Appendix no. 3

Model-calculations results

Suspended solids dispersion
in the OWF Baltica Area

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Abbreviations and definitions

AWAC	Acoustic wave and current (profiler) manufactured by Nortek
Baltica OWF Area	The Area of the Baltica Offshore Wind Farm
DHI	Danish Hydraulic Institute
Forcing	The assumed impact on numerical models
HD	The hydrodynamic module integrated in MIKE model
HIRLAM	High resolution limited area model – a mesoscale weather model
HIROMB	High Resolution Operational Model for the Baltic Sea – a hydrodynamic forecast mode
MT	The mud transport module integrated in MIKE model
SW	The spectral wave module integrated in MIKE model
Principal/Investor	Baltica-2 Wind Farm LLC (*Elektrownia Wiatrowa Baltica-2 Sp. z o.o.*) and Baltica-3 Wind Farm LLC (*Elektrownia Wiatrowa Baltica-3 Sp. z o.o.*)

1 Non-specialist synopsis

This report concerns the propagation of suspended matter in sea deep and its deposition on the seabed, describes the numeric models used for calculations, as well as includes a set of calculation results carried out using these models.

Different variants of suspended matter propagation will be presented, their concentration and deposition of sediment during works related with preparation of the seabed for setting support structures of wind power stations and burials of energy and teletechnical cables.

A numeric model was constructed to represent suspended matter transportation in a dynamic marine environment when carrying out subsea and dredging works at seabed in the area intended for the implementation of the Baltica OWF project.

The created model was used to analyse maximum distances reached by suspended matter of specific concentrations travelling in water (created during long-term works at the seabed), as well as thicknesses and range of deposition of this suspended matter on the seabed. Variant calculations were carried out, with different data regarding the type of soil where seabed works were carried out, as well as the size of the base of the settled support structure and the depth at which they were carried out.

Force conditions were assumed and applied in the model, in a form of winds blowing over the entire surveyed sea area as well sea currents which are natural factors that force the movement of water and at the same time the travel of suspended matter in the sea deep.

The results of calculations unambiguously indicate that the works carried out on cohesive soil seabed cause greater impact of suspended matter on marine environment than works on non-cohesive soils (it will be noted that in surface layers of the seabed areas in question, there is an insignificant prevalence of cohesive soils). Concentrations of suspended matter when carrying out works related with settlement of foundations reach value higher than concentrations present when laying energy cables. Therefore, higher concentration values may be taken into consideration in analyses because the above-mentioned actions (works) take place in the same areas, but at a different time. When determining thickness of newly created sediments, the effect of both types of actions is added up.

The conducted analyses lead to a conclusion that, e.g. the highest impact of suspended matter occurred at moderate winds with a constant direction, while the highest suspended matter concentrations were generated at currents of smallest speeds (in the area of several $cm \cdot s^{-1}$) and of a circulating current type. At the same time, suspended matter impact on marine environment in the least favourable scenario does not last longer than 42 hours, counting from the moment the works at the seabed are started at a single foundation.

2 Introduction

This report was carried out on commission of the Baltica-2 Wind Farm Sp. z o.o. and Baltica-3 Wind Farm Sp. z o.o. The goal of the report was to determine the concentration of suspended matter in the sea deep and the manner of its distribution and deposition on the seabed when performing works related with seabed preparation (possible soil replacement) for works regarding foundations of offshore wind power stations. At the current stage, there have been no decisions regarding the manner of setting foundations, the analyses are carried out using an envelope method, which is the worst possible technological and hydrological scenarios regarding the Baltica OWF project are considered. The experience gathered during the implementation of this type of projects indicates that the installation of heavy gravity Based Structures is, from the point of view of suspended matter impact, the least beneficial case both during the analysis of the Investor's variant, as well as a rational alternative variant. The remaining types of support structures considered for application in the analysed wind farm are the following structure types: jacket, monopile and tripod, as well as floating structures, particularly tension leg platforms and semi-submersible structures.

The primary task involved the development of a numeric model which would make it possible to assess the impact of suspended matter during the performance of installation works, that is at the construction stage. The impact of this stage caused by anthropogenic factors will occur in the highest concentration at the construction stage and will not be present during the exploitation stage. However, its degree in the liquidation stage is considered negligible.

Within the framework of works implementation, the following were carried out:

- analysis of hydrological and hydrodynamics conditions;
- preliminary analysis of soil conditions in the Baltica OWF Are based on available test results;
- construction of a numeric model using the MIKE 21 software;
- calculations of the assumed scenarios;
- summary of the carried out calculations.

This report deals with the analysis of hydrodynamic processes that take place during the implementation of subsea works related with the preparation and levelling of the seabed for foundations of support structures (dredging works) as well as works related with laying and burying energy and teletechnical cables in the seabed. The primary studied phenomenon was the process of spreading fine grained sediments suspended in the sea deep. The factors vital from the point of view of the assessment are both the suspension concentration as well as the spatial range impacted by sediments entering suspended state as a result of investment works. Another important aspect in the scope of impact on benthos habitats and benthos fauna is the assessment of its sedimentation.

3 Methods

3.1 General issues

Numeric calculations were carried out using a licensed, Danish software bundle MIKE 21 Coupled Model FM. It is a calculations bundle that has been developed in the Danish Hydraulic Institute for many years, intended for calculations of flows, wave motion, transportation of sediments in a sea coastal zone and in open sea. The Coupled version makes it possible to dynamically simulate hydraulic phenomena with interaction of all modules used. This software is widely used all around the world (e.g. Burcharth et al. 2007).

For the purposes of calculations related with the transportation of suspended sediments that are generated during dredging works related with the preparation of the seabed for settlement of gravity-based support structures of wind power stations as well as during works that accompany burying energy and teletechnical cables in the seabed, the following modules were used:

- hydrodynamic module (HD);
- spectral wave module (SW);
- mud transport module (MT).

A hydrodynamic module (HD) makes it possible to simulate the variability of the current field and the location of the water table level, depending on various forcing functions in sea areas. This module will make it possible to include the following hydraulic effects in the calculations (MIKE 21 HD, 2013):

- friction at the boundary of water and seabed (seabed roughness) and of water and atmosphere (wind action);
- discontinuities in the form of sources and releases;
- geometric variability of the submerged area, caused by the variability of the water table level;
- radiating strains caused by wave motion.

A spectral wave module (SW) makes it possible to calculate wave field parameters (wave height and period as well as its direction) generated by wind of variable direction and speed. In the performed calculations, in the initial phase, the test were made of direct impact of wave motion on propagation of suspended matter created as a result of works carried out in marine environment. However, taking into account the assumption that this type of works may be carried out only at small wave motion (limited to $H_S \approx 1.5$ m), it was concluded that the impact of wave motion for such conditions is negligibly small.

The mud transport module (MT) describes erosion, transportation and sedimentation of the smallest soil fractions caused by the impact of sea currents and wave motion. The MT module may be used both for silty and loamy sediments and for a mixture of these sediments with sand, with fine fractions prevailing, and cohesion is a significant feature that characterises such a mixture (MIKE 21 MT, 2013).

The following was taken into account and defined in simulations:

- most importantly sea currents as the main factor that forces the transport of suspended matter in the sea deep;
- the process of sediment descending due to their physical structure: descending of single particles and descending of flocculent particles.

A methodical creation of the numeric model involves defining the boundaries of the area regarded in the calculation and creation of a numeric mesh relevant to the surveyed phenomenon. At the boundaries of the model, physical conditions (called boundary conditions) for each of the considered phenomena have to be defined. These conditions may originate from other models, from actual measurements or may be formulated in an artificial manner in order to analyse variable forces in time and the ones that actually appear in marine environment. When introducing at model boundaries conditions obtained from the calculations, it is recommended to verify these values with measurement data, provided they exist. The results of preliminary *in situ* surveys carried out at the area for which the numeric model was created made it possible to recreate the features of the environment in a more accurate manner. It concerns both hydrodynamic conditions and the characteristics of sea sediments in which the dredging works are carried out.

3.2 Calculation assumptions

Bathymetric conditions in the considered Baltica OWF Area were calculated by the Maritime Institute in Gdańsk and, after digital processing, assumed in the numeric module. Depths are diverse and range between 25 m and 56 m. The measured depths were assigned to the calculation mesh of the model.

Direct measurements of hydrodynamic and physico-chemical parameters in the Baltica OWF Area were carried out in the period from March 2016 to April 2017. Wind speed variability from a large-scale model for this period is presented in Figure 1, while the significant wave heights measured using an Acoustic Waves and Currents (AWAC) profiler in the Baltica 2 OWF Area are presented in Figure 2. The location of measurement points is presented in figure (Figure 3). As the dredging works may be carried out only in moderate wave motion conditions (H_S < 1.5 m) (Grundlehner et al. 2003), two months were selected in order to carry out the modelling calculations (June–July, marked on Figure 1) from the period when wave motion is the weakest from the statistical point of view (the spring-summer period). There is no purpose in modelling the winter months, because these months include too many days with intensive wave motion which hinders the operation of the equipment. Dredging works in actual conditions may be carried out in any season, as long as the weather permits it.

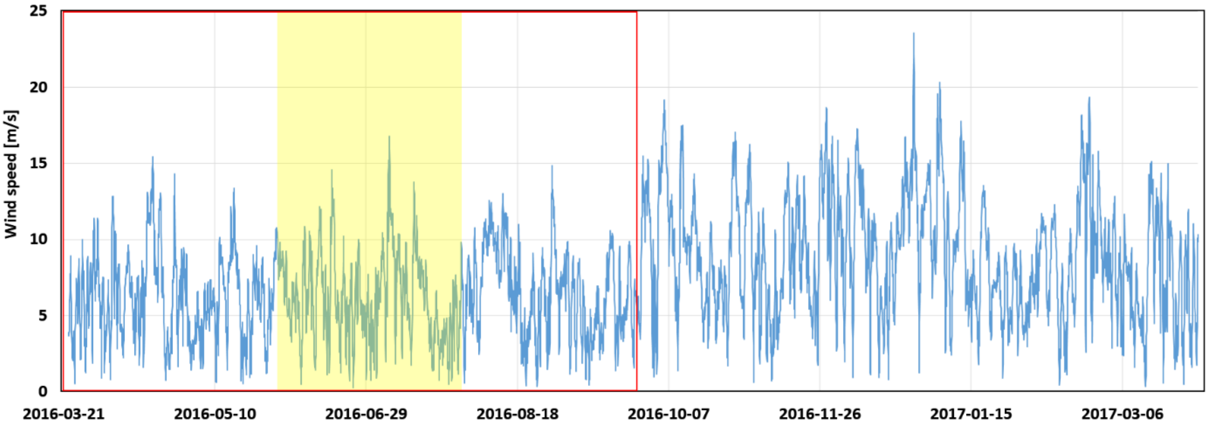

Figure 1. The wind speed distribution in the period of measurements in the Baltica OWF Area from the HIRLAM model

Selected periods: red enclosure – spring-summer period, yellow background – calculation period
Source: internal data

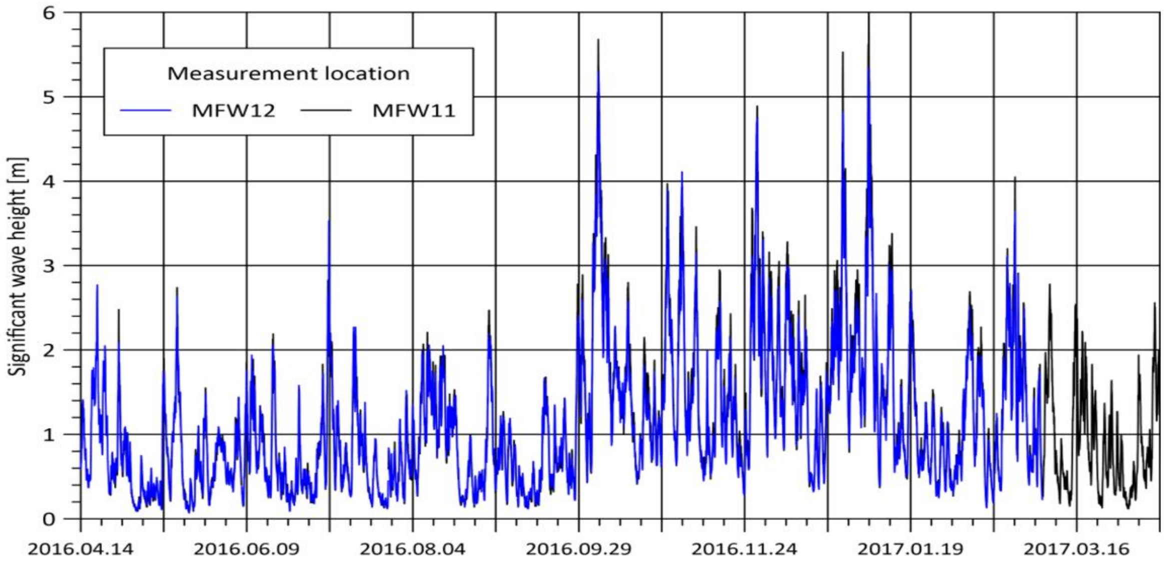

Figure 2. Wave motion measured in the Baltica 2 Area in points MFW11 and MFW12

Source: internal data

The boundary condition at the boundaries of the model defines the forces that cause the transport of suspended matter in sea deep. In the case of the considered phenomenon these are sea currents, water table variability and wind impact. The first two ones were introduced at the boundaries of the model in a form of a boundary condition of a Flather type, taking into account the sea level and the current speed components (*u, v*) as variables in time (using data from the local HIROMB model). The fact that the current speed is compatible with the current speed obtained from the regional HIROMB model and the speed measured with an acoustic profiler serves as a confirmation that the decision was correct. A graph presenting current values obtained from a regional model and from the AWAC device for the entire measurement period in the MFW12 location (Figure 3) is present in the Figure 4. A vast majority of current speeds does not exceed the value of 0.2 $m \cdot s^{-1}$, and only occasionally, during storms, maximum speeds reach the value of 0.5 $m \cdot s^{-1}$. The wind impact is introduced as a forcing factor acting above the modelled area.

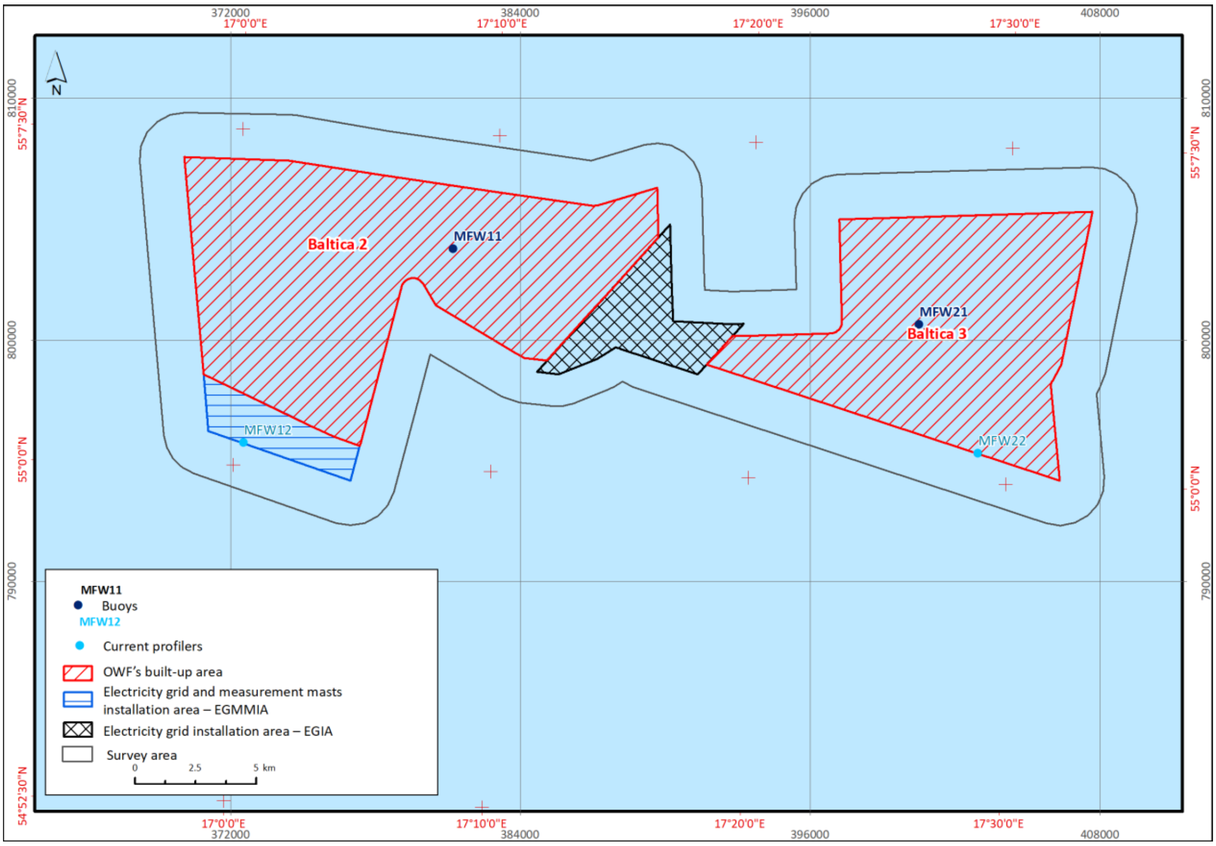

Figure 3. Location of measurement points in the Baltica OWF Area

Source: internal data

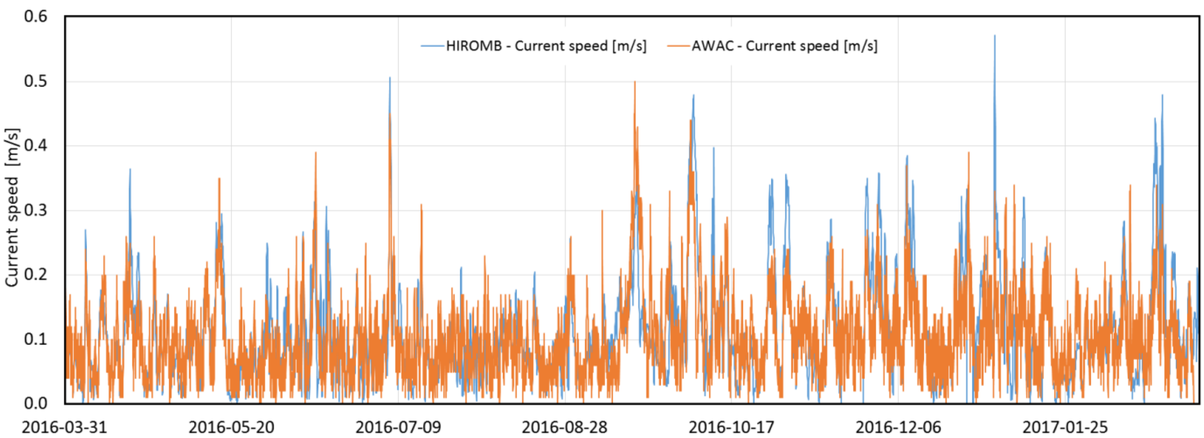

Figure 4. The current speeds from the model and the ones obtained from measurements (lines: blue and orange) in the place where the AWAC MEW12 measuring instrument was placed

Source: internal data

Grab dredgers were assumed as the equipment type used for dredging works. It was assumed that dredgers will work 24 hours a day, 7 days of the week. It was assumed that the share of fractions entering suspension state equals 3% in case there are works carried out in sandy soils and 15% for works carried out in the recognised cohesive soils. Experiments by people who carry out and implement these types of calculation simulations (*Technical Project Description for Offshore Wind Farms*, Energinet.dk 2015) indicate that these estimates are conservative. Sediments that enter the suspension state will be evenly propagated in the entire water column.

In the model, removal of sediments that enter suspended matter state was located in places where dredgers work at the foundations.

The Table 1 presents parameters that characterise the Investor's variant and the rational alternative variant, differing primarily in the size of the foundation base and a total number of wind power stations.

Table 1. Assumptions for dredging works at a gravity-based support structure

Specification	**Scenario**	
	The rational alternative variant	**The Investor's variant**
Shape of the foundation base	Round	Round
Diameter of the foundation base [m]	35	40
Diameter of a protective layer against seabed erosion [m]	65	70
Maximum trench thickness [m]	3	3
Total volume of removed soil for 1 foundation [m^3]	3990*	5010*
Number of foundations	344	234
Total volume of soil intended for removal [m^3]	1,372,560	1,172,340
Dredging method	Grab dredger	Grab dredger
Distribution of suspended sediment	Water column	Water column
Amount of material entering suspended matter state [%] (fine fractions: silt and loam) – sandy seabed	3	3
Amount of material entering suspended matter state [%] (fine fractions: silt and loam) – cohesive soils seabed (scourable)	15	15
The assumed soil thickness in dry state [$kg \cdot m^{-3}$]	1800	1800
Total volume of suspended solids [m^3] – sandy seabed	41,177	35,170
Total volume of suspended solids [m^3] – cohesive soils	205,884	175,851
Time of performing a trench for 1 structure [h]	24	24
Effectiveness of dredging works [$kg \cdot s^{-1}$]	83	104
Intensiveness of suspended matter generation [$kg \cdot s^{-1}$] – sandy seabed	2.5	3.1
Intensiveness of suspended matter generation [$kg \cdot s^{-1}$] – cohesive soils seabed	12.5	15.6
The number of dredgers	3	2

**Volume calculated in accordance with the formula for volume of a truncated cone $V = 1/3*\pi*h*(R^2+Rr+r^2)$, where R and r are the radios at the top and the bottom of the cone, respectively, and h is its height*
Source: internal data

A diversified number of operating dredgers results from the assumption based on a comparable time of performing dredging works for both of the considered performance variants.

The second operation carried out during the implementation of wind farms which had a direct impact on the generation and propagation of suspended matter is laying and burying energy cables that connect specific wind power stations. The main assumption regarding the schedule of works (resulting from the experience gathered from the already finished wind farms) is a gap between finishing the works related with the preparation of the basement for the foundation and starting the subsea works that involve burying the cable for a specific wind power station. It was assumed that burying the cable will take place 2 weeks after the dredging works are started at the foundation. This period is intended primarily for setting the support structure and the remaining installation works. As a result, there is no possibility that both actions analysed in the model (preparatory works for the foundations and laying the cable) for a specific wind power station are carried out simultaneously. Consequently, the suspended matter agitated by works at foundations will settle at the seabed before cable laying in the vicinity of the analysed wind power station starts in each possible case.

The calculation model assumed that cables will be buried 3 m under the seabed, using a jetting method, with the use of devices that apply energy of multi-point water jets. During such an action, water entering the processed area at a large pressure washes out the finest fractions from the soil contained within an area of a trapeze section above the energy cable. Parts of fine fractions washed out this way enter the suspended state in the sea deep.

The geological and geotechnical works carried out earlier in the OWF Baltica Area made it possible to assume in the numeric model, for the purposes of a variant, the types of sea sediments present on the seabed in the place where works are carried out. In calculation simulations, the movement of machines for burying cables was taken into account.

The Table 2 presents the parameters that characterize subsea works related with laying cables in both variants – in the Investor's variant and a rational alternative variant.

Table 2. Assumptions for laying energy cables inside a field

Specification	**Scenario**	
	The rational alternative variant	**The Investor's variant**
Internal cables of the Baltica OWF [km]	638*	418*
Burying of cables in the seabed [m]	3	3
Width of the seabed strip covered by the works [m]	3	3
Cable laying method	Jetting	Jetting
Total volume of the seabed covered by the works [m^3]	1,173,920	769,120
Amount of material becoming suspended [%] (fine sediments only) – sandy seabed	3	3
Amount of material becoming suspended [%] (fine sediments only) – seabed consisting of cohesive soil (softening prone)	15	15
Pace of works (m/day)	1000	1000
Removed mass of sediments [t] – sandy seabed	63,392	41,532
Removed mass of sediments [t] – cohesive soils seabed	316,958	207,662
Intensiveness of suspended matter generation [$kg \cdot s^{-1}$] – sandy seabed	2.3	2.3
Intensiveness of suspended matter generation [$kg \cdot s^{-1}$] – cohesive soils seabed	11.5	11.5
Number of vessels	3	2
Cable laying duration [days]	106	105

**Maximum values indicated by the Requestor*

Source: internal data

Similarly to foundations, a differentiated number of operating watercrafts results from the assumption based on a comparable time of burying cables for both considered performance variants.

The model takes into account fine fractions of sediments below 64 μm, assuming the sediment particles with larger diameters will fall to the seabed instantly, not entering the state of suspension in the sea deep. It is a so-called “redundant” model, which means that only the sediment that was introduced in the suspended state is modelled. The modelling does not take into account the suspended matter that is a natural background in the considered marine environment. 0.5 $mm \cdot s^{-1}$ was assumed as a value of sediment unconstrained fall speed, which corresponds to the average size of silt grains. The critical value of shear stresses for the start of erosive processes equals 0.1 $N \cdot m^{-2}$. Hence the sediment deposited above this value will undergo the resuspension process. Threshold shear stress of settling was set to 0.07 $N \cdot m^{-2}$. It is a shear stress value below which the sediment starts settling on the seabed.

4 Assumed calculation scenarios

After the bathymetric surveys of the seabed were carried out in the Baltica OWF Area and seabed sediments deposited in this area were analysed, it was decided that the sea area will be divided into characteristic subareas that differ in water depth and type of sediments. Due to bathymetric concerns, the first area includes depths from 23 to 30 m, the second from 30 to 45 m, while the third from 45 to 52. Such a depth division takes into consideration the specific character of seabed sediments (Figure 5).

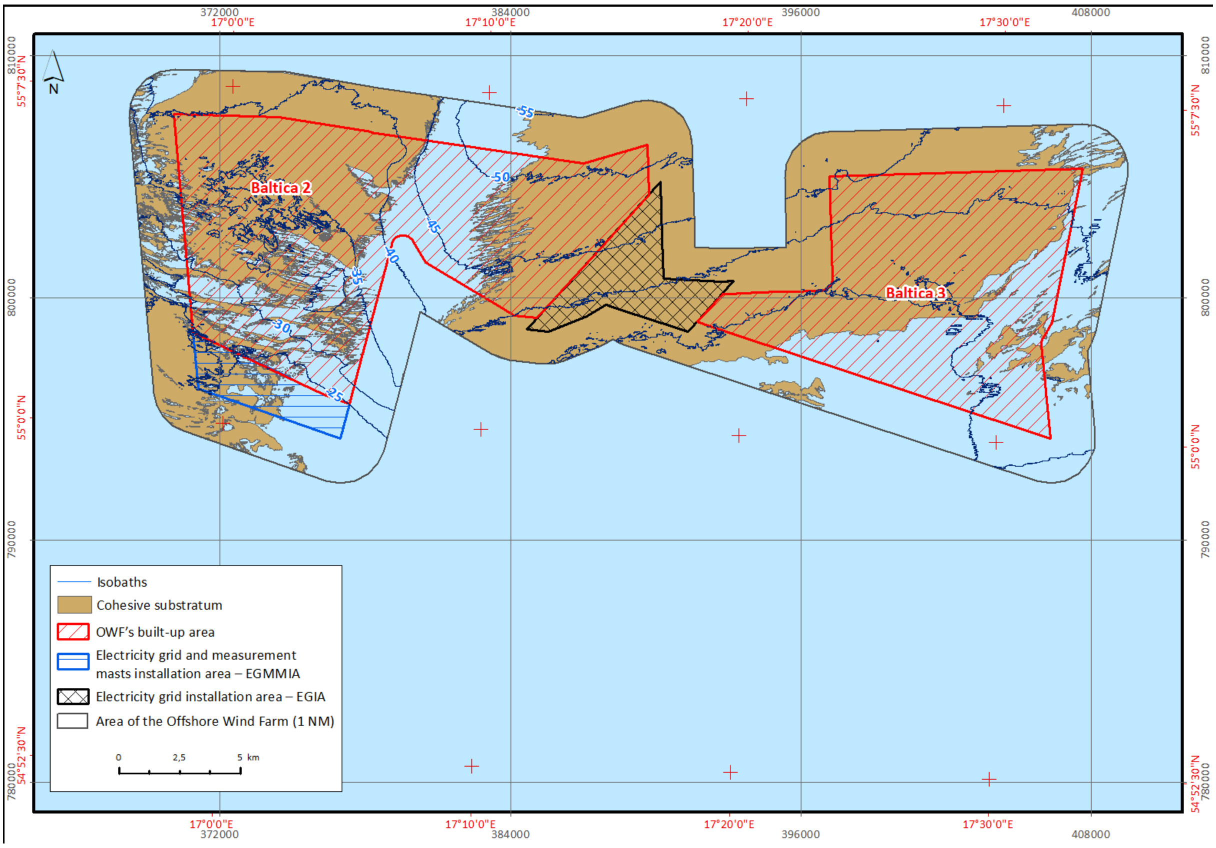

Figure 5. Bathymetric division of the sea area in the Baltica OWF Area and types of seabed sediments

Source: internal data

The performance of dredging works (levelling the seabed/replacement of low bearing capacity soils) in non-cohesive soils (predominant share of the sand fraction) as well as in cohesive soils with a prevailing share of finer fractions (dust, silt) causes important differences in the size of material entering suspension state in the sea deep. Another factor that decides about classification to a specific calculation variant is the assumed amount of the foundation base.

In the assumed envelope curve method, a full set of calculations needs to be carried out for all possible variants: water depth, type of sediment on the seabed and the value of support structure base diameter. The results of calculations will be presented for all possible configurations of the parameters in question, thereby creating the following variants:

- Variant 1 (1SD) – low water depth (23 < *h* < 30 m), sediments with dominating cohesive fraction (a significant share of silty and loamy fractions), foundation base diameter ø = 40 m;
- Variant 2 (1Sd) – low water depth (23 < *h* < 30 m), sediments with dominating cohesive fraction, foundation base diameter ø = 35 m;
- Variant 3 (1ND) – low water depth (23 < *h* < 30 m), sediments with dominating non-cohesive fraction (a significant share of sand fraction), foundation base diameter ø = 40 m;
- Variant 4 (1Nd) – low water depth (23 < *h* < 30 m), sediments with dominating non-cohesive fraction, foundation base diameter ø = 35 m;
- Variant 5 (2SD) – average water depth (30 < *h* < 45 m), sediments with dominating cohesive fraction, foundation base diameter ø = 40 m;
- Variant 6 (2Sd) – average water depth (30 < *h* < 45 m), sediments with dominating cohesive fraction, foundation base diameter ø = 35 m;
- Variant 7 (2ND) – average water depth (30 < *h* < 45 m), sediments with dominating non-cohesive fraction, foundation base diameter ø = 40 m;
- Variant 8 (2Nd) – average water depth (30 < *h* < 45 m), sediments with dominating non-cohesive fraction, foundation base diameter ø = 35 m;
- Variant 9 (3SD) – significant water depth (45 < *h* < 52 m), sediments with dominating cohesive fraction, foundation base diameter ø = 40 m;
- Variant 10 (3Sd) – significant water depth (45 < *h* < 52 m), sediments with dominating cohesive fraction, foundation base diameter ø = 35 m;
- Variant 11 (3ND) – significant water depth (45 < *h* < 52 m), sediments with dominating non-cohesive fraction, foundation base diameter ø = 40 m;
- Variant 12 (3Nd) – significant water depth (45 < *h* < 52 m), sediments with dominating non-cohesive fraction, foundation base diameter ø = 35 m.

As underlined above, the main factor that forces suspended matter movement is the sea current impact. Since these current constantly change their values and directions, for all assumed scenarios the distribution values and directions of currents from two summer months (June and July) are assumed as boundary conditions, as shown in the Figure 1. This manner of assuming hydrodynamic conditions in suspended matter propagation will make it possible to:

- fulfil the requirement of dredging equipment in the summer period, that is with the largest number of days favourable for this type of works;
- take into account the actual chaotic character of the forcing action.

5 Calculation results

The calculations were carried out in the form of numeric simulations for all assumed variants described in chapter 4. In the case of calculations that make it possible to analyse the impact of dredging equipment operation on marine environment, the allowed forcing conditions (mainly sea currents and changes of water table position, wave motion to a smaller extent) are pre-set. It results from the fact that this type of works may not be carried out in storm conditions, during excessive wind or too high wave motion. However, the variability of sea current parameters (speeds and directions) in a marine environment is great; therefore appropriately long periods were selected in order to capture the random character of its impact. The calculation results presented in the work were created thanks to high level processing and preparing basic simulation results.

This chapter includes drawings (maps and graphs) regarding maximum suspended matter concentrations and maximum ranges of impact for sediments created as a result of works carried out in the Baltica OWF Area in order to settle wind power stations support structures for all considered variants.

Suspended matter concentrations presented in maps (Figure 7, Figure 11, Figure 15, Figure 19, Figure 23, Figure 27, Figure 31, Figure 35, Figure 39, Figure 43, Figure 47, Figure 51) present the maximum possible distributions of their values, assuming hypothetical forcing elements from the entire two-month simulation period. The simulation was prepared assuming the use of actual measured hydrodynamic parameters and a simulation of constant works in locations of a single foundation. It means that these figures present the envelope curve of maximum values of concentrations in the entire simulation period; in other words – they show which maximum concentration values were present at each point of the analysed area not in the given moment, but in the entire two-month calculation period. It is well illustrated by the comparison of the map of the envelope curve of maximum concentrations for the entire calculation period (Figure 6 left hand side) with the map of concentrations distribution at the moment the maximum concentration was achieved (Figure 6 right hand side), as presented using the example of variant 1.

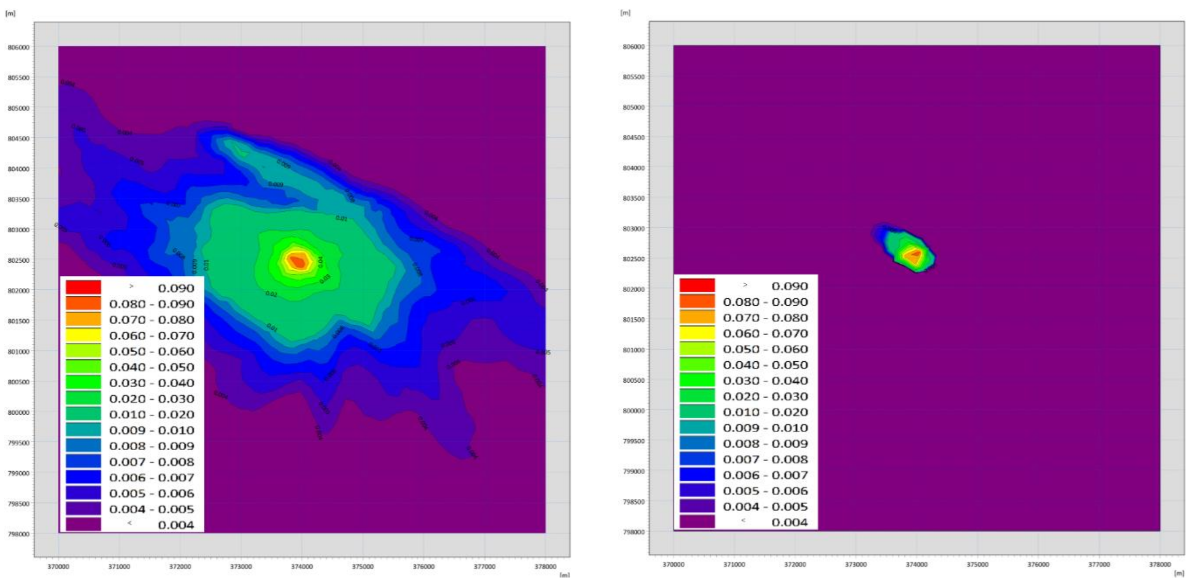

Figure 6. Comparison of sample envelope curves of maximum concentrations for the entire calculation period (left hand side) and concentration distribution at the moment maximum concentration is achieved (right hand side)

Source: internal data

Within the two-month period, highly varied forcing elements that cause movement of suspended matter could be observed. On one hand, there were currents with speeds reaching up to 0.30 $m \cdot s^{-1}$

and acting for a prolonged time in approximately the same direction, causing the suspended matter to be lifted to greater distances, on the other hand – currents with minimum speeds due to which suspended matter range of impact was minimum, but its concentration reached highest values. The manner of presentation of maps in the form of envelope curves of maximum concentrations for the entire simulation period is mainly selected due to the main purpose of their use at the subsequent stage of works, namely for impact assessments. Additionally, the graphs of range for maximum concentrations (Figure 8, Figure 12, Figure 16, Figure 20, Figure 24, Figure 28, Figure 32, Figure 36, Figure 40, Figure 44, Figure 48, Figure 52) show that they decrease as a function of distance from the foundation base edge. It was shown for two characteristic directions, that is in the direction of the greatest suspended matter cloud extent (blue line in the figures) and in the direction of the greatest decrease of suspended matter concentration (orange line in the figures).

Calculated amounts of sediments that deposit on the seabed (Figure 9, Figure 13, Figure 17, Figure 21, Figure 25, Figure 29, Figure 33, Figure 37, Figure 41, Figure 45, Figure 49, Figure 53) as a result of dredging works were shown both in the form maximum maps of thickness for the material put aside, as well as graphs of range at which they are deposited (Figure 10, Figure 14, Figure 18, Figure 22, Figure 26, Figure 30, Figure 34, Figure 38, Figure 42, Figure 46, Figure 50, Figure 54). In these calculations, uninterrupted, 24-hour operation of the dredger was assumed in order to prepare an excavation for a single foundation of a gravity based support structure. Both types of graphical representations have an envelope curve character, that is they present maximum values of thickness of deposited sediments which are a result of 24 hours of preparatory works in order to make the seabed suitable for the gravity based foundation of the support structure for various current regimes which were present in the entire two month period of calculation simulations.

Division of calculations into variants, in accordance with the assumed scenario, concerned the scope of depths, type of sediments and the dimensions of the support structure. Consequently, the following results were obtained for the following calculation variants:

- Variant 1 – works in cohesive soils for implementation of a foundation with the diameter of 40 m, at the depth of $h < 30$ m (Figure 7, Figure 8, Figure 9, Figure 10);
- Variant 2 – works in cohesive soils for implementation of a foundation with the diameter of 35 m, at the depth of $h < 30$ m (Figure 11, Figure 12, Figure 13, Figure 14);
- Variant 3 – works in non-cohesive soils for implementation of a foundation with the diameter of 40 m, at the depth of $h < 30$ m (Figure 15, Figure 16, Figure 17, Figure 18);
- Variant 4 – works in non-cohesive soils for implementation of a foundation with the diameter of 35 m, at the depth of $h < 30$ m (Figure 19, Figure 20, Figure 21, Figure 22);
- Variant 5 – works in cohesive soils for implementation of a foundation with the diameter of 40 m, at the depth of $30 < h < 45$ m (Figure 23, Figure 24, Figure 25, Figure 26);
- Variant 6 – works in cohesive soils for implementation of a foundation with the diameter of 35 m, at the depth of $30 < h < 45$ m (Figure 27, Figure 28, Figure 29, Figure 30);
- Variant 7 – works in non-cohesive soils for implementation of a foundation with the diameter of 40 m, at the depth of $30 < h < 45$ m (Figure 31, Figure 32, Figure 33, Figure 34);

- Variant 8 – works in non-cohesive soils for implementation of a foundation with the diameter of 35 m, at the depth of 30 < h < 45 m (Figure 35, Figure 36, Figure 37, Figure 38);
- Variant 9 – works in cohesive soils for implementation of a foundation with the diameter of 40 m, at the depth of h > 45 m (Figure 39, Figure 40, Figure 41, Figure 42);
- Variant 10 – works in cohesive soils for implementation of a foundation with the diameter of 35 m, at the depth of h > 45 m (Figure 43, Figure 44, Figure 45, Figure 46);
- Variant 11 – works in non-cohesive soils for implementation of a foundation with the diameter of 40 m, at the depth of h > 45 m (Figure 47, Figure 48, Figure 49, Figure 50);
- Variant 12 – works in non-cohesive soils for implementation of a foundation with the diameter of 35 m, at the depth of h > 45 m (Figure 51, Figure 52, Figure 53, Figure 54).

5.1 Variant 1

Variant 1 – the minimum water depth (23 < h < 30 m), sediments with dominating cohesive fraction, foundation base diameter ø = 40 m

The maximal concentration of suspended solid resulting from human activities was 110 $mg{\cdot}l^{-1}$ in the place of dredging work performance in the full period devoted to calculations concerning the calculation variant (Figure 7). The highest concentration of suspended solids in the place where the nearest wind power station is to be located may reach the value of 17 $mg{\cdot}l^{-1}$ during the works implementation. The suspended solids impact recorded at a point located at a distance of 3 km from the work site is not significant and does not exceed 7 $mg{\cdot}l^{-1}$. Taking into account the condition (introduced in the description of the methods), the “outbalance model” was applied in the calculations, hence the suspended solids concentrations presented above should be treated as an outbalance over the background in natural conditions. The maximal range of the suspended solids cloud with the concentration of over 4 $mg{\cdot}l^{-1}$ is approx. 6 km.

The chart (Figure 8) presents the range of the maximal suspended solids concentrations in the least favourable current conditions regarding the entire calculation period. The main information provided by the chart is that the concentration decreases as the distance from the foundation base edge increases. The suspended solids concentrations do not exceed 89 $mg{\cdot}l^{-1}$ at the distance of 100 m from the area covered by dredging works and they quickly decrease to the level of approx. 60 $mg{\cdot}l^{-1}$ at the distance of 250 m. At the distance of 1000 m, the concentration may reach the level of 16 $mg{\cdot}l^{-1}$ at maximum, considering the direction of the suspended solid cloud broadest range, and 18 $mg{\cdot}l^{-1}$ in the case of the direction of the fastest suspended solids dispersion (the highest initial concentrations). In the directions of the broadest range and the fastest dispersion, at the distance of 2 km, the concentration levels are, respectively, 8 $mg{\cdot}l^{-1}$ and 9 $mg{\cdot}l^{-1}$.

The maximum thickness values of deposited sediments inside the envelope enclosing the entire calculation period are presented in Figure 9. In the direct vicinity of the area covered by the dredging works conducted in non-cohesive soils, the thickness is up to 28 mm. Thickness of the sediment formed from the material redeposited at the distance of approx. 1 km does not exceed 4 mm in the least favourable sea current conditions.

The range of sediment deposition is illustrated in Figure 10, which shows that the deposition is spatially limited. Thickness values decrease very fast with the growing distance from the source of sediment resuspension. In the case of cohesive soil, the maximum thickness values do not exceed 12 mm at the distance of 200 m. The sediment newly deposited on the seabed may be subject (in the initial stage) to resuspension caused by more intensive storms.

Within the framework of the performed calculations, also the maximum persistence of suspended solids in the water column has been determined. In the discussed variant, the minimum concentrations of suspended solids equal 2 $mg{\cdot}l^{-1}$ and caused by the implemented works may persist in water for up to 38 h from the moment when the works on a single foundation start.

- concentrations [$g \cdot l^{-1}$], depth h < 30 m, COHESIVE soil, foundation diameter – 40 m

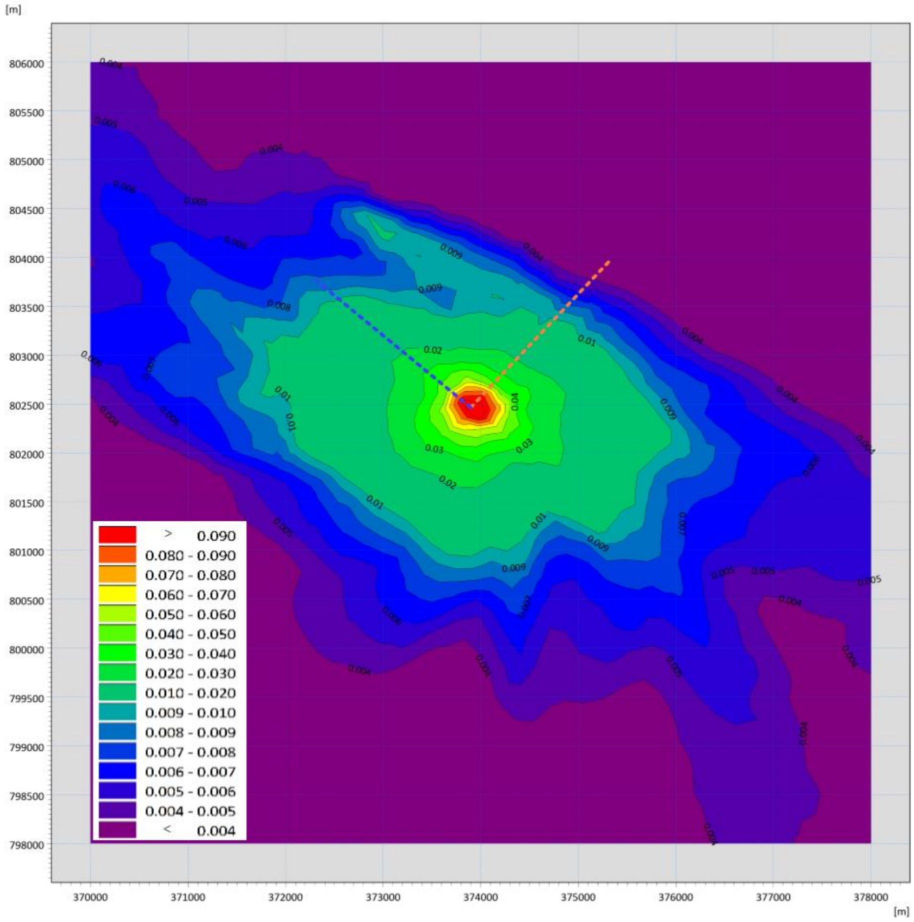

Figure 7. Variant 1 – the maximal concentration values [$g \cdot l^{-1}$]

The blue line marks the direction of the maximum impact range, while the red line marks the minimum impact range
Source: internal data

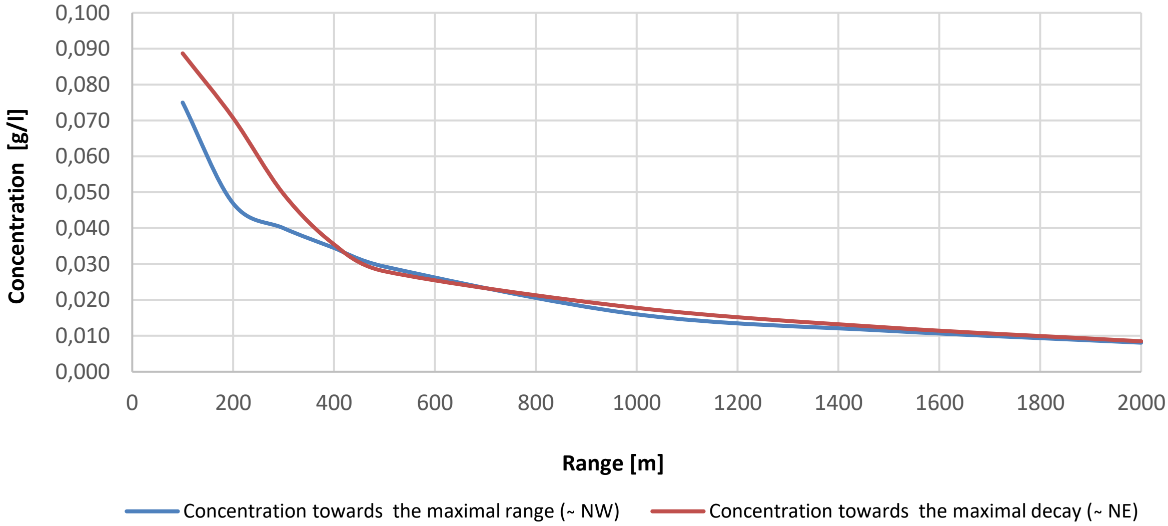

Figure 8. Variant 1 – the maximal concentration range [m]

Source: internal data

- sediment [mm], depth h < 30 m, COHESIVE soil, foundation diameter – 40 m

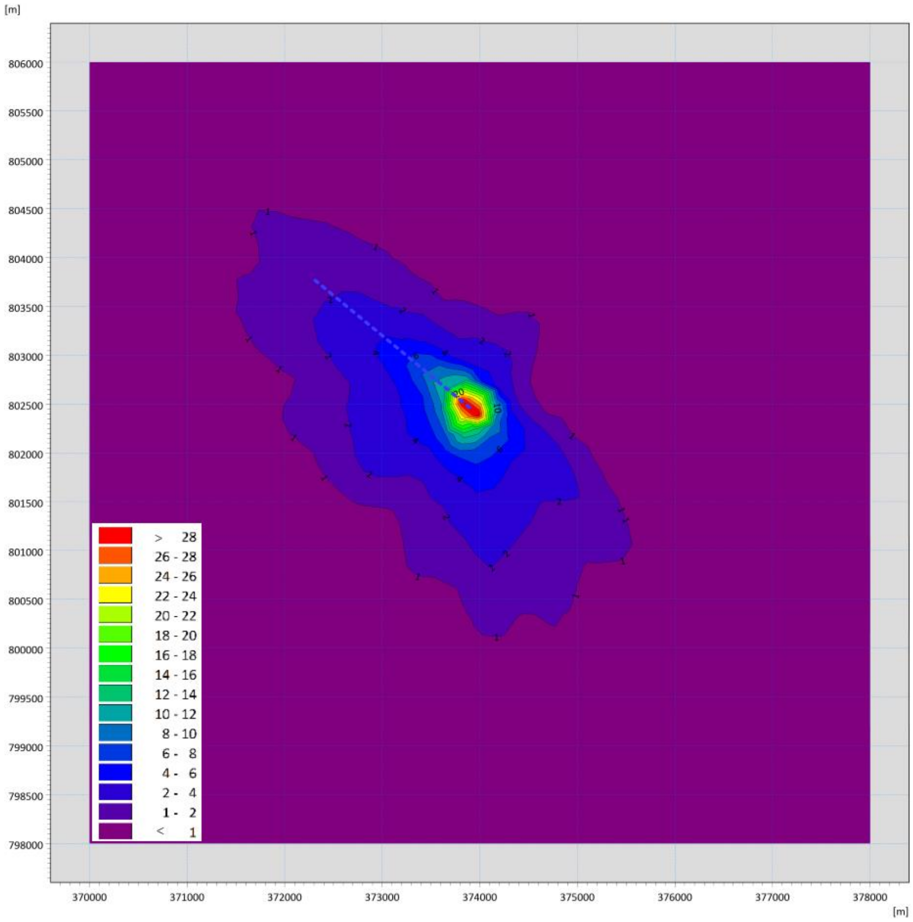

Figure 9. Variant 1 – the maximal thickness of deposited sediments [mm]

The blue line marks the direction of the maximum impact range
Source: internal data

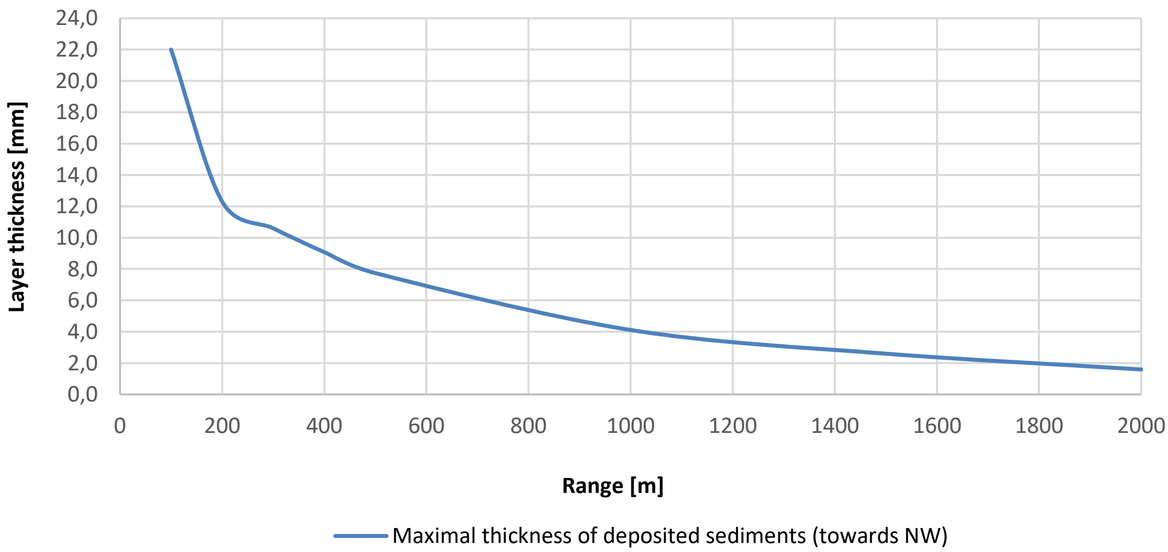

Figure 10. Variant 1 – the sediment deposition range [m]

Source: internal data

5.2 Variant 2

Variant 2 – the minimum water depth (23 < h < 30 m), sediments with dominating cohesive fraction, foundation base diameter ø = 35 m

In the discussed calculation variant, the maximal concentration of suspended solid resulting from human activities was 86 $mg \cdot l^{-1}$ in the place of dredging work performance in the full survey period (Figure 11). The maximum concentration of suspended solids in the place where the nearest wind power station is to be located may reach the value of 14 $mg \cdot l^{-1}$ during the works implementation. The suspended solids impact recorded at a point located at a distance of 3 km from the work site is very low and does not exceed 5 $mg \cdot l^{-1}$. Taking into account the condition (introduced in the description of the methods), the “outbalance model” was applied in the calculations, hence the suspended solids concentrations presented above should be treated as an outbalance over the background in natural conditions. The maximal range of the suspended solids cloud with the concentration of over 4 $mg \cdot l^{-1}$ has been estimated at approx. 5 km.

The chart (Figure 12) presents the range of the maximal suspended solids concentrations in the least favourable current conditions regarding the entire calculation period. The basic information provided by the chart is that the concentration decreases with the distance from the foundation base edge. The suspended solids concentrations do not exceed 70 $mg \cdot l^{-1}$ at the distance of 100 m from the area covered by dredging works and they quickly decrease to the level of approx. 35 $mg \cdot l^{-1}$ at the distance of 250 m. At the distance of 1000 m, the concentration may reach the level of 13 $mg \cdot l^{-1}$ at maximum, considering the direction of the suspended solid cloud broadest range, and 10 $mg \cdot l^{-1}$ in the case of the direction of the fastest suspended solids dispersion (the highest initial concentrations). In the direction of the maximum range, the concentrations may be up to 7 $mg \cdot l^{-1}$ at the distance of 2 km, while at the same distance but in the direction of the fastest dispersion they are of negligible values.

The maximum thickness values of deposited sediments inside the envelope enclosing the entire calculation period are presented in Figure 13. Only in the direct vicinity of the area covered by the dredging works conducted in cohesive soils, the thickness is up to 25 mm. Thickness of the sediment formed from the material redeposited at the distance of approx. 2 km does not exceed 1 mm.

The range of sediment deposition is illustrated in detail in Figure 14, which shows that the deposition is spatially limited. Thickness values decrease very fast with the growing distance from the source of sediment resuspension. In the case of cohesive soil, the maximum thickness values do not exceed 10 mm at the distance of 200 m. Additionally, the sediment newly deposited on the seabed may be prone to resuspension caused by storms in the initial stage.

Within the framework of the performed calculations, also the maximum persistence of suspended solids in the water column has been determined. In the discussed calculation variant, the minimum concentrations of suspended solids equal 2 $mg \cdot l^{-1}$ and caused by the implemented works may persist in water for up to 35 h from the moment when the works on a single foundation start.

- concentrations [$g \cdot l^{-1}$], depth h < 30 m, COHESIVE soil, foundation diameter – 35 m

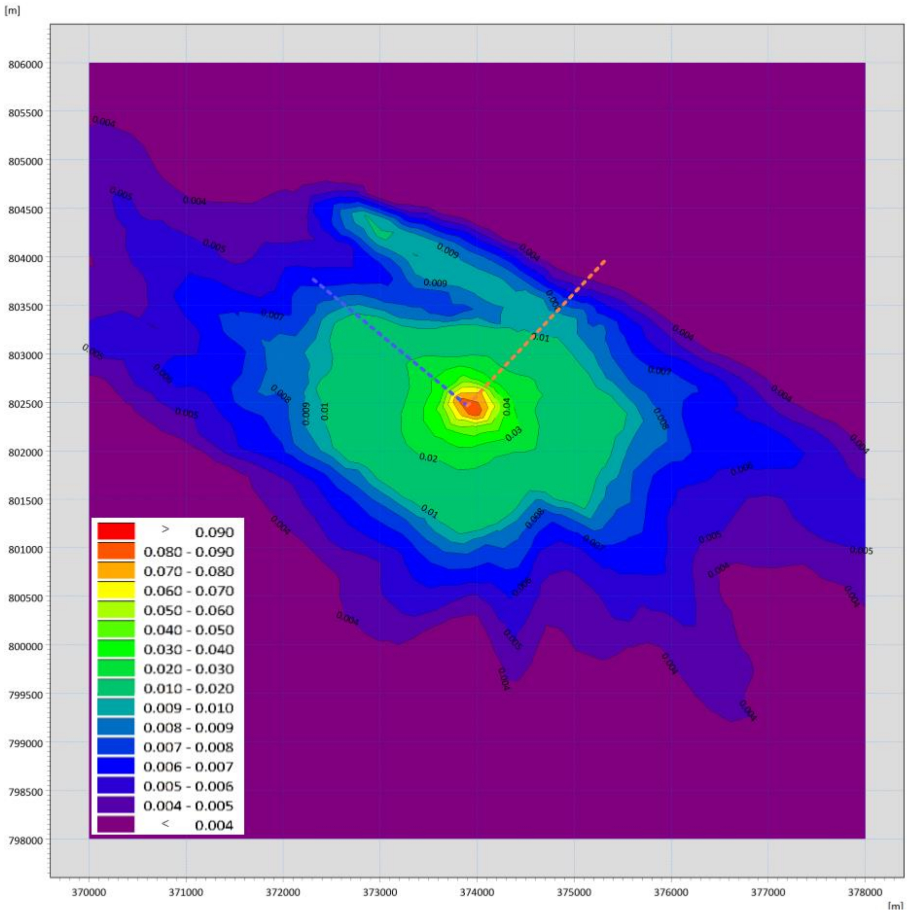

Figure 11. Variant 2 – the maximal concentration values [$g \cdot l^{-1}$]

The blue line marks the direction of the maximum impact range, while the red line marks the minimum impact range

Source: internal data

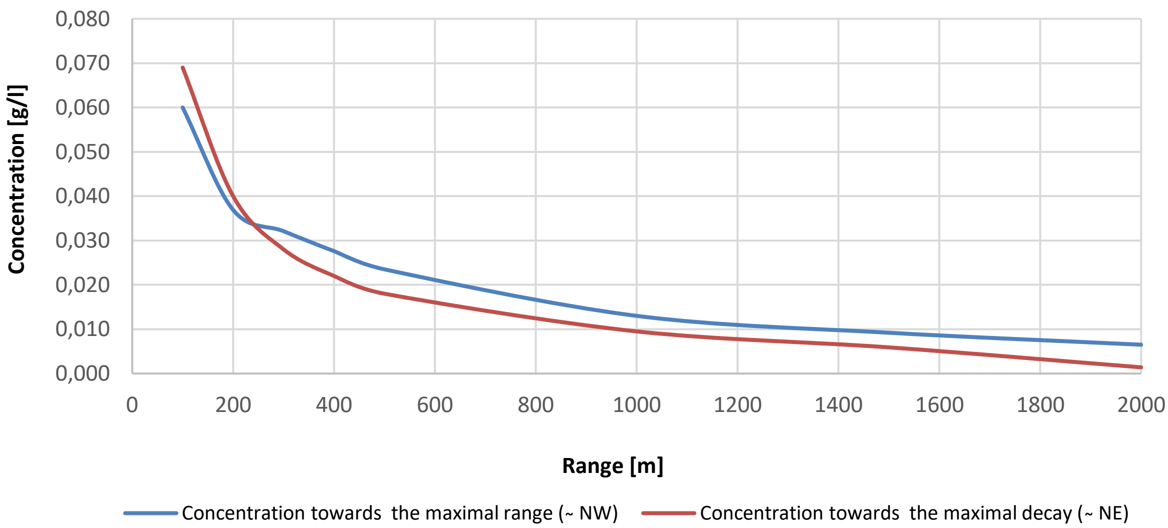

Figure 12. Variant 2 – the maximal concentration range [m]

Source: internal data

- sediment [mm], depth h < 30 m, COHESIVE soil, foundation diameter – 35 m

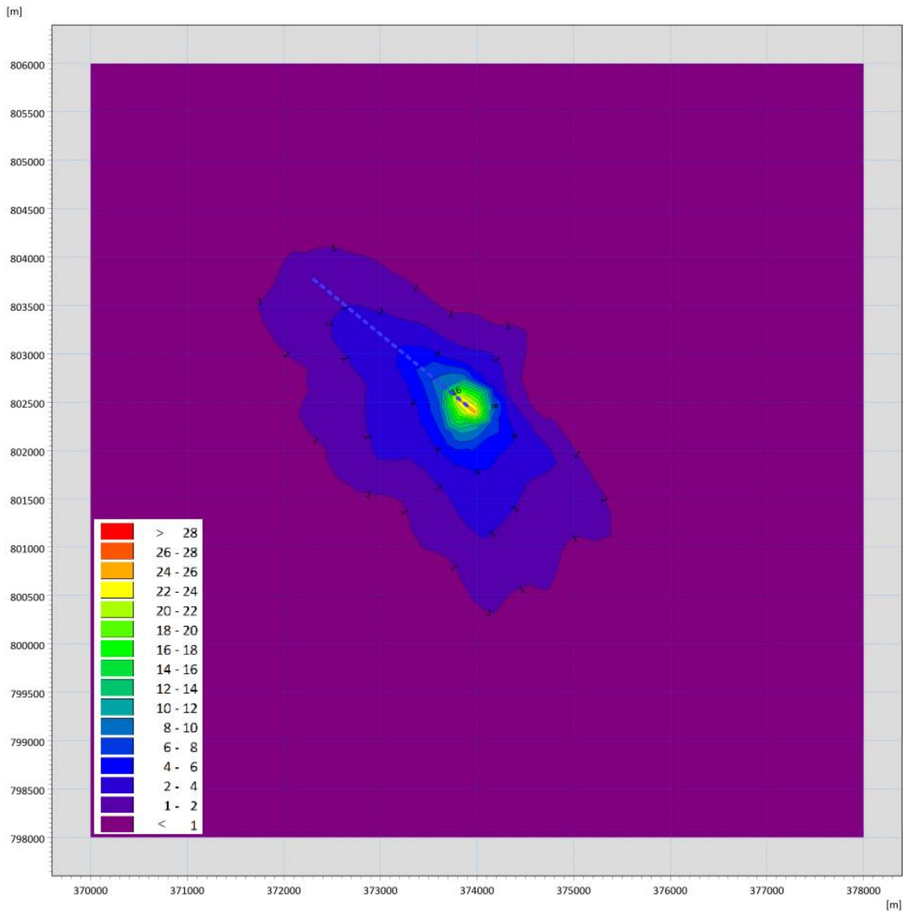

Figure 13. Variant 2 – the maximal thickness of deposited sediments [mm]

The blue line marks the direction of the maximum impact range
Source: internal data

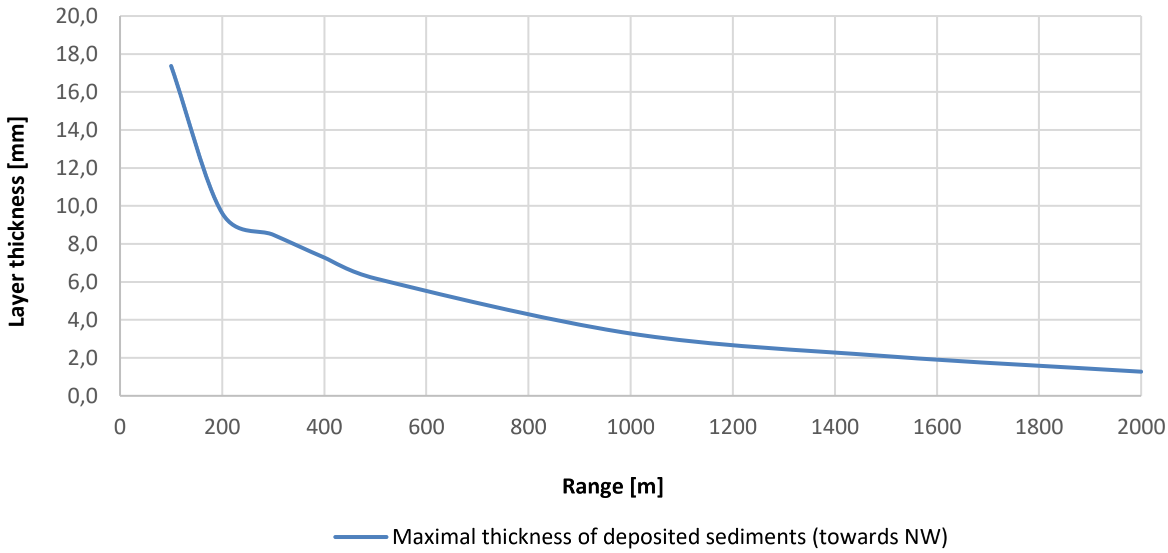

Figure 14. Variant 2 – the sediment deposition range [m]

Source: internal data

5.3 Variant 3

Variant 3 – the minimum water depth (23 < h < 30 m), sediments with dominating non-cohesive fraction, foundation base diameter ø = 40 m

In the discussed calculation variant, the maximum concentrations of solids suspended as a result of human activity were 18 $mg \cdot l^{-1}$ in the area covered by dredging works in the entire calculation period (Figure 15). The maximum concentration of suspended solids in the point where the nearest wind power station is to be located may reach the value of 3 $mg \cdot l^{-1}$ during the works implementation. The suspended solids impact recorded at a point located at a distance of 3 km from the work site is very low and does not exceed 1 $mg \cdot l^{-1}$. Taking into account the condition (introduced in the description of the methods), the “outbalance model” was applied in the calculations, hence the suspended solids concentrations presented above should be treated as an outbalance over the background in natural conditions. The maximal range of the suspended solids cloud with the concentration of over 4 $mg \cdot l^{-1}$ has been estimated at approx. 1 km.

The chart (Figure 16) presents the range of the maximal suspended solids concentrations in the least favourable current conditions regarding the entire calculation period. The most crucial information provided by the chart is that the concentration decreases with the distance from the foundation base edge. The suspended solids concentrations do not exceed 18 $mg \cdot l^{-1}$ at the distance of 100 m from the area covered by dredging works and they quickly decrease to the level of approx. 14 $mg \cdot l^{-1}$ at the distance of 200 m. At the distance of 1000 m, the concentration may reach the level of 4 $mg \cdot l^{-1}$ at maximum, considering the direction of the suspended solid cloud broadest range, and 3 $mg \cdot l^{-1}$ in the case of the direction of the fastest suspended solids dispersion (the highest initial concentrations). In the direction of the maximum range, the concentrations may be up to 2 $mg \cdot l^{-1}$ at the distance of 2 km, while at the same distance but in the direction of the fastest dispersion they are 4 $mg \cdot l^{-1}$.

The maximum thickness values of deposited sediments inside the envelope enclosing the entire calculation period are presented in Figure 17. Only in the direct vicinity of the area covered by the dredging works conducted in non-cohesive soils, the thickness is up to 6 mm. Thickness of the sediment formed from the material redeposited at the distance of approx. 1 km does not exceed 1 mm.

The sediment deposition range is presented in more detail in Figure 18. It shows clearly that the deposition is limited in terms of space. The extreme thickness values decrease very fast with the growing distance from the source of sediment resuspension. In the case of cohesive soil, the maximum thickness values do not exceed 2.5 mm at the distance of 200 m. The newly deposited sediment will be prone to resuspension caused by storms in the initial stage.

Within the framework of the performed calculations, also the maximum persistence of suspended solids in the water column has been determined. In the discussed variant, very low concentrations of suspended solids equal 2 $mg \cdot l^{-1}$ and caused by the implemented works may persist in water for up to 30 h from the moment when the works on a single foundation start.

- concentrations [g·l^{-1}], depth h < 30 m, NON-COHESIVE soil, foundation diameter – 40 m

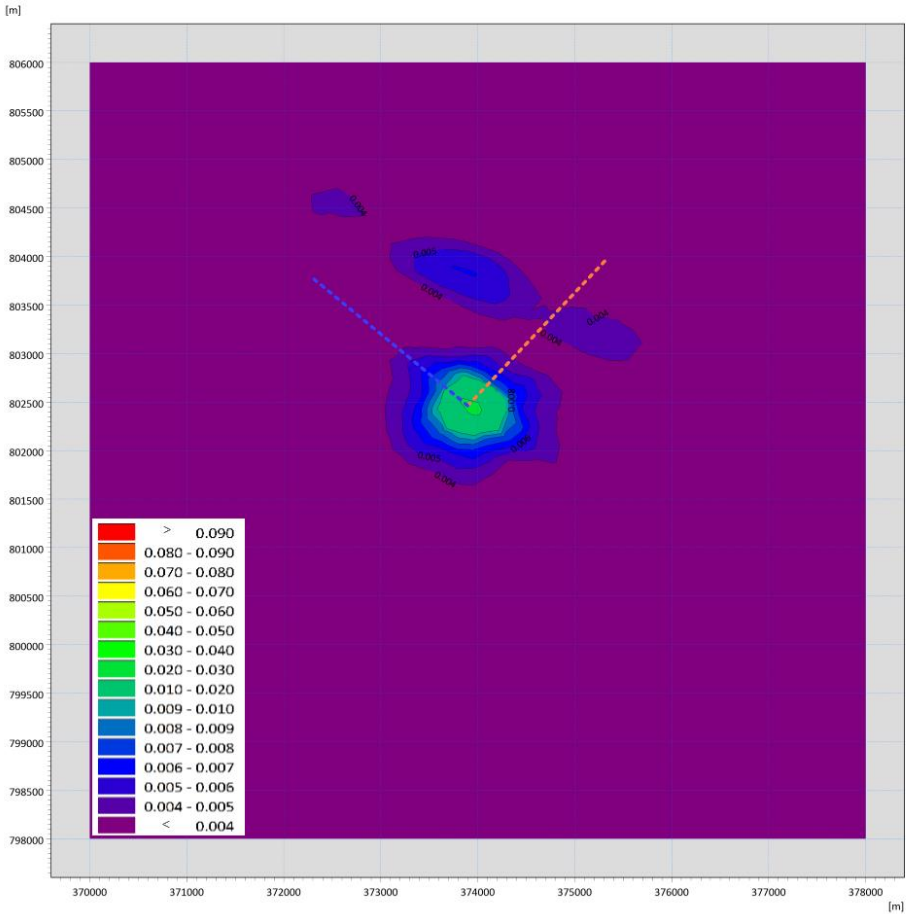

Figure 15. Variant 3 – the maximal concentration values [g·l^{-1}]

The blue line marks the direction of the maximum impact range, while the red line marks the minimum impact range

Source: internal data

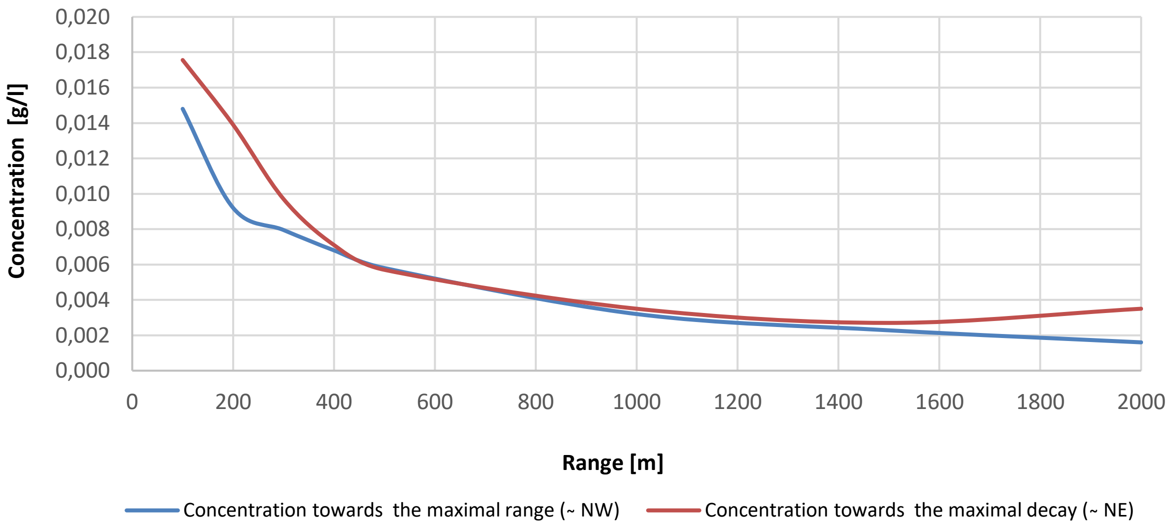

Figure 16. Variant 3 – the maximal concentration range [m]

Source: internal data

- sediment [mm], depth h < 30 m, NON-COHESIVE soil, foundation diameter – 40 m

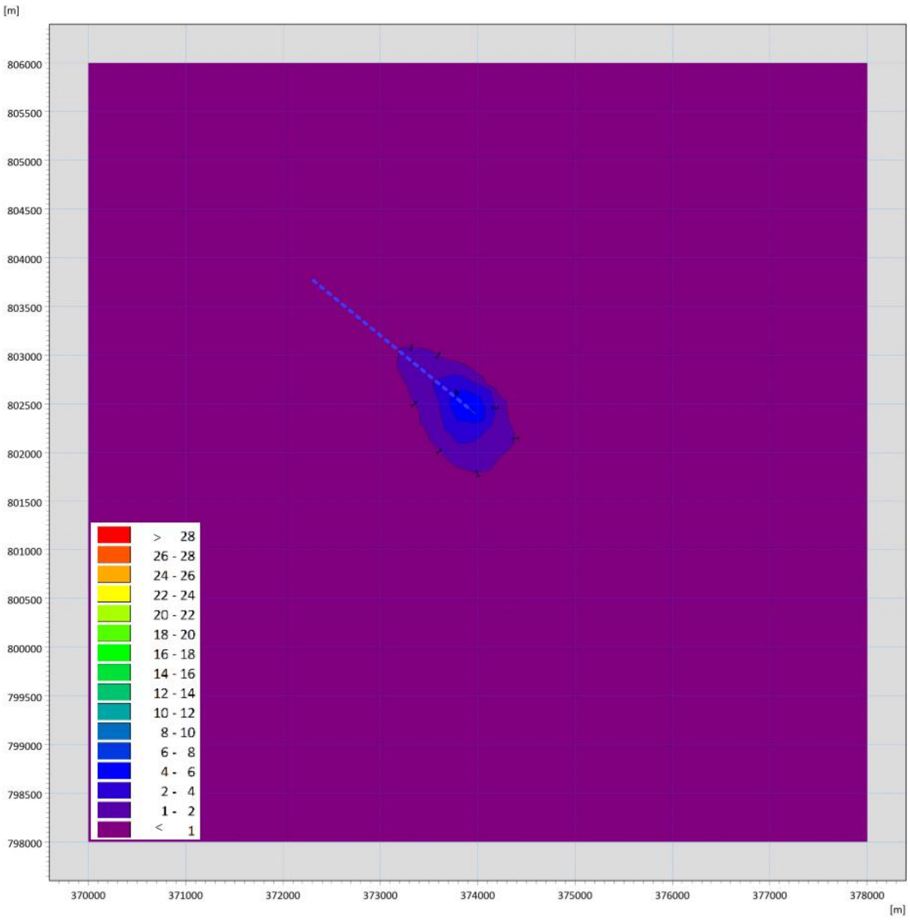

Figure 17. Variant 3 – the maximal thickness of deposited sediments [mm]

The blue line marks the direction of the maximum impact range
Source: internal data

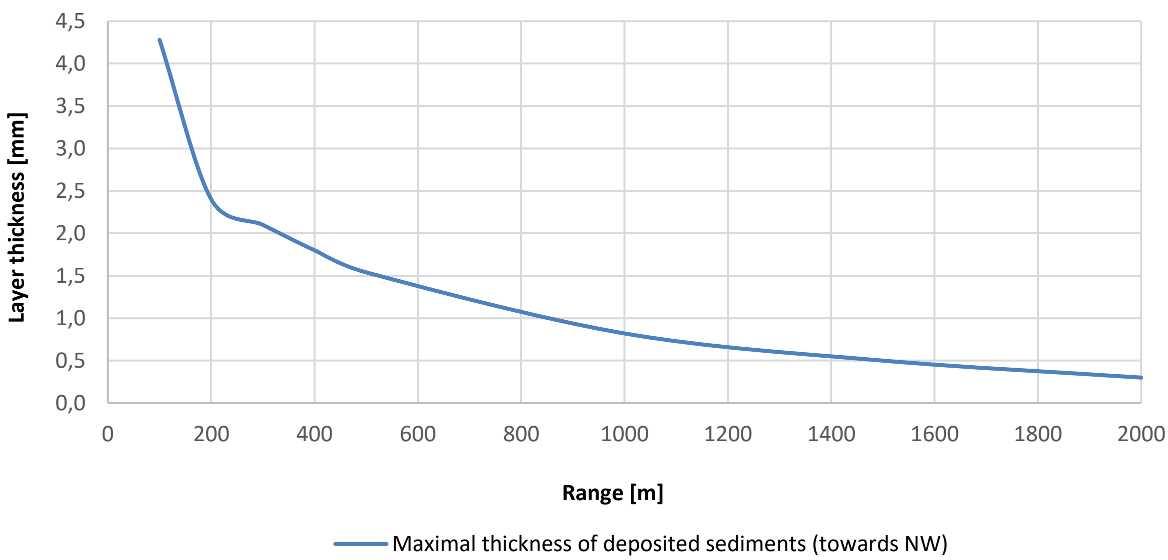

Figure 18. Variant 3 – the sediment deposition range [m]

Source: internal data

5.4 Variant 4

Variant 4 – the minimum water depth (23 < h < 30 m), sediments with dominating non-cohesive fraction, foundation base diameter ø = 35 m

The maximal concentration of suspended solid resulting from human activities was 18 $mg \cdot l^{-1}$ in the place of dredging work performance in the full period devoted to calculations concerning the calculation variant (Figure 19). The highest concentration of suspended solids in the place where the nearest wind power station is to be located may reach the value of 5 $mg \cdot l^{-1}$ during the works implementation. The suspended solids impact recorded at a point located at a distance of 2 km from the work site is negligible and does not exceed 3 $mg \cdot l^{-1}$. Taking into account the condition (introduced in the description of the methods), the “outbalance model” was applied in the calculations, hence the suspended solids concentrations presented above should be treated as an outbalance over the background in natural conditions. The maximal range of the suspended solids cloud with the concentration of over 4 $mg \cdot l^{-1}$ is approx. 2 km.

The chart (Figure 20) presents the range of the maximal suspended solids concentrations in the least favourable current conditions regarding the entire calculation period. The main information provided by the chart is that the concentration decreases as the distance from the foundation base edge increases. The suspended solids concentrations do not exceed 14 $mg \cdot l^{-1}$ at the distance of 100 m from the area covered by dredging works and they quickly decrease to the level of approx. 7 $mg \cdot l^{-1}$ at the distance of 250 m. At the distance of 1000 m, the concentration may reach the level of 3 $mg \cdot l^{-1}$ at maximum, considering the direction of the suspended solid cloud broadest range, and 4 $mg \cdot l^{-1}$ in the case of the direction of the fastest suspended solids dispersion (the highest initial concentrations). In the directions of the broadest range and the fastest dispersion, at the distance of 2 km, the concentration levels are negligible.

The maximum thickness values of deposited sediments inside the envelope enclosing the entire calculation period are presented in Figure 21. In the direct vicinity of the area covered by the dredging works conducted in non-cohesive soils, the thickness is up to 5 mm. Thickness of the sediment formed from the material redeposited at the distance of approx. 1 km does not exceed 1 mm in the least favourable sea current conditions.

The range of sediment deposition is illustrated in Figure 22, which shows that the deposition is spatially limited. Thickness values decrease very fast with the growing distance from the source of sediment resuspension. In the case of non-cohesive soil, the maximum thickness values do not exceed 2 mm at the distance of 200 m. The newly deposited sediment may be subject (in the initial stage) to resuspension caused by more intensive storms.

Within the framework of the performed calculations, also the maximum persistence of suspended solids in the water column has been determined. In the discussed variant, the minimum concentrations of suspended solids equal 2 $mg \cdot l^{-1}$ and caused by the implemented works may persist in water for up to 28 h from the moment when the works on a single foundation start.

- concentrations [g·l^{-1}], depth h < 30 m, NON-COHESIVE soil, foundation diameter – 35 m

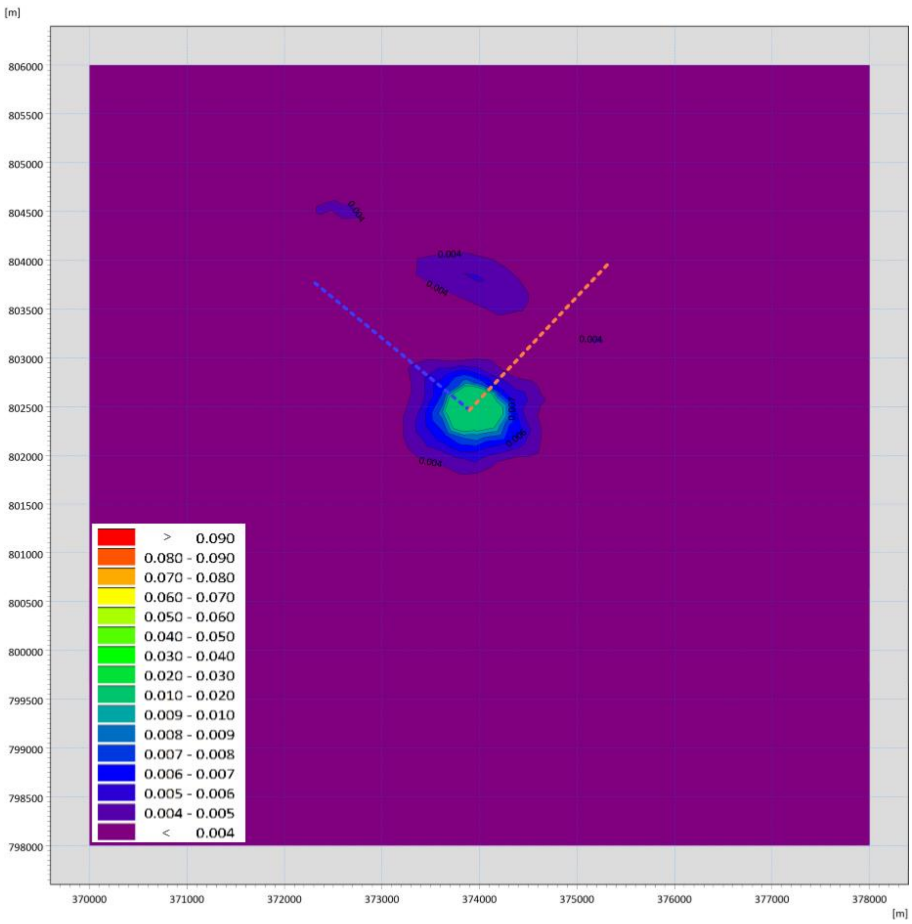

Figure 19. Variant 4 – the maximal concentration values [g·l^{-1}]

The blue line marks the direction of the maximum impact range, while the red line marks the minimum impact range

Source: internal data

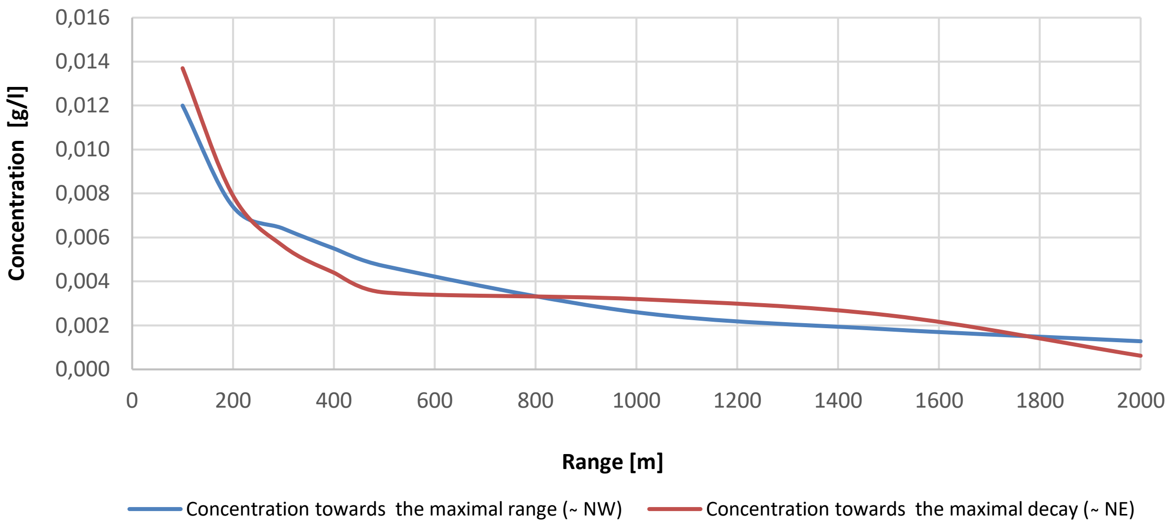

Figure 20. Variant 4 – the maximal concentration range [m]

Source: internal data

- sediment [mm], depth h < 30 m, NON-COHESIVE soil, foundation diameter – 35 m

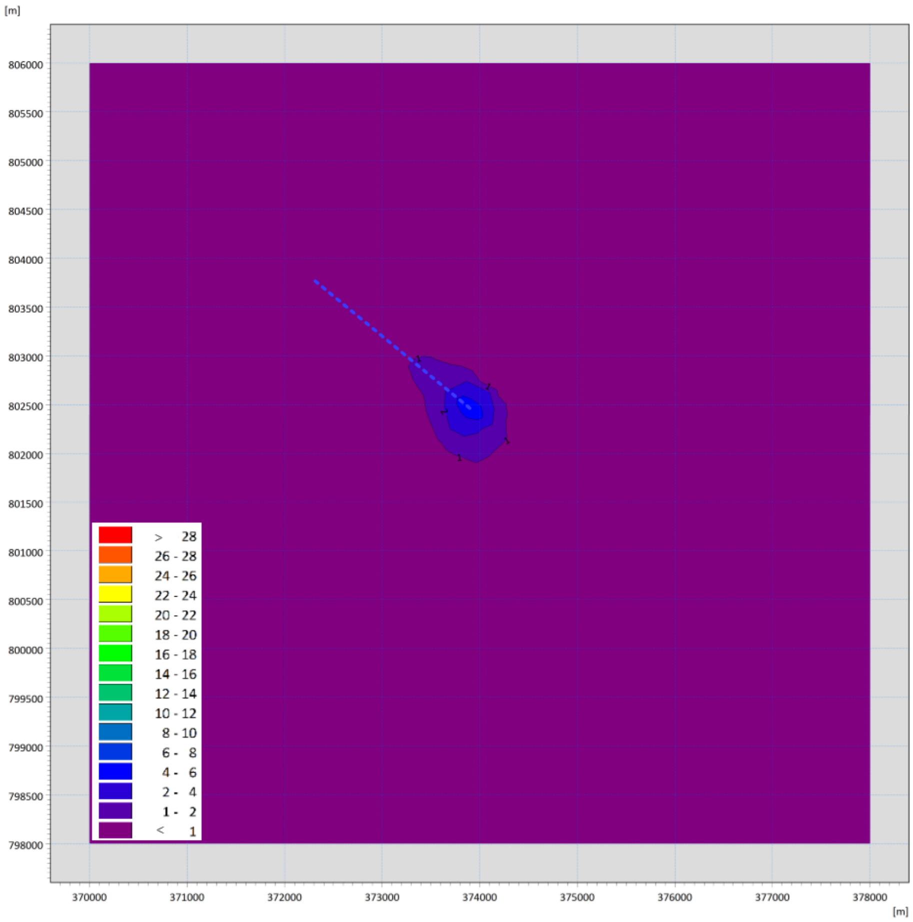

Figure 21. Variant 4 – the maximal thickness of deposited sediments [mm]

The blue line marks the direction of the maximum impact range
Source: internal data

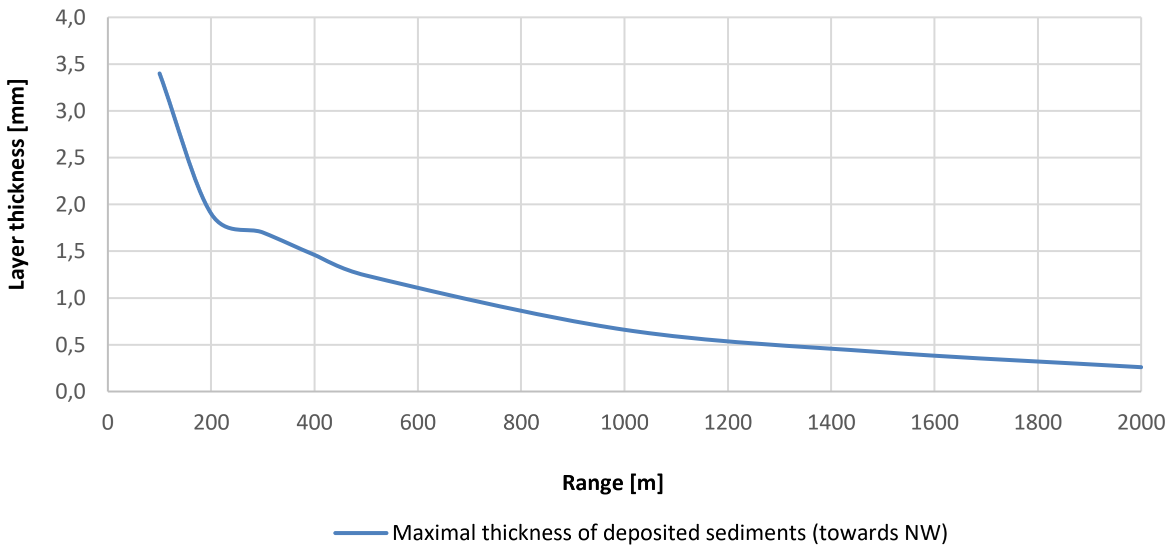

Figure 22. Variant 4 – the sediment deposition range [m]

Source: internal data

5.5 Variant 5

Variant 5 – the average water depth (30 < h < 45 m), sediments with dominating cohesive fraction, foundation base diameter ø = 40 m

In the discussed calculation variant, the maximum concentrations of solids suspended as a result of human activity were 90 $mg \cdot l^{-1}$ in the area covered by dredging works in the entire calculation period (Figure 23). The maximum concentration of suspended solids in the point where the nearest wind power station is to be located may reach the value of 15 $mg \cdot l^{-1}$ during the works implementation. The suspended solids impact recorded at a point located at a distance of 3 km from the work site is very low and does not exceed 6 $mg \cdot l^{-1}$. Taking into account the condition (introduced in the description of the methods), the “outbalance model” was applied in the calculations, hence the suspended solids concentrations presented above should be treated as an outbalance over the background in natural conditions. The maximal range of the suspended solids cloud with the concentration of over 4 $mg \cdot l^{-1}$ has been estimated at approx. 5 km.

The chart (Figure 24) presents the range of the maximal suspended solids concentrations in the least favourable current conditions regarding the entire calculation period. The most crucial information provided by the chart is that the concentration decreases with the distance from the foundation base edge. The suspended solids concentrations do not exceed 65 $mg \cdot l^{-1}$ at the distance of 100 m from the area covered by dredging works and they quickly decrease to the level of approx. 35 $mg \cdot l^{-1}$ at the distance of 220 m. At the distance of 1000 m, the concentration may reach the level of 14 $mg \cdot l^{-1}$ at maximum, considering the direction of the suspended solid cloud broadest range, and 8 $mg \cdot l^{-1}$ in the case of the direction of the fastest suspended solids dispersion (the highest initial concentrations). In the direction of the maximum range, the concentrations may be up to 7 $mg \cdot l^{-1}$ at the distance of 2 km, while at the same distance but in the direction of the fastest dispersion they are of negligible values.

The maximum thickness values of deposited sediments inside the envelope enclosing the entire calculation period are presented in Figure 25. Only in the direct vicinity of the area covered by the dredging works conducted in cohesive soils, the thickness is up to 24 mm. Thickness of the sediment formed from the material redeposited at the distance of approx. 2 km does not exceed 1.5 mm.

The sediment deposition range is presented in more detail in Figure 26. It shows clearly that the deposition is limited in terms of space. The extreme thickness values decrease very fast with the growing distance from the source of sediment resuspension. In the case of cohesive soil, the maximum thickness values do not exceed 10 mm at the distance of 200 m. The newly deposited sediment will be prone to resuspension caused by storms in the initial stage.

Within the framework of the performed calculations, also the maximum persistence of suspended solids in the water column has been determined. In the discussed variant, very low concentrations of suspended solids equal 2 $mg \cdot l^{-1}$ and caused by the implemented works may persist in water for up to 39 h from the moment when the works on a single foundation start.

- concentrations [$g \cdot l^{-1}$], depth 30 < h < 45 m, COHESIVE soil, foundation diameter – 40 m

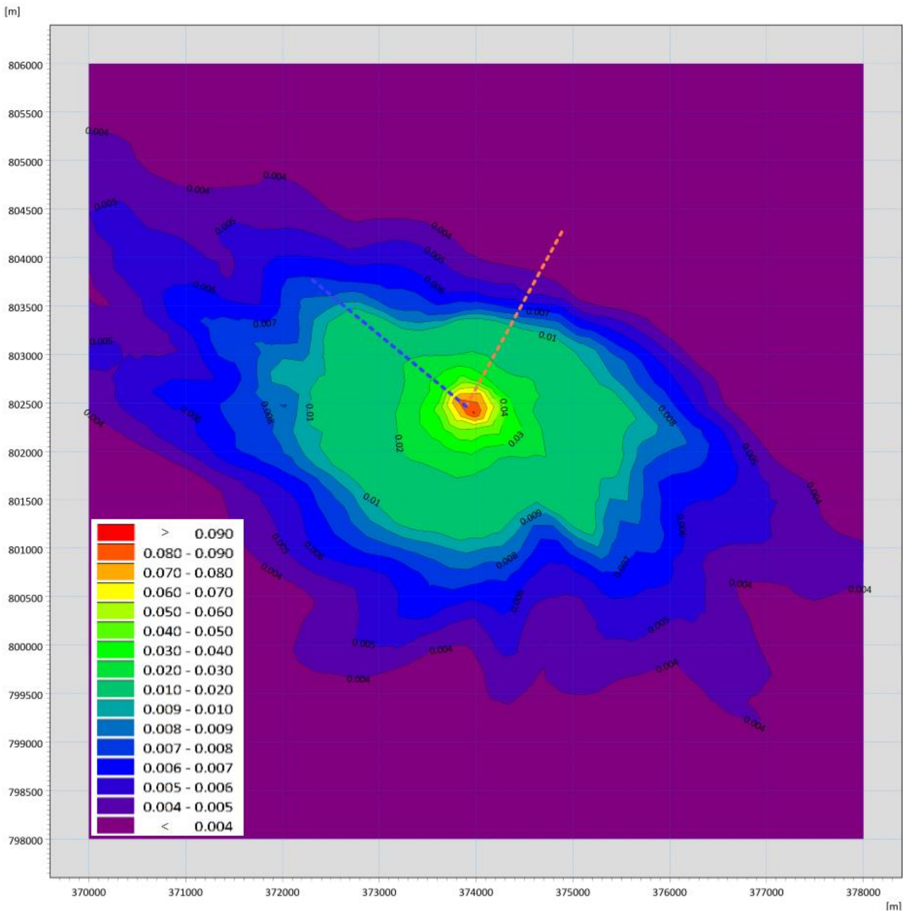

Figure 23. Variant 5 – the maximal concentration values [$g \cdot l^{-1}$]

The blue line marks the direction of the maximum impact range, while the red line marks the minimum impact range

Source: internal data

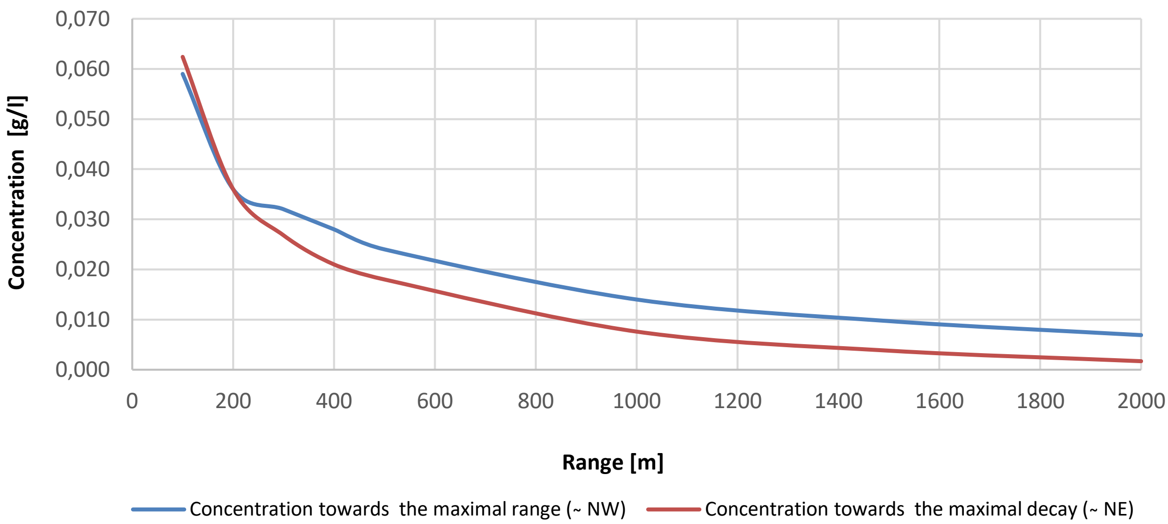

Figure 24. Variant 5 – the maximal concentration range [m]

Source: internal data

- sediment [mm], depth 30 < h < 45 m, COHESIVE soil, foundation diameter – 40 m

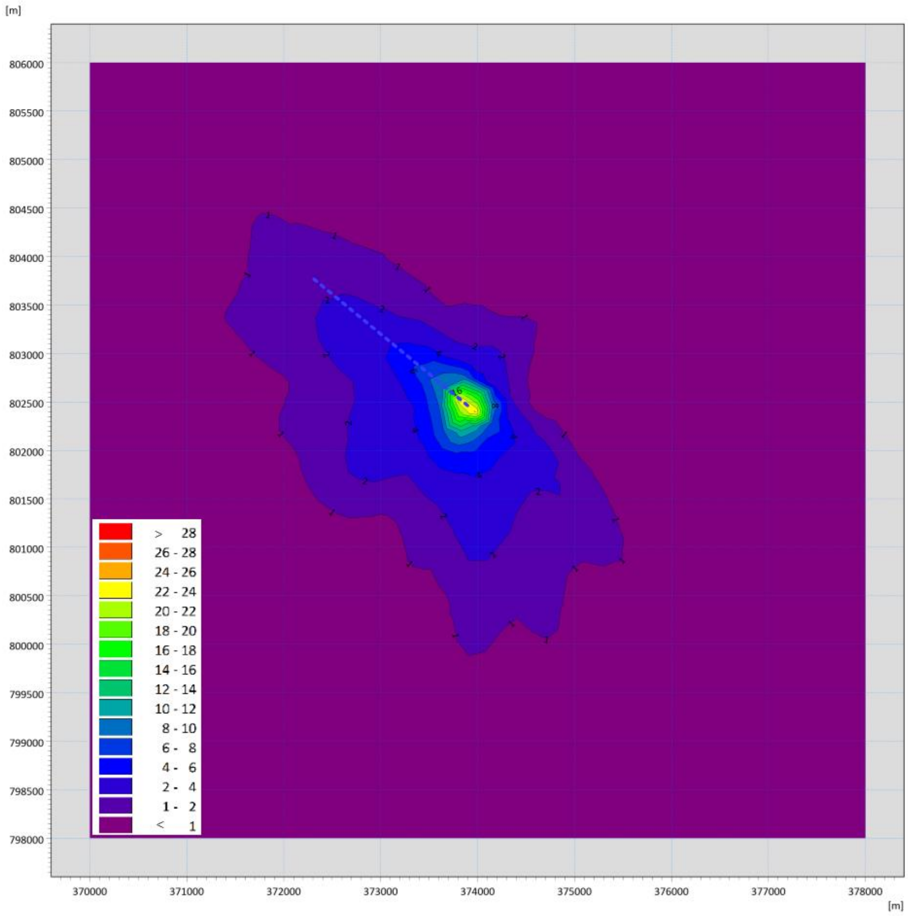

Figure 25. Variant 5 – the maximal thickness of deposited sediments [mm]

The blue line marks the direction of the maximum impact range
Source: internal data

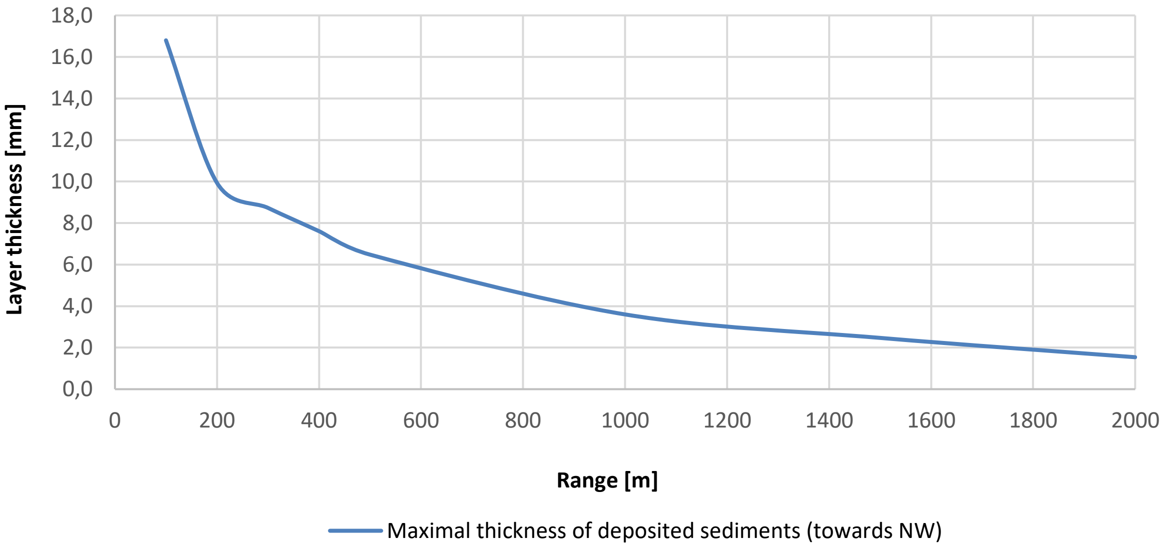

Figure 26. Variant 5 – the sediment deposition range [m]

Source: internal data

5.6 Variant 6

Variant 6 – the average water depth (30 < h < 45 m), sediments with dominating cohesive fraction, foundation base diameter ø = 35 m

The maximal concentration of suspended solid resulting from human activities was 72 $mg \cdot l^{-1}$ in the place of dredging work performance in the full survey period (Figure 27). The maximal concentration of suspended solids in the place where the nearest wind power station is to be located may reach the value of 12 $mg \cdot l^{-1}$ during the works implementation. The suspended solids impact recorded at a point located at a distance of 3 km from the work site is very low and does not exceed 5 $mg \cdot l^{-1}$. Taking into account the condition (introduced in the description of the methods), the “outbalance model” was applied in the calculations, hence the suspended solids concentrations presented above should be treated as an outbalance over the background in natural conditions. The furthest range of the suspended solids cloud with the concentration of over 4 $mg \cdot l^{-1}$ has been estimated at approx. 4 km.

The chart (Figure 28) presents the range of the maximal suspended solids concentrations in the least favourable current conditions regarding the entire calculation period. The basic information provided by the chart is that the concentration decreases with the distance from the foundation base edge. The suspended solids concentrations do not exceed 50 $mg \cdot l^{-1}$ at the distance of 100 m from the area covered by dredging works and they quickly decrease to the level of approx. 29 $mg \cdot l^{-1}$ at the distance of 200 m. At the distance of 1000 m, the concentration may reach the level of 11 $mg \cdot l^{-1}$ at maximum, in the direction of the suspended solid cloud broadest range, and 6 $mg \cdot l^{-1}$ in the case of the direction characterised by the fastest suspended solids dispersion (the highest initial concentrations). In the direction of the maximum range, the concentrations may be up to 6 $mg \cdot l^{-1}$ at the distance of 2 km, while at the same distance but in the direction of the fastest dispersion they reach negligible values.

The maximum thickness values of deposited sediments inside the envelope enclosing the entire calculation period are presented in Figure 29. In the direct vicinity of the area covered by the dredging works conducted in cohesive soils, the thickness is up to 20 mm. Thickness of the sediment formed from the material redeposited at the distance of approx. 2 km does not exceed 1 mm.

The range of sediment deposition is illustrated in detail in Figure 30, which shows that the deposition is spatially limited. The highest thickness values decrease very fast with the growing distance from the source of sediment resuspension. In the case of cohesive soil, the maximum thickness values do not exceed 8 mm at the distance of 200 m. The sediment newly deposited on the seabed may be subject, in the initial stage, to resuspension caused by more intensive storms.

Within the framework of the performed calculations, also the maximum persistence of suspended solids in the water column has been determined. In the discussed variant, the minimum concentrations of suspended solids equal 2 $mg \cdot l^{-1}$ and caused by the implemented works may persist in water for up to 37 h from the moment when the works on a single foundation start.

- concentrations [$g \cdot l^{-1}$], depth 30 < h < 45 m, COHESIVE soil, foundation diameter – 35 m

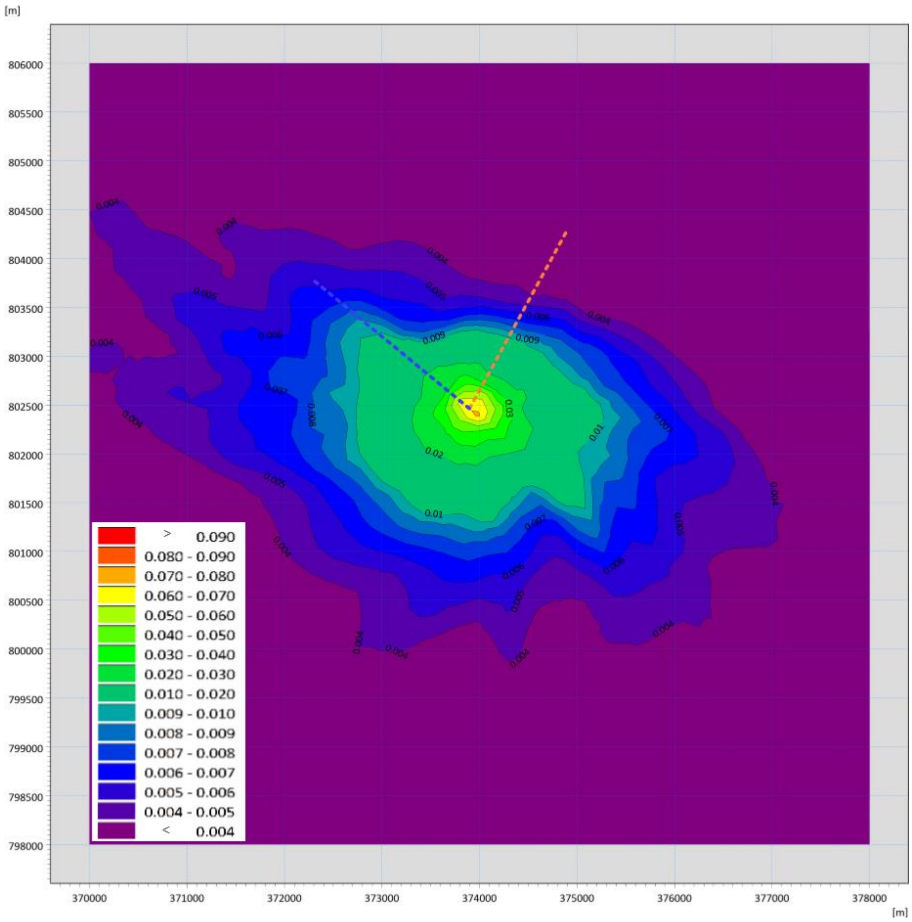

Figure 27. Variant 6 – the maximal concentration values [$g \cdot l^{-1}$]

The blue line marks the direction of the maximum impact range, while the red line marks the minimum impact range

Source: internal data

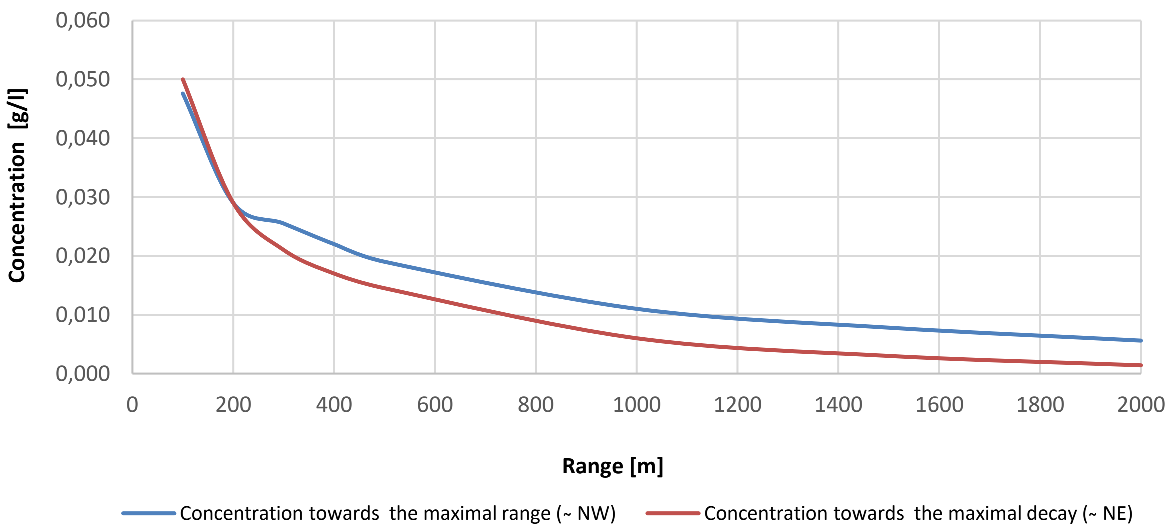

Figure 28. Variant 6 – the maximal concentration range [m]

Source: internal data

- sediment [mm], depth 30 < h < 45 m, COHESIVE soil, foundation diameter – 35 m

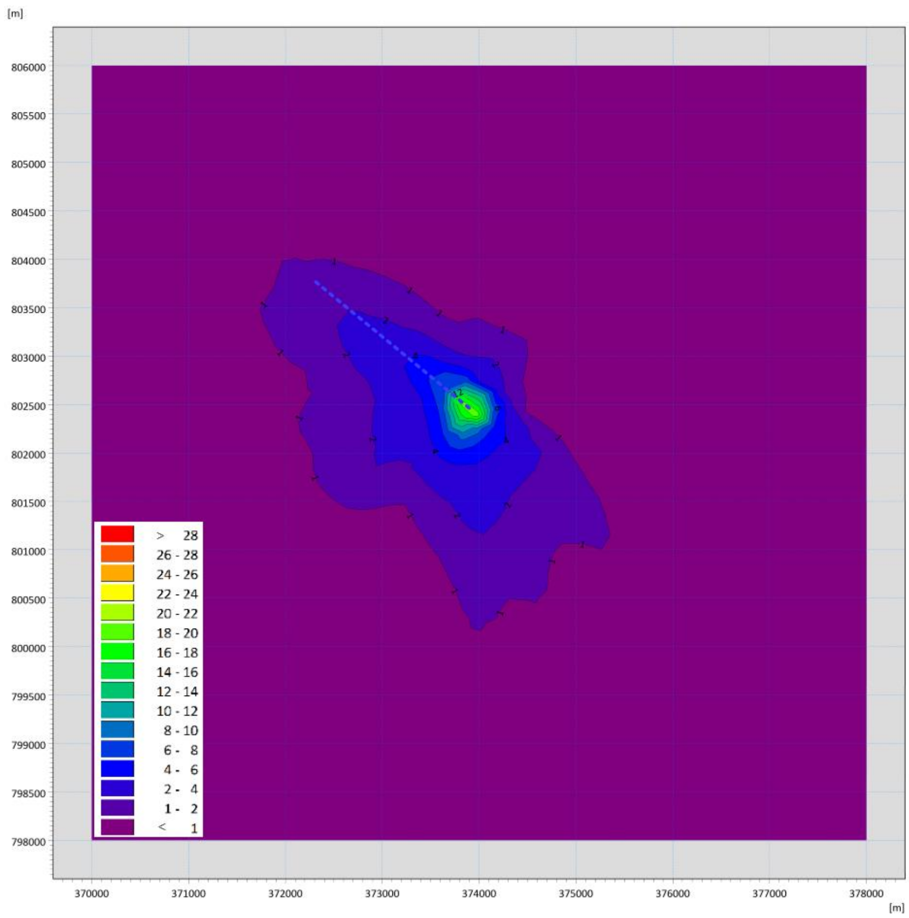

Figure 29. Variant 6 – the maximal thickness of deposited sediments [mm]

The blue line marks the direction of the maximum impact range
Source: internal data

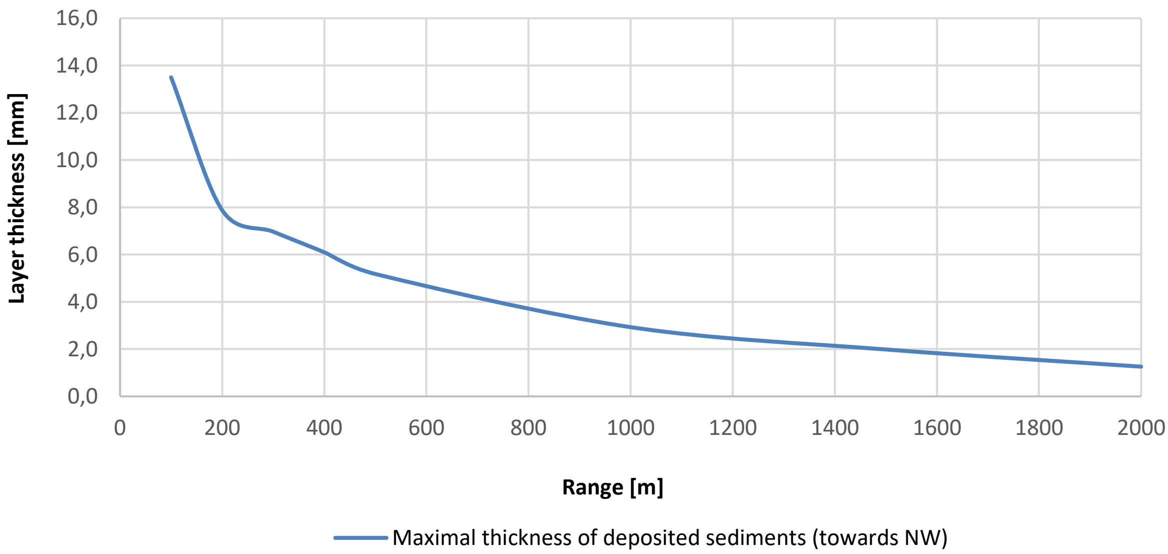

Figure 30. Variant 6 – the sediment deposition range [m]

Source: internal data

5.7 Variant 7

Variant 7 – the minimum water depth (30 < h < 45 m), sediments with dominating non-cohesive fraction, foundation base diameter ø = 40 m

The maximal concentration of suspended solid resulting from human activities was 18 $mg \cdot l^{-1}$ in the place of dredging work performance in the full period devoted to calculations concerning the calculation variant (Figure 31). The maximal concentration of suspended solids in the place where the nearest wind power station is to be located may reach the value of 3 $mg \cdot l^{-1}$ during the works implementation. The suspended solids impact recorded at a point located at a distance of 2 km from the work site is very low and does not exceed 2 $mg \cdot l^{-1}$. Taking into account the condition (introduced in the description of the methods), the “outbalance model” was applied in the calculations, hence the suspended solids concentrations presented above should be treated as an outbalance over the background in natural conditions. The maximum range of the suspended solids cloud with the concentration of over 4 $mg \cdot l^{-1}$ is no greater than 1 km.

The chart (Figure 32) presents the range of the maximal suspended solids concentrations in the least favourable current conditions regarding the entire calculation period. The most important information provided by the chart is that the concentration decreases with the distance from the foundation base edge. The suspended solids concentrations do not exceed 14 $mg \cdot l^{-1}$ at the distance of 100 m from the area covered by dredging works and they quickly decrease to the level of approx. 7 $mg \cdot l^{-1}$ at the distance of 220 m. At the distance of 1000 m, the concentration may reach the level of 3 $mg \cdot l^{-1}$ at maximum, considering the direction of the suspended solid cloud broadest range, and 2 $mg \cdot l^{-1}$ in the case of the direction of the fastest suspended solids dispersion (the highest initial concentrations). In the direction of the maximum range, the concentrations may be up to 8 $mg \cdot l^{-1}$ at the distance of 2 km, while at the same distance but in the direction of the fastest dispersion they are of negligible values.

The maximum thickness values of deposited sediments inside the envelope enclosing the entire calculation period are presented in Figure 33. In the direct vicinity of the area covered by the dredging works conducted in non-cohesive soils, the thickness is up to 5 mm. Thickness of the sediment formed from the material redeposited at the distance of approx. 1 km does not exceed 1 mm in the least favourable sea conditions.

The sediment deposition range is presented in more detail in Figure 34. It shows that the range of this deposition is limited in terms of space. The extreme thickness values decrease very fast with the growing distance from the source of sediment resuspension. In the case of non-cohesive soil, the maximum thickness values do not exceed 2 mm at the distance of 200 m. Additionally, the sediment newly deposited on the seabed may be also prone to resuspension caused by storms in the initial stage.

Within the framework of the performed calculations, also the maximum persistence of suspended solids in the water column has been determined. In the discussed variant, very low concentrations of suspended solids equal 2 $mg \cdot l^{-1}$ and caused by the implemented works may persist in water for up to 30 h from the moment when the works on a single foundation start.

- concentrations [$g \cdot l^{-1}$], depth 30 < h < 45 m, NON-COHESIVE soil, foundation diameter – 40 m

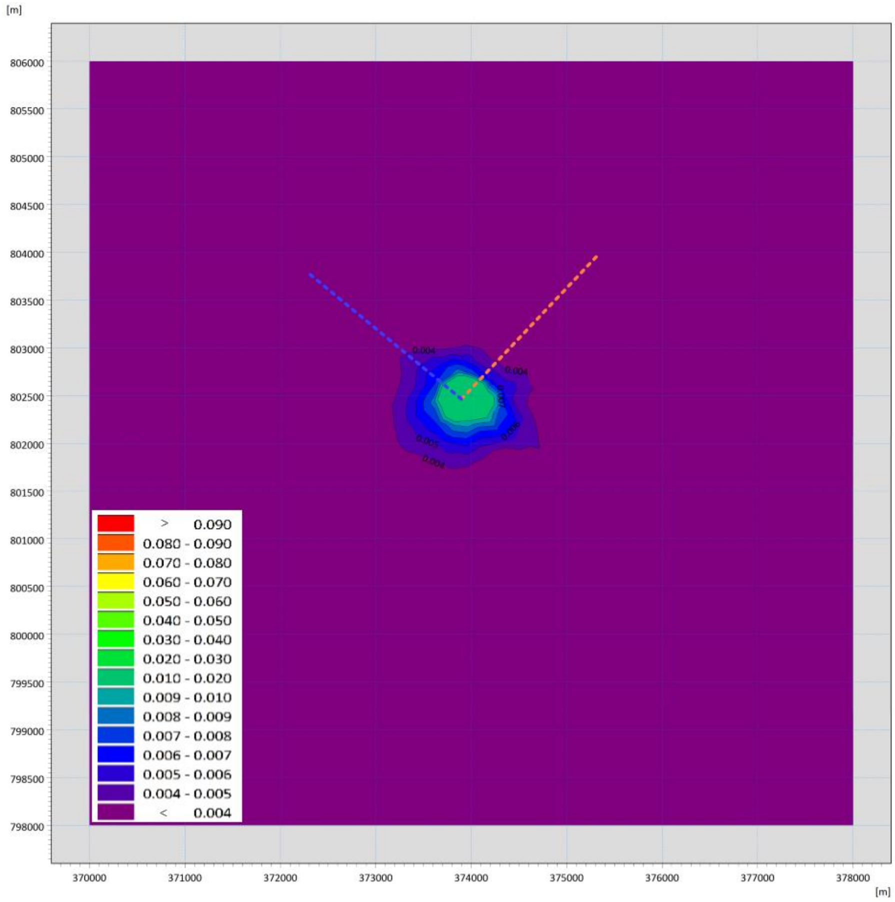

Figure 31. Variant 7 – the maximal concentration values [$g \cdot l^{-1}$]

The blue line marks the direction of the maximum impact range, while the red line marks the minimum impact range

Source: internal data

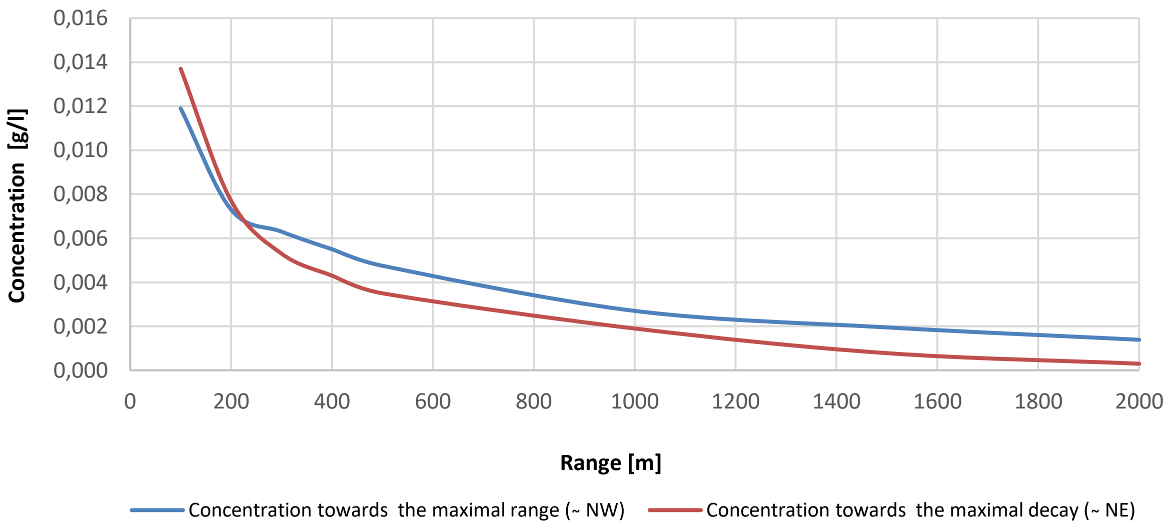

Figure 32. Variant 7 – the maximal concentration range [m]

Source: internal data

- sediment [mm], depth 30 < h < 45 m, NON-COHESIVE soil, foundation diameter – 40 m

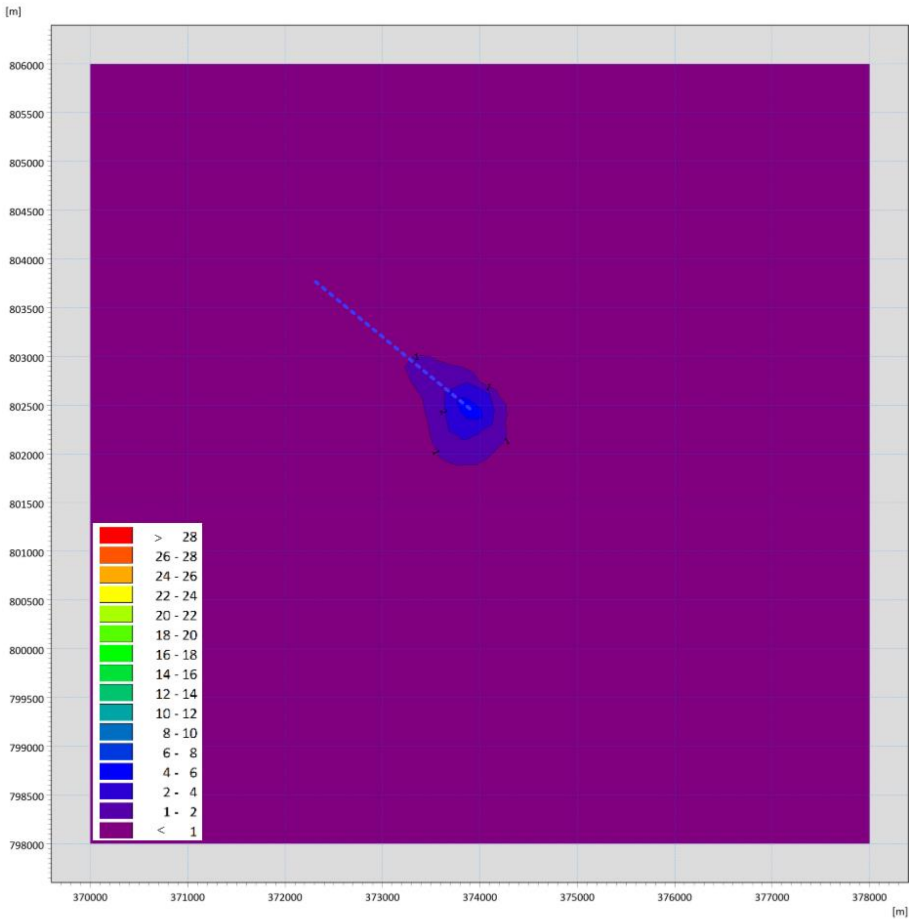

Figure 33. Variant 7 – the maximal thickness of deposited sediments [mm]

The blue line marks the direction of the maximum impact range
Source: internal data

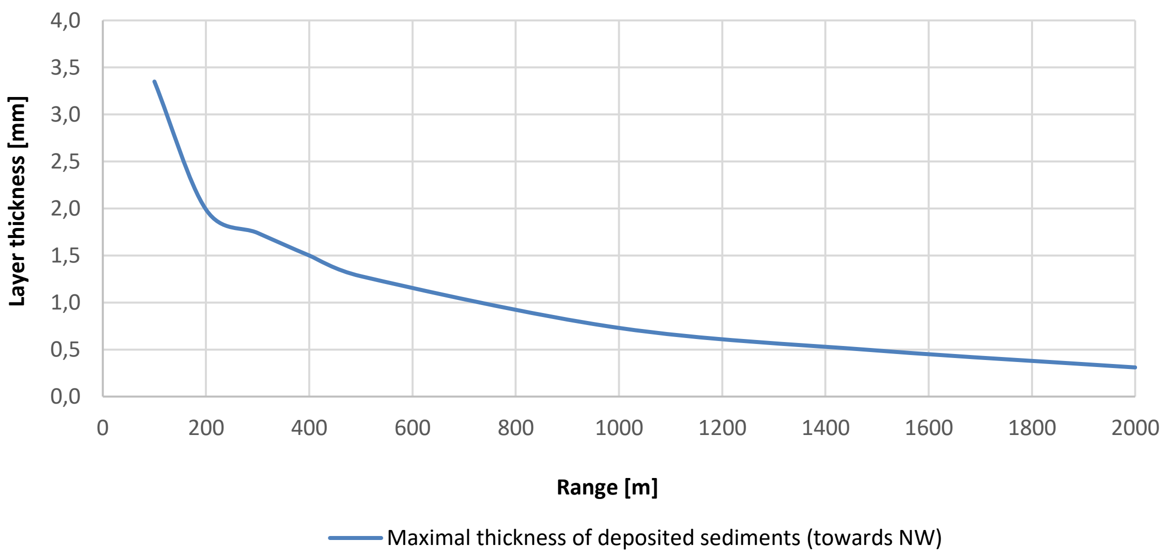

Figure 34. Variant 7 – the sediment deposition range [m]

Source: internal data

5.8 Variant 8

Variant 8 – the minimum water depth (30 < h < 45 m), sediments with dominating non-cohesive fraction, foundation base diameter ø = 35 m

In the discussed calculation variant, the maximum concentrations of solids suspended as a result of human activity were 15 $mg \cdot l^{-1}$ in the area covered by dredging works in the entire calculation period (Figure 35). The maximum concentration of suspended solids in the place where the nearest wind power station is to be located may reach the value of 3 $mg \cdot l^{-1}$ during the works implementation. The suspended solids impact recorded at a point located at a distance of 2 km from the work site is very low and does not exceed 1.5 $mg \cdot l^{-1}$. Taking into account the condition (introduced in the description of the methods), the "outbalance model" was applied in the calculations, hence the suspended solids concentrations presented above should be treated as an outbalance over the background in natural conditions. The maximum range of the suspended solids cloud with the concentration of over 4 $mg \cdot l^{-1}$ is approx. 0.5 km.

The chart (Figure 36) presents the range of the maximal concentrations in the least favourable current conditions regarding the entire calculation period. The main information provided by the chart is that the concentration decreases with the distance from the foundation base edge. The suspended solids concentrations do not exceed 11 $mg \cdot l^{-1}$ at the distance of 100 m from the area covered by dredging works and they quickly decrease to the level of approx. 6 $mg \cdot l^{-1}$ at the distance of 200 m. At the distance of 1000 m, the concentration may reach the level of 2 $mg \cdot l^{-1}$ at maximum, considering the direction of the suspended solid cloud broadest range, and 1 $mg \cdot l^{-1}$ in the case of the direction of the fastest suspended solids dispersion (the highest initial concentrations).

The maximum thickness values of deposited sediments inside the envelope enclosing the entire calculation period are presented in Figure 37. In the direct vicinity of the area covered by the dredging works conducted in non-cohesive soils, the thickness is up to 4 mm. Thickness of the sediment formed from the material redeposited at the distance of approx. 1 km does not exceed 1 mm.

The range of sediment deposition is illustrated in detail in Figure 38, which shows that the deposition is spatially limited. Thickness values decrease very fast with the growing distance from the source of sediment resuspension. In the case of non-cohesive soil, the maximum thickness values do not exceed 2 mm at the distance of 200 m. The sediment newly deposited on the seabed may be subject, in the initial stage, to resuspension caused by more intensive storms.

Within the framework of the performed calculations, also the maximum persistence of suspended solids in the water column has been determined. In the discussed variant, the minimum concentrations of suspended solids equal 2 $mg \cdot l^{-1}$ and caused by the implemented works may persist in water for up to 29 h from the moment when the works on a single foundation start.

- concentrations [g·l^{-1}], depth 30 < h < 45 m, NON-COHESIVE soil, foundation diameter – 35 m

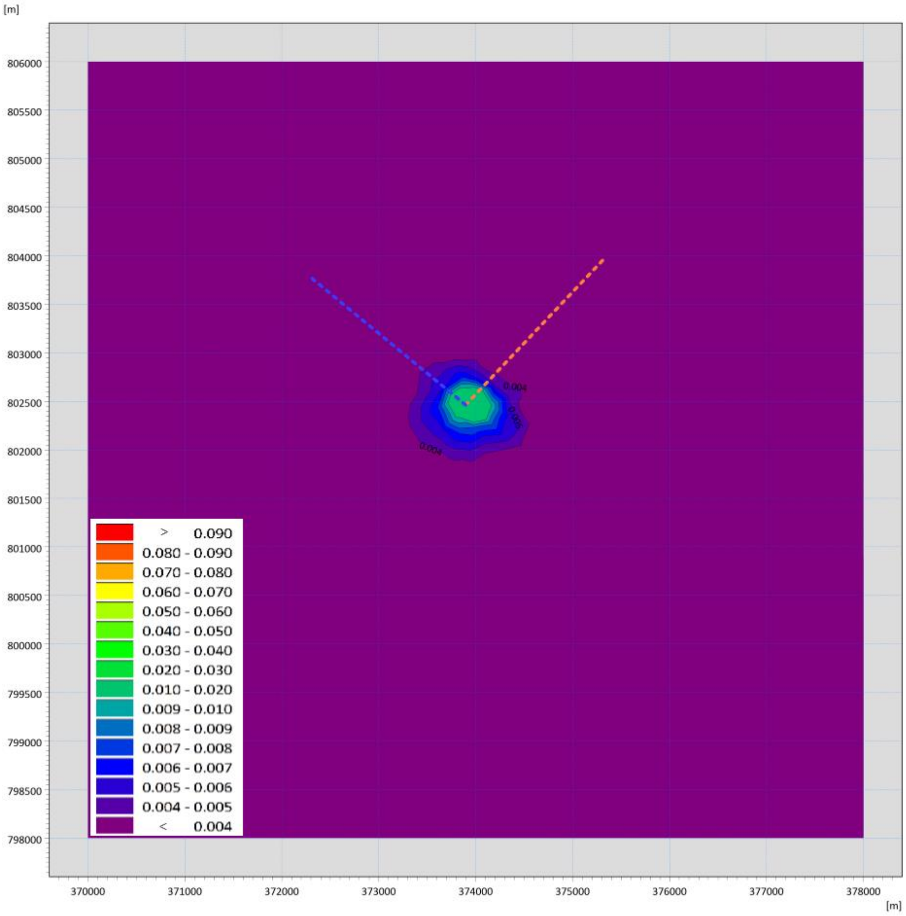

Figure 35. Variant 8 – the maximal concentration values [g·l^{-1}]

The blue line marks the direction of the maximum impact range, while the red line marks the minimum impact range

Source: internal data

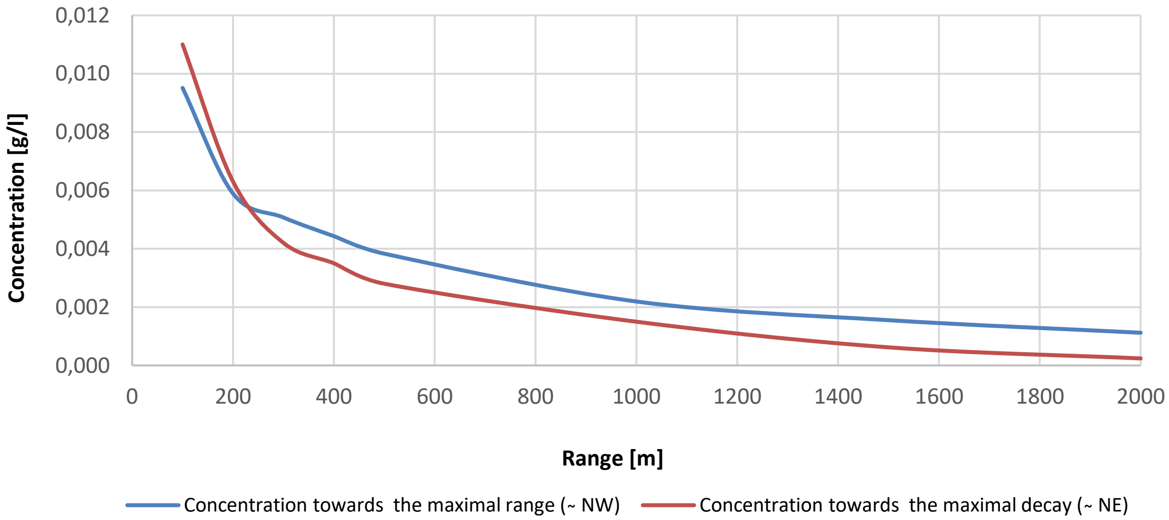

Figure 36. Variant 8 – the maximal concentration range [m]

Source: internal data

- sediment [mm], depth 30 < h < 45 m, NON-COHESIVE soil, foundation diameter – 35 m

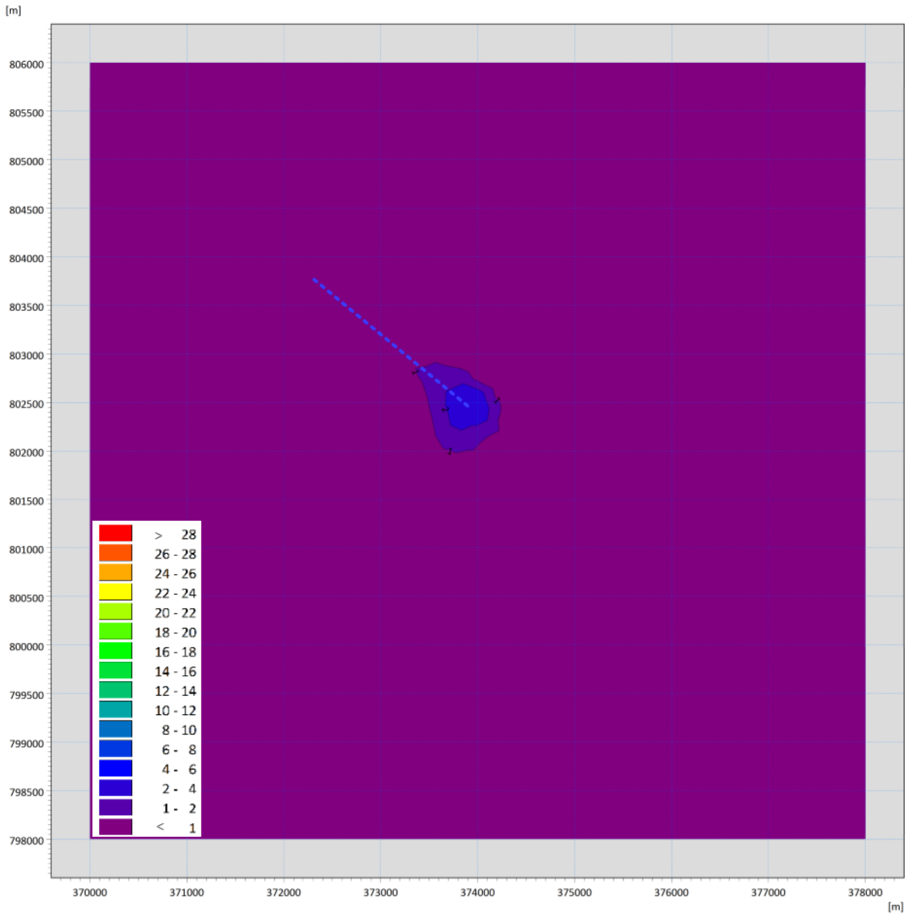

Figure 37. Variant 8 – the maximal thickness of deposited sediments [mm]

The blue line marks the direction of the maximum impact range
Source: internal data

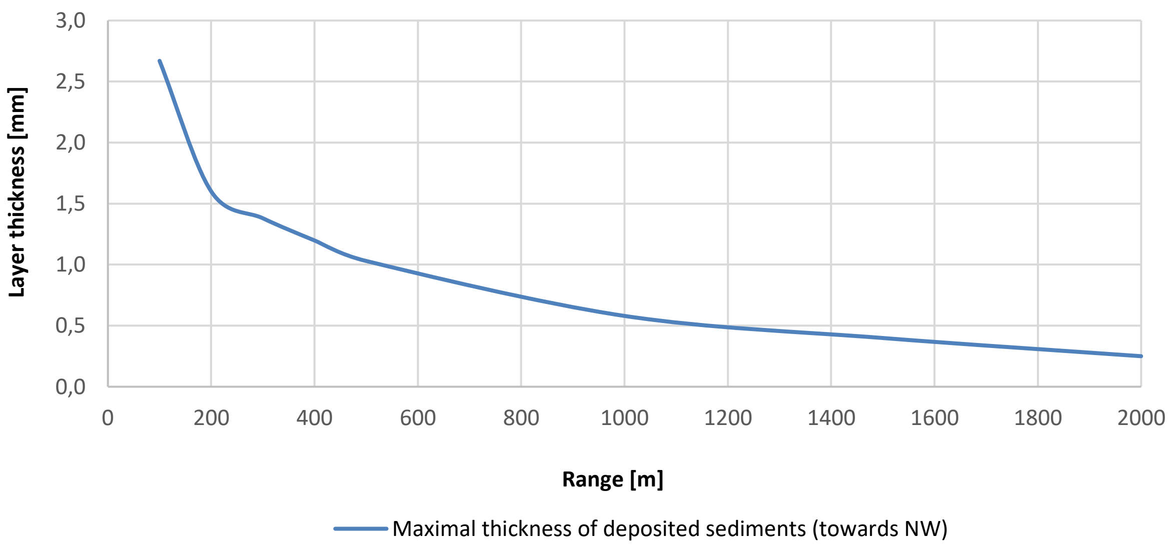

Figure 38. Variant 8 – the sediment deposition range [m]

Source: internal data

5.9 Variant 9

Variant 9 – significant water depth (45 < h < 52 m), sediments with dominating cohesive fraction, foundation base diameter ø = 40 m

In the discussed calculation variant, the maximum concentrations of solids suspended as a result of human activity were 72 $mg \cdot l^{-1}$ in the area covered by dredging works in the entire calculation period (Figure 39). The highest concentration of suspended solids in the place where the nearest wind power station is to be located may reach the value of 12 $mg \cdot l^{-1}$ during the works implementation. The suspended solids impact recorded at a point located at a distance of 3 km from the direct work site is very low and does not exceed 5 $mg \cdot l^{-1}$. Taking into account the condition introduced in the description of the methods, the “outbalance model” was applied in the calculations, hence the suspended solids concentrations presented above should be treated as an outbalance over the background in natural conditions. The furthest range of the suspended solids cloud with the concentration of over 4 $mg \cdot l^{-1}$ has been estimated at approx. 4 km.

The chart (Figure 40) presents the range of the maximal concentrations in the least favourable current conditions regarding the entire calculation period. The basic information provided by the chart is that the concentration decreases with the distance from the foundation base edge. The suspended solids concentrations do not exceed 53 $mg \cdot l^{-1}$ at the distance of 100 m from the area covered by dredging works and they quickly decrease to the level of approx. 25 $mg \cdot l^{-1}$ at the distance of 250 m. At the distance of 1000 m, the concentration may reach the level of 11 $mg \cdot l^{-1}$ at maximum, considering the direction of the suspended solid cloud broadest range, and 8 $mg \cdot l^{-1}$ in the case of the direction of the fastest suspended solids concentration decrease (the highest initial concentrations). In the direction of the maximum range, the concentrations may be up to 6 $mg \cdot l^{-1}$ at the distance of 2 km, while at the same distance but in the direction of the fastest dispersion they are of negligible values.

The maximum thickness values of deposited sediments inside the envelope enclosing the entire calculation period are presented in Figure 41. Only in the direct vicinity of the area covered by the dredging works conducted in cohesive soils, the thickness is up to 18 mm. Thickness of the sediment formed from the material redeposited at the distance of approx. 1 km does not exceed 1 mm in the least favourable sea current conditions.

The sediment deposition range is presented in more detail in Figure 42. It shows clearly that the range of this deposition is limited in terms of space. Thickness values decrease very fast with the growing distance from the source of sediment resuspension. In the case of cohesive soil, the maximum thickness values do not exceed 8 mm at the distance of 200 m. The newly deposited sediment will be prone to resuspension caused by storms (in the initial stage).

Within the framework of the performed calculations, also the maximum persistence of suspended solids in the water column has been determined. In the discussed calculation variant, very low concentrations of suspended solids equal 2 $mg \cdot l^{-1}$ and caused by the implemented works may persist in water for up to 42 h from the moment when the works on a single foundation start.

- concentrations [$g \cdot l^{-1}$], depth h > 45 m, COHESIVE soil, foundation diameter – 40 m

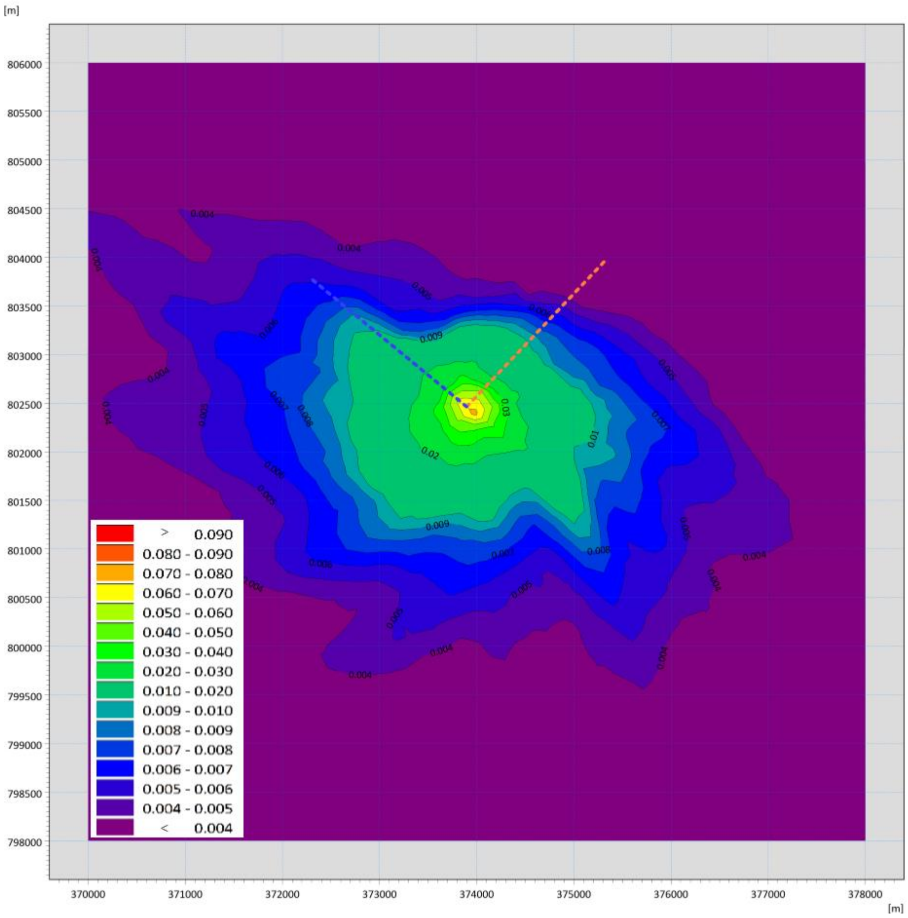

Figure 39. Variant 9 – the maximal concentration values [$g \cdot l^{-1}$]

The blue line marks the direction of the maximum impact range, while the red line marks the minimum impact range

Source: internal data

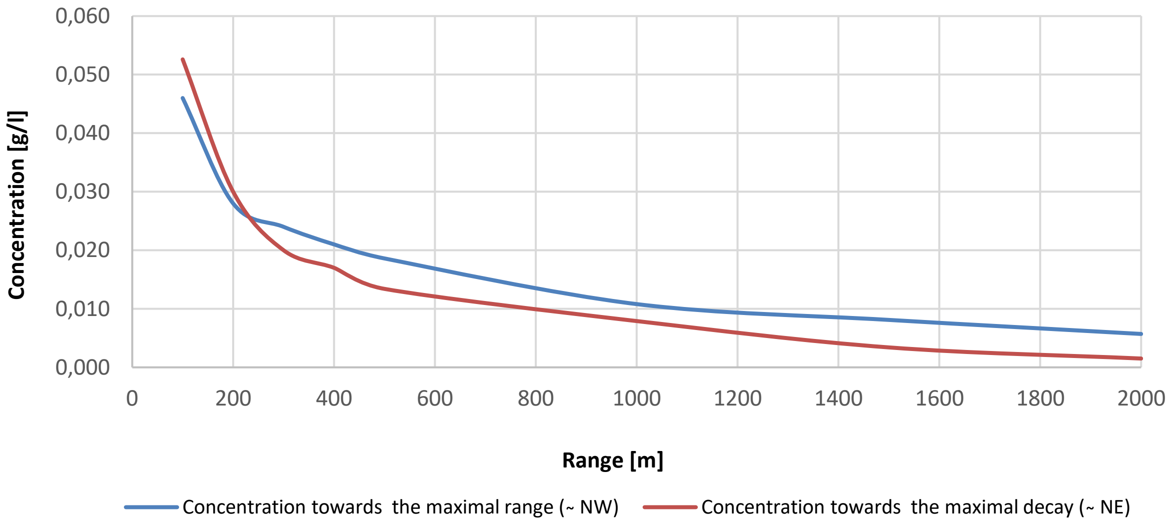

Figure 40. Variant 9 – the maximal concentration range [m]

Source: internal data

- sediment [mm], depth h > 45 m, COHESIVE soil, foundation diameter – 40 m

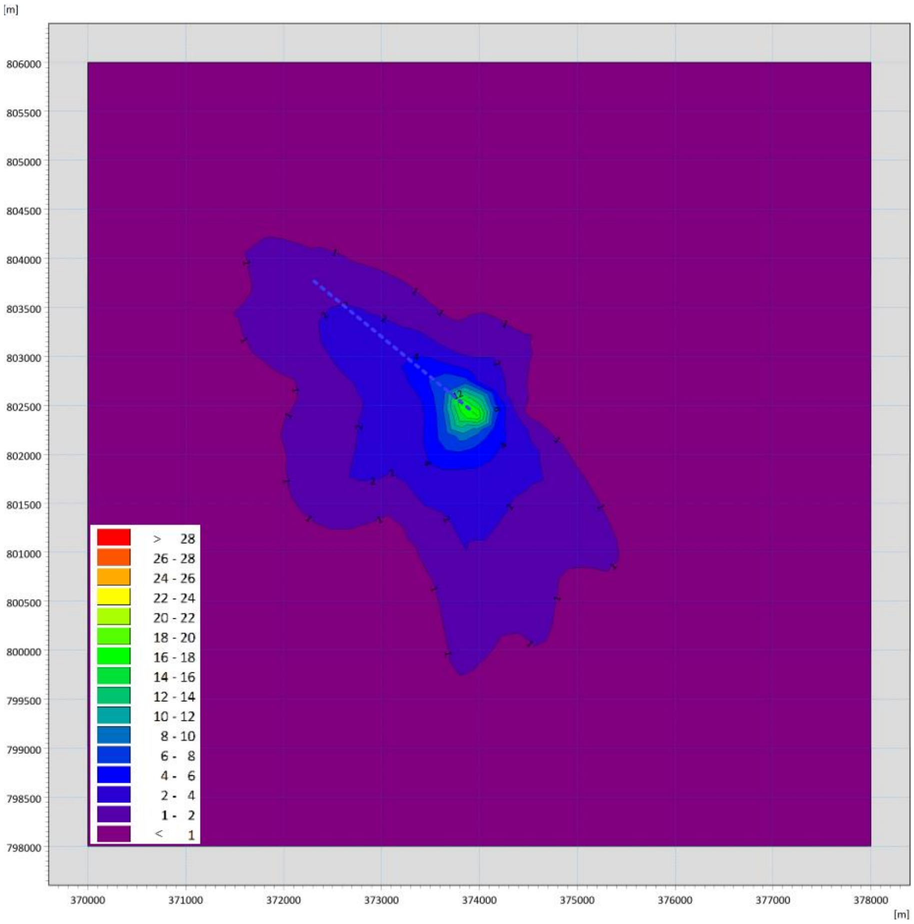

Figure 41. Variant 9 – the maximal thickness of deposited sediments [mm]

The blue line marks the direction of the maximum impact range
Source: internal data

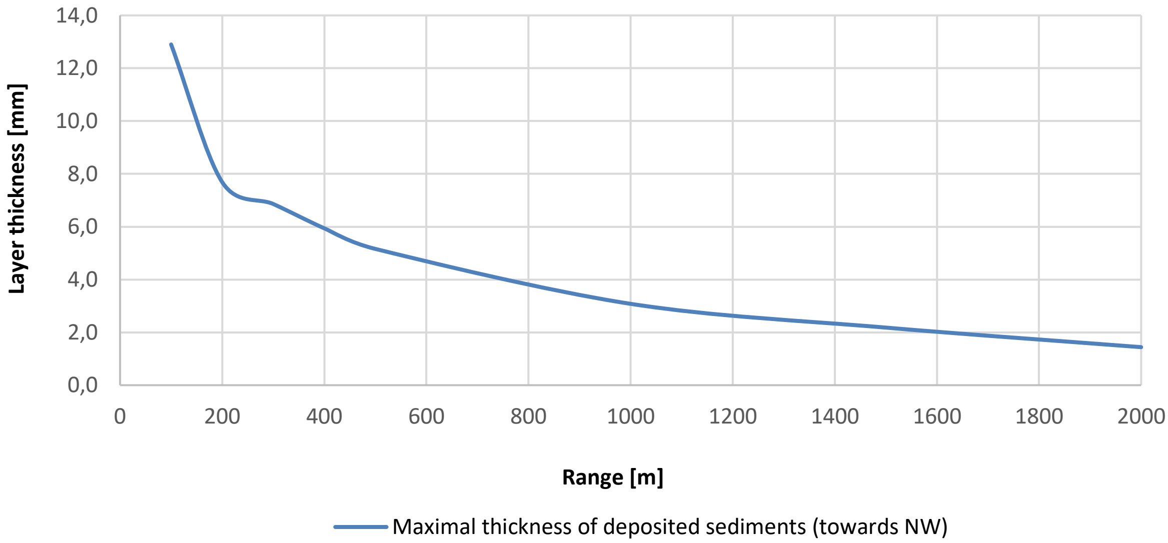

Figure 42. Variant 9 – the sediment deposition range [m]

Source: internal data

5.10 Variant 10

Variant 10 – significant water depth (45 < h < 52 m), sediments with dominating cohesive fraction, foundation base diameter ø = 35 m

The maximal concentration of suspended solid resulting from human activities was 56 $mg \cdot l^{-1}$ in the place of dredging work performance in the full survey period (Figure 43). The maximal concentration of suspended solids in the place where the nearest wind power station is to be located may reach the value of 9 $mg \cdot l^{-1}$ during the works implementation. The suspended solids impact recorded at a point located at a distance of 3 km from the work site is very low and does not exceed 4 $mg \cdot l^{-1}$. Taking into account the condition (introduced in the description of the methods), the “outbalance model” was applied in the calculations, hence the suspended solids concentrations presented above should be treated as an outbalance over the background in natural conditions. The furthest range of the suspended solids cloud with the concentration of over 4 $mg \cdot l^{-1}$ has been estimated at approx. 3 km.

The chart (Figure 44) presents the range of the maximal suspended solids concentrations in the least favourable current conditions regarding the entire calculation period. The basic information provided by the chart is that the concentration decreases with the distance from the foundation base edge. The suspended solids concentrations do not exceed 46 $mg \cdot l^{-1}$ at the distance of 100 m from the area covered by dredging works and they quickly decrease to the level of approx. 36 $mg \cdot l^{-1}$ at the distance of 200 m. At the distance of 1000 m, the concentration may reach the level of 9 $mg \cdot l^{-1}$ at maximum, in the direction of the suspended solid cloud broadest range considering the direction of fastest suspended solids dispersion (the highest initial concentrations). In the direction of the maximum range, the concentrations may be up to 5 $mg \cdot l^{-1}$ at the distance of 2 km, while at the same distance but in the direction of the fastest concentration decrease.

The maximum thickness values of deposited sediments inside the envelope enclosing the entire calculation period are presented in Figure 45. In the direct vicinity of the area covered by the dredging works conducted in cohesive soils, the thickness is up to 14 mm. Thickness of the sediment formed from the material redeposited at the distance of approx. 2 km does not exceed 1.2 mm.

The range of sediment deposition is illustrated in detail in Figure 46, which shows that the deposition is spatially limited. The highest thickness values decrease very fast with the growing distance from the source of sediment resuspension. In the case of cohesive soil, the maximum thickness values do not exceed 6.5 mm at the distance of 200 m. The sediment newly deposited on the seabed may be subject, in the initial stage, to resuspension caused by more intensive storms.

Within the framework of the performed calculations, also the maximum persistence of suspended solids in the water column has been determined. In the discussed variant, the minimum concentrations of suspended solids equal 2 $mg \cdot l^{-1}$ and caused by the implemented works may persist in water for up to 39 h from the moment when the works on a single foundation start.

- concentrations [g·l^{-1}], depth h > 45 m, COHESIVE soil, foundation diameter – 35 m

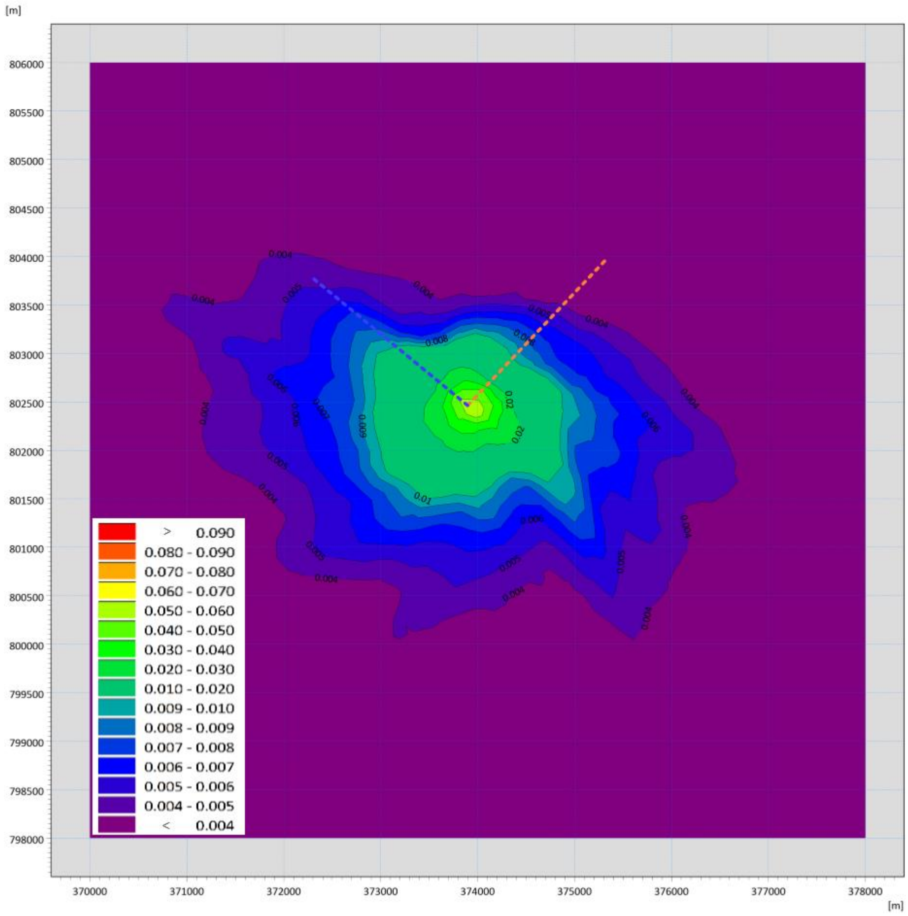

Figure 43. Variant 10 – the maximal concentration values [g·l^{-1}]

The blue line marks the direction of the maximum impact range, while the red line marks the minimum impact range

Source: internal data

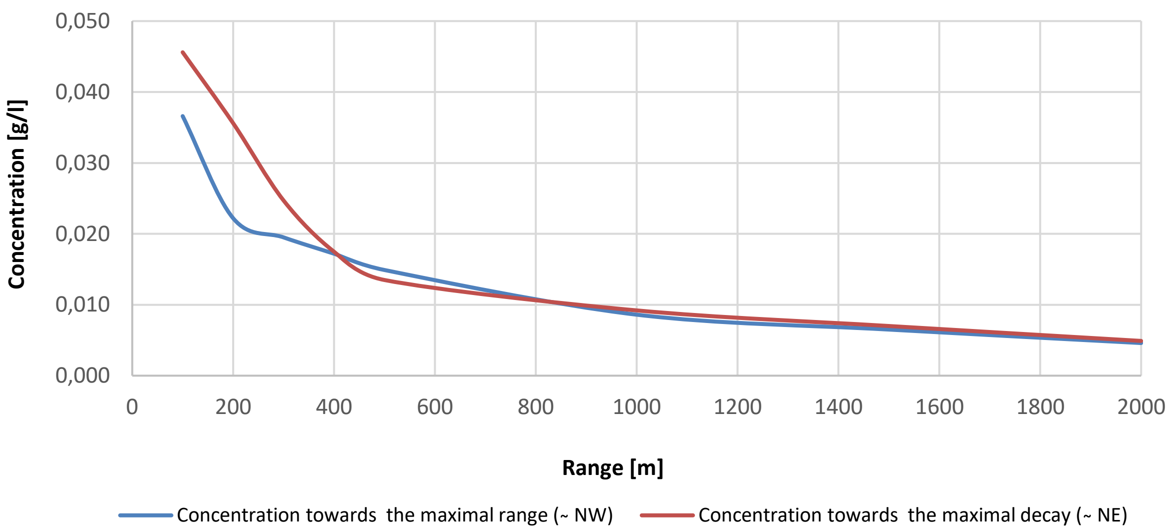

Figure 44. Variant 10 – the maximal concentration range [m]

Source: internal data

- sediment [mm], depth h > 45 m, COHESIVE soil, foundation diameter – 35 m

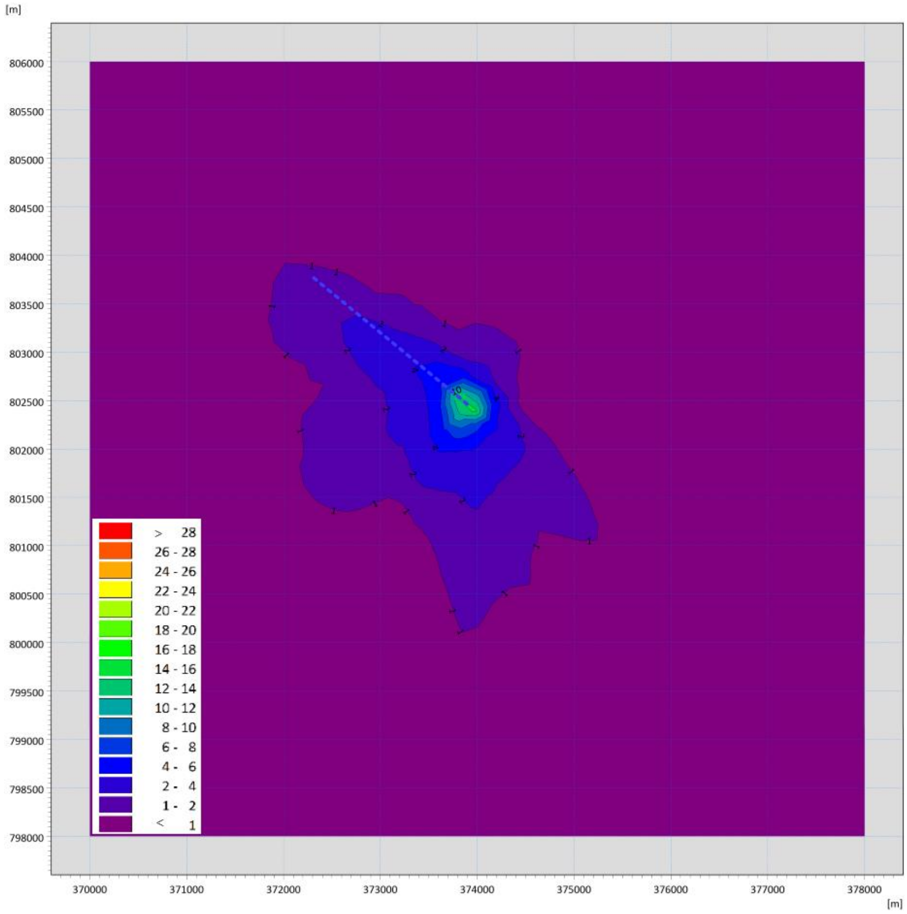

Figure 45. Variant 10 – the maximal thickness of deposited sediments [mm]

The blue line marks the direction of the maximum impact range
Source: internal data

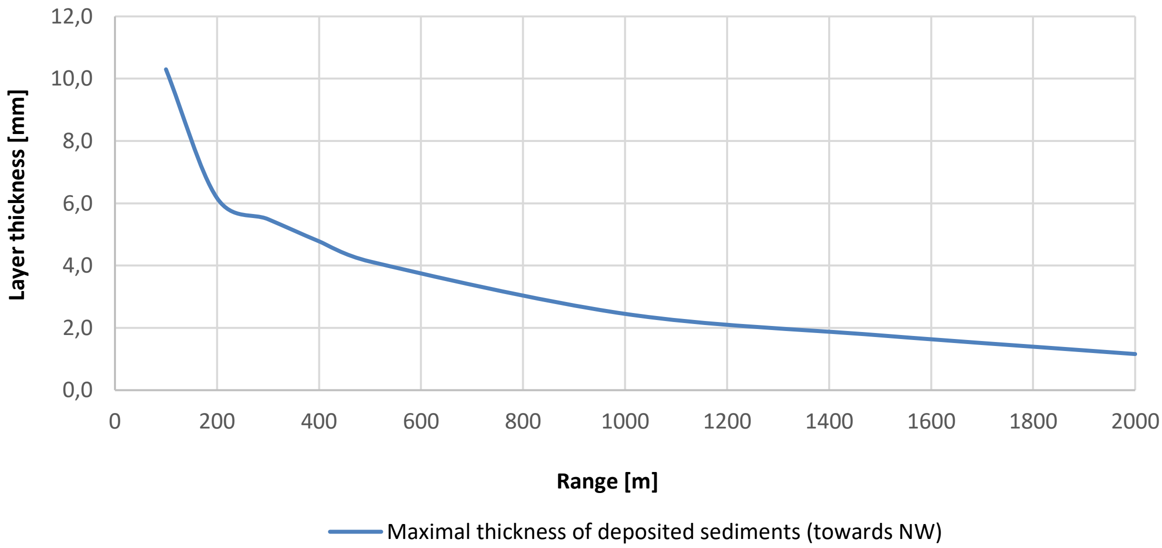

Figure 46. Variant 10 – the sediment deposition range [m]

Source: internal data

5.11 Variant 11

Variant 11 – significant water depth (45 < h < 52 m), sediments with dominating non-cohesive fraction, foundation base diameter ø = 40 m

In the discussed calculation variant, the maximum concentrations of solids suspended as a result of human activity were 15 $mg \cdot l^{-1}$ in the area covered by dredging works in the entire calculation period (Figure 47). The maximal concentration of suspended solids in the place where the nearest wind power station is to be located may reach the value of 3 $mg \cdot l^{-1}$ during the works implementation. The suspended solids impact recorded at a point located at a distance of 2 km from the work site is very low and does not exceed 2 $mg \cdot l^{-1}$. Taking into account the condition (introduced in the description of the methods), the "outbalance model" was applied in the calculations, hence the suspended solids concentrations presented above should be treated as an outbalance over the background in natural conditions. The maximum range of the suspended solids cloud with the concentration of over 4 $mg \cdot l^{-1}$ is approx. 0.5 km.

The chart (Figure 48) presents the range of the maximal concentrations in the least favourable current conditions regarding the entire calculation period. The basic information provided by the chart is that the concentration decreases with the distance from the foundation base edge. The suspended solids concentrations do not exceed 10 $mg \cdot l^{-1}$ at the distance of 100 m from the area covered by dredging works and they quickly decrease to the level of approx. 5 $mg \cdot l^{-1}$ at the distance of 250 m. At the distance of 1000 m, the concentration may reach the level of 2 $mg \cdot l^{-1}$ at maximum, in the direction of the suspended solid cloud broadest range, and 2 $mg \cdot l^{-1}$ in the case of the direction characterised by the fastest suspended solids dispersion (the highest initial concentrations). In the directions of the broadest range and the fastest dispersion the concentration levels are negligible as they do no exceed the level of 1 $mg \cdot l^{-1}$.

The maximum thickness values of deposited sediments inside the envelope enclosing the entire calculation period are presented in Figure 49. In the direct vicinity of the area covered by the dredging works conducted in non-cohesive soils, the thickness is up to 4 mm. Thickness of the sediment formed from the material redeposited at the distance of approx. 1 km does not exceed 1 mm.

The range of sediment deposition is illustrated in detail in Figure 50, which shows clearly that the deposition is spatially limited. The extreme thickness values decrease very fast with the growing distance from the source of sediment resuspension. In the case of non-cohesive soil, the maximum thickness values do not exceed 2 mm at the distance of 200 m. The sediment newly deposited on the seabed may be subject, in the initial stage, to resuspension caused by more intensive storms.

Within the framework of the performed calculations, also the maximum persistence of suspended solids in the water column has been determined. In the discussed variant, very low concentrations of suspended solids equal 2 $mg \cdot l^{-1}$ and caused by the implemented works may persist in water for up to 30 h from the moment when the works on a single foundation start.

- concentrations [$g \cdot l^{-1}$], depth h > 45 m, NON-COHESIVE soil, foundation diameter – 40 m

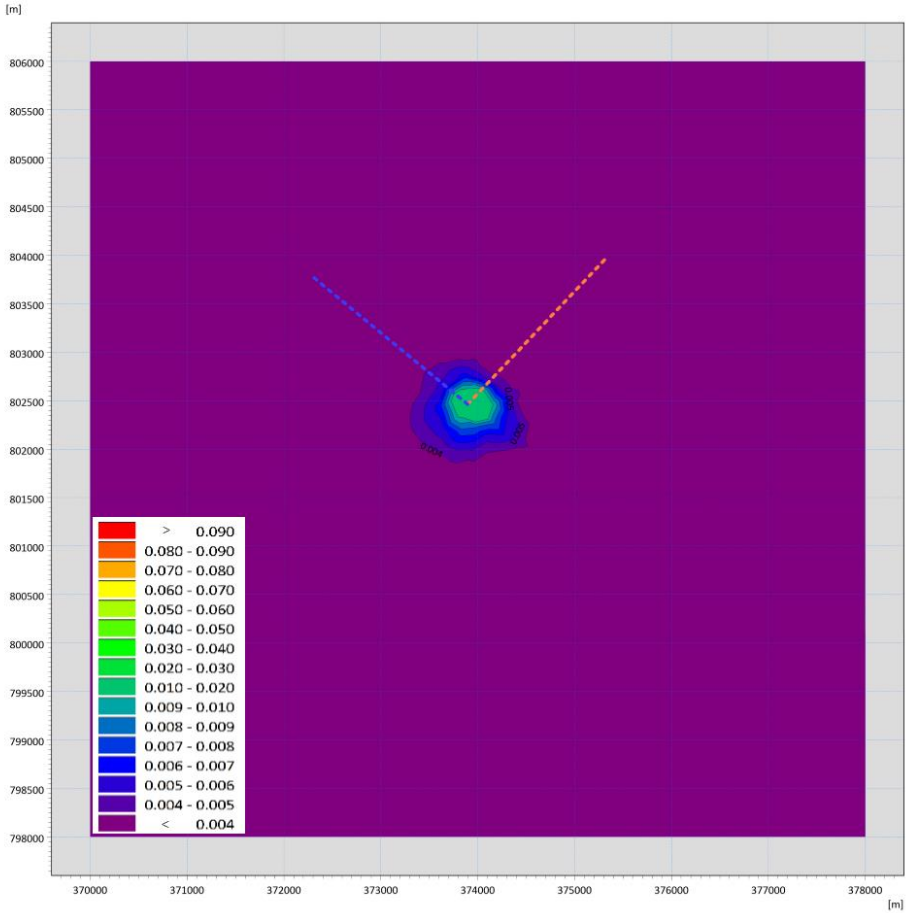

Figure 47. Variant 11 – the maximal concentration values [$g \cdot l^{-1}$]

The blue line marks the direction of the maximum impact range, while the red line marks the minimum impact range

Source: internal data

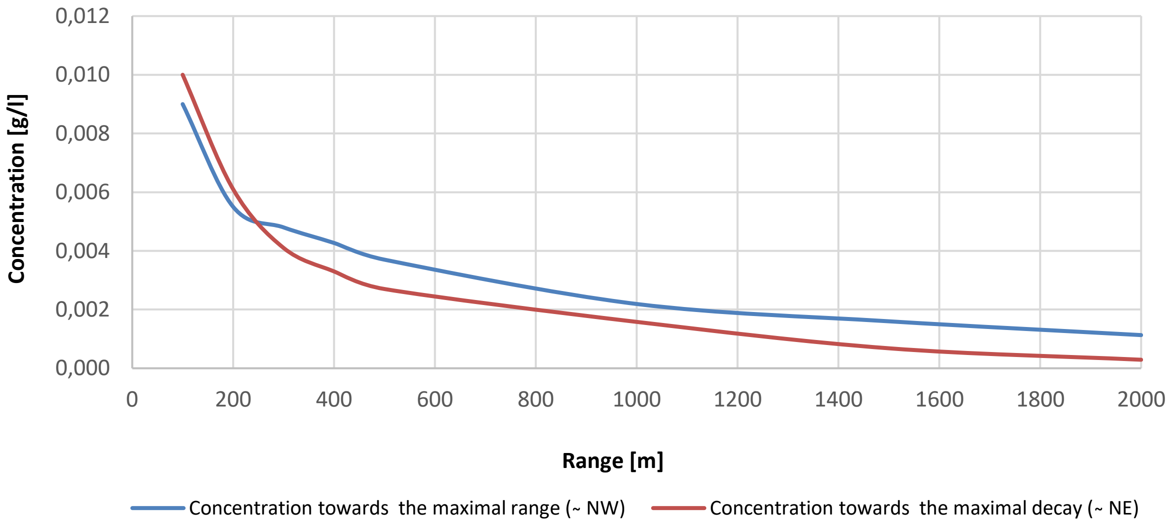

Figure 48. Variant 11 – the maximal concentration range [m]

Source: internal data

- sediment [mm], depth h > 45 m, NON-COHESIVE soil, foundation diameter – 40 m

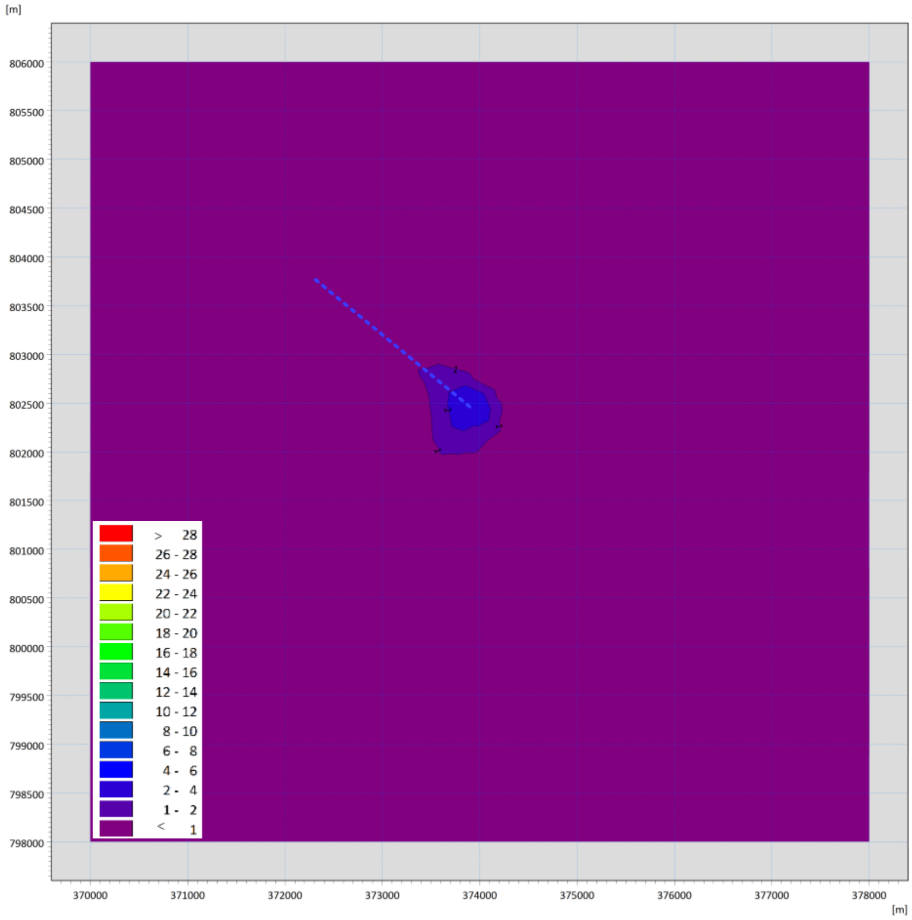

Figure 49. Variant 11 – the maximal thickness of deposited sediments [mm]

The blue line marks the direction of the maximum impact range
Source: internal data

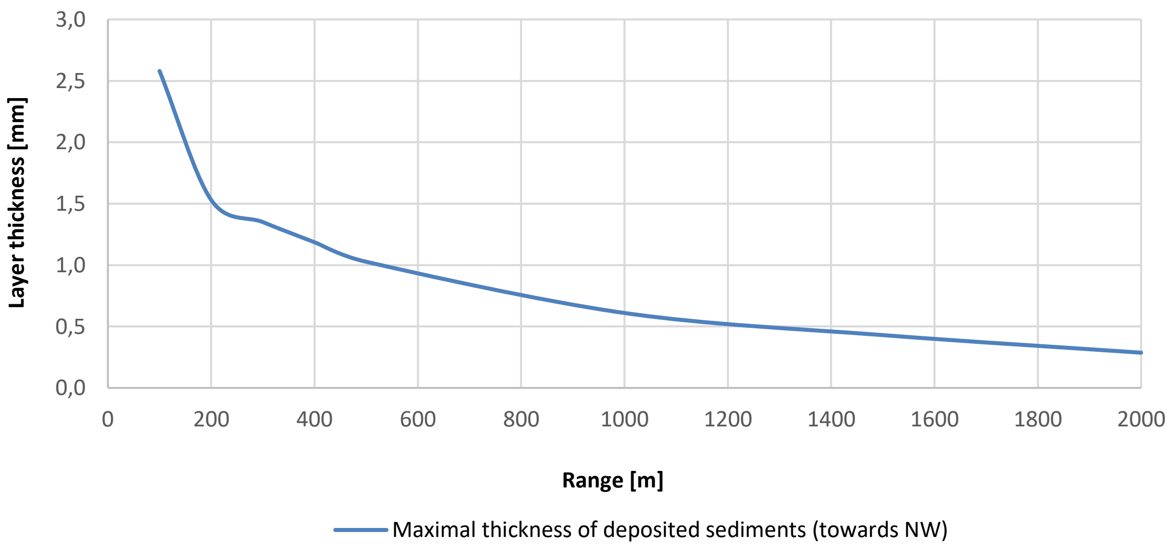

Figure 50. Variant 11 – the sediment deposition range [m]

Source: internal data

5.12 Variant 12

Variant 12 – significant water depth (45 < h < 52 m), sediments with dominating non-cohesive fraction, foundation base diameter ø = 35 m

The maximal concentration of suspended solid resulting from human activities was 11 mg·l^{-1} in the place of dredging work performance in the full period devoted to calculations concerning the calculation variant (Figure 51). The maximal concentration of suspended solids in the place where the nearest wind power station is to be located may reach the value of 2 mg·l^{-1} during the works implementation. The suspended solids impact recorded at a point located at a distance of 2 km from the work site is very low and does not exceed 1 mg·l^{-1}. Taking into account the condition (introduced in the description of the methods), the “outbalance model” was applied in the calculations, hence the suspended solids concentrations presented above should be treated as an outbalance over the background in natural conditions. The maximum range of the suspended solids cloud with the concentration of over 4 mg·l^{-1} is no greater than 0.4 km.

The chart (Figure 52) presents the range of the maximal suspended solids concentrations in the least favourable current conditions regarding the entire calculation period. The most important information provided by the chart is that the concentration decreases with the distance from the foundation base edge. The suspended solids concentrations do not exceed 9 mg·l^{-1} at the distance of 100 m from the area covered by dredging works and they quickly decrease to the level of approx. 7 mg·l^{-1} at the distance of 200 m. At the distance of 1000 m, the concentration may reach the level of 2 mg·l^{-1} at maximum, considering the direction of the suspended solid cloud broadest range, and 2 mg·l^{-1} in the case of the direction of the fastest suspended solids dispersion (the highest initial concentrations). In the direction of the maximum range, the concentrations may be up to 1 mg·l^{-1} at the distance of 2 km, while at the same distance but in the direction of the fastest decrease.

The maximum thickness values of deposited sediments inside the envelope enclosing the entire calculation period are presented in Figure 53. In the direct vicinity of the area covered by the dredging works conducted in non-cohesive soils, the thickness is up to 2.8 mm. Thickness of the sediment formed from the material redeposited at the distance of approx. 1 km does not exceed 0.5 mm in the least favourable sea conditions.

The sediment deposition range is presented in more detail in Figure 54. It shows that the range of this deposition is limited in terms of space. The extreme thickness values decrease very fast with the growing distance from the source of sediment resuspension. In the case of non-cohesive soil, the maximum thickness values do not exceed 1.5 mm at the distance of 200 m. Additionally, the sediment newly deposited on the seabed may be also prone to resuspension caused by storms in the initial stage.

Within the framework of the performed calculations, also the maximum persistence of suspended solids in the water column has been determined. In the discussed variant, very low concentrations of suspended solids equal 2 mg·l^{-1} and caused by the implemented works may persist in water for up to 30 h from the moment when the works on a single foundation start.

- concentrations [$g \cdot l^{-1}$], depth h > 45 m, NON-COHESIVE soil, foundation diameter – 35 m

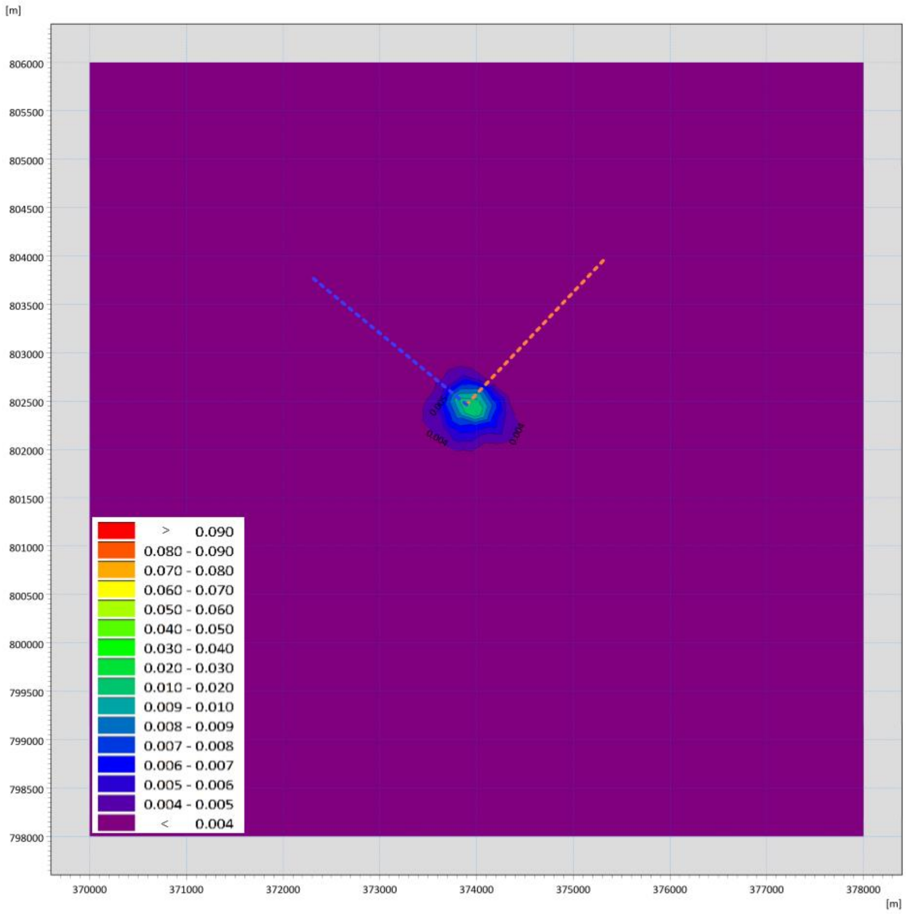

Figure 51. Variant 12 – the maximal concentration values [$g \cdot l^{-1}$]

The blue line marks the direction of the maximum impact range, while the red line marks the minimum impact range

Source: internal data

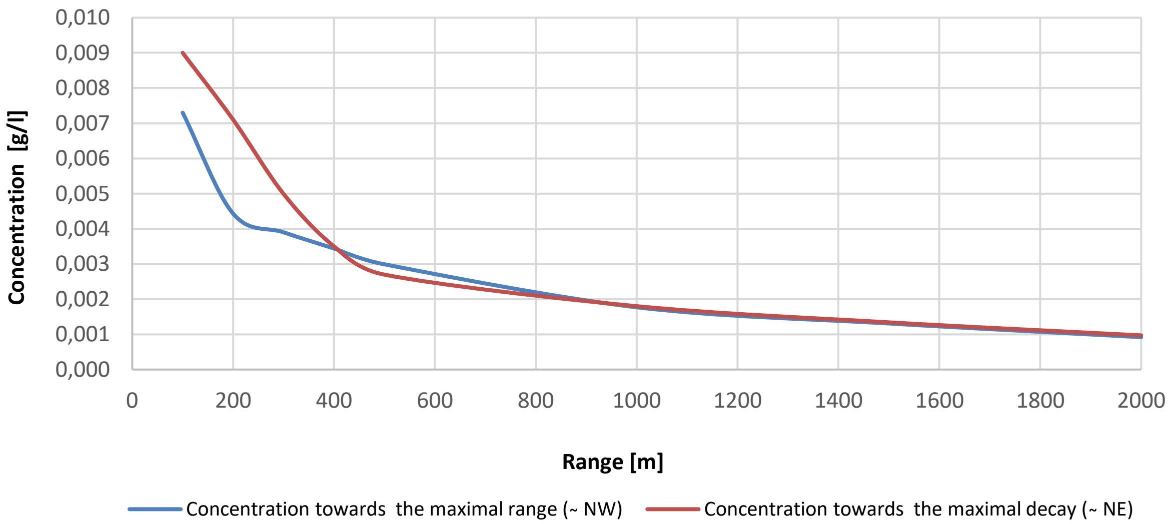

Figure 52. Variant 12 – the maximal concentration range [m]

Source: internal data

- sediment [mm], depth h > 45 m, NON-COHESIVE soil, foundation diameter – 35 m

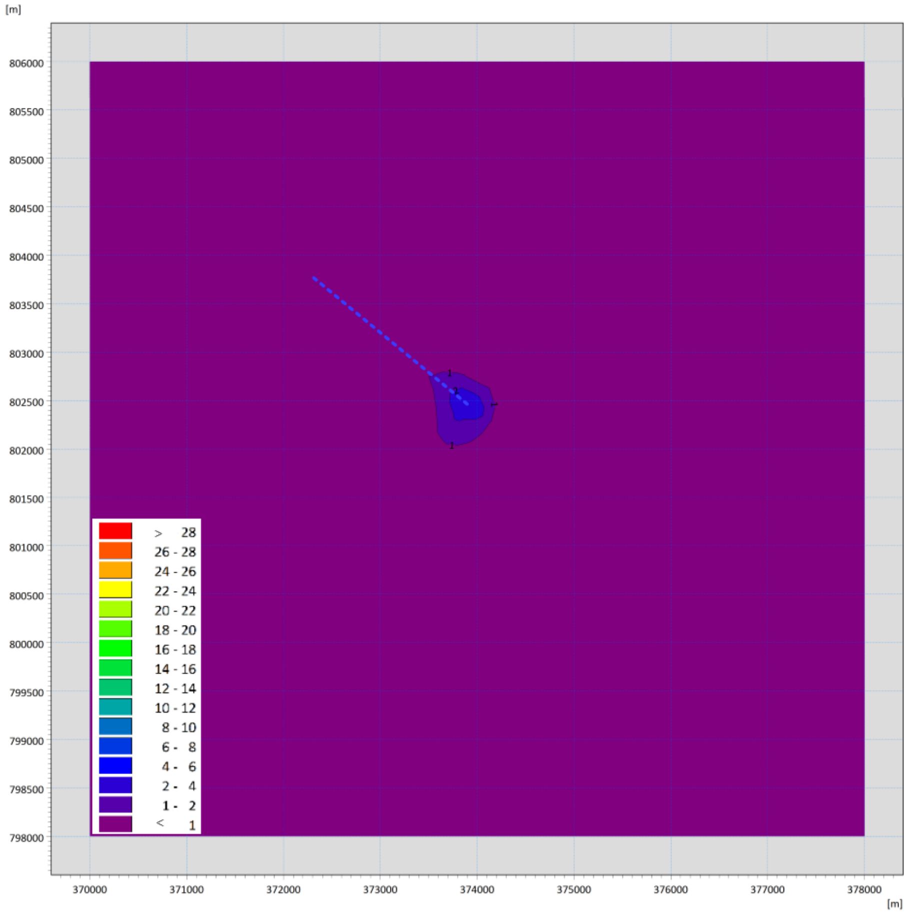

Figure 53. Variant 12 – the maximal thickness of deposited sediments [mm]

The blue line marks the direction of the maximum impact range
Source: internal data

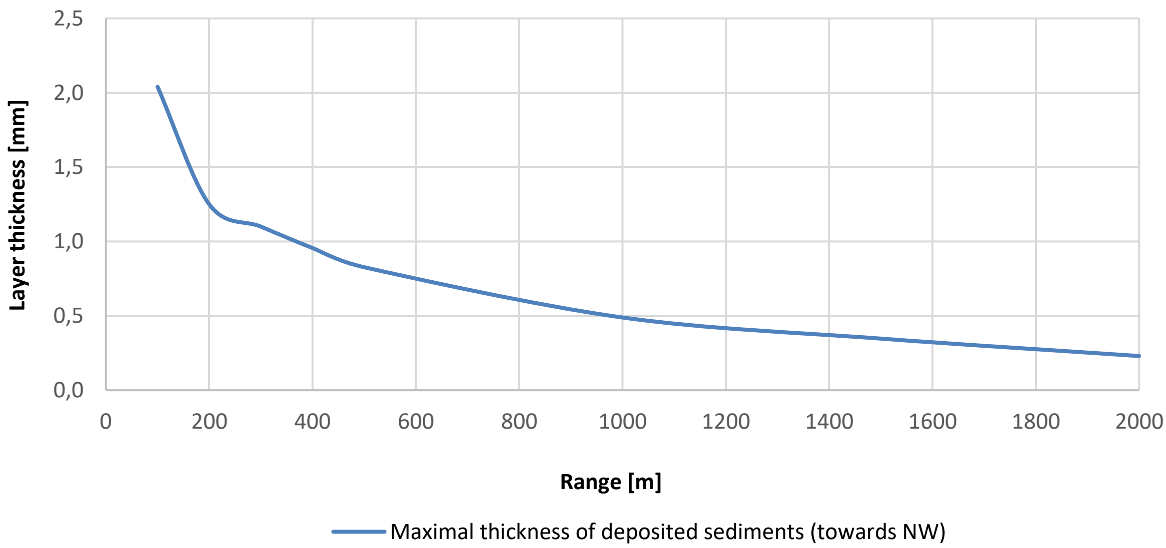

Figure 54. Variant 12 – the sediment deposition range [m]

Source: internal data

5.13 Laying energy and teletechnical cables

Works related with laying energy and teletechnical cables (in the Baltica OWF Area) also impact the seabed, causing suspended matter to be created, moved, and in the final phase, settled on the seabed. In the calculation simulations carried out, the impact of this type was taken into consideration. As it was specified, dredging works related with preparatory works of the seabed for the foundations have a limited range. Even in the least favourable variant (smallest water depths, works carried out in cohesive soils, hydrodynamic conditions that make it possible to create highest suspension concentration), the concentration of suspended matter in the distance of 600 m from the place where the works are carried out does not exceed the value of 20 $mg \cdot l^{-1}$. From the technical point of view, works related with preparation of the seabed for the foundation of the specific power plant may not be carried out concurrently with burying the cable for the same power plant, which means that both impacts do not cumulate. The suspended matter level of impact on the natural marine environment caused by laying cable and burying it, in accordance with the results of the carried out calculations, is lower than the one caused by the preparation of seabed for the foundations of the power plant support structure. Thereby, for all analyses related with the investment's environmental impact, with regard to the impact of suspended matter concentration, in the interior part of the offshore wind farm the higher concentration will be taken into account, that is the ones caused by works related with levelling/replacement of soil for the foundation. The only place where the suspended matter concentrations caused by works related with laying cables may reach values greater than the ones caused by preparatory works for foundation, is the area located within an equal distance from both power plants. However, in this region as well, the absolute concentration values are lower than the concentrations present in the zone adjacent with the foundation works.

The next parameter of suspended matter impact, that is the size of sediment deposited on the seabed, or more specifically its thickness, will be treated in a different manner. Even though both anthropogenic actions (seabed works at the foundations and burying cable) that cause the creation of suspended matter are not carried out concurrently, their final effect in the form of sediment deposition on the seabed is cumulated. The results of calculations indicate that the thickness of sediment newly created as a result of burying cables is lower than the thickness of the sediment created during works at the foundations. During the least favourable hydrodynamic conditions and in the case of works carried out in cohesive soils the analysed thickness may reach to the value in the region of 9 mm within the distance of 100 m from the buried cable. However, in case the same works are carried out in a non-cohesive soil, this thickness is much lower and can reach 2 mm at most in an analogous distance from the cable. It will be added that newly created sediment is susceptible to a repeated movement in the resuspension process caused by more significant storm phenomena and greater speeds of near-bottom currents.

Marine sediments lifted from the seabed as a result of cable laying works in the seabed remain in a suspended form for a short time, which ranges between ten and twenty hours from the time this type of works is finished in the given location.

6 Summary of calculations carried out

The goal of calculations carried out was to determine the parameter of marine environmental impact for suspended matter generated by anthropogenic activity related to the construction of wind farms.

The main impact parameters were: suspended matter concentrations that may be formed in a marine environment, as well as ranges and durations of their impacts, as well as thicknesses of sediments created in the suspended matter sedimentation phase.

The calculation results indicate clearly that the works carried out on the seabed in cohesive soils cause a greater impact of suspended matter on the marine environment than the works in non-cohesive soils. It should be emphasized that in the surface layers of the Baltica OWF Area seabed in question, cohesive soils slightly prevail.

The table (Table 3) presented a summary of results of calculations for all calculation scenarios (variants) in the selected points (distances from the place of works carried out on the seabed).

Table 3. The table of results of maximum concentration ranges and the maximum spread of seabed sediments

Calculation variant	**Concentration [$mg \cdot l^{-1}$]**	**Distance from the centre [m]**				
	Sediment layer [mm]	**100**	**200**	**500**	**1000**	**2000**
1. Depth h < 30 m, COHESIVE soil, foundation diameter – 40 m	Concentration values in the direction of the maximum range	75	47	29	16	8
	The maximum sediment layer	22.0	12.3	7.7	4.1	1.6
2. Depth h < 30 m, COHESIVE soil, foundation diameter – 35 m	Concentration values in the direction of the maximum range	60	37	24	9	7
	The maximum sediment layer	17.4	9.6	6.2	3.3	1.3
3. Depth h < 30 m, NON-COHESIVE soil, foundation diameter – 40 m	Concentration values in the direction of the maximum range	15	9	6	3	2
	The maximum sediment layer	4.3	2.4	1.5	0.8	0.3
4. Depth h < 30 m, NON-COHESIVE soil, foundation diameter – 35 m	Concentration values in the direction of the maximum range	12	7	5	3	1
	The maximum sediment layer	3.4	1.9	1.2	0.7	0.3
5. Depth 30 < h < 45 m, COHESIVE soil, foundation diameter – 40 m	Concentration values in the direction of the maximum range	59	36	24	14	7
	The maximum sediment layer	16.8	9.9	6.5	3.6	1.5
6. Depth 30 < h < 45 m, COHESIVE soil, foundation diameter – 35 m	Concentration values in the direction of the maximum range	48	29	19	11	6
	The maximum sediment layer	13.5	7.9	5.2	2.9	1.3
7. Depth 30 < h < 45 m, NON-COHESIVE soil, foundation diameter – 40 m	Concentration values in the direction of the maximum range	12	7	5	3	1
	The maximum sediment layer	3.4	2.0	1.3	0.7	0.3
8. Depth 30 < h < 45 m, NON-	Concentration values in	10	6	4	2	1

Calculation variant	Concentration [mg·l^{-1}]	Distance from the centre [m]				
	Sediment layer [mm]	100	200	500	1000	2000
COHESIVE soil, foundation diameter – 35 m	the direction of the maximum range					
	The maximum sediment layer	2.7	1.6	1.0	0.6	0.3
9. Depth h > 45 m, COHESIVE soil, foundation diameter – 40 m	Concentration values in the direction of the maximum range	46	28	19	11	6
	The maximum sediment layer	12.9	7.7	5.2	3.1	1.4
10. Depth h > 45 m, COHESIVE soil, foundation diameter – 35 m	Concentration values in the direction of the maximum range	37	22	15	9	5
	The maximum sediment layer	10.3	6.2	4.1	2.5	1.2
11. Depth h > 45 m, NON-COHESIVE soil, foundation diameter – 40 m	Concentration values in the direction of the maximum range	9	6	4	2	1
	The maximum sediment layer	2.6	1.5	1.0	0.4	0.3
12. Depth h > 45 m, NON-COHESIVE soil, foundation diameter – 35 m	Concentration values in the direction of the maximum range	7	4	3	2	1
	The maximum sediment layer	2.0	1.3	0.8	0.4	0.2

Source: internal data

The summary of calculation results related with laying energy cable in the seabed was presented in an analogous manner. In this case the key parameter is the thickness of sediments formed on the seabed and their scope. The results indicate that for various forcing conditions, this kind of impact on the seabed practically disappears at the distance of 1 km from the axis of the laid cable.

Table 4. The findings on the maximal thickness and extent of seabed sediments generated while laying the energy cable

Calculation variant	Sediment layer [mm]	Distance from the installed cable axis [m]			
		100	200	500	1000
1. Depth h < 30 m, COHESIVE soil	The maximum sediment layer	9.3	6.4	2.1	0.7
2. Depth h < 30 m, NON-COHESIVE soil	The maximum sediment layer	2.0	1.2	0.4	0.2

Source: internal data

In accordance with the comment included in chapter 5.12, the value of the parameter defined as thickness of sediments created as a result of carrying out two actions (preparation of works for the foundation and burying the cable in the seabed) is a sum (culmination) of these two impacts. Table (Table 5) presents the culminated, maximum value of sediment thickness, which is the result of the carried out calculations, and may be created in locations adjacent to the route of the internal energy cable as well as at the place where the support structure is settled.

Table 5. The findings on the maximal thickness and extent of seabed sediments generated while laying the energy cable and works preparing the soil for foundation installation

Calculation variant	**Sediment layer [mm]**	**Distance from the work site [m]**			
		100	**200**	**500**	**1000**
1. Depth h < 30 m, COHESIVE soil	The maximum sediment layer	31.3	18.7	9.8	4.8
2. Depth h < 30 m, NON-COHESIVE soil	The maximum sediment layer	6.3	3.6	1.9	1.0

Source: internal data

7 Conclusions

Calculations including various forcing conditions (wind, currents) created the possibility of the impact analysis for these conditions on specific suspended matter impact parameters. The results of the carried out simulations lead to the following conclusions:

- the greatest suspended matter impact ranges are present at moderate winds, with determined direction;
- the highest concentration of suspended matter is generated at lowest current speeds (around several $cm \cdot s^{-1}$) and circulatory character of small speed currents;
- higher suspended matter concentrations (between more than a dozen and several tens of $mg \cdot l^{-1}$) have a local range as compared to the place of dredging works;
- the culmination effect does not refer to the increase of suspended matter concentration, because various actions that cause that sediments enter the suspension state in the water column and their impact times do not overlap;
- the greatest thicknesses of newly created sediments in the least favourable cases (current arrangements, work in cohesive soils in shallower waters) at the distance of 100 m from the place the works are carried out do not exceed the value of 22 mm as a result of preparatory works for the foundations and 9 mm as a result of laying energy and teletechnical cables;
- thicknesses of newly formed sediments at a distance of 1000 m from the place the works are carried out do not exceed the value of 5 mm;
- the effect of accumulation of newly formed sediments caused by various anthropogenic actions at the construction phase (preparatory works for foundations and burying cables) is possible, however accumulated impacts will have a local and short-term impact. Natural sediment resuspension processes caused by storm phenomena (increase of near-bottom currents) will be responsible for changes of sediment thicknesses in the OWF Area and outside at the wind farm exploitation stage;
- additionally, in the least favourable case the average thickness value of sediments deposited as a result of works will not exceed 1 mm in the Investor’s variant, as well as 1.5 mm in a rational alternative variant in the entire Baltica OWF Area, the mobilised sediments will be natural and local ones;
- environmental impact of suspended matter on the marine environment in the least favourable scenario does not last for longer than 42 hours, counting from the moment the

works at the seabed are started with regard to a single foundation (this condition is determined by the moment the negligible concentration is achieved, lower than 2 $mg \cdot l^{-1}$);

- dredging works are carried out concurrently in two locations of settlement of support structures within the distance of 3 km from one another, with regard to the joint impact of suspended matter do not impact one another in the case of works in non-cohesive soils and have a minimum impact in the case of cohesive soils.

8 References

Burcharth F.H., Hawkins S.J., Zanuttigh B., Lamberti A., Environmental Design Guidelines for Low Crested Coastal Structures, Elsevier, Netherlands 2007.

Grundlehner G.J., van der Wal R. J., de Boer G. J., Downtime Analysis Methods for Offshore Dredging Operations. CEDA, Amsterdam 2003.

ISLES, Irish-Scottish Links on Energy Study, Construction and Deployment Report, The Scottish Government 2012, www.islesproject.eu.

MIKE 21/3 Coupled Model FM, User Guides, DHI Software 2008.

MIKE 21 HD Flow Model FM, Hydrodynamic Module, User Guide, DHI Software 2013.

MIKE 21 MT Flow Model FM, Mud Transport Module User Guide, DHI Software 2013.

Technical Project Description for Offshore Wind Farms (200 MW), Offshore Wind Farms at Vesterhav Nord, Vesterhav Syd, Sæby, Sejerø Bugt, Smålandsfarvandet and Bornholm 2015, Energinet.dk.

Review of Cabling Techniques and Environmental Effects Applicable to the Offshore Wind Farm Industry – Technical Report, Department for Business Enterprise & Regulatory Reform, United Kingdom 2008.

Van Rijn L.C., Principles of sediment transport in rivers, estuaries and coastal seas. Aqua Publications, the Netherlands 1993.

9 List of tables

10 List of figures