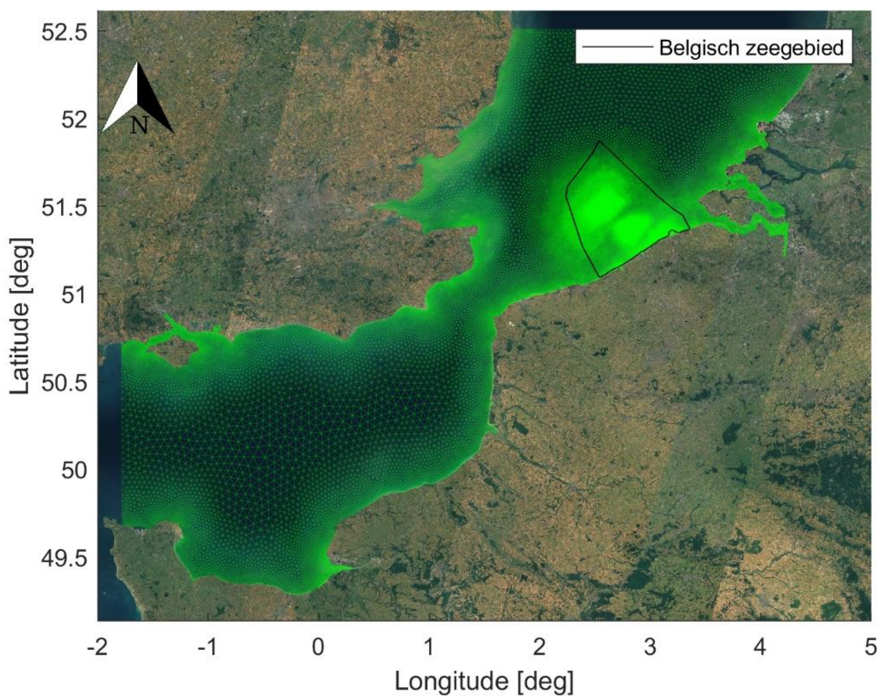


Figure 2-1 Computational mesh

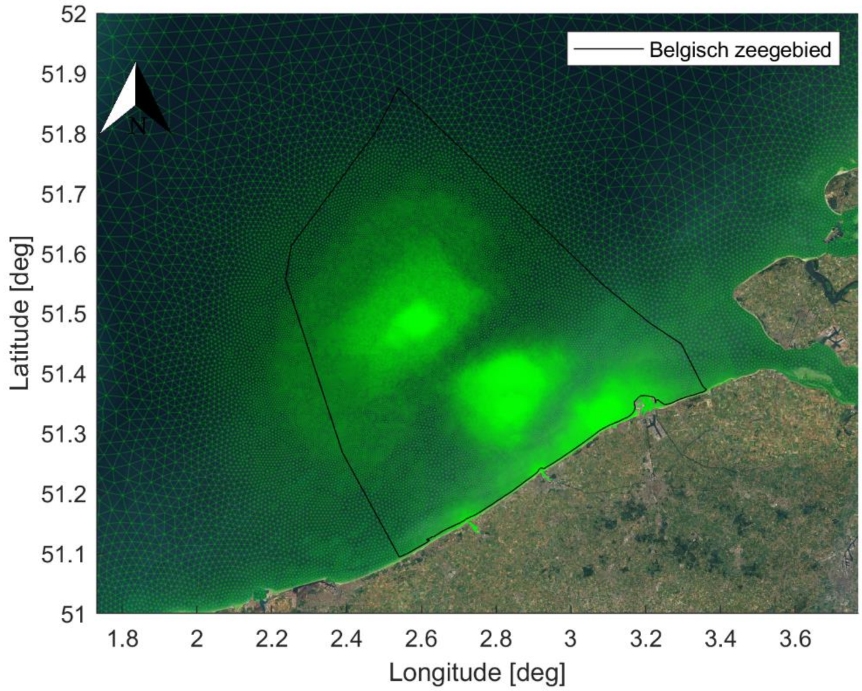


Figure 2-2 Computational mesh, zoom-in around the Belgian part of the North sea.

The model bathymetry is shown in Figure 2-3. The model bathymetry was setup using data from three different data sources: the "Bathymetrische databank" of Afdeling Kust for the Belgian coastal zone, EMODNET 2020 data (150 x 150 m resolution) and a higher resolution 20 x 20 m dataset "210412_BELGIUM_BCP_MSL_20m_ETRS89-UTM31". All data are converted to mean sea level (MSL) and hereafter interpolated on the computational mesh. For the scenario cases where the model contains an island ring, the toe's bathymetry is implemented in accordance with the current island layout drawings (Figure 2-4). For the study of case plume generation and deposition as a result of natural erosion after construction of the island, a bathymetric dataset provided by Svašek (Svašek Hydraulics, 2022) with simulated scour holes in the vicinity of the island, is interpolated on top of the model mesh.

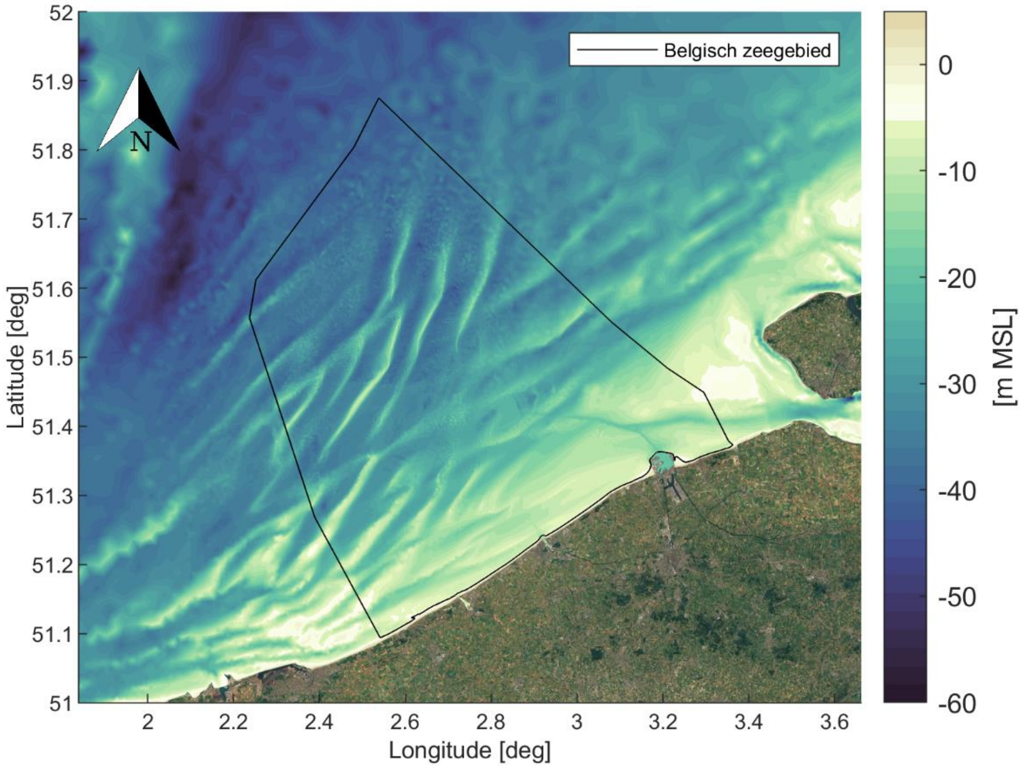


Figure 2-3 Model Bathymetry in m MSL

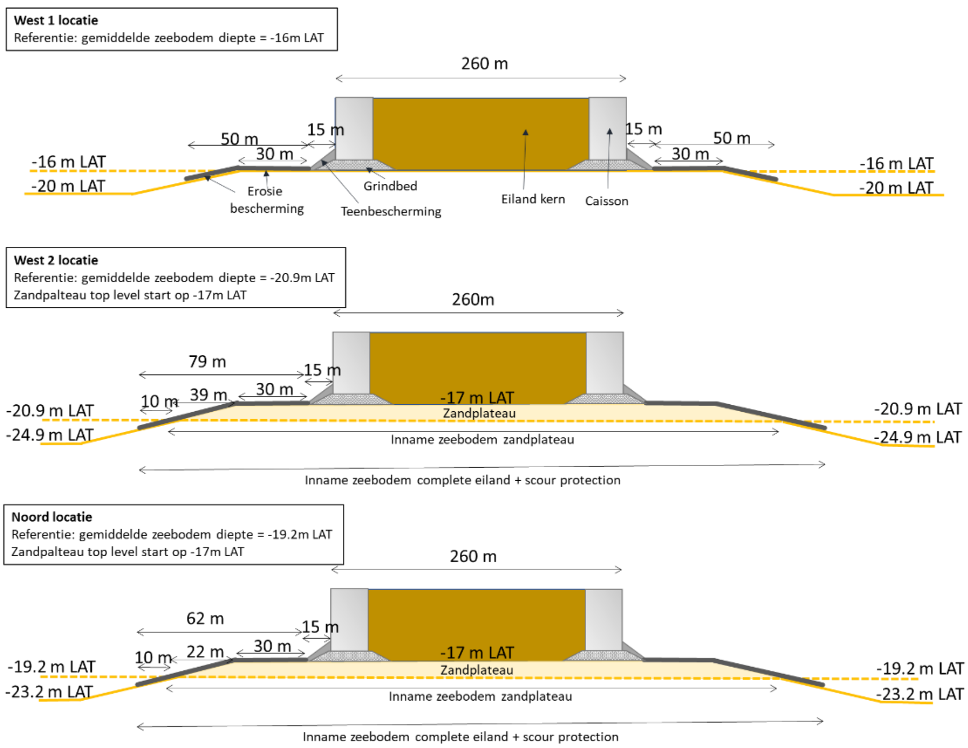


Figure 2-4 Cross-section of proposed island and scour protection dimensions for the West 1 (top), West 2 (mid) and Noord (bottom) location.

2.1.3 Vertical layer distribution

The model uses 9 vertical nodes (8 layers) with a sigma coordinate distribution. The thickness of the layers varies over the water depth, with the smallest mesh size near the sea bed (Table 2-1).

Table 2-1 Distribution of the vertical layers

Node number	Sigma coordinate of the elevation of the node
1	0.00
2	0.03
3	0.07
4	0.12
5	0.22
6	0.36
7	0.50
8	075
9	1.00

2.1.4 Boundary conditions and forcing

The model is forced by water levels and depth averaged velocities from the iCSM model (Chu *et al.*, 2020). This model was run using tidal boundary conditions from OSU/TPXO (Egbert and Erofeeva, 2002) as well as meteorological data (wind and air pressure) from the ERA-5 meteorological reanalysis model.

Figure 2-5 Mesh of the iCSM continental shelf model

The data from the iCSM model (water levels and depth averaged velocities) are interpolated to the boundaries of the model.

2.1.5 Settings

A list of the physical and numerical parameters of the hydrodynamic model is shown in Table 2-2. In the project area, it is found by Svašek (Svašek Hydraulics, 2022) that the effects of waves on the simulated sediment transport magnitude are limited to an increase of 15%. (i.e. at 20 m depth 15% and at 30 m 5%). This limited impact justifies the assumption of not considering wave effects in this study in order to save computational time when performing longer term sediment dispersion calculations.

Table 2-2 Physical and numerical settings of the hydrodynamic model

Parameter	Value
Time step	30 [s]
Number of vertical nodes	9
Advection-diffusion of tracers	On
Roughness law	Nikuradse law (Spatially varying roughness field)
Horizontal Turbulence model	4: Smagorinsky
Vertical turbulence model	6: k-epsilon model (GOTM)
Coriolis coefficient	Varying in space
Meteorological forcing	On
Advection scheme for momentum	Method of characteristics
Mass lumping for water depth	1.0

2.1.6 Model validation

2.1.6.1 Water level

The results of the modelled water level were compared with measurement data from “Meetnet Vlaamse Banken” for the period June 2th to August 30th 2019. The results for the model simulations are shown in Table 2-3. In this table, the bias (average error), root mean square error (RMSE) and the root mean square error corrected for the bias ($RMSE_0$) are shown. Two time series of the measured and modelled, water levels at station locations of Nieuwpoort and Westhinder are shown in Figure 2-6 and Figure 2-7. The table and the figures show that the model performs well for calculating the hydrodynamic conditions in the area with a RMSE below 0.1 m for the water levels.

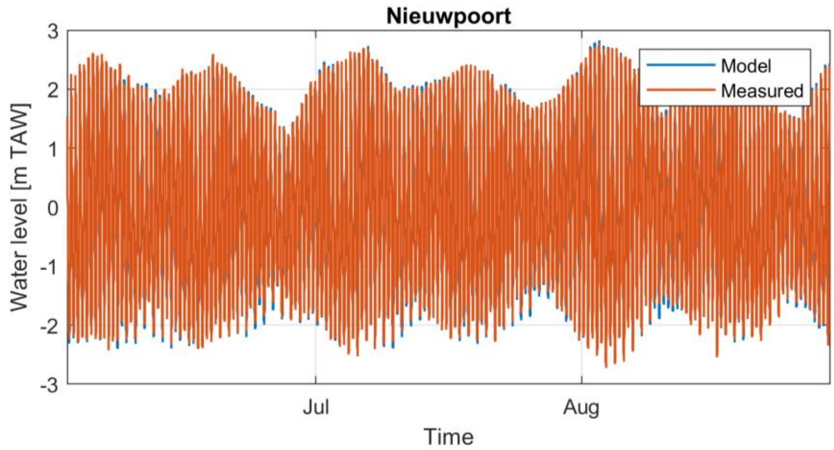


Figure 2-6 Timeseries of modelled and measured water level [m MSL] from 02-0-2019 till 30-08-2019 at the Nieuwpoort measurement station.

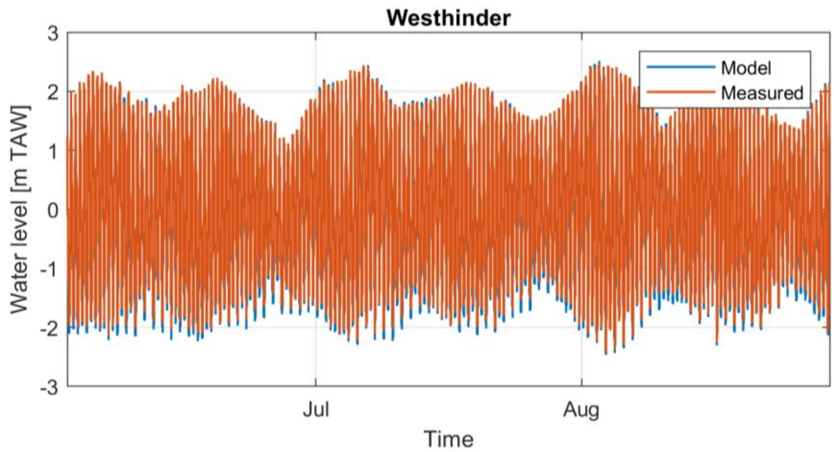


Figure 2-7 Timeseries of modelled and measured water level [m MSL] from 02-0-2019 till 30-08-2019 at the Westhinder measurement station.

Table 2-3 Statistics results for the comparison of the water levels .

Station	Bias Water level [m]	RMSE Water Level [m]	$RMSE_0$ Water level [m]
Nieuwpoort	-0.01	0.08	0.08
Westhinder	-0.06	0.09	0.07

2.1.6.2 Flow velocity

The results of the modelled depth averaged flow velocities were compared with measurement data from the measurement frame F3 (IMDC, 2022) just east of the proposed West 1 island location for the period August 13th to August 28th 2022. The results for the model simulations are shown in Figure 2-8 and Table 2-4. The table, the bias (average error), root mean square error (RMSE) and the root mean square error corrected for the bias ($RMSE_0$) are shown. The table and the figure show that the model performs well for calculating the depth averaged flow velocities in the area with a RMSE of 0.06 m/s and maximum peak flow velocities which match with observed values.

Furthermore, the modelled flow direction is very comparable to the measured flow direction.

Based on this analysis, the model is deemed valid for the further use of it when performing sediment dispersion calculations.

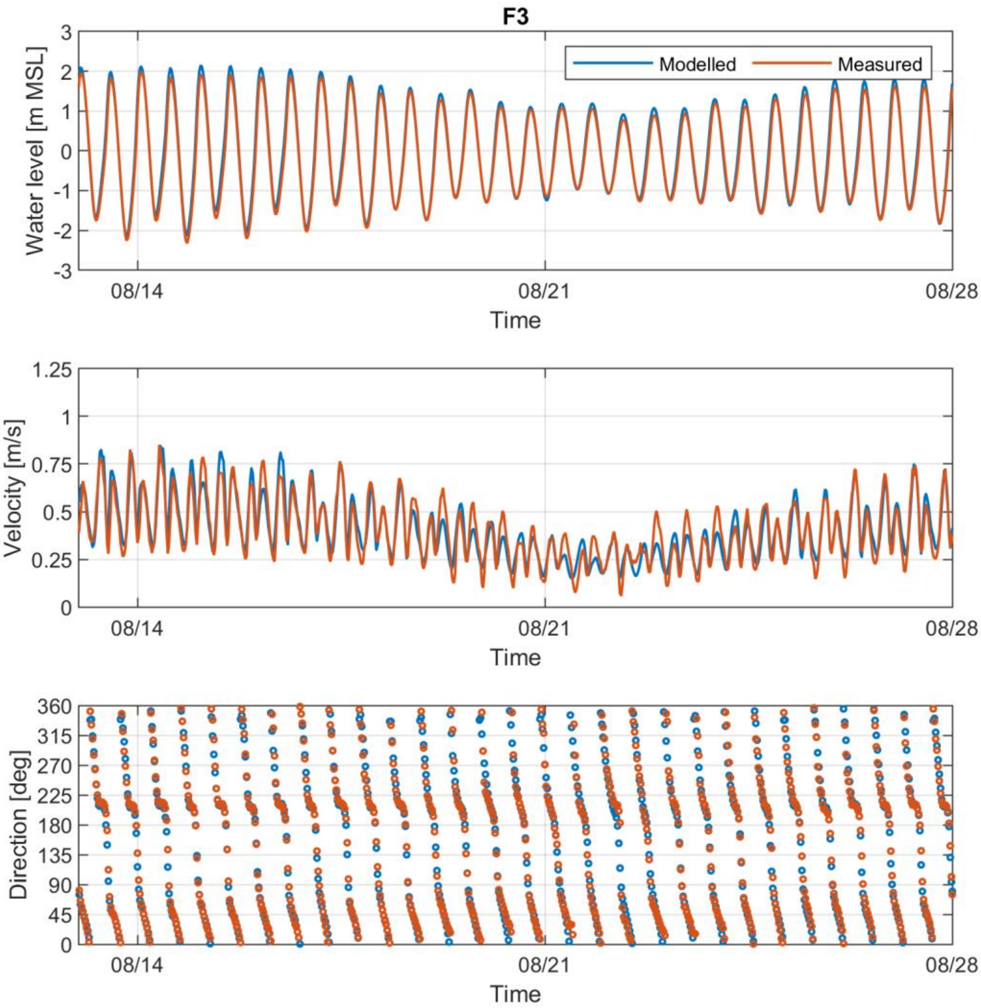


Figure 2-8 Timeseries of modelled and measured depth averaged flow velocity magnitude [m/s] (top figure) and direction [°] (bottom figure) from 13-08-2022 till 28-08-2022 at the location of the F3 frame (IMDC, 2022).

Table 2-4 Statistics results for the comparison of the depth averaged flow velocities.

Station	Bias depth averaged flow velocity [m/s]	RMSE depth averaged flow velocity [m/s]	$RMSE_0$ depth averaged flow velocity [m/s]
F3 frame	0.005	0.064	0.064

2.2 Sediment transport model

2.2.1 Sediment characterisation

Based on geophysical interpretation data of the subsurface horizons along proposed cable sections (Figure 2-9, Figure 2-11 and Figure 2-12, Cathie draft report (2021)) and Vibrocore data near the proposed MOG2 island locations (Figure 2-13, Figure 2-14 and Figure 2-15, (Depret-G-Tec, 2009)), sediment characteristics at locations of interest for this study have been identified. Values hereof are presented per scenario in section 3. In general, it is found that the proposed MOG2 island locations (Figure 1-1) are situated in an area with a sandy substratum. Going shoreward, the sandy regime is alternated with gravel patches and stiff clay layers. Ultimately, around 20 kilometres offshore of Zeebrugge, there is a sharp transition going from a sandy bed to a muddy/silty substratum (Figure 2-9, Figure 2-10).

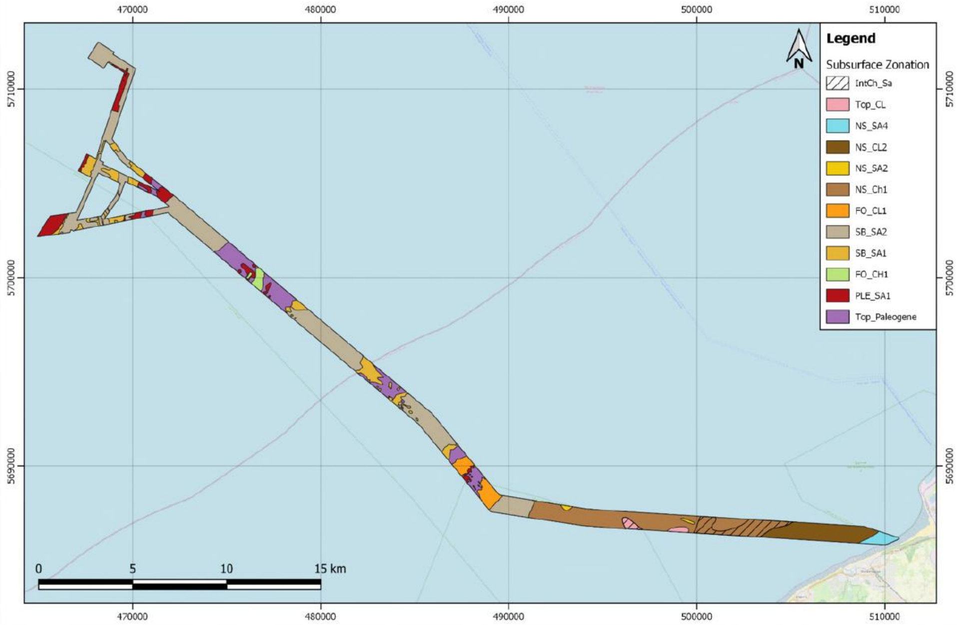


Figure 2-9 Subsurface sediment unitization, adapted from Cathie draft report (2021) along the power cable track. Grey zones = sandy regime, purple and orange zones = stiff clayey regime, brown zones = muddy/silty regime.

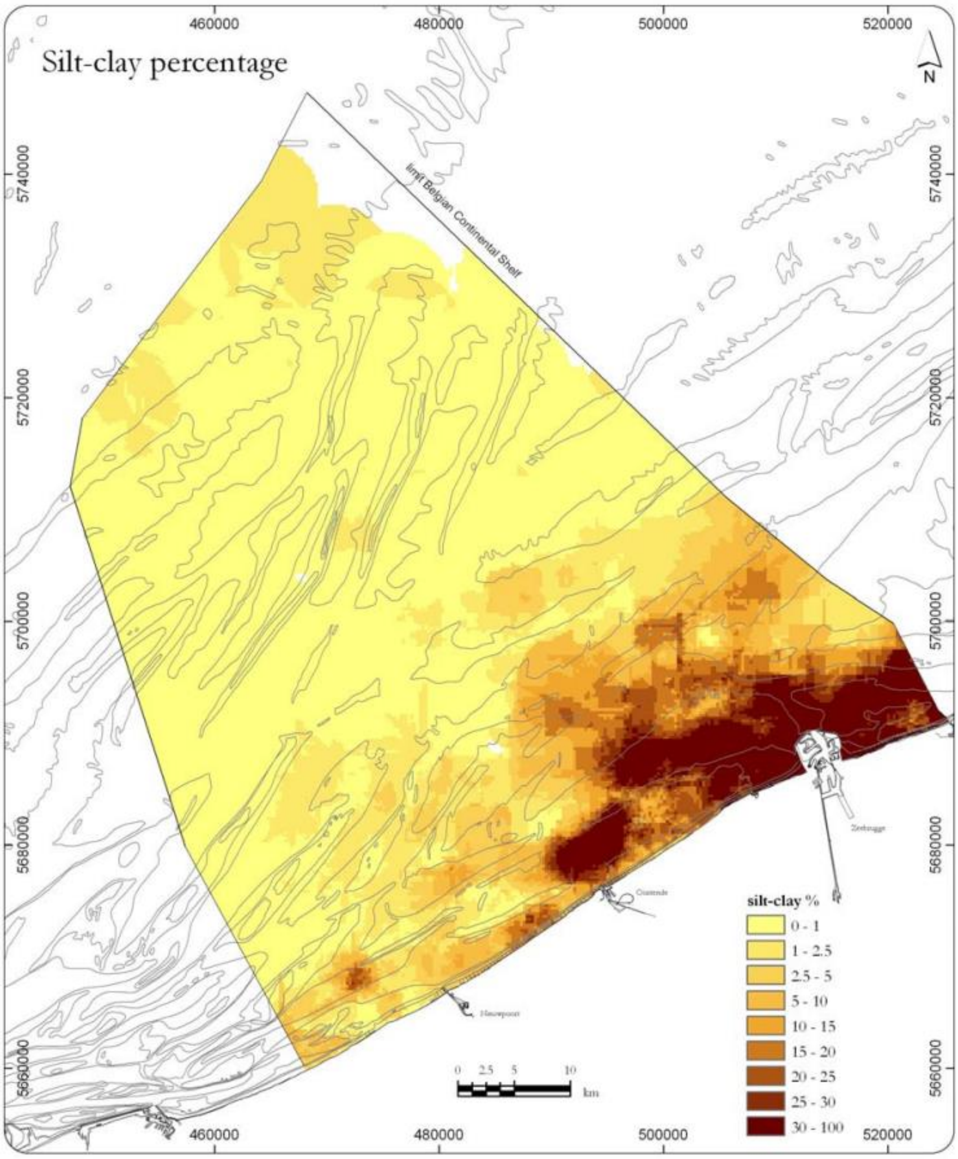


Figure 2-10 Map showing estimated silt-clay percentage in the Belgian sea zone (Van Lancker *et al.*, 2007).

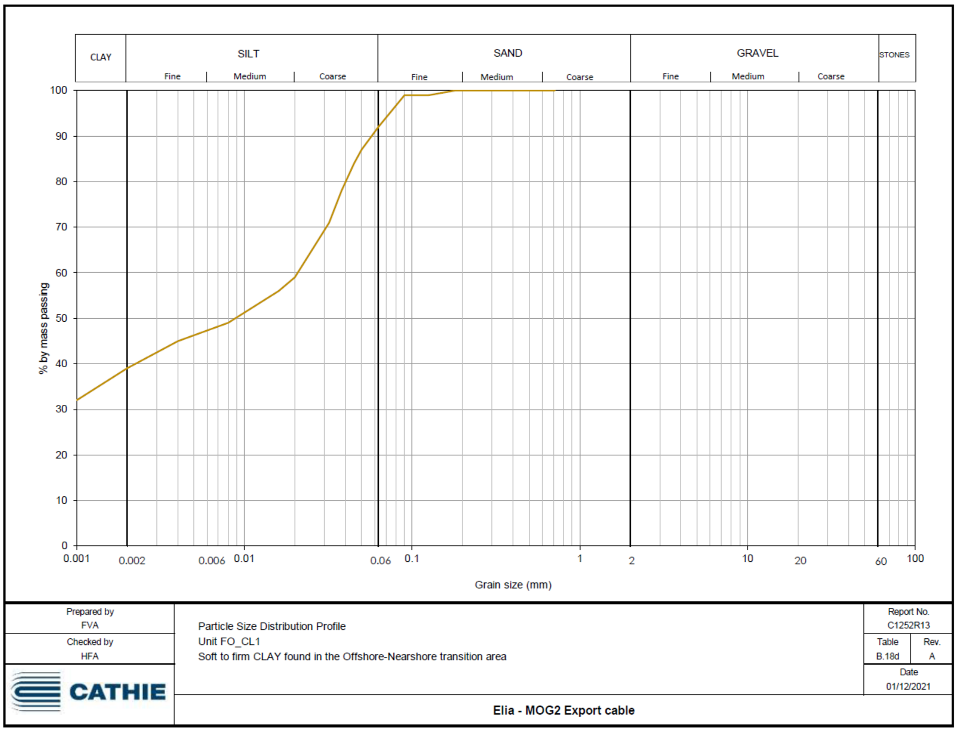


Figure 2-11 Particle size distribution profile of unit FO_CL1 (soft to firm clay found in the offshore-nearshore transition zone), adapted from Cathie draft report (2021).

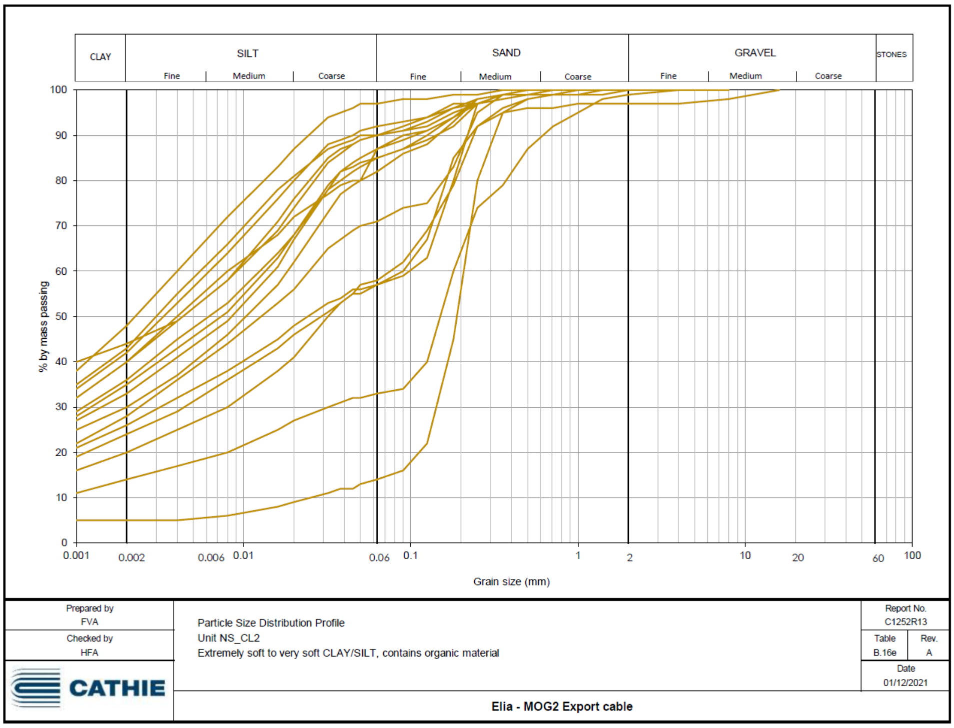


Figure 2-12 Particle size distribution profile of unit NS_CL2 (extremely soft to very soft clay/silt, contains organic material), adapted from Cathie draft report (2021)

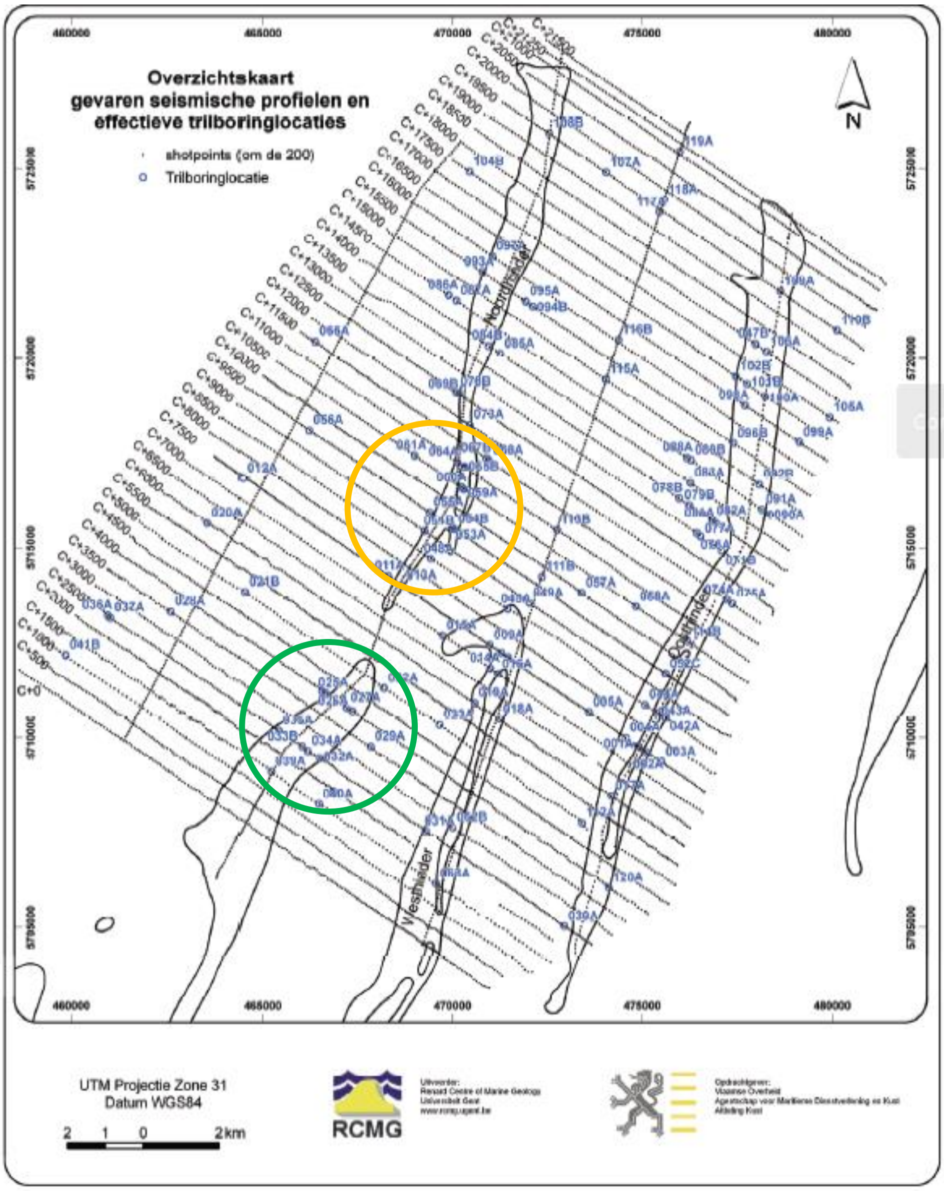


Figure 2-13 Overview map of sailed seismic profiles and effective Vibrocore locations (Mathys *et al.*, 2009). Vibrocores within the green circles are used for the grain size distribution analysis of the West1 and West 2 locations, and within the orange circle for the Noord location.

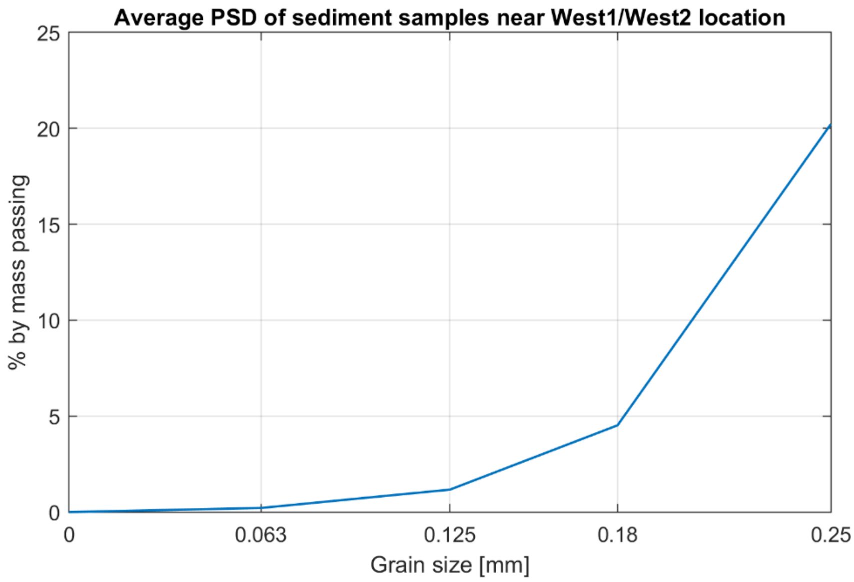


Figure 2-14 Average particle size distribution (PSD) of vibrocore locations (Mathys *et al.*, 2009) within the green circle of Figure 4-4.

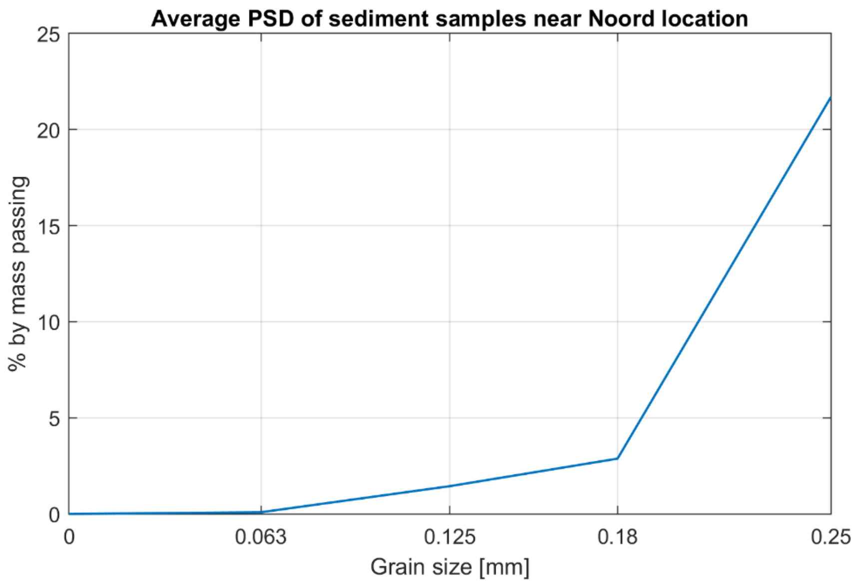


Figure 2-15 Average particle size distribution (PSD) of vibrocore locations (Mathys *et al.*, 2009) within the orange circle of Figure 4-4.

The natural background turbidity will be taken into account for the analysis of the model results, using it as a baseline value to which the excess suspended sediment concentration (SSC) will be compared. Given that the average natural background turbidity varies over the Belgian part of the North sea, as indicated in Figure 2-16, baseline values are selected based on the locations of the dredging works for each scenario. Minimal values of the background turbidity (SPM) at Blighbank (Van den Eynde et al., 2010) and from IMDC (2022) can be applied to areas of the proposed MOG2 island locations (Figure 1-1) and is about 4 mg/L. Going shoreward towards temporary disposal site number 3 (Figure 1-1), baseline values of 25 to 50 mg/L are found.

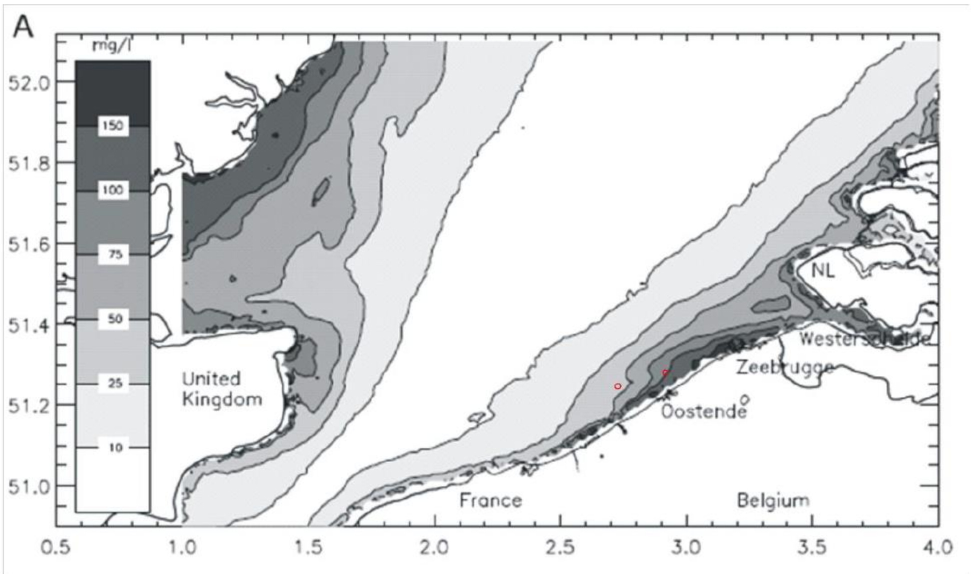


Figure 2-16 Yearly average of depth averaged SPM (Suspended Particulate Matter) concentrations [mg/L] in the southern part of the North sea estimated by Fettweis et al. (2010) .

2.2.2 Settings

The motion of the disposed sediment is modelled using an advection-diffusion equation. Naturally occurring sediment in the system is not considered in the model. Instead the disposal plumes are released into an "empty" model. The settings of the sediment transport model are shown in Table 2-5 Table 2-6 for modelling the cohesive and non-cohesive sediment, respectively.

Table 2-5 Settings of the cohesive sediment (mud) in the TELEMAC-3D plume model

Parameter	Setting	Remarks
Settling velocity	Constant in space and time with a value of 1.0 [mm/s]	This is a characteristic value of slightly flocculated sediment typically found in estuaries or coastal seas and often used as default setting for simulating dynamics of cohesive sediments.
Erosion law	Off & On	Resuspension excluded in construction phase scenario's (section 3.1) and included in operational phase scenario's (section 3.2)
	Partheniades equation Critical shear stress: 0.2 [Pa] Partheniasdes coefficient: 0.00025 [kg/m²/s]	Used in the scenario with resuspension (section 3.1.1.2). Bed shear stresses are calculated from near bed flow velocity. The influence of waves is considered.
Threshold for deposition	Not used	The continuous deposition paradigm is used in agreement with the latest scientific insights (Winterwerp and van Kesteren, 2004)
Advection scheme	NERD scheme	

Parameter	Setting	Remarks
Horizontal diffusion	off	Sensitivity tests performed in previous plume modelling studies showed that the difference in the predicted results for simulations with and without horizontal diffusion are very small. The most important horizontal diffusion process is shear induced mixing. As this is an apparent horizontal process, this process needs to be parameterized in a two-dimensional model. In a three-dimensional model, such as used in the present study, this process is included in the problem that is resolved. Hence no additional horizontal diffusion is needed to parameterize this.

Table 2-6 Settings of the non-cohesive sediment (sand) in the TELEMAC-3D plume model

Parameter	Setting	Remarks
Sediment diameter	Scenario dependant	Used to calculate the critical shear stress for erosion in the model.
Erosion law	From the near-bed sediment concentration of Van Rijn (1984)	Bed shear stresses are calculated from the near bed flow velocity. The influence of waves is not taken into account.
Settling velocity	Calculated by Van Rijn equation with sediment diameter as input	
Bed porosity	0.4 [-]	Used in combination with the sediment density to relate the thickness of the deposition to the deposited sediment mass.
Sediment density	2650 [kg/m³]	Used in combination with the porosity to relate the thickness of the deposition to the deposited sediment mass.
Advection scheme	NERD scheme	
Horizontal diffusion	off	Sensitivity tests performed in previous plume modelling studies showed that the difference in the predicted results for simulations with and without horizontal diffusion are very small. The most important horizontal diffusion process is shear induced mixing. As this is an apparent horizontal process, this process needs to be parameterized in a two-dimensional model. In a three-dimensional model, this case, this processes is included in the problem that is resolved. Hence no additional horizontal diffusion is needed to parameterize this.

Parameter	Setting	Remarks
Bed load	Off	In the present simulations, only the suspended sediment is taken into account, as the focus is on the suspended transport of fine sediments. Extensive simulations of the total load (i.e. bedload and suspended load) on the evolution of the bed are presented in the study of Svašek (Svašek Hydraulics, 2022).

2.2.3 Sediment losses and spill parametrisations

Dredging activities can generate turbidity plumes due to hydraulic and mechanical processes bringing sediment into suspension (Decrop, 2015). Increased turbidity around the dredging activities is caused by e.g. head losses, overflow spills, dredge spoil placement activities, containment bund outflow and other. These turbidity generating dredging activities can be implemented as sediment sources in the numerical model for cohesive sediment transport. In this report, the term 'spills' is used and is to be considered as sediment losses in relation to model source terms.

The common methodology to calculate spill rates is based on the application of a loss factor to the amount of fine sediments dredged or available for suspension. For each source term, loss factors have to be assigned based on available literature, measurements or experience (Decrop, 2018). The spill percentages of the dredging activities of Trailing suction hopper dredgers (TSHD) taken into account in the current TELEMAC-3D model are shown in Table 2-7.

Table 2-7 Types of spill and corresponding loss percentages used the current TELEMAC-3D model

Type of loss	Loss percentage
Draghead loss TSHD	0.77%. Based on a study (Anchor Environmental CA L.P., 2003) in which data was collected from over 43 dredging projects
Overflow loss TSHD	100% of all sediments released from the overflow will go into suspension
Disposal loss	30% of the sediments will go into suspension

The source terms consist of a spill rate, i.e. a sediment flux [kg/s] that is implemented in the model at the location of the dredging activity according to a specific vertical distribution (Decrop, 2015; Decrop and Bollen, 2016). Depending on the type of dredging method, equipment and activity, different fluxes of fine sediment will be discharged in different locations of the water column. At IMDC, a toolbox has been developed to generate spill rates based on a number of inputs (Table 2-8).

Table 2-8 Overview of the inputs and outputs of the spill rate toolbox

Inputs

• Equipment involved
• Sediment characteristics:
    ○ Density in situ [kg/m³]
    ○ Density grains [kg/m³]
    ○ Density water [kg/m³]

- Fine content (%)
- Dredge production information about timings:
  - Downtime [hr]
  - Operational time [hr]
  - Cycle time [min]
  - Loading time [min]
  - Overflow time [min]
- Dredge rate production information:
  - Production [m³is/OH]

  OR
  - Maximum hopper volume [m³]
  - Bulking factor [-]

The overflow concentration and duration is calculated with the two-box model of Jensen and Saremi (2014) for TSHD's or for a larger 'container' such as an island ring ('caisson island' cf. 3.1.1.3). This model solves the mass balance of different sediment fractions inside a hopper over time and takes the hindered settling of polydisperse mixtures into account. It requires input such as a particle size distribution of the dredged material, the dimensions of the hopper and a maximum loading height. In case of a TSHD, the assumed initial water in the barge is 0.1 [m]. For an island ring, it is assumed to start from a ring fully filled with clear sea water.

To represent the different spill types inside the numerical model, different parametrization of the vertical profile are available.. The following parametrizations are available:

- F1. This flag type corresponds to a sigma profile. The spill is distributed over the water column in a customised way (Figure 2-17).
- F2. This flag type corresponds to a block profile. This profile is defined by two blocks with a certain height near the surface and near the bed and the mass fraction they contain. The rest of the spill is implemented in between (Figure 2-17). This is typically used for Backhoe dredger spills.
- F3. This flag type represents the parameter model for overflow schematisation (Decrop, 2015; Decrop and Bollen, 2016). It calculates the vertical profile of sediment behind the TSHD, depending on density, overflow discharge/diameter and the local flow conditions. The required inputs are:
  - Characteristic draught
  - Distance overflow - stern
  - Pipe diameter
  - Spill rate of material through overflow (not to passive plume)

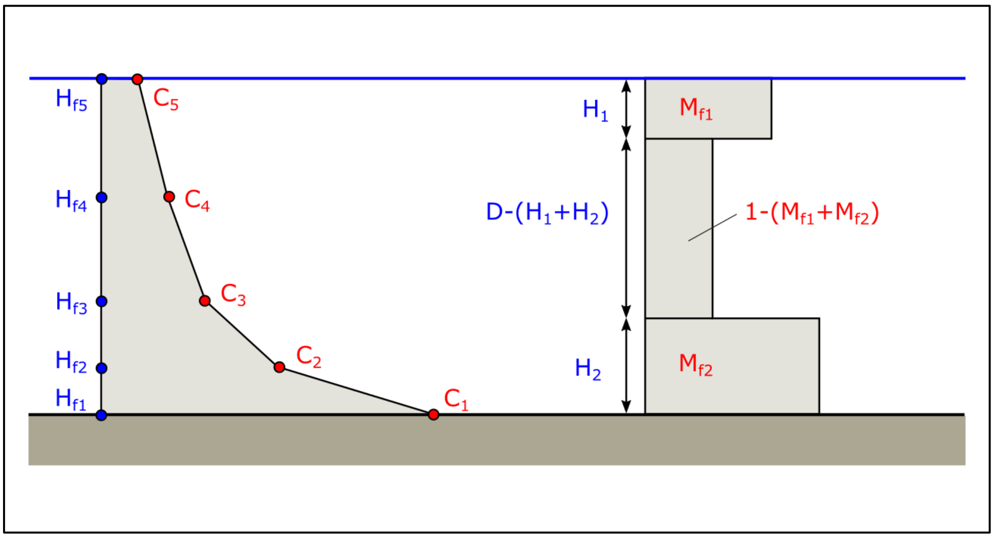
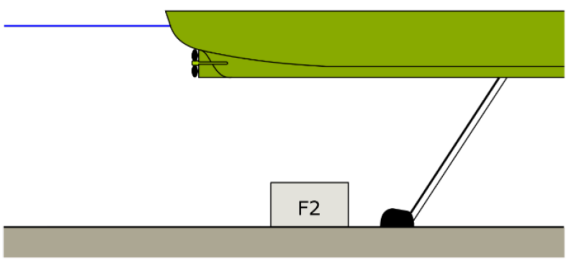
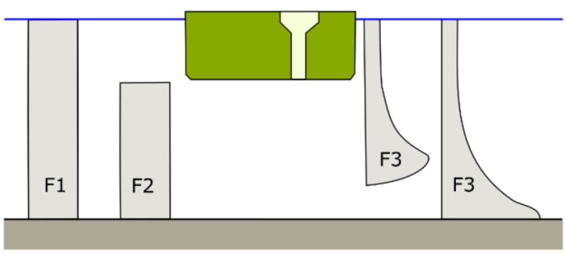


Figure 2-17 Two types of representing vertical distributions. Left: Flag type F1 based on a sigma distribution over the vertical and the concentration profile, Right: Flag type F2 based on representing the heights and mass fractions of two blocks near the surface and near the bed, in between the rest of the material is distributed.

Different vertical distributions can be generated based on the parameters of the three presented flag types. Examples of profiles for the spills included in this study are shown in Table 2-9. In case of disposals, a F2 block profile is used by which 50% of the discharged material is put in the first 2 m of the water column. The other 50% is put between the first 2 m beneath the water surface and 5 m above the sea bed.

Table 2-9 Overview of the different type of dredging spills and the vertical profiles that are included in the model.

	Common profiles	Used profiles
Draghead and cutterhead		F2 : 2 [m] above bed
Overflow		F3: calculated profiles with parameter model

2.2.4 Simulation period

The simulation period that is chosen is depends on the length of the dredging works and varies thus per scenario. Note that for the model simulations, the ideal situation of continuous dredging 24h/24h is considered without down time or delay. Thus, in reality the works can take longer. For the simulation, the works are started on August 2th 2019, which corresponds to the most extreme springtide in the summer period of 2019. This period contains the validation period of the hydrodynamic model shown in section 2.1.6. All simulations were begun from hydrodynamic conditions that had a day of spin-up.

3 Scenario definition

The numerical TELEMAC-3D plume model is used for the investigation of the plume dispersion of fine sediments (d_{50} < 250 µm) and the deposition that is generated during and after dredging works. For the construction phase and operational phase the following scenarios were set-up:

Construction phase:

- Detailed simulations of dredging activities related to the construction of the island:
  - Scenario 1: Plume generation while levelling sand ridges and disposing dredged material at a temporary disposal site (site 1, levelling of sand ridges only for location West 1)
  - Scenario 2: Plume generation while pre-dredging scour holes and disposing dredged material at the island location for the creation of a sand 'pancake' or plateau (only for locations West 2 and Noord) (Figure 2-4)
  - Scenario 3: Plume generation while pre-dredging scour holes and filling the island ring with dredged sand through pipes, leading to overflow from the island ring (all island locations)
- Detailed simulations of dredging activities related to power cable installation
  - Plume generation while dredging trenches for the power cables and disposing dredged material at a temporary disposal site (site 3)

Operational phase:

- Plume generation and deposition of fines (<250 µm) as a result of natural erosion after island construction (all island locations)

Given the size of the temporary disposal sites with respect to the volumes of the sediment to be disposed, it is ought valid to assume that there will be no observable impacts of the disposals on the local hydrodynamics of the disposal sites. Hence, no additional hydrodynamical simulations are performed to investigate this impact.

3.1 Construction phase

3.1.1 Island construction

3.1.1.1 Scenario 1: levelling sand ridges and disposal at a temporary disposal site

In this scenario, sand ridges at the West 1 island location are leveled to -16 m LAT (Figure 3-1) and dredged sediment is disposed at the temporary disposal site 1 (Figure 1-1). Given that currently no schedule of dredging works exist, it is assumed that the works will be executed by a single TSHD with a representative barge of 5600 m^3. Here, sediment losses that are taken into account are losses at the dredge head, overflow losses and losses during disposal (see section 2.2.3). The properties of this THSD and the sediment settings are shown in Table 3-1. Figures of the resulting sediment sources in the TELEMAC-3D plume model are shown in appendix section A.1.

Table 3-1 TSHD sand ridge crest dredging properties

Properties	Value
Dredging volume	0.15 [M m³]
In situ density for TSHD productions	1.9 [t/m³]
Bulking percentage	10% (situ – in pipe)
Percentage of fines	20% (< 250 [µm]) , 0.2% (< 63 [µm])
Grain size (d_{50}) of fraction fine sand in TELEMAC	201 [µm]. Determined from a computed average PSD near West 1 (Figure 4-5).
Volume of hopper bin	5600 [m³]
Overflow utilized	Yes
Diameter of overflow	1700 [mm]
Draught of the hopper (full)	7.1 [m]
Time to fill the hopper till overflow	30 minutes
Location of disposal	temporary disposal site 1
Sailing speed	12.3 knots
Disposal time	10 minutes
Total duration of dredging works	2 days

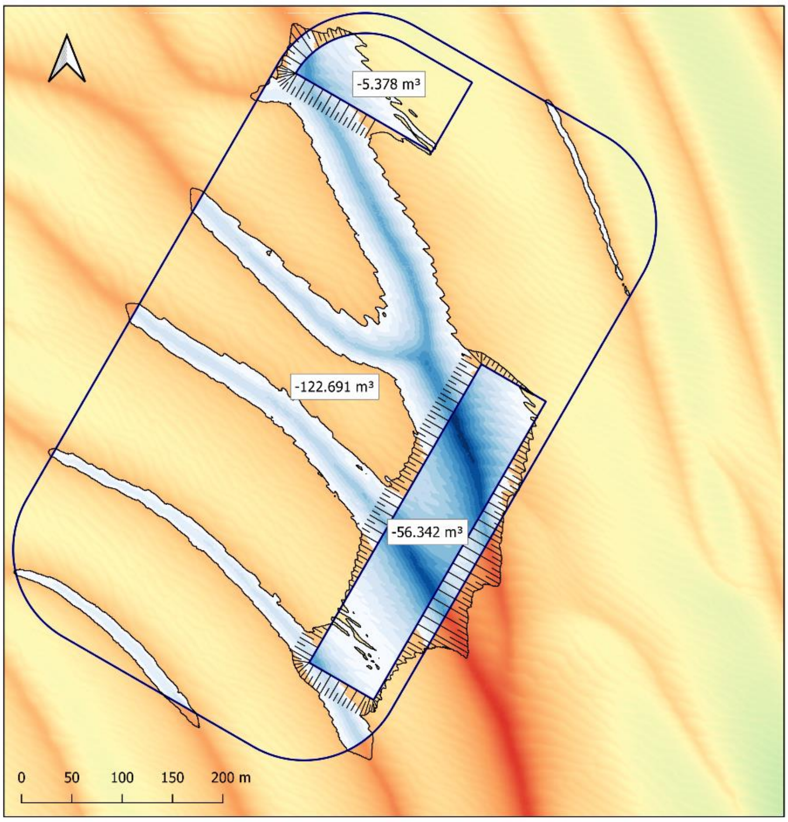


Figure 3-1 Bathymetry of island location West 1, where black polygons with blueish fillings indicate locations where sand ridge crests are to be leveled to -16 [m LAT].

3.1.1.2 Scenario 2: pre-dredging scour holes and creation of sand plateau

In this scenario, expected scour holes are being pre-dredged, of which the sediment is being disposed at the island location for the creation of a sand plateau. The total volume of sediment needed to be dredged for the creation of this plateau is assumed to be 30% higher than the actual volume of the sand plateau, based on previous observations on the Belgian part of the North Sea related to initial sediment loss after sand disposals (Van den Eynde *et al.*, 2010). Given that currently no schedule of dredging works exist, it is assumed that the works will be executed by one TSHD with a representative barge of 5600 m^3. Here, sediment losses that are taken into account are losses at the dredge head, overflow losses and losses during disposal (see section 2.2.3). The properties of this assumed THSD and the sediment settings are shown for the two simulated cases of the West 2 and Noord locations in Table 3-2 and Table 3-3, respectively. Figures of the resulting sediment sources in the TELEMAC-3D plume model are shown in appendix section A.2.

Table 3-2 TSHD pre-dredging West 2 dredging properties

Properties	Value
Dredging volume	1.09 [M m^3]
In situ density for TSHD productions	1.9 [t/m^3]
Bulking percentage	10% (situ – in pipe)
Percentage of fines	20% (< 250 [µm]) , 0.2% (< 63 [µm])
Grain size (d_{50}) of fraction fine sand in TELEMAC	201 [µm]. Determined from a computed average PSD near West 2 (Figure 4-5).
Volume of hopper bin	5600 [m^3]
Overflow TSHD utilized	Yes
Diameter of overflow	1700 [mm]
Draught of the hopper (full)	7.1 [m]
Time to fill the hopper till overflow	30 minutes
Location of disposal	West 2 island location
Sailing speed	12.3 knots
Disposal time	10 minutes
Total duration of dredging works	6 days

Table 3-3 TSHD pre-dredging Noord dredging properties

Properties	Value
Dredging volume	0.57 [M m^3]
In situ density for TSHD productions	1.9 [t/m^3]
Bulking percentage	10% (situ – in pipe)
Percentage of fines	21.7% (< 250 [µm]) , 0.1% (< 63 [µm])
Grain size (d_{50}) of fraction fine sand in TELEMAC	209 [µm]. Determined from a computed average PSD near Noord (Figure 4-6).
Volume of hopper bin	5600 [m^3]
Overflow TSHD utilized	Yes
Diameter of overflow	1700 [mm]
Draught of the hopper (full)	7.1 [m]
Time to fill the hopper till overflow	30 minutes
Location of disposal	Noord island location
Sailing speed	12.3 knots
Disposal time	10 minutes
Total duration of dredging works	3 days

3.1.1.3 Scenario 3: pre-dredging scour holes and filling the island ring

In this scenario, expected scour holes are being pre-dredged, of which the sediment is being transported through pipes from a TSHD directly into the island ring, leading to overflow from the island ring. In order to fill the entire island ring with dense sediment, it is assumed that an additional amount needs to be dredged to compensate for the estimated 15% sediment loss during the process. Given that currently no schedule of dredging works exist, it is assumed that at three different locations of the island ring (i.e. north, south and east side) near the water surface overflow pipes are located which alternate in a consecutive manner. In order to implement this source in the TELEMAC-3D model, a block profile is used (see section 2.2.3) with 50% of the discharged material in the top 2 m of the water column. The other 50% is put between the first 2 m beneath the water surface and 5 m above the sea bed. This block profile distribution differs from the TSHD overflow plume distribution, since the former is a static overflow and because the concentrations coming from the spill of the island ring are low, meaning that the downward motion of sediment due to density currents will be slow. The properties of the assumed THSD, island overflow and the sediment settings are shown for the three simulated cases of the West 1, West 2 and Noord locations in Table 3-4 till

Table 3-6. Figures of the resulting sediment sources in the TELEMAC-3D plume model are shown in appendix section A.3.

Table 3-4 TSHD pre-dredging West 1 dredging properties

Properties	Value
Dredging volume	2.82 [M m³]
In situ density for TSHD productions	1.9 [t/m³]
Bulking percentage	10% (situ – in pipe)
Percentage of fines	20% (< 250 [µm]) , 0.2% (< 63 [µm])
Grain size (d_{50}) of fraction fine sand in TELEMAC	201 [µm]. Determined from a computed average PSD near West 1 (Figure 4-5).
Volume of hopper bin	5600 [m³]
Overflow TSHD utilized	No
Diameter of overflow	1700 [mm]
Draught of the hopper (full)	7.1 [m]
Location of overflow at island ring	North, east and south side. Continuously alternated between three locations.
Total duration of dredging works	11 days

Table 3-5 TSHD pre-dredging West 2 dredging properties

Properties	Value
Dredging volume	2.82 [M m³]
In situ density for TSHD productions	1.9 [t/m³]
Bulking percentage	10% (situ – in pipe)
Percentage of fines	20% (< 250 [µm]) , 0.2% (< 63 [µm])
Grain size (d_{50}) of fraction fine sand in TELEMAC	201 [µm] . Determined from a computed average PSD near West 2 (Figure 4-5).
Volume of hopper bin	5600 [m³]
Overflow TSHD utilized	No
Diameter of overflow	1700 [mm]
Draught of the hopper (full)	7.1 [m]
Location of overflow at island ring	North, east and south side. Continuously alternated between three locations.
Total duration of dredging works	11 days

Table 3-6 TSHD pre-dredging Noord dredging properties

Properties	Value
Dredging volume	2.82 [M m³]
In situ density for TSHD productions	1.9 [t/m³]
Bulking percentage	10% (situ – in pipe)
Percentage of fines	21.7% (< 250 [µm]) , 0.1% (< 63 [µm])
Grain size (d_{50}) of fraction fine sand in TELEMAC	209 [µm]. Determined from a computed average PSD near Noord (Figure 4-6).
Volume of hopper bin	5600 [m³]
Overflow TSHD utilized	No
Diameter of overflow	1700 [mm]
Draught of the hopper (full)	7.1 [m]
Location of overflow at island ring	North, east and south side. Continuously alternated between three locations.
Total duration of dredging works	11 days

3.1.2 Cable installation

3.1.2.1 Dredging cable trenches and disposal at a temporary disposal site

In this scenario, three cable sections consisting of four trenches with each a length, width and depth of 1000, 5 and 2 m, respectively (i.e. volume of 4 x 24000 m³]) are dredged. Each scenario has different subsurface sediment properties, which are selected such that the scenarios represent three typical parts of the total power cable track from KP-0 to KP-46 (Figure 3-2).

- Trench section 1:
  - Represents a sandy section (≈ 33% of total track length)
- Trench section 2:
  - Represents a soft to hard clay section (≈ 25% of total track length)
- Trench section 3:
  - Represents a silty section (≈ 42% of total track length)

The dredged sediment is disposed at the temporary disposal site 3 (Figure 1-1). Disposal site 3, located centrally along the export cable trajectory, represents average sailing distances. Given that currently no schedule of dredging works exist, it is assumed that the works will be executed by a single TSHD with a representative barge of 5600 m³. Here, sediment losses that are taken into account are losses at the dredge head, overflow losses (in case of fines <20%) and losses during disposal (see section 2.2.3). The properties of this THSD and the sediment settings are shown in Table 3-7 to Table 3-9. Figures of the resulting sediment sources in the TELEMAC-3D plume model are shown in appendix section A.4.

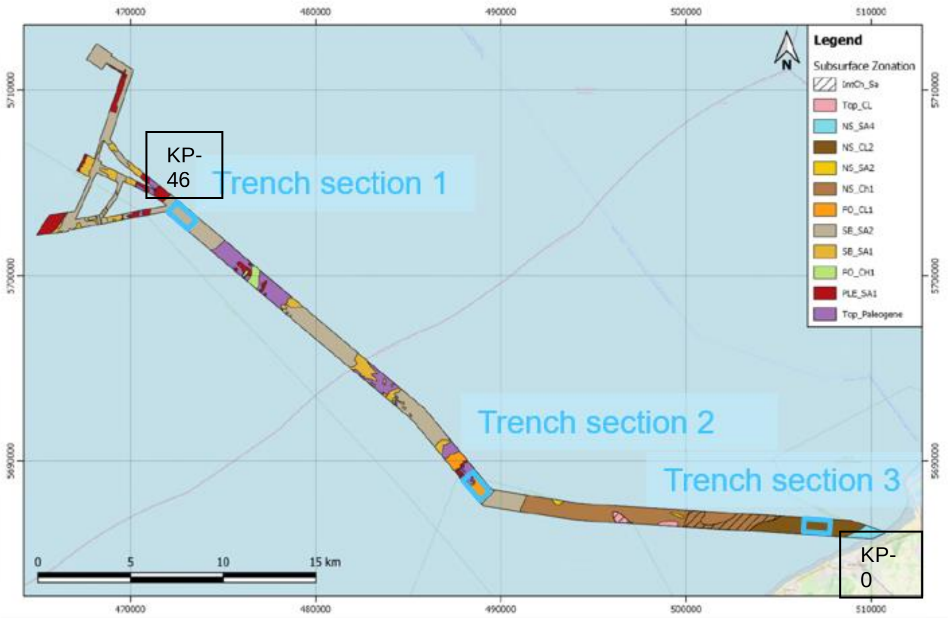


Figure 3-2 Subsurface sediment unitization, adapted from Cathie draft report (2021) along the power cable track and locations of simulated trench sections.

Table 3-7 TSHD pre-dredging trench section 1 dredging properties

Properties	Value
Dredging volume	0.096 [M m³]
In situ density for TSHD productions	1.9 [t/m³]
Bulking percentage	10% (situ – in pipe)
Percentage of fines	21.7% (< 250 [μm]) , 0.03% (< 63 [μm])
Grain size (d_{50}) of fraction fine sand in TELEMAC	209 [μm]. Determined from the PSD of Vibrocore sample 030A (Mathys *et al.*, 2009) near Trench section 1.
Volume of hopper bin	5600 [m³]
Overflow TSHD utilized	Yes
Diameter of overflow	1700 [mm]
Draught of the hopper (full)	7.1 [m]
Time to fill the hopper till overflow	30 minutes
Location of disposal	temporary disposal site 3
Sailing speed	12.3 knots
Disposal time	10 minutes
Total duration of dredging works	2 days

Table 3-8 TSHD pre-dredging trench section 2 dredging properties

Properties	Value
Dredging volume	0.096 [M m³]
In situ density for TSHD productions	1.3 [t/m³]
Bulking percentage	200% (situ – in pipe)
Percentage of fines	100% (< 250 [μm]) , 92% (< 63 [μm])
Grain size (d_{50}) of fraction fine sand in TELEMAC	80 [μm]. Determined from the average of the PSD's of Figure 3-3
Volume of hopper bin	5600 [m³]
Overflow TSHD utilized	No
Diameter of overflow	1700 [mm]

Draught of the hopper (full)	7.1 [m]
Time to fill the hopper till overflow	30 minutes
Location of disposal	temporary disposal site 3
Sailing speed	12.3 knots
Disposal time	10 minutes
Total duration of dredging works	3 days

Table 3-9 TSHD pre-dredging trench section 3 dredging properties

Properties	Value
Dredging volume	0.096 [M m³]
In situ density for TSHD productions	1.3 [t/m³]
Bulking percentage	200% (situ – in pipe)
Percentage of fines	97% (< 250 [μm]) , 85% (< 63 [μm])
Grain size (d_{50}) of fraction fine sand in TELEMAC	160 [μm]. Determined from the average of the PSD's of Figure 4-2.
Volume of hopper bin	5600 [m³]
Overflow TSHD utilized	No
Diameter of overflow	1700 [mm]
Draught of the hopper (full)	7.1 [m]
Time to fill the hopper till overflow	30 minutes
Location of disposal	temporary disposal site 3
Sailing speed	12.3 knots
Disposal time	10 minutes
Total duration of dredging works	6 days

3.2 Operational phase

3.2.1 Plume generation and deposition as a result of natural erosion after island construction

Sediment sources are introduced into the TELEMAC-3D plume model based on the morphological evolution of the scour hole(s) in the direct vicinity of the island (i.e. Figure 3-3), which is modelled by Svašek (Svašek Hydraulics, 2022). Here, only erosion deeper than one meter is taken into account. The spatially averaged erosion rate [m/s] is determined from the time derivative of the total eroded sediment volume (Figure 3-4 and Table 3-10) by dividing it by the area where the erosion is larger than one meter. An exponential function was fit to the curve of the total eroded volume, in order to filter out short time variation. Using this method, local differences in erosion rate are not accounted for. This implies that at some locations inside the scour pit, the erosion rate is overestimated and at other locations it is underestimated. By substituting the erosion rate in the erosion term of the Exner equation, a net erosion term E [kg/(m²·s)] is introduced in TELEMAC at the locations of the scour as follows:

$$E = \rho_s(1-\epsilon)\frac{\partial \eta_{fi}}{\partial t} + w_{si} c_i$$

Here, ρ_s is the sediment density, ϵ denotes the bed porosity, w_{si} and c_i the settling velocity and near bed concentration of fraction i, respectively. The erosion rate of fine sediment fraction i ($\frac{\partial \eta_{fi}}{\partial t}$) is defined as follows:

$$\frac{\partial \eta_{fi}}{\partial t} = \frac{\partial (f_i \eta)}{\partial t}$$

with, f_i the fraction of fine sediment fraction i. The value of η_f is only applied one hour before and after max ebb and max flood velocities, when maximum erosion is expected, and set to zero for the rest of the tidal cycle. and is corrected for the time there is no resuspension within a tidal cycle.

The erosion term E is used further inside TELEMAC to calculate the concentration profile.

Two moments in time are simulated in order to capture the suspended sediment transport for different stages of the scour hole development:

- After 1.0 year (initial scour)
- After 4 years (equilibrium scour)

For the aforementioned periods, simulations will cover a period of a spring-neap cycle. Given that resuspension is included in these operational phase model scenario's (with settings of Table 2-5), a MOFAC of 25 is used to determine yearly sedimentation values of this hydrodynamic spring-neap cycle.

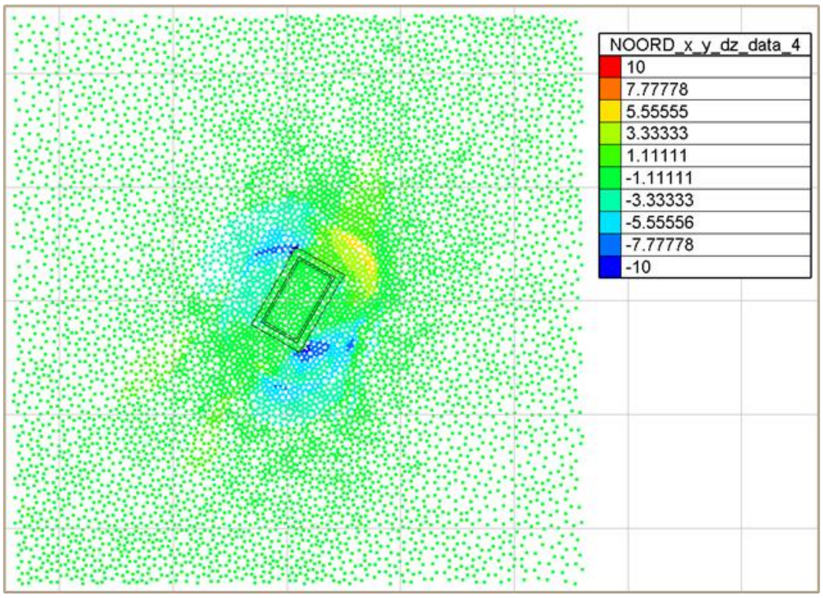


Figure 3-3 Example of a x-y-dz dataset provided by Svašek with simulated bed level differences due to the implementation of the MOG2 island at the Noord location after 4 years.

Table 3-10 Values erosion rate [m/s] for West 1, West 2 and Noord cases obtained from Svašek.

Island location	Initial scour [m/s] at 1.0 years	Equilibrium scour [m/s] at 4 years
West 1	8.4117e-07	4.6603e-08
West 2	8.7807e-07	5.3666e-08
Noord	4.0782e-07	5.0363e-08

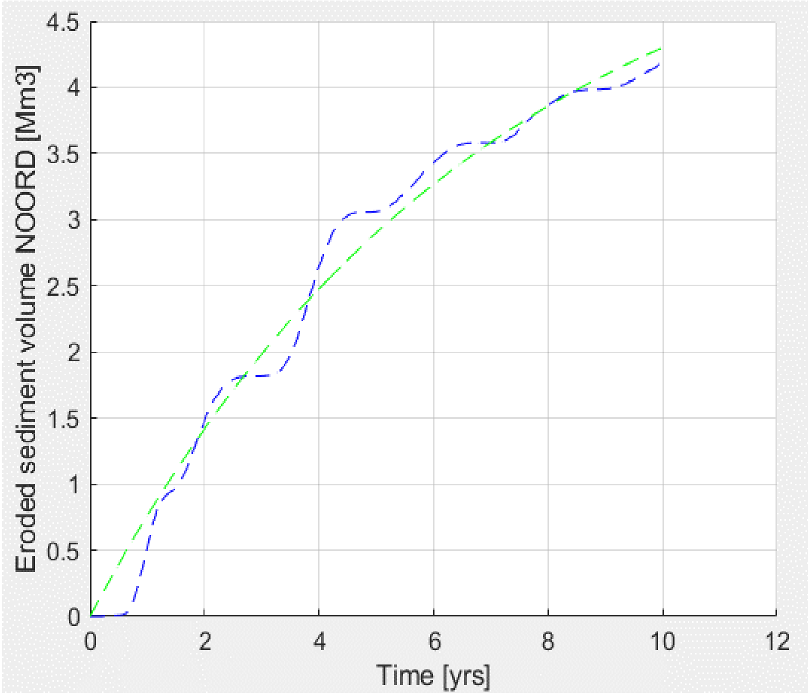


Figure 3-4 Example of total simulated eroded sediment volume due to the implementation of the MOG2 island at the Noord location (blue line) provided by Svašek. The green line shows a fit through the original dataset.

3.2.2 Investigation of effectiveness of pre-scour dredging

For the investigation of the effect of pre-scour dredging of a pre-scour design on the plume generation and deposition of fine material as a result of natural erosion after island construction, a similar scenario as shown in the preceding section has been set-up for the West 1 location. However now two datasets have been provided by Svašek at one year, for a case with pre-scour dredging and one without. The erosion rates for this specific case are read from the actual data and not from the exponential fit, given that this specific dataset did not include the full 10 years and thus has no reliable fit. The resulting erosion rates [m/s] are shown in Table 3-11. Given that after one year, the scour hole for the case without pre-scour design is larger than for the case with pre-scour design, the actual amount of released sediment over the total scour area is largest for the former case. This is opposite to what might be expected from the erosion rates from Table 3-11.

Table 3-11 Values erosion rate [m/s] for West 1 cases obtained from Svašek.

Island location	Initial scour [m/s] at 1 year including pre-scour design	Initial scour [m/s] at 1 year without pre-scour design
West 1	2.3827e-06	2.2543e-06

4 Results

This chapter shows the results of the performed scenario simulations. In order to assess the potential impact of the MOG2 project on the background turbidity and sedimentation of fine sediment, the following maps have been generated:

- Maps showing maximal encountered depth averaged sediment concentration [mg/L] of fine material (< 250 µm) during the simulation period.
- Maps showing maximal encountered sedimentation [mm] of fine material (< 250 µm) during the simulation period.

Both maps show maximal values per grid cell that can have occurred at different moments during the simulation period. It are not screenshot of time. For both the sediment concentration and sedimentation maps, results of the two simulated fractions (i.e. fines (< 63 µm) and fine sand (between 63 and 250 µm)) are added up to provide for each output variable an overall map. The resulting material is hereafter called "fine material" (all sediments small than 250 µm).

4.1 Construction phase

4.1.1 Island construction

4.1.1.1 Scenario 1: levelling sand ridges and disposal at a temporary disposal site

Filled contours in Figure 4-1 show the maximal depth averaged sediment concentration of fine material (< 250 µm) during the simulation period, in which dredging activities related to sand ridge leveling at the West 1 location have been taking place. From the extent of these contours, it becomes evident that a surpassing of the background turbidity of 4 mg/L occurs only in the direct vicinity of the West 1 location and the temporary disposal site (Stockage1). In case of the latter site, maximal values can exceed 50 mg/L. The total area where certain levels of depth averaged concentrations are exceeded, are shown in Table 4-1. The extent of the plume from the dredging site is up to 500 m, whereas it reaches up to 3 km from the disposal site.

Table 4-1 Total area of exceeding depth averaged concentrations in 1000 × [m²]. Scenario 1: levelling sand ridges and disposal at a temporary disposal site (island location West 1).

Depth averaged concentrations (c) of fine material [mg/L]	Total area (1000 × [m²])
c ≥ 4 [mg/L]	3.456
c ≥ 10 [mg/L]	1.989
c ≥ 25 [mg/L]	1.068
c ≥ 50 [mg/L]	582

The maximal sedimentation of fine material (< 250 µm) that occurs in this scenario (Figure 4-2) is, constrained to both the dredging site and disposal location. At the latter location, a sedimentation contour of 0.01 m extends up to 2 km from the temporary disposal site. The figure shows furthermore that there is no exceedance of 0.01 m sedimentation over the gravel beds. Deposition areas for multiple fine sediment thickness contours are provided in Table 4-2.

Table 4-2 Total area of deposition in 1000 × [m²] for different sediment thickness contours. Scenario 1: levelling sand ridges and disposal at a temporary disposal site (island location West 1).

Sediment thickness (d) of fine material [mm]	Deposition area (1000 × [m²])
d ≥ 10 [mm]	63
d ≥ 25 [mm]	6
d ≥ 50 [mm]	0

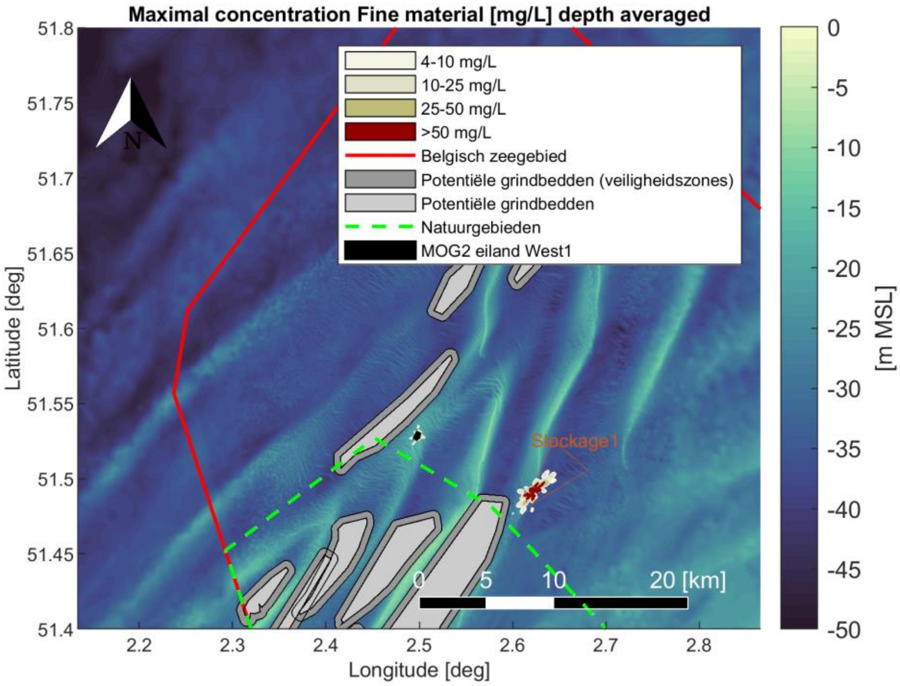


Figure 4-1 Maximal encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during the simulation period Scenario 1: levelling sand ridges and disposal at a temporary disposal site (island location West 1).

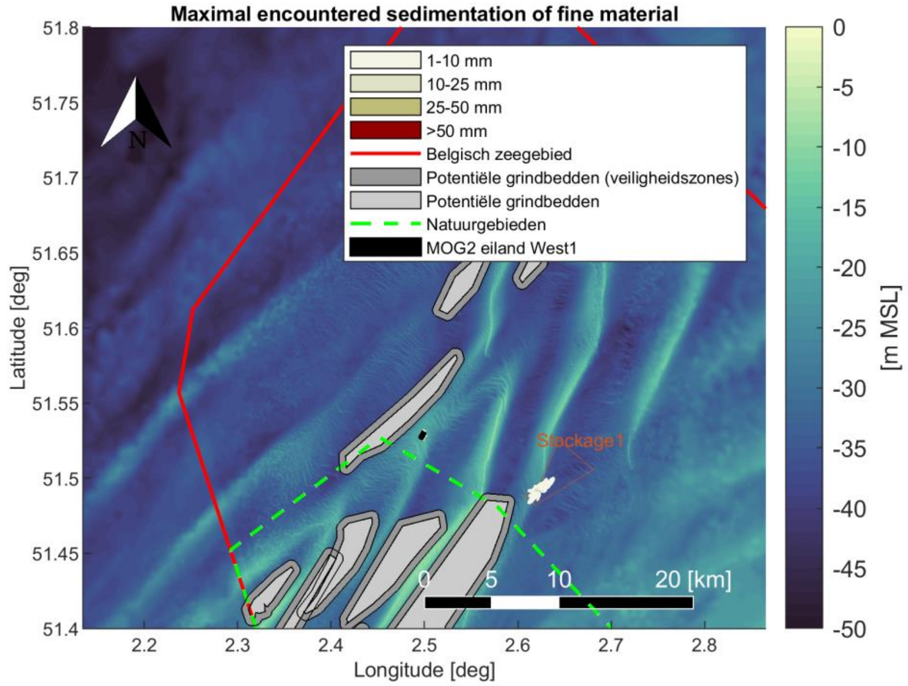


Figure 4-2 Maximal encountered sedimentation [mm] of fine material (< 250 [µm]) during the simulation period. Scenario 1: levelling sand ridges and disposal at a temporary disposal site (island location West 1).

4.1.1.2 Scenario 2: pre-dredging scour holes and creation of sand plateau

Filled contours in Figure 4-3 show the maximal encountered depth averaged sediment concentration of fine material (< 250 µm) during the simulation period in which dredging activities related to pre-dredging of scour holes and disposing on the West 2 island site have been taking place. From the extent of these contours it becomes evident that a surpassing of the background turbidity of 4 mg/L occurs only in the direct vicinity of the West 2 location (within 3 km).The total areas where certain levels of depth averaged concentrations are exceeded, are shown in Table 4-3.

Table 4-3 Total area of exceeding depth averaged concentrations in 1000 × [m²]. Scenario 2: pre-dredging scour holes and creation of sand plateau at the island location West2.

Depth averaged concentrations (c) of fine material [mg/L]	Total area (1000 × [m²])
c ≥ 4 [mg/L]	3.107
c ≥ 10 [mg/L]	1.942
c ≥ 25 [mg/L]	1.260
c ≥ 50 [mg/L]	846

The maximal sedimentation of fine material (< 250 µm) that occurs in this scenario (Figure 4-4) is, , constrained to the island location. The sedimentation contour of 0.01 m extends up to 2 km from the island location. The figure shows furthermore that there is no exceedance of 0.01 m sedimentation over the gravel beds. Deposition areas for multiple fine sediment thickness contours are provided in Table 4-4.

Table 4-4 Total area of deposition in 1000 × [m²] for different sediment thickness contours. Scenario 2: pre-dredging scour holes and creation of sand plateau at the island location West2.

Sediment thickness (d) of fine material [mm]	Deposition area (1000 × [m²])
d ≥ 10 [mm]	954
d ≥ 25 [mm]	605
d ≥ 50 [mm]	310

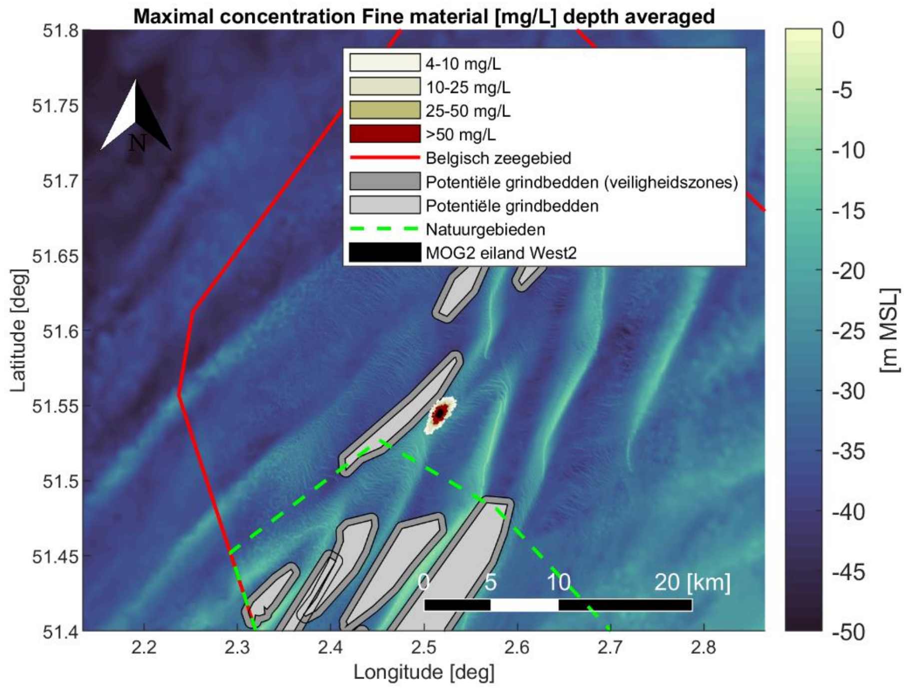


Figure 4-3 Maximal encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during the simulation period. Scenario: Plume generation while pre-dredging scour holes and ridges and disposing dredged material at the island location West 2.

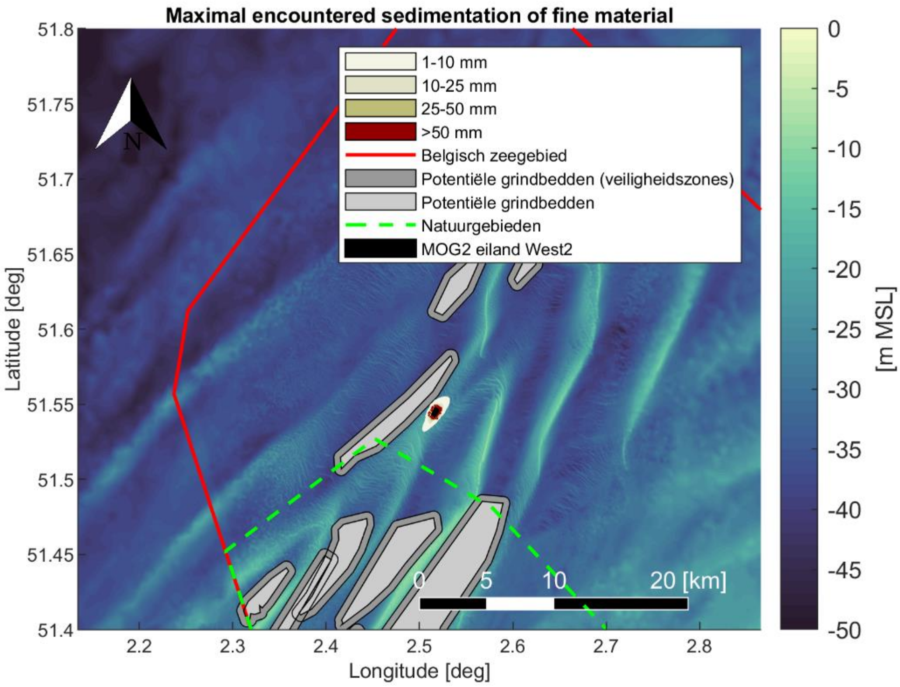


Figure 4-4 Maximal encountered sedimentation [mm] of fine material (< 250 [µm]) during the simulation period. Scenario 2: pre-dredging scour holes and creation of sand plateau at the island location West2.

Filled contours in Figure 4-5 show the maximal encountered depth averaged sediment concentration of fine material (< 250 µm) during the three day simulation period in which dredging activities related to pre-dredging of scour holes and disposing on the Noord island site have been taking place. From the extent of these contours it becomes evident that a surpassing of the background turbidity of 4 mg/L occurs only in the direct vicinity of the Noord location (within 3 km). The total areas where certain levels of depth averaged concentrations are exceeded, are shown in Table 4-5.

Table 4-5 Total area of exceeding depth averaged concentrations in 1000 × [m²] Scenario 2: pre-dredging scour holes and creation of sand plateau at the island location Noord.

Depth averaged concentrations (c) of fine material [mg/L]	Total area (1000 × [m²])
c ≥ 4 [mg/L]	2.916
c ≥ 10 [mg/L]	1.826
c ≥ 25 [mg/L]	1.240
c ≥ 50 [mg/L]	905

The maximal sedimentation of fine material (< 250 µm) that occurs in this scenario (Figure 4-6) is constrained to the island location. The sedimentation contour of 0.01 m extends up to 2 km from the island location. The figure shows furthermore that there is no exceedance of 0.01 m sedimentation over the gravel beds. Deposition areas for multiple fine sediment thickness contours are provided in Table 4-6.

Table 4-6 Total area of deposition in 1000 × [m²] for different sediment thickness contours. Scenario 2: pre-dredging scour holes and creation of sand plateau at the island location Noord.

Sediment thickness (d) of fine material [mm]	Deposition area (1000 × [m²])
d ≥ 10 [mm]	849
d ≥ 25 [mm]	438
d ≥ 50 [mm]	102

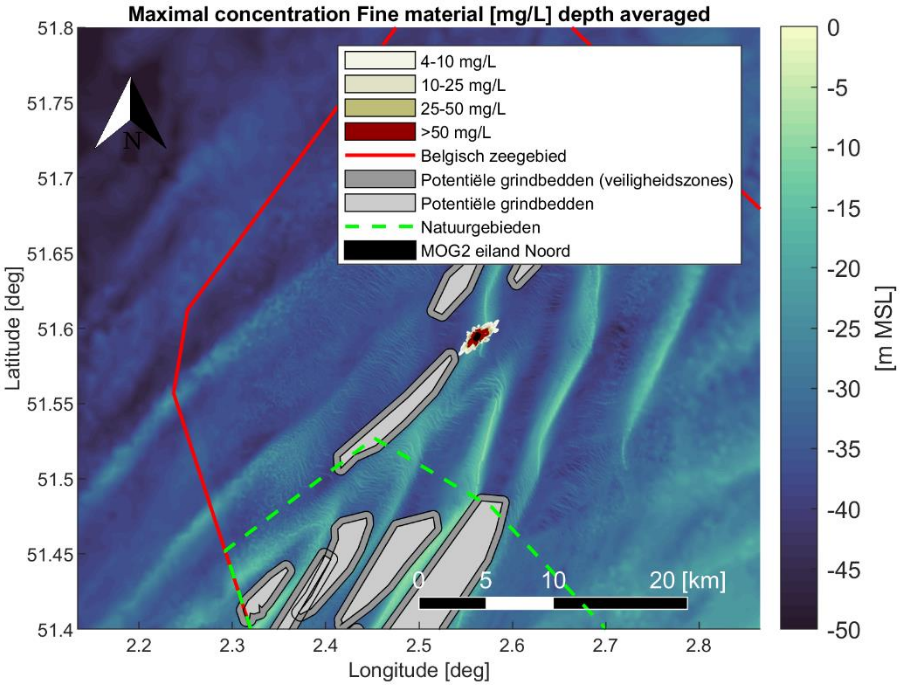


Figure 4-5 Maximal encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during the simulation period. Scenario 2: pre-dredging scour holes and creation of sand plateau at the island location Noord.

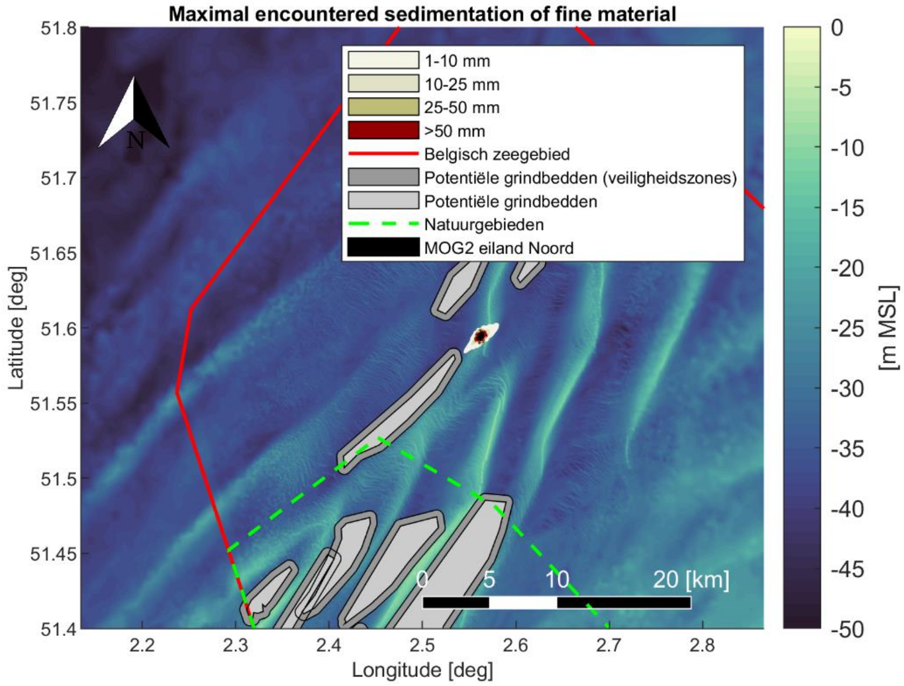


Figure 4-6 Maximal encountered sedimentation [mm] of fine material (< 250 [μm]) during the simulation period. Scenario 2: pre-dredging scour holes and creation of sand plateau at the island location Noord.

4.1.1.3 Scenario 3: pre-dredging scour holes and filling the island ring

Filled contours in Figure 4-7 show the maximal depth averaged sediment concentration of fine material (< 250 μm) during the simulation period in which dredging activities related to pre-dredging of scour holes and overflow through the island ring at the West 1 site have been taking place. From the extend of these contours it becomes evident that a surpassing of the background turbidity of 4 mg/L occurs only in the direct vicinity of the West 1 location within only several hundreds of meters. This can be explained by the fact that there is only a draghead loss near the bed, but no overflow losses from the dredging vessel, and that the overflow concentrations of the water going out of the island ring are significantly lower than overflow concentrations of a barge, due to its larger area. The total areas where certain levels of depth averaged concentrations are exceeded, are shown in Table 4-7.

Table 4-7 Total area of exceeding depth averaged concentrations in 1000 × [m²]. Scenario 3: pre-dredging scour holes and filling the West 1 island ring.

Depth averaged concentrations (c) of fine material [mg/L]	Total area (1000 × [m²])
c ≥ 4 [mg/L]	1.206
c ≥ 10 [mg/L]	1.150
c ≥ 25 [mg/L]	243
c ≥ 50 [mg/L]	76

The maximal sedimentation of fine material (< 250 μm) that occurs in this scenario (Figure 4-8) is constrained to the island location. The sedimentation contour of 0.01 m extends up to only a couple of hundreds of meters the island location. The figure shows furthermore that there is no exceedance of 0.01 m sedimentation over the gravel beds. Deposition areas for multiple fine sediment thickness contours are provided in Table 4-8.

Table 4-8 Total area of deposition in 1000 × [m²] for different sediment thickness contours. Scenario 3: pre-dredging scour holes and filling the West 1 island ring.

Sediment thickness (d) of fine material [mm]	Deposition area (1000 × [m²])
d ≥ 10 [mm]	90
d ≥ 25 [mm]	9
d ≥ 50 [mm]	1

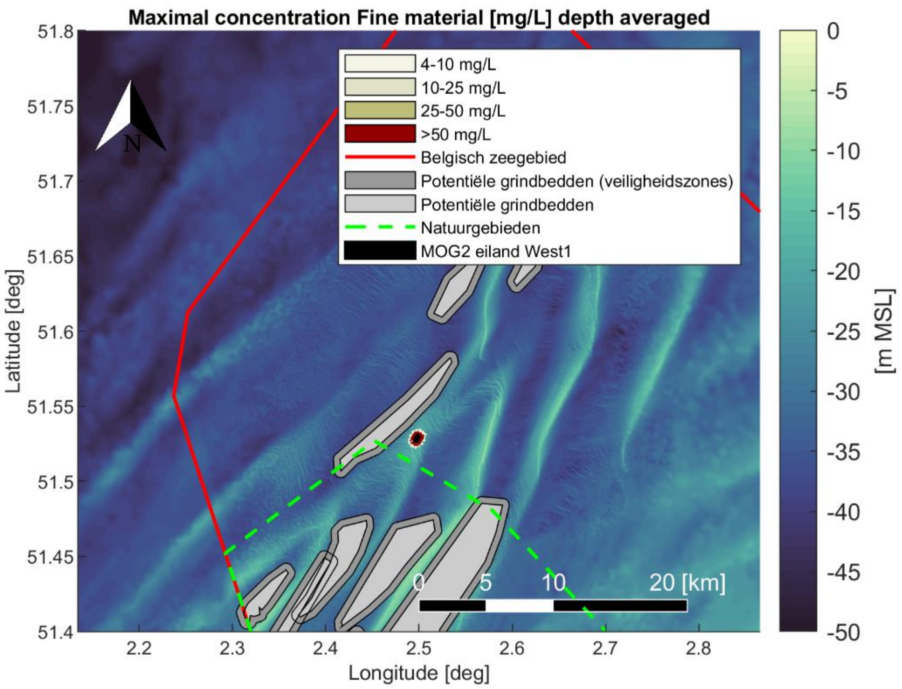


Figure 4-7 Maximal encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [μm]) during the simulation period. Scenario 3: pre-dredging scour holes and filling the West 1 island ring.

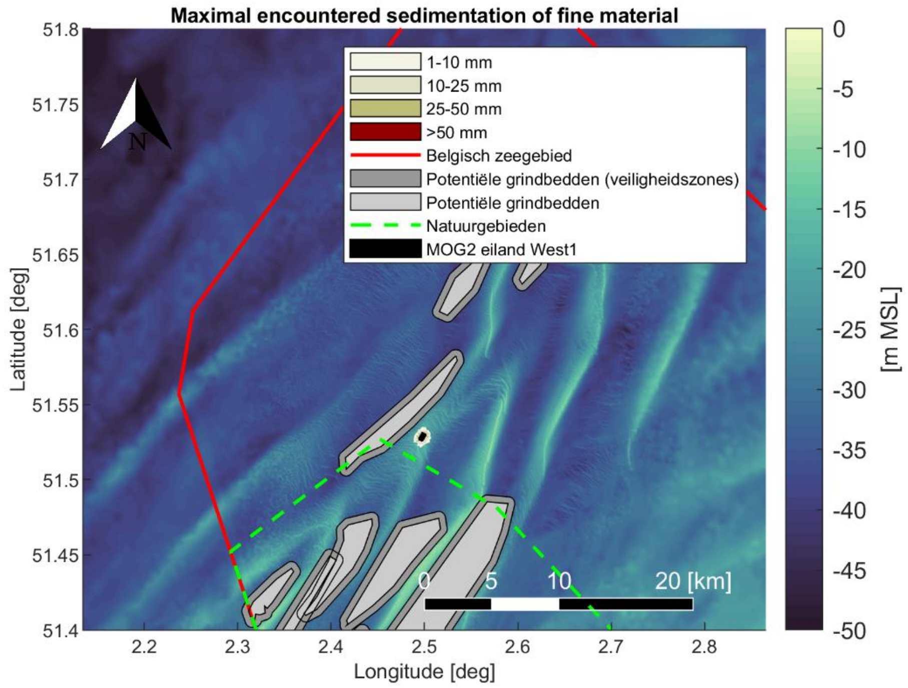


Figure 4-8 Maximal encountered sedimentation [mm] of fine material (< 250 [μm]) during the simulation period. Scenario 3: pre-dredging scour holes and filling the West 1 island ring.

Filled contours in Figure 4-9 show the maximal encountered depth averaged sediment concentration of fine material (< 250 μm) during the simulation period in which dredging activities related to pre-dredging of scour holes and overflow through the island ring at the West 2 site have been taking place. From the extent of these contours it becomes evident that a surpassing of the background turbidity of 4 mg/L occurs only in the direct vicinity of the West 2 location within several hundreds of meters. This can be explained by the fact that there is only a draghead loss near the bed, but no overflow losses from the dredging vessel, and that the overflow concentrations of the water going out of the island ring are significantly lower than overflow concentrations of a barge, due to its larger area. The total areas where certain levels of depth averaged concentrations are exceeded, are shown in Table 4-9.

Table 4-9 Total area of exceeding depth averaged concentrations in 1000 × [m²]. Scenario 3: pre-dredging scour holes and filling the West 2 island ring.

Depth averaged concentrations (c) of fine material [mg/L]	Total area (1000 × [m²])
c ≥ 4 [mg/L]	1.274
c ≥ 10 [mg/L]	1.092
c ≥ 25 [mg/L]	205
c ≥ 50 [mg/L]	61

The maximal sedimentation of fine material (< 250 μm) that occurs in this scenario (Figure 4-10) is constrained to the island location. The sedimentation contour of 0.01 m extends up to only a couple of hundreds of meters the island location. The figure shows furthermore that there is no exceedance of 0.01 m sedimentation over the gravel beds. Deposition areas for multiple fine sediment thickness contours are provided in Table 4-10.

Table 4-10 Total area of deposition in 1000 × [m²] for different sediment thickness contours. Scenario 3: pre-dredging scour holes and filling the West 2 island ring.

Sediment thickness (d) of fine material [mm]	Deposition area (1000 × [m²])
d ≥ 10 [mm]	74
d ≥ 25 [mm]	5
d ≥ 50 [mm]	0,4

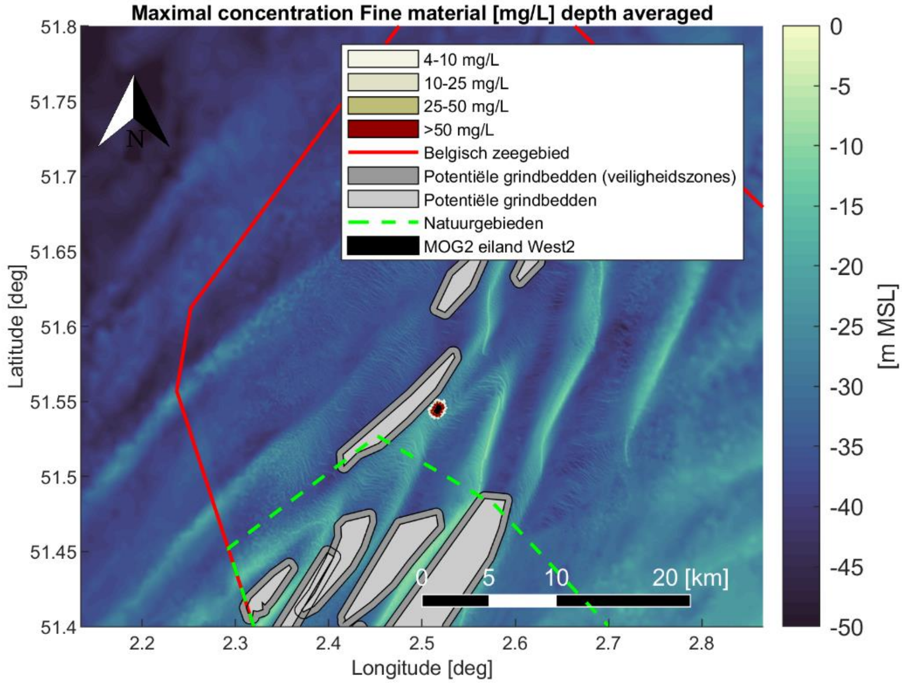


Figure 4-9 Maximal encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during the simulation period. Scenario 3: pre-dredging scour holes and filling the West 2 island ring.

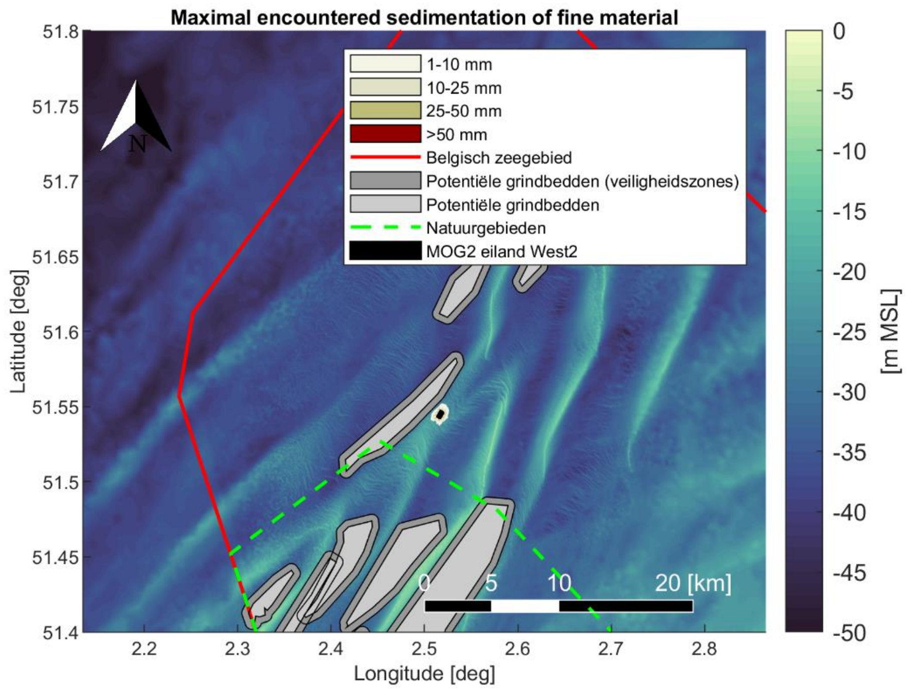


Figure 4-10 Maximal encountered sedimentation [mm] of fine material (< 250 [µm]) during the simulation period. Scenario 3: pre-dredging scour holes and filling the West 2 island ring.

Filled contours in Figure 4-11 show the maximal depth averaged sediment concentration of fine material (< 250 µm) during the simulation period in which dredging activities related to pre-dredging of scour holes and overflow through the island ring at the Noord site have been taking place. From the extent of these contours it becomes evident that a surpassing of the background turbidity of 4 mg/L occurs only in the direct vicinity of the Noord location within several hundreds of meters. This can be explained by the fact that there is only a draghead loss near the bed, but no overflow losses from the dredging vessel, and that the overflow concentrations of the water going out of the island ring are significantly lower than overflow concentrations of a barge, due to its larger area. The total areas where certain levels of depth averaged concentrations are exceeded, are shown in Table 4-11.

Table 4-11 Total area of exceeding depth averaged concentrations in 1000 × [m^2]. Scenario 3: pre-dredging scour holes and filling the Noord island ring.

Depth averaged concentrations (c) of fine material [mg/L]	Total area (1000 × [m^2])
c ≥ 4 [mg/L]	1.244
c ≥ 10 [mg/L]	1.103
c ≥ 25 [mg/L]	231
c ≥ 50 [mg/L]	66

The maximal sedimentation of fine material (< 250 [µm]) that occurs in this scenario (Figure 4-12) is constrained to the island location. The sedimentation contour of 0.01 [m] extends up to only a couple of hundreds of meters the island location. The figure shows furthermore that there is no exceedance of 0.01 m sedimentation over the gravel beds. Deposition areas for multiple fine sediment thickness contours are provided in Table 4-12.

Table 4-12 Total area of deposition in 1000 × [m²] for different sediment thickness contours. Scenario 3: pre-dredging scour holes and filling the Noord island ring.

Sediment thickness (d) of fine material [mm]	Deposition area (1000 × [m²])
d ≥ 10 [mm]	81
d ≥ 25 [mm]	4
d ≥ 50 [mm]	0,3

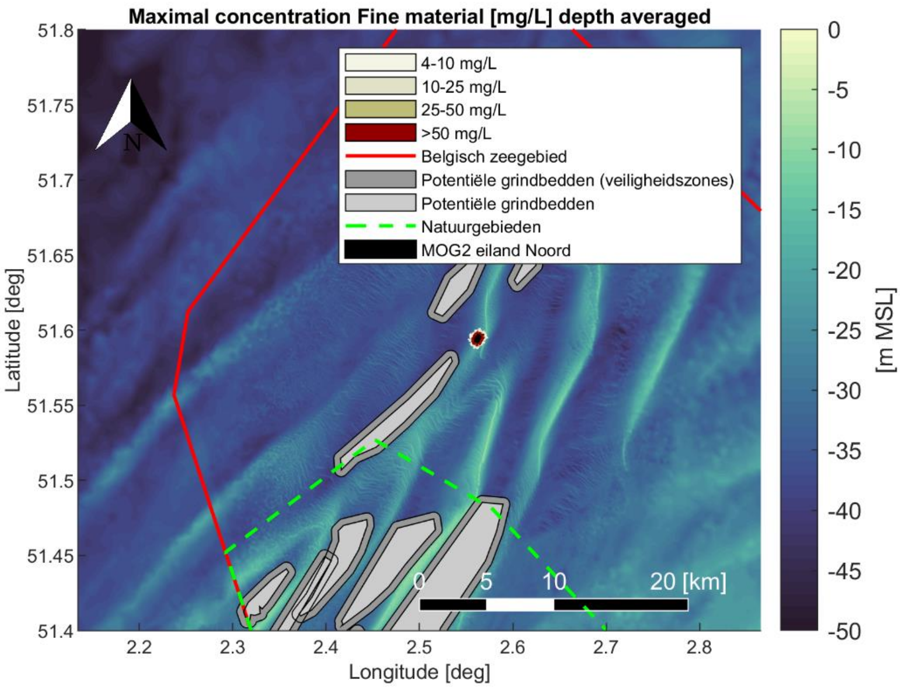


Figure 4-11 Maximal encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during the simulation period. Scenario 3: pre-dredging scour holes and filling the Noord island ring.

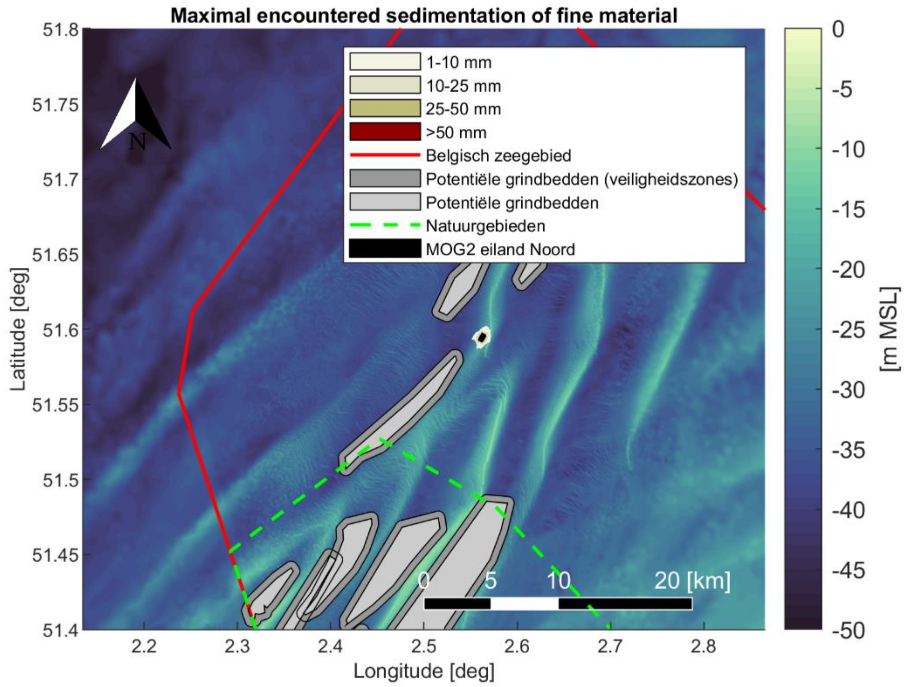


Figure 4-12 Maximal encountered sedimentation [mm] of fine material (< 250 [µm]) during the simulation period. Scenario 3: pre-dredging scour holes and filling the Noord island ring.

4.1.2 Cable installation

4.1.2.1 Dredging cable trenches and disposal at a temporary disposal site

Section 1

Filled contours in Figure 4-13 show the maximal depth averaged sediment concentration of fine material (< 250 µm) during the simulation period in which dredging activities related to dredging trenches for the power cables at section 1 and disposing dredged material at a temporary disposal site (Stockage site 3) took place. From the extent of these contours, it becomes evident that a surpassing of the background turbidity of 4 mg/L occurs only in the direct vicinity of the trench1 location within several hundreds of meters. When viewing the contours at temporary disposal site Stocakge3, it is visible that here the background turbidity surpasses 50 mg/L only within one kilometer of the disposal site. The total areas where certain levels of depth averaged concentrations are exceeded, are shown in Table 4-13.

Table 4-13 Total area of exceeding depth averaged concentrations in 1000 × [m²]. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

Depth averaged concentrations (c) of fine material [mg/L]	Total area (1000 × [m²])
c ≥ 4 [mg/L]	1.633
c ≥ 10 [mg/L]	942
c ≥ 25 [mg/L]	503
c ≥ 50 [mg/L]	331

The maximal sedimentation of fine material (< 250 µm) that occurs in this scenario (Figure 4-14) is constrained to the dredge and disposal locations. The sedimentation contour due to the dredging works at the trench1 location shows only values of 0.01 m within a couple of hundreds of meters of the dredging site. In case of the disposal of the dredged sediment, contours show an exceedance of 0.01 m within 2 km. The figure shows furthermore that there is no exceedance of 0.01 m sedimentation over the gravel beds. Deposition areas for fine multiple sediment thickness contours are provided in Table 4-14.

Table 4-14 Total area of deposition in 1000 × [m²] for different sediment thickness contours. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

Sediment thickness (d) of fine material [mm]	Deposition area (1000 × [m²])
d ≥ 10 [mm]	108
d ≥ 25 [mm]	27
d ≥ 50 [mm]	0

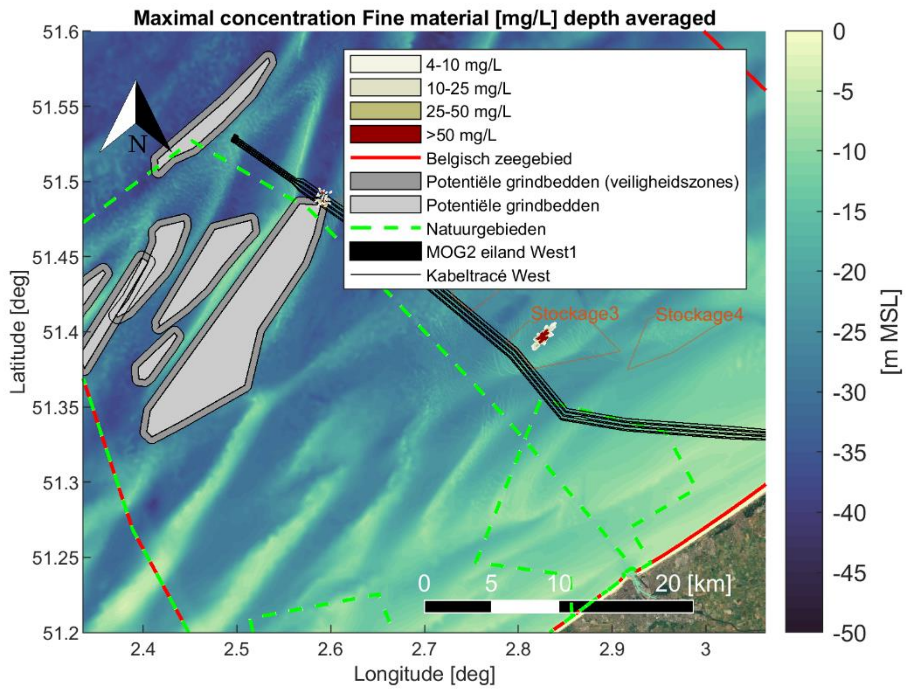


Figure 4-13 Maximal depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

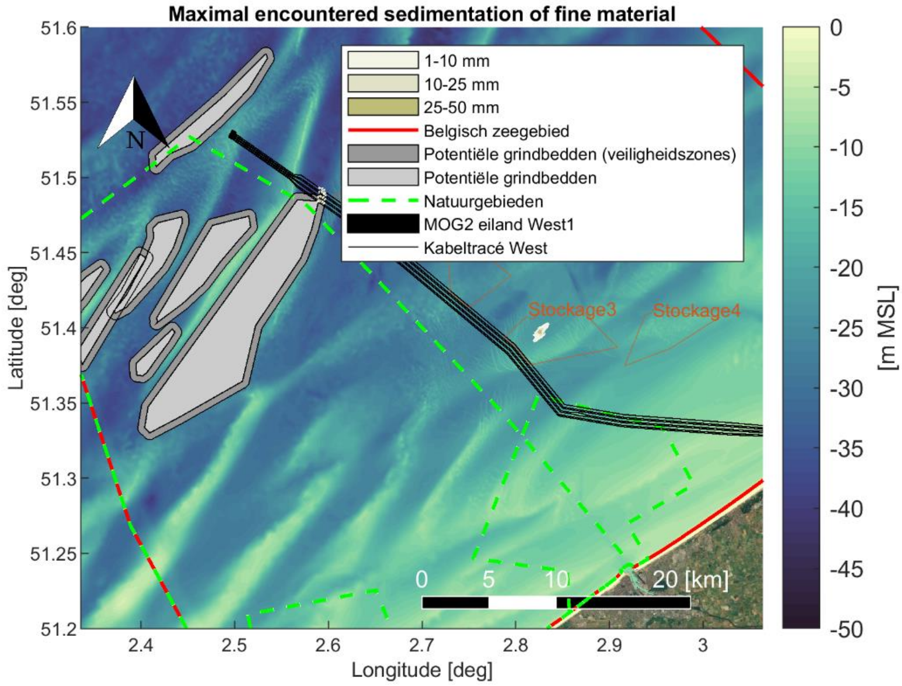


Figure 4-14 Maximal sedimentation [mm] of fine material (< 250 [μm]) during the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

Section 2

Filled contours in Figure 4-15 show the maximal depth averaged sediment concentration of fine material (< 250 μm) during the simulation period in which dredging activities related to dredging trenches for the power cables at section 2 and disposing dredged material at a temporary disposal site (Stockage3) took place. From the extent of these contours, it becomes evident that a surpassing of the background turbidity of 50 mg/L occurs only in the direct vicinity of the trench2 location within several hundreds of meters. When viewing the contours at temporary disposal site 3, it is visible that the background turbidity surpasses 50 mg/L up to five kilometers from the disposal site. This is significantly larger than the plume extent of the dredged sediment from the trench1 section and can be attributed to the large percentage of fines (d_{50}< 63 μm) at the trench2 site. The 'ray-like' character of the contours is related to the intermittent sources from disposal, in combination with different flow directions, during a relatively limited time. The total areas where certain levels of depth averaged concentrations are exceeded, are shown in Table 4-15.

Table 4-15 Total area of exceeding depth averaged concentrations in 1000 × [m²]. Scenario: Dredging cable trenches (trench 2 section) and disposal at a temporary disposal site (Stockage3).

Depth averaged concentrations (c) of fine material [mg/L]	Total area (1000 × [m²])
c ≥ 4 [mg/L]	71.610
c ≥ 10 [mg/L]	29.320
c ≥ 25 [mg/L]	8.989
c ≥ 50 [mg/L]	3.157

The footprint of the sedimentation of fine material (< 250 µm) in this scenario (Figure 4-16) is smaller than the plume extent and is merely constrained to the dredging and disposal locations. In case of the disposal location, contours show an exceedance of 0.01 m within 2 km. The figure shows furthermore that there is no exceedance of 0.01 m sedimentation over the gravel beds. Deposition areas for multiple fine sediment thickness contours are provided in Table 4-16. It shows that there is no area with a thickness larger than 0.01 m.

Table 4-16 Total area of deposition in 1000 × [m²] for different sediment thickness contours. Scenario: Dredging cable trenches (trench 2 section) and disposal at a temporary disposal site (Stockage3).

Sediment thickness (d) of fine material [mm]	Deposition area (1000 × [m²])
d ≥ 10 [mm]	0
d ≥ 25 [mm]	0
d ≥ 50 [mm]	0

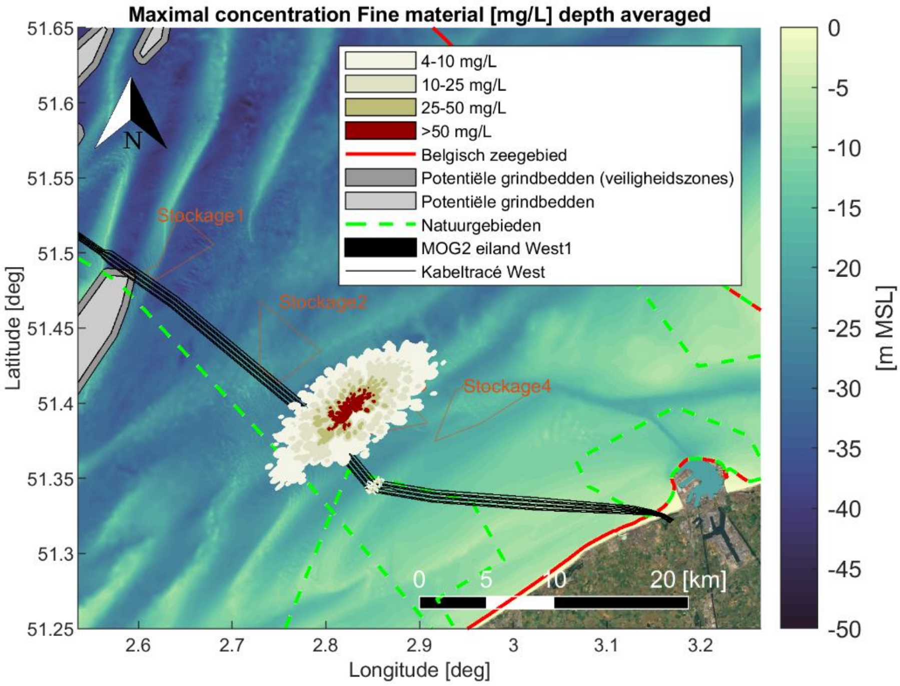


Figure 4-15 Maximal depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during the simulation period. Scenario: Dredging cable trenches (trench 2 section) and disposal at a temporary disposal site (Stockage3).

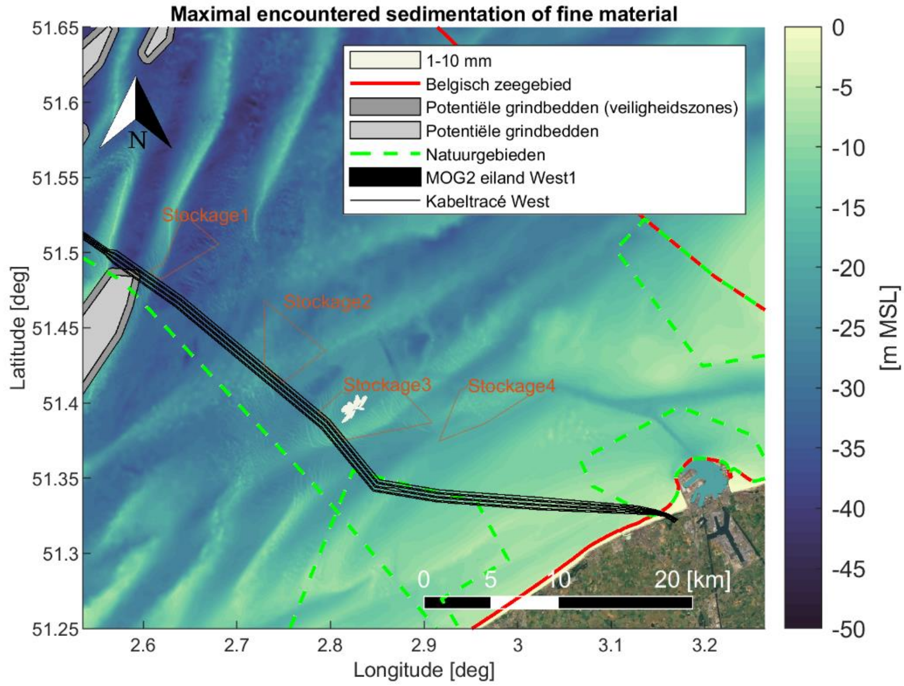


Figure 4-16 Maximal sedimentation [mm] of fine material (< 250 [µm]) during the simulation period. Scenario: Dredging cable trenches (trench 2 section) and disposal at a temporary disposal site (Stockage3).

Section 3

Filled contours in Figure 4-17 show the maximal depth averaged sediment concentration of fine material (< 250 µm) during the simulation period in which dredging activities related to dredging trenches for the power cables at section 3 and disposing dredged material at a temporary disposal site (Stockage3) took place. From the extent of these contours, it becomes evident that the background turbidity surpasses 50 mg/L only in the direct vicinity of the trench3 location within several hundreds of meters. When viewing the contours at temporary disposal site 3, it is visible that the background turbidity surpasses 50 mg/L up to five kilometers from the disposal site. This is similar to the plume extent of the dredged sediment from the trench2 section and can be attributed to the large percentage of fines (d_{50}< 63 µm) at the trench3 site. The total areas where certain levels of depth averaged concentrations are exceeded, are shown in Table 4-17. Timeseries of the maximal sediment concentration [mg/L] of fine sediment at the temporary disposal site 3 are shown in Figure 4-19 and Figure 4-20. From these it can be concluded that peak concentrations drop to quasi-zero within an hour, without showing a gradual buildup of concentration over time. An animation (series of figures with consecutive moments in time) of the first simulated day is shown in Annex A.

Table 4-17 Total area of exceeding depth averaged concentrations in 1000 × [m²]. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

Depth averaged concentrations (c) of fine material [mg/L]	Total area (1000 × [m²])
c ≥ 4 [mg/L]	62.484
c ≥ 10 [mg/L]	26.320
c ≥ 25 [mg/L]	8.385
c ≥ 50 [mg/L]	2.881

The footprint of the sedimentation of fine material (< 250 µm) that occurs in this scenario (Figure 4-18) is smaller than the plume extend and is merely constrained to the dredging and disposal locations. In case of the disposal location, contours show only an exceedance of 0.01 m within 2 km. The figure shows furthermore that there is no exceedance of 0.01 m sedimentation over the gravel beds. Deposition areas for multiple fine sediment thickness contours are provided in Table 4-18. It shows that there is no area with a thickness larger than 0.01 [m].

Table 4-18 Total area of deposition in 1000 × [m²] for different sediment thickness contours. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

Sediment thickness (d) of fine material [mm]	Deposition area (1000 × [m²])
d ≥ 10 [mm]	0
d ≥ 25 [mm]	0
d ≥ 50 [mm]	0

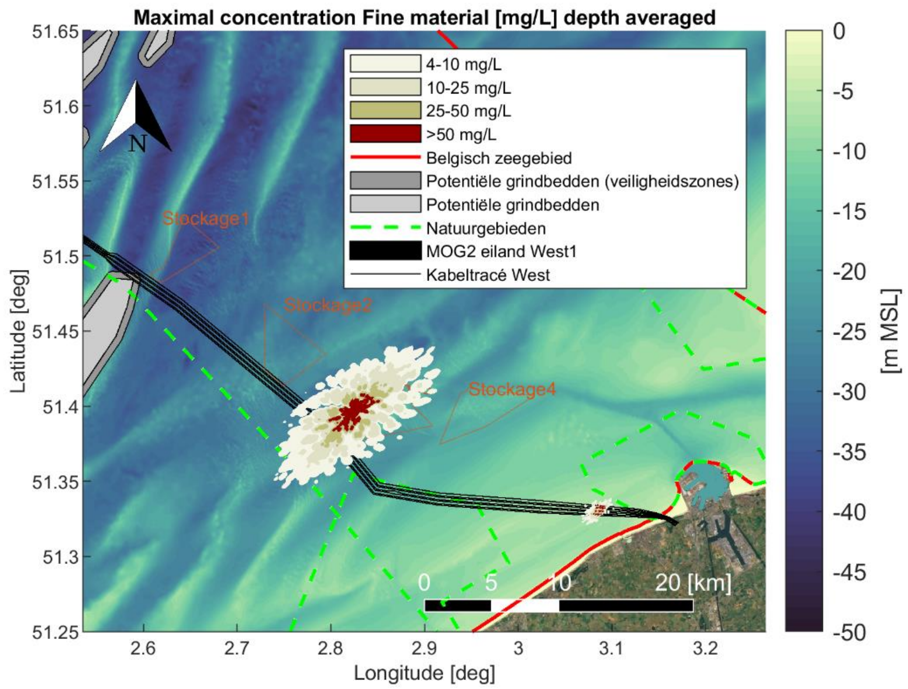


Figure 4-17 Maximal encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during the simulation period. Scenario: Dredging cable trenches (trench 3 section) and disposal at a temporary disposal site (Stockage3).

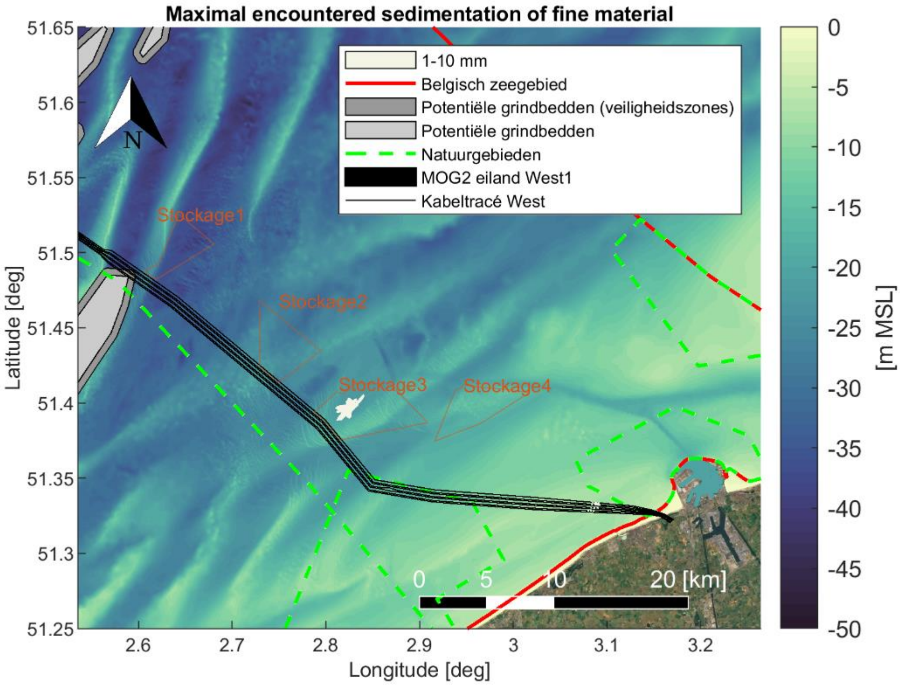


Figure 4-18 Maximal sedimentation [mm] of fine material (< 250 [µm]) during the simulation period. Scenario: Dredging cable trenches (trench 3 section) and disposal at a temporary disposal site (Stockage3).

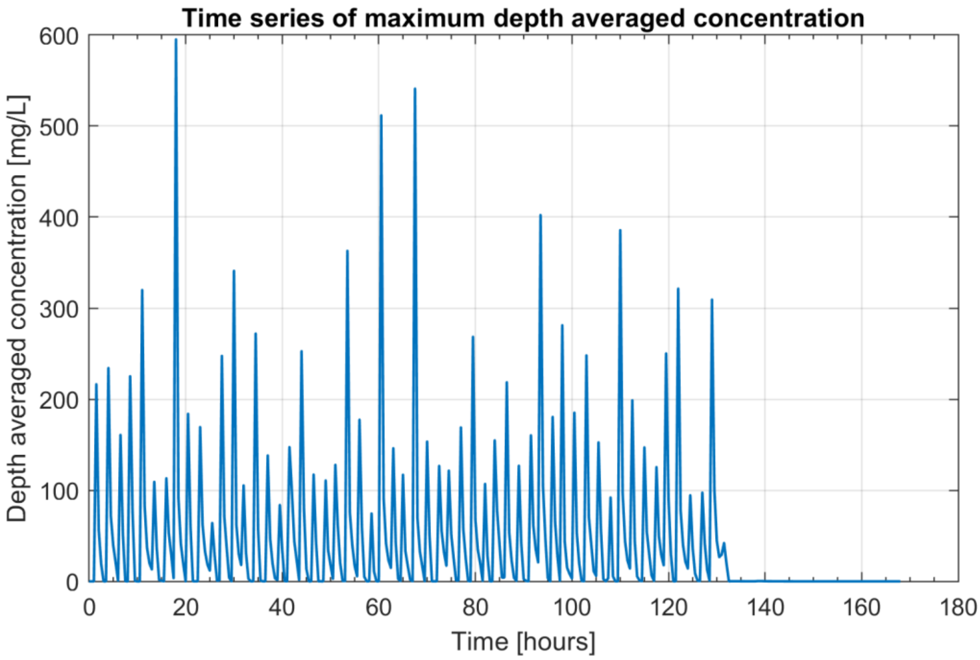


Figure 4-19 Time series of maximal sediment concentration [mg/L] of fine sediment at the temporary disposal site 3, using half-hourly model output.

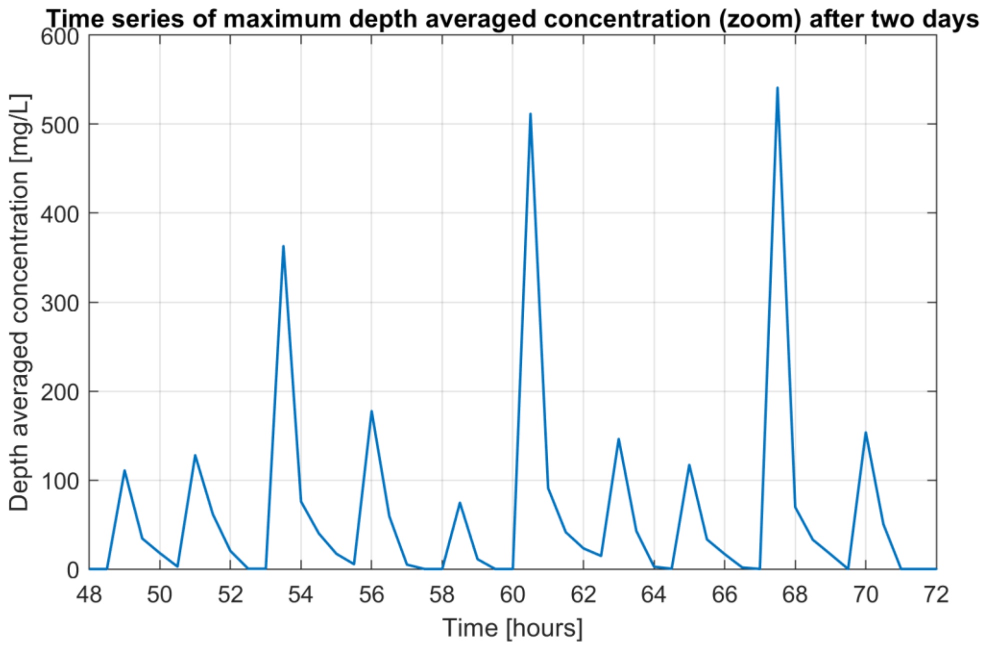


Figure 4-20 Time series of maximal sediment concentration [mg/L] of fine sediment at the temporary disposal site 3, using half-hourly model output. Zoom-in of 24 hours after two simulation days.

4.2 Operational phase

4.2.1 Plume generation and deposition as a result of natural erosion after island construction

4.2.1.1 West 1

Filled contours in Figure 4-21 and Figure 4-23 show the maximal sedimentation of fine material (< 250 µm) in one year time as a result of erosion and natural resuspension of fine sediment in the scour holes (as explained in section 3.2.1) surrounding the West1 island for the 'after one year' and 'after four year' cases, respectively. The contours show that for both the one year and four year cases, there is no exceedance of 0.01 m sedimentation within the gravel bed polygons. Deposition areas for multiple fine sediment thickness contours are provided for the one year and four year cases in Table 4-19 and Table 4-20, respectively.

Table 4-19 Total area of deposition in 1000 × [m²] for different sediment thickness contours. Scenario: Plume generation and deposition as a result of natural erosion in one year time after West 1 island construction, after one year case.

Sediment thickness (d) of fine material [mm]	Deposition area (1000 × [m²])	Deposition area (1000 × [m²]) inside gravel bed polygons	Deposition area (1000 × [m²]) inside Natura2000 zone
d ≥ 10 [mm]	1.332	0	0
d ≥ 25 [mm]	186	0	0
d ≥ 50 [mm]	57	0	0

Table 4-20 Total area of deposition in 1000 × [m²] for different sediment thickness contours. Scenario: Plume generation and deposition as a result of natural erosion in one year time after West 1 island construction, after four year case.

Sediment thickness (d) of fine material [mm]	Deposition area (1000 × [m²])	Deposition area (1000 × [m²]) inside gravel bed polygons	Deposition area (1000 × [m²]) inside Natura2000 zone
d ≥ 10 [mm]	2.061	0	0
d ≥ 25 [mm]	662	0	0
d ≥ 50 [mm]	592	0	0

Maximal values of depth averaged sediment concentrations are found to exceed the minimal background concentration of 4 mg/L for both the 'after one year' and 'after four year' cases up to 7.5 km from the island location (Figure 4-22 and Figure 4-24, Table 4-21 and Table 4-22).

Table 4-21 Total area of exceeding depth averaged concentrations in 1000 × [m²]. Scenario: Plume generation and deposition as a result of natural erosion in one year time after West 1 island construction, one year case

Depth averaged concentrations (c) of fine material [mg/L]	Total area (1000 × [m²])
c ≥ 4 [mg/L]	22.510
c ≥ 10 [mg/L]	6.727
c ≥ 25 [mg/L]	203
c ≥ 50 [mg/L]	8

Table 4-22 Total area of exceeding depth averaged concentrations in 1000 × [m²]. Scenario: Plume generation and deposition as a result of natural erosion in one year time after West 1 island construction, four year case

Depth averaged concentrations (c) of fine material [mg/L]	Total area (1000 × [m²])
c ≥ 4 [mg/L]	22.367
c ≥ 10 [mg/L]	8.390
c ≥ 25 [mg/L]	684
c ≥ 50 [mg/L]	2

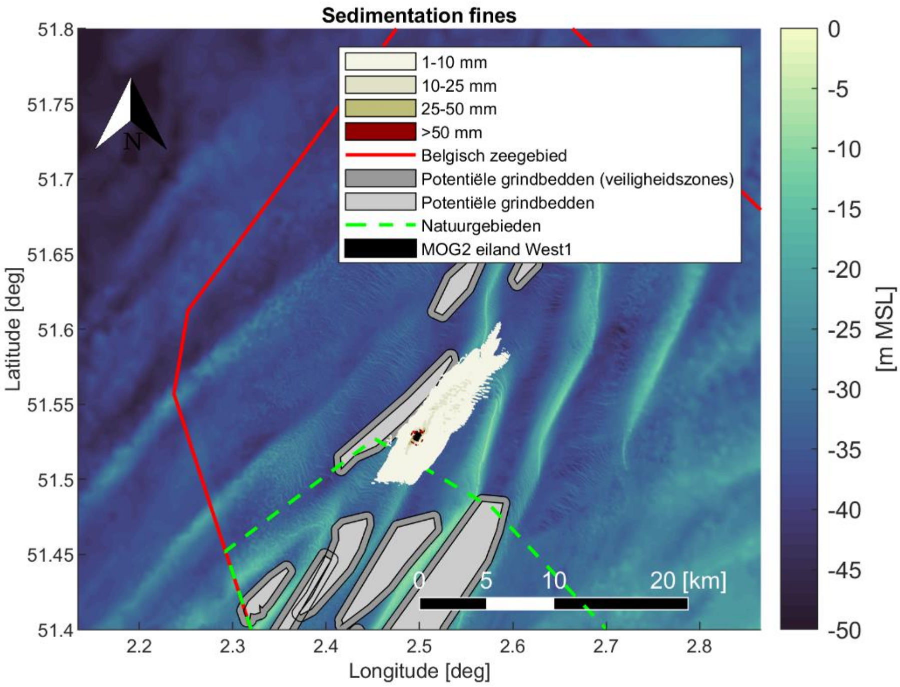


Figure 4-21 Maximal sedimentation [mm] of fine material (< 250 [μm]) during the simulation period. Scenario: Plume generation and deposition as a result of natural erosion in one year time after West 1 island construction, after one year case.

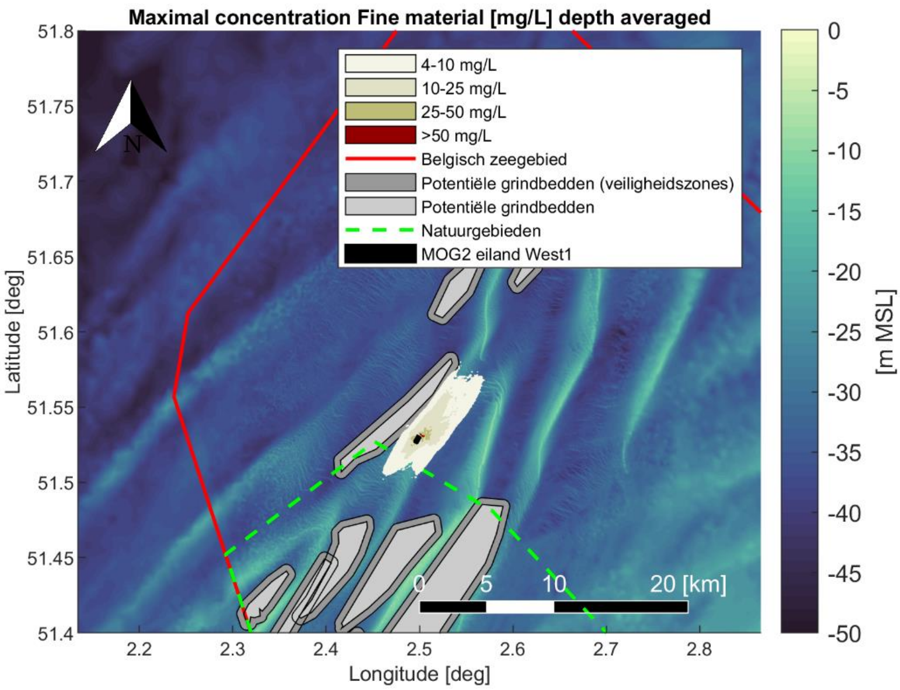


Figure 4-22 Maximal depth averaged sediment concentration [mg/L] of fine material (< 250 [μm]) during the simulation period. Scenario: : Plume generation and deposition as a result of natural erosion in one year time after West 1 island construction, after one year case..

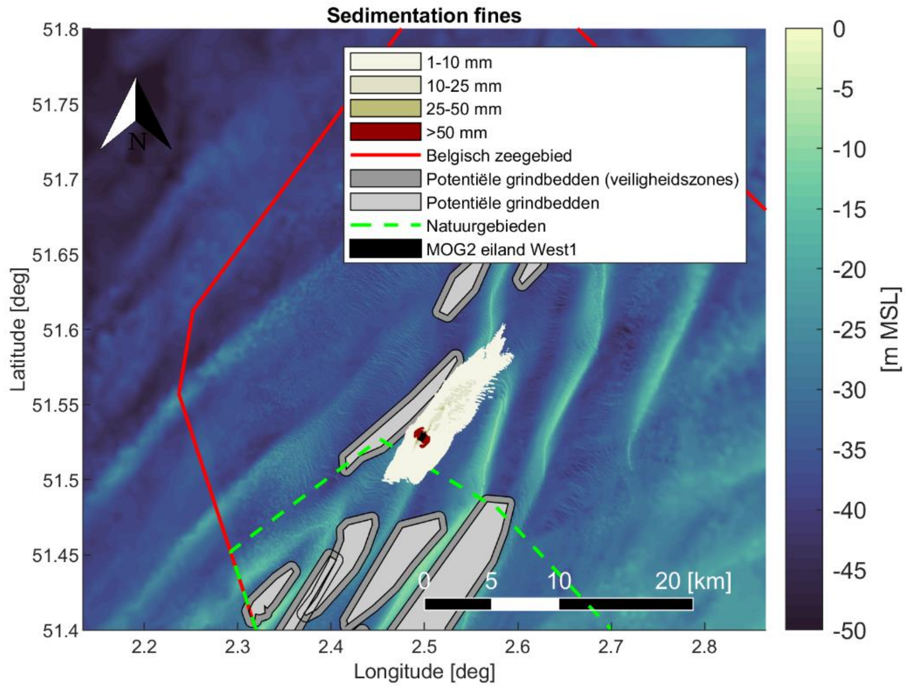


Figure 4-23 Maximal sedimentation [mm] of fine material (< 250 [µm]) during the simulation period. Scenario: : Plume generation and deposition as a result of natural erosion in one year time after West 1 island construction, after four year case.

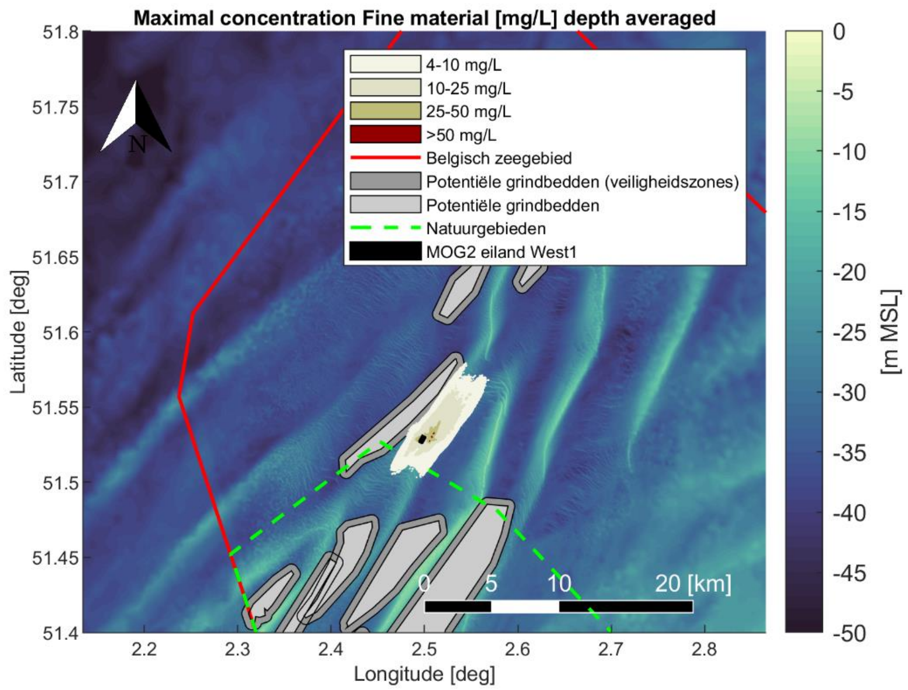


Figure 4-24 Maximal depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during the simulation period. Scenario: : Plume generation and deposition as a result of natural erosion in one year time after West 1 island construction, after four year case..

4.2.1.2 West 2

Filled contours in Figure 4-25 and Figure 4-27 show the maximal sedimentation of fine material (< 250 µm) in one year time as a result of erosion and natural resuspension of fine sediment in the scour holes (as explained in section 3.2.1) surrounding the West 2 island for the 'after one year' and 'after four year' cases, respectively. The contours show that for both the 'after one year' and 'after four year' cases, there is no exceedance of 0.01 m sedimentation within the gravel bed polygons. Deposition areas for multiple fine sediment thickness contours are provided for the one year and four year cases in Table 4-23 and Table 4-24, respectively.

Table 4-23 Total area of deposition in 1000 × [m²] for different sediment thickness contours. Scenario: Plume generation and deposition as a result of natural erosion in one year time after West 2 island construction, after one year case.

Sediment thickness (d) of fine material [mm]	Deposition area (1000 × [m²])	Deposition area (1000 × [m²]) inside gravel bed polygons	Deposition area (1000 × [m²]) inside Natura2000 zone
d ≥ 10 [mm]	881	0	0
d ≥ 25 [mm]	210	0	0
d ≥ 50 [mm]	63	0	0

Table 4-24 Total area of deposition in 1000 × [m²] for different sediment thickness contours. Scenario: Plume generation and deposition as a result of natural erosion in one year time after West 2 island construction, after four year case.

Sediment thickness (d) of fine material [mm]	Deposition area (1000 × [m²])	Deposition area (1000 × [m²]) inside gravel bed polygons	Deposition area (1000 × [m²]) inside Natura2000 zone
d ≥ 10 [mm]	1.364	0	19
d ≥ 25 [mm]	752	0	0
d ≥ 50 [mm]	640	0	0

Maximal values of depth averaged sediment concentrations are found to exceed the minimal background concentration of 4 mg/L for both the 'after one year' and 'after four year' cases up to 7.5 km from the island location (Figure 4-26 and Figure 4-28, Table 4-25 and Table 4-26).

Table 4-25 Total area of exceeding depth averaged concentrations in 1000 × [m²]. Scenario: Plume generation and deposition as a result of natural erosion in one year time after West 2 island construction, after one year case

Depth averaged concentrations (c) of fine material [mg/L]	Total area (1000 × [m²])
c ≥ 4 [mg/L]	24.421
c ≥ 10 [mg/L]	4.313
c ≥ 25 [mg/L]	68
c ≥ 50 [mg/L]	0

Table 4-26 Total area of exceeding depth averaged concentrations in 1000 × [m2]. Scenario: Plume generation and deposition as a result of natural erosion in one year time after West 2 island construction, after four year case

Depth averaged concentrations (c) of fine material [mg/L]	Total area (1000 × [m²])
c ≥ 4 [mg/L]	24.510
c ≥ 10 [mg/L]	5.018
c ≥ 25 [mg/L]	223
c ≥ 50 [mg/L]	3

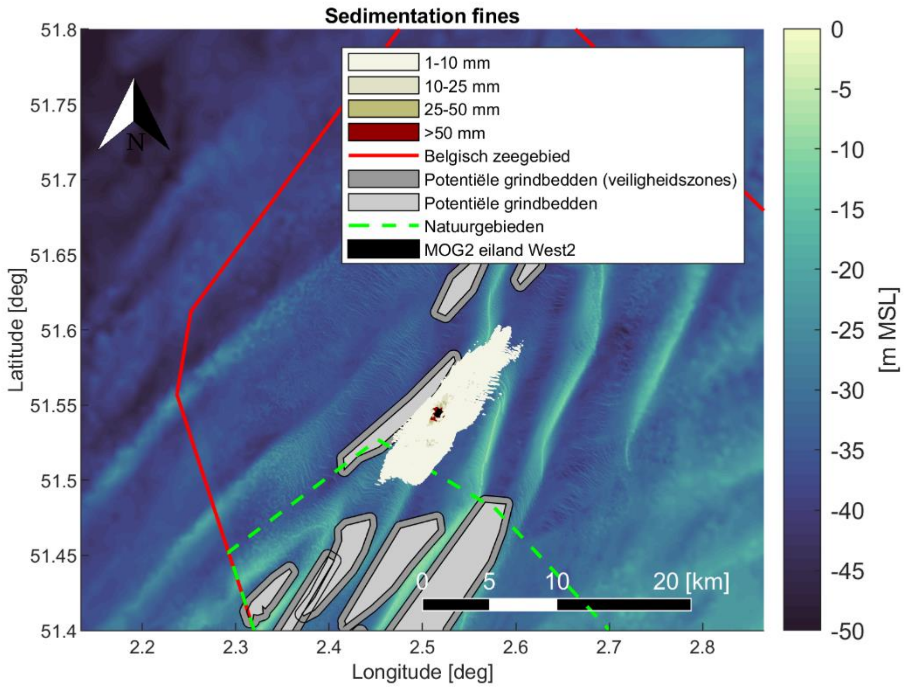


Figure 4-25 Maximal encountered sedimentation [mm] of fine material (< 250 [µm]) during the simulation period. Scenario: Plume generation and deposition as a result of natural erosion in one year time after West 2 island construction, after one year case..

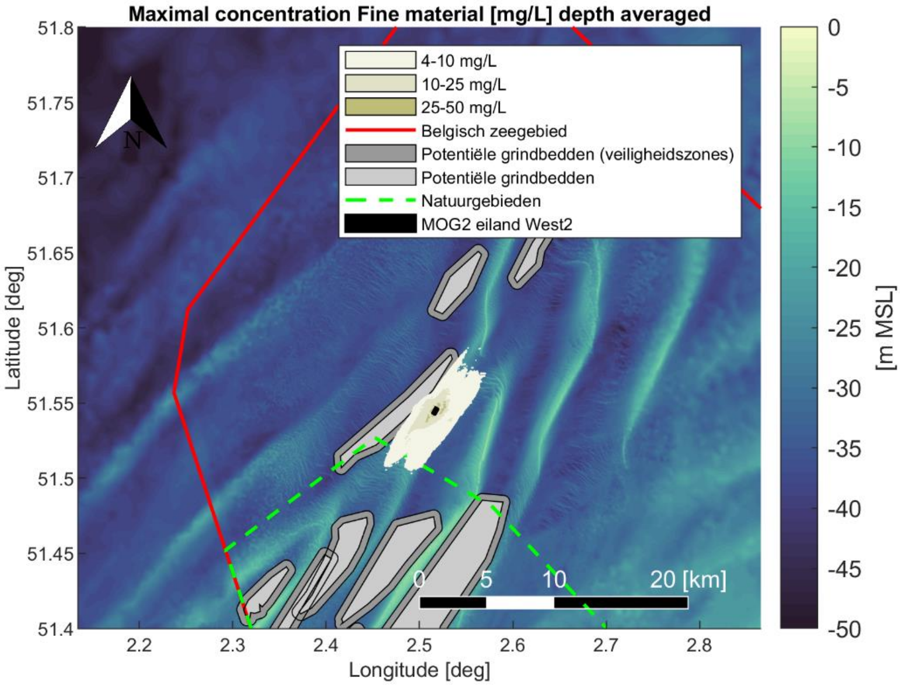


Figure 4-26 Maximal encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during the simulation period. Scenario: Plume generation and deposition as a result of natural erosion in one year time after West 2 island construction, after one year case.

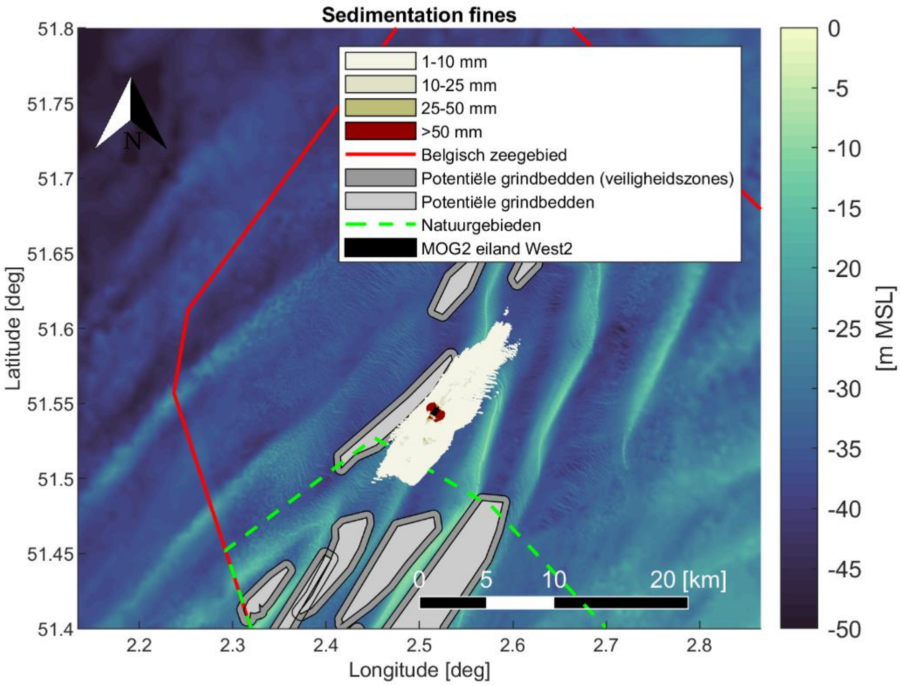


Figure 4-27 Maximal encountered sedimentation [mm] of fine material (< 250 [µm]) during the simulation period. Scenario: Plume generation and deposition as a result of natural erosion in one year time after West 2 island construction, after four year case.

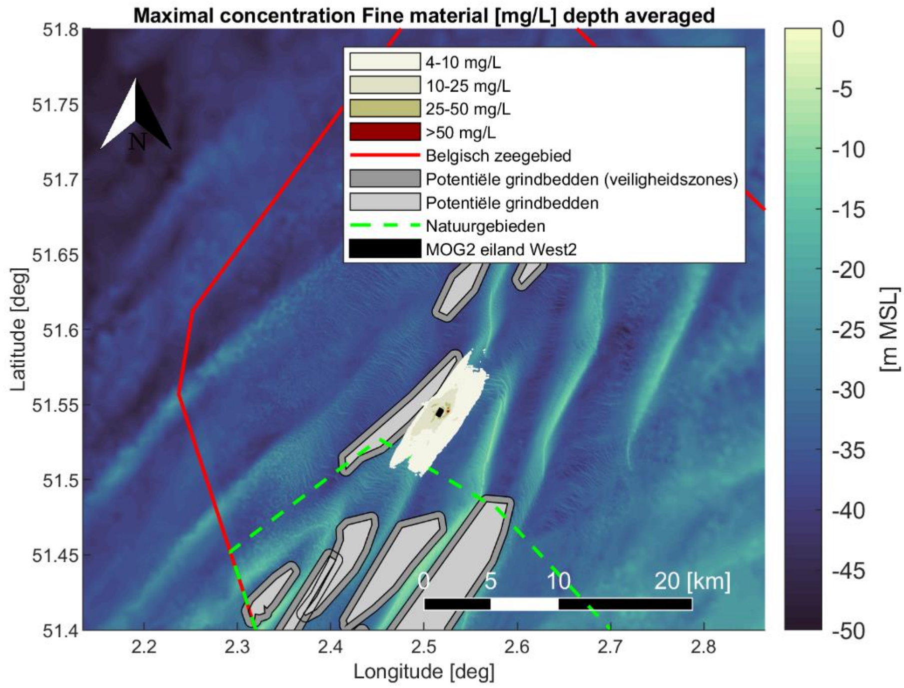


Figure 4-28 Maximal encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [μm]) during the simulation period. Scenario: Plume generation and deposition as a result of natural erosion in one year time after West 2 island construction, after four year case.

4.2.1.3 Noord

Filled contours in Figure 4-29 and Figure 4-31 show the maximal sedimentation of fine material (< 250 μm) in one year time as a result of erosion and natural resuspension of fine sediment in the scour holes (as explained in section 3.2.1) surrounding the Noord island for the 'after one year' and 'after four year' cases, respectively. The contours show that for both the 'after one year' and 'after four year cases', there is no exceedance of 0.01 m sedimentation within the gravel bed polygons. Deposition areas for multiple fine sediment thickness contours are provided for the one year and four year cases in Table 4-27 and Table 4-28, respectively.

Table 4-27 Total area of deposition in 1000 × [m²] for different sediment thickness contours. Scenario: Plume generation and deposition as a result of natural erosion in one year time after Noord island construction, after one year case.

Sediment thickness (d) of fine material [mm]	Deposition area (1000 × [m²])	Deposition area (1000 × [m²]) inside gravel bed polygons	Deposition area (1000 × [m²]) inside Natura2000 zone
d ≥ 10 [mm]	4.306	0	0
d ≥ 25 [mm]	460	0	0
d ≥ 50 [mm]	228	0	0

Table 4-28 Total area of deposition in 1000 × [m²] for different sediment thickness contours. Scenario: Plume generation and deposition as a result of natural erosion in one year time after Noord island construction, after four year case.

Sediment thickness (d) of fine material [mm]	Deposition area (1000 × [m²])	Deposition area (1000 × [m²]) inside gravel bed polygons	Deposition area (1000 × [m²]) inside Natura2000 zone
d ≥ 10 [mm]	1.442	0	0
d ≥ 25 [mm]	896	0	0
d ≥ 50 [mm]	765	0	0

Maximal values of depth averaged sediment concentrations are found to exceed the minimal background concentration of 4 mg/L for both the 'after one year' and 'after four year' cases up to 10 km from the island location (Figure 4-30 and Figure 4-32, Table 4-29 and Table 4-30).

Table 4-29 Total area of exceeding depth averaged concentrations in 1000 × [m²]. Scenario: Plume generation and deposition as a result of natural erosion in one year time after Noord island construction, after one year case

Depth averaged concentrations © of fine material [mg/L]	Total area (1000 × [m²])
c ≥ 4 [mg/L]	23.569
c ≥ 10 [mg/L]	8.421
c ≥ 25 [mg/L]	979
c ≥ 50 [mg/L]	26

Table 4-30 Total area of exceeding depth averaged concentrations in 1000 × [m²]. Scenario: Plume generation and deposition as a result of natural erosion in one year time after Noord island construction, after four year case

Depth averaged concentrations (c) of fine material [mg/L]	Total area (1000 × [m²])
c ≥ 4 [mg/L]	14.259
c ≥ 10 [mg/L]	2.797
c ≥ 25 [mg/L]	20
c ≥ 50 [mg/L]	0

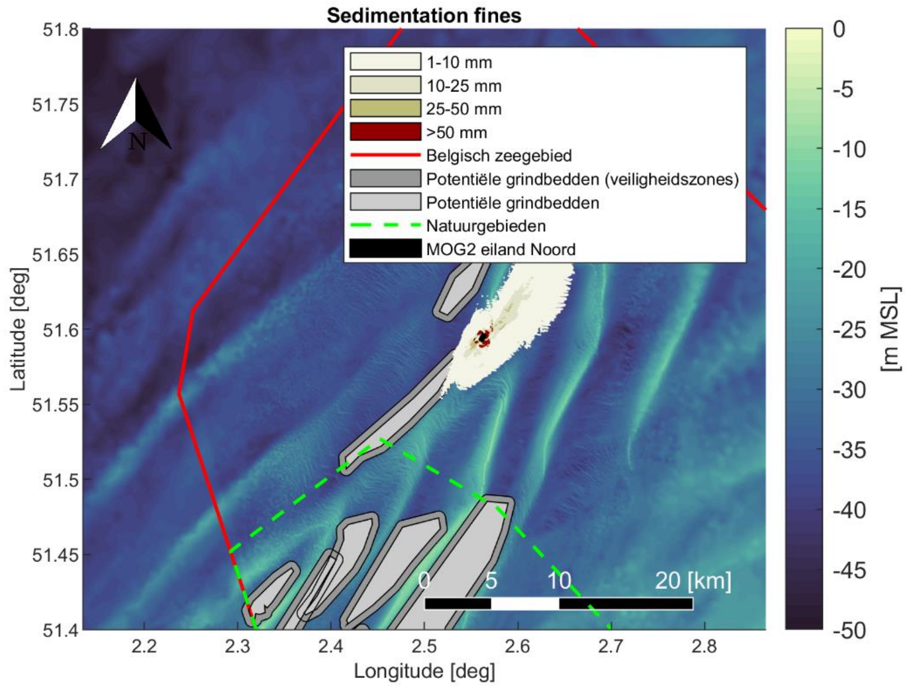


Figure 4-29 Maximal encountered sedimentation [mm] of fine material (< 250 [µm]) during the simulation period. Scenario: Plume generation and deposition as a result of natural erosion in one year time after Noord island construction, after one year case.

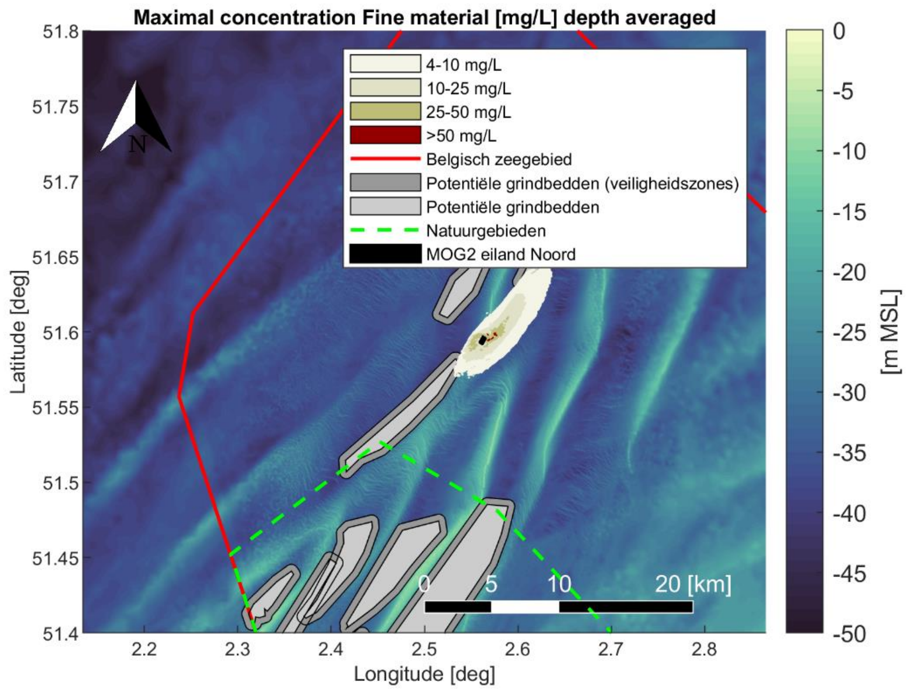


Figure 4-30 Maximal encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during the simulation period. Scenario: Plume generation and deposition as a result of natural erosion in one year time after Noord island construction, after one year case.

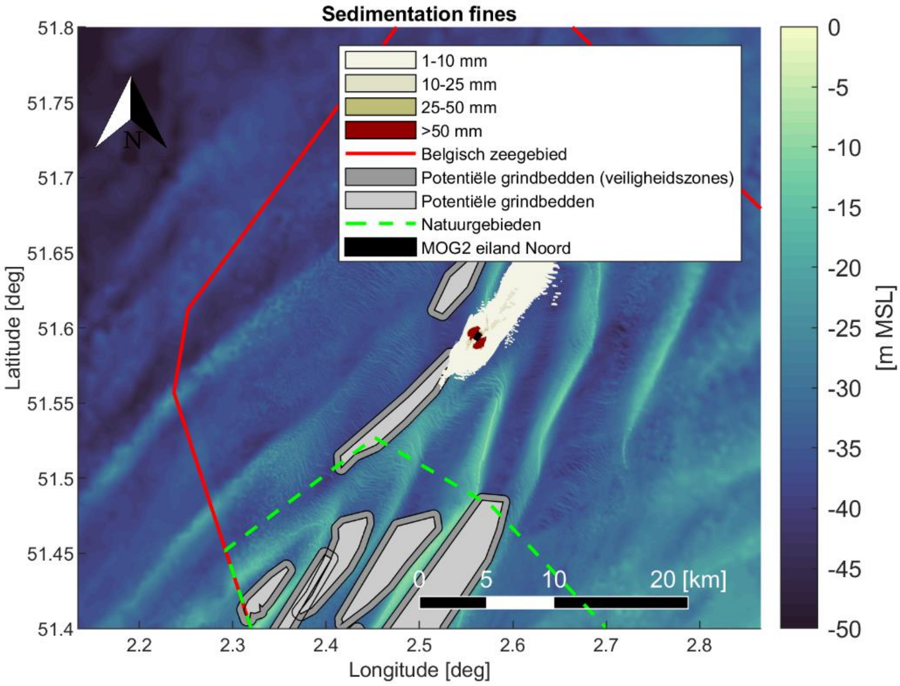


Figure 4-31 Maximal encountered sedimentation [mm] of fine material (< 250 [µm]) during the simulation period. Scenario: Plume generation and deposition as a result of natural erosion in one year time after Noord island construction, after four year case.

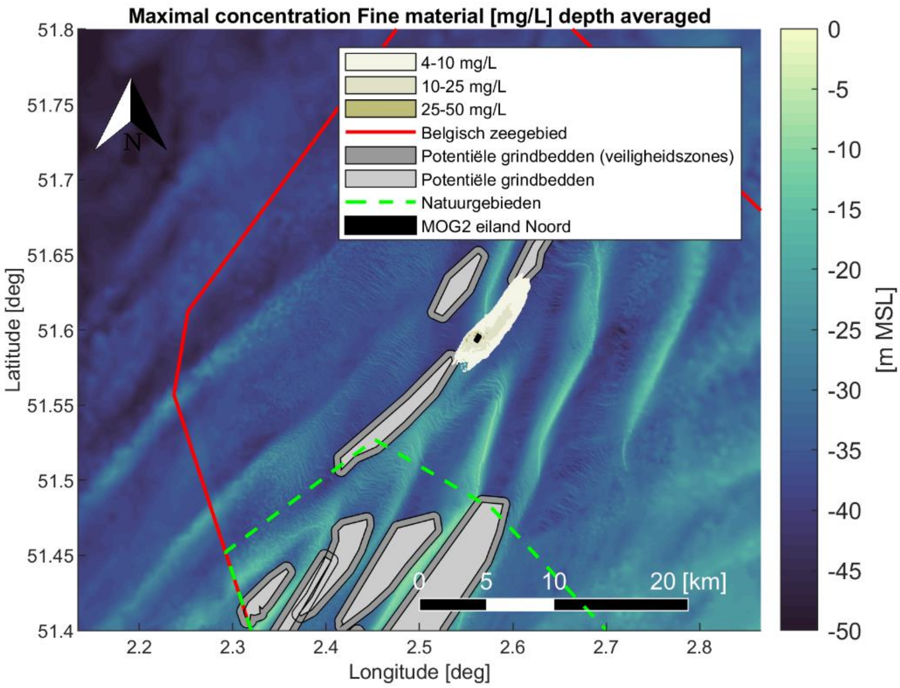


Figure 4-32 Maximal encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during the simulation period. Scenario: Plume generation and deposition as a result of natural erosion in one year time after Noord island construction, after four year case.

4.2.2 Investigation of effectiveness of pre-scour dredging

Filled contours in Figure 4-33 and Figure 4-34 show the maximal sedimentation of fine material (< 250 µm) in one year time as a result of natural source of fine sediment in the scour holes (as explained in section 3.2.1) surrounding the West 1 island for the 'after one year' case with and without pre-dredging design, respectively. The contours show that the latter case without pred-dredging design has a 1.9 times larger area where the exceedance of 0.01 m sedimentation occurs. Though for both cases, there is no exceedance of the 0.01 m within the gravel bed polygons.

Table 4-31 Total area of deposition in 1000 × [m²] for different sediment thickness contours. Scenario: Plume generation and deposition as a result of natural erosion in one year time after West 1 island construction, after one year case with and without pre-scour dredging.

Sediment thickness (d) of fine material [mm]	Deposition area (1000 × [m²]) (including pre-scour design)	Deposition area (1000 × [m²]) (without pre-scour design)
d ≥ 10 [mm]	16.842	31.945
d ≥ 25 [mm]	1.857	10.673
d ≥ 50 [mm]	356	1.985

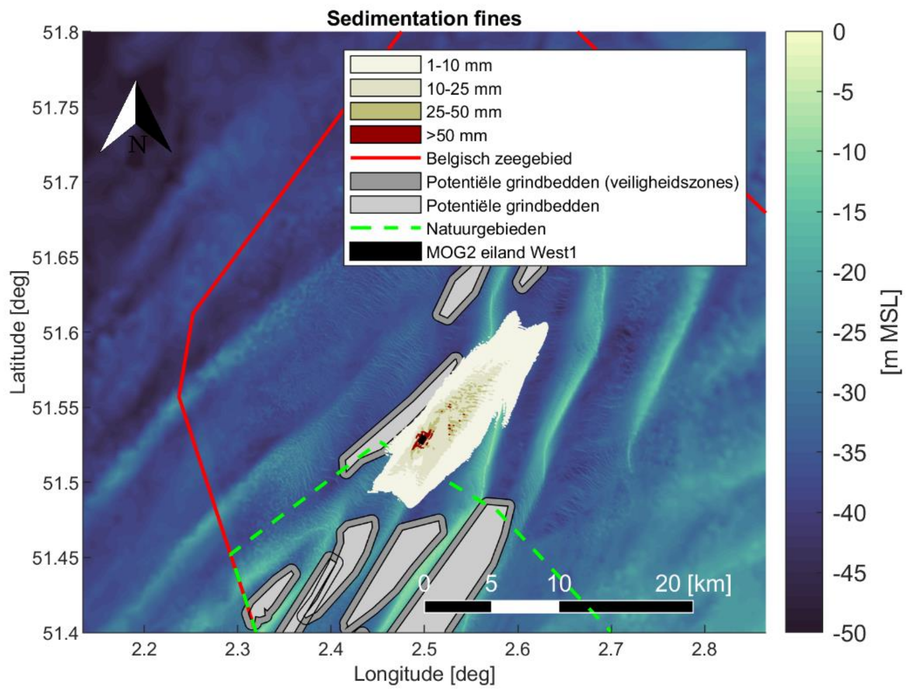


Figure 4-33 Maximal encountered sedimentation [mm] of fine material (< 250 [µm]) during the simulation period. Scenario: Plume generation and deposition as a result of natural erosion in one year time after West 1 island construction, after one year case including pre-scour design.

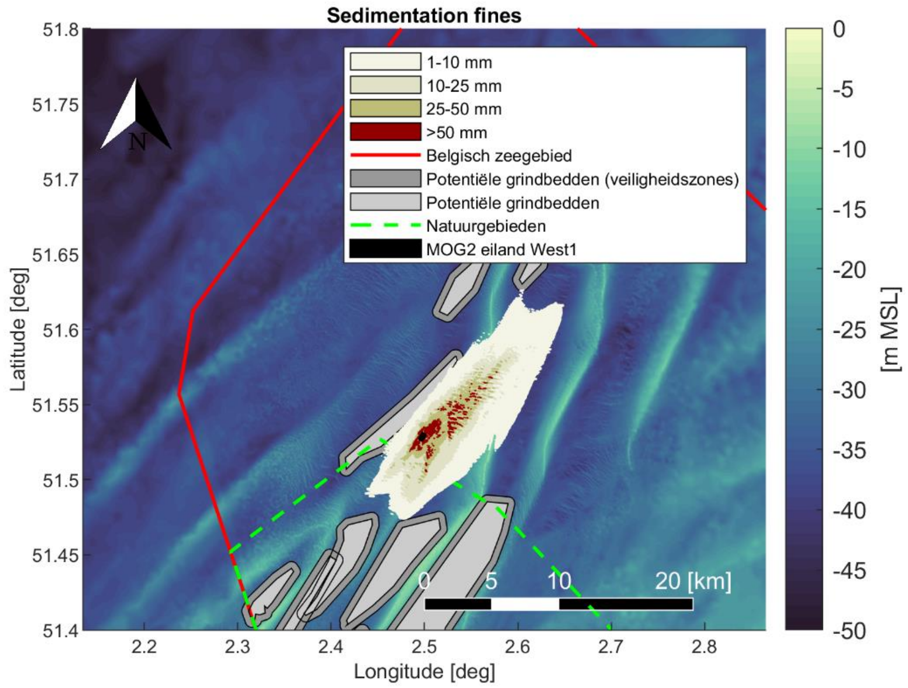


Figure 4-34 Maximal encountered sedimentation [mm] of fine material (< 250 [µm]) during the simulation period. Scenario: Plume generation and deposition as a result of natural erosion in one year time after West 1 island construction, after one year case without pre-scour design.

5 Conclusions

In this report, the impact of dredging and disposing fine sediment (< 250 µm) related to maritime works needed during the construction phase of the MOG2 project and the natural release of fine sediments due to the presence of the MOG2 island during the operational phase have been investigated using a 3D numerical plume model for three different island locations (West 1, West 2, and Noord). An important assumption of the current plume model is that, for the construction phase, it does not take resuspension of sediment into account. Once sediment is released inside the model, it is only able to disperse and settle. Results of the construction phase should therefore be interpreted within this context.

Multiple scenarios were studied, each representing a different process during either the construction or operational phase:

Construction phase:

- Detailed simulations of dredging activities related to the construction of the island
    - Scenario 1: Plume generation while levelling sand ridges and disposing dredged material at a temporary disposal site (at location West1)
    - Scenario 2: Plume generation while pre-dredging scour holes and ridges and disposing dredged material at the island location (at location West 2 and Noord)
    - Scenario 3: Plume generation while pre-dredging scour holes and ridges and filling the island ring with dredged sand through pipes, leading to overflow from the island ring (all three locations)
- Detailed simulations of dredging activities related to power cable installation
    - Plume generation while dredging trenches for the power cables and disposing dredged material at a temporary disposal site (for three different sections of the trench)

Operational phase:

- Plume generation and deposition as a result of natural erosion after island construction (including the effect of resuspension)

In terms of turbidity implications, results of the construction phase scenario's show that the maximal enhanced plume-induced depth averaged suspended sediment concentrations only locally exceed baseline background concentrations. In case the dredged sediment only contains fine sand, the extend of the exceedance polygon is at maximum one kilometer from the location of the marine works. For scenarios having mostly fines dredged, the extent of the exceedance polygon increases up to five kilometers. Results of the operational phase scenario's show that the plume, generated by natural erosion after island construction has (in one year time) and exceeding the baseline concentration of 4 mg/L, has a maximal reach of 10 km from the island location.

In terms of sedimentation, results of both the construction and operational phase scenario's show that the maximal sedimentation of fine material (< 250 µm) for all scenarios remain below the 0.01 m threshold for sedimentation within the gravel bed polygons.

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7 Annex

Annex A Figures of sediment sources

A.1 Plume generation while levelling sand ridges and disposing dredged material at a temporary disposal site (construction island – Scenario 1)

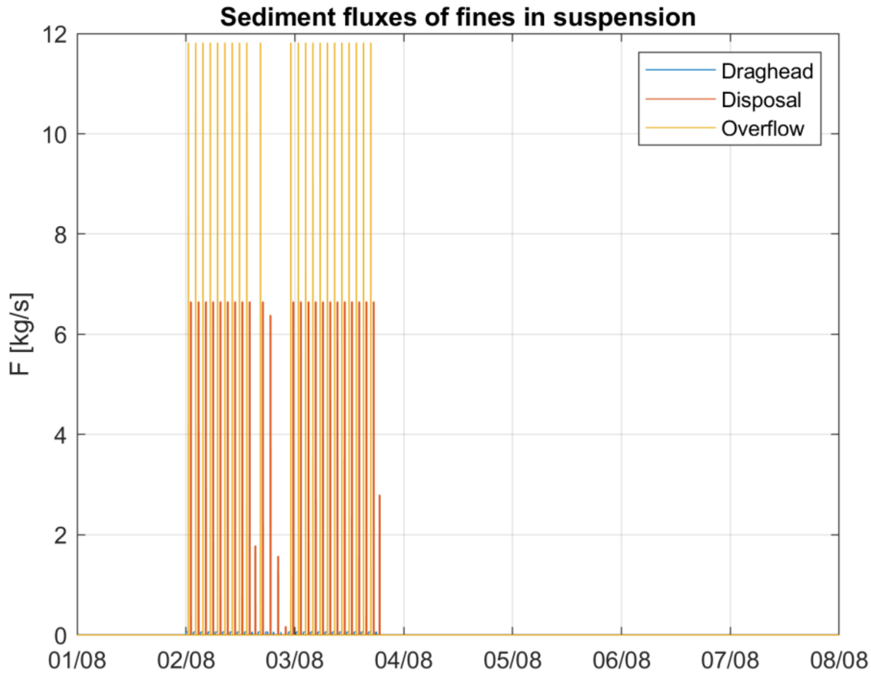

Figure 7-1 Time series of the implemented source of fines (d_p<63 mm) [kg/s] as a result of dredging works related to the levelling of sand ridge crests at the West 1 location.

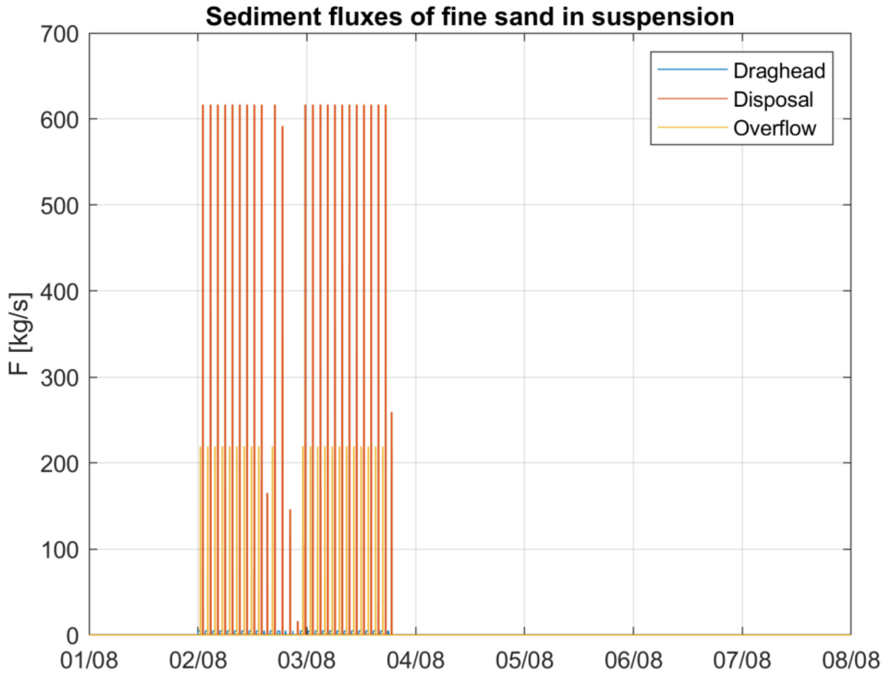

Figure 7-2 Time series of the implemented source of fine sand [kg/s] as a result of dredging works related to the levelling of sand ridge crests at the West 1 location.

A.2 Plume generation while pre-dredging scour holes and disposing dredged material at the island location (construction island – Scenario 2)

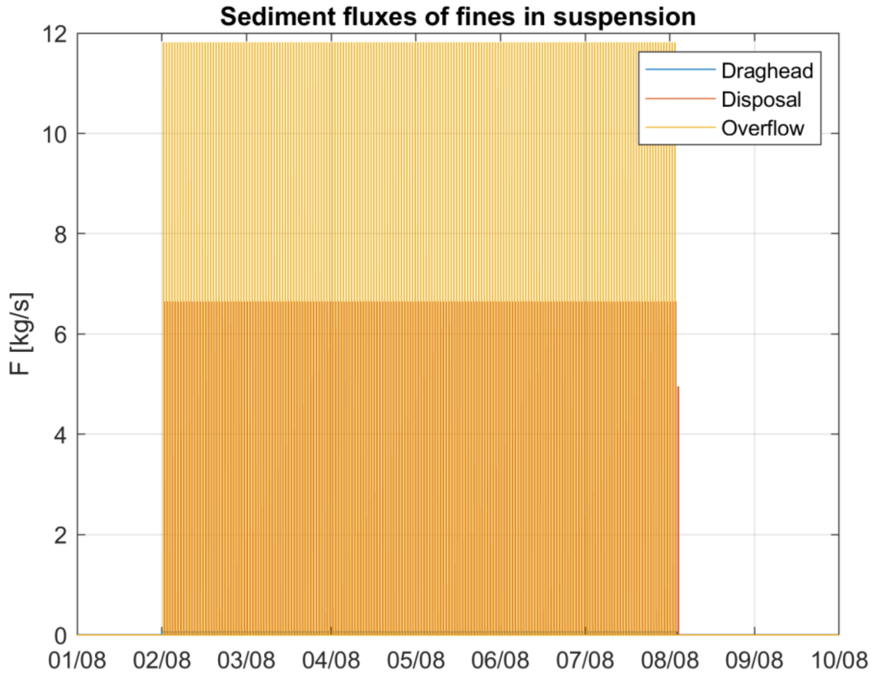

Figure 7-3 Time series of the implemented source of fines (d_p<63 mm) [kg/s] as a result of pre-dredging scour holes and ridges and disposing dredged material at the island location at the West 2 location.

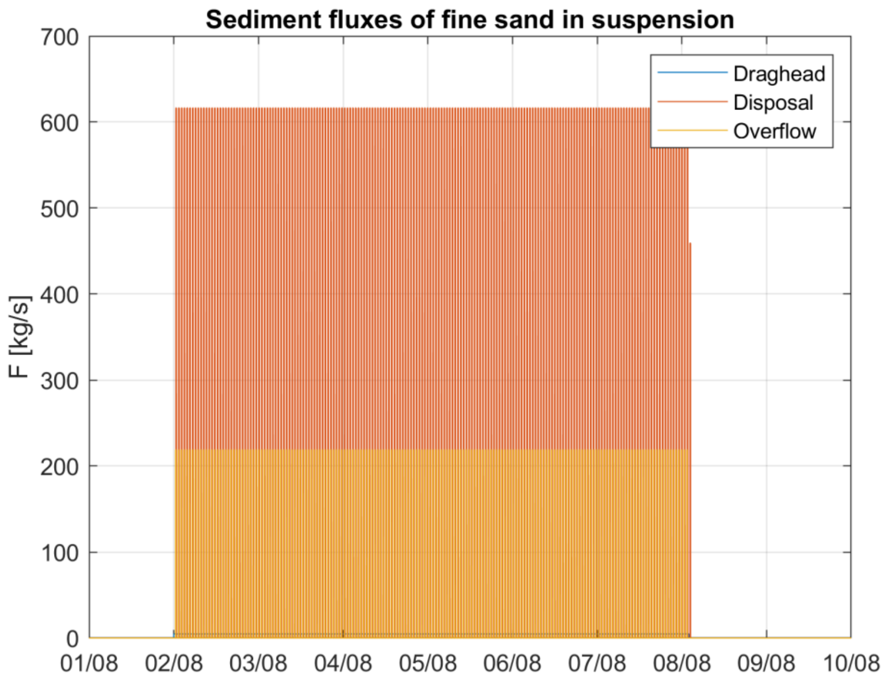

Figure 7-4 Time series of the implemented source of fine sand [kg/s] as a result of pre-dredging I scour holes and ridges and disposing dredged material at the island location at the West 2 location.

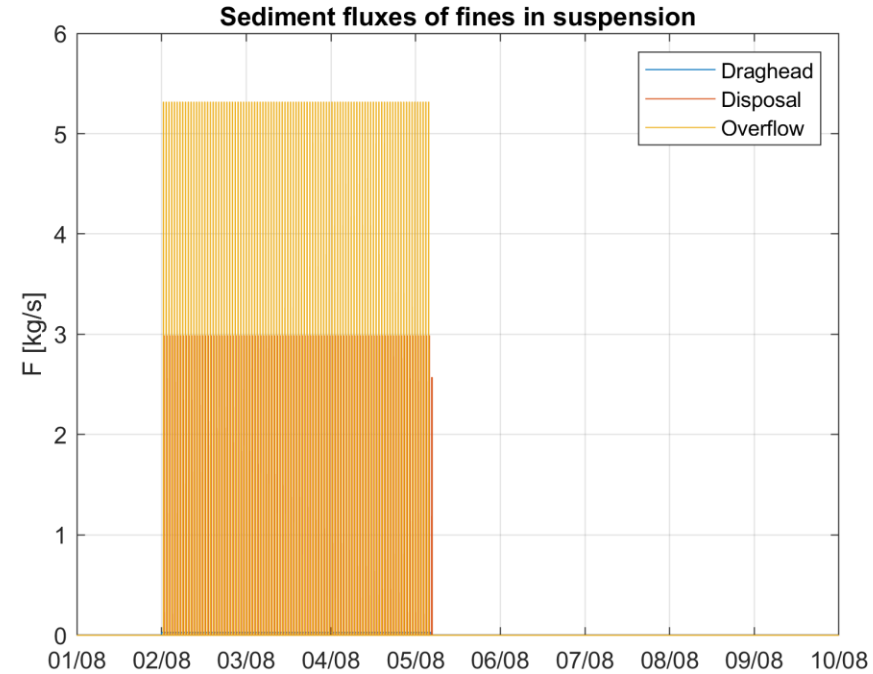

Figure 7-5 Time series of the implemented source of fines (d_p<63 mm) [kg/s] as a result of pre-dredging scour holes and ridges and disposing dredged material at the island location at the Noord location.

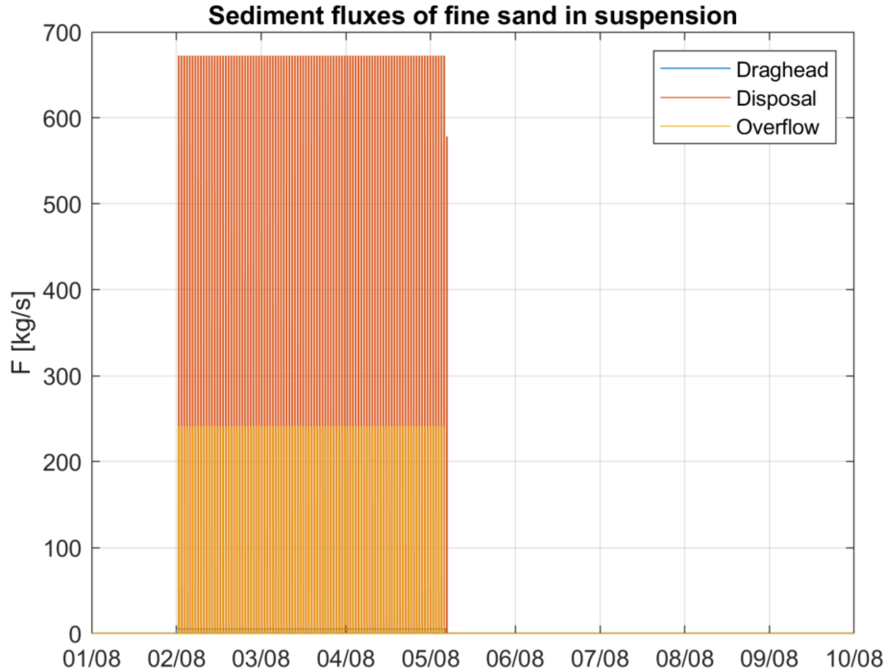

Figure 7-6 Timeseries of the implemented source of fine sand [kg/s] as a result of pre-dredging scour holes and ridges and disposing dredged material at the island location at the Noord location.

A.3 Plume generation while pre-dredging scour holes and filling the island ring with dredged sand through pipes, leading to overflow from the island ring (construction island – Scenario 3)

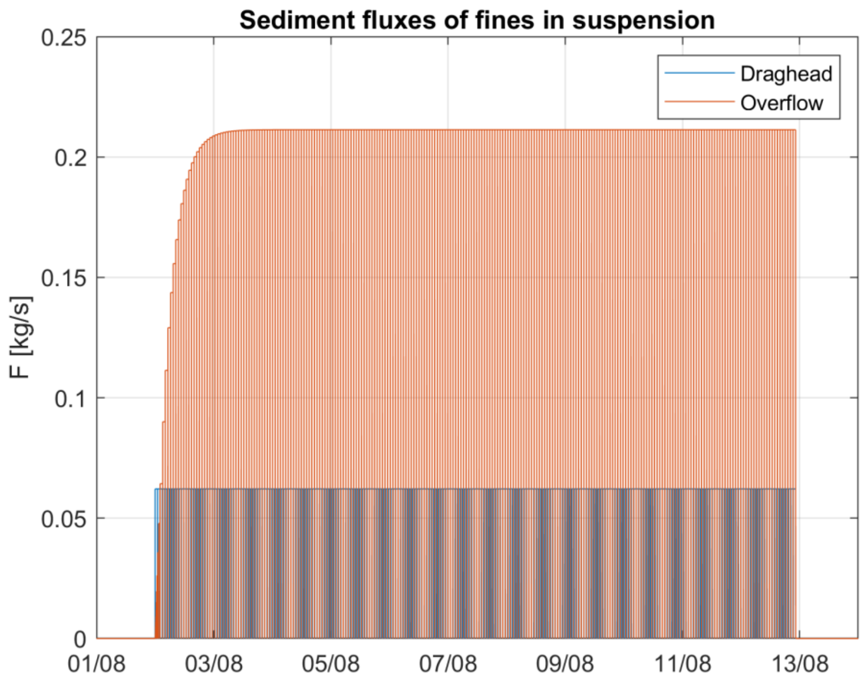

Figure Annex A-1 Time series of the implemented source of fines (d_p<63 mm) [kg/s] as a result of pre-dredging scour holes and ridges and filling the island ring with dredged sand through pipes, leading to overflow from the island ring at the West 1 location.

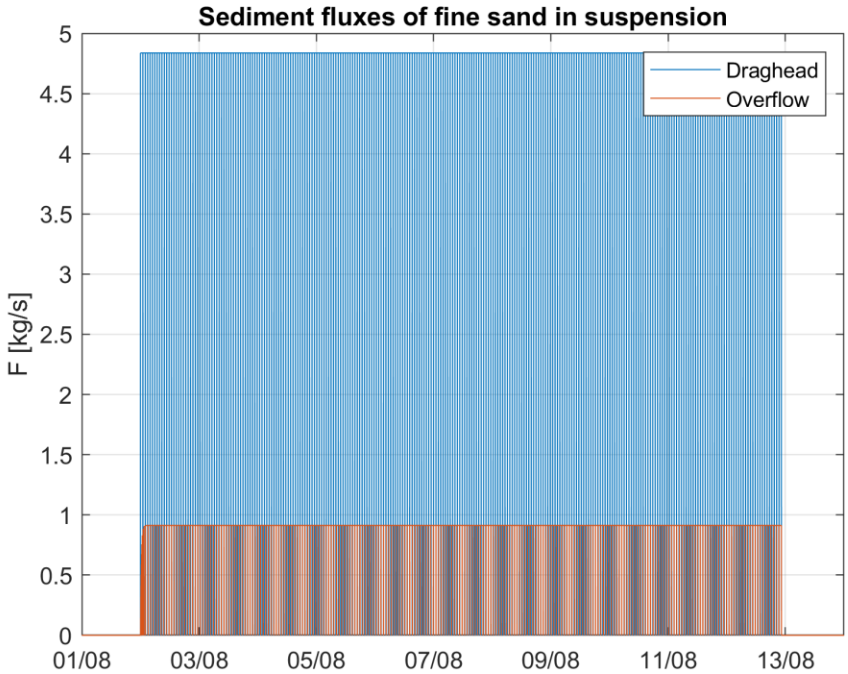

Figure Annex A-2 Time series of the implemented source of fine sand [kg/s] as a result of pre-dredging scour holes and ridges and filling the island ring with dredged sand through pipes, leading to overflow from the island ring at the West 1 location.

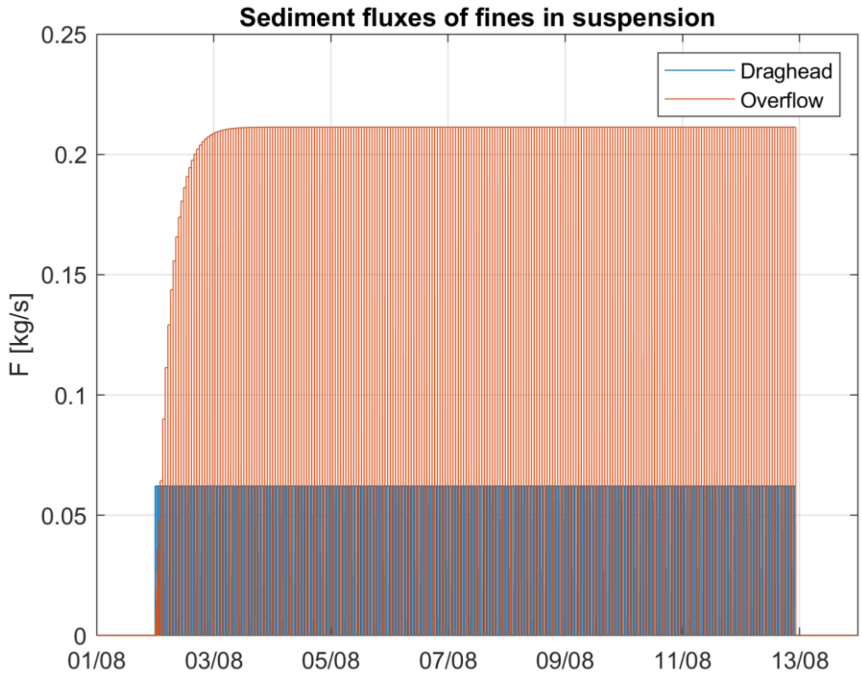

Figure Annex A-3 Time series of the implemented source of fines (d_p<63 mm) [kg/s] as a result of pre-dredging scour holes and ridges and filling the island ring with dredged sand through pipes, leading to overflow from the island ring at the West 2 location.

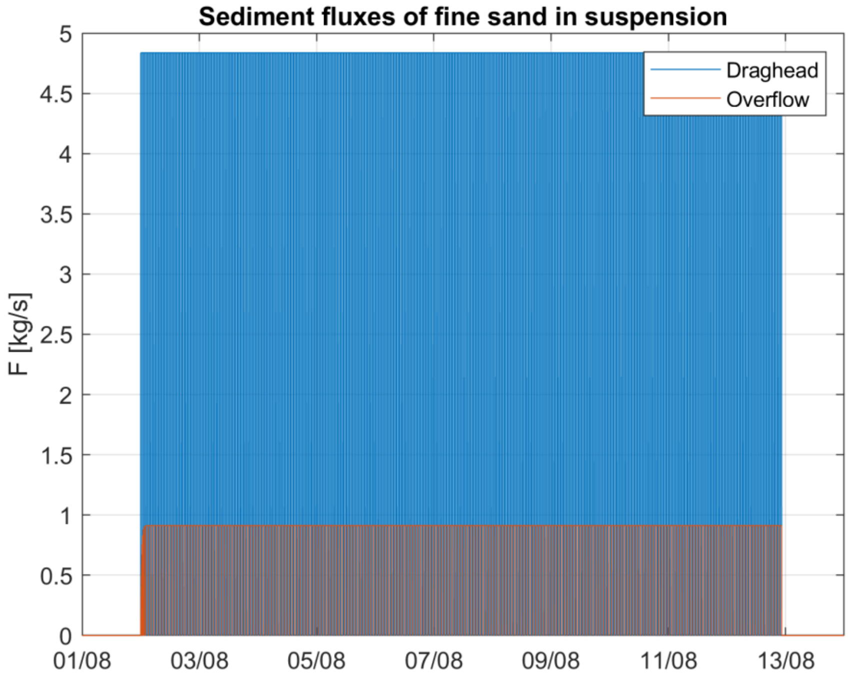

Figure Annex A-4 Time series of the implemented source of fine sand [kg/s] as a result of pre-dredging scour holes and ridges and filling the island ring with dredged sand through pipes, leading to overflow from the island ring at the West 2 location.

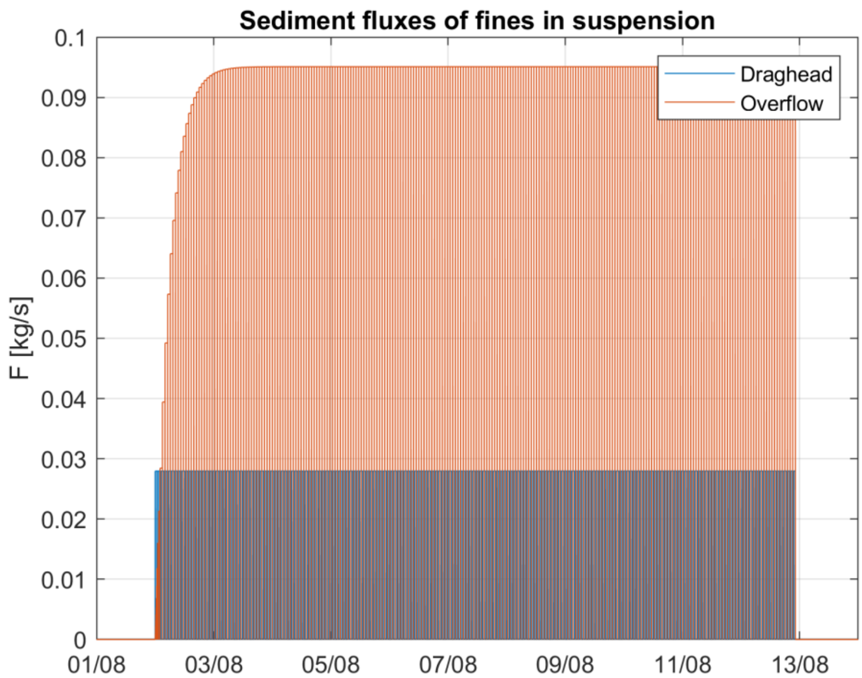

Figure Annex A-5 Time series of the implemented source of fines (d_p<63 mm) [kg/s] as a result of pre-dredging scour holes and ridges and filling the island ring with dredged sand through pipes, leading to overflow from the island ring at the Noord location.

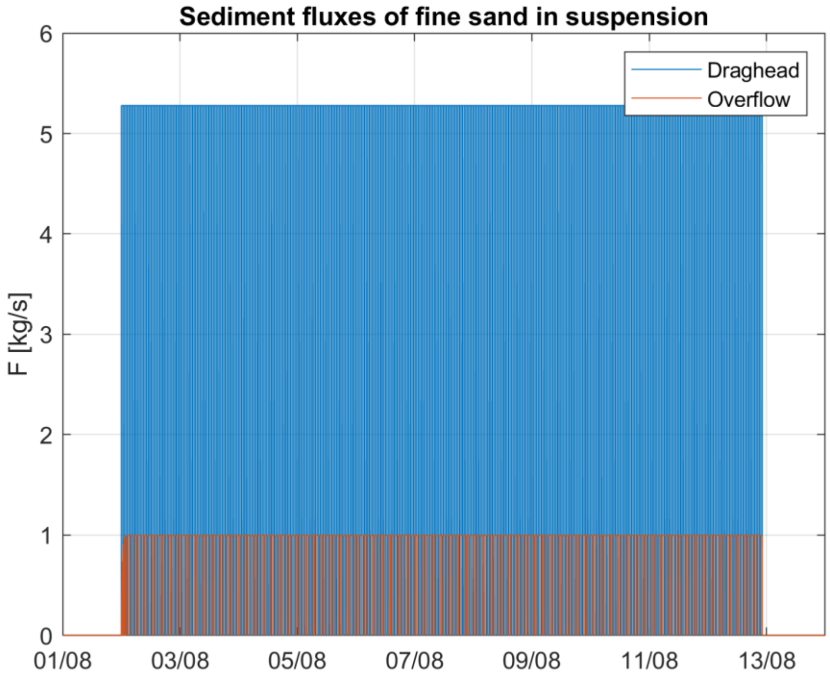

Figure Annex A-6 Time series of the implemented source of fine sand [kg/s] as a result of pre-dredging scour holes and ridges and filling the island ring with dredged sand through pipes, leading to overflow from the island ring at the Noord location.

A.4 Plume generation while dredging trenches for the power cables and disposing dredged material at a temporary disposal site (cable installation)

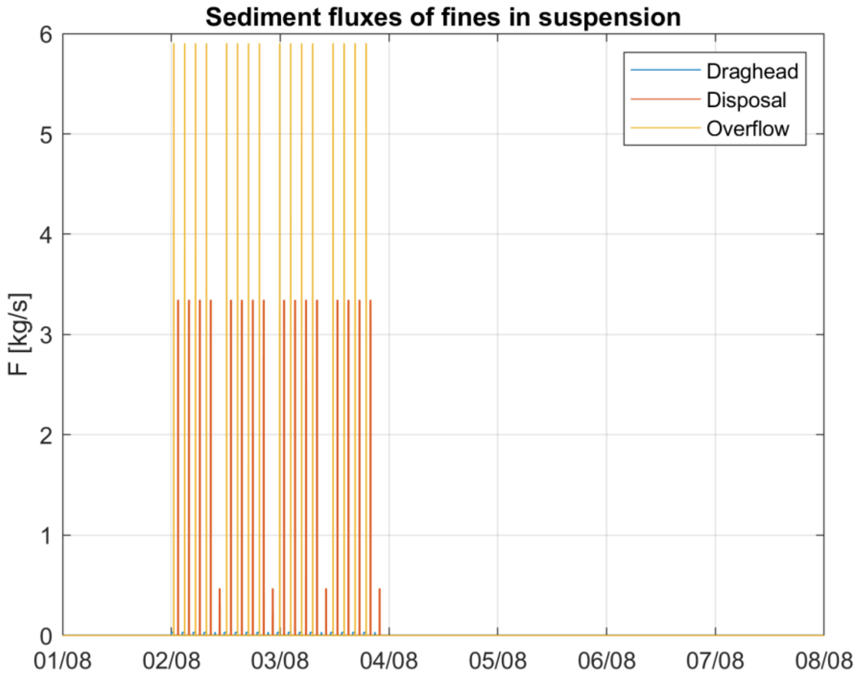

Figure Annex A-7 Timeseries of the implemented source of fines (d_p<63 mm) [kg/s] as a result dredging trenches at trench section 1 for the power cables and disposing dredged material at a temporary disposal site 3.

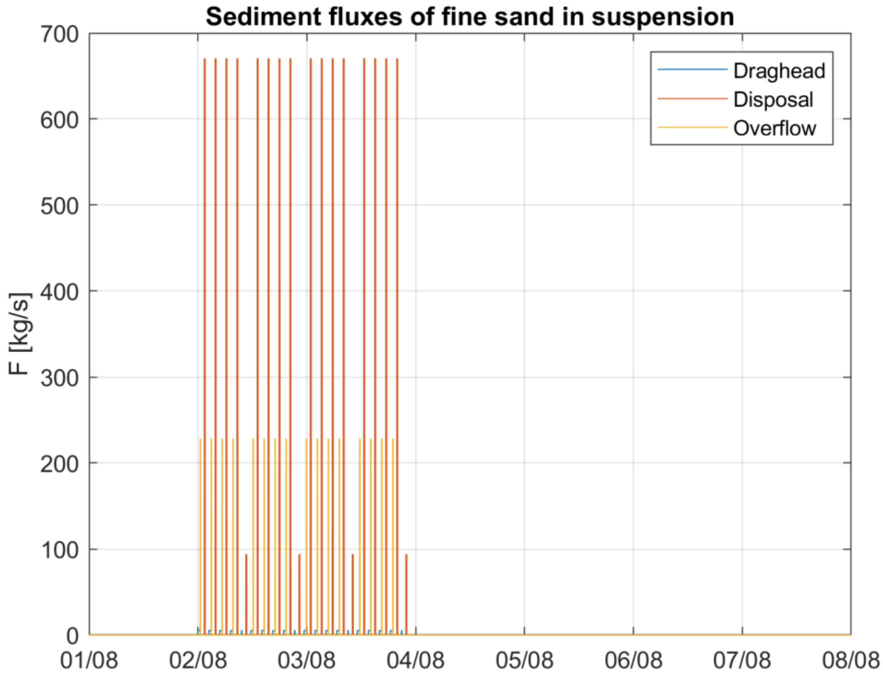

Figure Annex A-8 Timeseries of the implemented source of fine sand [kg/s] as a result dredging trenches at trench section 1 for the power cables and disposing dredged material at a temporary disposal site 3.

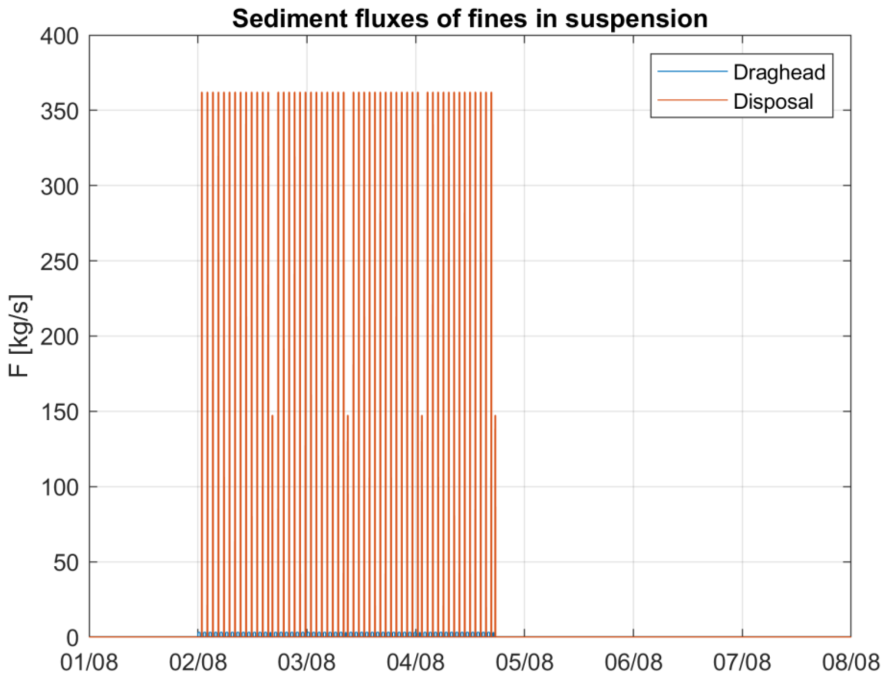

Figure Annex A-9 Timeseries of the implemented source of fines (d_p<63 mm) [kg/s] as a result dredging trenches at trench section 2 for the power cables and disposing dredged material at a temporary disposal site 3.

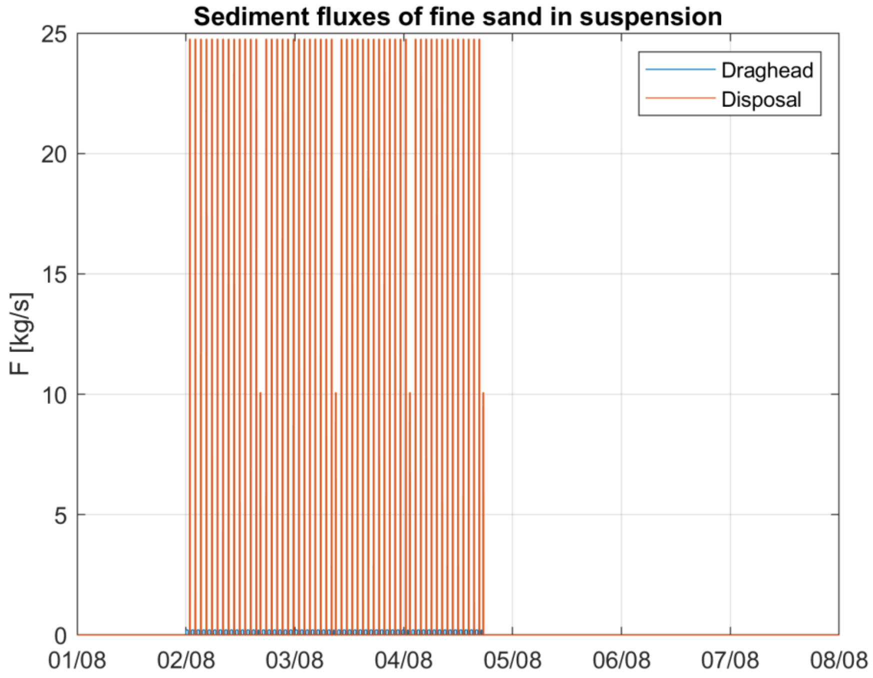

Figure Annex A-10 Time series of the implemented source of fine sand [kg/s] as a result dredging trenches at trench section 2 for the power cables and disposing dredged material at a temporary disposal site 3.

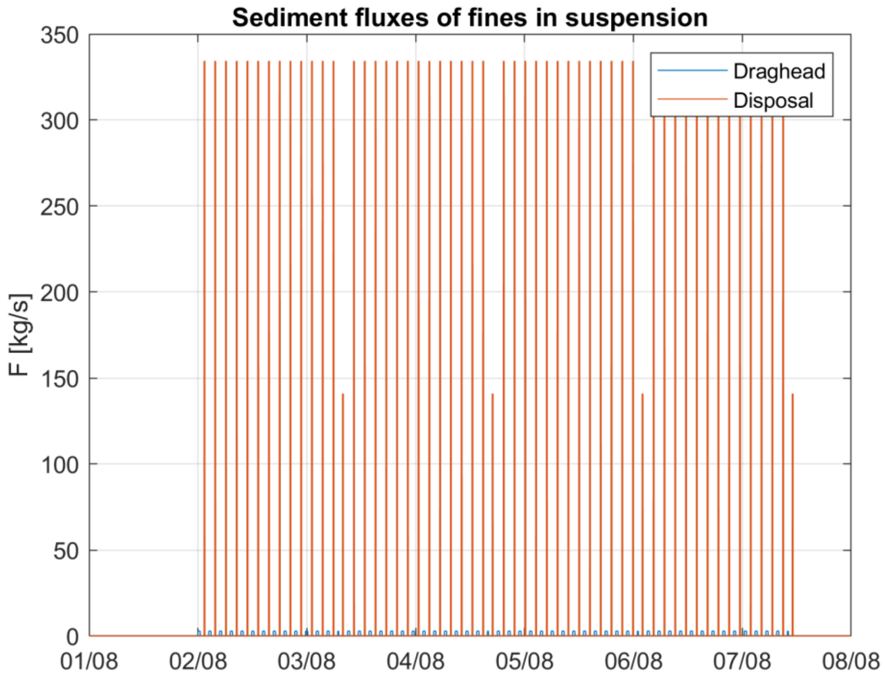

Figure Annex A-11 Time series of the implemented source of fines (d_p<63 mm) [kg/s] as a result dredging trenches at trench section 3 for the power cables and disposing dredged material at a temporary disposal site 3.

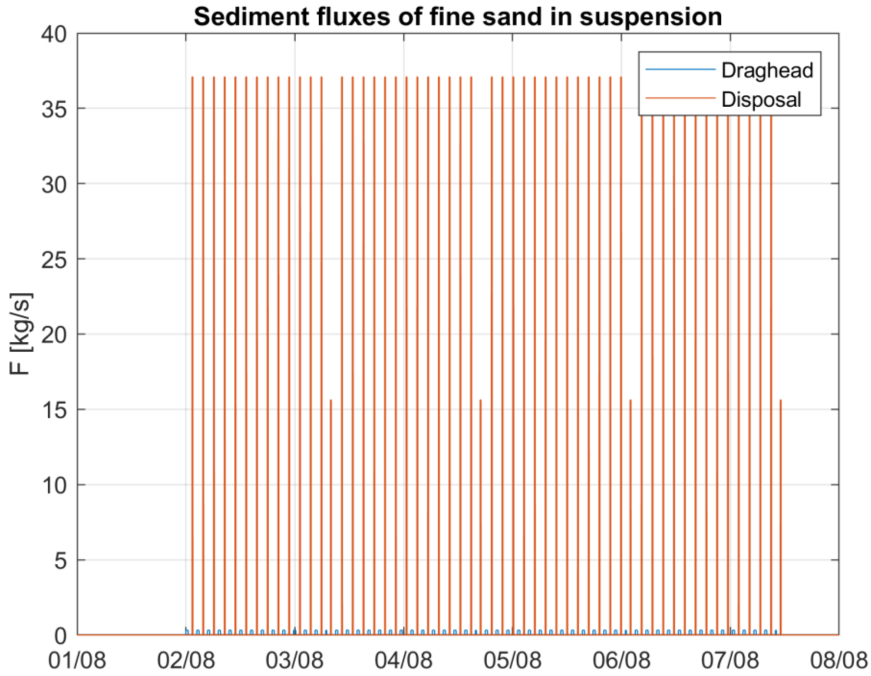

Figure Annex A-12 Time series of the implemented source of fine sand [kg/s] as a result dredging trenches at trench section 3 for the power cables and disposing dredged material at a temporary disposal site 3.

Annex B Figures of sediment concentrations during a dredging cycle

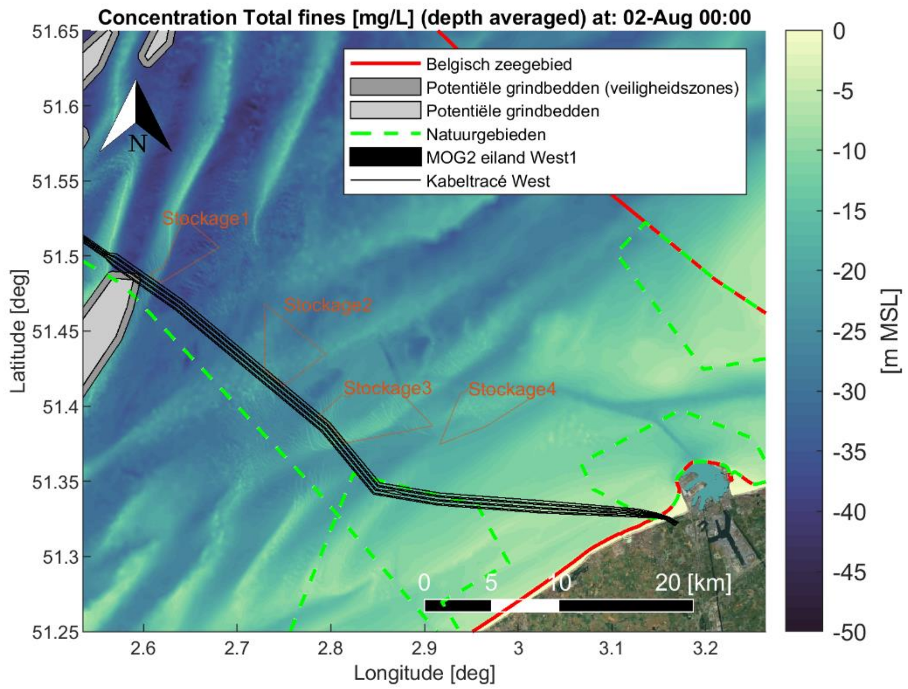

Figure Annex B-1 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

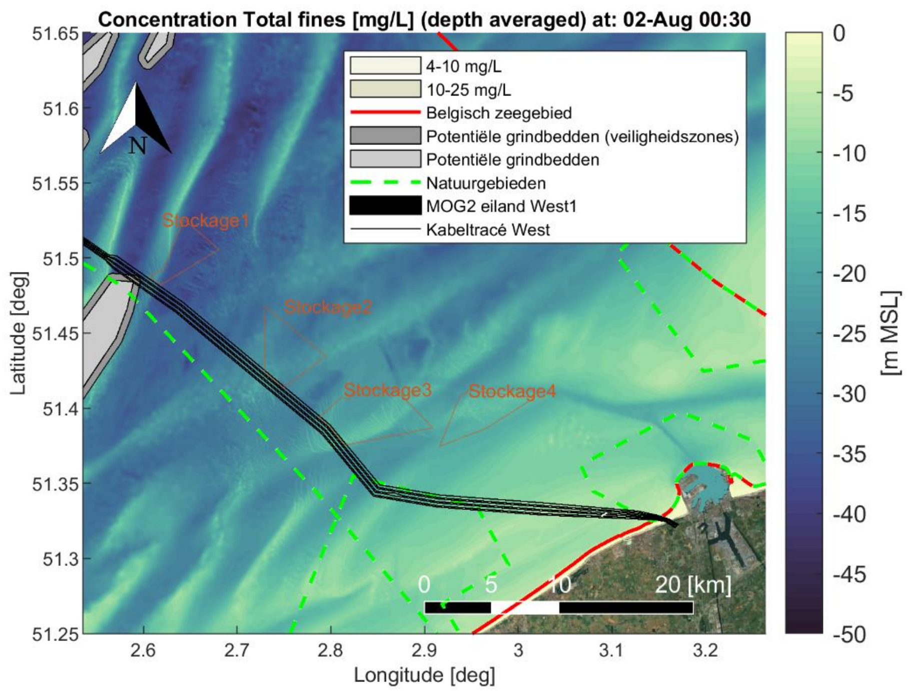

Figure Annex B-2 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

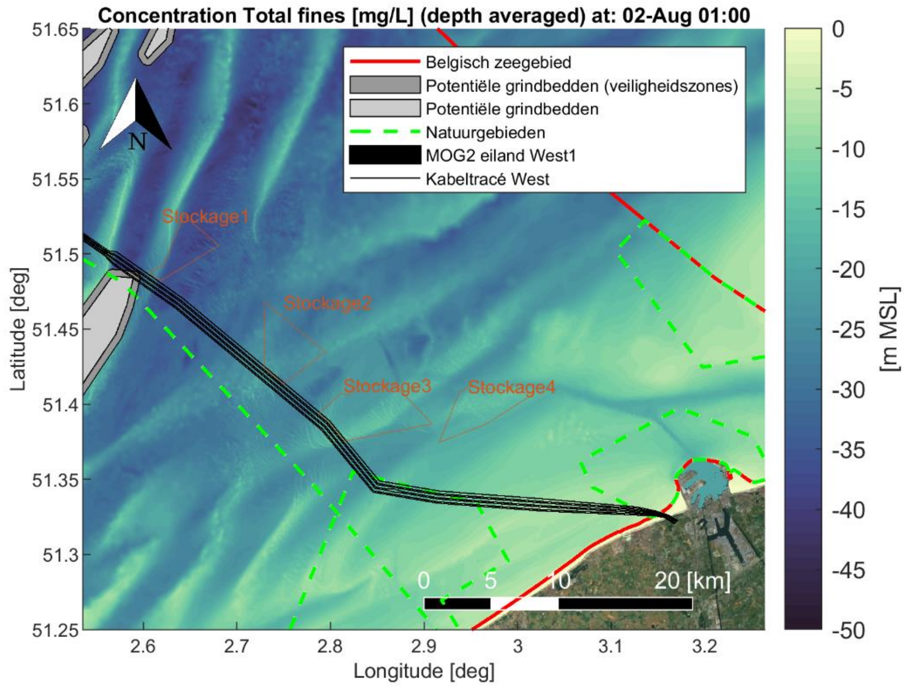

Figure Annex B-3 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

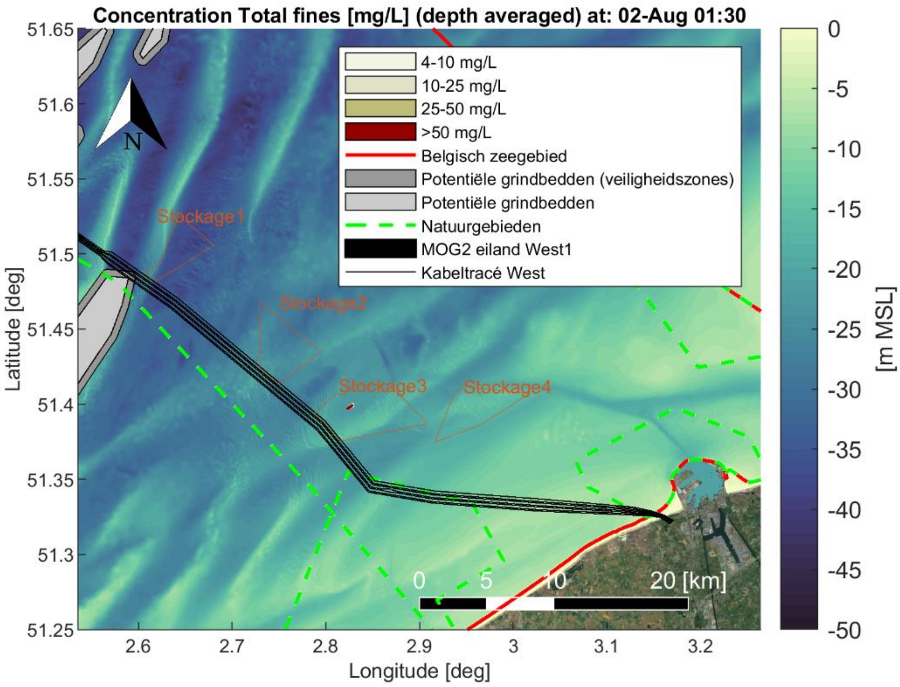

Figure Annex B-4 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [μm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

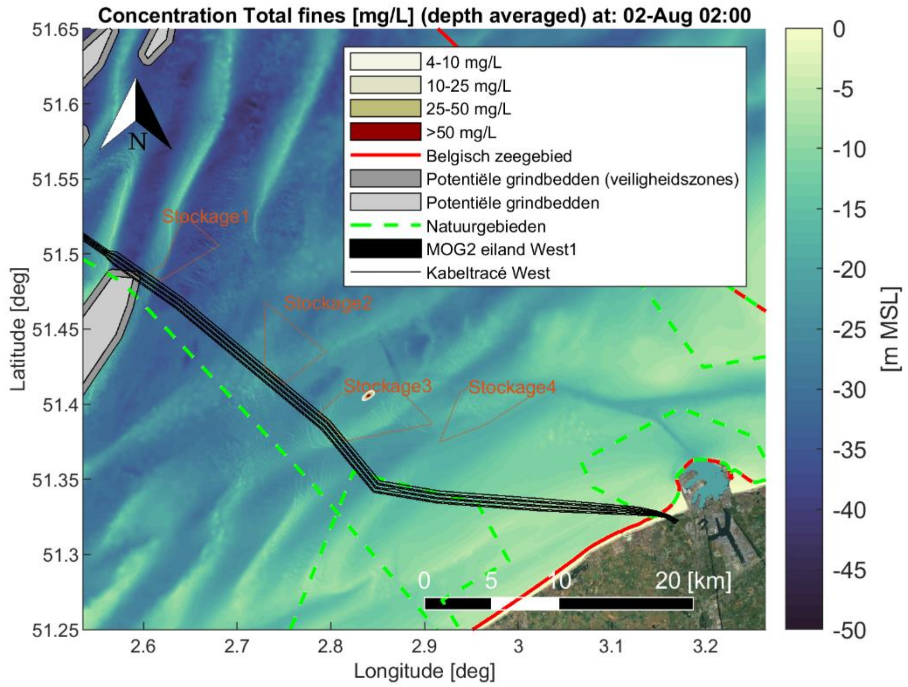

Figure Annex B-5 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [μm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

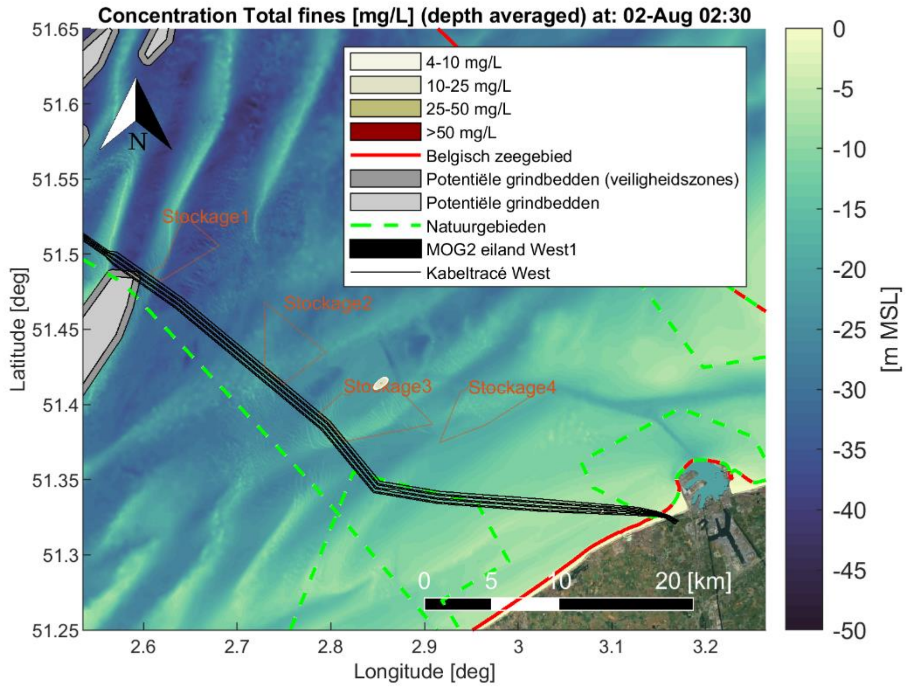

Figure Annex B-6 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

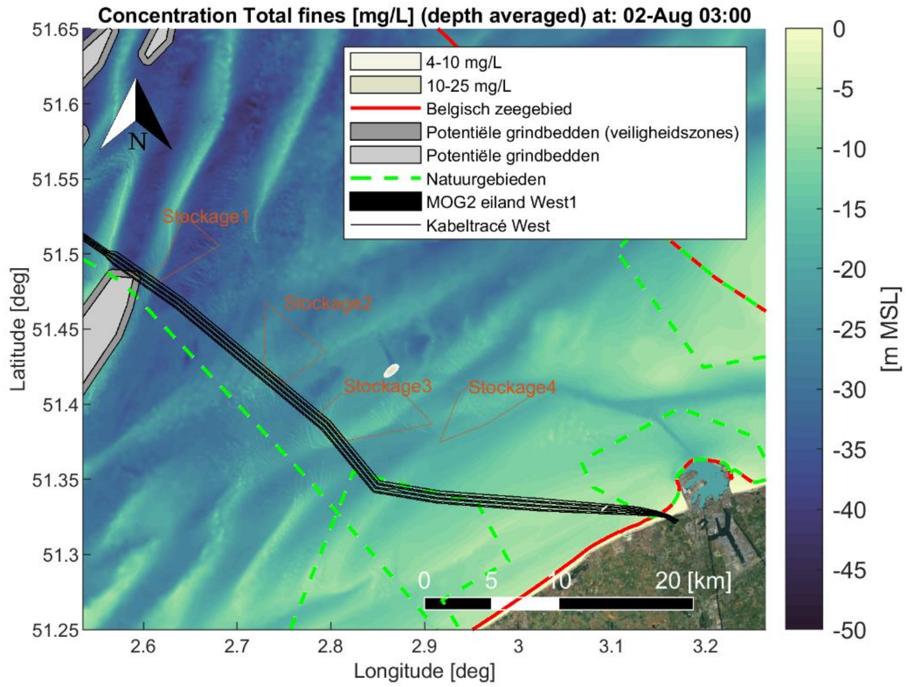

Figure Annex B-7 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

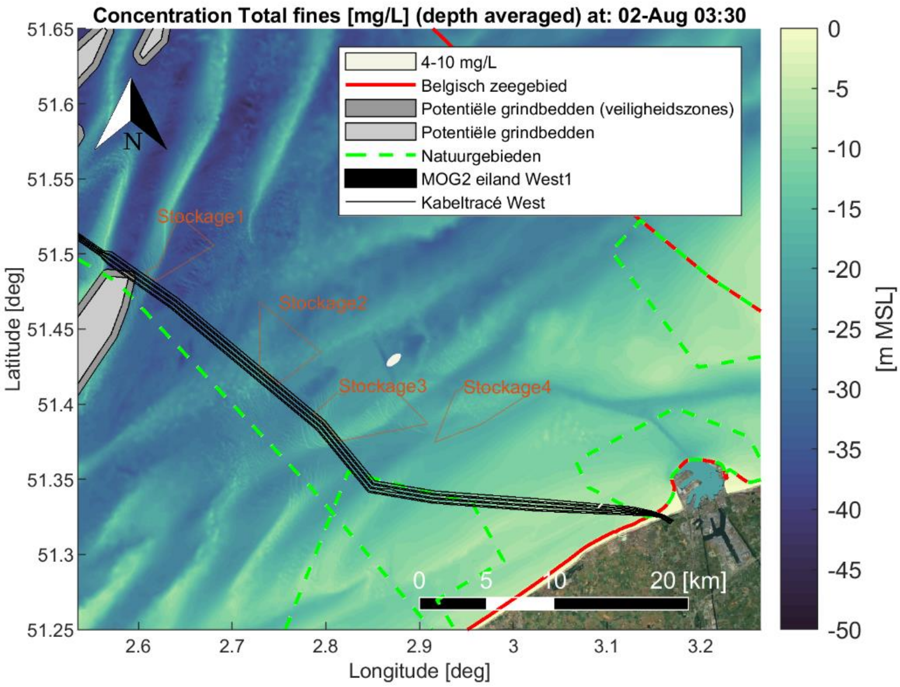

Figure Annex B-8 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

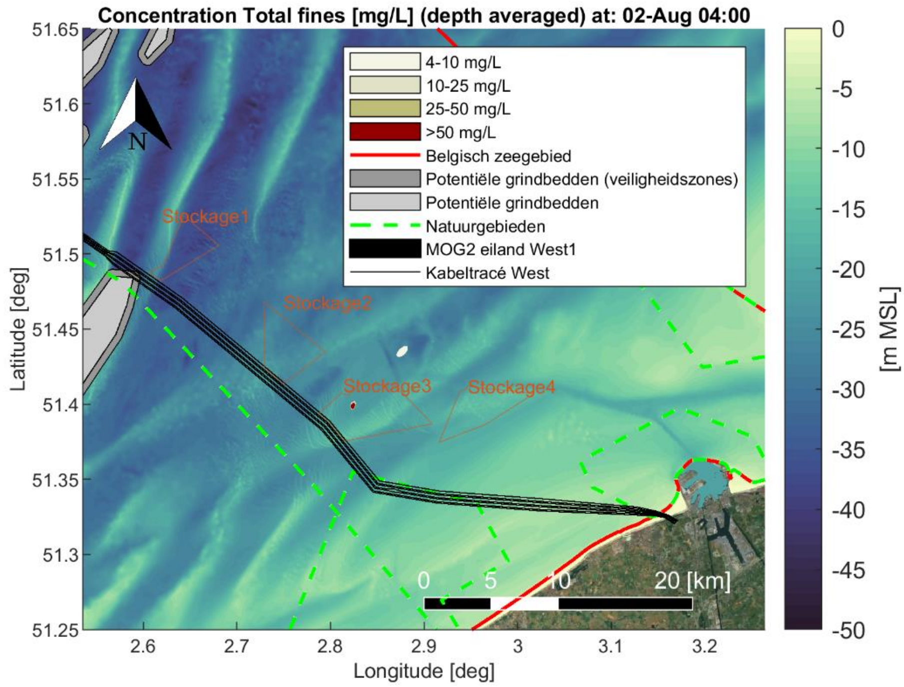

Figure Annex B-9 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

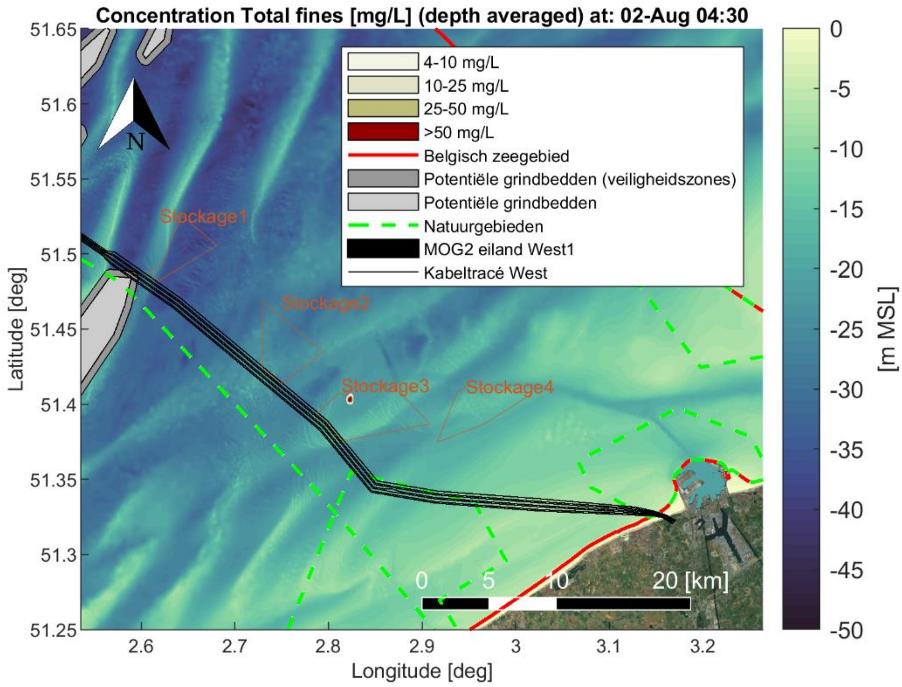

Figure Annex B-10 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

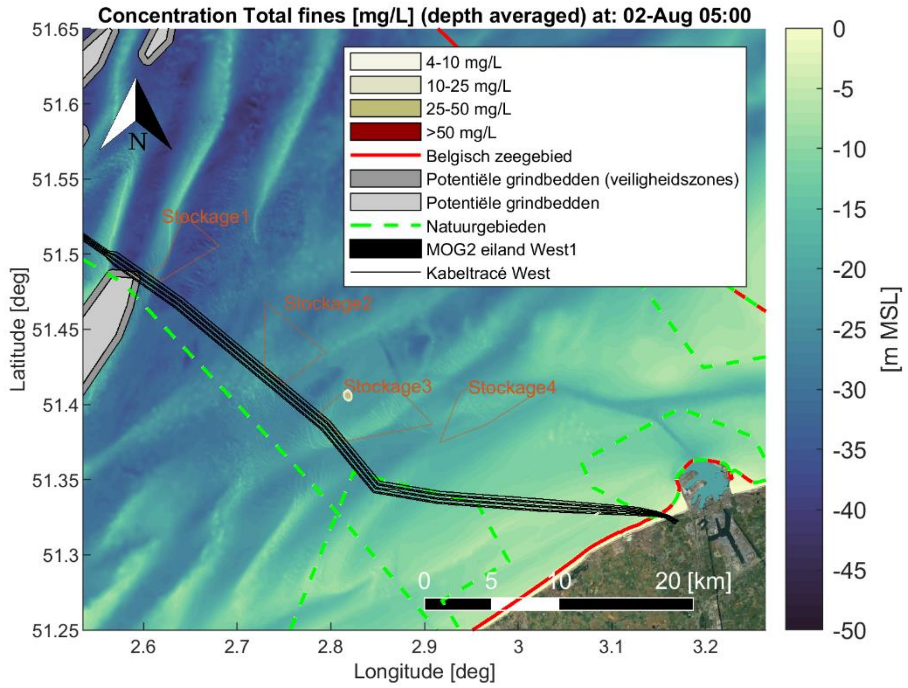

Figure Annex B-11 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [μm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

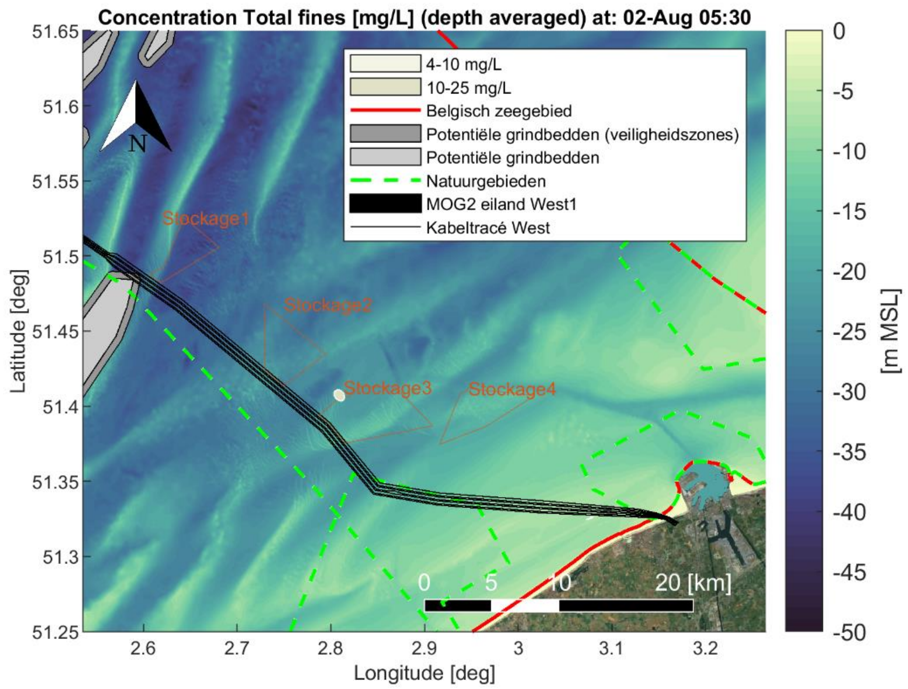

Figure Annex B-12 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

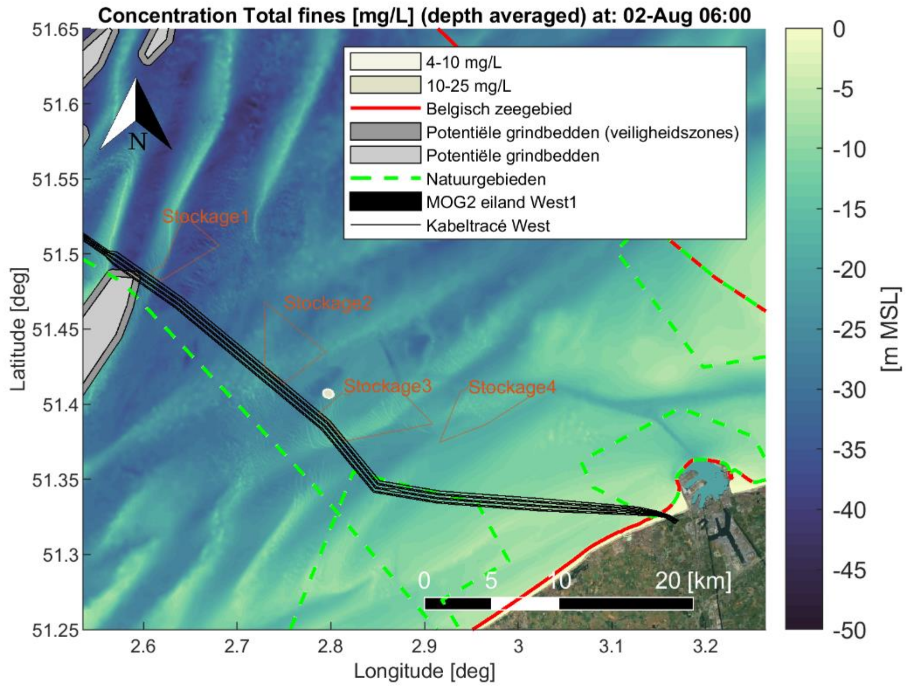

Figure Annex B-13 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

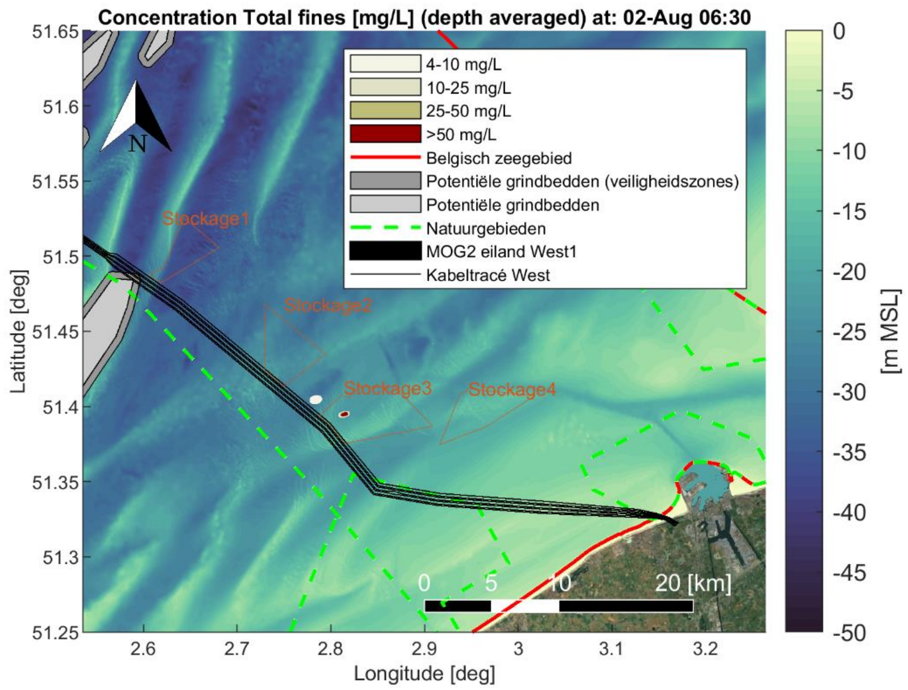

Figure Annex B-14 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

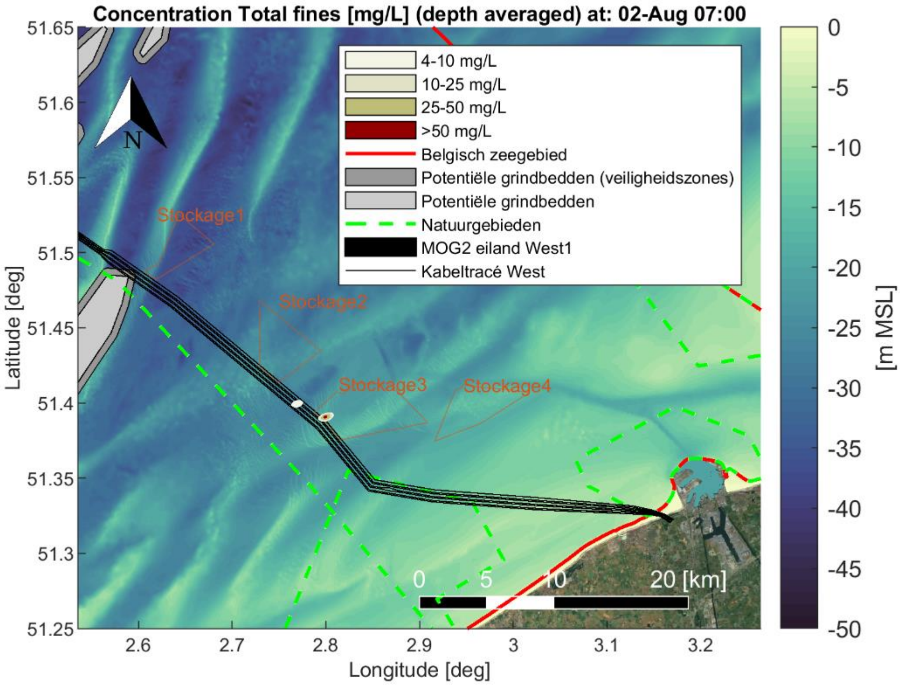

Figure Annex B-15 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

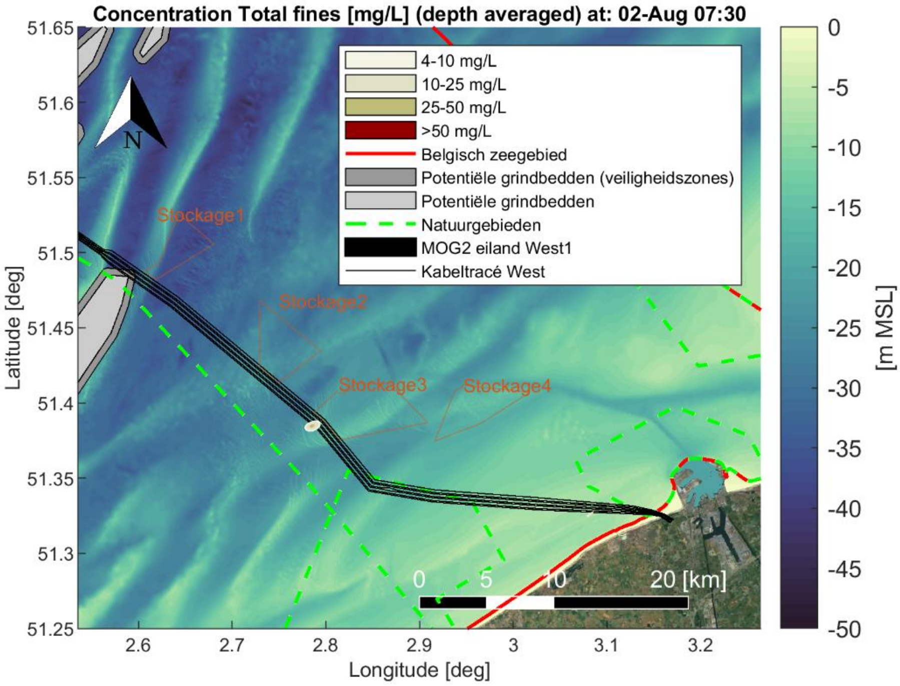

Figure Annex B-16 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

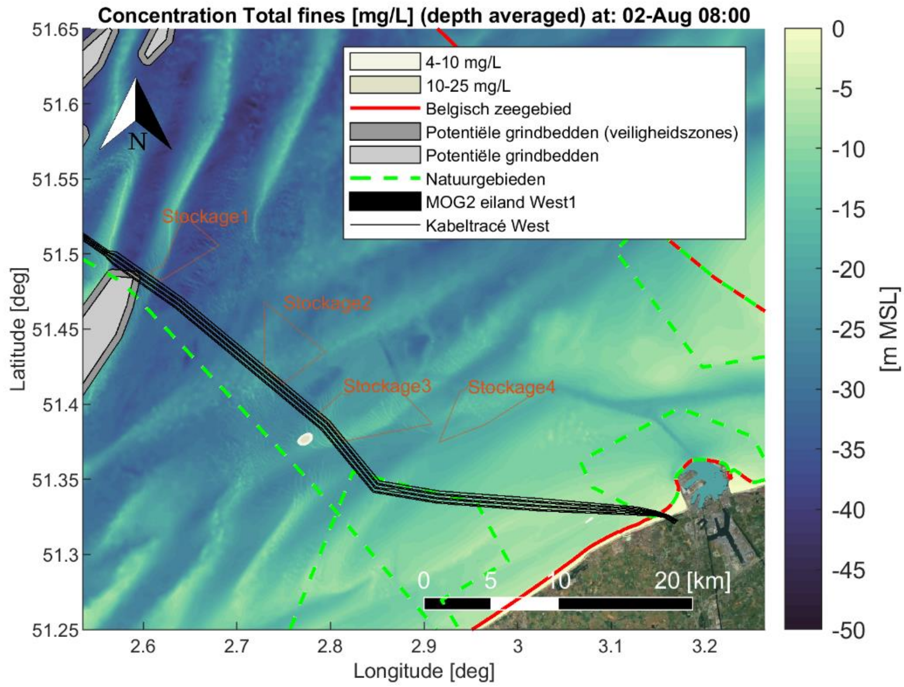

Figure Annex B-17 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

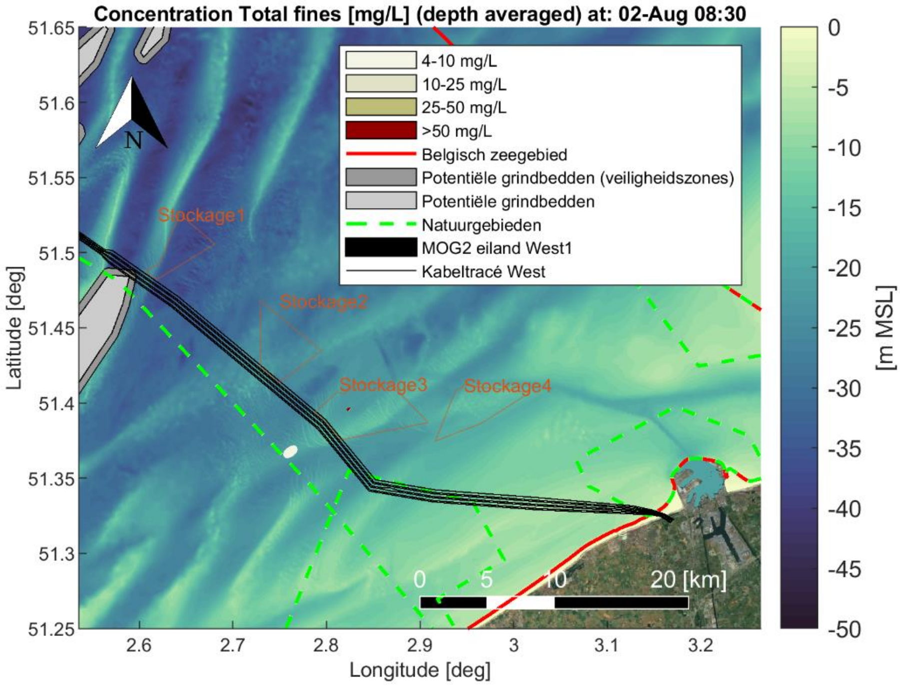

Figure Annex B-18 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

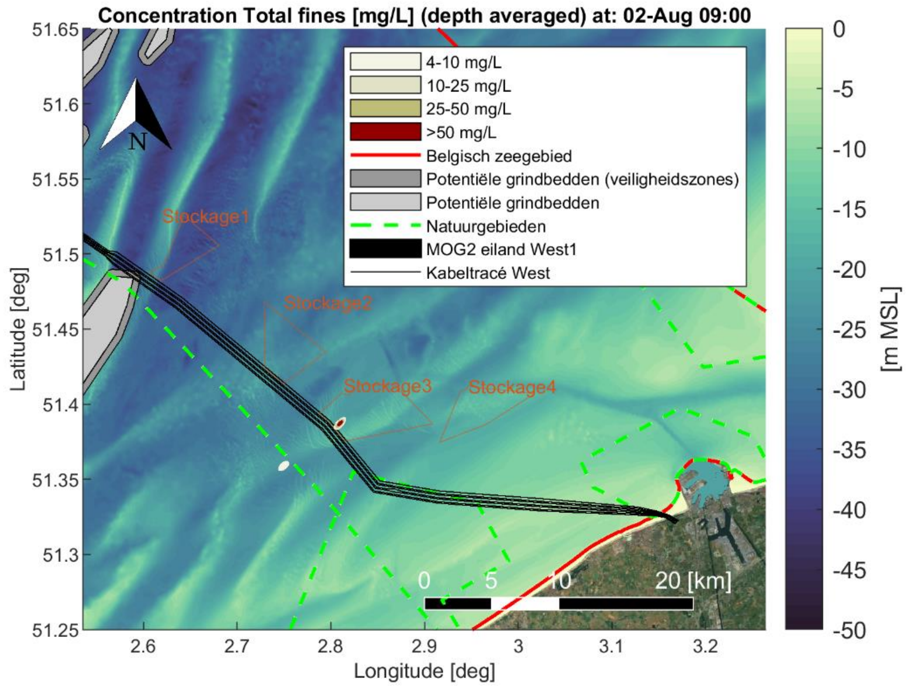

Figure Annex B-19 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

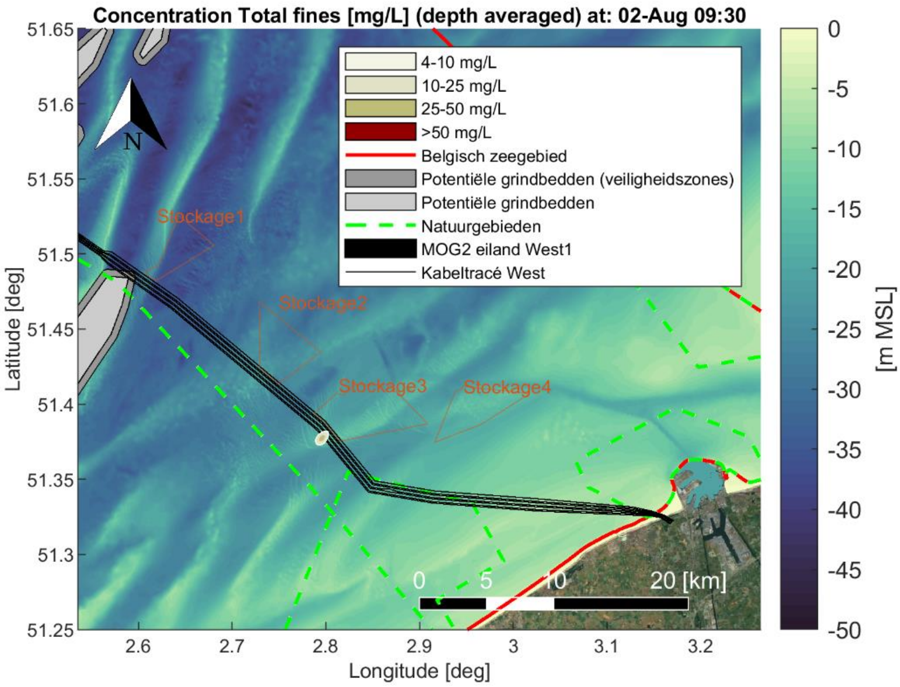

Figure Annex B-20 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

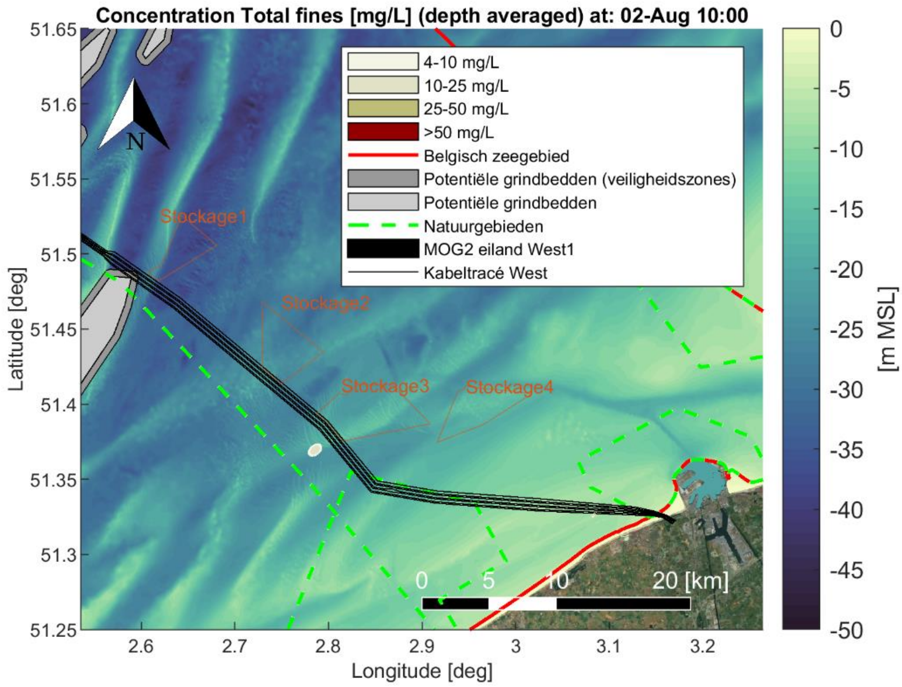

Figure Annex B-21 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [μm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

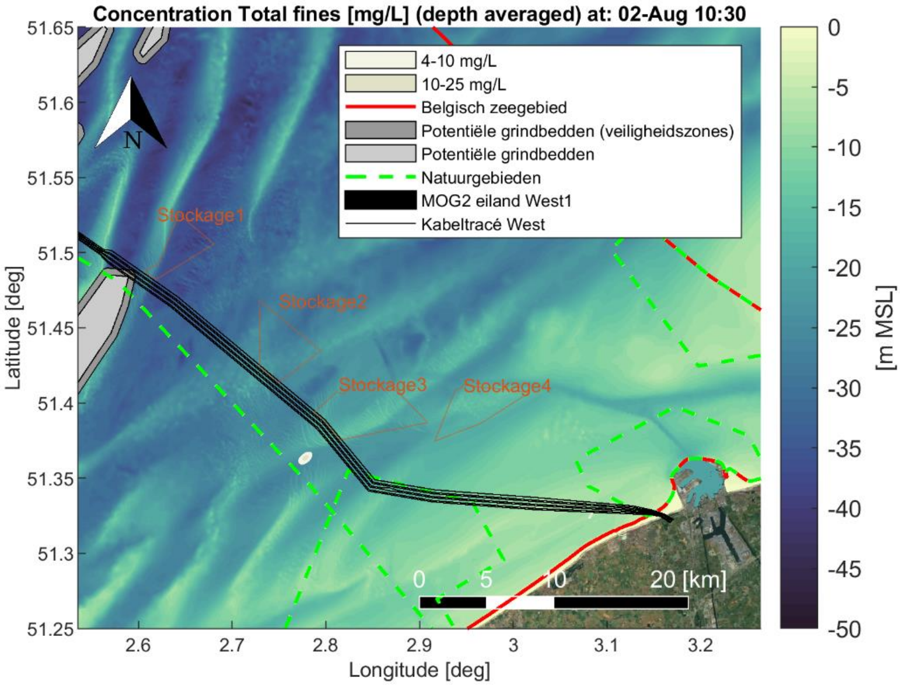

Figure Annex B-22 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

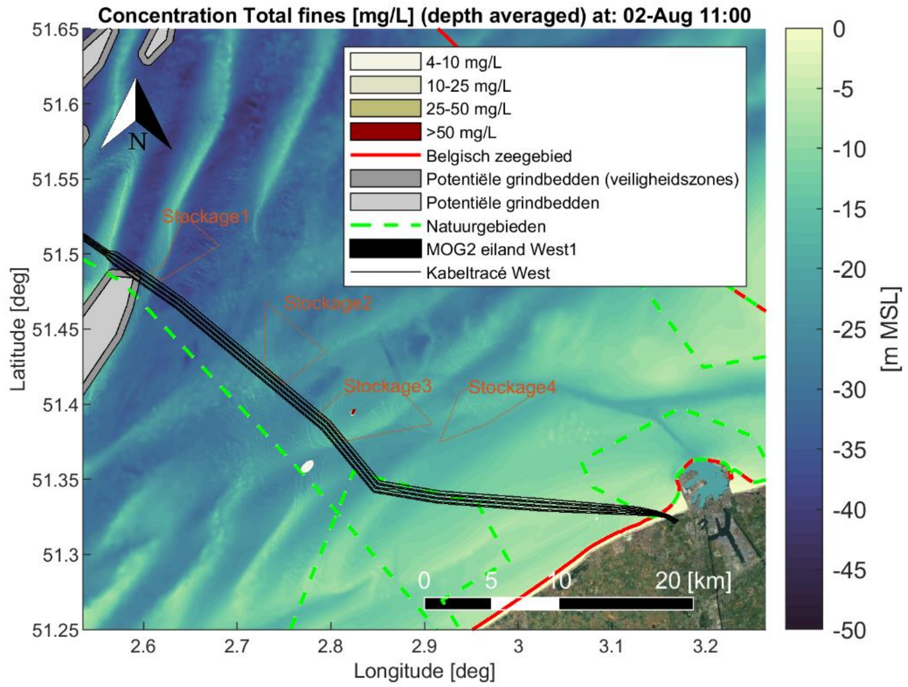

Figure Annex B-23 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

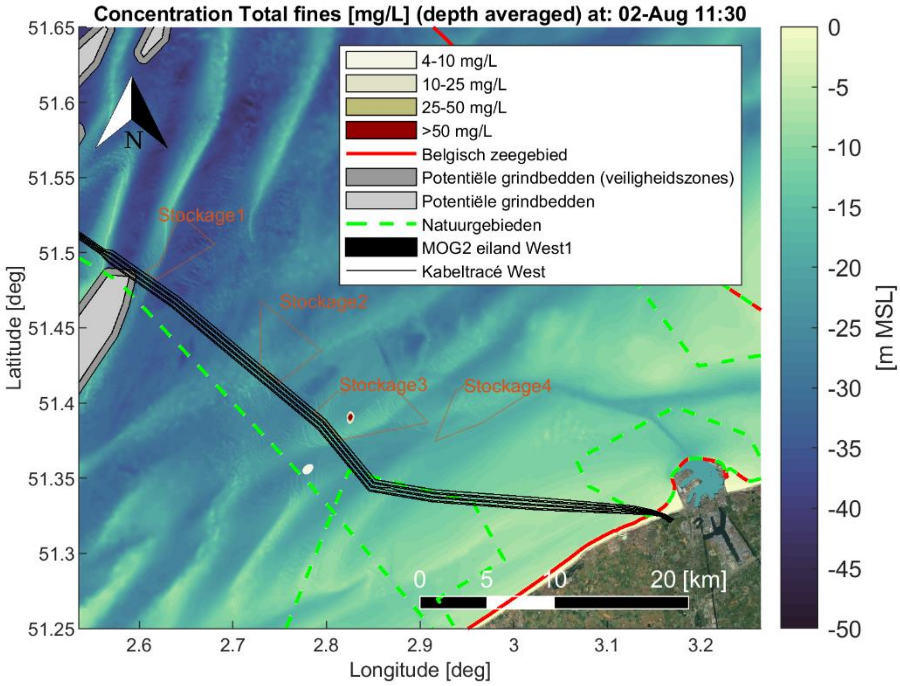

Figure Annex B-24 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

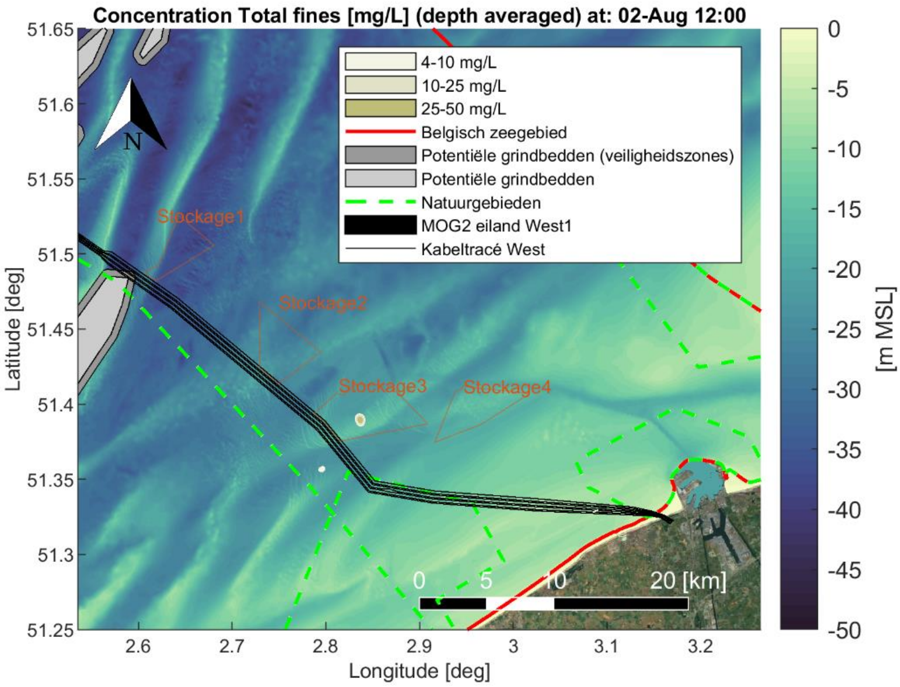

Figure Annex B-25 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).

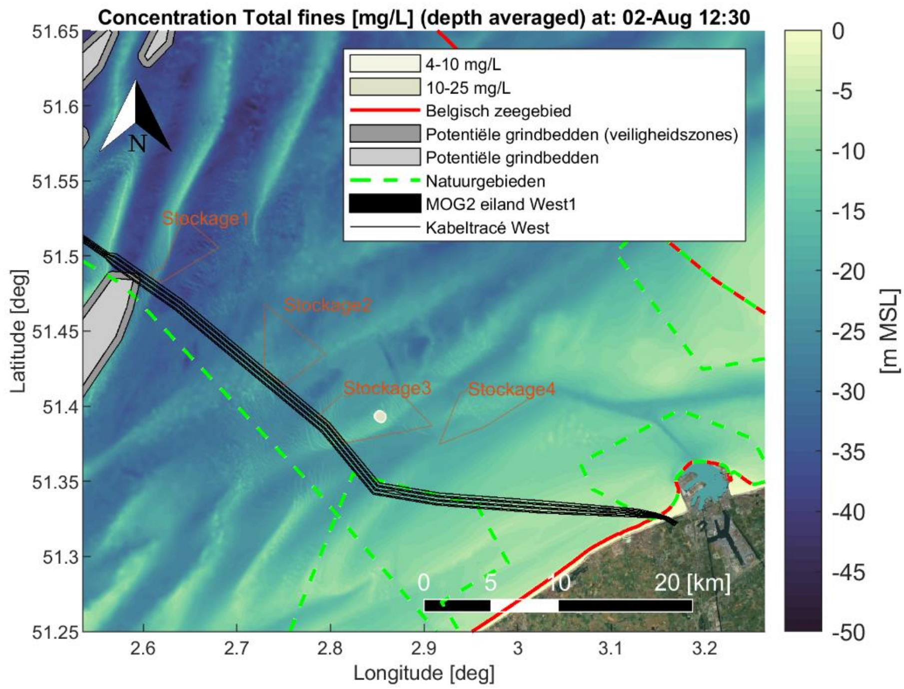

Figure Annex B-26 Map showing encountered depth averaged sediment concentration [mg/L] of fine material (< 250 [µm]) during a time instant of the simulation period. Scenario: Dredging cable trenches (trench1 section) and disposal at a temporary disposal site (Stockage3).