

Bilaga 3

Halla havsbaserad vindkraftpark, hydrodynamik, sediment- och saltlösningsdispersionsmodellering

Utredning och utlåtande om hydrodynamiska modelleringsdokument och modelleringsparametrar för den havsbaserade vindkraftsparken Halla (Eng.)

Modellering av sediment- och saltlösningsdispersion (Eng.)

Påverkan på den fysiska miljön, vindkraftverk på 25 MW (Eng.)

Processavloppsvatten från centraliserad vätgasproduktion, påverkan på den fysiska miljön (Eng.)

Bilagorna till de rapporter som saknas i detta dokument (Modellering av sediment- och saltvattendispersion 41 st + Effekter på den fysiska miljön, 25 MW vindkraftverk 3 st.) kan på begäran beställas separat på adressen: patrick.lees@ox2.com.

Clarification and statement on Halla offshore wind farm hydrodynamic modelling documents and modelling parameters

Niras has conducted the following work for Halla Offshore Wind Oy EIA report regarding the projects impacts on hydrodynamics, sediment dispersal and brine dispersal.

Following reports have been made regarding hydrodynamics of the project:

- Halla OWF, hydrodynamics 20.12.2023 REV02
- Halla OWF, H₂ wastewater, impact to physical environment 24.11.2024 REV03
- Halla OWF, Impact on the physical environment, 25 MW wind turbine 10.12.2024 REV03

The impacts of an offshore wind farm on the physical environment are complex and influenced by various factors, including local wind and water current conditions, the number and arrangement of turbines, the size of the foundations, the physical dimensions of the turbines, and the turbine power curve, which is related to the power output of the turbines.

Main report (Halla OWF, hydrodynamics 20.12.2023 REV02) consists of following options:

- Option 1 (VE1) with 160 wind turbines 15 MW each
- Option 2 (VE2) with 120 wind turbines 20 MW each

The report mentions single turbine power (15 or 20 MW) often based on options set above even though it would not have any impact on the model itself, for example sediment dispersal modelling where the foundations size and dredged masses plays key role.

However, EIA options are considering 15 MW (160 pcs) and 25 MW (120 pcs) turbines. To ensure that all modellings cover also 25 MW turbine, the additional report of 25 MW impact on hydrodynamics was created (Halla OWF, Impact on the physical environment, 25 MW wind turbine 10.12.2024 REV03). Other parts of the report are not impacted by the turbine power.

The reports mentioned above provide details on each impact type, considering both the maximum impact approach and the precautionary principle. The sediment dispersal modelling includes options for 15 MW and 20 MW scenarios, with the 20 MW case also representing the 25 MW scenario.

Date: 16.12.2024

A handwritten signature in black ink, reading "Tony E. Bergøe", written over a horizontal line.

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Halla OWF, hydrodynamics

Sediment & Brine Dispersal modelling

OX2 AB

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1. Introduction

Halla OWF has appointed NIRAS to quantify the impact on the dispersal of sediment in the construction phase and the dispersal of brine in the operation phase.

During the construction of the wind farm installation activities such as seabed preparations and cable burial may involve dredging at the foundation location and jetting of the cables to bury them safe for fishing activities, anchors, etc. This will potentially release sediments to the water resulting in excess sediment concentrations and when the sediments settle excess sedimentation rates.

Moreover, in the operation phase the project plans to produce hydrogen at each turbine position which require clean water and cooling resulting in outlets of high saline water and excess temperatures.

For the impact on the physical environment, both issues are investigated using numerical modelling.

2. Scope of Work

The purpose of the sediment dispersion study is to present the potential impact of sediment dispersal due to dredging, jetting etc. during the construction of the wind farm and, for the hydrogen production in the operational phase, the impact on the ambient water temperature and salinity due to the discharge of water with excessive temperature and salinity.

3. Abbreviation

CFD	Computational Fluid Dynamic
Current direction	Going towards
FOU	Foundation and substructure, lower support structure
GBS	Gravity Based Structure
IAC	Inter array cable
JUV	Jack-up vessel
MP	Monopile
OSS	Offshore substation
OWF	Offshore Wind Farm
TP	Transition piece, substructure
Wave direction	Coming from
Wind direction	Coming from
WTG	Wind turbine generator

4. Summary

In the present study, on the one hand, sediment spreading during the construction phase was investigated and, on the other hand, the effects of hydrogen production, in which water with excessive temperature and salinity is discharged, as well as the effects of the substructures and wind turbines (increased resistance to the flow and reduction in the wind) on the current pattern, water temperature and salinity due during the operation phase were analysed. For this purpose, three types of numerical models were used:

- 1) A 3D hydrodynamic model to simulate water level, currents, salinity, and temperature.
- 2) A CFD model to gain details about the dispersal of wastewater from the hydrogen production.
- 3) A sediment model to simulate the spreading and deposition of sediments stirred up during the construction.

Prior to assessing potential impacts, the hydrodynamic model was calibrated using data collected during the project (current, salinity, and temperature) and publicly available water level, salinity, and temperature data from Sweden and Finland.

The final wind farm layout is still open and to cover the potential range the impact from two cases is investigated:

- A case with 160 15MW turbines placed on gravity-based substructures and
- A case with 120 20 MW turbines also on gravity-based substructures.

Same with the export cable thus 3 potential corridors where 2 of them has 2 potential landfall locations. Moreover, the cables can either be buried with the use of jetting or by a combination of jetting and dredging with the latter in water depths less of 3 meters.

4.1. Baseline and representative year

The Bothnian Sea, where Halla OWF is located, constitutes the northern part of the Gulf of Bothnia, which is separated from the Baltic Proper by a strait at the Åland Sea. Hydrographic conditions (based on SMHI's 3D model) are characterised by a low salinity (1-3 PSU) and a weak vertical salinity gradient (halocline). Sea surface temperature varies from 0-2°C during the winter to over 20°C between July and August. Temperature is strongly stratified during the summer with a thermocline (zone of maximum temperature gradient) around 10-20m depth.

Between September and October, the water may warm up to 12-15° down to around 30 m. Ice cover spreads from north to south starting in December and reaches a maximum extent in March, with the entire length of the west coast of Finland covered with ice.

From June, the entire Gulf of Bothnia is ice-free again. Due to the absence of tides, water level variations are mostly driven by variations at the Åland boundary, wind and pressure differences and account for ±150 cm around their average during the year.

Based on data from SMHI's 3D model of the Baltic Sea the year-to-year variations were investigated and the year 2021 was found to be close to an average year and thus to be used as a baseline for description of the potential impact. In general, the year-to-year variation is small and unlikely to impact the conclusion.

4.2. Sediment dispersal

For the purpose of investigating the sediment spreading from the installation of the inter-array cables, gravity-based foundations for support of the wind turbines and the offshore substations the following four types of sources were considered:

- 1) Dredging of the gravity-based substructures and offshore substations with a dredge capacity of 1000m³/hour with 5% spill dispersed just above the seabed (released 2 meters over the seabed). The coarse sediment fraction settles next to the GBS (Gravity Base Structure, or the WTG and the OSS), and the finer ones are available for transport in the surrounding waters.
- 2) 10% of the total dredged sediments are assumed to overflow from the barge and are released at the surface and available for transport in the surrounding waters.
- 3) 30% spill when the barge disposed the sediment below the surface at the dumping site.
- 4) Burial of the inter array cable via jetting of a 1.5 x 2 metre trench where all the fine sediments are assumed to be brought into suspension and released 2 metre over the seabed.

In total, 900,000 m³ sediment are released at the seabed and around 2,300,000 m³ close to the surface. Although the 20 MW case includes 40 fewer wind turbines than the 15 MW case, the volumes excavated and released are in the same order of magnitude as the smaller number is compensated by larger diameters of the wind turbines.

For the export cables the sediment dispersal from a number of options has been investigated:

- Case 1: All cable sections buried via jetting of a 1.5 x 2 metre trench where all the fine sediments are assumed to be brought into suspension and released 2 metre over the seabed.
- Case 2: All cable sections in deeper water than 15 m were buried via jetting and in water shallower than 15 m excavated with the material placed at predefined dump sites. For the latter, a dredged spill of 5% at the bottom, 10% overrun from the barge and for the dumping 10% at the surface and 20% at the bottom are assumed.

Sediment concentrations:

Wind farm: The results show transport of sediments up to a few kilometres from the site. Concentrations are generally highest above the dumping site, where all the dredged sediment is released. Due to the similar volume of the two cases studied, the processes are readily comparable.

Export Cable: For the burial of the export cable the concentrations reach shortly close to the seabed levels up to 1000 mg/l. Levels of 100 mg/l occur only in minor areas having a duration of less than 1 day. There is no significant difference between the different main corridor and landfalls. If the cables are dredged the extent with concentrations above 10 mg/l increases slightly and the areas with the dumpsites experience significantly higher concentrations.

Sedimentation:

Wind farm: Sedimentation locally reaches deposition heights of more than 0.1 m and a sedimentation of 1 mm or more extends over 20,000 ha, although being limited to the vicinity of the dumping site (4 km to the south and east) and the areas located within the wind farm along the cables between the turbines. Due to the similar volume of the two cases studied, the processes are readily comparable.

Export Cable: Sedimentation of more than 1 mm happens within a distance of +/-400m when the cable are jetted increasing to +/-500m.

4.3. Hydrodynamic Impact

To analyse the impact of the wind farm, the pressure on hydrodynamics (circulation and stratification patterns) was modelled by adding the foundations, brine and warm water outlets from hydrogen production, and wind field reduction to the baseline model (calibrated HD model without wind farm).

Current: The wind farm causes a slowing down of the mean annual current speed at the surface within the windfarm site, to approx. 80 km north of and 30 km south of with about 0.002-0.008 m/s. At the same time an acceleration is seen west and east of the wind farm in the same order as the deceleration but for a smaller extent. The changes found are reduced with water depth but are still visible down to 40m. The comparison of the two cases shows a slightly higher impact of the 15MW case, probably due to a larger number of turbines and thus a larger cross-sectional area occupied by the foundations.

Salinity: The change in annual average salinity in the Bay of Bothnia (in the vicinity of the wind farm) due to the operation wind farm is less than +/-0.1 PSU, corresponding to approximately 1% of the natural salinity and is negligible in comparison to the natural variability. When comparing the two cases, no significant difference can be detected.

Temperature: The effect of the planned windfarm is smaller than -0.5 to 0.5°C in respect of the annual average temperature, independent of the water depth. The greatest impact is observed in summer, revealing increased warming with up to 1°C of the upper an a similar cooling in another parts; e.g. in August the temperature increases at the surface north the wind farm, at -5 to -30 areas southwest and northeast is cooled down and warming are seen northwest and southeast fo the windfarm. Compared to the seasonal and year-to-year variations, the impact appears to be rather small. Comparing the two cases, hardly any differences could be identified. This is due to the mixing caused by the foundation and reduction in the wind. The impact from the wastewater from the hydrogen production is limited to an extent of less than 10 metre from the outlet.

Upwelling: No clear effects of the wind farms on the vertical currents are evident. Enhanced upwelling and downwelling processes occur to a very small extent, with differences amounting to a maximum of $1.2 \cdot 10^{-5}$ m/s and mainly limited to a 40-kilometer radius around the wind farm.

5. Methodology

To estimate the pressure on the hydrodynamics and the dispersal of sediment three types of numerical models are used:

- 1) A 3D hydrodynamic model to simulate effect of the dispersal of wastewater, the substructures and the wind turbines on water levels, currents, salinity, and temperature.
- 2) A CFD model for simulation of the local dispersal of wastewater with excess temperature and salinity from the hydrogen production.
- 3) A sediment model to simulate the dispersal and deposit of the sediments dispersed due to the installation.

Before any evaluation of potential impacts the base model; the hydrodynamic model, is calibrated toward the data collected by the project (current, salinity and temperature) and publicly available water level, salinity and temperature data from Sweden and Finland.

Based on 10 years of data the Baseline is described and a representative period is identified for input to the construction and operation Phase.

The numerical models used to simulate the baseline and the pressure from the wind farm are described shortly below and further information can be found here: <https://www.mikepoweredbydhi.com/products>.

Bathymetric data for the model domain are extracted from the EMODnet 2022 Bathymetry Database (EMODnet, Bathymetry, 2023) which is based on modelled data from among others the countries around the Baltic Sea and is delivered as a grid with an resolutions of approximately 50 x 120 meter. Freely available boundary data of water level conditions will be applied at the boundary towards the Baltic Sea (Copernicus, Baltic Sea Physics Analysis and Forecast, 2x2km, 2022) combined with wind fields and air pressure at the surface of the model domain. Wind data is obtained from ECMWF, ERA5 (ECMWF, 2022).

Four models will be set up:

- 1) A general MIKE 3 HD model of the Gulf of Bothnia (regional model) used for calibration.
- 2) A detailed MIKE 3 HD model covering the same extent as the regional model, but with a higher spatial (vertical and horizontal) resolution in the vicinity of the windfarm area in order to investigate the hydrodynamic pressure.
- 3) A CFD model for a detailed description of the hydrogen production cooling water and high saline water.
- 4) A detailed MIKE 21/3 PT model covering the same extent as the regional model, but with a higher spatial (vertical and horizontal) resolution in the vicinity of the windfarm area and along the export cables for the purpose of modelling the sediment dispersal.

5.1.1. Hydrodynamic model

MIKE 3 HD FM (Hydrodynamics) is a hydrodynamic model with a flexible mesh. Based on tidal, current, salinity and temperature inputs along the open boundaries together with the meteorological conditions at the sea surface, the model simulates tide, current speed and direction, temperature, and salinity throughout the model domain across the water column. The benefit of a flexible mesh is the possibility of using varying sizes of the mesh across the domain. Therefore, the focus area can have a high resolution, and areas further away can have a coarser resolution. This makes the model run faster, with a minor impact on the simulation results.

5.1.2. CFD model

The wastewater effluent from the cooling and clean water production is a rather small source in volume with an excess of temperature and salinity that can potentially affect the local environment. To investigate this in detail, a CFD model of the GBS and surrounding waters has been set up for a low ambient flow using the freeware CFD model OpenFOAM using the Multicomponent solver to handle the differences in density and temperature.

5.1.3. Sediment model

MIKE 21/3 PT (Particle Tracking) is a so-called Lagrangian model which over time considers both the position and properties of the particles e.g., keeping track of the particle position in both x, y- and z-direction according to the mean current field. This is the opposite of a Eulerian model which does it cell-wise where e.g. the concentration will be an average of the volume over each cell. This type of model is extremely sensitive to the model resolution both horizontally and vertically, whereas the Lagrangian approach is independent of cell sizes.

The selection of MIKE 21/3 PT for modelling the sediment dispersal is due to the nature of the plumes created by dredging, drilling, ploughing, and jetting. The plumes are initially narrow and occur in various water column depths. This is difficult to describe in a traditional model e.g., MIKE 21 MT mesh while maintaining a reasonable calculation time.

To assess the quantity and duration of spillage, it is important to understand the construction activities. Will they be carried out simultaneously or will they be carried out independently at short intervals from each other? This will have an impact on the modelling study as in the former scenario, a higher quantity of sediments will be spilled in a shorter duration and in the latter scenario, spillage will occur in smaller quantities but repeatedly at certain intervals.

6. Background data

This chapter presents the background data used in the numerical modelling and the description of the seabed geology, oceanographic and hydraulic conditions for the wind farm. This includes project specifications, metocean data, grab samples and bathymetric data.

6.1. Halla, Project description

6.1.1. Wind farm Layout

The layout of Halla Offshore Wind Farm is illustrated in Figure 6.1. The footprint covers an area of 575 km², the total number of turbines for the 15 MW case is 160 and for the 20 MW case it is 120, there are 6 offshore sub-station and 314/270 km infield cables.

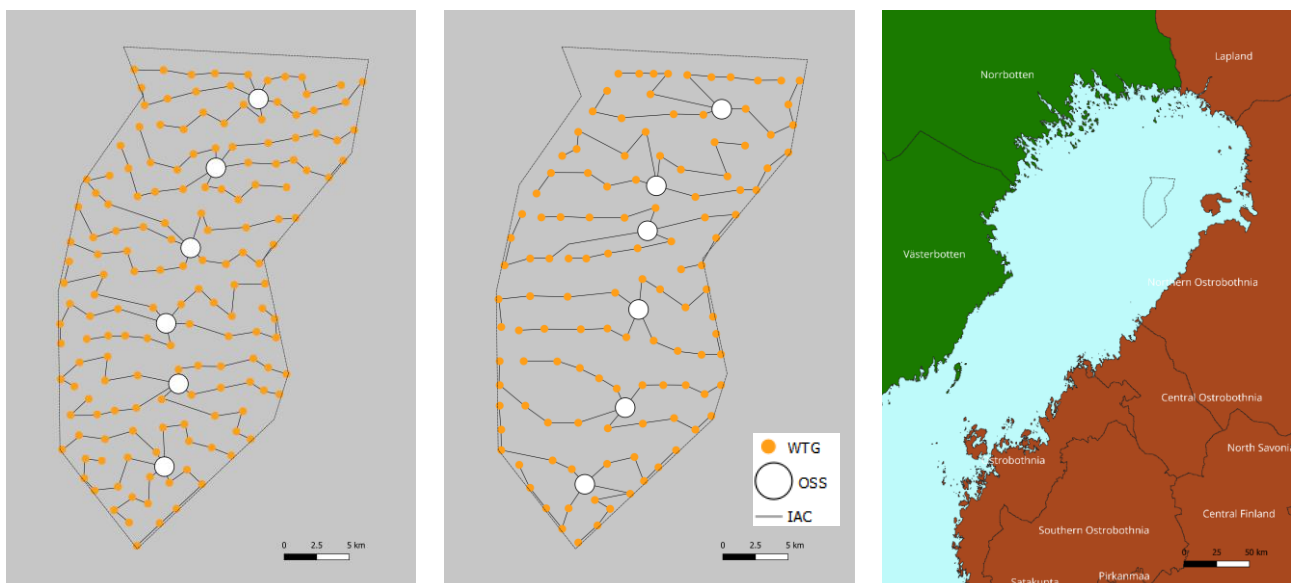


Figure 6.1: Halla, wind farm layout. Left: 15 MW turbines, Mid: 20 MW turbines and Right: Overview (Brown: Finland, Green: Sweden).)

For the export cables the following options are open:

- Cable A with 1 landfall (Ax).
- Cable B with 2 potential landfalls (B1x and B2x).
- Cable C with 2 potential landfalls (C1x and C2x).

As illustrated on Figure 6.2.

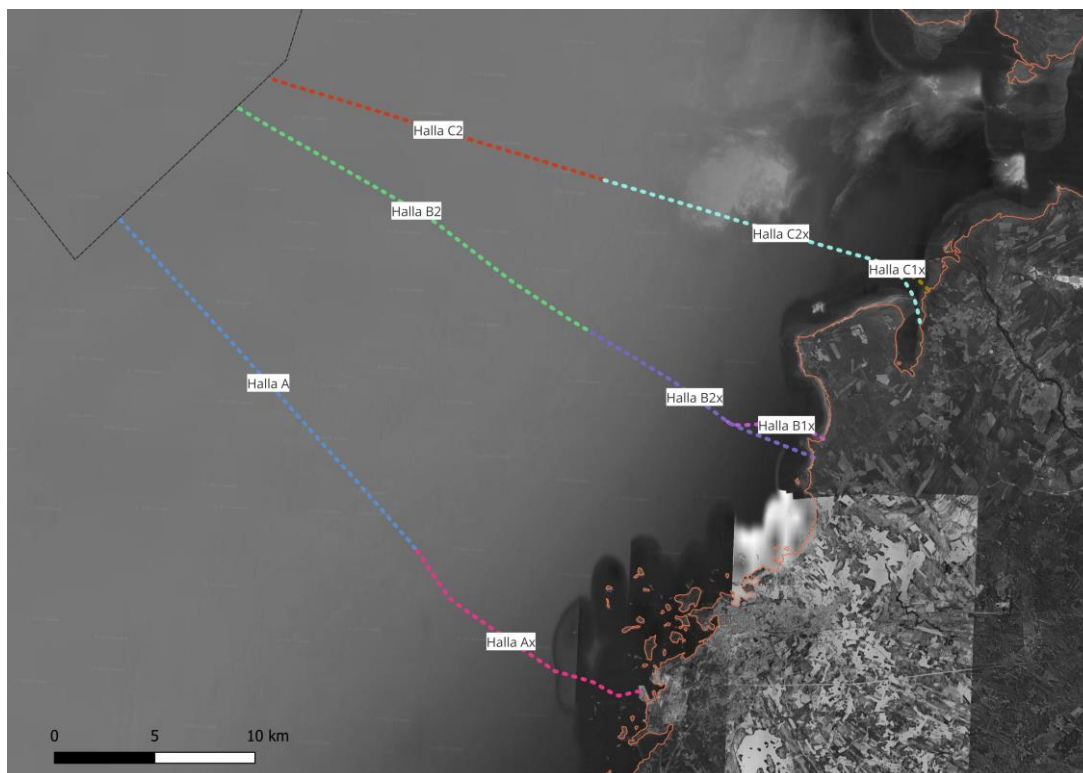


Figure 6.2: Halla OWF, export cable options.

6.1.2. Dimensions

In Table 6-1 the dimensions of the wind turbines and supporting structures to be used for the hydrodynamic modelling are listed for both the 15MW and 20MW case. It is assumed that the lower part (base slab and cone) of the substructure is independent of the water depth thus only the length of the shaft changes from position to position as illustrated in Figure 6.3.

Table 6-1: Turbine and substructure dimensions.

c		Unit	Case	
			15 MW	20 MW
WTG	Rotor diameter	m	236	276
	Hub height	m	150	170
GBS, WTG	Shaft, diameter	m	10	12
	Base diameter, bottom	m	45	52
	Base diameter, top	m	10	12
	Base, height cone	m	12	12
	Base, height slab	m	5	5
GBS, OSS	Shaft, diameter	m	10	10
	Base diameter, bottom	m	45	45
	Base diameter, top	m	10	10
	Base, height cone	M	12	12
	Base, height slab	M	5	5

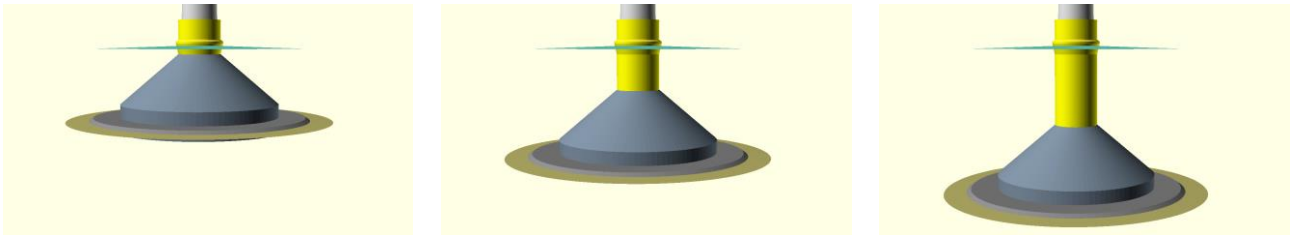


Figure 6.3: Sketch of the GBS for the WTG used as input to the hydrodynamic modelling illustrated for 20 m, 30 m and 40 m water depth.

6.1.3. Sediment sources - Construction Phase

The considered cases for the site are as described in the previous chapter and as listed in Table 6-2 based on the use of GBS that requires levelling/excavation of the seabed prior to installation. The cables between foundations first are surface laid on the seabed and then jetted down to 2 metres.

For the export cables two cases are also considered: one where the cables are jetted and one where the cables in deep water are jetted and in shallow water excavated. Moreover, a number of potential options are investigated covering 3 main corridors (A, B2 & C2), of which B2 and C2 both have 2 potential landfalls. In the final project, only one of the routes will be used. For details see Table 6-3.

The sediment spills from these activities are assumed to be:

Wind farm

- Levelling/excavation 5% (conservative estimate, 3.5% used for the Femern Belt Link (DHI/IOW Consortium, 2013)) of the fines released 2 m above the seabed.
- Overrun from the barge discharging another 10% (L.C. van Rijn, 2019) of the fines at the surface.
- Dumping of the dredged sediment at predefined dumping sites with 10% of the fine sediments brought into suspension 2 m below the surface and 20% 2 m above the seabed to account for the high-density current effect (estimated based on (L.C. van Rijn, 2019)).

When dredged using a grab some parts of the dredged material will consist of intact seabed. The intact seabed layers will most likely clump together, changing the physical properties of the material. The clumps of intact seabed will fall through the water column and settle on the seabed without much entrainment and subsequent spreading along the seabed. In which case the above assumption likely will overestimate the sediment spill.

- Jetting fluidized the sediment in the trench, which is assumed to bring 100% of the fines into suspension to 2 m above the seabed.

Export cable

- Burial of the export cable:
 - o Case 1: Jetting in both deep and shallow water with 100% spill of the fines 2 m above the seabed or

- Case 2: Jetting in deep water with 100% spill of the fines 2 m above the seabed and dredging in shallow water with 5% spill of the fines 2 m above the seabed, 10% of the fines 2 m below the surface and the dredged material dumped at specified dumpsites where 10% of the fines is spilled 2 m below the surface and 20% of the fines 2 m above the seabed.

Where the fines are defined as the sediment with a grain size smaller than 0.25 mm i.e. fine sand, silt and clay. Coarser sediment is assumed for the jetting to settle in the trench and for the dredging, overrun and dumping not to be released.

Table 6-2: Case 15MW & 20 MW – sediment sources, spill percentage and gross spill

Case	-	15MW GBS	20MW GBS
Capacity	MW/Unit	15	20
Hub height	m	150	170
Rotor diameter	m	236	276
Nos	#	160	120
Capacity, total	MW	2400	2400
Substructure	-	GBS	GBS
Bottom diameter, base	m	45	52
Dredging depth	m	8	8
Spill percentage, bottom	%	5%	5%
Spill percentage, barge overrun	%	10%	10%
Vol. to be removed	m ³ /pos.	12,723	16,990
Total dredged vol.	m ³	2,035,752	2,038,768
Spill, gross foundation	m ³	305,363	305,815
Length infield cable	m	313,598	269,742
Trench 1.5x2m, Dispersed	m ³	940,793	809,225
Spill percentage, bottom	%	100%	100%
Spill gross	m ³	940,793	809,225
Spill, gross infield cable	m ³	940,793	809,225
OSS	#	6	6
Bottom diameter, base	m	45	45
Dredging depth	m	8	8
Spill percentage, bottom	%	5%	5%
Spill percentage, barge overrun	%	10%	10%
Vol. to be removed	m ³ /pos.	76,341	76,341
Total dredged vol.	m ³	458,044	458,044
Spill, gross OSS	m ³	68,707	68,707
Dumping, GBS+OSS	m ³	2119727	2122290
Spill, percentage, 2 m below surface	%	10%	10%
Spill, percentage, 2 m above seabed	%	20%	20%
Dumped amount	m ³	1,483,809	1,485,603
Spill gross	m ³	635,918	636,687
Spill, gross	m ³	1,950,781	1,820,434

Table 6-3: Export cable lengths, volumes, and spill percentages for the two cases inclusive options. Case 1: jetting, Case 2: jetting in deep water and excavation in shallow water.

Case		Jetting				Jetting in deep water and dredging in shallow water			
Activity	-	Export Cable Jetting	Export Cable Jetting	Export Cable Jetting	Export Cable Jetting	Export Cable Jetting/Dredging	Export Cable Jetting/Dredging	Export Cable Jetting/Dredging	Export Cable Jetting/Dredging
Total length	m	35962	38787	39522		35962	38787	39522	
Deep water	Deep ↓	-	A	B2	C2	A	B2	C2	
	Length	m	22080	20685	17483	22080	20685	17483	
	Nos	#	10	5	5	10	5	5	
	Jetting/Dredging amount	m ³ /m	0.5	0.5	0.5	0.5	0.5	0.5	
	Spill percentage, bottom	%	100%	100%	100%	100%	100%	100%	
	Spill percentage, barge overrun	%	0%	0%	0%	0%	0%	0%	
	Vol. to be removed	m ³	110400	51713	43708	110400	51713	43708	
	Spill, gross	m ³	110,400	51,713	43,708	110,400	51,713	43,708	
	Shallow (< 15 m) ↓	-	Ax	B2x	C2x	Ax	B2x	C2x	
	Length	m	13882	13109	18217	13882	13109	18217	
Shallow water	Nos	#	10	5	5	10	5	5	
	Jetting/Dredging amount	m ³ /m	0.5	0.5	0.5	10	10	10	
	Spill percentage, bottom	%	100%	100%	100%	5%	5%	5%	
	Spill percentage, barge overrun	%	0%	0%	0%	10%	10%	10%	
	Vol. to be removed	m ³	69410	32773	45543	1388200	655450	910850	
	Spill, gross	m ³	69,410	32,773	45,543	208,230	98,318	136,628	
		-		B1x	C1x		B1x	C1x	
	Length	m		4993	3822		4993	3822	
	Nos	#		5	5		5	5	
	Jetting/Dredging amount	m ³ /m		0.5	0.5		10	10	
Dumping	Spill percentage, bottom	%		100%	100%		5%	5%	
	Spill percentage, barge overrun	%		0%	0%		10%	10%	
	Vol. to be removed	m ³		12483	9555		249650	191100	
	Spill, gross	m ³		12,483	9,555		37,448	28,665	
	Spill, gross	m ³	179,810	96,968	98,805	375,583	318,630	187,478	209,000
	Dumping	m ³	0	0	0		1179970	655450	910850
	Dumping, spill surface, 10%	m ³	0	0	0		117997	65545	91085
	Dumping, spill bottom, 20%	m ³	0	0	0		235994	131090	182170
	Dumping	m ³	0	0	0		0	249650	191100
	Dumping, spill surface, 10%	m ³	0	0	0		0	24965	19110
Dumping	Dumping, spill bottom, 20%	m ³	0	0	0		0	49930	38220
	Dumping spill, gross	m ³	0	0	0	0	353,991	196,635	273,255
									823,881

6.1.4. Hydrogen production, wastewater – Operation Phase

At each position of the either 15MW or 20MW wind turbines it is planned to produce hydrogen which requires purified water and water for cooling of the equipment as listed in Table 6-4. The assumed background salinity is around 2.5 PSU resulting in an outlet of 5 PSU.

Table 6-4 Hydrogen production, in- and outputs per turbine.

Case	Parameter	Unit	Inlet	Outlet
15 MW turbine	Water	[m ³ /s]	0.004	0.002
	Salinity	[PSU]	background	5
	Temperature	[°C]	background	excess 15
20 MW turbine	Water	[m ³ /s]	0.006	0.003
	Salinity	[PSU]	background	5
	Temperature	[°C]	background	excess 15

Both the intake and the outlet are assumed located around 10 m below the surface.

6.2. Bathymetry data

The water depths in the model are based project data and data from EMODnet 2022 mean sea level bathymetry (EMODnet, Bathymetry, 2023) and are presented in Figure 7.1 (together with the mesh).

6.3. Observations

Observational data are used for model calibration. Figure 6.4 provides an overview of the locations of the measuring points for the individual parameters.

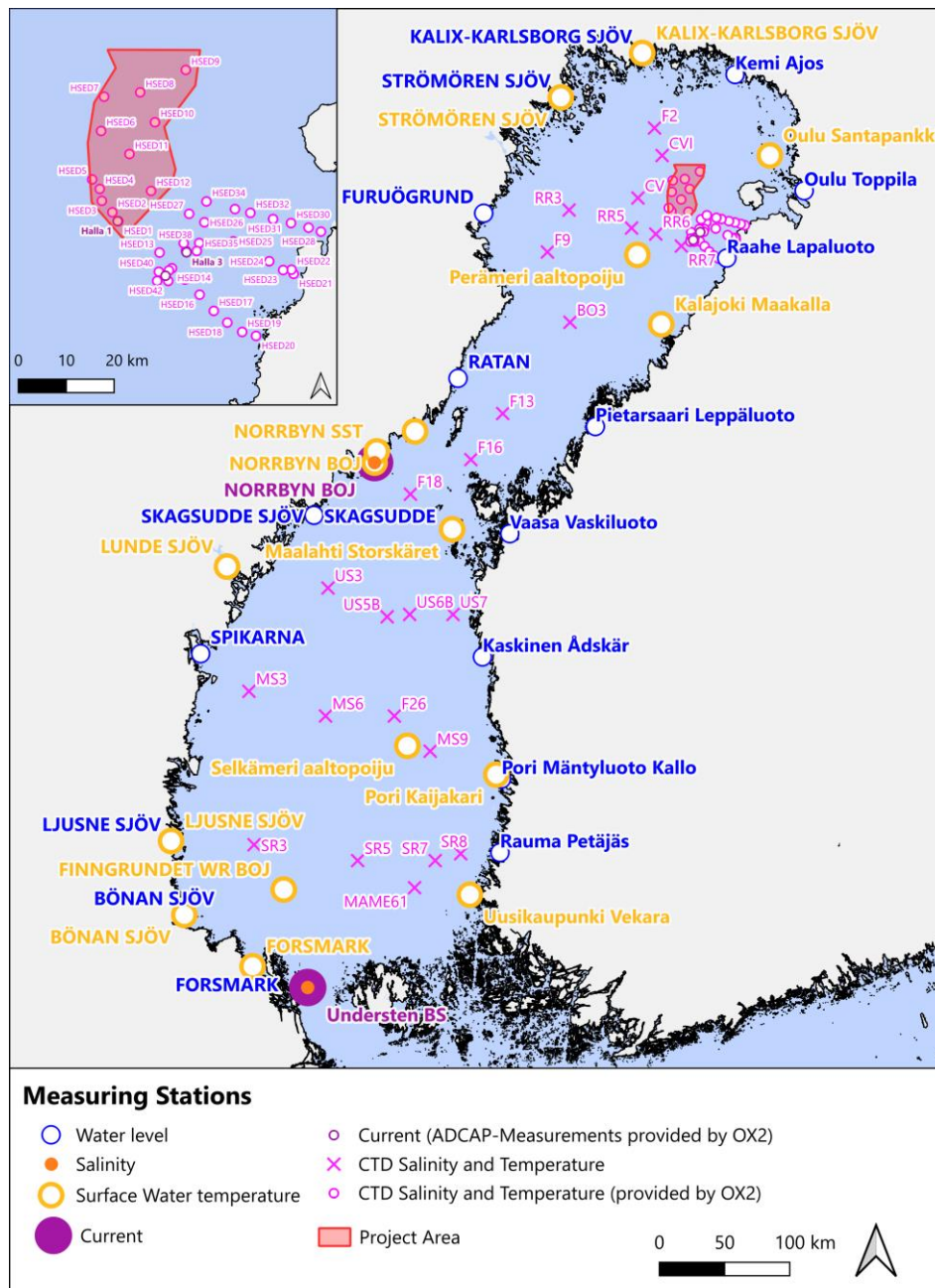


Figure 6.4: Location of water level, current, water temperature, and salinity monitoring stations used for calibration and validation of the hydrodynamic model.

6.3.1. Water levels

Water levels with an hourly resolution have been obtained from the SMHI (Swedish) and the FMI (Finish) stations (see table in Appendix 10), extracted for the time period available. The locations of the water level stations are displayed in Figure 6.4. Due to the large number of available stations, the water level variations are discussed using three stations located in the immediate vicinity of the project (Figure 6.4). Water levels for these

stations are displayed in Figure 6.5 to Figure 6.7, showing a maximum variation of ± 1.50 m around a mean of approximately 0 m. No dominant tidal pattern is evident.

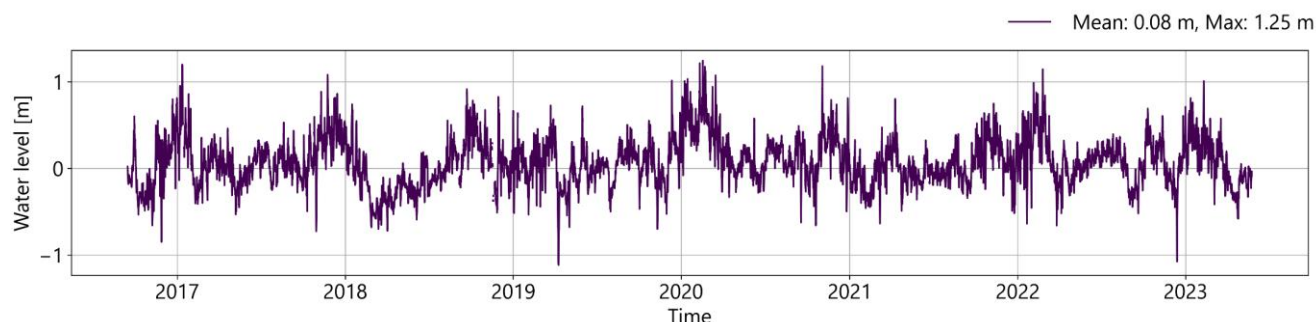


Figure 6.5: Measured water level at STRÖMÖREN SJÖV (SMHI-Station)

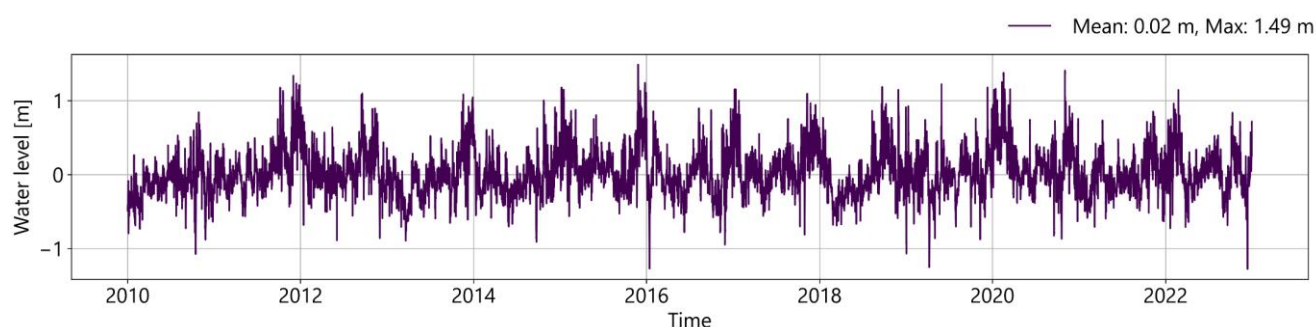


Figure 6.6: Measured water level at Kemi Ajos (FMI-Station)

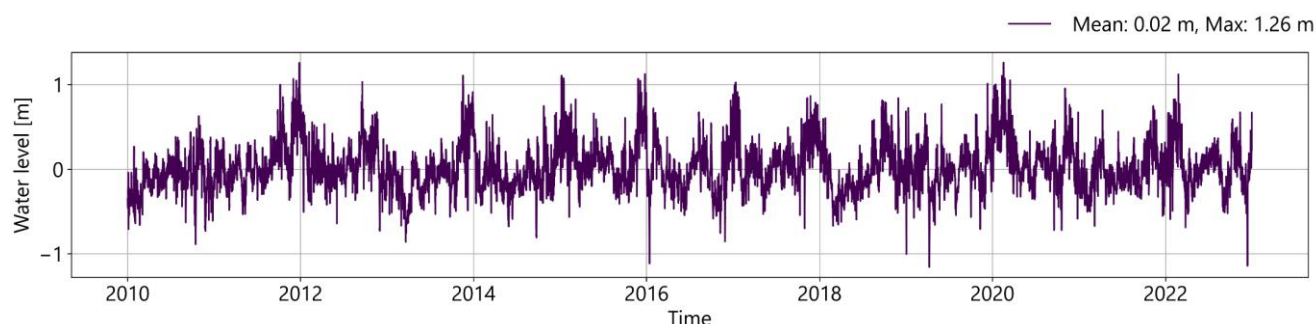


Figure 6.7: Measured water level at Raahe Lapaluoto (FMI-Station)

6.3.2. Currents

Current speeds and directions with an hourly resolution have been obtained from the following SMHI stations (Table 6-5)

- NORRBYN BOJ between 1 and 41 m depths for the period 2016-2021 (Figure 6.8 and Figure 6.9) and
- Understen BS (lat: 60.2715, long: 18.9302) at 217-219 m depth for the year 2021 (Figure 6.10 and Figure 6.11).

In addition, data from three ADCP-campaigns (Table 6-5), recorded in the close vicinity of the project area in period between September and November 2022 (15 minutes interval), have been provided by OX2 (see Figure 6.12, Figure 6.13, Appendix 11).

Table 6-5: Current measuring stations used in the present study.

Name	ID	Lat	Long	Source
NORRBYN BOJ	33021	63.4990	19.8044	SMHI
Understen BS	33038	60.2715	19.9302	SMHI
Halla 1		64.8684	23.7600	OX2
Halla 2		64.7673	23.9677	OX2
Halla 3		64.8108	24.0592	OX2

In the following, the characteristics derived from the measurements are briefly presented, with the publicly available data and the data recorded as part of the project being discussed separately.

6.3.2.1. Publicly available Data

Speed: The speeds recorded at the measurement station Understen BS with a mean of 20 approx. 20 cm/s are significantly higher than at NORRBYN and at Halla OWF (Figure 6.4) with means < 10 cm/s. This is due to the location of the measuring stations. While Understen BS is located in the narrows of the Åland Sea at least 13 km from the coast, NORRBYN BOJ is located further north, in a wider section approximately 3 kilometres from the coast.

Direction: A dominant current in the north, north-east direction can be identified at the measuring station Understen BS. In contrast, the flow direction at NORRBYN BOJ is evenly distributed, with a slight trend towards the east, increasing with depth.

6.3.2.2. ADCAP-Measurements of 2022

Speed: The measured current speeds (Figure 6.12) in the project area show a clear dependence on the water depth. In the deeper layers (deeper than 15 m) the mean value accounts to 6-7 cm/s. In contrast, significantly higher current speeds were measured in the upper layers (mean value at 3 m: 54 cm/s). The order of magnitude of the current speeds measured in the deeper water layers fits well with the other publicly available measurements (e.g., at NORRBYN BOJ, Figure 6.8). However, the significantly higher current speeds measured in the uppermost 3 m do not correspond to the expectation. For example, according to the Finnish Institute of Meteorology (<https://en.ilmatieteenlaitos.fi/seacurrents>), the average surface speed in the Gulf of Bothnia is in the order of 5-10 cm/s and higher velocities only occur during strong storms or in narrow straits. Since no storms were observed during the observation period (cf. time series of wind in the project area from ERA5, Figure 6.14) and the project area is also not located in a pronounced strait, this leads to the assumption that the measurements overestimate the surface current velocities.

Upon inquiry, this assumption was confirmed, as the increased surface speeds are due to wind-induced waves (Email from Olli Takalammi, 2023-07-07). For this reason, only the velocity measurements in the deeper water layers were used for verification.



Figure 6.8: Measured current speed at NORRBYN at 5 m, 15 m, and 25 m depth (from top to bottom)

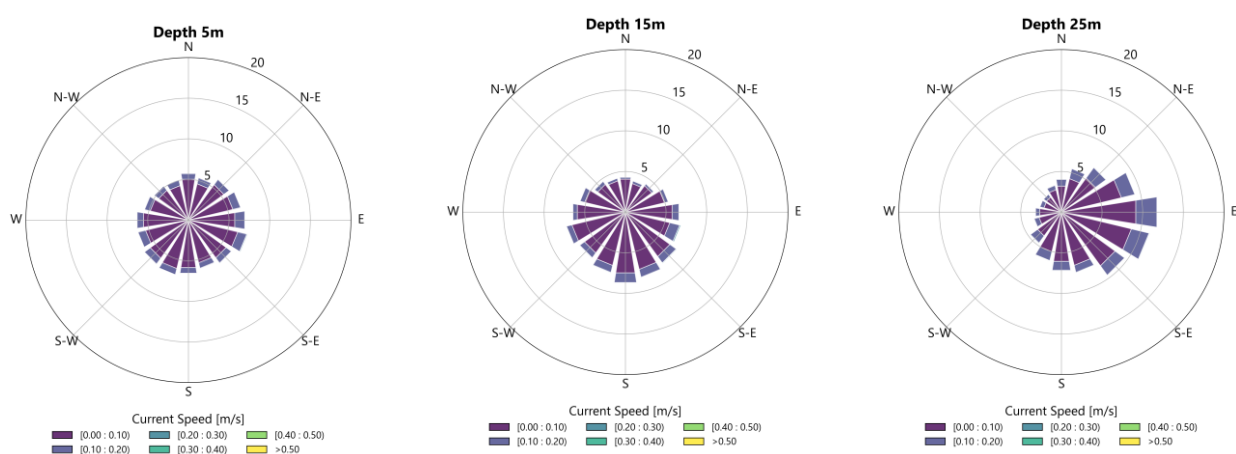


Figure 6.9: Measured current direction at NORRBYN at 5 m, 15 m, and 25 m depth (from left to right).

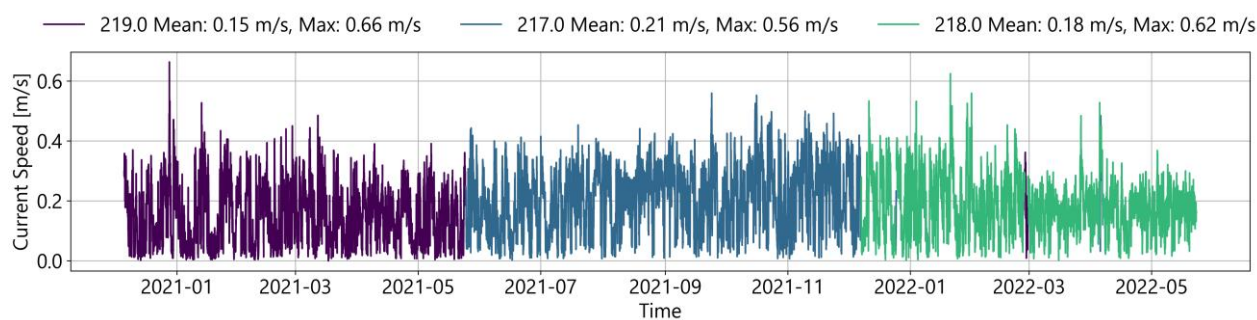


Figure 6.10: Measured current speed at Understen BS between 217 and 219 m.

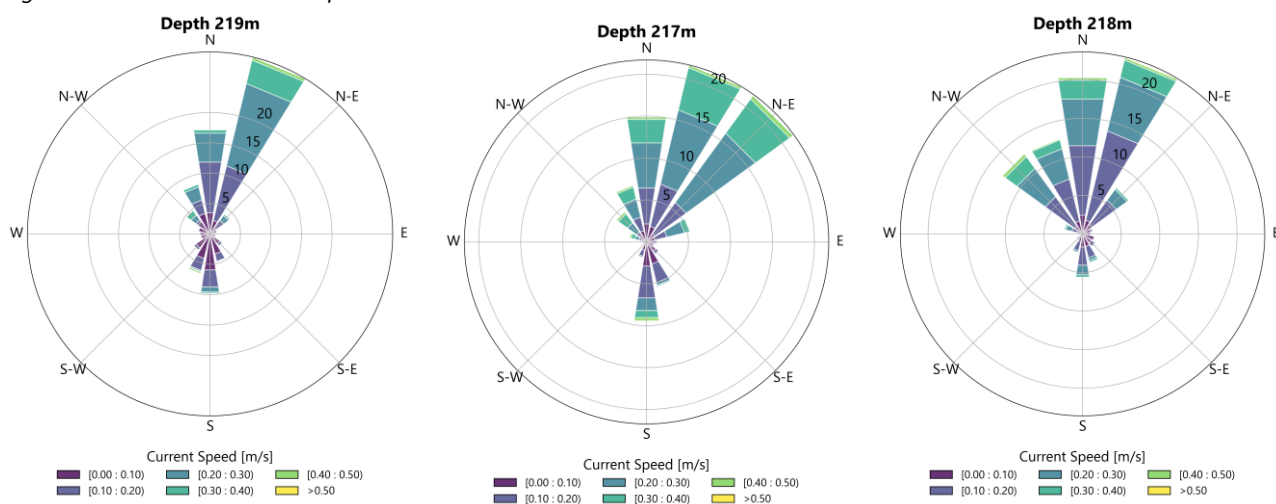


Figure 6.11: Measured current direction at Understen BS between 217 m and 219 m (the corresponding time period of the measurement is depicted in Figure 6.10)

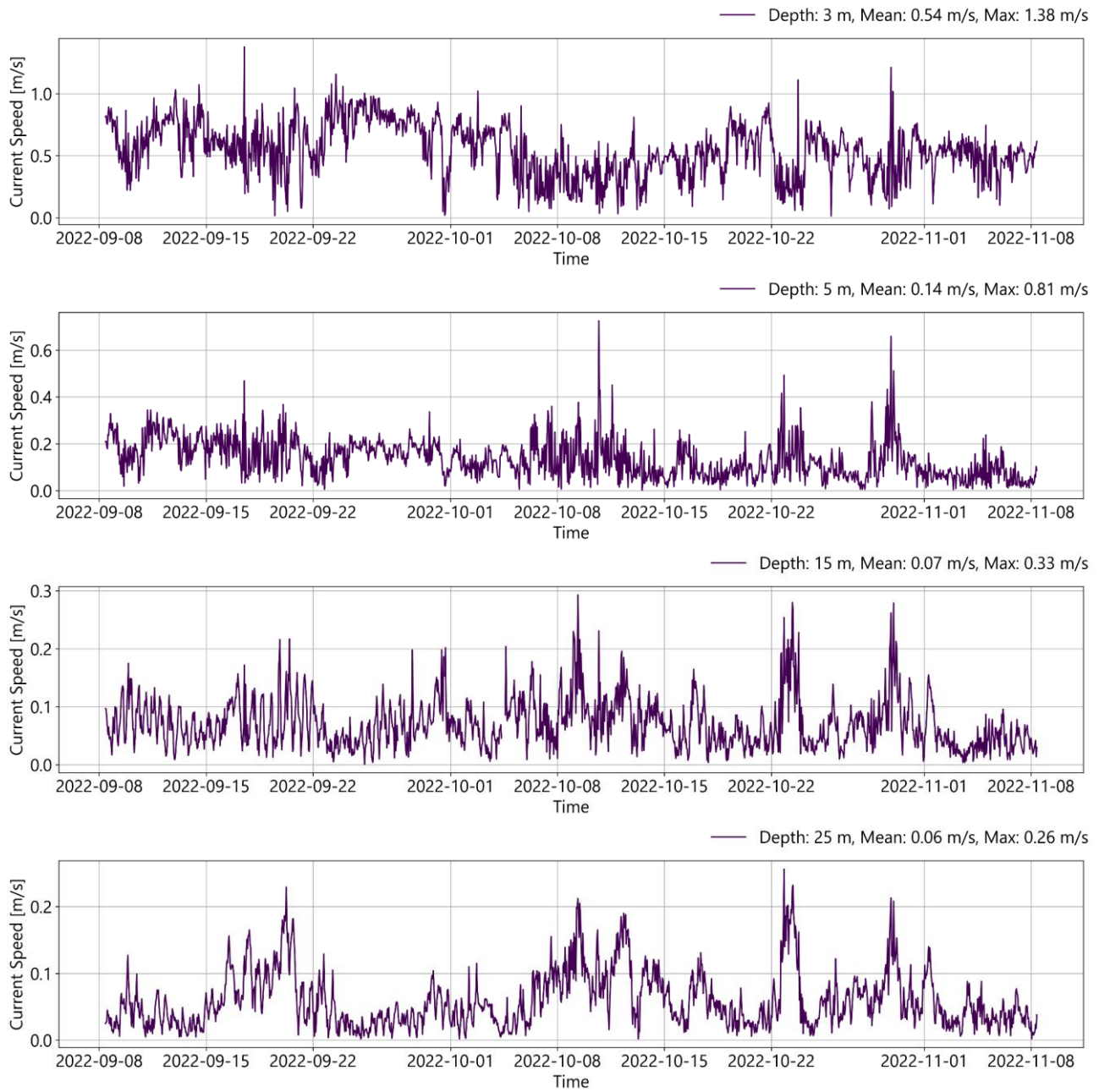


Figure 6.12: Measured current speed at Halla OWF 1 at 3 m, 5 m, 15 m, and 25 m depth (from top to bottom)

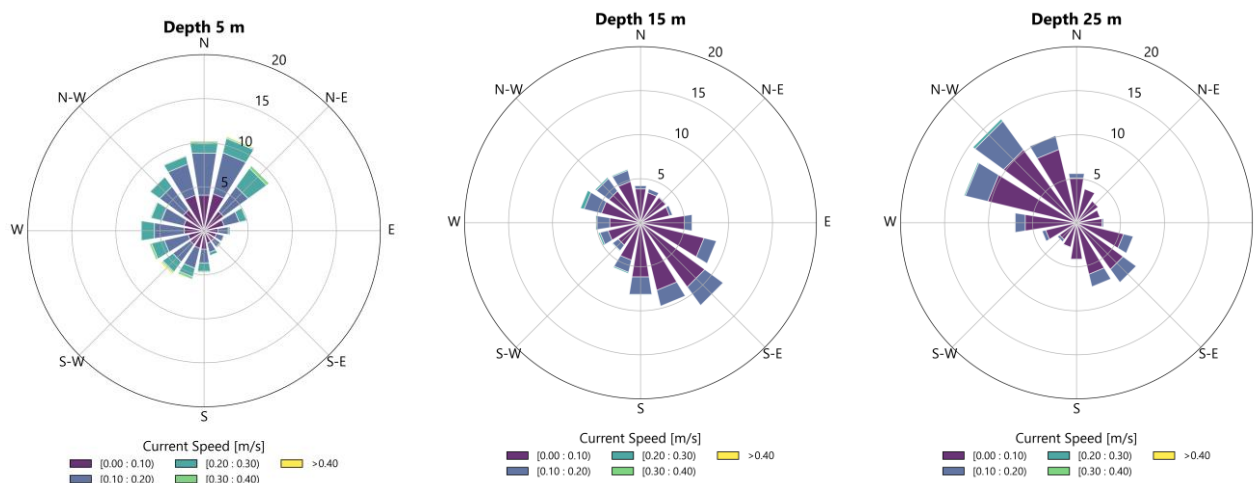


Figure 6.13: Measured current direction at Halla OWF 1 at 5 m, 15 m, and 25 m depth (from left to right).

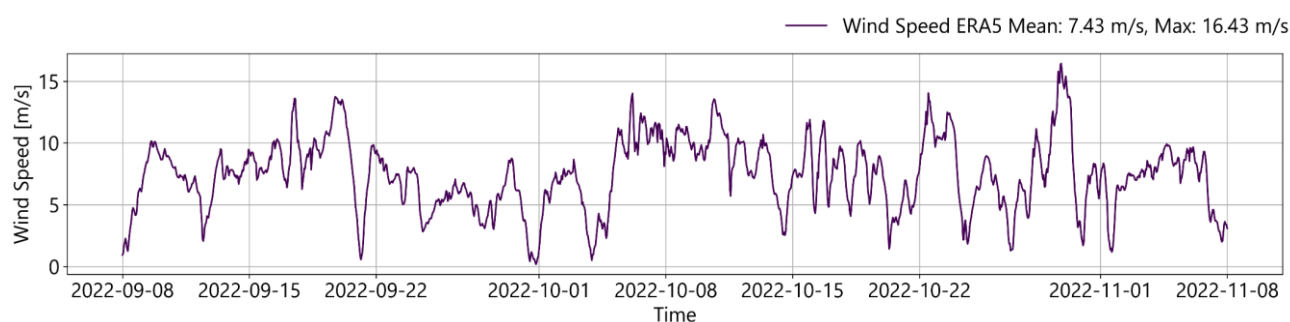


Figure 6.14: Wind Speed @ 10 m from ERA5 in the project area during the ADCAP-measuring period

6.3.3. Salinity

Salinity data with an hourly resolution have been obtained from the SMHI stations NORRBYN BOJ (lat: 63.499, long: 19.8044, depth: 7 m) for the period 2016-2021 (Figure 6.15) and Understen BS (lat: 60.2715, long: 18.9302 depth: 220 m) for the year 2021 (Figure 6.16). Despite the large data gaps, the following two patterns are recognisable:

- Spatial pattern tending towards lower salinity in the northern area (as there are no strong vertical variations, see chapter 6.3.4).
- Annual pattern with tendency towards lower salinity between February and April.

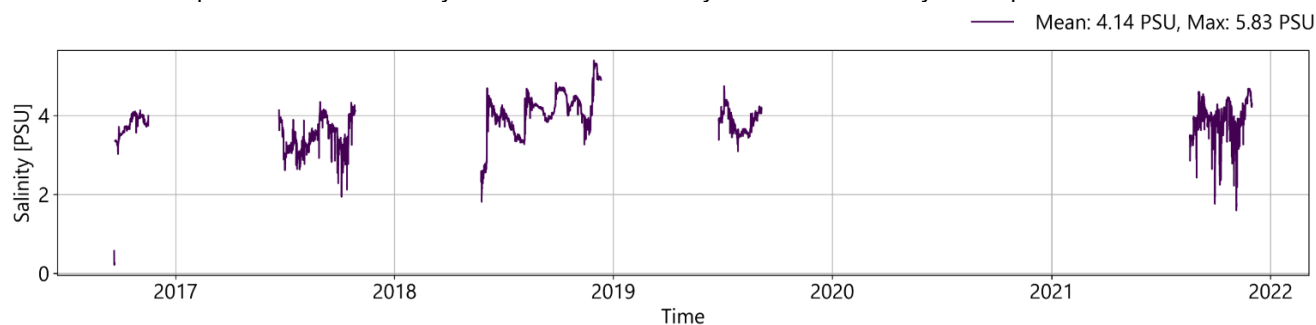


Figure 6.15: Measured salinity at Norrbyn Boj at 7 m (SMHI-Station)

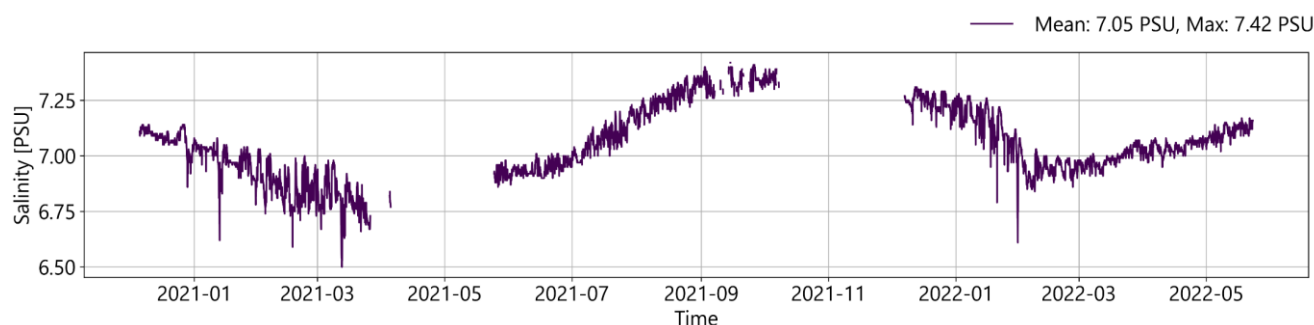


Figure 6.16: Measured surface salinity at Understen BS at 220 m (SMHI-Station)

6.3.4. Vertical Profiles (CTD) Measurements of Salinity

6.3.4.1. Publicly available data of 2021

Publicly available vertical salinity profiles have been downloaded from Merihavainnot.fi (an open-access marine data service maintained by the Finnish Environment Institute (SYKE)). Out of the approximately 230 available monitoring stations, 25 were considered in more detail and used for model verification (see table in Appendix 12).

Due to the large number of available stations, salinity profiles and their temporal evolution are discussed based on the example of two stations only; CVI (Figure 6.17) and SR3 (Figure 6.18) in the northern and southern parts, respectively (see Figure 6.4). While the temporal and vertical variations are small regardless of location, there is a significant difference in salinity between the two stations. Similar to the surface salinity, lower salinity concentrations are measured at the station further north (CVI, Figure 6.17).

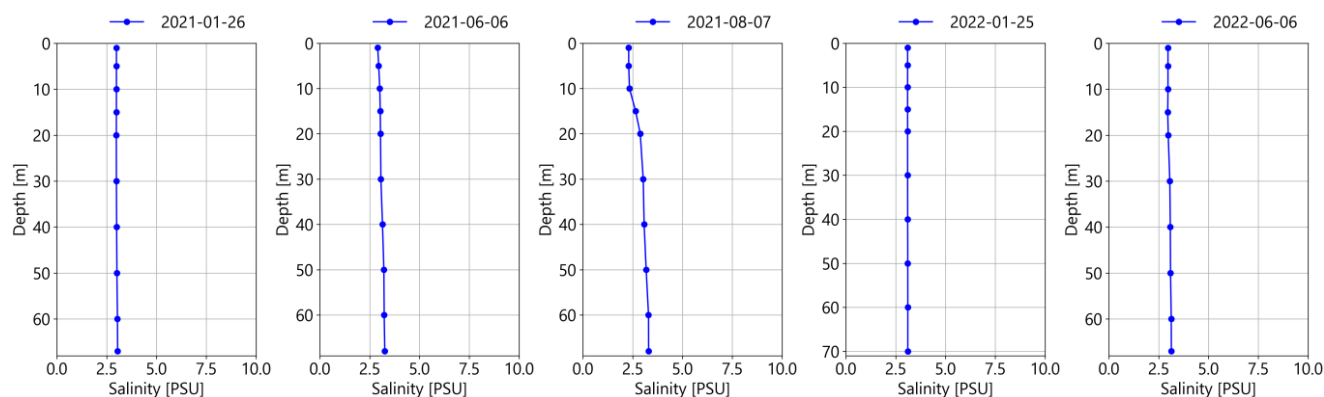


Figure 6.17: Measured Salinity profile at station CVI (source: merihavainnot.fi, location see Figure 6.4)

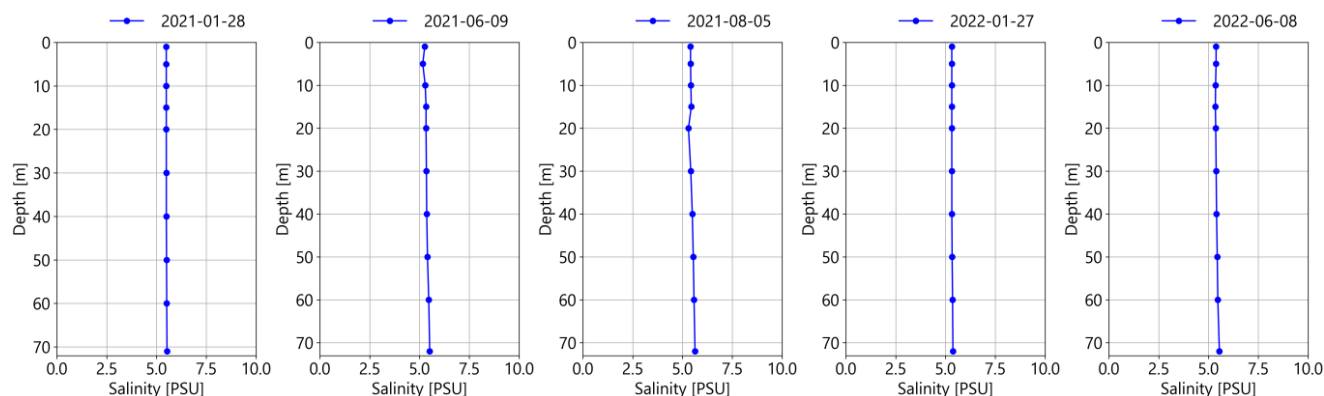


Figure 6.18: Measured Salinity profile at station SR3 (source: merihavainnot.fi, location see Figure 6.4)

6.3.4.2. Measurements from OX2 in 2022

In addition, 41 profiles, recorded in the project area in September 2022, have been provided by OX2 (see table in Appendix 12).

6.3.5. Surface temperature

Surface temperature with an hourly resolution have been obtained from 9 SMHI (Swedish) and 7 FMI (Finish) stations (see table in Appendix 13). The locations of the surface temperature stations are displayed in Figure 6.4. Due to the large number of available stations, the temporal surface temperature variations are discussed based on two locations, located either in the northern part (KALIX-KARLSBORG SJÖV, Figure 6.19) or in the southern part (FORSMARK, Figure 6.20).

Significant annual fluctuations can be observed at both stations. While the measured minimum and maximum temperatures are at both stations varying between 0° and approx. 25°, the northern station (KALIX-KARLSBORG SJÖV, Figure 6.19) shows a clearly longer period (approx. November to May) during which the surface temperatures stands at around 0°. At the southern station (FORSMARK, Figure 6.20), the surface temperature is only around 0° for about 3 months (January-March) explaining the 2° higher annual mean value.

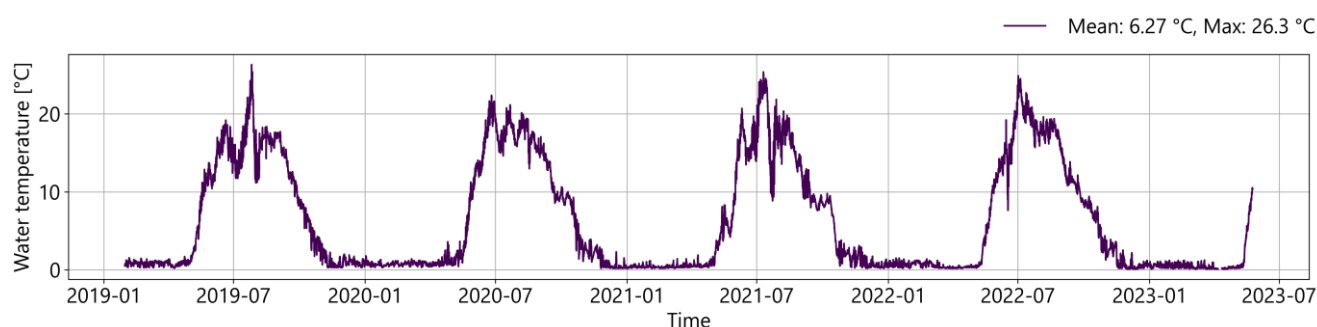


Figure 6.19: Measured surface water temperature at KALIX-KARLSBORG SJÖV (SMHI-Station)

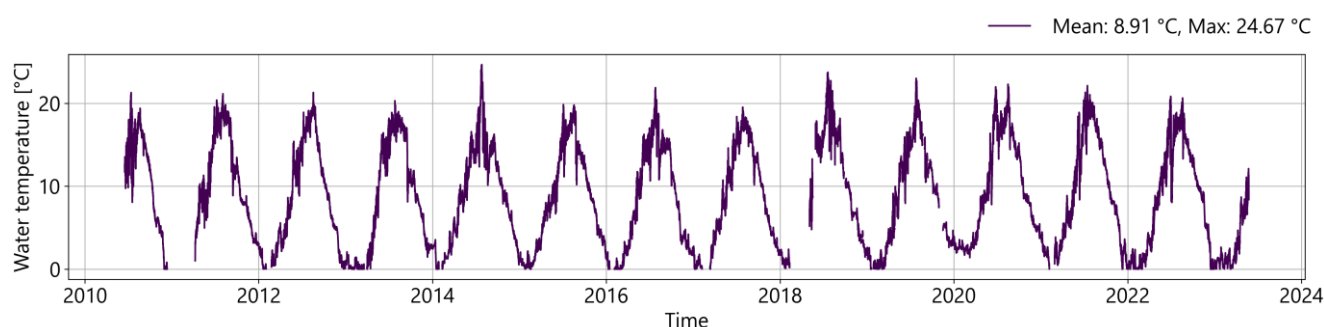


Figure 6.20: Measured surface water temperature at FORSMARK (SMHI-Station)

6.3.6. Vertical Profiles (CTD) Measurements of Temperature

6.3.6.1. Publicly available data of 2021

Temperature profiles are available at the same locations as salinity (see table in Appendix 12 and Figure 6.4). As with the salinity, due to the large number of available stations, the temperature profiles and their temporal evolution are discussed for two stations only, namely CVI and SR3 (in the northern and southern part respectively, see Figure 6.4).

The measurements of the temperature profiles (in contrast to the vertical profiles of salinity) show seasonal and vertical fluctuations in temperature at both stations. While the vertical variations in temperature are relatively small in January, there is a thermocline visible between 20-30 m in August. Comparing the two stations, it can be seen that the water at station SR3 (in the southern part) tends to be warmer, while the surface temperature at CVI fluctuates more.

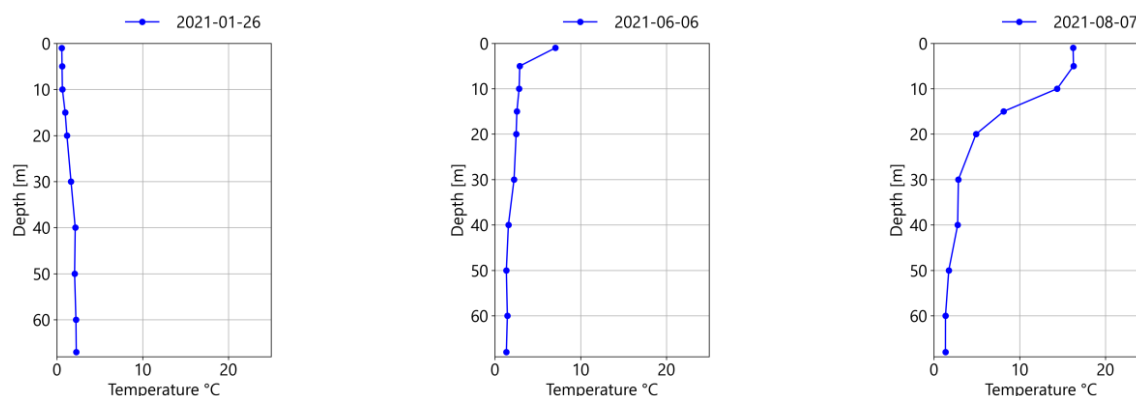


Figure 6.21: Measured temperature profile at station CVI (source: merihavainnot.fi, location see Figure 6.4)

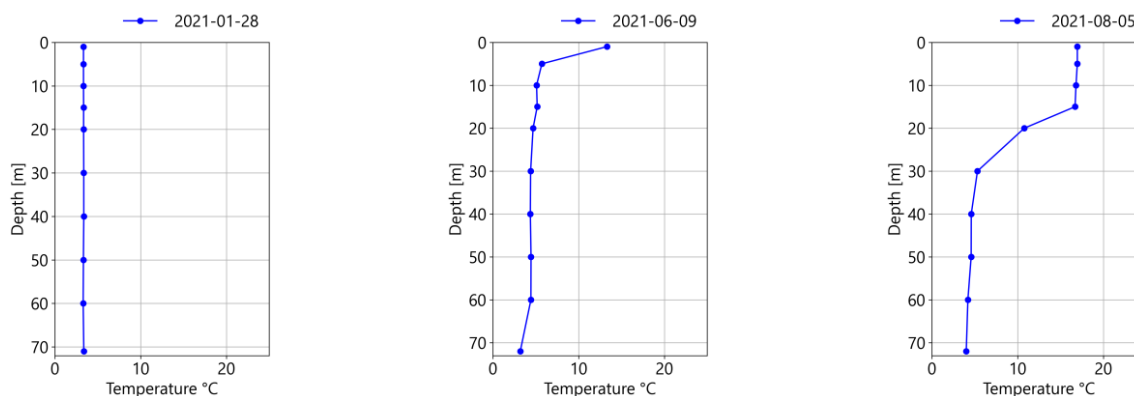


Figure 6.22: Measured temperature profile at station SR3 (source: merihavainnot.fi, location see Figure 6.4)

6.3.6.2. Measurements from OX2 in 2022

Similar to the salinity, 41 profiles, recorded in the project area in September 2022, have been provided by OX2 (see table in Appendix 12).

6.4. Hydrodynamic data from models

6.4.1. Water levels

Data from the 2km by 2km SMHI 3D Baltic Sea model are used at the Åland Sea boundary conditions to feed the MIKE model (Copernicus, Baltic Sea Physics Analysis and Forecast, 2x2km, 2022) and (Copernicus, Baltic Sea Physics Reanalysis 4x4km, 2022).

6.4.2. Currents

To identify a representative year for simulating impacts on hydrodynamics and sediment dispersal, SMHI 3D Baltic Sea model results at Halla OWF (Copernicus, Baltic Sea Physics Analysis and Forecast, 2x2km, 2022) and (Copernicus, Baltic Sea Physics Reanalysis 4x4km, 2022) are presented in Appendix 2, Appendix 7 and Appendix 8.

6.4.3. Salinity and Temperature

For initialisation and to feed the model at the boundary, data from SMHI's numerical model of the Baltic Sea are used, (Copernicus, Baltic Sea Physics Analysis and Forecast, 2x2km, 2022) and (Copernicus, Baltic Sea Physics Reanalysis 4x4km, 2022).

Data from selected years are presented in Appendix 3 to Appendix 6.

6.5. Wind, Air Pressure, Air Temperature, Net long and short-wave radiations

Atmospheric data in the form of instantaneous wind speed at 10 mMSL in x and y-directions, air pressure at the surface, air temperature at 2 m above the surface, relative air humidity, and net long and short-wave radiation at the surface have been extracted from ECMWF (ECMWF, 2022). The data have a horizontal resolution of 0.25 degrees and a temporal resolution of 1 hour.

6.6. Sea ice

The presence of sea ice is based on data produced by SMHI, (Copernicus, Baltic Sea Physics Analysis and Forecast, 2x2km, 2022) and (Copernicus, Baltic Sea Physics Reanalysis 4x4km, 2022) as ice thickness and concentration (Figure 6.23 and Figure 6.24). As the figures illustrate, the ice cover spreads from north to south starting in December and reaches a maximum extent in March, with the entire length of the west coast of Finland covered with ice. From June, the entire Gulf of Bothnia is ice-free again.

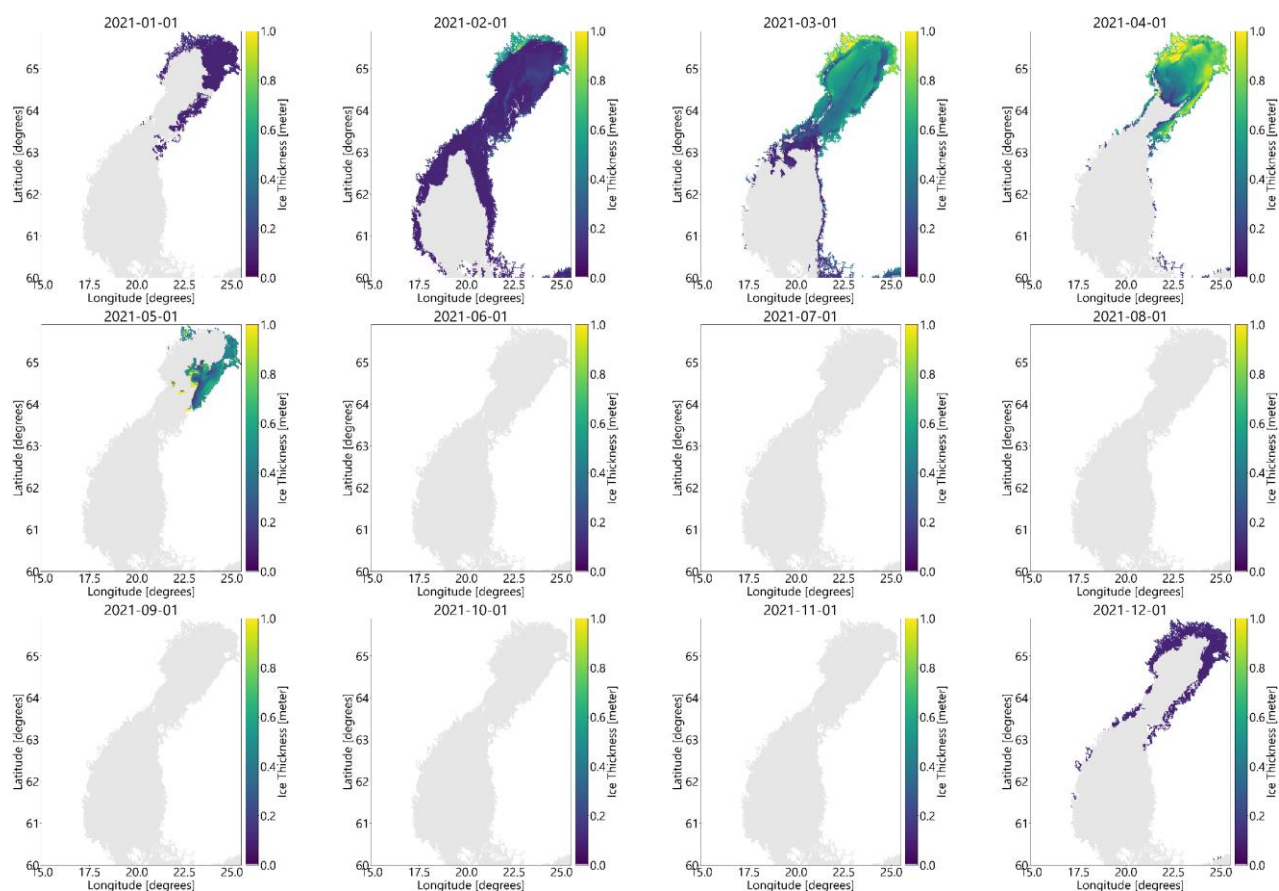


Figure 6.23: Temporal evolution of the ice thickness in during the year of 2021.

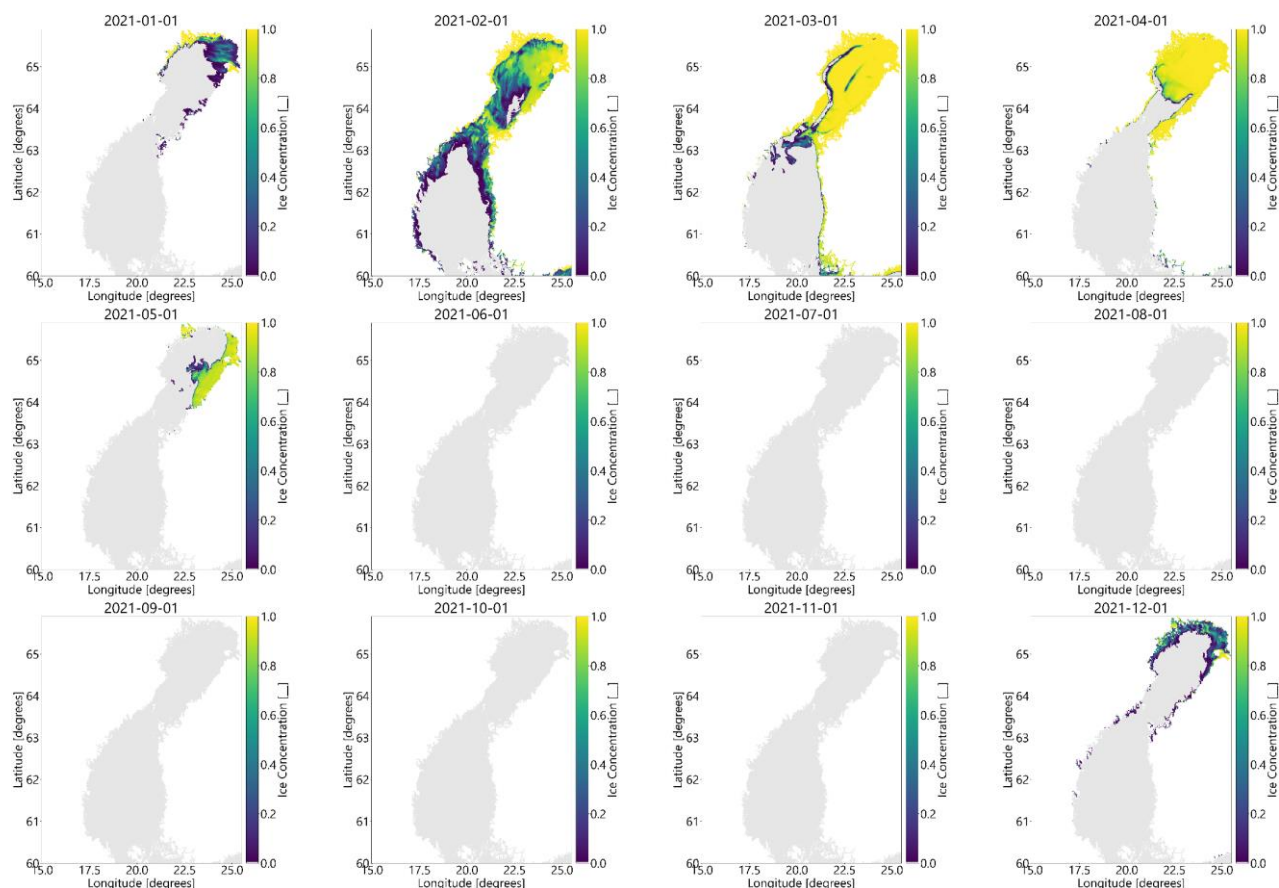


Figure 6.24: Temporal evolution of the ice concentration during the year of 2021.

6.7. Run-off

The following major freshwater discharges (average discharge greater than 100m³/s) to the Gulf of Bothnia are used as input to the model:

- Kokemäenjoki (Harjavalta station, lat: 61.34, long: 22.11; Finland)
- Oulujoki (Merikoski station, lat: 65.023, long: 25.47; Finland)
- Iijoki (Raasakka station, lat: 65.33, long: 25.41; Finland)
- Kemijoki (Taivalkoski station, lat: 65.93, long: 24.71; Finland)
- Tornionjoki (Karunki station, lat: 66.03, long: 24.02; Finland)
- Kalixälven (lat: 65.8, long: 23.25; Sweden)
- Luleälven (lat: 65.56, long: 22.05; Sweden)
- Piteälven (lat: 65.30, long: 21.44; Sweden)
- Skellefteälven (lat: 64.71, long: 21.18; Sweden)
- Umeälven (lat: 63.74, long: 20.36; Sweden)
- Ångerman (lat: 63.03, long: 17.78; Sweden)
- Indalsälven (lat: 62.5, long: 17.5; Sweden)
- Ljungan (lat: 62.28, long: 17.4; Sweden)
- Ljusnan (lat: 61.2, long: 17.13; Sweden)
- Dalälven (lat: 60.62, long: 17.49; Sweden)

For the Swedish rivers, modelled and station-corrected daily discharges and temperatures have been obtained from the SMHI VattenWebb platform for the years 2020-2022. For the Finnish rivers, observed daily discharges have been obtained from the Finnish environmental institute Ymparisto, and water temperatures have been assumed similar to those of the Swedish river at the closest latitude. The discharges and temperatures of the main rivers are shown in Figure 6.26 and Figure 6.28, respectively, the total river discharge in Figure 6.27 and their location in Figure 6.25.

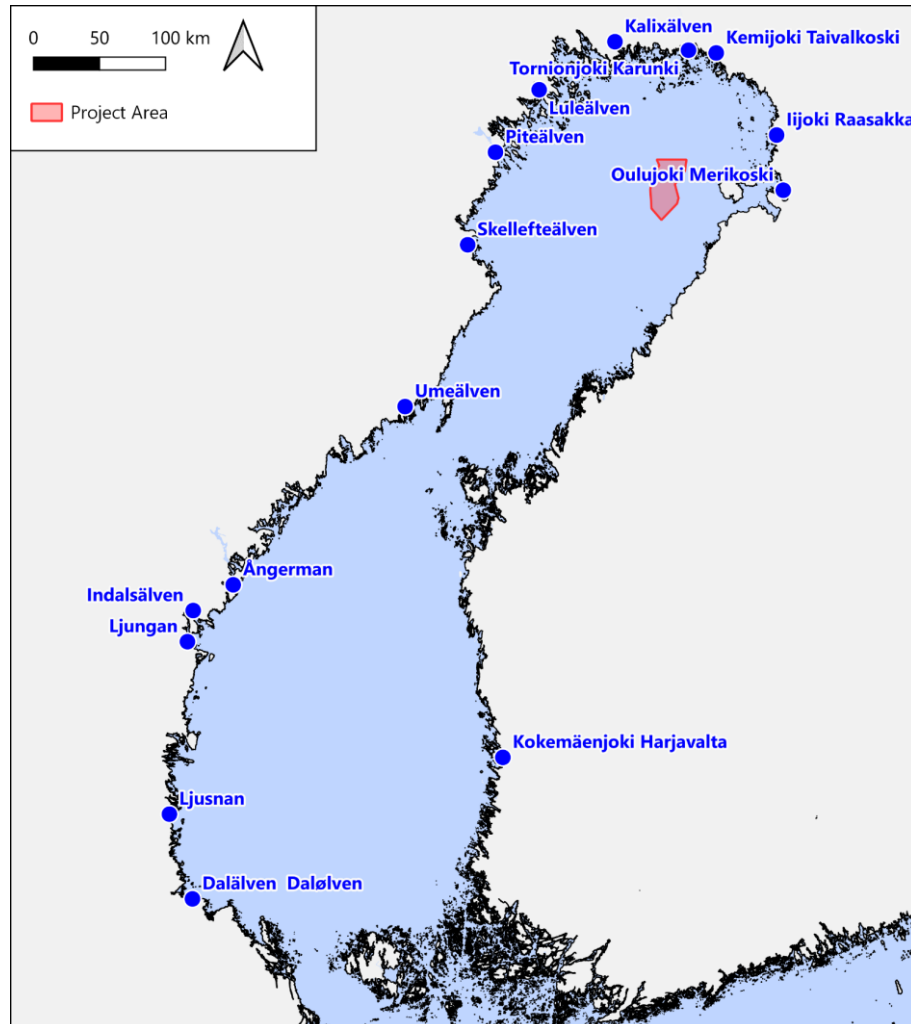


Figure 6.25: Location of the main rivers included in the model.

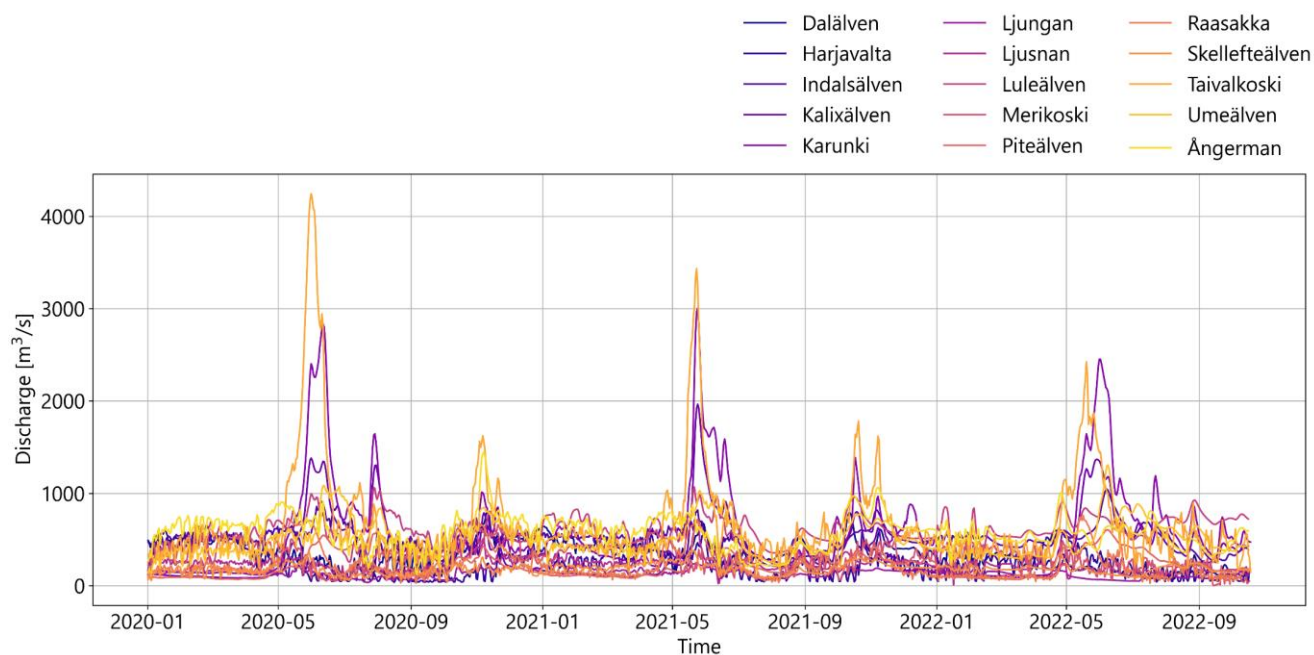


Figure 6.26: Daily discharges [m^3/s] for the main rivers considered in the model.

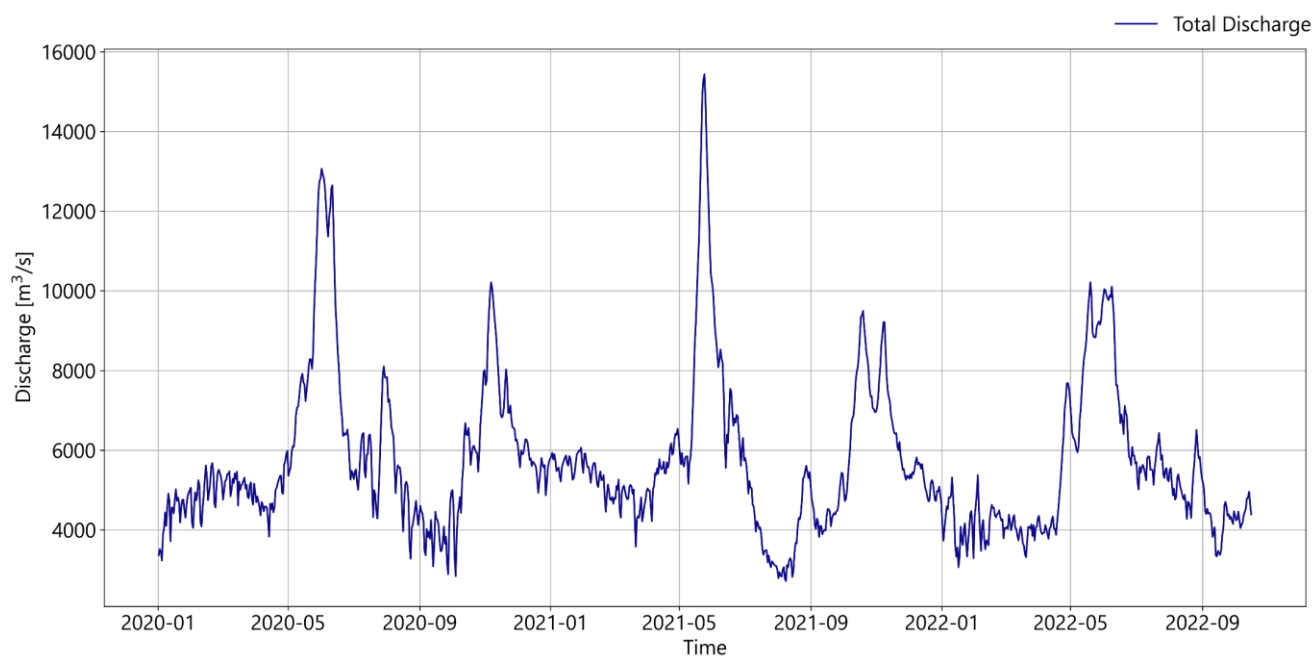


Figure 6.27: Total river discharge [m^3/s] into the model.

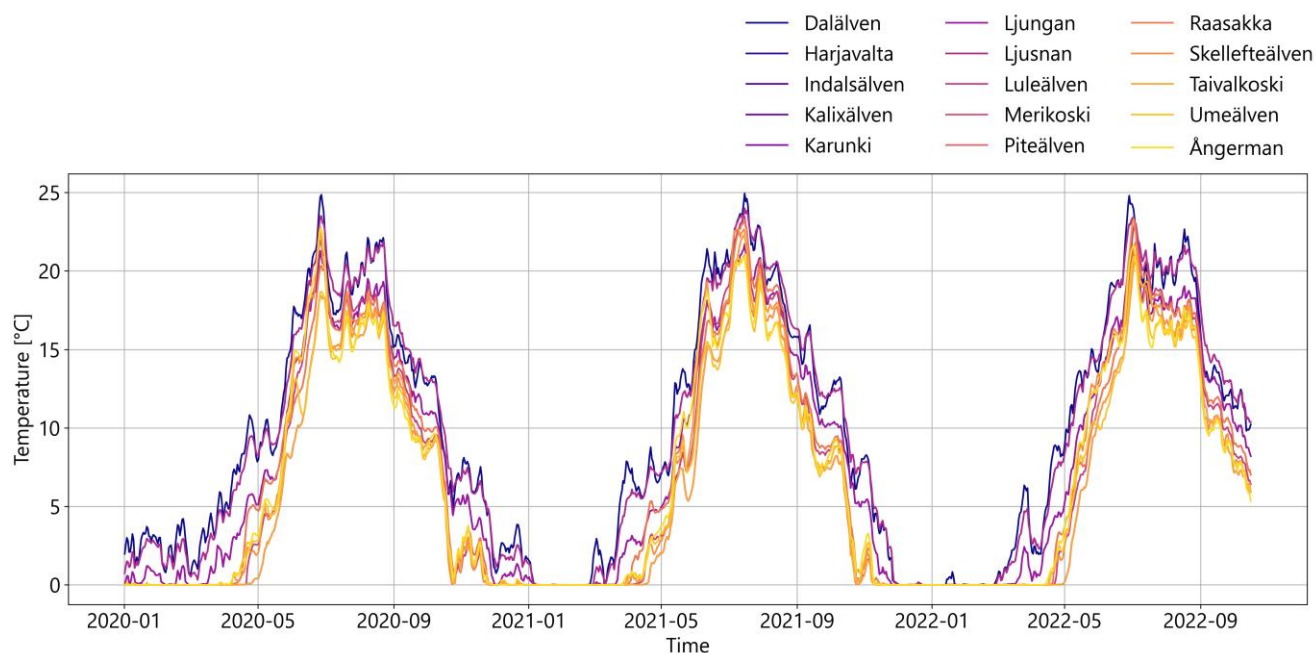


Figure 6.28: Daily water temperatures [°C] for the main rivers considered in the model.

6.8. Surficial sediments, seabed geology

The general image of the surficial sediments present in the wind farm and the surrounding area is based on data provided by the client as grains sieves analyses, Appendix 1, and EMODnet substrates (EMODnet, 2022), Figure 6.29.

The majority of the seabed within the wind farm consists of silty sand (in average 15% clay and silt) and mixed sediment (in average 15% clay and silt).

For each of the two EMODnet categories, the grain size distribution of sediment spill sources located in that category has been represented by an average sample based on project specific data collected in and around the project area.

Along the export cables the cables have been jointed to the nearest grab sample for sections of 200 m.

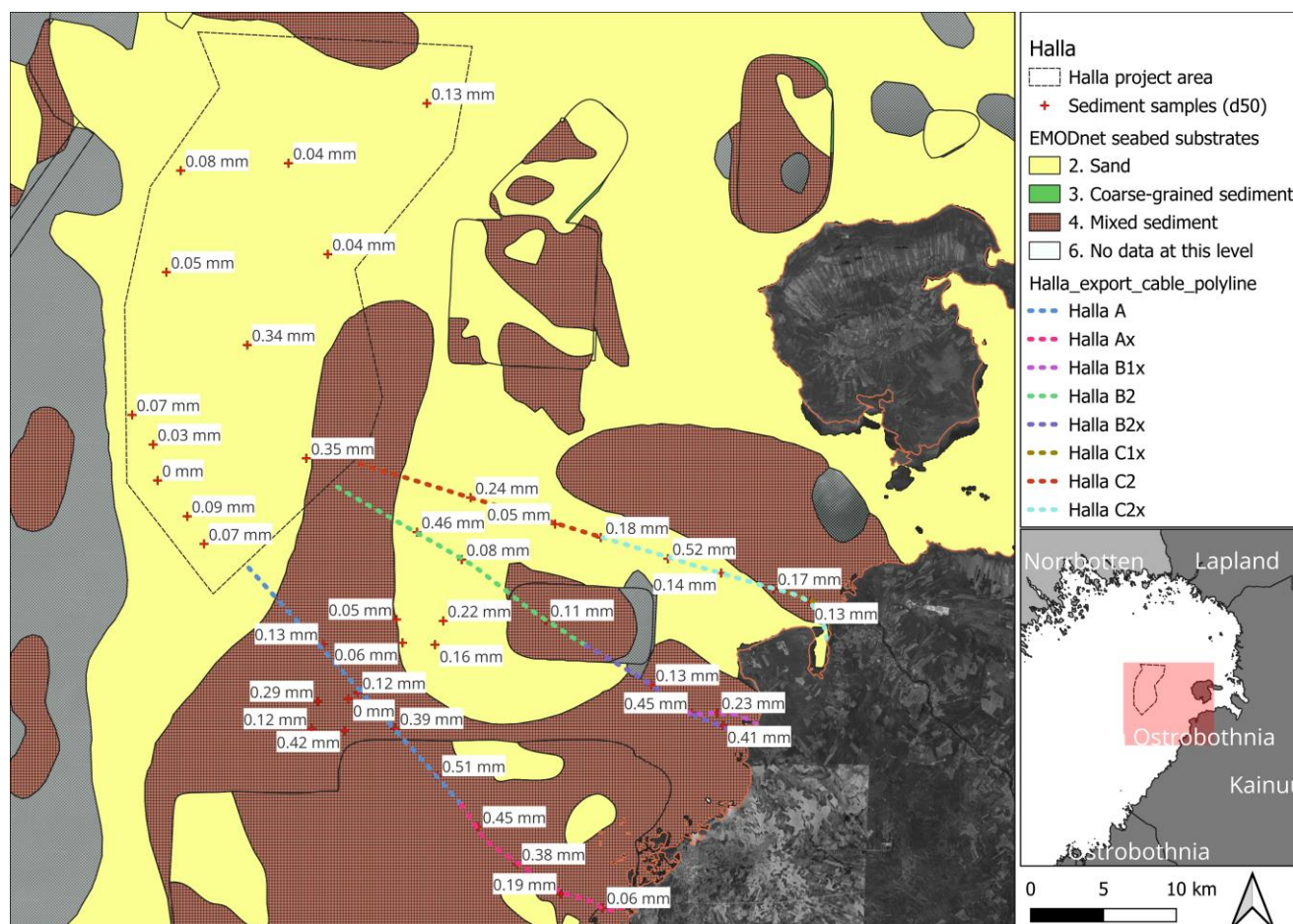


Figure 6.29: Sediment, sediment samples provided by the project and substrate by (EMODnet, 2022). Left figure - Grey: "No data".

6.9. Baseline description

The Halla OWF is located along the northern end of the Bay of Bothnia, separated by a relatively narrow and shallow area (the Quark) from the Bothnian Sea, which restricts water exchange¹.

Hydrographic conditions within the Halla OWF are characterised by a low salinity (1-3 PSU) and a weak vertical salinity gradient (halocline). Salinity varies within and also between years (4x4 km grid: Appendix 5 and 2x2 km grid: Appendix 6), with the generally higher values in Appendix 6 Probably due to the different resolution.

Water temperature varies from 0-2°C during the winter to over 20°C between July and August (Appendix 3 and Appendix 4). Temperature is strongly stratified during the summer with a thermocline (zone of maximum temperature gradient) around 10-20 m depth. Between September and October, the water may warm up to 12-15° over the entire depth.

¹ The Bay of Bothnia form together with Bothnian Bay the Gulf of Bothnia, which is separated from the Baltic Proper by a strait at the Åland Sea.

Ice cover spreads from north to south in the Gulf of Bothnia starting in December and reaches a maximum extent in March, with the entire length of the west coast of Finland covered with ice. From June, the entire Gulf of Bothnia is ice-free again. Due to the absence of tides, water level variations are mostly driven by variations at the Åland boundary, wind and pressure differences and amount to $\pm 150\text{cm}$ around their average during the year.

Due to the limited variations in water levels, currents are generally weak, around 0.15m/s at the surface (maximum of 0.5m/s) and less than 0.07m/s below 30m , and mostly driven by wind as well as temperature and salinity differences. The average circulation in the Bay of Bothnia is counter-clockwise in winter, spring and autumn, and changes to clockwise in summer, Appendix 2.

Background concentrations of suspended matter is according to (Jean-François Berthon and Giuseppe Zibordi, 2010) around 1 mg/l in the Baltic Proper to Bothnian Bay to 0.6 mg/l .

7. Hydrodynamic 3D model (Regional & Local)

7.1. Bathymetry and mesh

7.1.1. Regional model

To account for regional circulation patterns, the regional 3D hydrodynamic model encompasses the whole Gulf of Bothnia (see Figure 7.1, Bothnian Sea and Bothnian Bay). The boundary with the Baltic Proper is located at the narrowest zone of the Åland Sea. The regional model is used for calibration and validation of the hydrodynamic processes, and to force the local pressure model (see below). To maintain reasonable simulation times, the model has a relatively coarse horizontal resolution (4km^2). The mesh constitutes of 42,207 elements and 22,268 nodes. To capture temperature and salinity stratification, which are more pronounced in the surface layer, the water column is divided into 15 vertical elements for depths up to 30 meters (hybrid sigma layers), giving a minimum vertical resolution of 3 meters. The part of the water column deeper than 30 meters is described using constant depth layers of 12 meters. The bathymetry in the Gulf of Bothnia varies between 0 meter at the coast to 250 meters for the north-western Bothnian Sea. The assessment of the impact of the project is based on the regional model, with the mesh being refined to up to $0,09\text{ km}^2$ in the immediate vicinity of the project area (49,588 elements, 26,012 nodes, see Figure 7.1).

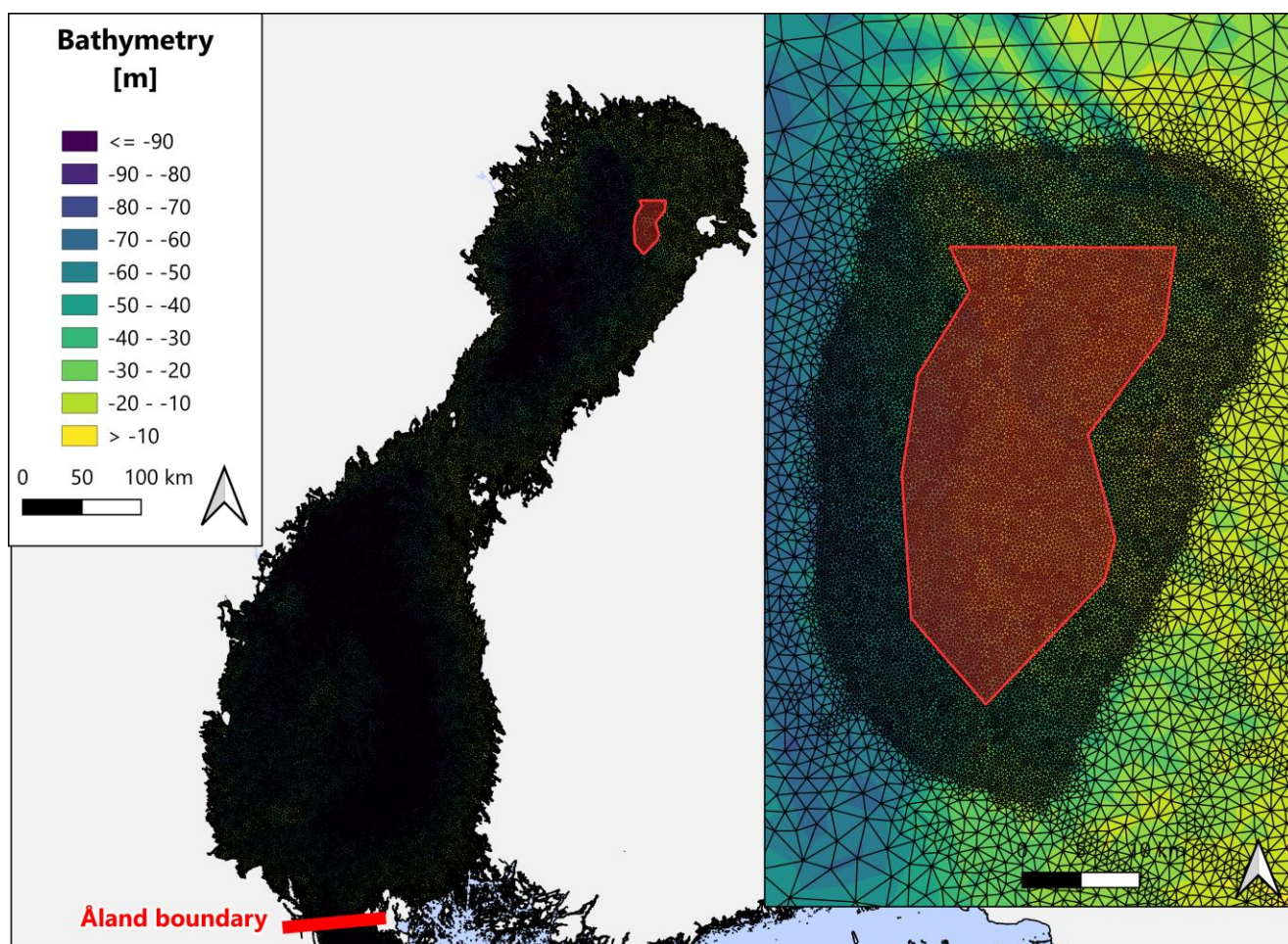


Figure 7.1: Mesh and associated bathymetry (MSL) of the regional hydrodynamic model for calibration and validation (left) and local refinement in the close vicinity of the project area (red polygon) in order to assess the hydrodynamic impact.

7.1.2. Local sediment model

To model sediment dispersal (Figure 7.2), the local sediment model represents the same area as the regional model with the difference that the vertical mesh only consist of sigma-layers instead of a combination of sigma and z-layer to avoid artificial sediment traps due to the z-layers.

The model consists of 60,442 elements and 21,466 nodes, and its vertical resolution is 10 sigma layers. The local model has a varying horizontal resolution, coarser further than 10km from the project area outer boundary, where negligible impacts of sediment dispersal can be expected due to the low currents, gradually increasing to 0.09km² within 5km of the project area and along the export cables where the impact are of sediment dispersal are expected to be the strongest. It is forced by the same boundary data as the regional model.

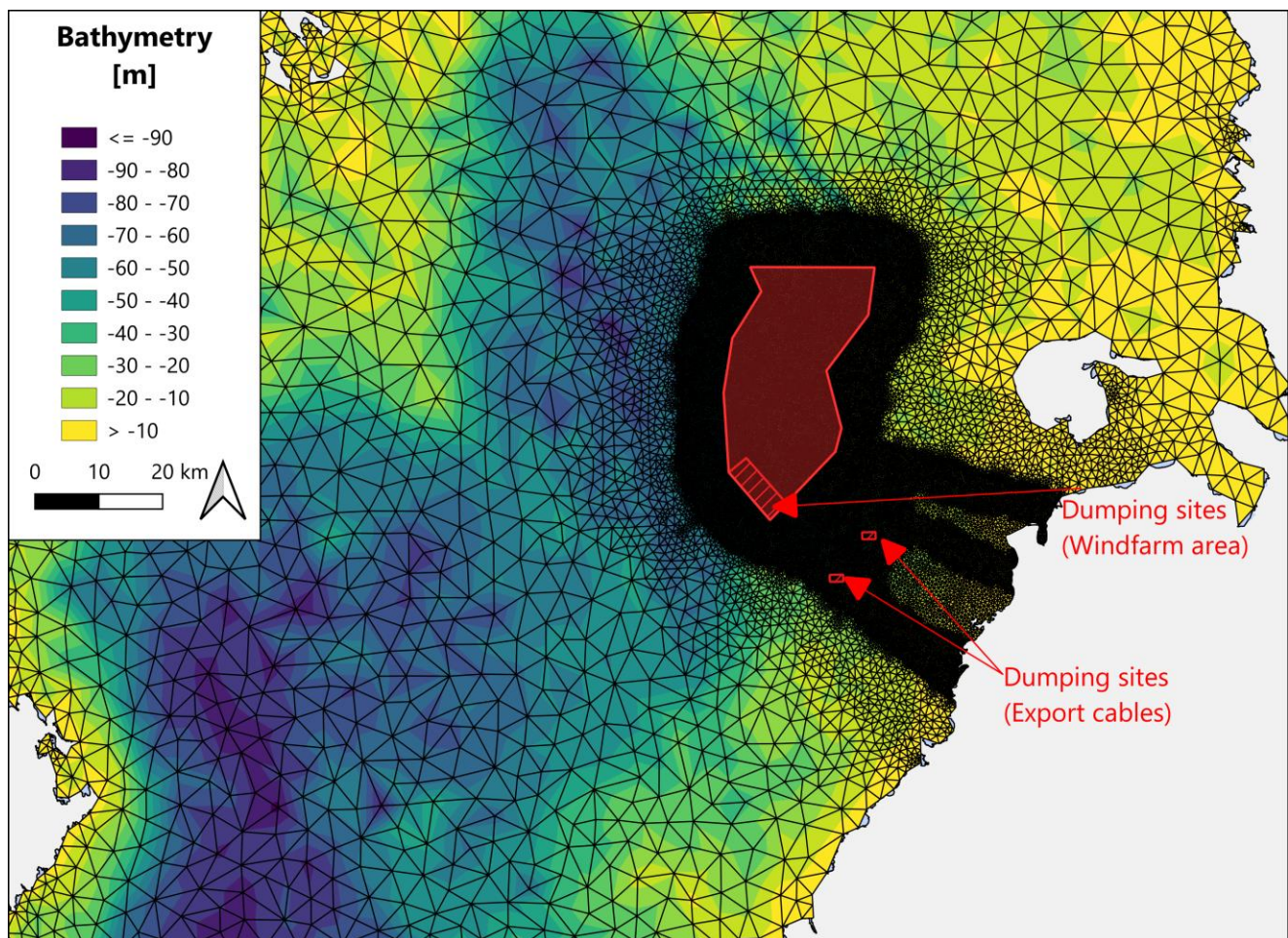


Figure 7.2: Mesh and associated bathymetry of the local sediment model for analysis of sediment dispersal.

7.2. Boundary data

The regional model at the open boundary towards the Baltic Sea is forced with modelled SMHI data regarding salinity, temperature, and water level. At the surface, ECMWF's ERA5 wind data in the form of wind fields, air pressure, precipitation and evaporation, and sea ice concentration and thickness from the Baltic SMHI model are considered. Heat exchange with the atmosphere has been taken into account via data from ECMWF's ERA5 of net short and longwave radiation, air temperature and humidity at the sea surface. Forcings from the catchment are also considered through the freshwater discharges temperatures from the major rivers listed in chapter 6.7.

To minimize the spin-up period the model is for the first time-step initialized with salinity, temperature and surface elevation from the Baltic Sea SMHI model.

7.3. Model setup and calibration

The regional model is forced at the southern boundary using specified water levels, and salinity and temperature profiles from the Baltic SMHI model. Water levels have been calibrated by adjusting the wind friction coefficients to get a reasonable agreement with observation data.

To account for salinity and temperature stratification, the vertical eddy viscosity is resolved using the k- ϵ turbulence model. Salinity and temperature profiles have been calibrated against available measurements within the project area by adjusting the vertical and horizontal dispersion coefficients, and surface temperatures have been calibrated through the light extinction coefficient determining the depth of the light penetration in the water column.

7.4. Identification of a representative period

Based on modelled temperature, salinity and currents at Halla OWF from SMHI Baltic Sea model, presented in Appendix 2, Appendix 3 to Appendix 8, an average year is identified by comparing yearly conditions. Interannual variation is generally low for salinity, temperature and currents, with a general anti-clockwise circulation pattern in the Bothnian Sea except for the summer months where the current in general is weak with a trend to a clockwise current circulation. Furthermore, the comparison of the different particle tracks (Appendix 9) shows that the dispersion of particles varies more between the individual months of a year than between the four years studied.

The year 2021 has been chosen as a representative year as it follows the general increase in salinity end of spring and the lower surface salinity end of summer. Temperature is highest in late summer with a thermocline going down to 15 meters. Thermocline depth in this area varies between 10-30 m, so that 15 m is on the lower side and indicates slightly reduced vertical mixing. Furthermore, the particle tracking shows that 2021 is a suitably representative year, with a track behaviours within the range of the other years for each month.

Comparison between modelled currents by the 2 km by 2 km and 4 km by 4 km SMHI models indicate increased current speeds and more evenly spread direction components in the finer version. The average magnitude of the current is in general less than 0.1 m/s with an anti-clockwise circulation in the winter, spring and autumn and a clockwise circulation in the summer months with some variations (Appendix 2). The year 2021 experiences clockwise currents circulation in the months April, May, August and September, weak current in June and July and anti-clockwise circulations in October and November aligned with the general variations in the current pattern. On that background the year 2021 was chosen to investigate the effects of the wind farm on hydrodynamics and of its construction on sediment spreading.

7.5. Verification

The verification of the regional model is based on the comparison of the simulated and measured, publicly available data from 2021. The following parameters are taken into account:

- Observed water levels.
- Observed current.
- Observed timeseries of surface temperature and salinity.
- Observed CTD measurements.

In addition, the ADCAP and CTD measurements collected within the project area in September 2022 are analysed separately.

7.5.1. Water levels

The visual comparison of the calculated water levels with the observed water levels in 2021 (Figure 7.3 to Figure 7.5, as well as entire overview of all stations in Appendix 14 demonstrates good agreement for all stations in the period mid-May and mid-November with correlation coefficients varying between 0.88 - 0.95 (July in Appendix 14) and between 0.89-0.97 (September in Appendix 14).

While the agreement between calculated and measured water levels at the southwestern stations (FORSMARK Figure 7.3), BÖNAN SJÖV LJUSNE SJÖV, SPIKARNA, SKAGSUDDE SJÖV (see Appendix 14) is comparably good over the entire year with correlation coefficients between 0.93 -0.95 (Table 7-1), lower correlation coefficients are observed at the remaining stations.

The visual comparison (Appendix 14) reveals an underestimation of the water levels by the model between December and May. The further north or east the station lies, the more pronounced the difference is. For example, the calculated water levels at the RATAN station in March show a mean error of -0.49 m (Figure 7.4), while those at the KALIX-KARLSBORG SJÖV (Figure 7.5) station show a mean error of -0.73 m (see Appendix 14). As shown by the comparison of the location of stations with ice cover (Figure 6.23 and Figure 6.24), there is a correlation between ice cover and low water levels in the model compared to the measurements (as the difference occurs mainly at stations and in the period when ice cover is documented). The underestimation can be explained by the fact that ice thickness is not included in water levels in MIKE.

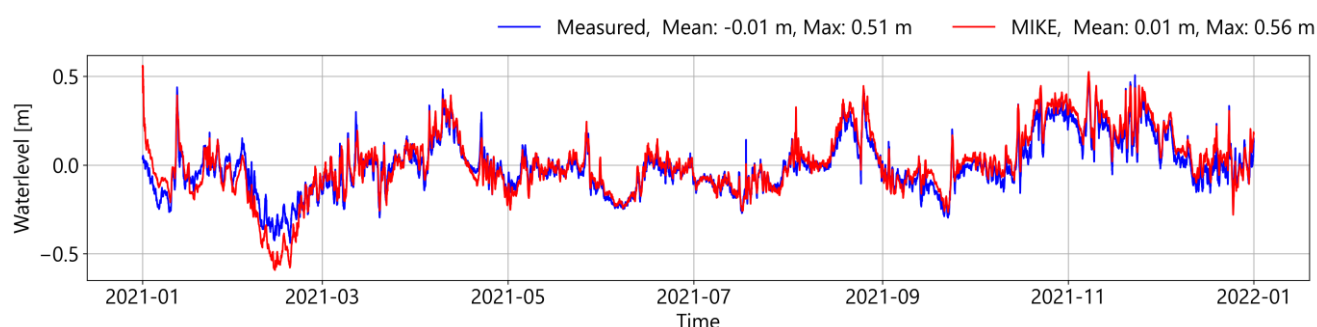


Figure 7.3: Comparison between observed water level in mMSL (blue line) and modelled water level (red line) for FORSMARK (SMHI-Station).

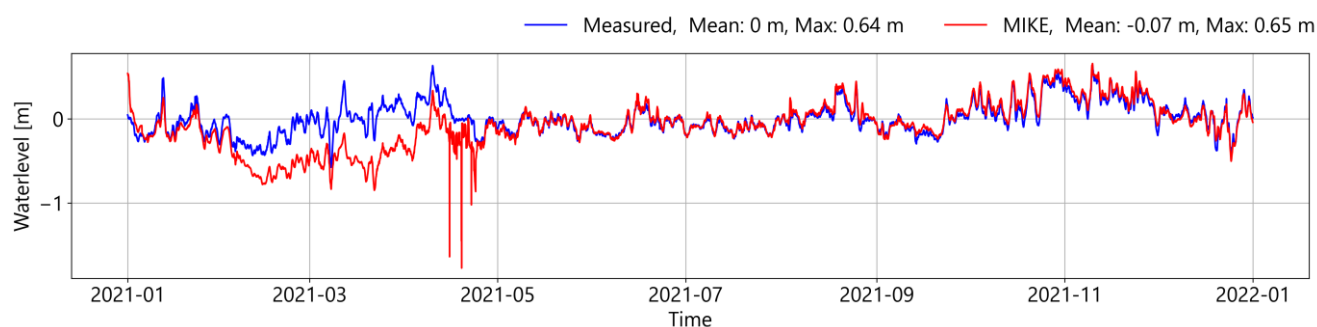


Figure 7.4: Comparison between observed water level in mMSL (blue line) and modelled water level (red line) for RATAN (SMHI-Station).

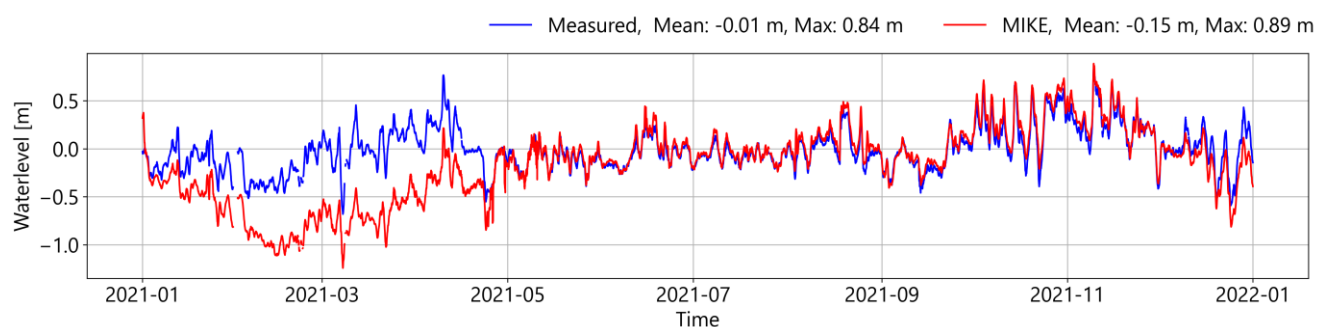


Figure 7.5: Comparison between observed water level in mMSL (blue line) and modelled water level (red line) for KALIX-KARLSBORG SJÖV (SMHI-Station).

Table 7-1: Performance Metrics of the HD-Model in respect to the Water levels (over 2021)

Name	ME [m]	MAE [m]	RMSE [m]	Std. of Residuals [m]	Correlation Coefficients [-]
FORSMARK	0.01	0.05	0.06	0.06	0.95
BÖNAN SJÖV	-0.01	0.04	0.06	0.06	0.95
LJUSNE SJÖV	-0.02	0.05	0.07	0.06	0.94
SPIKARNA	-0.01	0.04	0.06	0.06	0.95
SKAGSUDE SJÖV	-0.03	0.06	0.09	0.08	0.93
Holmsund	-0.07	0.10	0.17	0.15	0.82
RATAN	-0.08	0.12	0.20	0.19	0.73
FURUÖGRUND	-0.16	0.20	0.32	0.28	0.66
STRÖMÖREN SJÖV	-0.20	0.24	0.36	0.30	0.66
KALIX-KARLSBORG SJÖV	-0.15	0.20	0.32	0.28	0.68
Kemi Ajos	-0.09	0.18	0.27	0.25	0.69
Oulu Toppila	-0.11	0.20	0.28	0.25	0.69
Raahe Lapaluoto	-0.07	0.16	0.25	0.24	0.68
Pietarsaari Leppäluoto	-0.06	0.12	0.20	0.19	0.77

7.5.2. Current

Due to the suboptimal location of the publicly accessible measuring station (immediate proximity to the open model boundary (Understen BS) or to the coast (NORRBYN BOY)), the modelled currents are only compared with the measurements within the wind farm area (ADCP measurements from OX2 in September 2022).

7.5.2.1. ADCP-Measurements of 2022

The comparison of the modelled flows with the ADCAP measurements in the project perimeter is discussed using the September 2022 data. Due to the influence of waves during velocity measurement in the upper water layers (compare explanations in chapter 6.3.2.2), the calculated and measured velocities are compared only from a depth of 15 m.

Speed: The measured current speeds in the upper water layers (cf. vertical profiles Figure 7.7 and Appendix 15) cannot be reproduced as they seems to be affected by the waves. However, the agreement of the modelled flow velocities increases with increasing depth (Figure 7.6 and Appendix 15).

Direction: The comparison of the modelled and observed flow directions (Figure 7.8 and Appendix 15) shows that the different flow distribution depending on the depth can be mainly reproduced with the model.

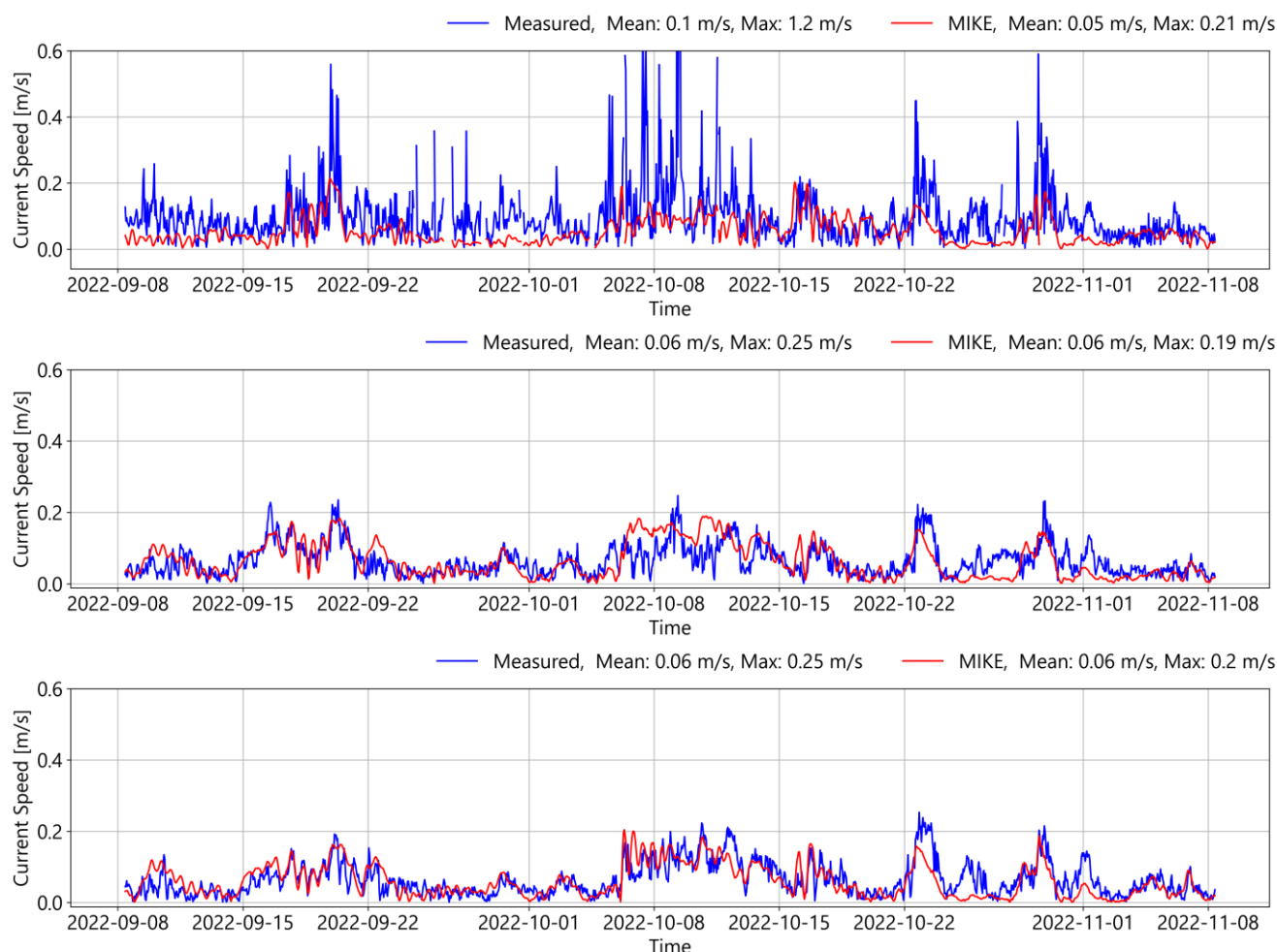


Figure 7.6: Comparison between observed (blue lines) and modelled (red lines) current speeds at 9 m, 21 m, and 35 m depth (from top to bottom) at Halla 1.

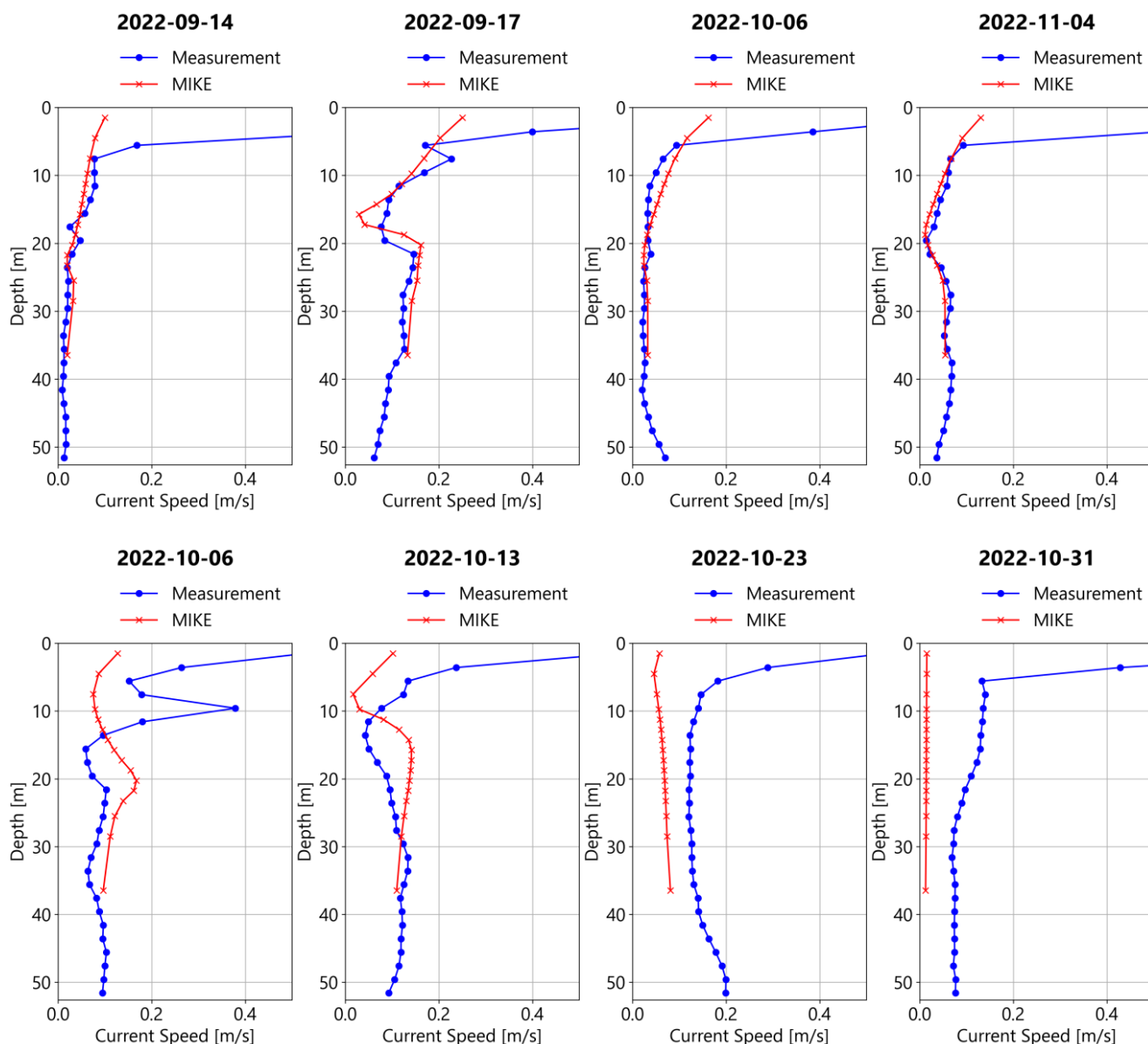


Figure 7.7: Selection of vertical Profiles comparing observed (blue lines) and modelled (red lines) current speeds of horizontal current speed at Halla 1 (examples in top row show good agreement, whereas there is a significant difference regarding the ones in the lower column).

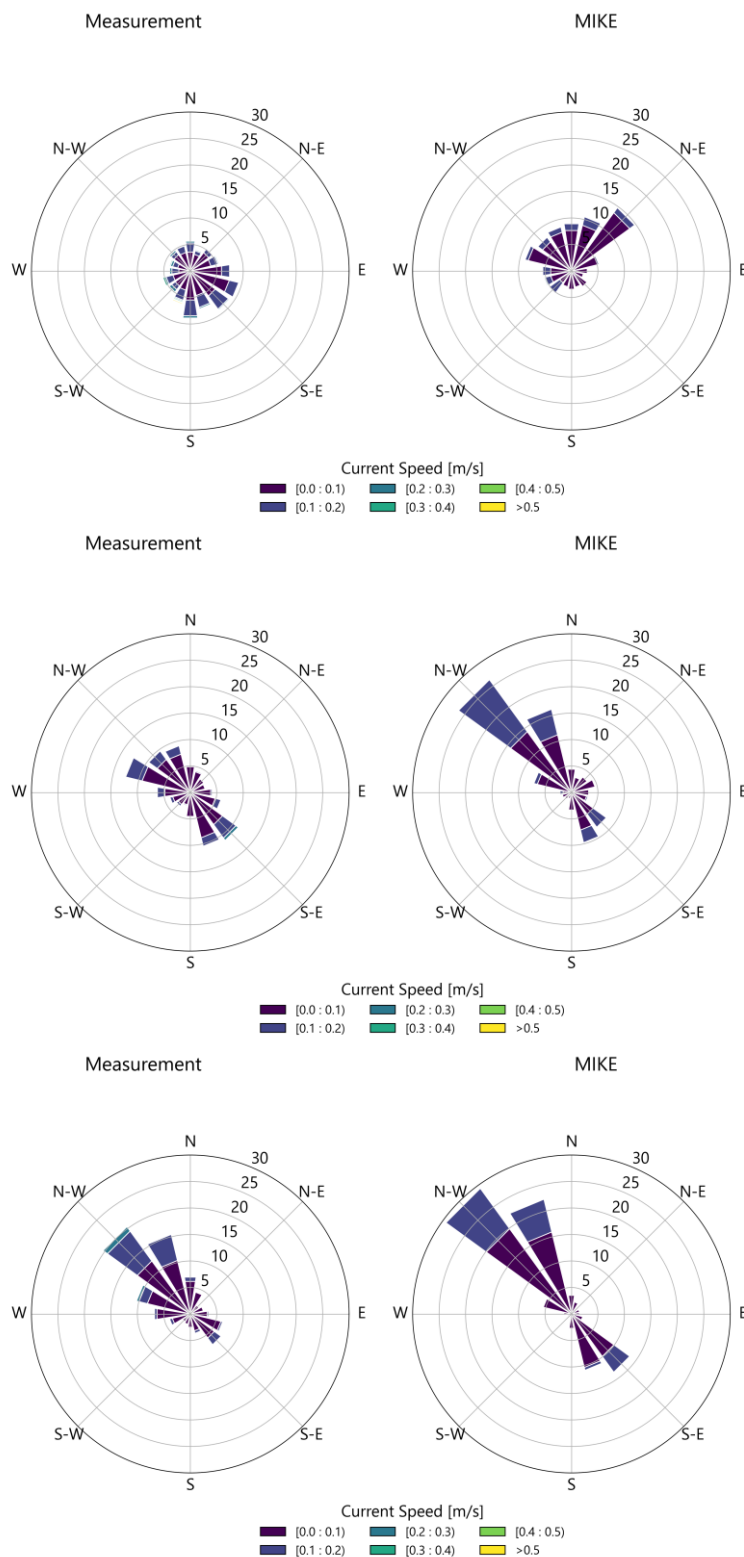


Figure 7.8: Current roses representing the distribution of directions and current speeds for the observed current (left) and currents modelled by MIKE (right) at 9 m, 21 m, and 35 m (from top to bottom) at Halla 1

7.5.3. Salinity

The model performance with respect to the temporal evolution of the salinity is presented on the basis of the available measurement data at stations NORRBYN BOJ and Understen BS (see locations in Figure 6.4). While the salinity at the southern station (Understen BS, Figure 7.10) tends to be underestimated by the model (mean error of -0.49 PSU, see Table 7-2), the model overestimates the salinity at the northern station NORRBYN BOJ (Figure 7.9 and Table 7-2, mean error of +0.64 PSU). The overestimation of salinity in the Bay of Bothnia is also evident in the data from the SMHI Baltic Sea model (Copernicus, Baltic Sea Physics Analysis and Forecast, 2x2km, 2022)

Due to the temporally incomplete measurement data and the sparse spatial distribution of the measurement sites, the significance of the comparison is limited and in view of the large number of CTD measurements, a detailed analysis of the temporal evolution of the salinity at these two stations is dispensed with.

Table 7-2: Performance Metrics of the HD-Model in respect to the salinity (over 2021, given the measurement periods available)

Name	ME [PSU]	MAE [PSU]	RMSE [PSU]	Std. of Residuals [PSU]	Correlation Coefficients [-]
NORRBYN BOJ	0.64	0.65	0.75	0.40	0.51
Understen BS	-0.49	0.49	0.56	0.26	0.87

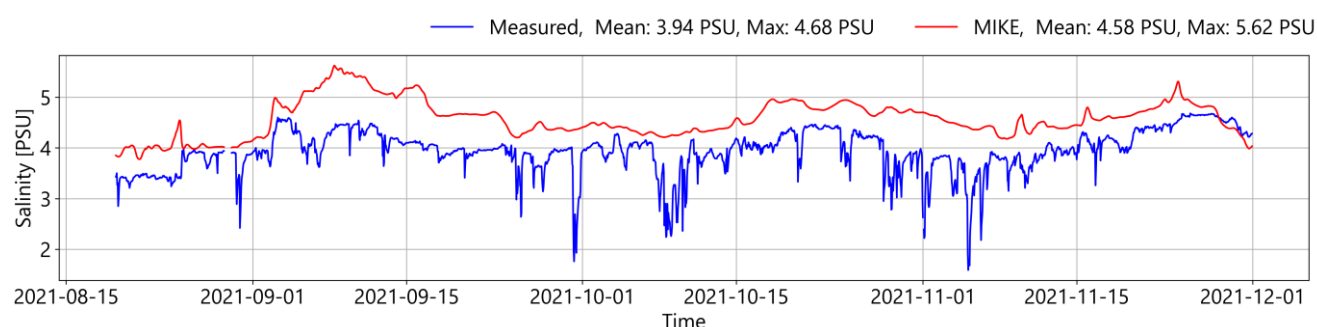


Figure 7.9: Comparison between observed salinity (blue line) and modelled salinity (red line) for NORRBYN BOJ (SMHI-Station).

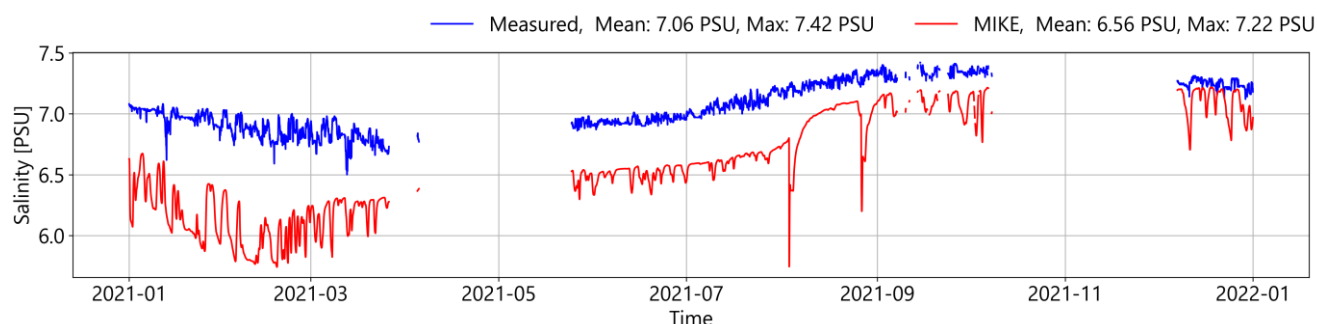


Figure 7.10: Comparison between observed salinity (blue line) and modelled salinity (red line) for Understen BS (SMHI-Station).

7.5.4. Salinity Profiles

The comparison with the CTD measurements is discussed separately for the publicly available measurements of 2021 and the profiles recorded by OX2 in the project area in September 2022.

7.5.4.1. Publicly available Data of 2021

The comparison of the calculated and measured vertical salinity profiles (Figure 7.11 and Figure 7.12, as well as figures in Appendix 16) indicates good agreement for the majority of the profiles. The slight stratification occurring towards summer can be reproduced with the model. However, the MIKE model tends to overestimate the salinity at the measuring points to the north and with increasing depth (e.g. compare Figure 7.11 (located in the south) vs. Figure 7.12 (located in the north)).

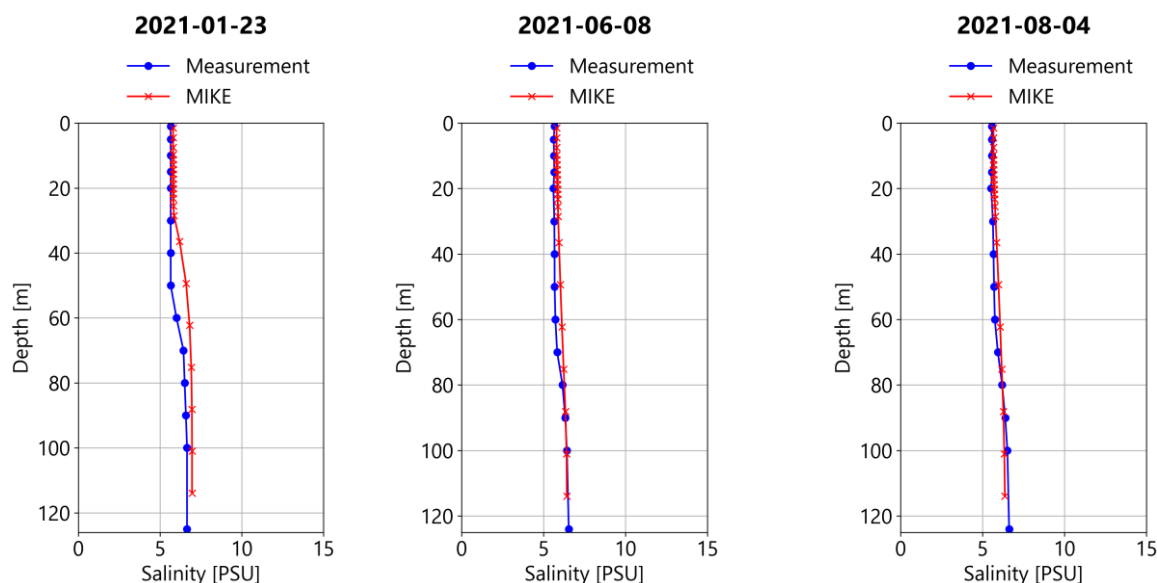


Figure 7.11: Comparison between modelled and measured salinity profiles at location SR5 (source: merihavainnot.fi, location see Figure 6.4)

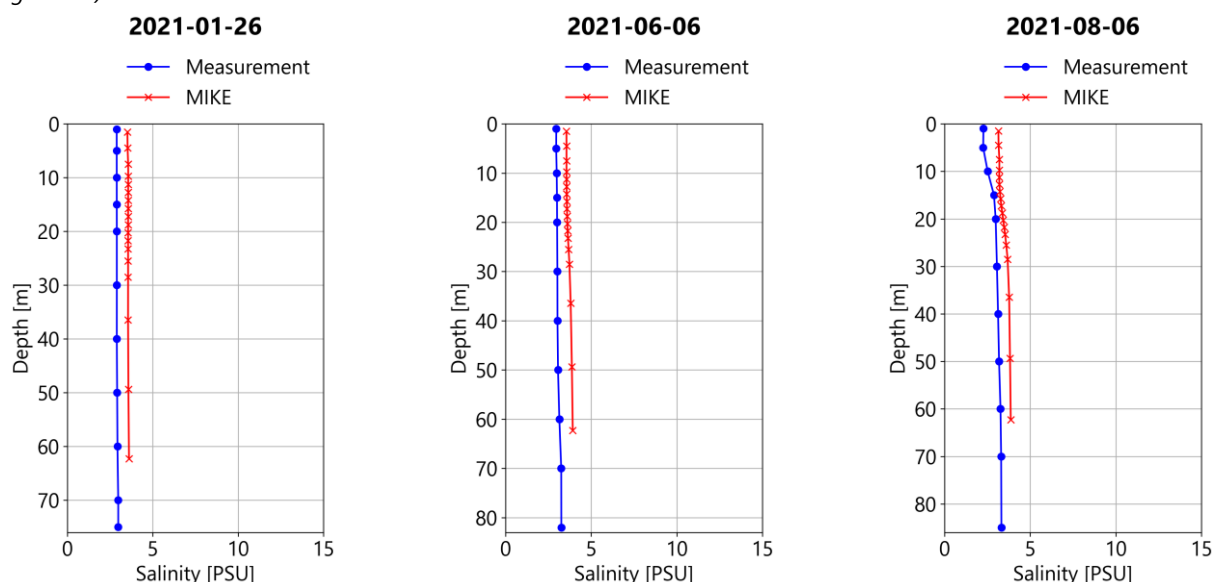


Figure 7.12: Comparison between modelled and measured salinity profiles at location F2 (source: merihavainnot.fi, location see Figure 6.4)

7.5.4.2. Measurements from OX2 in 2022

For the assessment of the model quality with regard to the vertical salinity distribution in the project perimeter, 42 profiles (recorded in September 2022) are available, which are compared with the modelled profiles (see Appendix 17).

The slight stratification of salinity (with lower salinity values at the surface) documented at approx. 23 sites in the measurement campaign in September 2022 cannot be reproduced with the model. However, the magnitude of the salinity of the modelled profiles is consistent with that of the measurements (see e.g. Appendix 17).

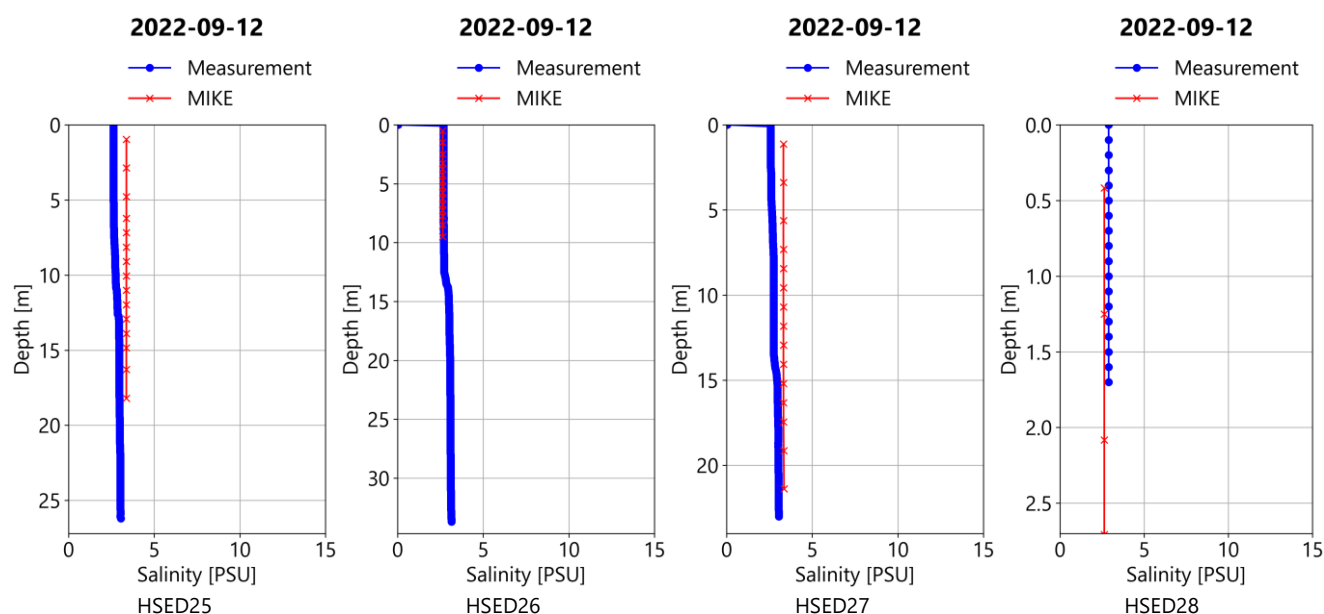


Figure 7.13: Comparison between modelled and measured salinity profiles on the 12th September 2022 (source: OX2)

7.5.5. Water temperature

For the evaluation of the MIKE model with regard to the surface temperature, 17 measuring stations are available (Figure 7.14 and Figure 7.15 and Appendix 18). The surface temperatures calculated with the model, with correlation coefficients between 0.91-0.99 and a mean error -2.4 to +1.2° (Table 7-3, Figure 7.14 and Figure 7.15), agree well with the (partly incomplete) measured values, regardless of spatial location and season.

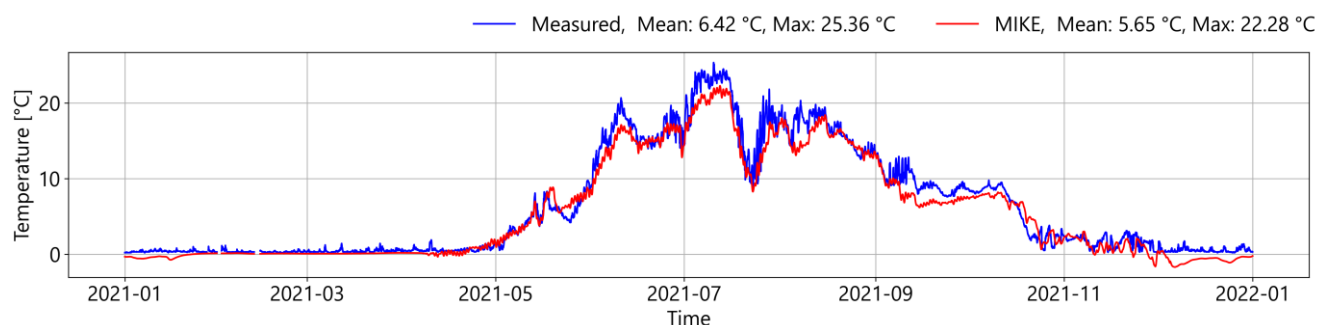


Figure 7.14: Comparison observed surface water temperature (blue line) and modelled surface water temperature (red line) for KALIX-KARLSBORG SJÖV (SMHI-Station).

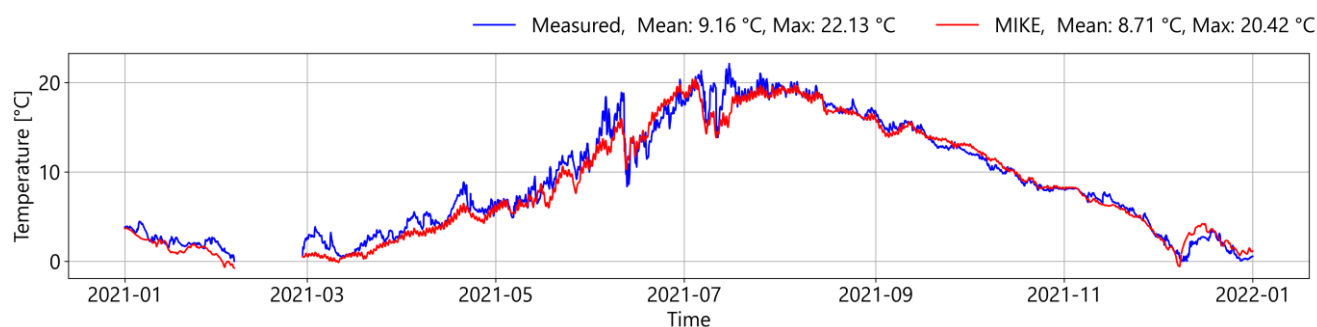


Figure 7.15: Comparison between observed surface water temperature (blue line) and modelled surface water temperature (red line) for FORSMARK (SMHI-Station).

Table 7-3: Performance Metrics of the HD-Model in respect to the surface temperature (over 2021)

Name	ME [°C]	MAE [°C]	RMSE [°C]	Std. of Residuals [°C]	Correlation Coefficients [°C]
FORSMARK	-0.45	0.85	1.17	1.08	0.99
BÖNAN SJÖV	0.10	1.11	1.43	1.43	0.98
FINNGRUNDET WR BOJ	0.82	1.04	1.37	1.10	0.98
LJUSNE SJÖV	-0.23	1.02	1.57	1.56	0.98
NORRBYN SST	-0.05	1.91	2.63	2.63	0.94
NORRBYN BOJ	0.86	1.08	1.23	0.88	0.97
Holmsund	-2.26	2.29	2.55	1.18	0.99
STRÖMÖREN SJÖV	-0.38	1.88	2.12	2.08	0.98
KALIX-KARLSBORG SJÖV	-0.77	1.04	1.41	1.19	0.99
Oulu Santapankki	0.27	0.77	0.97	0.93	0.99
Perämeri aaltopoiju	1.15	1.47	1.74	1.31	0.97
Kalajoki Maakalla	1.05	1.70	2.14	1.86	0.93
Maalahti Storskäret	0.80	1.15	1.32	1.05	0.98
Selkämeri aaltopoiju	0.64	1.07	1.50	1.36	0.98
Pori Kaijakari	0.34	1.52	2.12	2.10	0.91
Uusikaupunki Vekara	0.26	1.19	1.56	1.54	0.94

7.5.6. Temperature Profiles

The comparison with the CTD measurements is discussed separately for the publicly available measurements from 2021 and the profiles recorded by OX2 in the project area in September 2022.

7.5.6.1. Publicly available Data of 2021

Not only does the comparison of the over 60 modelled and measured vertical temperature profiles (in Appendix 19) demonstrate the model's capability to reproduce the temporal evolution of the water temperature in the

Gulf of Bothnia, but it also reveals an overall satisfactory reproduction of the vertical profiles. Despite the general good agreement between modelled and measured profiles, the following limitations of the model can be observed:

- overestimation of stratification (i.e. overestimation of the warming of the upper water layers, underestimation of the mixture respectively) in June at around 8 stations (e.g. F26, MS3, F18, BO3, RR3, CV, CVI, F2 (e.g. Figure 7.16 and Figure 7.17)).
- underestimation of the water depth, which is warmed in August (affecting mainly southern sites, e.g., MS6).
- overestimation of the water depth, which is warmed in August (affecting mainly northern sites, e.g., US7, CV (Figure 7.18) and RR7).

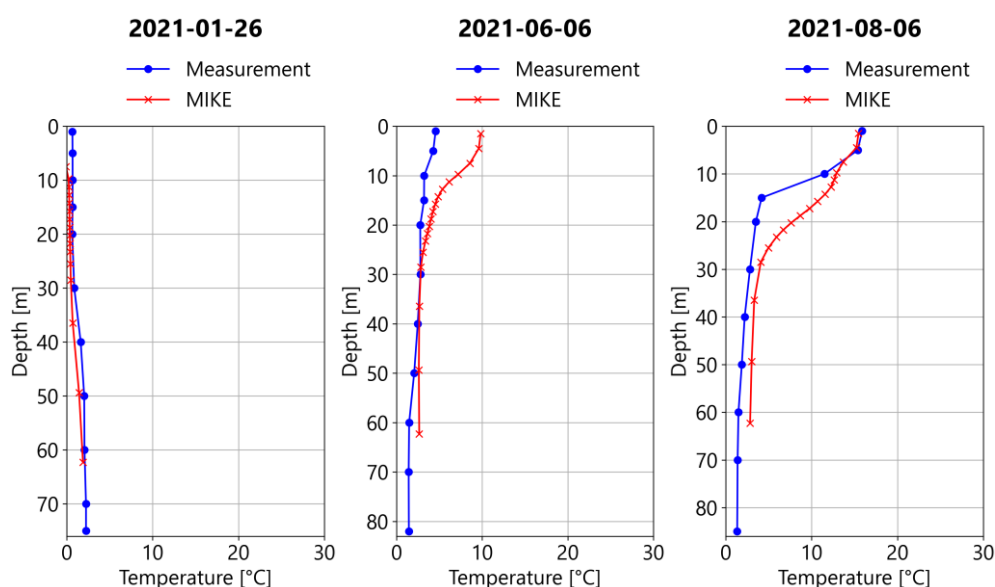


Figure 7.16: Comparison between modelled and measured temperature profiles at location F2 (source: merihavainnot.fi, location see Figure 6.4)

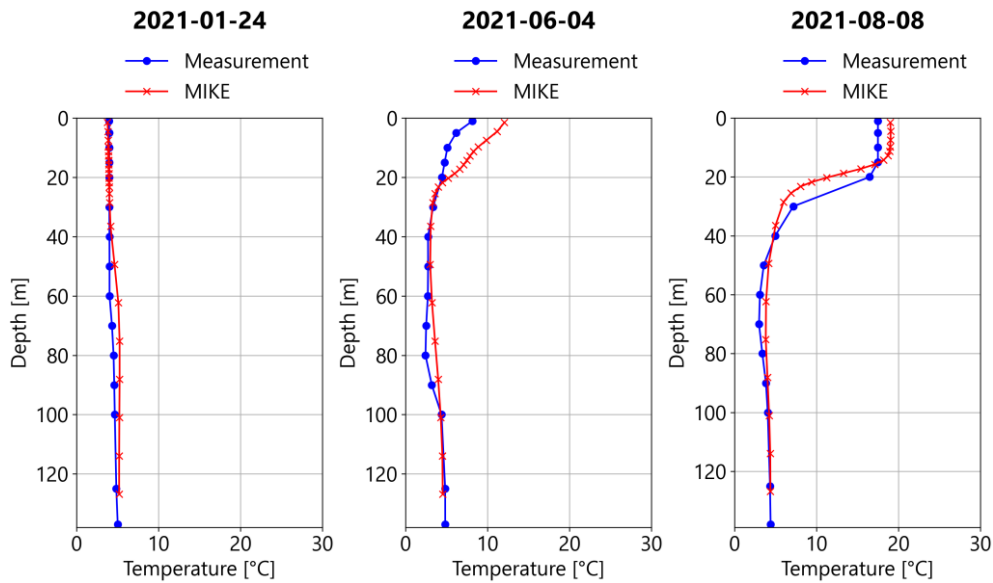


Figure 7.17: Comparison between modelled and measured temperature profiles at location F26 (source: merihavainnot.fi, location see Figure 6.4)

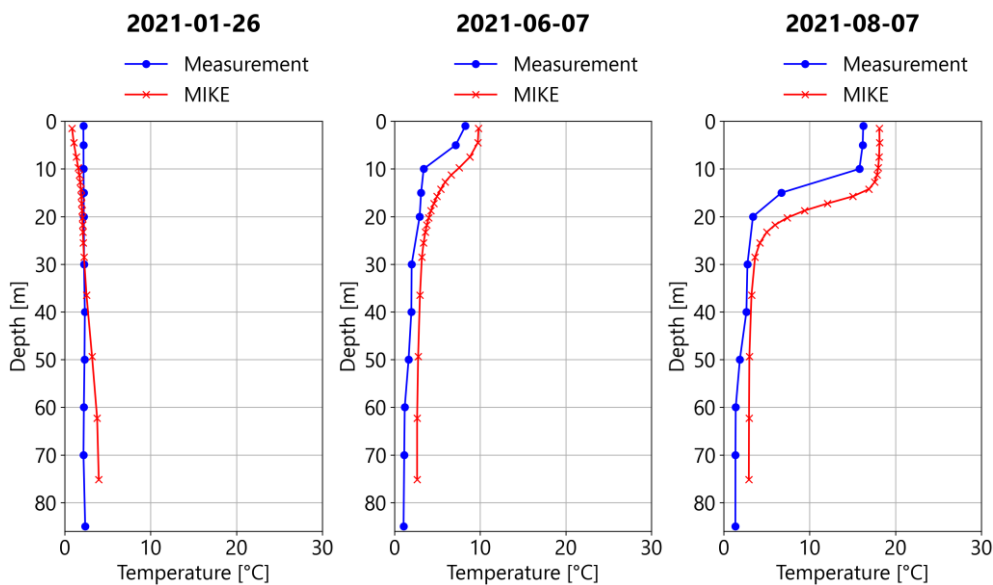


Figure 7.18: Comparison between modelled and measured temperature profiles at location CV (source: merihavainnot.fi, location see Figure 6.4)

7.5.6.2. Measurements from OX2 in 2022

Depending on the location (Figure 7.19), the measured temperature profiles show different patterns (Figure 7.20 and Appendix 20). It should be noted that the model quality is assessed on the basis of the coarse mesh (Figure 7.19). Small-scale processes, which can be seized by the high density of the measured CTD profiles, are not reproduced due to the coarse mesh resolution.

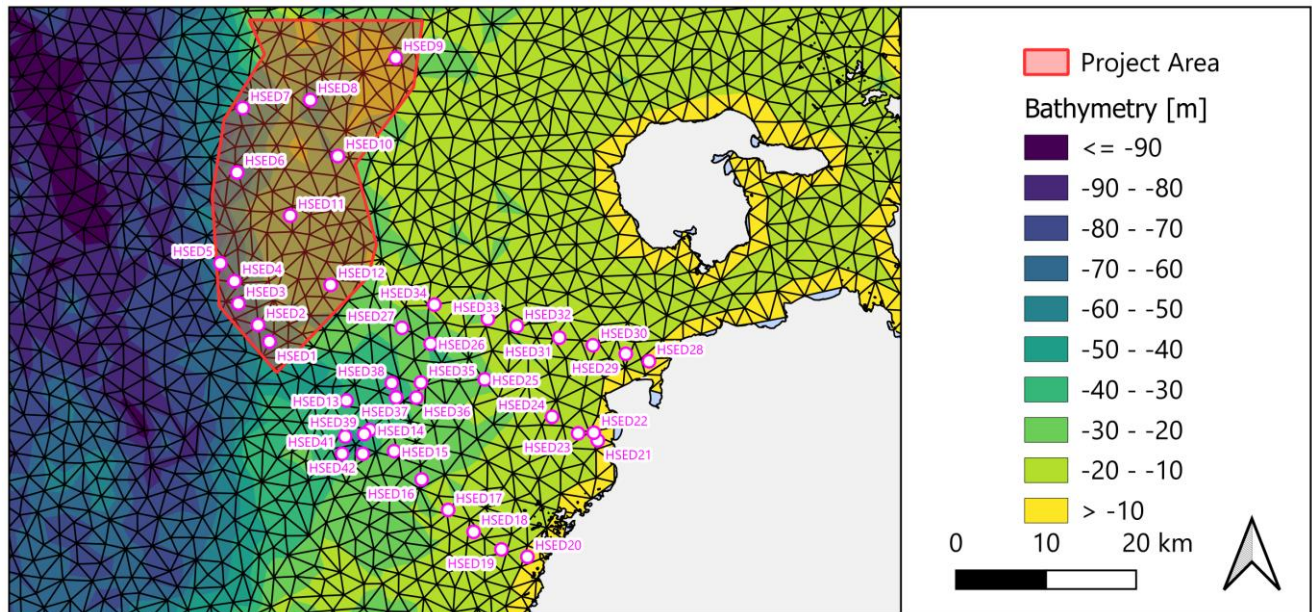


Figure 7.19: Detailed map of the CTD-measuring sites of OX2 with the mesh in the background, that is used for the regional model (Bathymetry based on (EMODnet, Bathymetry, 2023))

The comparison of the measured and calculated profiles shows the following properties:

- Profiles 6, 11, and 15 are located in waters with depth > 20 m, where a clear thermocline is visible, which can be well reproduced with the model
- Profiles 18-29 are located close to the coast in shallow waters, where the temperature tends to be overestimated by the model.
- The model tends to overestimate the surface temperature and the depth of the thermocline for the rest of the profiles.

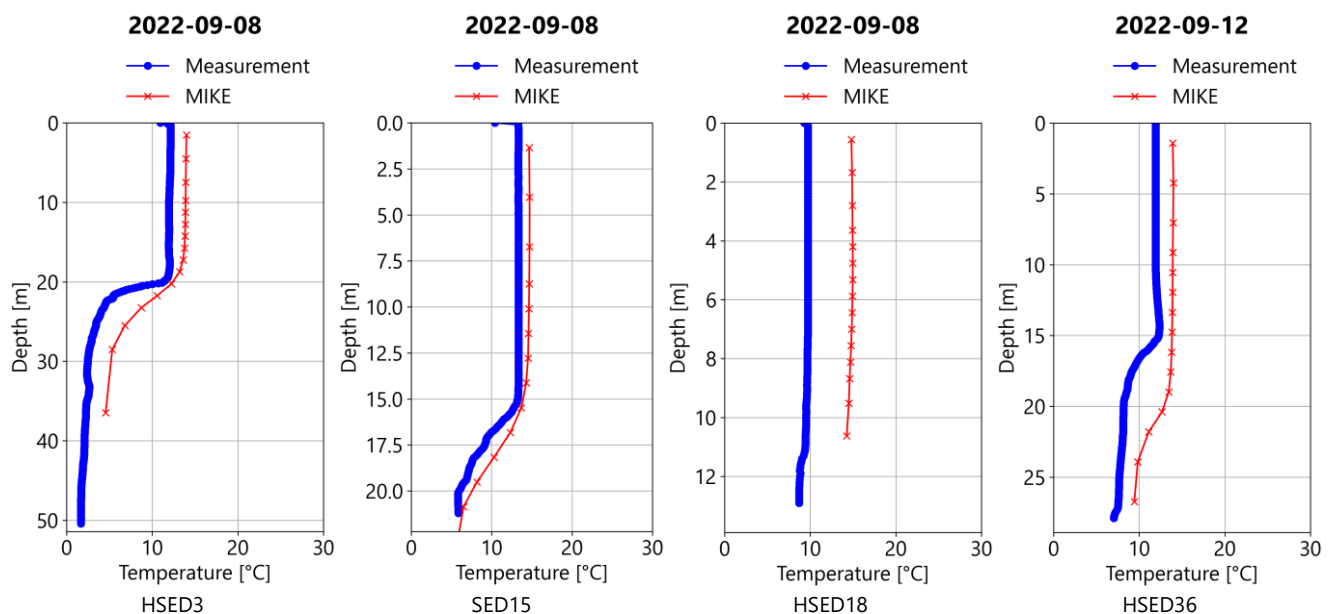


Figure 7.20: Selected examples of the comparison between modelled (red) and measured (blue) temperature profiles in 2022 (source: OX2). Note that the crosses along the red lines represent the centres of the individual layers in the model. The total water depth is therefore slightly deeper than shown.

7.5.7. Summary – model verification

The overall picture shows that the model can reproduce water level, current, salinity and temperature across the seasons both horizontally and vertically to a level where the model is aligned with the measured data and thus the relevant processes for evaluating the impact of the project on hydrography.

8. Sediment dispersal model

The input to the sediment model is described in the first three sections of this chapter and the outcome of the model in the last two sections.

8.1. Sediment sources and spill program

8.1.1. Wind farm area

For the wind farm area two case (15MW and 20MW) both with four types of sources are considered:

- 1) Dredging of the gravity-based substructures and offshore substations with a dredge capacity of 1000m³/hour with 5% spill dispersed just above the seabed (released 2 meters over the seabed). The coarse sediment fraction settles next to the GBS (Gravity Base Structure, or the WTG and the OSS), and the finer ones are available for transport in the surrounding waters.
- 2) 10% of the total dredged sediments are assumed to overflow from the barge and are released at the surface and available for transport in the surrounding waters.
- 3) 30% spill when the barge disposed the sediment at surface above the dumping site.
- 4) Burial of the inter array cable via jetting of a 1.5 x 2 m trench whereof 100% the fine sediments are assumed to be brought into suspension and released 2 m over the seabed.

The two cases considered consist of:

- 1) The 15MW case where each of the 160 WTGs can generate 15MW and the GBS has a base slab with a diameter of 45m, yielding an excavation of 12,723m³ for each GBS.
- 2) The 20MW case where each of the 120 WTG can generate 20MW and the GBS has a base slab with a diameter of 52m, yielding an excavation of 16,990m³ for each GBS.

The offshore substation layouts are the same in both cases.

The installation programs for both cases are described Table 8-1 and Table 8-2, starting with the dredging of the GBS and offshore substations, and parallel installation of the foundations and laying of the inter array cables (IAC).

Table 8-1: Installation program for the 15MW case, starting May 1st and ending 25 weeks later, October 18th

Setup, Activity	Amount	Unit	Capacity	Unit	Days	Start	End
1 OSS, dredging	458044	m3	1000	m3/hour+0.5 day/OSS	22	01/05/2030	23/05/2030
1 OSS, dumping	389338	m3	1000	m3/hour+0.5 day/OSS	19	01/05/2030	23/05/2030
1 OSS, installation	6	#	3.00	days/(FOU, ballast, scour protection+topside)	18	01/05/2030	19/05/2030
1 GBS installation	80	#	1.875	days/FOU + 0.25 day/FOU	170	01/05/2030	18/10/2030
1 GBS seabed preparation	1017876	m3	1000	m3/hour + 0.5 day/FOU	82	01/05/2030	22/07/2030
1 GBS dumping	865195	m3	1000	m3/hour + 0.5 day/FOU over 30 min.	82	01/05/2030	22/07/2030
1 Infield cable, laying + pull in	152681	m	300	m/hour + 6 hours/pull in	41	06/09/2030	18/10/2030
1 Infield cable, burial	152681	m	150	m/hour + 6 hours/WTG	62	16/08/2030	18/10/2030
2 GBS installation	80	#	1.875	days/FOU + 0.25 day/FOU	170	01/05/2030	18/10/2030
2 GBS seabed preparation	1017876	m3	1000	m3/hour + 0.5 day/FOU	82	01/05/2030	22/07/2030
2 GBS dumping	865195	m3	1000	m3/hour + 0.5 day/FOU over 30 min.	82	01/05/2030	22/07/2030
2 Infield cable, laying + pull in	152681	m	300	m/hour + 6 hours/pull in	41	06/09/2030	18/10/2030
2 Infield cable, burial	152681	m	150	m/hour + 6 hours/WTG	62	16/08/2030	18/10/2030

Table 8-2: Installation program for the 20MW case, starting May 1st and ending 18 weeks later, September 5th.

Setup, Activity	Amount	Unit	Capacity	Unit	Days	Start	End
1 OSS, dredging	458044	m3	1000	m3/hour+0.5 day/OSS	22	01/05/2030	23/05/2030
1 OSS, dumping	389338	m3	850	m3/hour+0.5 day/OSS	22	01/05/2030	23/05/2030
1 OSS, installation	6	#	3.00	days/(FOU, ballast, scour protection+topside)	18	01/05/2030	19/05/2030
1 GBS installation	60	#	1.875	days/FOU + 0.25 day/FOU	128	01/05/2030	05/09/2030
1 GBS seabed preparation	1019384	m3	1000	m3/hour + 0.5 day/FOU	72	01/05/2030	12/07/2030
1 GBS dumping	866476	m3	850	m3/hour + 0.5 day/FOU over 30 min.	72	01/05/2030	12/07/2030
1 Infield cable, laying + pull in	152908	m	300	m/hour + 6 hours/pull in	36	31/07/2030	05/09/2030
1 Infield cable, burial	152908	m	150	m/hour + 6 hours/WTG	57	10/07/2030	05/09/2030
2 GBS installation	60	#	1.875	days/FOU + 0.25 day/FOU	128	01/05/2030	05/09/2030
2 GBS seabed preparation	1019384	m3	1000	m3/hour + 0.5 day/FOU	72	01/05/2030	12/07/2030
2 GBS dumping	866476	m3	850	m3/hour + 0.5 day/FOU over 30 min.	72	01/05/2030	12/07/2030
2 Infield cable, laying + pull in	152908	m	300	m/hour + 6 hours/pull in	36	31/07/2030	05/09/2030
2 Infield cable, burial	152908	m	150	m/hour + 6 hours/WTG	57	10/07/2030	05/09/2030

8.1.2. Export cables

For the export cable 3 main routes are considered (A, B and C) where of B and C both has 2 potential landfalls. In addition to these 2 potential installation methods are considered:

- 1) Jetting along the full cable lengths.
- 2) Jetting of the cables in deeper water than 15 m else dredging.

The details are given in Table 8.3 for both the jetting and the combined jetting/dredging situation in Table 8.4.

Table 8.3: Case 1, Export cable installation program.

Setup, Activity	Nos	Length	Unit	Capacity	Unit	Days	Start	End
A	10	22080	m	500	m/hour	18.4	2030-05-01	2030-05-19
Ax	10	13882	m	500	m/hour	11.6	2030-05-19	2030-05-31
B2	5	20685	m	500	m/hour	8.6	2030-06-01	2030-06-12
B2x	5	13109	m	500	m/hour	5.5	2030-06-12	2030-06-21
B1x	5	4993	m	500	m/hour	2.1	2030-06-21	2030-06-26
C2	5	17483	m	500	m/hour	7.3	2030-09-01	2030-09-11
C2x	5	18217	m	500	m/hour	7.6	2030-09-11	2030-09-21
C1x	5	3822	m	500	m/hour	1.6	2030-08-01	2030-08-05

Table 8.4: Case 2, Export cable installation program.

Setup, Activity	Nos	Amount	Unit	Capacity	Unit	Days	Start	End
A	10	22080	m	500	m/hour	18.4	2030-05-01	2030-05-19
Ax	10	138820	m3	500	m3/hour	115.7	2030-05-01	2030-08-24
B2	5	20685	m	500	m/hour	8.6	2030-06-01	2030-06-09
B2x	5	131090	m3	500	m3/hour	54.6	2030-06-01	2030-07-25
B1x	5	49930	m3	500	m3/hour	20.8	2030-08-01	2030-08-22
C2	5	17483	m	500	m/hour	7.3	2030-09-01	2030-09-08
C2x	5	182170	m3	500	m3/hour	75.9	2030-09-01	2030-11-15
C1x	5	38220	m	500	m/hour	15.9	2030-08-01	2030-08-16

8.2. Sediment type

The expected types of sediments are defined along the cables per 200 m and at the substructures as described by EMODnet in combination with sediment samples and backscatter collected by the project. Each sediment types are spatially joined to the sediment samples and an average grain distribution is calculated per sediment type as described in chapter 6.8.

The sediment model is an add-on to the hydrodynamic thus current data and water level data are transferred by time step for advective transport of the sediment and deposition/resuspension of near-bottom sediments.

The sediment model itself contains information about:

- 1) The sediment types are split into 5 categories based on grain sizes and settling velocities, Appendix 1.
- 2) For erosion a critical shear stress e.g., 0.3 N/m² (DHI/IOW Consortium, 2013).
- 3) Dispersion both horizontal and vertical.
- 4) A description of the sediment source in time and space.

The sediment data used for the model is listed in Appendix 1.

8.3. Estimated spill

In total is the spill estimated to 3,194,226 m³ for the 15MW and 3,197,975 m³ for the 20MW case, Table 8-5 and Table 8-6.

Table 8-5: Total spill for the 15MW case.

Sediment →	coarse	fine sand	coarse silt	medium silt	fine silt	Clay	Sum
Activity ↓	m ³	m ³	m ³	m ³	m ³	m ³	m ³
Dump-OSS-15MW-bottom_1	1,613	12,247	43,828	6,834	5,831	7,505	77,858
Dump-OSS-15MW-surface_1	807	6,124	21,914	3,417	2,915	3,753	38,929
Dump-WTG-15MW-bottom_1	4,328	30,305	95,986	14,710	13,304	16,542	175,175
Dump-WTG-15MW-bottom_2	1,995	20,794	101,977	16,468	12,386	17,230	170,850
Dump-WTG-15MW-surface_1	2,164	15,152	47,993	7,355	6,652	8,271	87,587
Dump-WTG-15MW-surface_2	998	10,397	50,988	8,234	6,193	8,615	85,425
IAC-15MW_1	10,820	78,701	264,815	40,945	35,953	45,489	476,723
IAC-15MW_2	5,426	56,755	279,033	45,070	33,870	47,142	467,297
SPILL-OSS-15MW-bottom_1	476	3,610	12,919	2,014	1,719	2,212	22,949
SPILL-OSS-15MW-surface_1	951	7,220	25,837	4,029	3,437	4,424	45,899
SPILL-WTG-15MW-bottom_1	1,290	9,030	28,600	4,383	3,964	4,929	52,196
SPILL-WTG-15MW-bottom_2	594	6,196	30,386	4,907	3,691	5,134	50,907
SPILL-WTG-15MW-surface_1	2,579	18,060	57,201	8,766	7,928	9,858	104,392
SPILL-WTG-15MW-surface_2	1,189	12,392	60,771	9,814	7,381	10,268	101,815
Sum	35,230	286,982	1,122,246	176,946	145,225	191,373	1,958,002
Proportion	2%	15%	57%	9%	7%	10%	100%

Table 8-6: Total spill for the 20MW case.

Sediment →	coarse	fine sand	coarse silt	medium silt	fine silt	Clay	Sum
Activity ↓	m ³	m ³	m ³	m ³	m ³	m ³	m ³
Dump-OSS-20MW-bottom_1	851	9,248	46,689	7,560	5,629	7,881	77,858
Dump-OSS-20MW-surface_1	426	4,624	23,345	3,780	2,815	3,940	38,929
Dump-WTG-20MW-bottom_1	4,099	29,259	95,628	14,724	13,112	16,452	173,275
Dump-WTG-20MW-bottom_2	2,234	21,917	102,634	16,501	12,618	17,371	173,275
Dump-WTG-20MW-surface_1	2,049	14,630	47,814	7,362	6,556	8,226	86,637
Dump-WTG-20MW-surface_2	1,117	10,959	51,317	8,251	6,309	8,686	86,637
IAC-20MW_1	7,470	58,375	217,011	34,004	28,524	37,093	382,478
IAC-20MW_2	5,117	52,663	255,880	41,285	31,154	43,249	429,349
SPILL-OSS-20MW-bottom_1	251	2,726	13,762	2,228	1,659	2,323	22,949
SPILL-OSS-20MW-surface_1	502	5,452	27,524	4,457	3,319	4,646	45,899
SPILL-WTG-20MW-bottom_1	1,217	8,690	28,402	4,373	3,894	4,886	51,463
SPILL-WTG-20MW-bottom_2	663	6,509	30,483	4,901	3,747	5,159	51,463
SPILL-WTG-20MW-surface_1	2,435	17,380	56,804	8,746	7,788	9,773	102,926
SPILL-WTG-20MW-surface_2	1,327	13,019	60,965	9,802	7,495	10,319	102,926
Sum	29,758	255,452	1,058,259	167,973	134,619	180,004	1,826,065
Proportion	2%	14%	58%	9%	7%	10%	100%

The spill from the 2 export cable burial cases inclusive options are given in Table 8-7 and Table 8-8.

Table 8-7: Total spill along export cables, case 1

Sediment →	coarse	fine sand	coarse silt	medium silt	fine silt	Clay	Sum
Activity ↓	m ³	m ³	m ³	m ³	m ³	m ³	m ³
A_1	43,637	43,983	8,092	3,640	5,821	5,617	110,790
Ax_1	43,080	15,519	5,635	1,489	1,252	2,823	69,798
B2_1	17,592	24,980	4,451	849	1,926	2,111	51,908
B2x_1	10,780	20,262	367	2	214	1,345	32,970
B1x_1	7,081	4,018	319	-	-	1,266	12,684
C2_1	20,548	16,420	3,442	1,414	850	1,230	43,904
C2x_1	16,923	27,829	379	69	-	535	45,735
C1x_1	695	8,558	304	55	-	146	9,758
Sum	160,336	161,570	22,990	7,517	10,063	15,072	377,548
Proportion	42%	43%	6%	2%	3%	4%	100%

Table 8-8: Total spill along export cables, case 2

Sediment →	coarse	fine sand	coarse silt	medium silt	fine silt	Clay	Sum
Activity ↓	m ³	m ³	m ³	m ³	m ³	m ³	m ³
A_2	43,637	43,983	8,092	3,640	5,821	5,617	110,790
Ax_bottom_2	43,084	15,349	5,517	1,459	1,226	2,802	69,437
Ax_surface_2	86,168	30,698	11,033	2,919	2,452	5,604	138,874
Ax_dump-bottom_2	146,488	52,122	18,712	4,951	4,159	9,518	235,950
Ax_dump-surface_2	73,244	26,061	9,356	2,475	2,079	4,759	117,975
B2_2	17,592	24,980	4,451	849	1,926	2,111	51,908
B2x_bottom_2	10,669	20,212	367	2	214	1,322	32,786
B2x_surface_2	21,337	40,425	734	5	428	2,643	65,571
B2x_dump-bottom_2	36,231	68,703	1,248	8	727	4,485	111,401
B2x_dump-surface_2	18,115	34,352	624	4	364	2,242	55,701
B1x_bottom_2	6,972	3,968	319	-	-	1,242	12,501
B1x_surface_2	13,944	7,935	638	-	-	2,484	25,002
B1x_dump-bottom_2	23,663	13,471	1,085	-	-	4,214	42,434
B1x_dump-surface_2	11,832	6,735	543	-	-	2,107	21,217
C2_2	20,548	16,420	3,442	1,414	850	1,230	43,904
C2x_bottom_2	16,921	27,660	372	67	-	532	45,553
C2x_surface_2	33,842	55,320	744	135	-	1,065	91,105
C2x_dump-bottom_2	57,531	93,980	1,261	228	-	1,809	154,810
C2x_dump-surface_2	28,765	46,990	631	114	-	905	77,405
C1x_bottom_2	692	8,385	298	54	-	143	9,572
C1x_surface_2	1,384	16,771	595	108	-	286	19,144
C1x_dump-bottom_2	2,352	28,446	1,009	183	-	485	32,475
C1x_dump-surface_2	1,176	14,223	505	91	-	243	16,238
Sum	716,189	697,189	71,575	18,706	20,246	57,847	1,581,752
Proportion	45%	44%	5%	1%	1%	4%	100%

8.4. Estimated sediment concentrations and associated durations

The sediment concentrations expected according to the simulation and the associated total time periods during which they will be reached or exceeded (not necessarily consecutive) are discussed separately for the cases hereafter.

Time series of concentrations are per cases presented in separate appendixes for the locations presented in Figure 8.1.

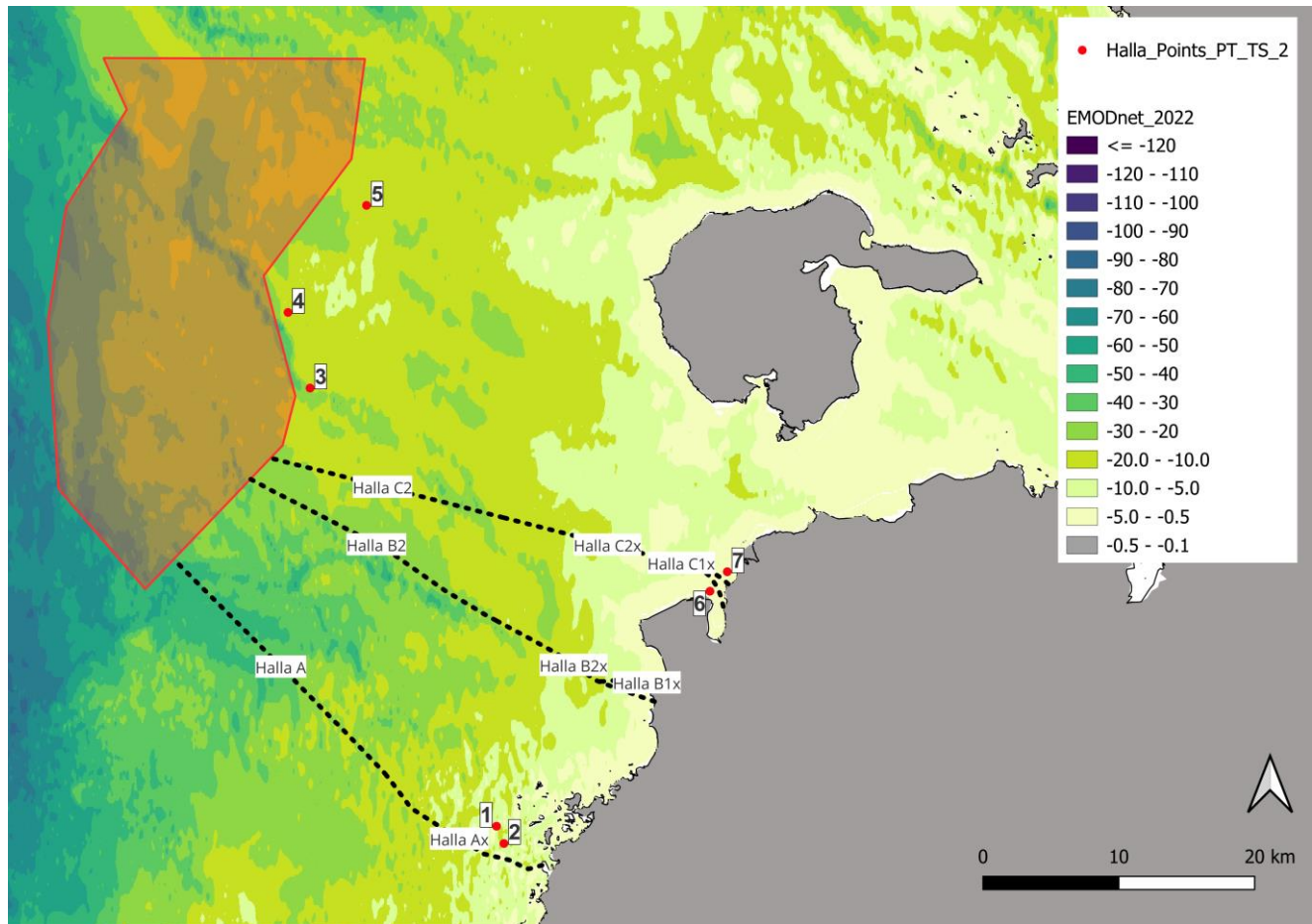


Figure 8.1: Location of points at where sediment concentration time series are presented.

8.4.1. 15MW case

Results relevant to the sediment distribution assessment for the 15 MW case are presented in Figure 8.2 to Figure 8.4, Table 8-9, Appendix 21 and Appendix 23, indicating a transport of sediments to a few kilometres from the site. Concentrations are generally highest above the dumping site, where most sediment is released.

Time series of sediment concentrations as an average for 0 to 5 m above the seabed and for 0 to 10 m below the surface are for the selected location presented in Appendix 22.

Surface: The total duration of the construction period during which the sediment concentrations in the surface layer reach or exceed 10mg/l and 100mg/l, respectively, is depicted in Figure 8.2. The shown sediment originates from the overflow from the barge (within the wind farm site) on the one hand and the sediment disposal on the surface above the dumping site on the other hand. The area of the dumping site is clearly identifiable, as

the area where a concentration of 10 mg/l is reached or exceeded for more than 7 days (out of 82 days with dumping) and that of 100 mg/l up to 1 day. The released sediments are transported and dispersed with surface currents while sinking through the water column. This process, leading to a decrease in sediment concentration at the surface the greater the distance from the source, is visible as plumes in Figure 8.2 and explains, why:

- a concentration of 100 mg/l is observed only in the area of the wind farm and dumping site while concentrations of 10 mg/l are distributed over larger areas (e.g., 32,000 ha vs 1,500 ha (during 6 hours), see Table 8-9) and are also observed on the Finnish east coast.
- after 7 days at the latest, the sediment concentration in the entire area decreases to below 10 mg/l.

Along the water column: The sediment plume reaches the greatest extent (see Figure 8.3) of at a depth between 10-30 m, where a concentration of 10 mg/l over 6 hours is documented over an area of around 28,000 ha (Table 8-9). Between 20 m and 30 m depth, a concentration of 100 mg/l is reached or exceeded over an area of just above 1,000 ha, whereas concentrations ≥ 100 mg/l can be observed over 2 days within an area 10 ha (Table 8-9).

At the bottom: Sediment is released near the bottom by dredging of the gravity-based substructures and the offshore substations, and by burying the inter-array cable using jets. In addition, sediments that are released at the surface arrive at the bottom through sedimentation processes before settling. Compared to the overlying water layers (compare Figure 8.4 with Figure 8.3), the extent of the sediment plume is larger and concentrations above 100 mg/l are documented almost only in the area of the wind farm as well as the dumping site.

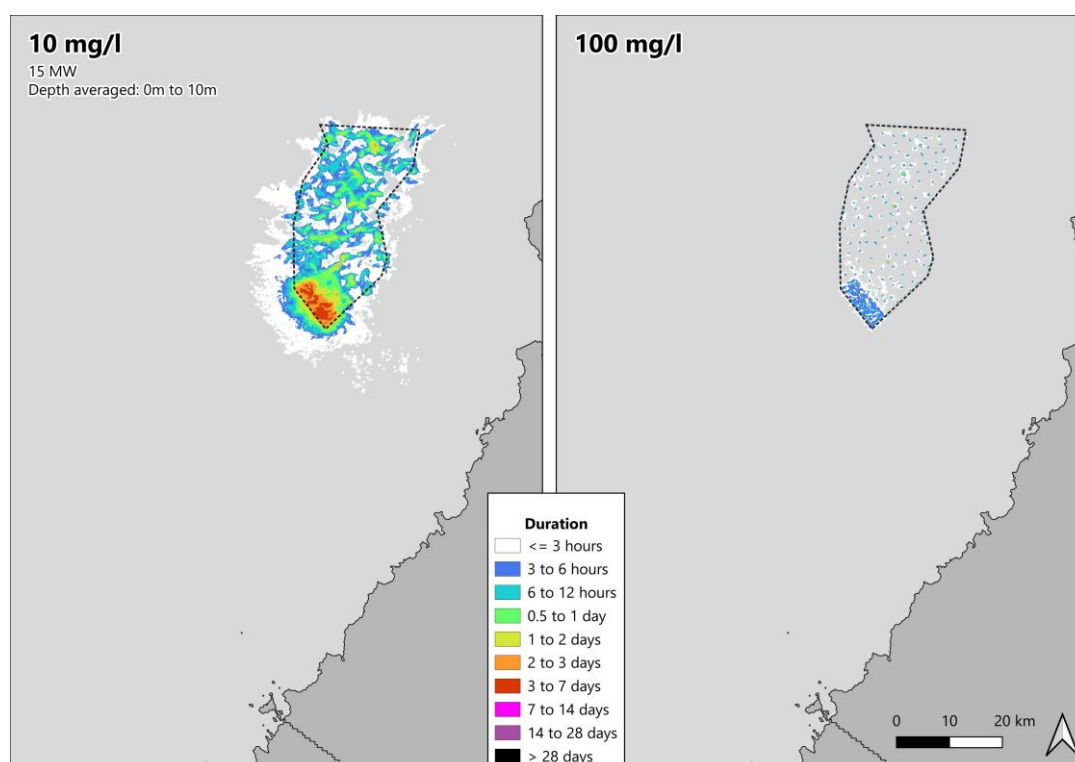


Figure 8.2: 15MW – Duration with sediment concentration of 10 mg/l (left) and 100 mg/l (right) is reached or exceeded in the upper 10 m of the water column (the seabed is shown in light gray, indicating the areas where no spilled sediments are observed).

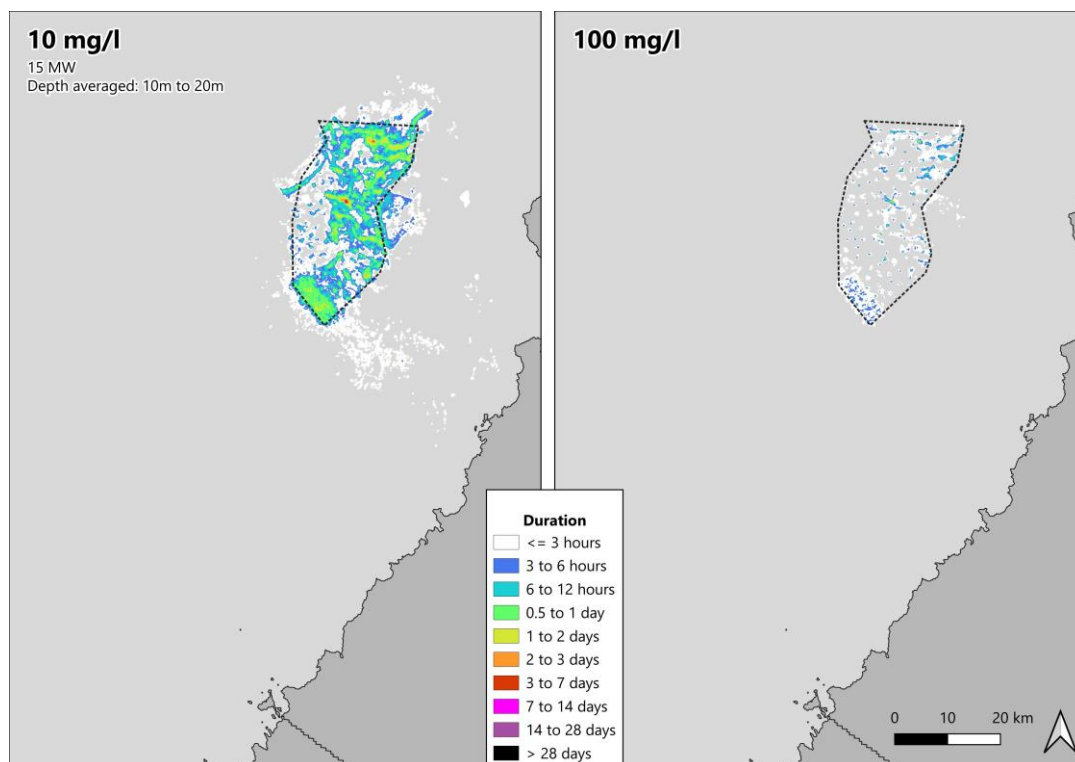


Figure 8.3: 15MW – Duration with sediment concentration of 10 mg/l (left) and 100 mg/l (right) is reached or exceeded in the at a depth of 10 – 20 m (the seabed is shown in light gray, indicating the areas where no spilled sediments are observed).

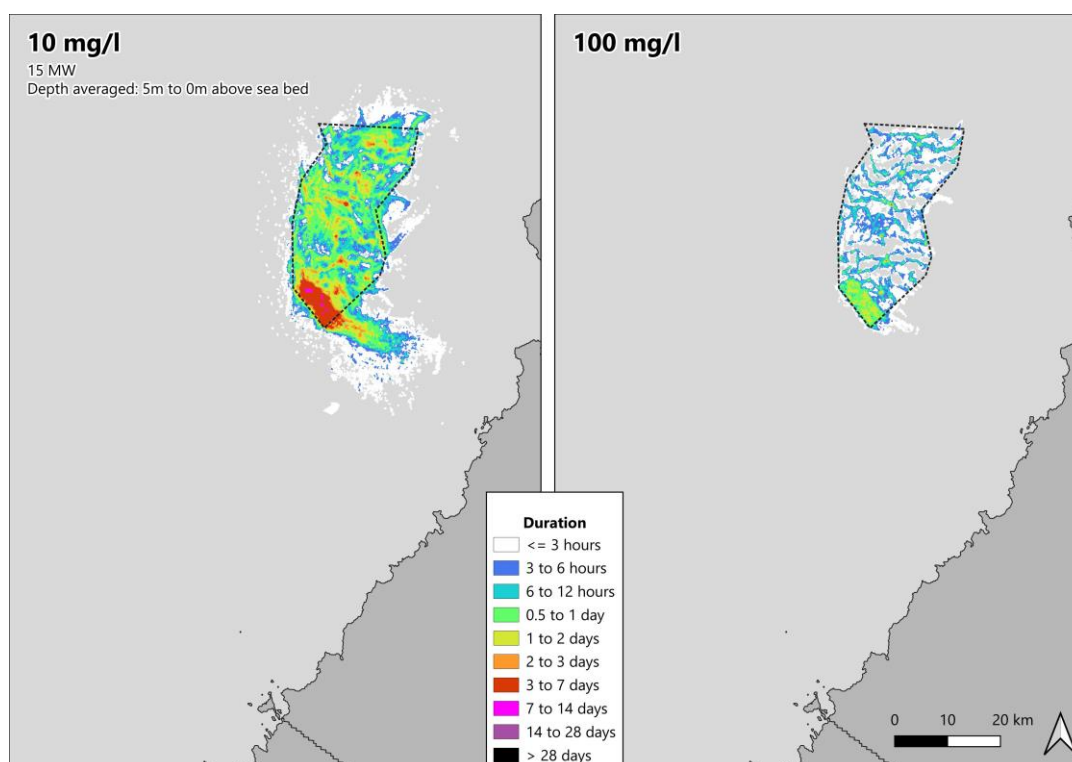


Figure 8.4: 15MW – Duration with sediment concentration of 10 mg/l (left) and 100 mg/l (right) is reached or exceeded in the lowest 5 m of the water column, 5 m above the sea bed (the seabed is shown in light gray, indicating the areas where no spilled sediments are observed).

Table 8-9: Area (ha) experiencing sediment concentration equal or greater than 10, 50, 100, 500, and 1000 mg/l for during varying durations and at different depths for the 15MW case. For Info: 100 ha = 1km².

	Concentration	Duration							
		6 h	12 h	24 h	2 d	7 d	14 d	21 d	28 d
0 - 10 m	10 mg/l	32,256	16,348	6,766	3,358	-	-	-	-
	50 mg/l	4,960	867	92	25	-	-	-	-
	100 mg/l	1,581	206	63	16	-	-	-	-
	500 mg/l	3	-	-	-	-	-	-	-
	1000 mg /l	-	-	-	-	-	-	-	-
10 - 20 m	10 mg/l	28,041	13,268	2,544	152	-	-	-	-
	50 mg/l	3,416	680	75	19	-	-	-	-
	100 mg/l	1,017	143	31	10	-	-	-	-
	500 mg/l	2	-	-	-	-	-	-	-
	1000 mg /l	-	-	-	-	-	-	-	-
20 - 30 m	10 mg/l	41,990	26,473	9,028	972	-	-	-	-
	50 mg/l	11,351	3,192	405	56	-	-	-	-
	100 mg/l	4,613	932	97	26	-	-	-	-
	500 mg/l	51	1	-	-	-	-	-	-
	1000 mg /l	0	-	-	-	-	-	-	-
30 - 40 m	10 mg/l	24,587	17,861	8,888	3,231	16	-	-	-
	50 mg/l	7,144	3,169	1,291	57	-	-	-	-
	100 mg/l	3,204	1,049	96	-	-	-	-	-
	500 mg/l	4	-	-	-	-	-	-	-
	1000 mg /l	-	-	-	-	-	-	-	-
5 m above seabed	10 mg/l	60,983	43,301	20,134	6,332	262	1	-	-
	50 mg/l	23,804	10,482	3,873	927	-	-	-	-
	100 mg/l	13,214	5,307	1,471	43	-	-	-	-
	500 mg/l	124	6	-	-	-	-	-	-
	1000 mg /l	-	-	-	-	-	-	-	-

8.4.2. 20MW case

Results of the simulations investigating sediment concentrations for the 20 MW case are presented in Figure 8.5 to Figure 8.7, Table 8-10, Appendix 24 and Appendix 26. Although the 20 MW case includes 40 fewer wind turbines than the 15 MW case (Table 6-1), the volumes excavated and released are in the same order of magnitude (see Table 8-5 and Table 8-6). This is due to the larger diameters of the wind turbines (e.g., 52 m versus 45 m base diameter, Table 6-1) in the 20 MW case. As a result of the similar volumes, the processes are basically well comparable. Thus, similar to the 15 MW case, the released sediment is transported to a few kilometres outside of the wind farm area. Concentrations are generally the highest above the dumping site, where most sediment is released.

Time series of sediment concentrations as an average for 0 to 5 m above the seabed and for 0 to 10 m below the surface are for the selected location presented in Appendix 25.

Surface: The total duration of the construction period during which the sediment concentrations in the surface layer reach or exceed 10mg/l and 100mg/l, respectively, is depicted in Figure 8.5. The shown sediment originates from the overflow from the barge (within the wind farm site) on the one hand and the sediment disposal on the surface above the dumping site on the other hand.

The area of the dumping site is clearly identifiable, as the area where a concentration of 10 mg/l is reached or exceeded for more than 7 days (out of 72 days with dumping) and that of 100 mg/l to 6 hours. The released sediments are transported and dispersed with surface currents while sinking through the water column. This process, leading to a decrease in sediment concentration at the surface the greater the distance from the source, is visible as plumes in Figure 8.2 and explains why:

- a concentration of 100 mg/l is observed only in the area of the wind farm and dumping site while concentrations of 10 mg/l are distributed over larger areas (e.g. 31,868 ha vs 3,719 ha (during 6 hours), see Table 8-10).
- after 2 days, sediment concentration above 10 mg/l is detected only in a 3,557 ha-area and after 7 days 0 ha.

Along the water column: The greatest extent (see Figure 8.6) of the sediment plume is reached at a depth between 10 - 20 m, where a concentration of 10 mg/l over 6 hours is recorded over an area of > 25,000 ha (Table 8-10). Between 20 m and 30 m depth, a concentration of 100 mg/l is reached or exceeded over an area of > 3,813 ha. Sediment concentrations are diluted, so no concentrations ≥ 100 mg/l can be observed after 7 days (Table 8-10).

At the bottom: Sediment is released near the bottom by dredging of the gravity-based substructures and the offshore substations, and by burying the inter-array cable using jetting. In addition, sediments that are released at the surface reach near the bottom through sedimentation processes before settling. Compared to the overlying water layers (compare Figure 8.7 with Figure 8.6), the extent of the sediment plume is larger concentrations above 100 mg/l are documented not only inside the wind farm but also south-east of the dumping area to an extent of 10 to 20 km.

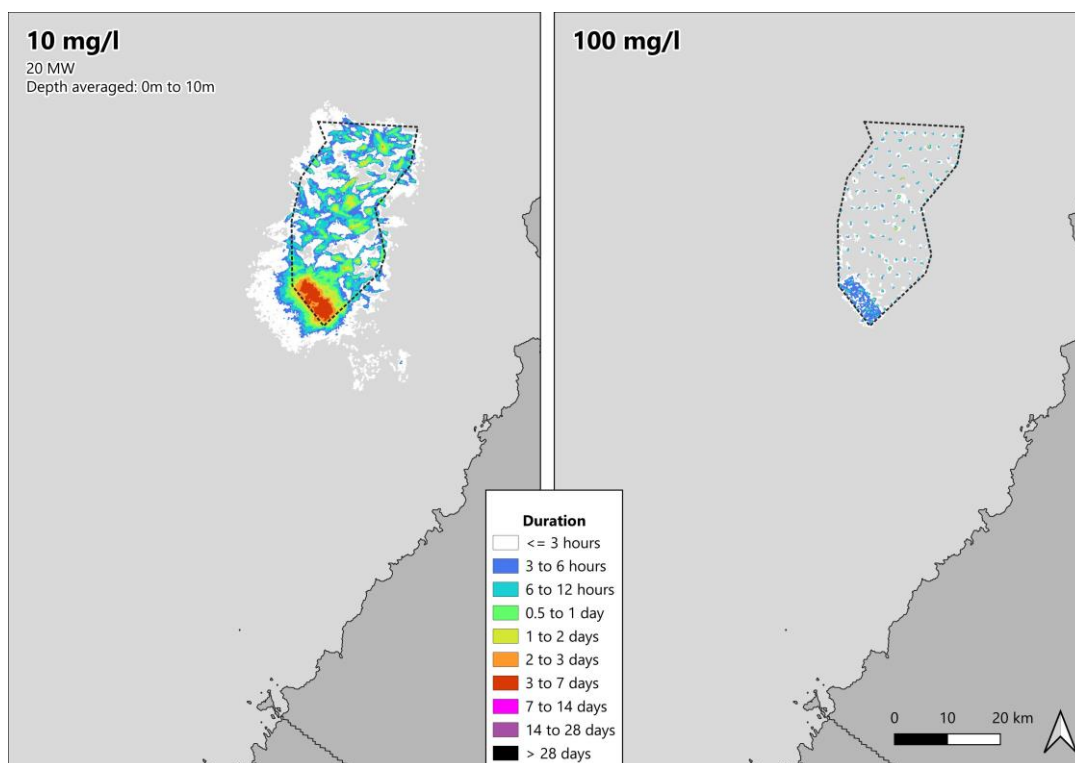


Figure 8.5: 20MW – Duration with sediment concentration of 10 mg/l (left) and 100 mg/l (right) is reached or exceeded in the upper 10 m of the water column (the seabed is shown in light gray, indicating the areas where no spilled sediments are observed).

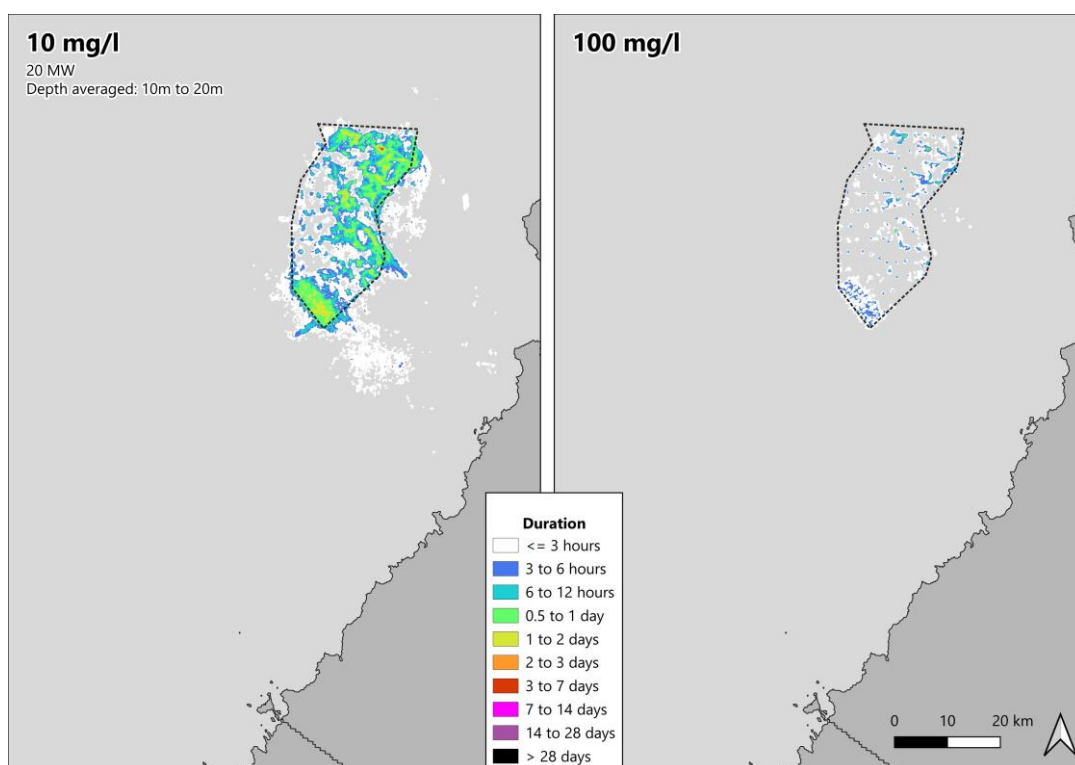


Figure 8.6: 20MW – Duration with sediment concentration of 10 mg/l (left) and 100 mg/l (right) is reached or exceeded in the at a depth of 10 – 20 m (the seabed is shown in light gray, indicating the areas where no spilled sediments are observed).

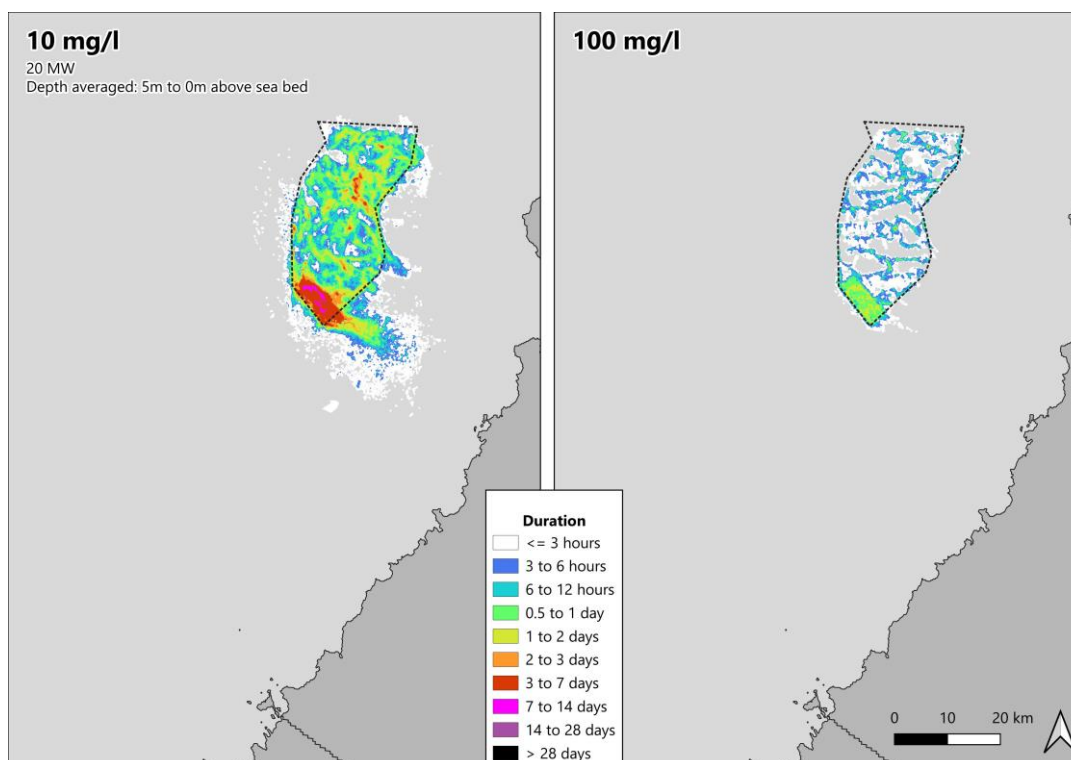


Figure 8.7: 20MW – Duration with sediment concentration of 10 mg/l (left) and 100 mg/l (right) is reached or exceeded in the lowest 5 m of the watercolumn, 5 m above the sea bed (the seabed is shown in light gray, indicating the areas where no spilled sediments are observed).

Table 8-10: Area (ha) experiencing sediment concentration equal or greater than 10, 50, 100, 500, and 1000 mg/l for during varying durations and at different depths for the 20MW case. For info: 100 ha = 1 km².

	Concentration	Duration							
		6 h	12 h	24 h	2 d	7 d	14 d	21 d	28 d
0 - 10 m	10 mg/l	31,868	16,823	7,397	3,557	-	-	-	-
	50 mg/l	5,217	1,180	112	29	-	-	-	-
	100 mg/l	1,719	426	78	21	-	-	-	-
	500 mg/l	6	-	-	-	-	-	-	-
	1000 mg /l	-	-	-	-	-	-	-	-
10 - 20 m	10 mg/l	26,258	14,196	3,067	65	-	-	-	-
	50 mg/l	3,650	700	55	12	-	-	-	-
	100 mg/l	1,051	174	22	8	-	-	-	-
	500 mg/l	0	-	-	-	-	-	-	-
	1000 mg /l	-	-	-	-	-	-	-	-
20 - 30 m	10 mg/l	38,418	24,052	8,566	945	-	-	-	-
	50 mg/l	9,174	2,467	264	31	-	-	-	-
	100 mg/l	3,813	773	71	15	-	-	-	-
	500 mg/l	56	11	3	-	-	-	-	-
	1000 mg /l	-	-	-	-	-	-	-	-
30 - 40 m	10 mg/l	23,534	15,908	8,558	3,772	34	-	-	-
	50 mg/l	6,414	3,190	1,337	67	-	-	-	-
	100 mg/l	3,186	1,097	84	11	-	-	-	-
	500 mg/l	25	9	5	1	-	-	-	-
	1000 mg /l	-	-	-	-	-	-	-	-
5 m above seabed	10 mg/l	56,814	39,460	19,341	6,698	491	-	-	-
	50 mg/l	21,071	9,477	3,764	827	-	-	-	-
	100 mg/l	11,723	5,041	1,359	49	-	-	-	-
	500 mg/l	180	9	1	-	-	-	-	-
	1000 mg /l	2	-	-	-	-	-	-	-

8.4.3. Export cable, Case 1

Results of the simulated sediment concentrations for the export cable Case 1 consisting of 3 main corridors and for the 2 northern corridors each with 2 potential landfalls are presented in Figure 8.8 to Figure 8.10 and Appendix 27 for the duration of selected concentrations levels.

The duration with concentration above 10 mg/l is maximum 1 day this being in the surface layer but also for the bottom layer. Concentration above 100 mg/l does occur but mainly within a distance of +/-500 m for a duration up to 12 hours.

Time series of sediment concentrations as an average for 0 to 5 m above the seabed and for 0 to 10 m below the surface are for the selected location presented in Appendix 27.

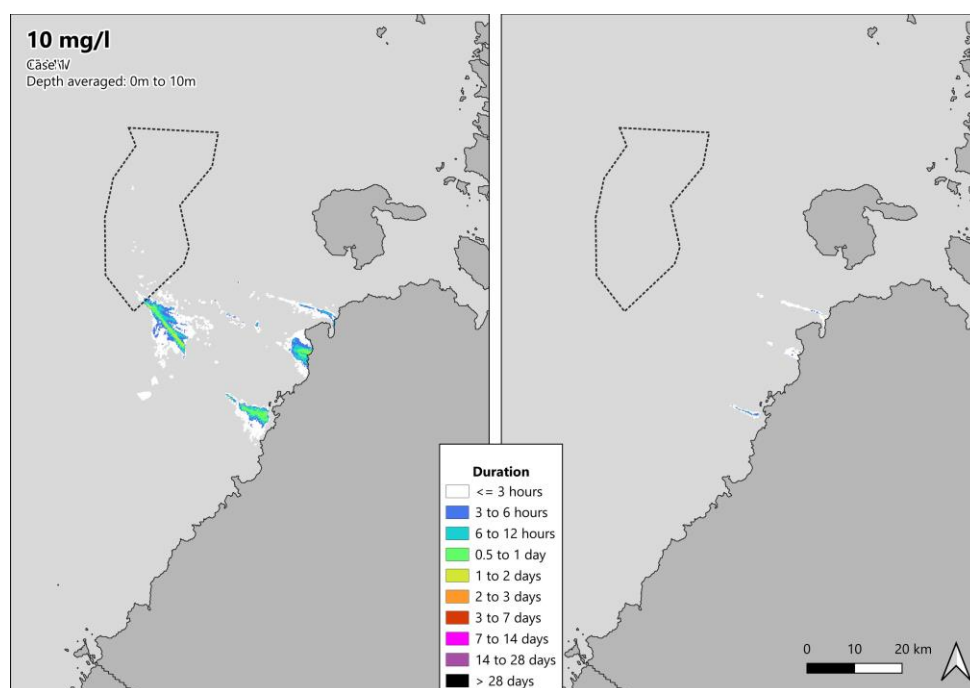


Figure 8.8: Export Cable, Case 1 – Duration with sediment concentration of 10 mg/l (left) and 100 mg/l (right) is reached or exceeded in the upper 10 m of the water column (the seabed is shown in light gray, indicating the areas where no spilled sediments are observed).

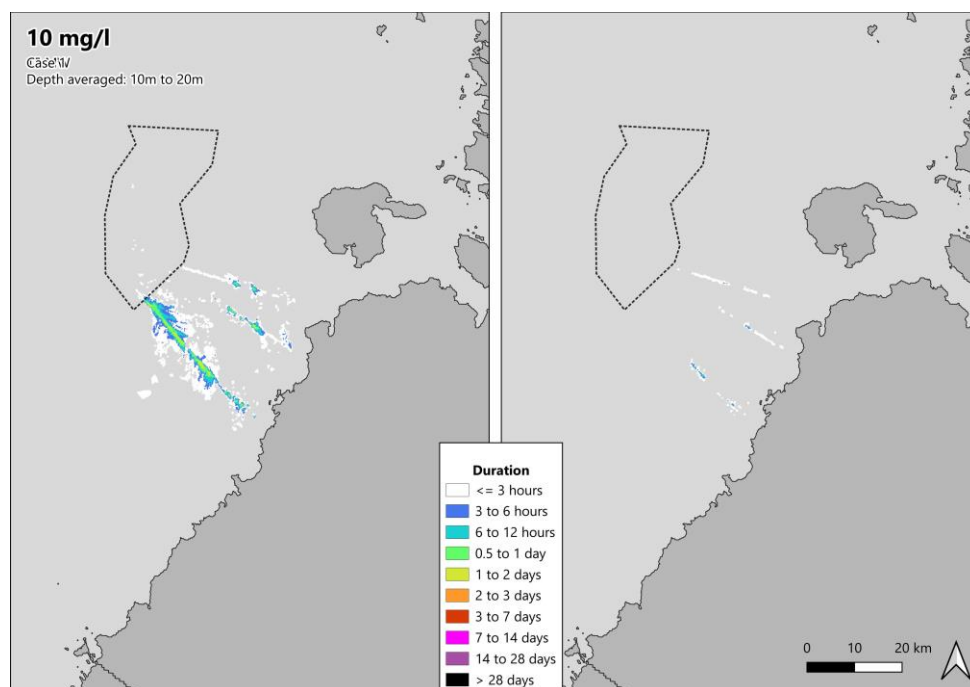


Figure 8.9: Export Cable, Case 1 – Duration with sediment concentration of 10 mg/l (left) and 100 mg/l (right) is reached or exceeded in the at a depth of 10 – 20 m (the seabed is shown in light gray, indicating the areas where no spilled sediments are observed)

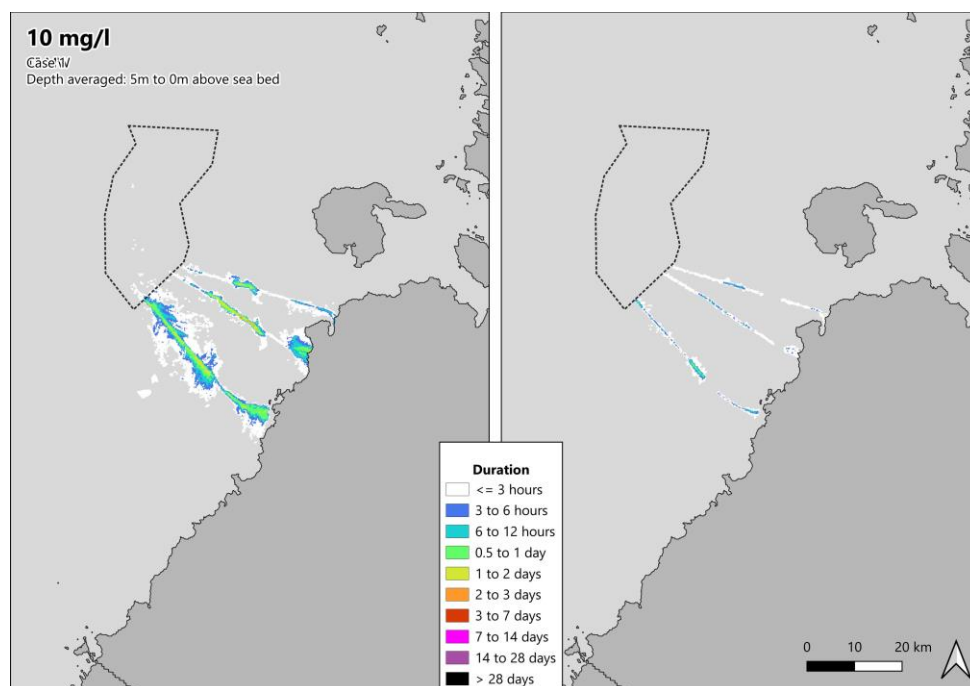


Figure 8.10: Export Cable, Case 1 – Duration with sediment concentration of 10 mg/l (left) and 100 mg/l (right) is reached or exceeded in the lowest 5 m of the watercolumn, 5 m above the sea bed (the seabed is shown in light gray, indicating the areas where no spilled

The monthly average of daily maximum concentration for depth 0 to 5 m above the seabed is presented Figure 8.11 illustrated for the different cable options:

- May: cable section A and Ax.
- June: cable section B2+B2x and B1x.
- Sep.: cable section C2 and C2x.
- Aug.: cable section C1x.

Despite the differences in number of cables and location the concentration reaches its maximum close to the shore (this due to shallower water). In all cases the maximum is around 1000 mg/l and dissipates down to approx. 5 mg/l in a distance of a few kilometers. However, for cable section A where 10 cables are installed (instead of 5 cables in the other corridors), the extent with 5 mg/l is closer to 10 km. Mean daily maximum for other parts of the water column can be found in Appendix 29. it should be noted that a monthly average containing days without spillage will result in a very low value, such as seen at Figure 8.11 lower right as the burial of C1x only takes a few days.

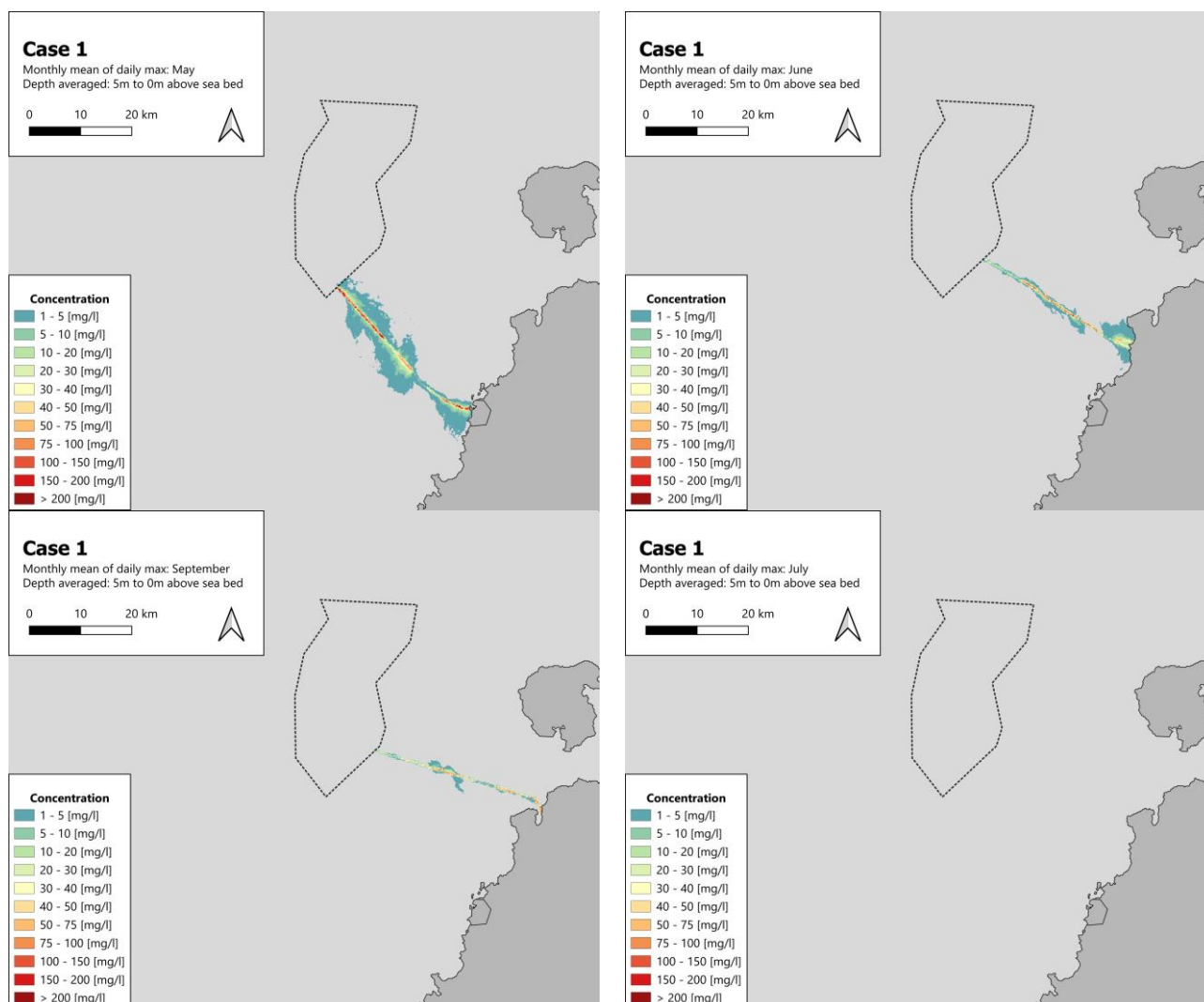


Figure 8.11: Depth 0 to 5m above seabed - Mean daily max, Upper right: Cable A+Ax, Upper left: Cable B2+B2x+B1x, Lower right: Cable C1x, Lower left: Cable C2+C2x.

8.4.4. Export cable, Case 2

Results of the simulated sediment concentrations for the export cable Case 2 consisting of 3 main corridors and for the 2 northern corridors each with 2 potential landfalls are for the duration of selected concentrations levels presented in Figure 8.12 to Figure 8.14 and Appendix 30.

The duration with concentration above 10 mg/l is maximum 7 days both in the surface layer and for the bottom layer. In between is the maximum duration being 3 days at the southern dumpsite. Concentration above 100 mg/l does occur but mainly within a distance of +/-500 m of the cable corridors for a duration up to 1 day.

Time series of sediment concentrations as an average for 0 to 5 m above the seabed and for 0 to 10 m below the surface are for the selected location presented in Appendix 31.

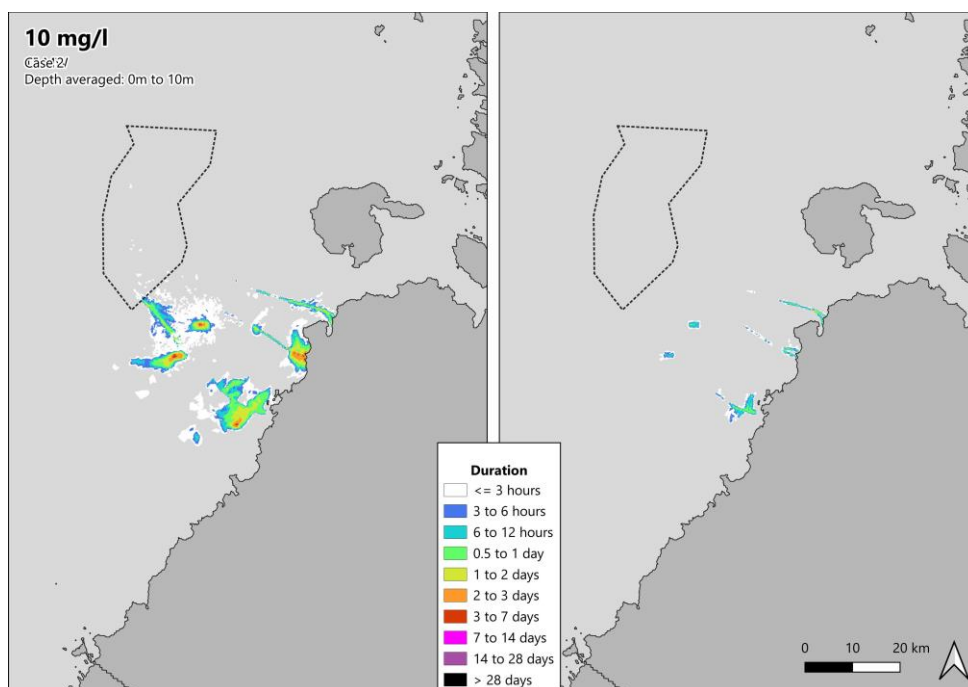


Figure 8.12: Export Cable, Case 2 – Duration with sediment concentration of 10 mg/l (left) and 100 mg/l (right) is reached or exceeded in the upper 10 m of the water column (the seabed is shown in light gray, indicating the areas where no spilled sediments are observed).

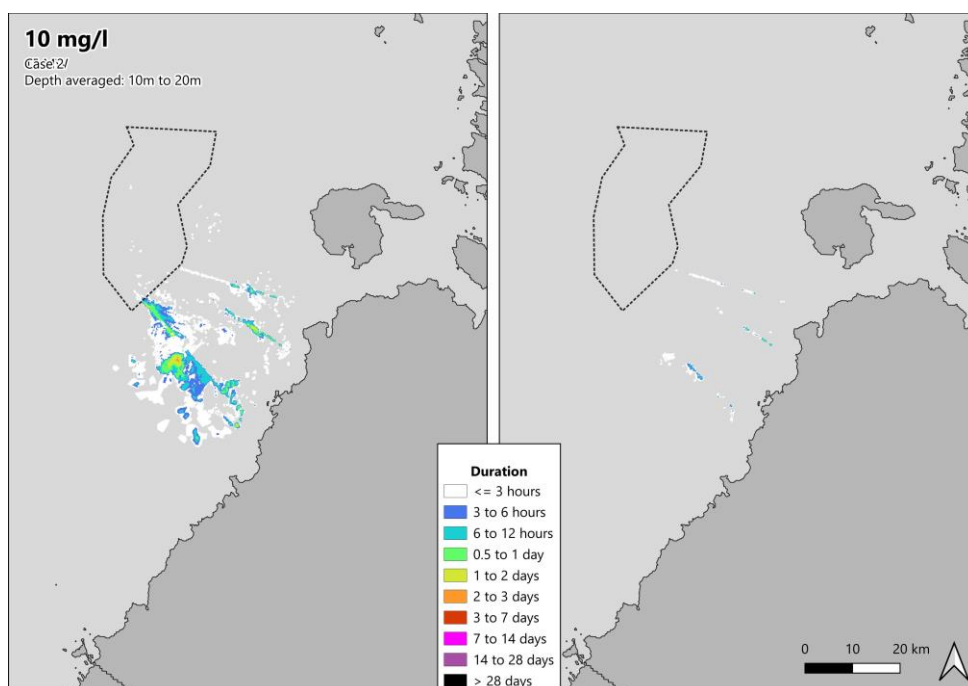


Figure 8.13: Export Cable, Case 2 – Duration with sediment concentration of 10 mg/l (left) and 100 mg/l (right) is reached or exceeded in the at a depth of 10 – 20 m (the seabed is shown in light gray, indicating the areas where no spilled sediments are observed)

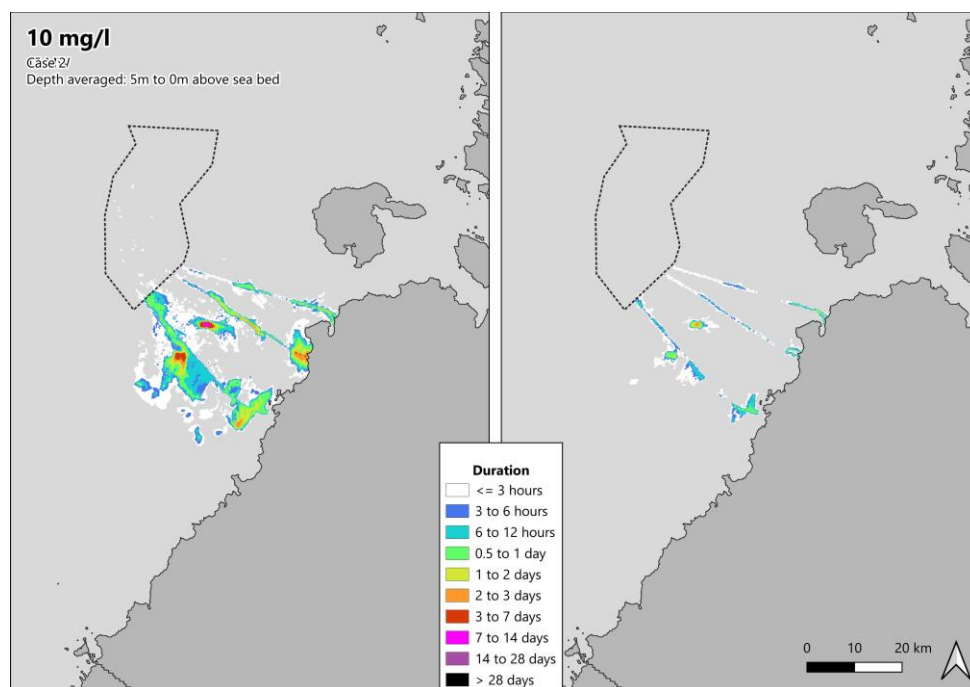


Figure 8.14: Export Cable, Case 2 – Duration with sediment concentration of 10 mg/l (left) and 100 mg/l (right) is reached or exceeded in the lowest 5 m of the watercolumn, 5 m above the sea bed (the seabed is shown in light gray, indicating the areas where no spilled

The monthly average of daily maximum concentration is for depth 0 to 5 m above the seabed illustrated for the different cable options:

- May to end Aug.: cable sections A and Ax.
- June to July: cable sections B2 and B2x.
- Sep. to mid Nov.: cable sections C2 and C2x.
- Aug.: cable sections B1x and C1x.

Despite the differences in number of cables and location the maximum concentration reaches its maximum at around 1000 mg/l in the jetted sections, above 1000 mg/l in the dredged sections and at the dumpsite whereafter the concentration dissipates down to approx. 5 mg/l in a distance of a few kilometers. However, for cable section A where 10 cables are installed (instead of 5 cables in the other corridors), the extent with 5 mg/l is closer to 10 km, Figure 8.15. Mean daily maximum for other parts of the water column can be found in Appendix 32.

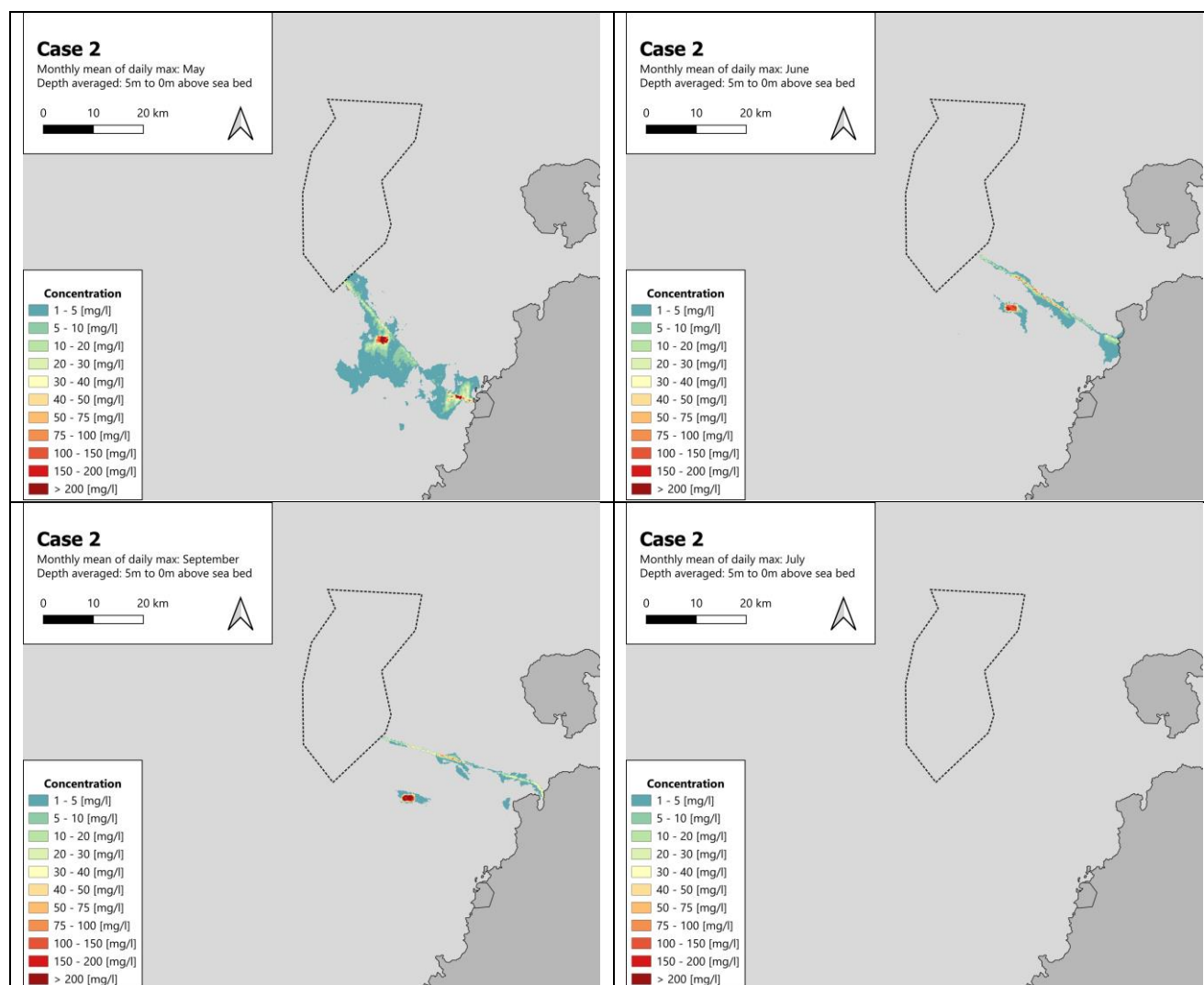


Figure 8.15: Depth 0 to 5m above seabed - Mean daily max, Upper right: Cable A+Ax, Upper left: Cable B2+B2x+B1x, Lower right: Cable C1x, Lower left: Cable C2+C2x.

8.5. Estimated sedimentation

Aligned to the sediment concentration, the results regarding sedimentation for the two cases (15MW vs 20 MW) are discussed separately and the same for the 2 export cable cases. The sediments originate from the dredging of the gravity-based substructures and the offshore substations, the burying the inter-array cable using jetting, the burial of the export cables using jetting/dredging, overrun and dispersal of sediment over the dumping site.

8.5.1. 15MW case

Results of the sedimentation for the 15 MW case are presented in Figure 8.16, Table 8-11 and Appendix 33. According to the simulation results (Figure 8.16), sedimentation above 1 mm is limited to the vicinity of the dumping site and within the windfarm site along the inter-array cables.

The strongest sedimentation is observed within the dumping site, where the largest amount of sediment is disposed. Sedimentation of more than 100 mm occurs on an area of around 1 ha (Table 8-11). For 477 ha a sedimentation height of 25 mm to 50 mm is reached. In contrast, sedimentation along the inter-array cables site is

much smaller. Enhanced sedimentation accounts to 30 mm and follows mostly the dredging operation for the wind turbine fundaments and installations of the offshore substations' sedimentation.

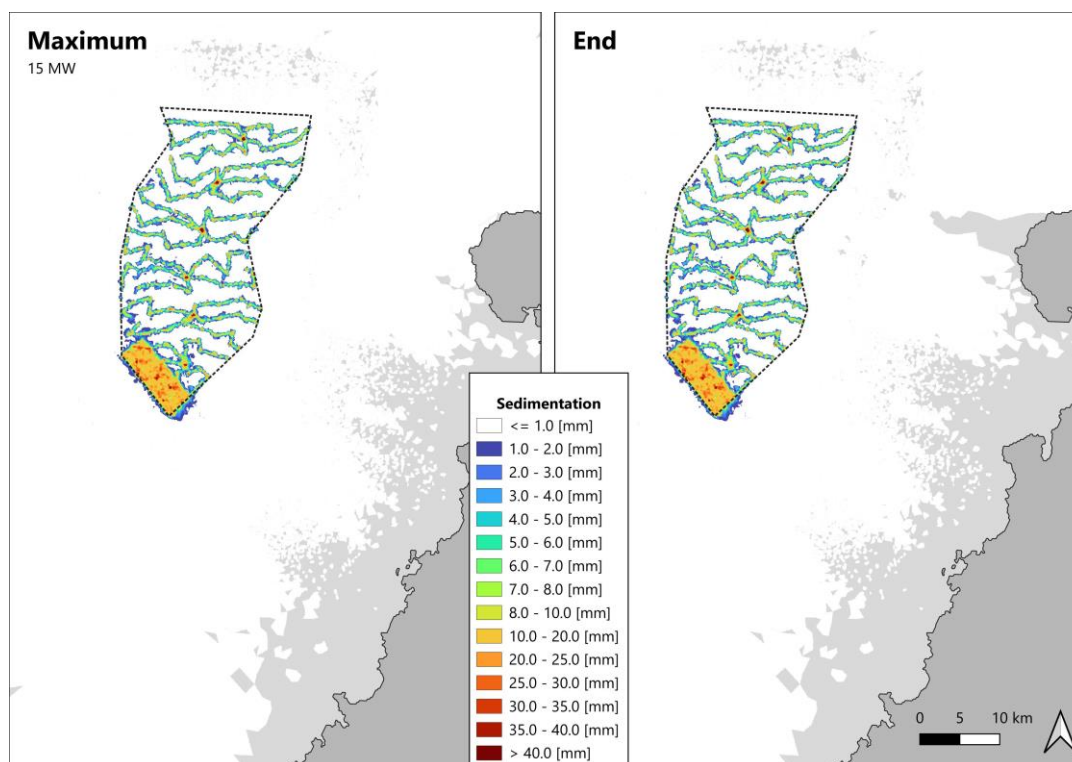


Figure 8.16: 15MW – Sedimentation (left: Maximum recorded sedimentation (10 minutes value), right: End of simulation period)

Table 8-11: Area (ha) experiencing sedimentation due to the sediment disposal in the 15MW case. For info: 100 ha = 1 km².

	Sedimentation [mm]								
	1	2	5	10	25	50	100	250	500
Maximum	23,694	19,094	12,197	5,616	477	30	1	-	-
End	23,694	19,094	12,197	5,616	477	30	1	-	-

8.5.2. 20MW case

Results of the sedimentation for the 20 MW case are presented in Figure 8.17, Table 8-12 and Appendix 34. According to the simulation results (Figure 8.16), aligned with the results for the 15MW case, sedimentation is limited to the vicinity of the dumping site and within the wind farm site to along the inter array cables.

The strongest sedimentation is observed within the dumping site, where sedimentation amounts to 50 mm within 35 ha (Table 8-12). Sedimentation of more than 100 mm can be observed on an area of more than 1 ha (Table 8-11).

Sedimentation within the windfarm site is much less pronounced. Enhanced sedimentation accounts to 40 mm around the substations and else less than 10 mm along the inter-array cables follows mostly the dredging operation for the wind turbine fundaments and installations of the offshore substations' sedimentation.

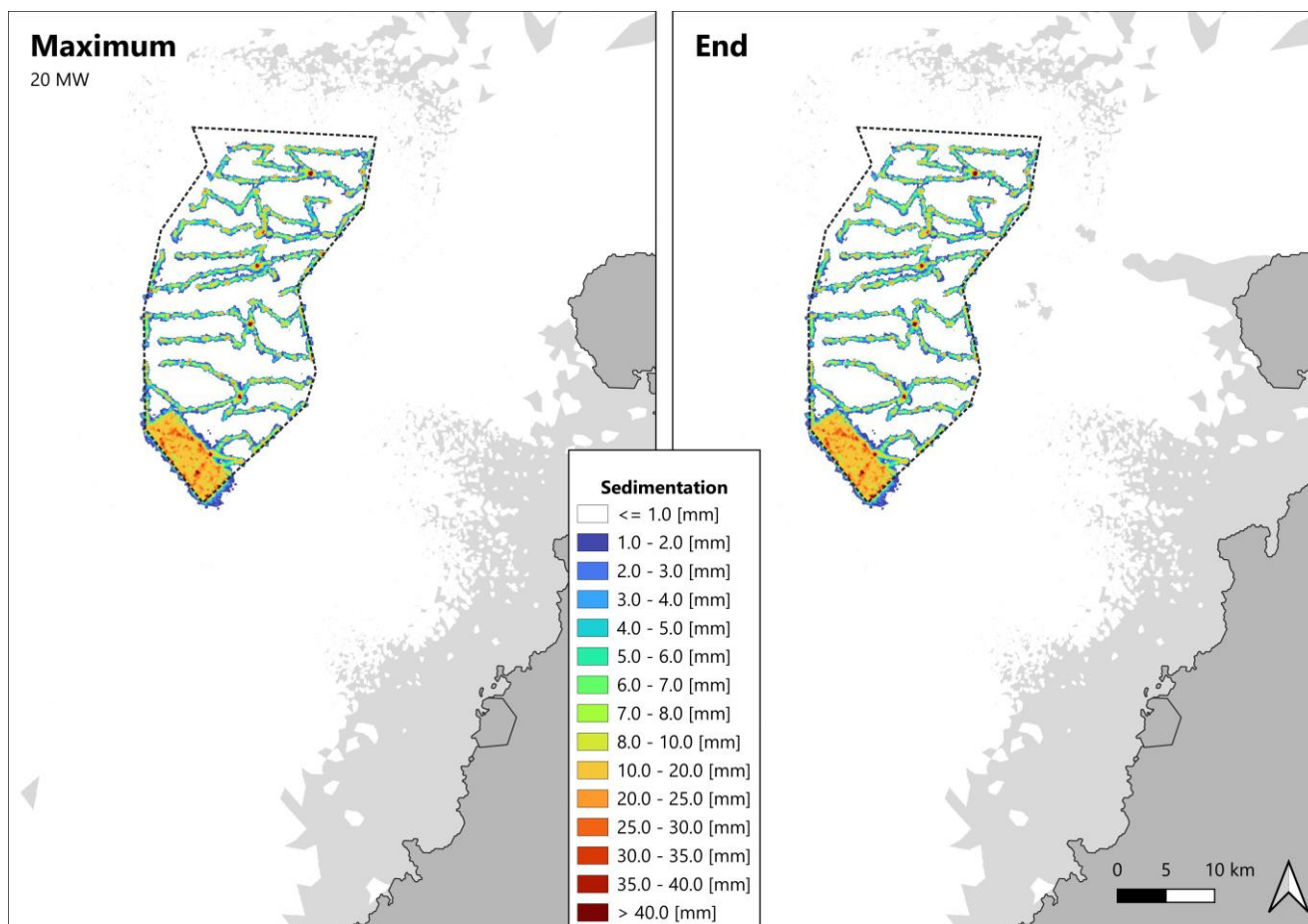


Figure 8.17: 20MW – Sedimentation (left: Maximum recorded sedimentation (10 minutes value), right: End of simulation period)

Table 8-12: Area (ha) experiencing sedimentation due to the sediment disposal in the 20MW case. For info: 100 ha = 1 km².

	Sedimentation [mm]								
	1	2	5	10	25	50	100	250	500
Maximum	21,207	17,321	11,224	5,458	502	35	1	-	-
End	21,204	17,320	11,223	5,457	502	35	1	-	-

8.5.3. Export cable, Case 1

Results of the sedimentation for the jetting of the potential export cables cases are presented in Figure 8.18 and Appendix 35.

The sedimentation is correlated to the type of sediment and the amount of disturbed material. For both Cable A and C, the short section where the sedimentation is less than 1 mm is due to the present of coarser material. Similar is for Cable B observed close the shore where the 2 potential landfalls separate from the cable connecting to the wind farm, Appendix 1.

In general, are there no major differences between the 3 options except that Cable section A consist of 10 cables versus 5 for Cable sections B and C and that the amount of fine material for the section of Cable A closes to the wind farm is significantly higher than along the other cable sections. The maximum sedimentation is around 20 mm and sedimentation of 1 mm over a range of +/- 400 m at the widest point.

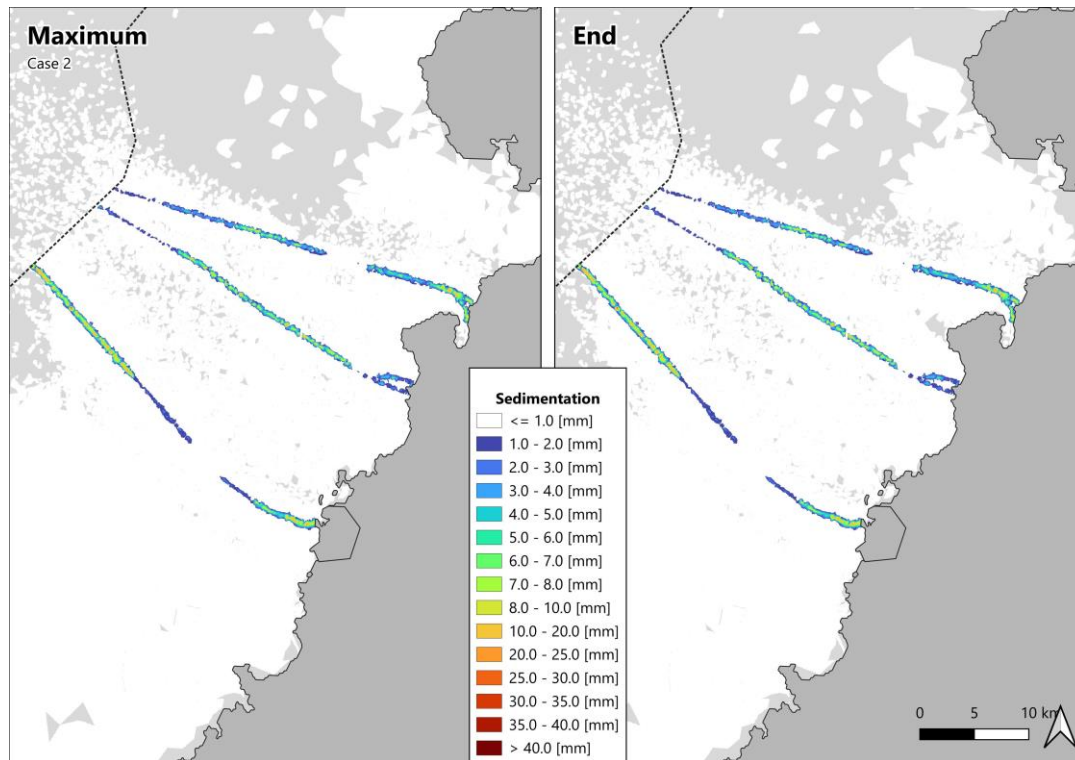


Figure 8.18: Case 1 – Sedimentation (left: Maximum recorded sedimentation (10 minutes value), right: End of simulation period)

8.5.4. Export cable, Case 2

Results of the sedimentation for the jetting/dredging of the potential export cables cases are presented in Figure 8.19, and Appendix 36.

The picture differs from the Case 1 along the dredged sections with a wider extent (+/-500 m) of sedimentation with more than 1 mm along the dredged sections and of cause at the dumpsites with a large sedimentation at these. Moreover, no significant differences are noted between the landfall options for Cable B and C.

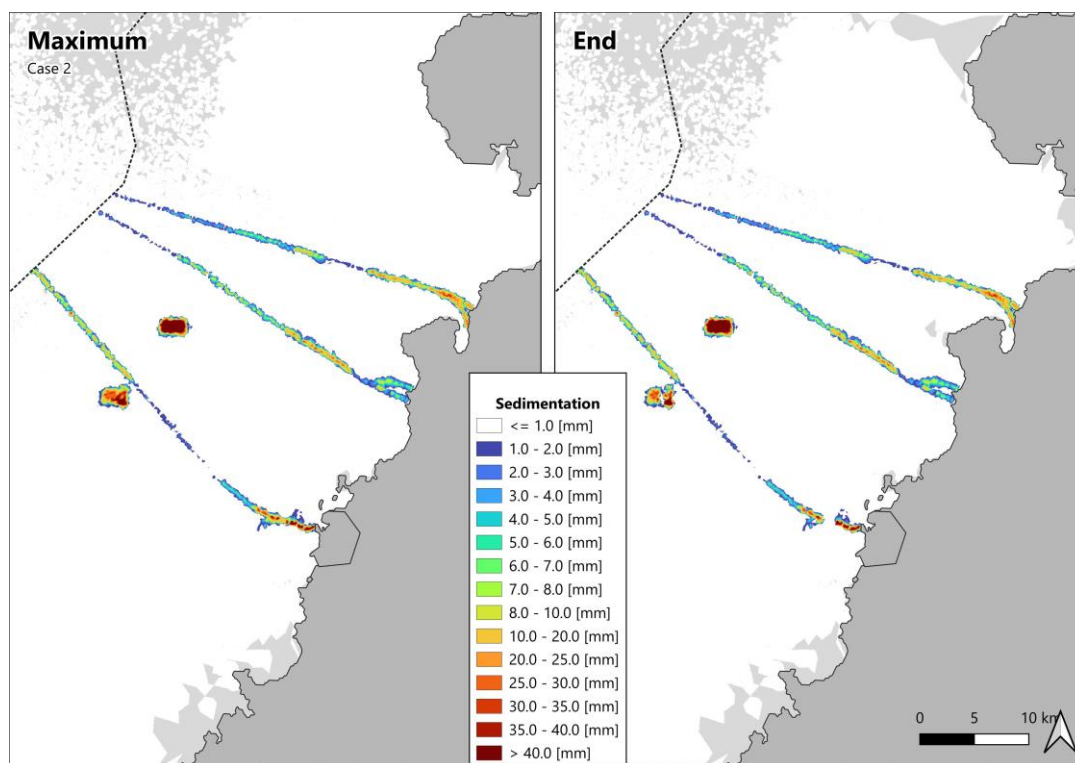


Figure 8.19: Case 2 – Sedimentation (left: Maximum recorded sedimentation (10 minutes value), right: End of simulation period)

9. Nearfield Hydrodynamic Impact (CFD)

9.1. Model setup

In principle, a CFD model for a case like this consists of two items:

- 1) The mesh of a flume inclusive the substructure (GBS) and outlet and
- 2) A solver to describe the fluid dynamic issue e.g., background current and density/temperature differences.

9.1.1. GBS model

Based on the available information it assumes that the GBS for the 15MW turbine at 30 m water is as described in chapter 6.1.2 with an outlet just about where the shaft meets the conical part; approx. 12 m below the surface. The background current is 2 cm/s (conservative value => less dispersal) and the density and temperature of the water 1002 kg/m³ and 2°C. The same for the brine and cooling water is 1005 kg/m³ and 25°C.

9.1.2. Flume

The main purpose of the flume is to contain the surrounding water and the patches for definition of the boundary conditions.

9.1.3. Boundaries and Mesh

For this low background current case the extent of the flume in the current direction is -50 m to 100 m, perpendicular to +/- 50m with a depth of 30 m. This to have sufficient space for the current to initiate upstream, having no influence from the downstream and to avoid eventual blocking.

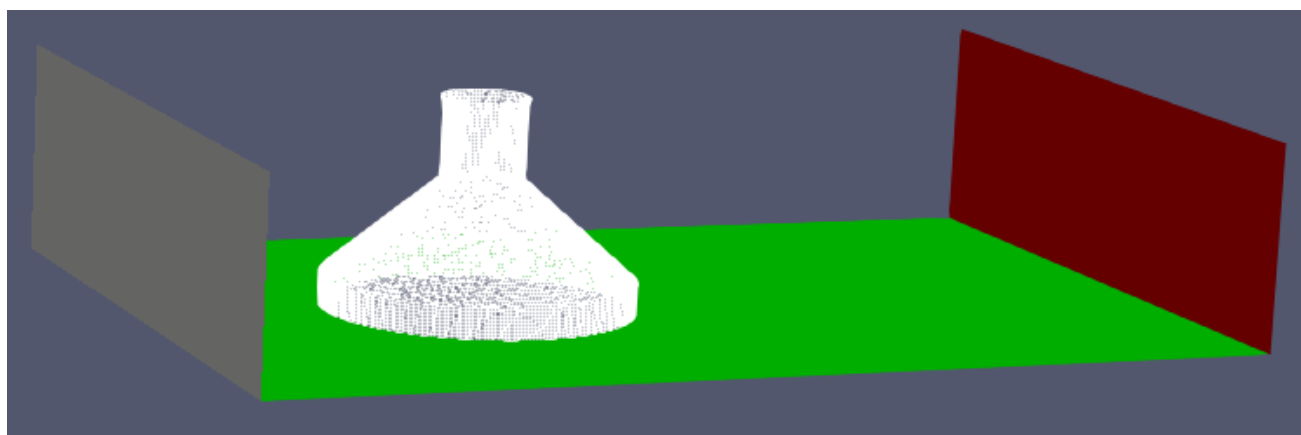


Figure 9.1: CFD mesh for the GBS together with in- and outlet (grey/red) boundary and the seabed (green)

9.2. Solver

OpenFOAM (Open Field Operation and Manipulation) is an open-source computational fluid dynamics (CFD) software that allows users to simulate and analyse complex fluid flow problems. One of the capabilities of OpenFOAM is the modelling of multicomponent fluids e.g., mixing of water with different densities where the density is a function of the temperature using the Boussinesq approximation to describe the density as function of the temperature.

Multicomponent fluids refer to mixtures that consist of multiple distinct chemical species. Examples include gas mixtures, liquid solutions, and multiphase flows. OpenFOAM provides a framework for simulating the behaviour of such fluids by employing various mathematical models and numerical techniques.

In OpenFOAM, the modelling of multicomponent fluids involves considering the transport and interaction of individual components within the mixture. This includes accounting for mass transfer, species diffusion, and chemical reactions inclusive the properties and behaviour of each component, such as density, viscosity, diffusivity, and reaction kinetics.

9.3. Results

The outcome of the modelling shows that the plume of excess saline and temperature water dissolves within a short period and achieves an equilibrium with an extent of approx. 8 m for an excess density of 1% as illustrated on Figure 9.2. For this example, the background current is 2 cm/s and thus have minimum effect on the mixing.

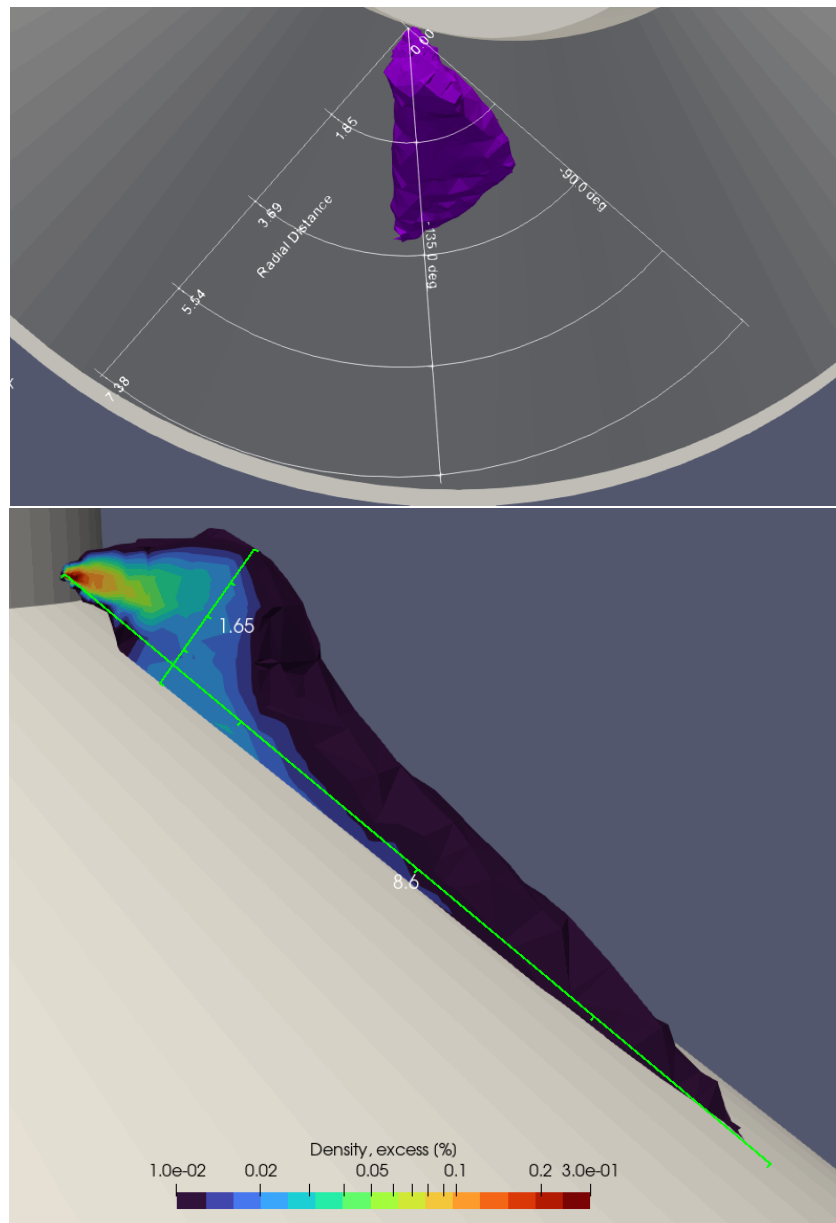


Figure 9.2: Extent of plume dissolved to 1% 600 s. Top: horizontal extent, Bottom: cross section along the GBS. Distances are in meters.

This indicates that the discharged water is fully mixed in a short distance to the outlet position and thus to be simulated with the MIKE 3D HD using a coarser mesh.

10. Regional Hydrodynamic Impact (MIKE3 HD)

10.1. Model setup

To simulate the impact due to the presence of the wind farm the pressure on the hydrodynamics (circulation and stratification patterns) have been modelled by adding the foundation, the outlet of the hydrogen-production and the reduction in the wind field to the baseline model:

- i. Wind turbines: The wind field downstream of the wind farm has been modified with the use of a wake function (Jensen, N.O., 1983) considering the roughness (0.001m), hub height and rotor diameter as listed in Table 6-1 and the thrust coefficient (c_t) for wind speeds of below 5, 5 to 11 and above 15 m/s at each turbine position with cut in at 3 m/s and cut off at 25 m/s. To capture the presence of the turbines the resolution of the wind fields was changed from 0.25° to 0.01° (approx. 0.65 km) and the effect of the wake was imprinted based on a wind direction in steps of 5° .
- ii. To be aligned with the wake simulated with WAsP the coefficient κ had to be changed from the recommended 0.04 for offshore wind farms to 0.13.
- iii. Substructure: In the hydrodynamic model the blocking from the substructures is described with a simple drag-law to increase the resistance at each position.
- iv. Outlet: The brine and warm water outlets from hydrogen production are considered as sources based on the information in Table 6-4.

For illustration of the wind speed and the reduction in the wind speed due to the two cases, the annual average wind speed in 2021 (ECMWF, 2022) and the reductions are presented in Figure 10.1.

At present the annual mean wind speed at the centre of Halla OWF is around 6.7 m/s at 10 mMSL, the predicted reduction from the 15MW case is 0.1 m/s 40km south and north of and 0.1 m/s 10km east and west. This is approximately the same for the 20MW case but with a slightly smaller extent.

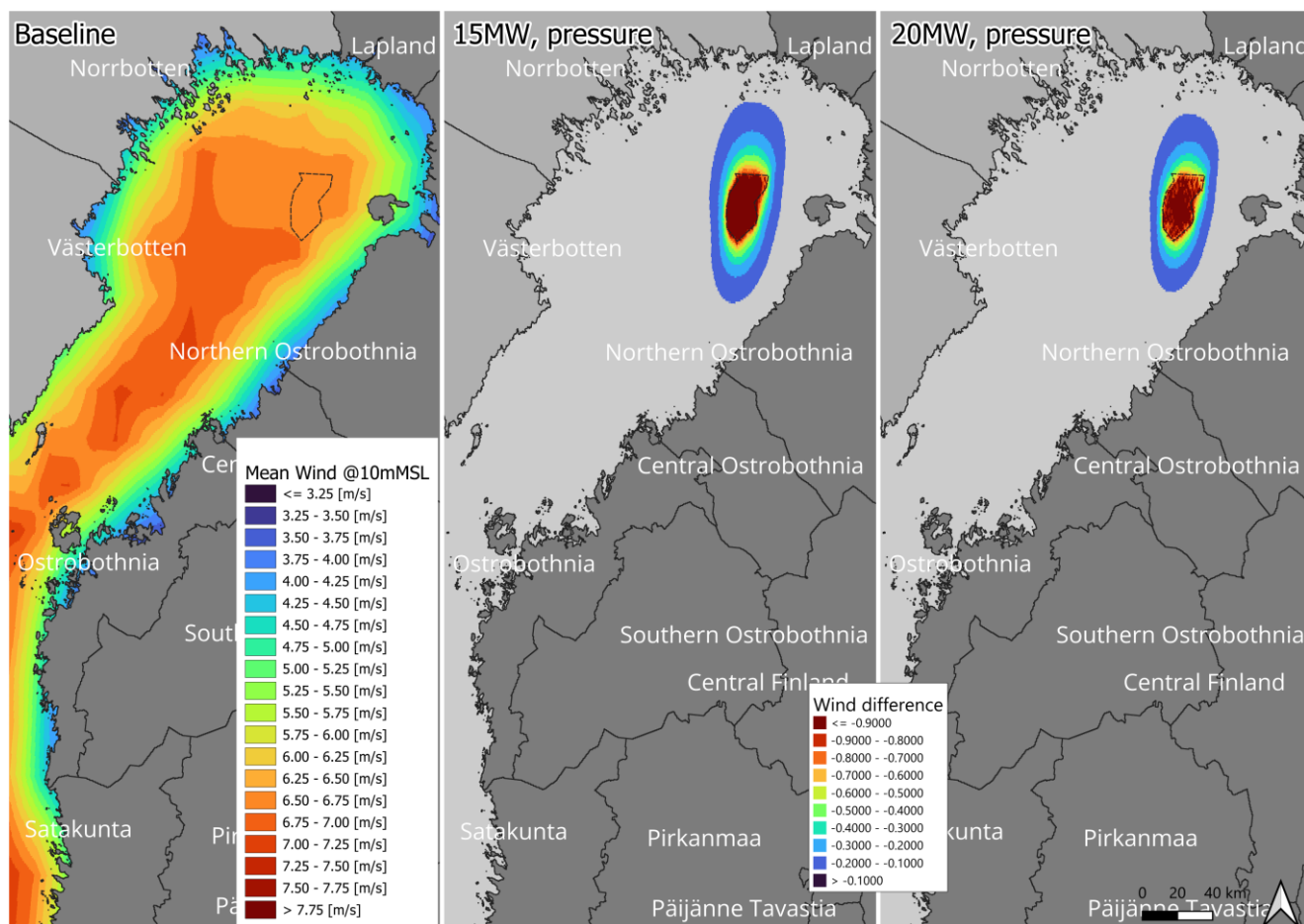


Figure 10.1: Annual mean wind speed 2021 at 10mMSL. Left: Baseline, Centre: reduction 15MW case, Right: reduction 20MW case.

10.2. Current

The effect of the planned windfarm on the annual current patterns are depicted in Figure 10.2 to Figure 10.4 for varying depths and for individual months separately in Appendix 37.

10.2.1. Baseline

Current speeds under average conditions of the year 2021 are generally low in the Bay of Bothnia due to the absence of tides in the Baltic Sea (see Figure 10.2 to Figure 10.4 and Appendix 37)., e.g. average surface currents between 0 and -5 m (Figure 10.2) range from 0.05 to 0.1 m/s decreasing with depth (Figure 10.3 and Figure 10.4). Considering the individual months, a seasonal pattern is recognisable, characterised by stronger currents in the summer months (May - September), whereas this seasonal variation is most pronounced at the surface and decreases with depth.

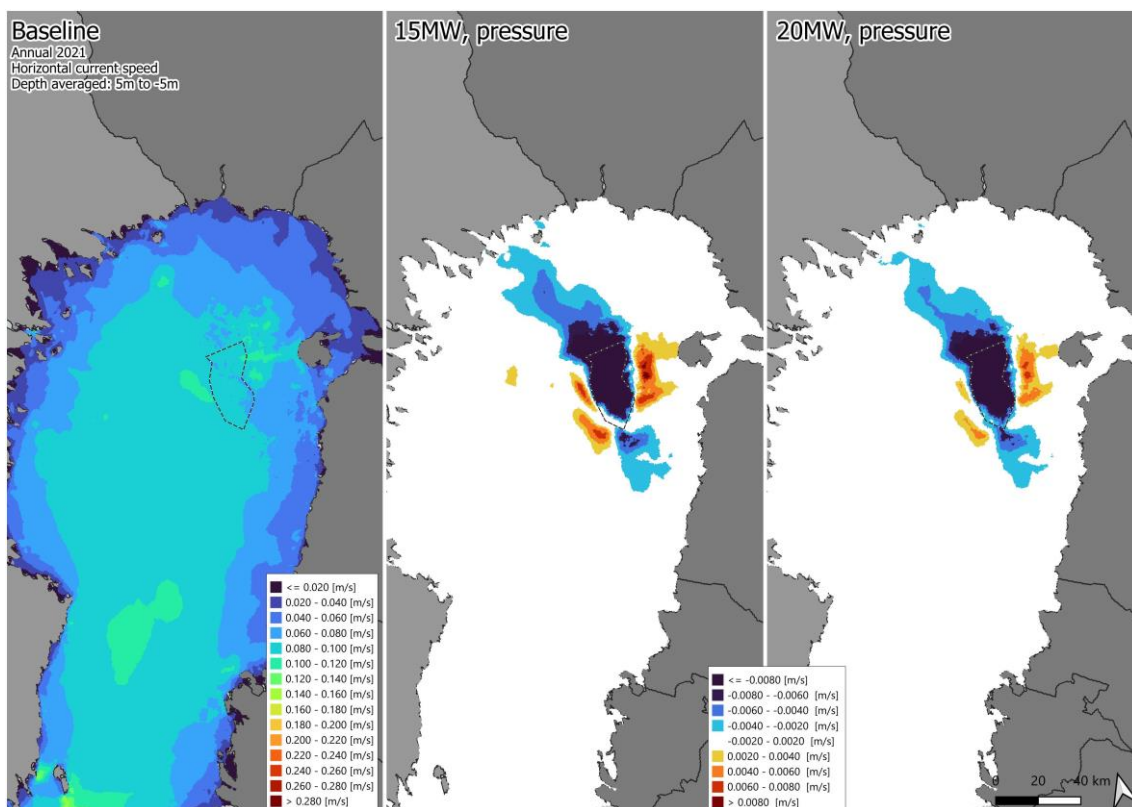


Figure 10.2: Left: Annual (2021) average current speed for the upper most 5 m. Center and Right: Change in current speeds due to the 15MW (120 Turbines) and the 20MW (160 Turbines)-Case.

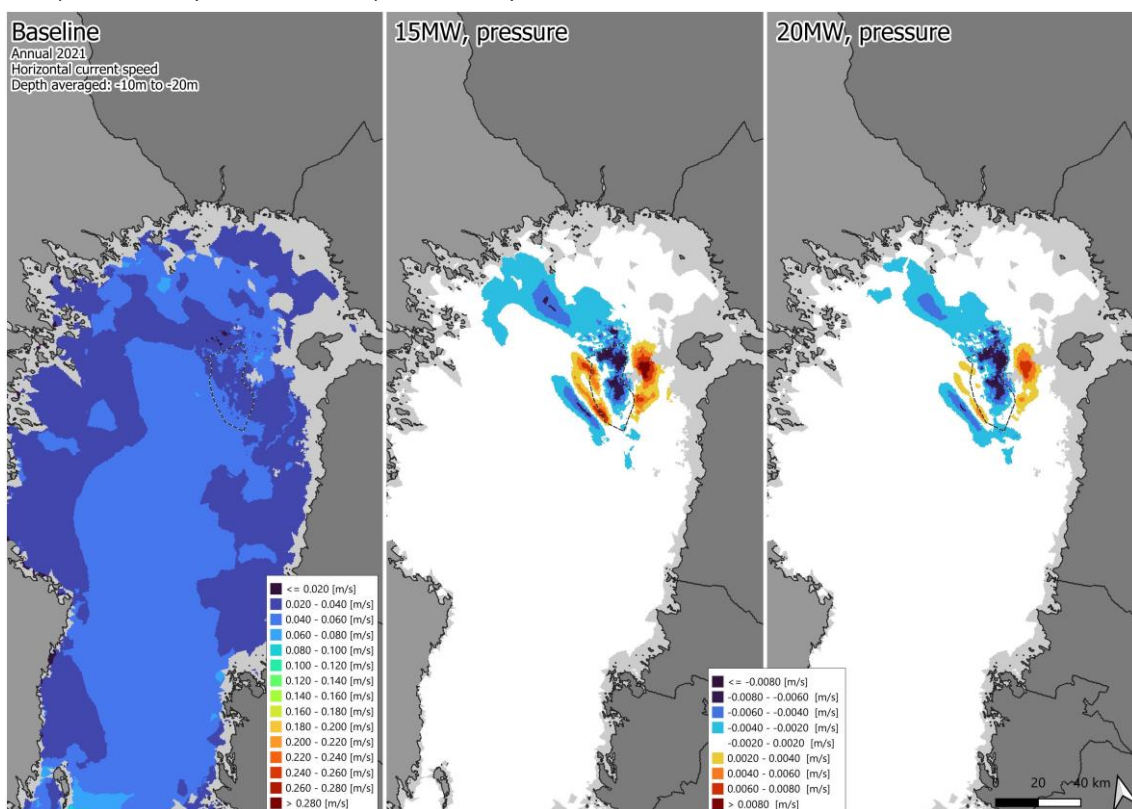


Figure 10.3: Left: Annual (2021) average current speed between – 10 and – 20 m. Center and Right: Change in current speeds due to the 15MW (160 Turbines) and the 20MW (120 Turbines)-Case.

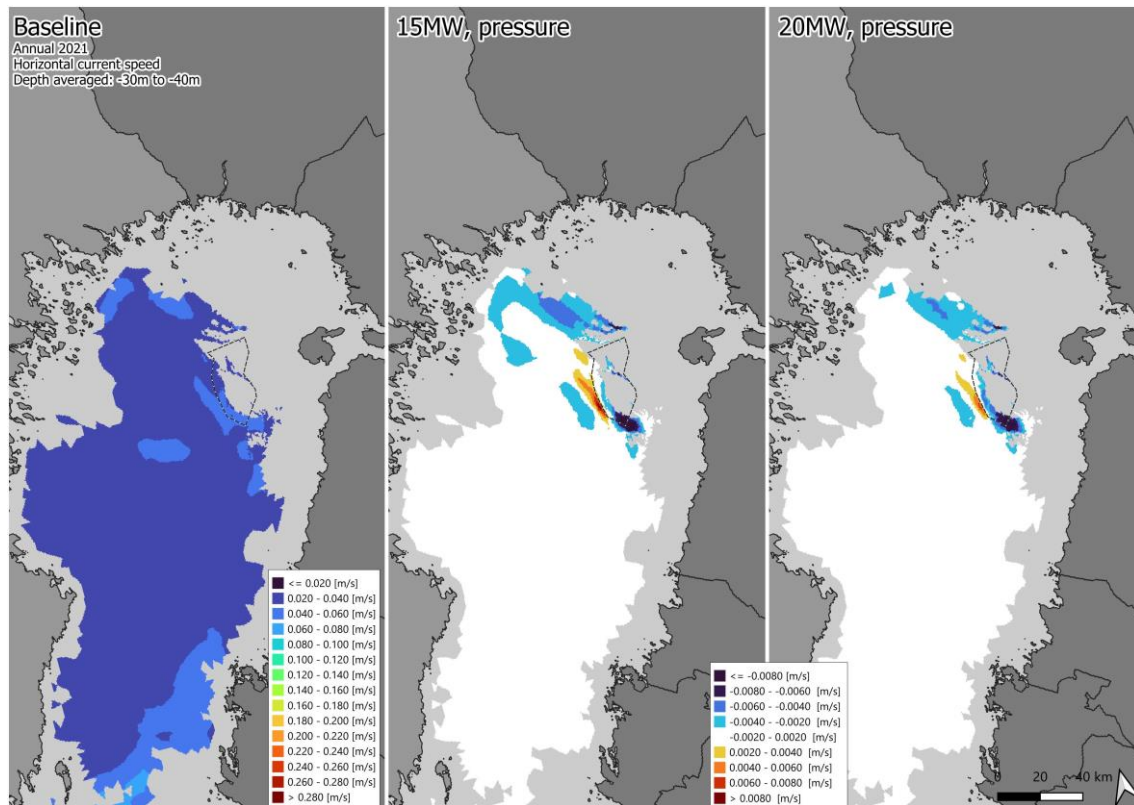


Figure 10.4: Left: Annual (2021) average current speed between – 20 and –30 m (white areas indicate a depth less than –20 m, bottom). Center and Right: Change in current speeds due to the 15MW (160 Turbines) and the 20MW (120 Turbines)-Case.

10.2.2. Pressure of the 15MW case

The 120 turbines of the planned wind farm leading to a decrease in the mean annual surface current speeds within the wind farm, to the south and north of it (approximately 0.008 m/s, corresponding to approximately 10%). A weakening of the surface current is recognisable as far as the coastal area of Sweden. At the same time, an acceleration of the current can be observed to the east and west of the wind farm. The effect decreases in magnitude and extent with depth.

As illustrated in Appendix 37, the effect is not equally pronounced throughout the year, whereby the largest-scale changes in the current pattern are to be expected in the months from July to September. In September, for example, a large-scale acceleration of the current south-west of the wind farm can be observed.

10.2.3. Pressure of the 20MW case

In general, there is no significant difference in the size of the effect and the spatial patterns of the 15 MW and 20 MW cases. The effect of the 20 MW case tends to be smaller due to the lower number of turbines (120 turbines compared to 160 turbines (15MW case)). However, the difference is not more pronounced because larger wind turbines are planned in the 20 MW case, individually causing a stronger impact on the wind (see Figure 10.1) and representing larger obstacles to the currents (rotor diameter 276 m compared to 236 m, base diameter 52m compared to 42m, Table 6-1).

10.3. Salinity

The effect of the planned windfarm on the annual salinity patterns are depicted in Figure 10.5 to Figure 10.7 for varying depths and for individual months separately in Appendix 38.

10.3.1. Baseline

Average salinity in the surface layer (0-10m) range from 0.1 PSU to 4.5 PSU, with higher values in the southern part of the Bay of Bothnia (Figure 10.5). Salinity is lowest along the coast (due to river discharges) and on the northern part (as a result of the greater distance from the Northern Sea). No clear seasonal pattern is discernible.

10.3.2. Pressure of the 15MW case

As a result of hydrogen production, water with an increased salinity is released at a depth of 10 metres (see Table 6-4). According to the simulation results, a decrease in salinity of up to a maximum of 0.05 PSU is to be expected at the surface regarding the annual average. At the same time, there can be observed an increase in salinity of the same order of magnitude between 10 and 20 metres.

Considering the individual months, changes in the salinity pattern can be expected in the northern part of the Gulf of Bothnia, whereby neither a dominant increase nor a decrease in salinity can be recognised. The effect decreases with depth.

10.3.3. Pressure of the 20MW case

Aligned with the current, the influence of the 20 MW case is also less pronounced than the 15 MW case in terms of salinity.

On an annual average (with the exception of the depth of the immediate source), the change in salinity is less than 0.05 PSU. When looking at the individual months, similar spatial patterns can be observed as in the 15MW case, albeit less pronounced.

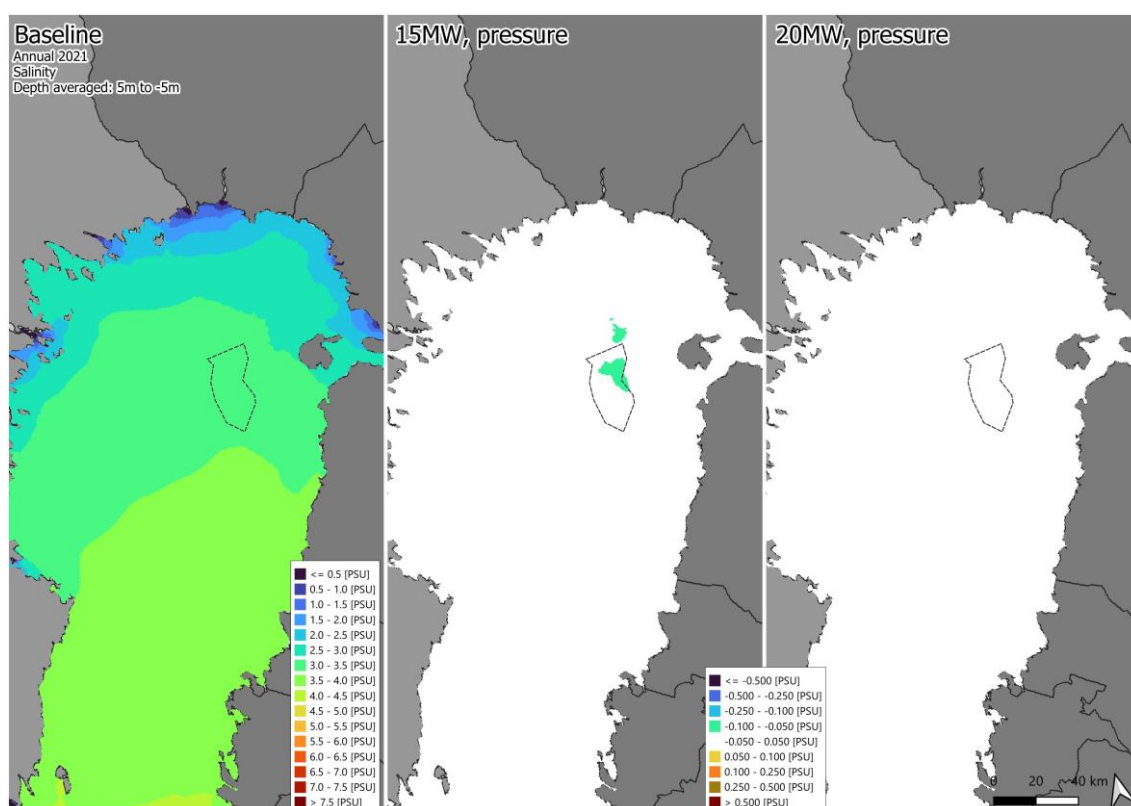


Figure 10.5: Left: Annual (2021) average salinity for the upper most 5 m. Center and Right: Change in salinity due to the 15MW (120 Turbines) and the 20MW (160 Turbines)-Case.

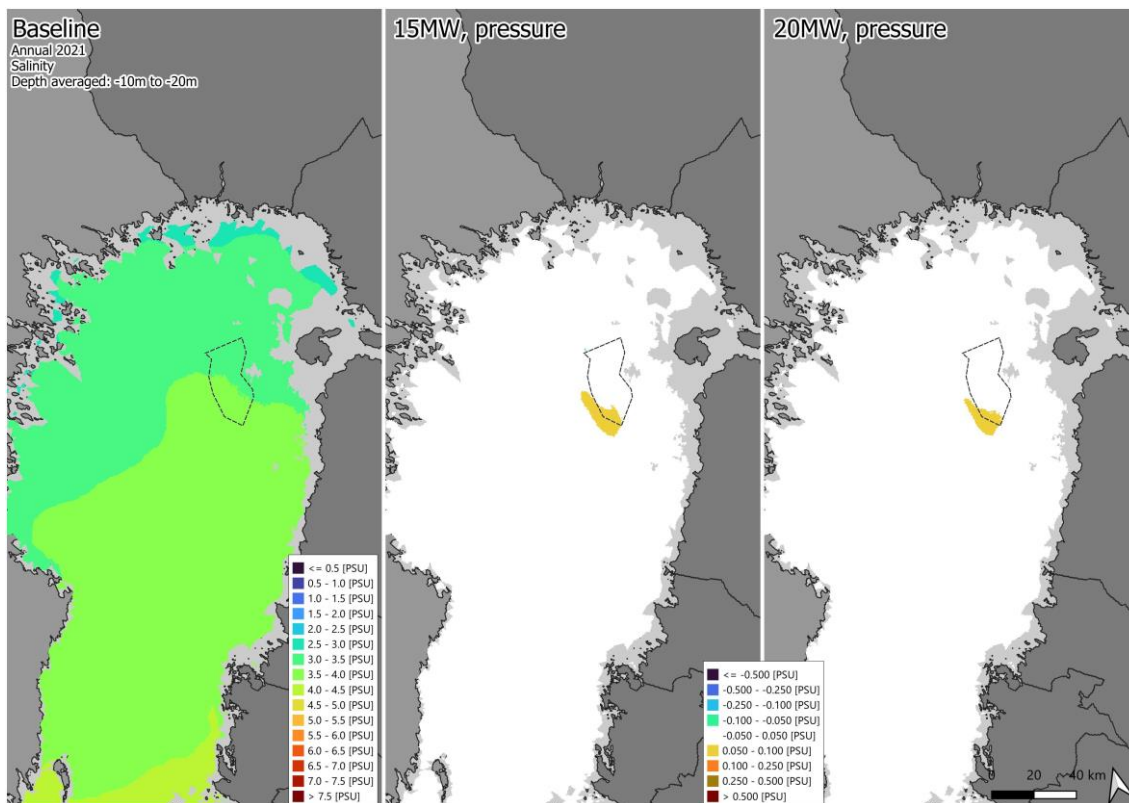


Figure 10.6: Left: Annual (2021) average salinity between – 10 and -20 m. Center and Right: Change in salinity due to the 15MW (160 Turbines) and the 20MW (120 Turbines)-Case.

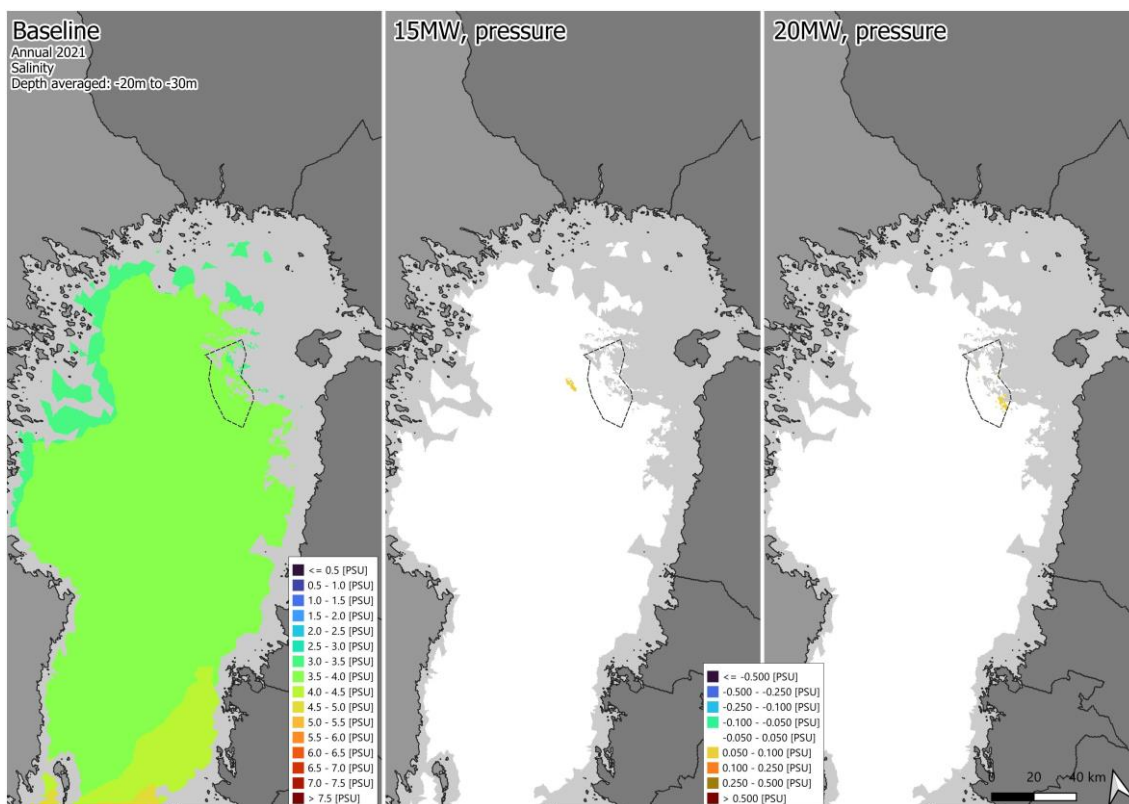


Figure 10.7: Left: Annual (2021) average salinity between – 20 and -30 m (white areas indicate a depth less than -20 m, bottom). Center and Right: Change in salinity due to the 15MW (160 Turbines) and the 20MW (120 Turbines)-Case.

10.4. Temperature

The effect of the planned windfarm on the spatial annual temperature patterns are depicted in Figure 10.8 to Figure 10.10 for varying depths and for individual months separately in Appendix 39. In addition, temperature profiles illustrating the mean of individual months can be found in Appendix 40.

10.4.1. Baseline

Annual average surface temperature (uppermost 5 m) for the year 2021 (Figure 10.8) is generally higher in the south and south-eastern part (accounting to approximately 7.5 °C) and lower along the coast and northern, north-western parts with values between 5-6 °C. The lowest values occur along the Swedish coast, south of the planned wind farm.

Since in summer the water warms up only at the surface to a certain depth, a stratification of the temperature takes place. The annual average temperatures decrease with depth (Figure 10.9 and Figure 10.10 and Appendix 39). The thermocline generally lies between 10 to 20 m in summer (Appendix 40). At this depth, the annual mean temperature of most of the Bay of Bothnia ranges between 4°C and 6°C, except some areas south of the wind farm with temperatures above 6°C. Between 20 m and 30 m depth, the average temperature decreases to 3-5 °C over most of the sea area.

Temperature conditions present strong seasonal variations (see Appendix 39 and Appendix 40) with large areas in the northern, north-eastern part of the Bothnian Sea experiencing negative values (indicating ice-coverage, as already shown in Figure 6.23 and Figure 6.24) between December and April. In spring, temperatures rise relatively sharply, with this effect being more pronounced along the Finnish coast, resulting in a strong spatial temperature gradient in July with low temperatures of about 4-8°C (between 20 m and the surface) along the northern part of the Swedish coast and high temperatures of more than 12-19°C (between 20 and the surface) along the Finnish coast. Overall water temperature peaks between August and September with values between 14-20°C at the surface and 8 – 13°C at 10 to 20 m depth. Temperatures start to decrease during September.

10.4.2. Pressure of the 15MW case

Regarding the annual average temperature, the effect of the planned windfarm is smaller than -0.5 to 0.5 °C (for the upper 10 m and at depths > 20 m), respectively -1.0 and 1.0°C (between 10 and 20 m).

The results corresponding to monthly temperatures reveal increased warming (0.25- 0.50°C) of the upper layers, whereas between 5 and 30 m simultaneous but spatially separated warming and cooling, which is most pronounced in the summer months (difference > ±1°C). North of the wind farm, warming dominates in most months, while cooling is to be expected in the area south of the wind farm.

Impacts on temperature are also illustrated through monthly vertical profiles in Appendix 40. The results reveal the following differences:

- Increased temperatures at deeper depths in January and February
- Increased warming in the center and northern part of the windfarm June, July, and August in
- Reduced warming in the southern part of the windfarm in June to September, leading to a shift of the thermocline by up to 10 m (10 m instead of 20 m in July)

10.4.3. Pressure of the 20MW case

Aligned with the observations of current and salinity, comparable, albeit less pronounced, changes in water temperature can be observed in the 20 MW case.

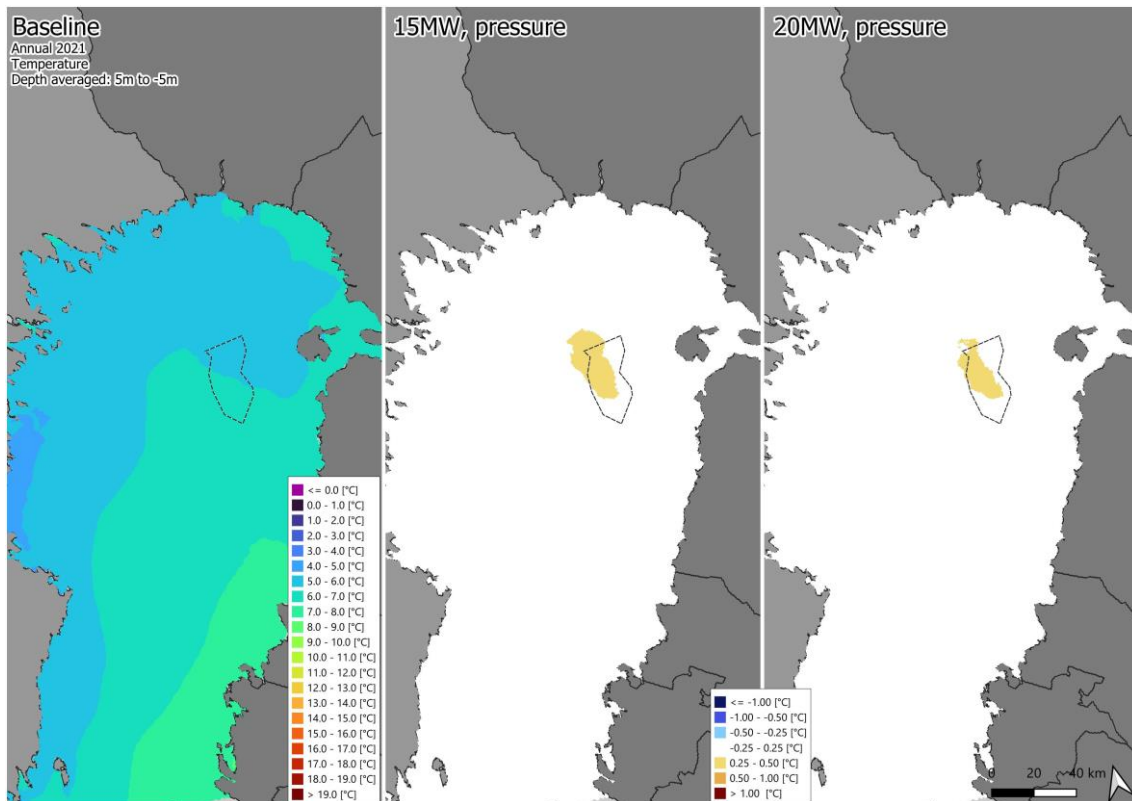


Figure 10.8: Left: Annual (2021) average temperature for the upper most 5 m. Center and Right: Change in temperature due to the 15MW (120 Turbines) and the 20MW (160 Turbines)-Case.

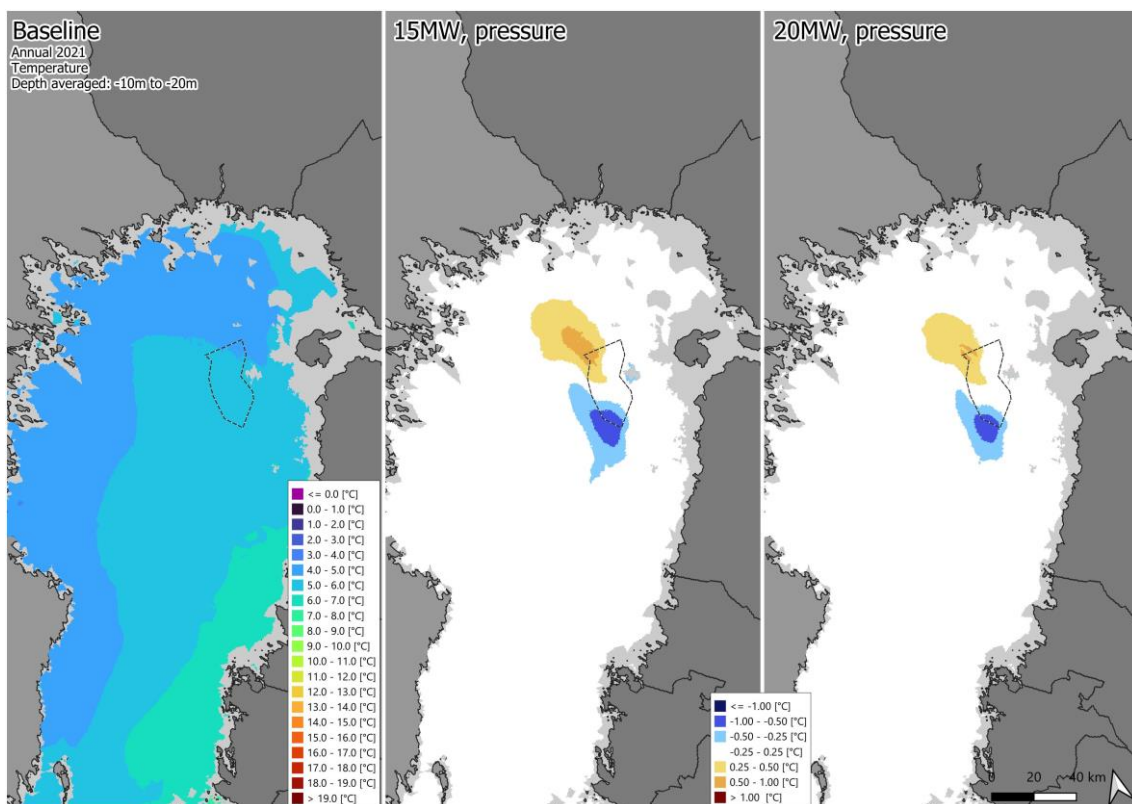


Figure 10.9: Left: Annual (2021) average temperature between – 10 and -20 m. Center and Right: Change in temperature due to the 15MW (160 Turbines) and the 20MW (120 Turbines)-Case.

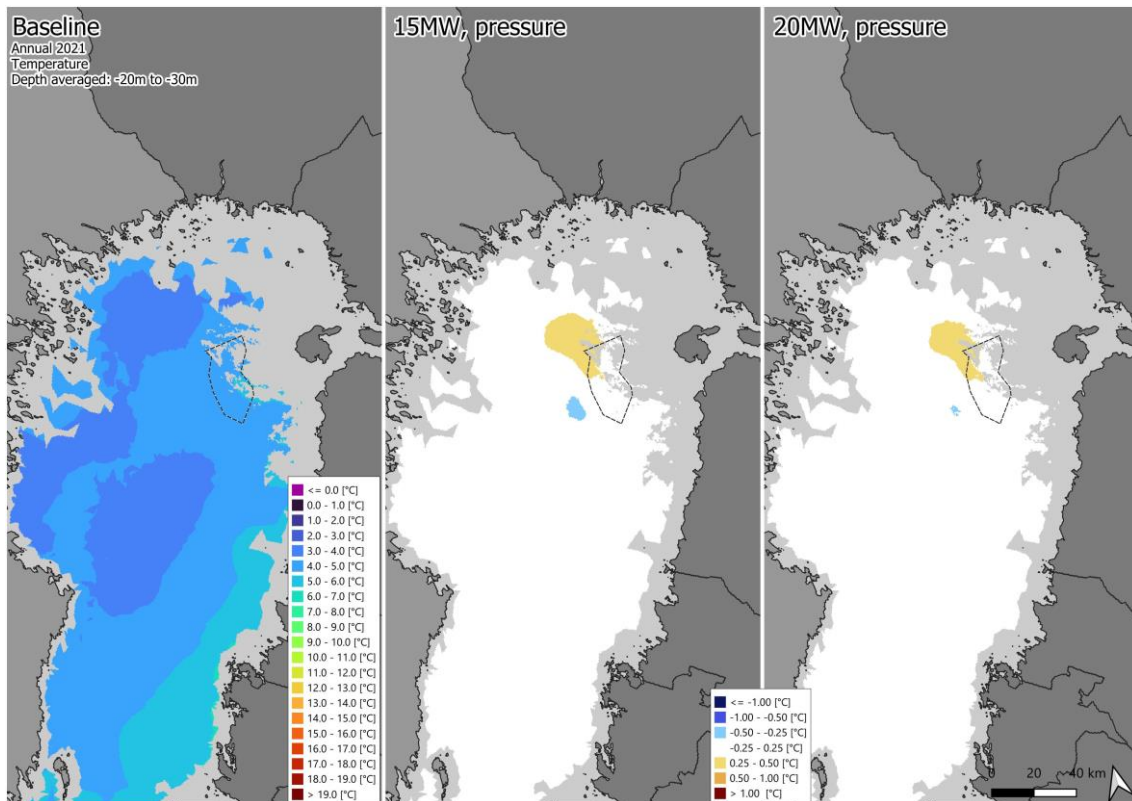


Figure 10.10: Left: Annual (2021) average temperature between – 20 and –30 m (white areas indicate a depth less than –20 m, bottom). Center and Right: Change in temperature due to the 15MW (160 Turbines) and the 20MW (120 Turbines)-Case.

10.5. Upwelling

The effect of the planned windfarm on the spatial annual upwelling patterns are depicted in Figure 10.11 to Figure 10.13 for varying depths and for individual months separately in Appendix 40.

10.5.1. Baseline

The observation of the average vertical current velocity (Figure 10.11 to Figure 10.13) shows a general upwelling trend along the coastal sections and a downwelling trend in the open sea, which is most pronounced at depths of 10 m to 20 m. With depicted vertical current speed of only ± 0.02 mm/s in the annual mean indicate a not strongly pronounced current.

In the course of the year (cf. Appendix 41), however, a different up- and downwelling patterns are seen. For example, upward currents dominate along the Swedish coast down to a depth of 30 m between February and April (monthly mean February up to > 0.08 mm/s). In March, upwelling can also be observed along the Finnish coast. The upwelling trend along the Swedish coast in combination with a downwelling trend along the Finish coast continues until July. In August the current changes and in autumn there is no clear pattern.

The locally more pronounced current fluctuations in the vicinity of the wind farm are due to the increased mesh resolution, while further away from the wind farm small-scale current differences are averaged out due to the larger cell sizes.

10.5.2. Pressure of the 15MW case

In addition to very small-scale, locally very strongly varying changes that occur throughout the year, it is recognisable when looking at the annual average of the vertical flow that the upward flow (upwelling) is strengthened by up to 0.000004 m/s between -40 and -5 m in the area to the south (up to 40 km else around 20 km).

The magnitude of the change varies over the course of the year, although no clear pattern is discernible.

10.5.3. Pressure of the 20MW case

Since there are hardly any differences compared to the 15 MW wind farm, the effect of the 20 MW case is assessed to be the same.

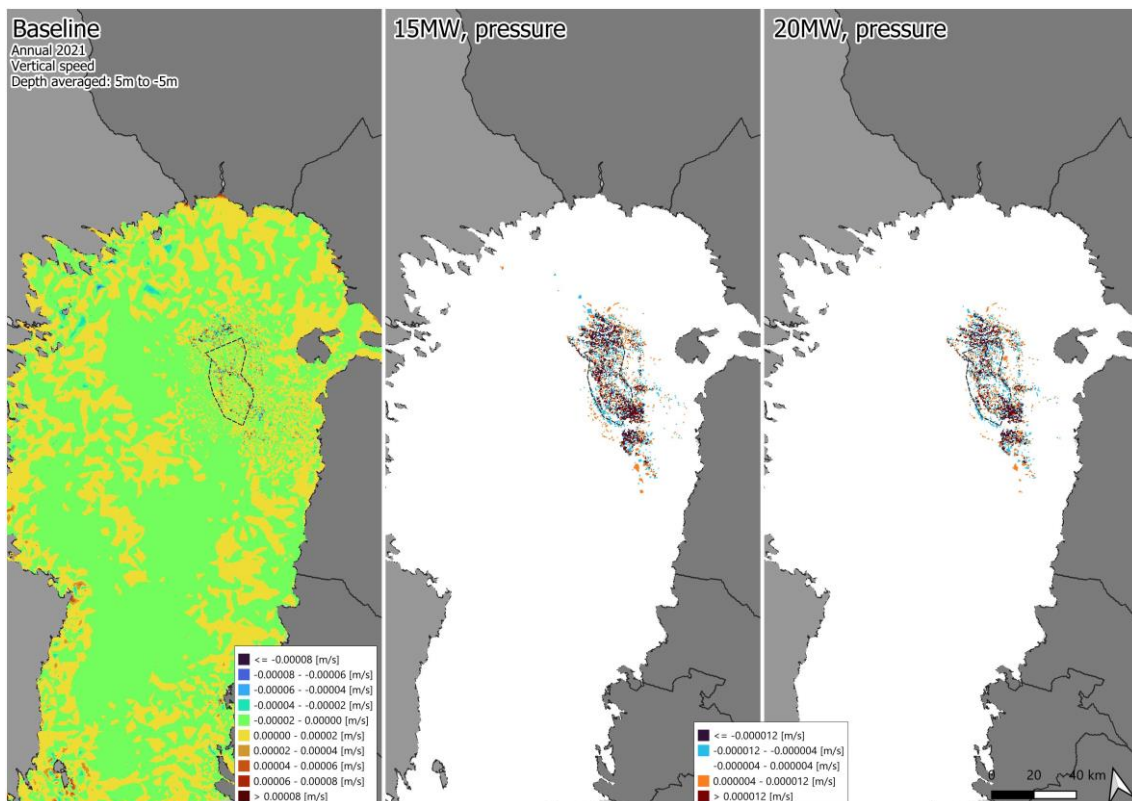


Figure 10.11: Left: Annual (2021) average vertical velocities for the upper most 5 m. Center and Right: Change in vertical velocities due to the 15MW (120 Turbines) and the 20MW (160 Turbines)-Case.

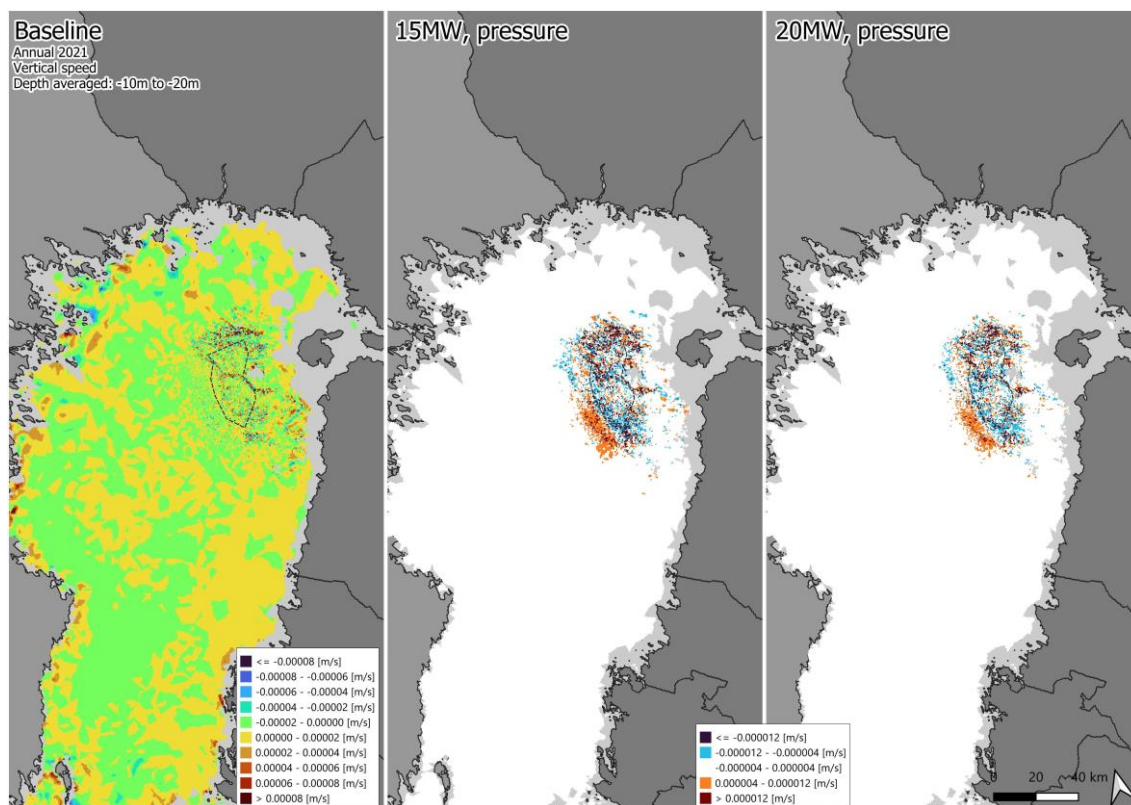


Figure 10.12: Left: Annual (2021) average vertical velocities between – 10 and -20 m. Center and Right: Change in vertical velocities due to the 15MW (160 Turbines) and the 20MW (120 Turbines)-Case.

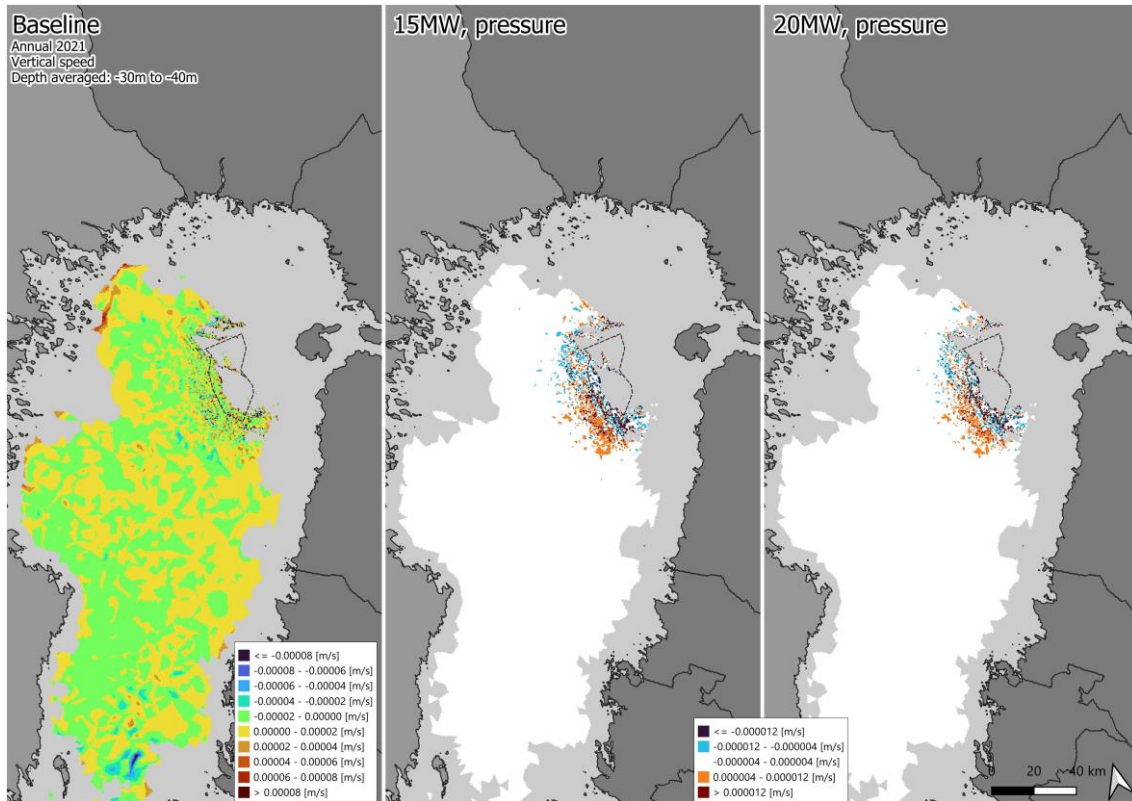


Figure 10.13: Left: Annual (2021) average vertical velocities between – 20 and -30 m (white areas indicate a depth less than -20 m, bottom). Center and Right: Change in vertical velocities due to the 15MW (160 Turbines) and the 20MW (120 Turbines)-Case.

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Appendix 1: Grain sieve analyses

The results are provided in a separate PDF.

Appendix 2Current field (SMHI)

The results are provided in a separate PDF.

Appendix 3: Halla OWF, Temperature profiles (SMHI, modelled 4x4km)

The results are provided in a separate PDF.

Appendix 4 Halla OWF, Temperature profiles (SMHI, modelled 2x2km)

The results are provided in a separate PDF.

Appendix 5 Halla OWF, Salinity profiles (SMHI, modelled 4x4km)

The results are provided in a separate PDF.

Appendix 6 Halla OWF, Salinity profiles (SMHI, modelled 2x2km)

The results are provided in a separate PDF.

Appendix 7 Halla OWF, Current roses (SMHI, modelled 4x4km)

The results are provided in a separate PDF.

Appendix 8 Halla OWF, Current roses (SMHI, modelled 2x2km)

The results are provided in a separate PDF.

Appendix 9 Halla OWF, Simplified Particle Tracks

The following maps show the resulting tracks of a simplified particle tracking model based on the horizontal currents of the SMHI Baltic Sea model (Copernicus, Baltic Sea Physics Analysis and Forecast, 2x2km, 2022). Every day, one particle is released at each of five locations in the wind farm area, and its horizontal path is tracked for 30 days before the particle disappears again. The maps show all paths of the particles released in the respective month.

Appendix 10 Observations: Water levels

The results are provided in a separate PDF.

Appendix 11 Observations: Currents

The results are provided in a separate PDF.

Appendix 12 Observations: CTD-Measuring sites

The results are provided in a separate PDF.

Appendix 13 Observations: Surface temperature

The results are provided in a separate PDF.

Appendix 14 Model verification: Water levels

The results are provided in a separate PDF.

Appendix 15 Model verification: Currents

The results are provided in a separate PDF.

Appendix 16 Model verification: Salinity profiles of 2021

The results are provided in a separate PDF.

Appendix 17 Model verification: Salinity profiles in the project area

The results are provided in a separate PDF.

Appendix 18 Model verification: Timeseries of surface temperature

The results are provided in a separate PDF.

Appendix 19 Model verification: Temperature profiles of 2021

The results are provided in a separate PDF.

Appendix 20 Model verification: Temperature profiles in the project area

The results are provided in a separate PDF.

Appendix 21 Sediment dispersal: Concentration - 15 MW

The results are provided in a separate PDF.

Appendix 22 Sediment dispersal: Concentration time series - 15 MW

The results are provided in a separate PDF.

Appendix 23 Sediment dispersal: Mean daily max. – 15 MW

The results are provided in a separate PDF.

Appendix 24 Sediment dispersal: Concentration - 20 MW

The results are provided in a separate PDF.

Appendix 25 Sediment dispersal: Concentration time series - 20 MW

The results are provided in a separate PDF.

Appendix 26 Sediment dispersal: Mean daily max. – 20MW

The results are provided in a separate PDF.

Appendix 27 Sediment dispersal: Concentration – Export cable Case 1

The results are provided in a separate PDF.

Appendix 28 Sediment dispersal: Concentration time series – Case 1

The results are provided in a separate PDF.

Appendix 29 Sediment dispersal: Mean daily max. – Export cable Case 1

The results are provided in a separate PDF.

Appendix 30 Sediment dispersal: Concentration – Export cable Case 2

The results are provided in a separate PDF.

Appendix 31Sediment dispersal: Concentration time series – Case 2

The results are provided in a separate PDF.

Appendix 32 Sediment dispersal: Mean daily max. – Export cable Case 2

The results are provided in a separate PDF.

Appendix 33 Sediment dispersal: Sedimentation - 15 MW

The results are provided in a separate PDF.

Appendix 34 Sediment dispersal: Sedimentation - 20 MW

The results are provided in a separate PDF.

Appendix 35 Sediment dispersal: Sedimentation – Case 1

The results are provided in a separate PDF.

Appendix 36 Sediment dispersal: Sedimentation – Case 2

The results are provided in a separate PDF.

Appendix 37 Hydrodynamic Impact: Current

The results are provided in a separate PDF.

Appendix 38 Hydrodynamic Impact: Salinity

The results are provided in a separate PDF.

Appendix 39 Hydrodynamic Impact: Temperature

The results are provided in a separate PDF.

Appendix 40 Hydrodynamic Impact: Temperature Profiles

The results are provided in a separate PDF.

Appendix 41 Hydrodynamic Impact: Upwelling

The results are provided in a separate PDF.



Halla OWF

Impact on the physical environment, 25 MW wind turbine

Halla Offshore Wind Oy
Date: 10 December 2024

Rev.no.	Date	Description	Prepared by	Verified by	Approved by
01	20241119	Rev. 1	AIRN	TEB	TEB
02	20241129	Rev. 2, minor corrections	TEB	AIRN	TEB
03	20241210	Rev. 3, frontpage updated	TEB	AIRN	TEB

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Appendix

Appendix 1 Hydrodynamic Impact: Current 2D-Maps
Appendix 2 Hydrodynamic Impact: Current Areal analyses
Appendix 3 Hydrodynamic Impact: Comparison of Mean current
Appendix 4 Hydrodynamic Impact: Salinity – 2D-Maps
Appendix 5 Hydrodynamic Impact: Salinity Areal analyses
Appendix 6 Hydrodynamic Impact: Comparison of Mean Salinity
Appendix 7 Hydrodynamic Impact: Temperature 2D-Maps
Appendix 8 Hydrodynamic Impact: Temperature Areal analyses
Appendix 9 Hydrodynamic Impact: Comparison of temperature

1. Introduction

Halla Offshore Wind Oy has asked NIRAS to address the impact from a windfarm with 25MW wind turbines on the hydrodynamics compared to the exiting results for the 15MW and 20MW cases conducted in a previous study (NIRAS, 2023-12-20) as described in CTR04 signed by both parties.

1.1. Scope of work

To rerun the existing hydrodynamic models with the impact on the wind from a windfarm with 25MW turbines applying the same wind farm layout as previous used for the 20MW case, e.g. number of turbines and dimension of the foundation.

1.2. Methodology

For the purpose of assessing the impact on the hydrodynamics from the 25 MW turbines, the 3D hydrodynamic model of the Bay of Bothnia calibrated as part of (NIRAS, 2023-12-20) is used as follows:

- 1) The 3D hydrodynamic model of the Bay of Bothnia including the windfarm layout of the 20MW case is updated with the wind impact from the 25MW turbines and the impact on current, salinity, and temperature is assessed by the comparison to the baseline (situation without windfarm).
- 2) The comparison of the impacts of the different wind farm cases (15MW, 20MW, and 25MW) is presented by the depth averaged (interval: 10 m) current, temperature and salinity on monthly basis in form of figures and GIS maps. The graphical representation is the same as in (NIRAS, 2023-12-20) except of the fact, that the impacts of the 3 cases are presented alongside and the baseline (the situation without windfarm) is not presented.
- 3) The 25 MW turbine is to have a rotor diameter of 340 m and a hub height of 200 m, according to the Client. The power and thrust curves are to be scaled from a 22MW turbine (REFWIND, IEA Wind Task 55, u.d.) and used as input for the wake model in order to modify the wind conditions.

1.3. Abbreviations

Current direction	Going towards
FOU	Foundation and substructure, lower support structure
GBS	Gravity Based Structure
MP	Monopile
OSS	Offshore substation
OWF	Offshore Wind Farm
Wave direction	Coming from
Wind direction	Coming from
WTG	Wind turbine generator
SMHI	Sveriges meteorologiska och hydrologiska institut
FMI	Finnish Meteorological Institute
ADCP	Acoustic Doppler current profiler
PSU	Practical salinity unit

2. Background data

The following subsections detail the dimensional variations among the 15MW, 20MW, and 25MW cases, as well as provide information on the wind farm's location and the layout utilized for the 25MW setup.

2.1. Dimensions

In Table 2.1 the dimensions of the wind turbines and supporting structures to be used for the hydrodynamic modelling are listed for both the 15MW, 20MW and 25MW case. It is assumed that the lower part (base slab and cone) of the substructure is independent of the water depth thus only the length of the shaft changes from position to position as illustrated in Figure 2.1.

Table 2.1: Turbine and substructure dimensions for the 15, 20 and 25MW cases

c		Unit	Case		
			15 MW	20 MW	25 MW
WTG	Rotor diameter	m	236	276	340
	Hub height	m	150	170	200
GBS, WTG	Shaft, diameter	m	10	12	12
	Base diameter, bottom	m	45	52	52
	Base diameter, top	m	10	12	12
	Base, height cone	m	12	12	12
	Base, height slab	m	5	5	5
GBS, OSS	Shaft, diameter	m	10	10	10
	Base diameter, bottom	m	45	45	45
	Base diameter, top	m	10	10	10
	Base, height cone	M	12	12	12
	Base, height slab	M	5	5	5

Power and thrust curves for 25MW turbine are scaled from a 22MW turbine (REFWIND, IEA Wind Task 55, u.d.) and used as input to the wake model (Jensen, N.O., 1983) for modification of the wind fields. In the previous study the 20 MW turbine was scaled from a 15MW turbine.

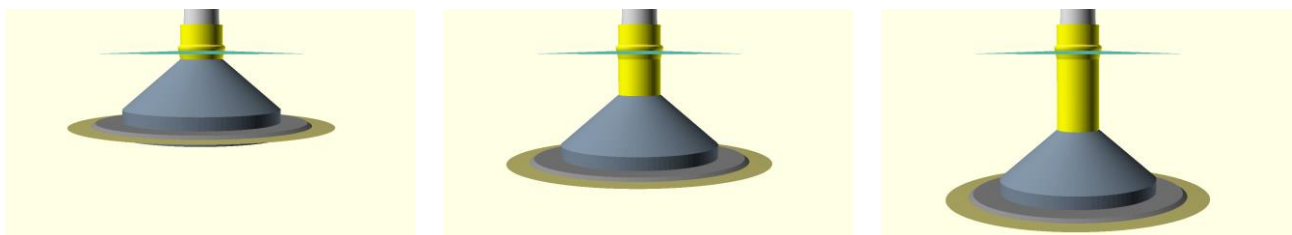


Figure 2.1: Sketch of the GBS for the WTG used as input to the hydrodynamic modelling illustrated for 20 m, 30 m and 40 m water depth.

2.2. Windfarm layout

The layout of Halla Offshore Wind Farm is illustrated in Figure 2.1 The footprint covers an area of 575 km², the total number of turbines for the 20/25 MW case it is 120. This model considers six offshore substations as a

representative number, in line with EIA's statement that project will have between three and eight offshore sub-stations.

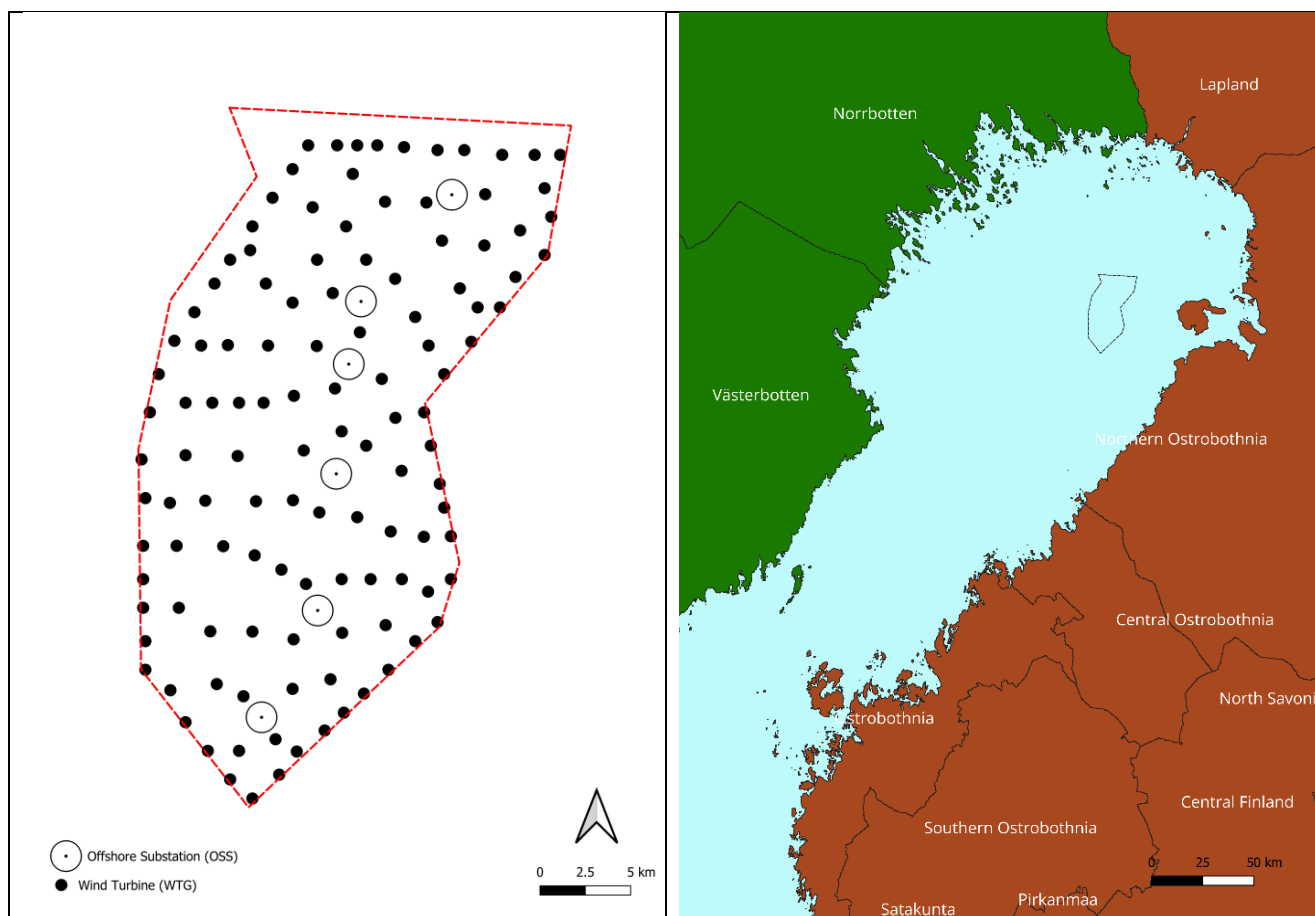


Figure 2.2: Halla, wind farm layout. Left: 20/25 MW turbines and Right: Overview (Brown: Finland, Green: Sweden).

2.2.1. Hydrogen production, wastewater – Operation Phase

At each position of the either 15MW, 20MW or 25MW wind turbines it is planned to produce hydrogen which requires purified water and water for cooling of the equipment as listed in Table 2.2.

Table 2.2 Hydrogen production, in- and outputs per turbine. Background salinity 2 PSU.

Case	Parameter	Unit	Inlet	Outlet
15 MW turbine	Process water	[m ³ /s]	0.004	0.002
	Salinity	[PSU]	background	excess 5
	Cooling water	[m ³ /s]	0.05	0.05
	Temperature	[°C]	background	excess 15
20 MW turbine	Process water	[m ³ /s]	0.006	0.003
	Salinity	[PSU]	background	excess 5
	Cooling water	[m ³ /s]	0.07	0.07
	Temperature	[°C]	background	excess 15
25MW turbine	Process water	[m ³ /s]	0.006	0.003
	Salinity	[PSU]	background	excess 5
	Cooling water	[m ³ /s]	0,07	0,07
	Temperature	[°C]	background	excess 15

Both the intake and the outlet are assumed located around 10 m below the surface.

2.3. Hydrodynamic model

The background for the present study is the 3D hydrodynamic model calibrated on water levels, current, salinity and temperatures in the previous study described in (NIRAS, 2023-12-20). For this study the model for the 20 MW turbines was reused regarding layout and substructure dimensions but with wind wakes given by the larger 25 MW wind turbines.

3. Results

The presentations below emphasize the effects of the 25MW turbine arrangement, along with the previously noted impacts for the 15MW and 20MW configurations. Here, the impact is represented as 2D maps of the annual or monthly depth averages per 10 m, calculated as the difference between the project (either 15MW, 20MW, or 25MW) and the Baseline scenario (without the wind farm).

Moreover, to quantify the impact the difference in the total mass flux between the case with turbines and the baseline scenario is given for 2 boxes surrounding the wind farm as illustrated on Figure 3.1. The result is presented as a percentage relative to the Baseline. A positive value indicates an increased flux, whereas a negative value signifies a decreased flux. It should be noted that significant changes in flux do not necessarily result in substantial changes in the actual values.

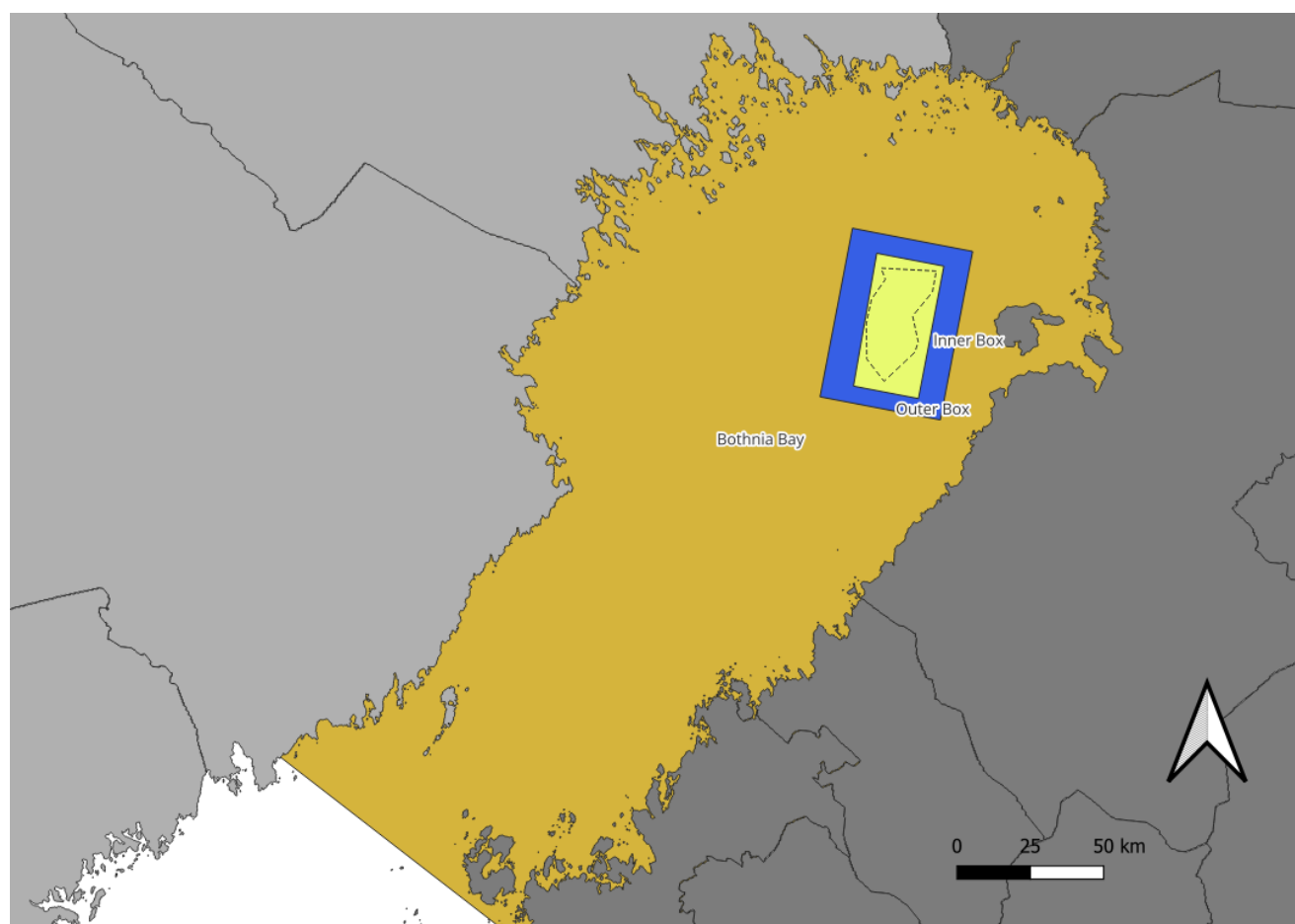


Figure 3.1: Halla OWF, Location of boxes for mass flux and area/depth analyses.

3.1. Wind

For illustration of the impact on the wind speed due to the three cases the reduction in the wind at a time with the 2021-08-25 6:00 is shown in Figure 3.2. At this moment, the average wind speed at 10 meters above mean sea level is 11.6 meters per second at the centre of the wind farm. The rated wind speed for the 15MW and 20MW is ≈ 10.5 m/s where the for the 25MW is 10.9 m/s.

The wind does not only influence the surface water movement but also the evaporation process, which in turn affects the surface water temperature. For instance, reduced wind leads to decreased evaporation, which raises the water surface temperature.

Given that the wind remains constant on an hourly basis, and atmospheric stability is not factored in, the influence of the wind is viewed as conservative. An unstable atmosphere would minimize the turbines' impact on the wind, both in scale and in horizontal/vertical spread. This also influences the predicted alterations in currents, salinity, and temperature, ultimately leading to a conservative effect.

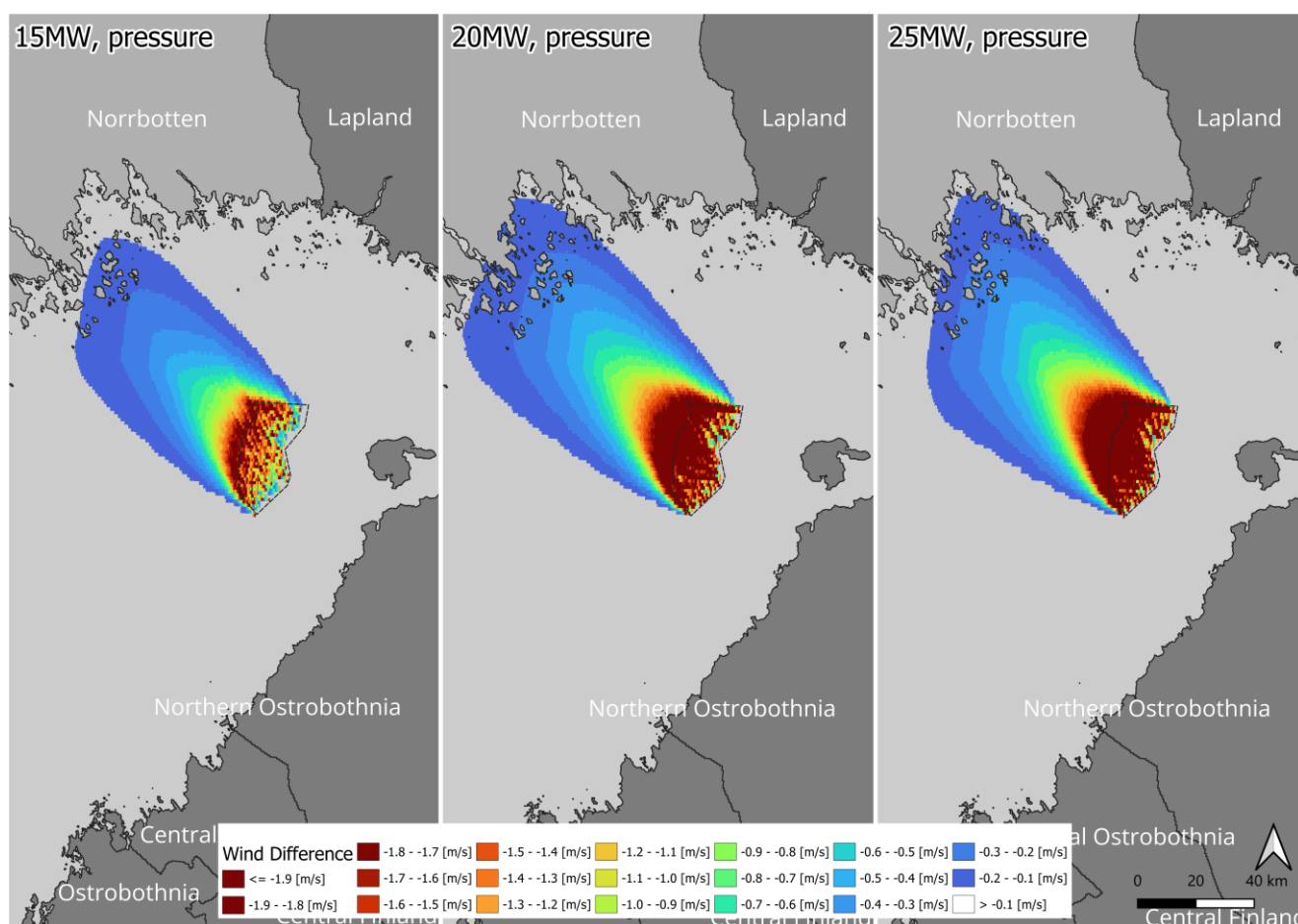


Figure 3.2: Impact on wind 2021-08-25 6:00, Left: 15MW, Mid: 20MW and Right: 25MW.

3.2. Current

Effects on the spatial current speed patterns are presented in Figure 3.3 to Figure 3.5, and Appendix 1. Table 6 to Table 8 in Appendix 2 summarize the maximum and minimum impact. With regard to the description of the baseline (situation without wind farm), please refer to (NIRAS, 2023-12-20).

Baseline (NIRAS, 2023-12-20): The average current speeds conditions of the year 2021 are generally low in the Bay of Bothnia due to the absence of tides in the Baltic Sea with average surface currents at depth 0 to -5m (Figure 3.3) ranging from 0.05 to 0.1 m/s decreasing with depth. Considering the individual months, a seasonal pattern is recognisable, characterised by stronger currents in the summer months (May - September) due to sea ice in the winter months, whereas this seasonal variation is most pronounced at the surface and decreases with depth.

General Impact of the investigated wind farm cases: The currents will be influenced by the wind farm due to physical blocking of the current - as the substructure act as obstacles – and the decrease in wind. The wind farm layout and cases investigated lead to a decrease of the annual average surface current speeds within the wind farm of approximately 0.008 m/s, corresponding to approximately 10% (Figure 3.3). A weakening of the surface current is recognisable as far as the coastal area of Sweden. At the same time, an acceleration of the current can be observed to the east and west of the wind farm. The effect decreases in magnitude and extent with depth and distance. As illustrated in Appendix 1, the effect is not equally pronounced throughout the year, whereby the largest-scale changes in the current pattern are to be expected in the months from July to September. In September, for example, a large-scale acceleration (0.004 to 0.006 m/s) of the current south-west of the wind farm can be observed.

Impact of the 25MW: Despite the reduced number of turbines in the 20 MW and 25 MW cases, which have 120 turbines compared to 160 turbines in the 15MW case, and the resulting decreased blockage impact on current and wake due to fewer turbines, there is almost no discernible difference between the cases in terms of surface current impact. This can be attributed to the larger wind turbines (with a rotor diameter of 340/276 m compared to 236 m, as shown in Table 2.1) causing a stronger impact on the wind (refer to Figure 3.1). Additionally, the larger substructures but smaller numbers (base diameter of 52m compared to 42m, resulting in a total vertical area at the bottom of 6240 m² versus 6720 m², as indicated in Table 2.1), only present minimal obstacles to the currents.

When examining the total fluxes over the two boxes (Table 3.1), the changes due to the 15MW are notably smaller than those for the 20MW and 25MW. Additionally, the change in the fluxes decreases with distance from the wind farm. The comparison of the 20MW case with the 25MW reveals, that the differences between the two cases account to less than 0.1%. Furthermore, it varies depending on the month and area considered, which of the two cases has a greater influence. The same pattern (no omni-dominant case with greatest impact) can be seen when considering the spatially and temporally averaged flow velocity at different depths (see tables in Appendix 3). For example, the flow is slowed down more in the upper 30 m in the 25MW case than in the 20MW case within the wind farm in August. Between 30 and 50 m, on the other hand, the 20MW seems to have a greater effect on the flow.

However, all three cases investigated demonstrate the same spatial and seasonal pattern in respect to the current impact, with the order of magnitude being considered comparable.

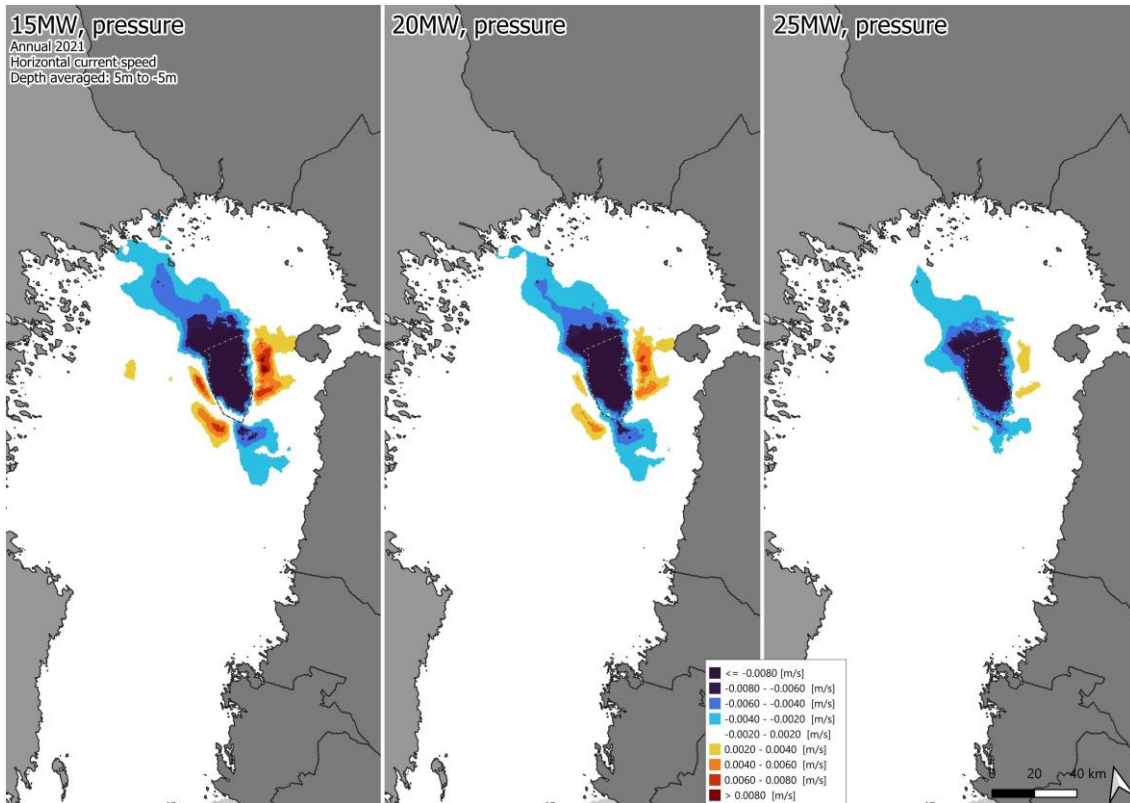


Figure 3.3: Change in annual (2021) average current speeds in the upper most 5 m due to the 15MW (160 Turbines, left), the 20MW (120 Turbines, centre) and the 25MW (120 Turbines, right).

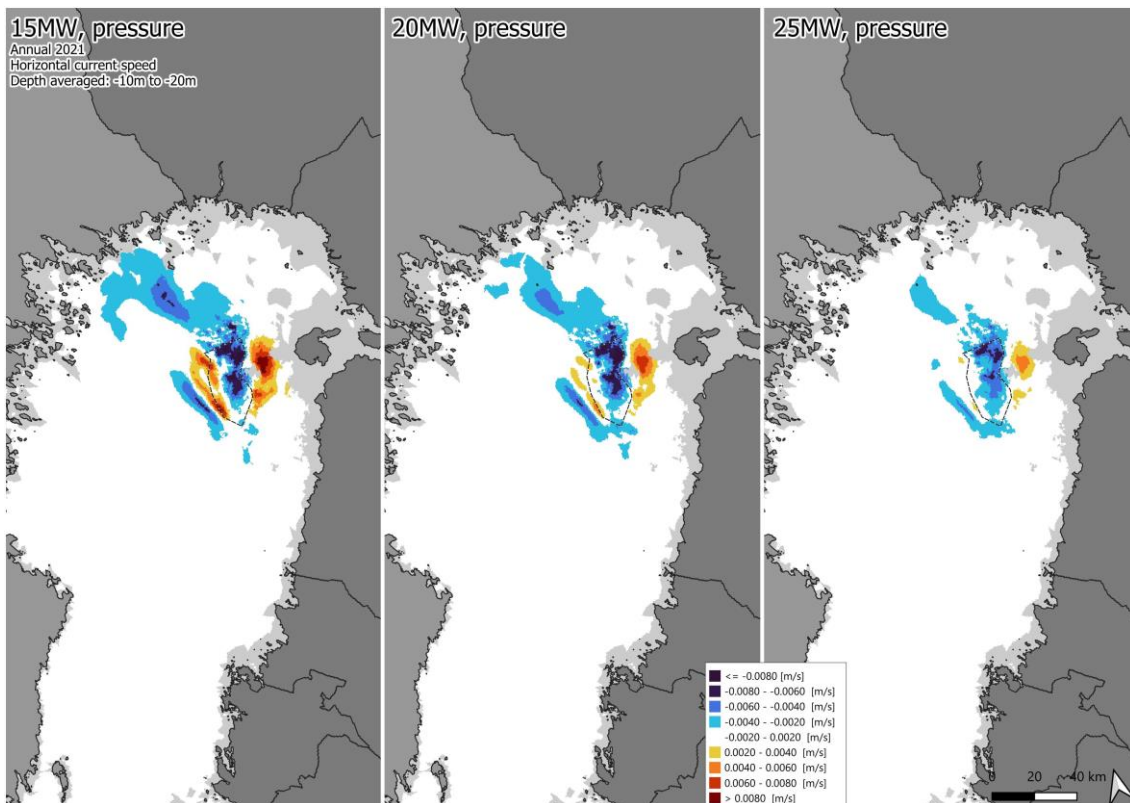


Figure 3.4: Change in annual (2021) average current speeds between -10 and -20 m due to the 15MW (160 Turbines, left), the 20MW (120 Turbines, centre) and the 25MW (120 Turbines, right).

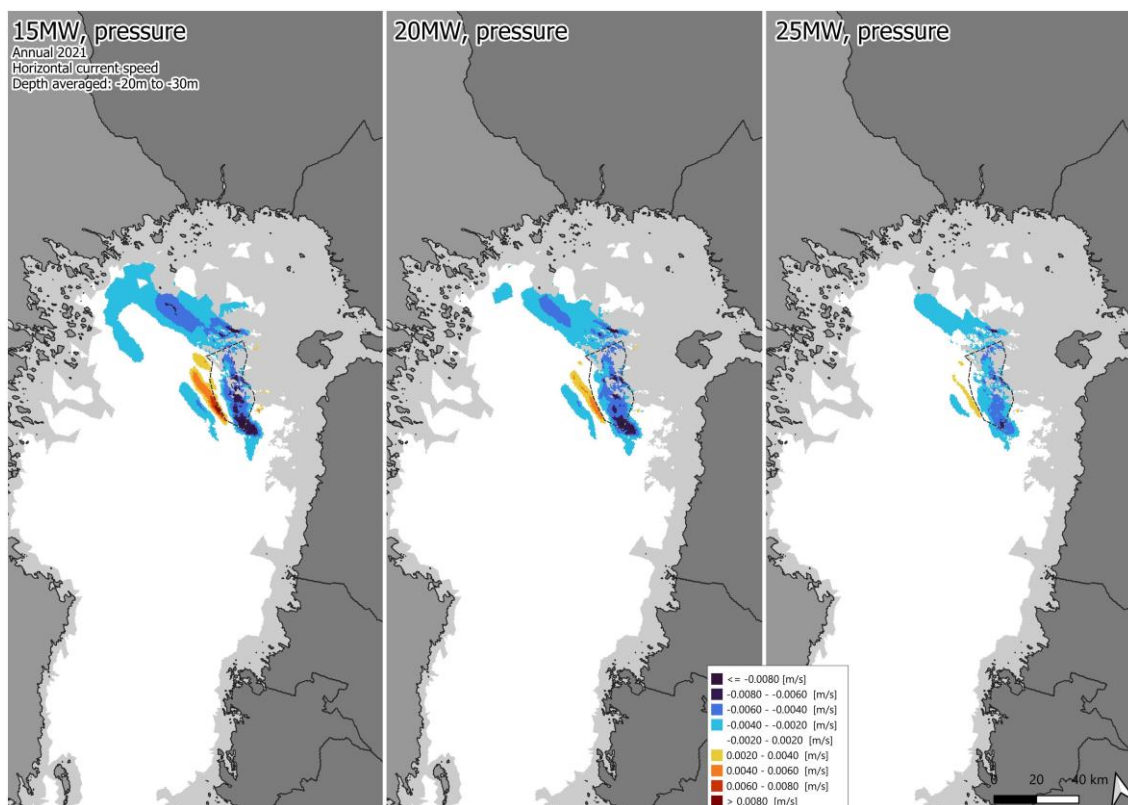


Figure 3.5: Change in annual (2021) average current speeds between – 20 m and -30 m due to the 15MW (160 Turbines, left), the 20MW (120 Turbines, centre) and the 25MW (120 Turbines, right).

Table 3.1: Changes in the total flow flux per month and on annual bases. Left: inner box, Right: outer box.

Month	15MW	20MW	25MW
2021-01-01	0.21%	-16.05%	-16.07%
2021-02-01	-0.11%	-18.93%	-18.93%
2021-03-01	-0.25%	-27.63%	-27.63%
2021-04-01	-0.31%	-40.77%	-40.80%
2021-05-01	-0.58%	-72.29%	-72.27%
2021-06-01	-0.96%	-86.77%	-86.74%
2021-07-01	-0.85%	-85.74%	-85.76%
2021-08-01	-0.74%	-94.15%	-94.13%
2021-09-01	-0.59%	-75.23%	-75.24%
2021-10-01	-0.87%	-105.42%	-105.42%
2021-11-01	-0.85%	-105.66%	-105.69%
2021-12-01	-0.60%	-76.63%	-76.64%
2021-2022	-0.56%	-69.17%	-69.18%

Month	15MW	20MW	25MW
2021-01-01	0.30%	-6.68%	-6.69%
2021-02-01	-0.05%	-8.02%	-8.02%
2021-03-01	-0.10%	-11.95%	-11.95%
2021-04-01	-0.14%	-17.02%	-17.03%
2021-05-01	-0.33%	-30.25%	-30.22%
2021-06-01	-0.45%	-36.61%	-36.59%
2021-07-01	-0.37%	-36.05%	-36.06%
2021-08-01	-0.40%	-39.59%	-39.55%
2021-09-01	-0.30%	-31.65%	-31.62%
2021-10-01	-0.29%	-44.08%	-44.09%
2021-11-01	-0.33%	-44.19%	-44.21%
2021-12-01	-0.25%	-32.28%	-32.28%
2021-2022	-0.24%	-29.15%	-29.15%

3.3. Salinity

Impact on the salinity is presented in Figure 3.6 to Figure 3.8, and Appendix 4. Table 10 to Table 12 in Appendix 5 summarize the maximum and minimum impact. With regard to the description of the baseline (situation without wind farm), please refer to (NIRAS, 2023-12-20).

Baseline (NIRAS, 2023-12-20): Average salinity in the surface layer (0-10m) range from 0.1 PSU to 4.5 PSU, with higher values in the southern part of the Bay of Bothnia. Salinity is lowest along the coast (due to river discharges) and on the northern part. With increasing depth, the salinity is increasing. No clear seasonal pattern is discernible.

General Impact of the investigated wind farm cases: Despite the inflow of water with excessive salinity due to the hydrogen production, limited change in annual average salinity (< 0.1 PSU, within the proximity of the wind farm) is observed (Figure 3.6 to Figure 3.8, and Appendix 4). Considering the individual months, local variations in terms of extent and magnitude are recognizable (order of magnitude 0.1-0.25 PSU), for example:

- Limited impact (< 0.05 PSU) in January, March, and April, independent of the depth considered.
- Simultaneous in- and decrease (depending on the location considered) in February.
- Net-increase of the salinity (up to 0.25 PSU) south-west of the windfarm in May.
- Decrease in salinity at the surface and north-west of the wind farm in June, whereas in deeper depths an increase is dominant.
- Strongest effect in terms of extent and magnitude observable in July (in- and decrease depending on the location considered).
- General decrease in salinity in the upper 10 m combined with an increase in deeper depths in August and September.
- Net-decrease in salinity in October to December.
- Effects observable at the northern coast in June, July, August, October, November and December.

Impact of the 25MW: The comparison of the impact of the 25MW case with that of the 20MW or 15MW reveals an impact of the same order of magnitude and similar seasonal pattern, whereas the effect appears to be stronger at some depths and months and less pronounced at others. This observation can be underlined by spatial and temporal averaged salinity (see tables in Appendix 6), where, for example, in May, the strongest impact on the surface salinity occurs in the 25MW case, whereas in deeper depth, the impact of the 20 MW is larger. Please note that the mentioned changes in the vicinity of the wind farm are at the second decimal point of a PSU range of 2 to 4. As for the flow flux, the impact on the salt flux (Table 3.2) decreases with the distance to the wind farm and increases as the turbine become larger. Although the percentage change is large, the actual impact remains small.

The effect of a 25MW turbine is similar in magnitude to that of 15MW and 20MW turbines.

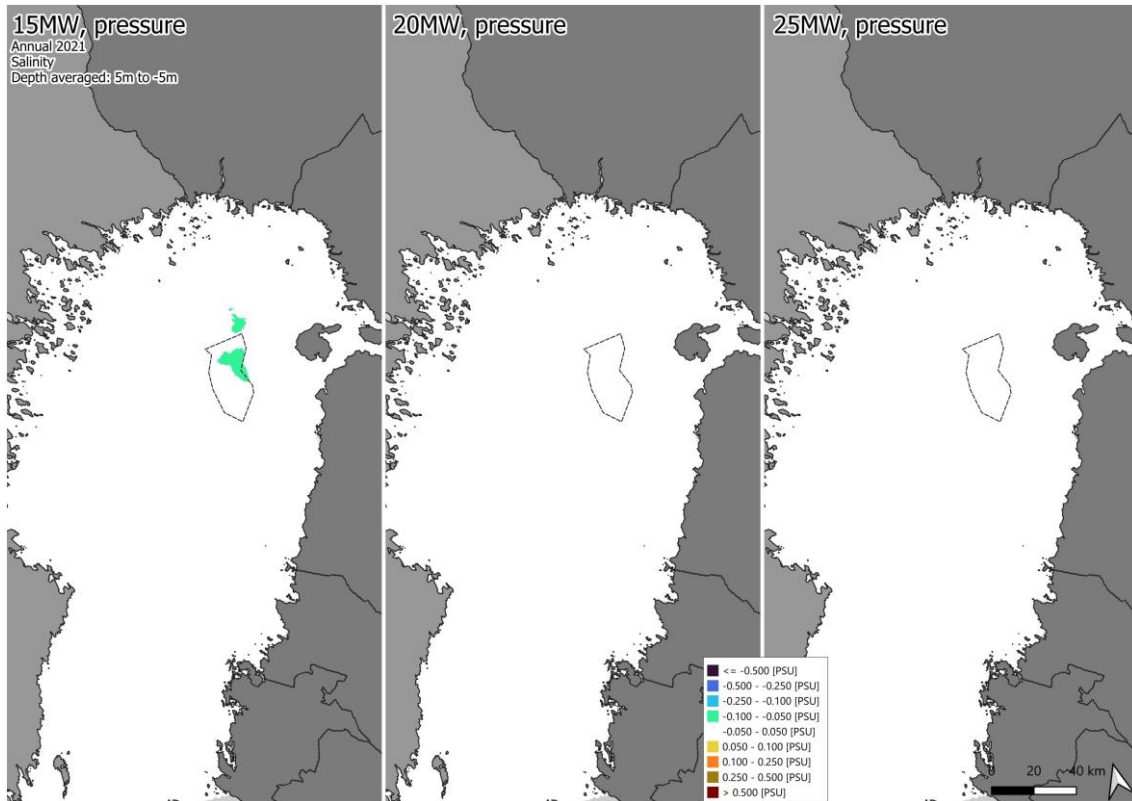


Figure 3.6: Change in annual (2021) average salinity in the upper most 5 m due to the 15MW (160 Turbines, left), the 20MW (120 Turbines, centre) and the 25MW (120 Turbines, right).

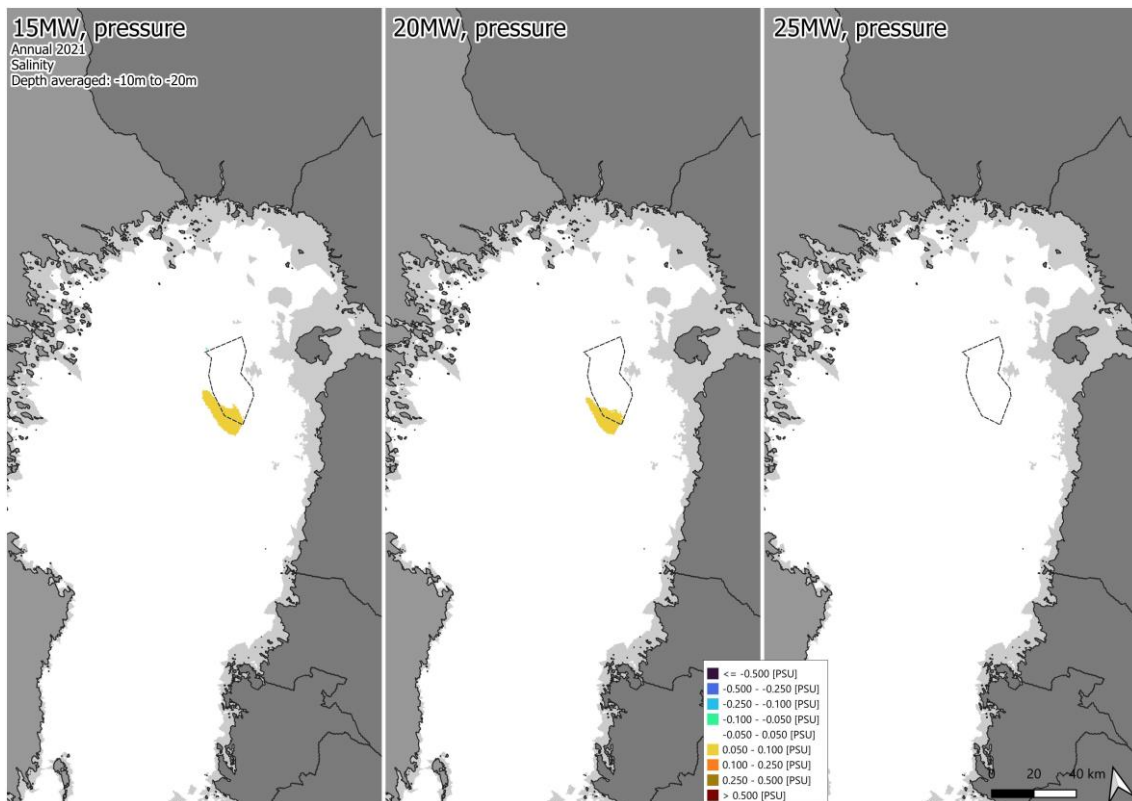


Figure 3.7: Change in annual (2021) average salinity between -10 and -20 m due to the 15MW (160 Turbines, left), the 20MW (120 Turbines, centre) and the 25MW (120 Turbines, right).

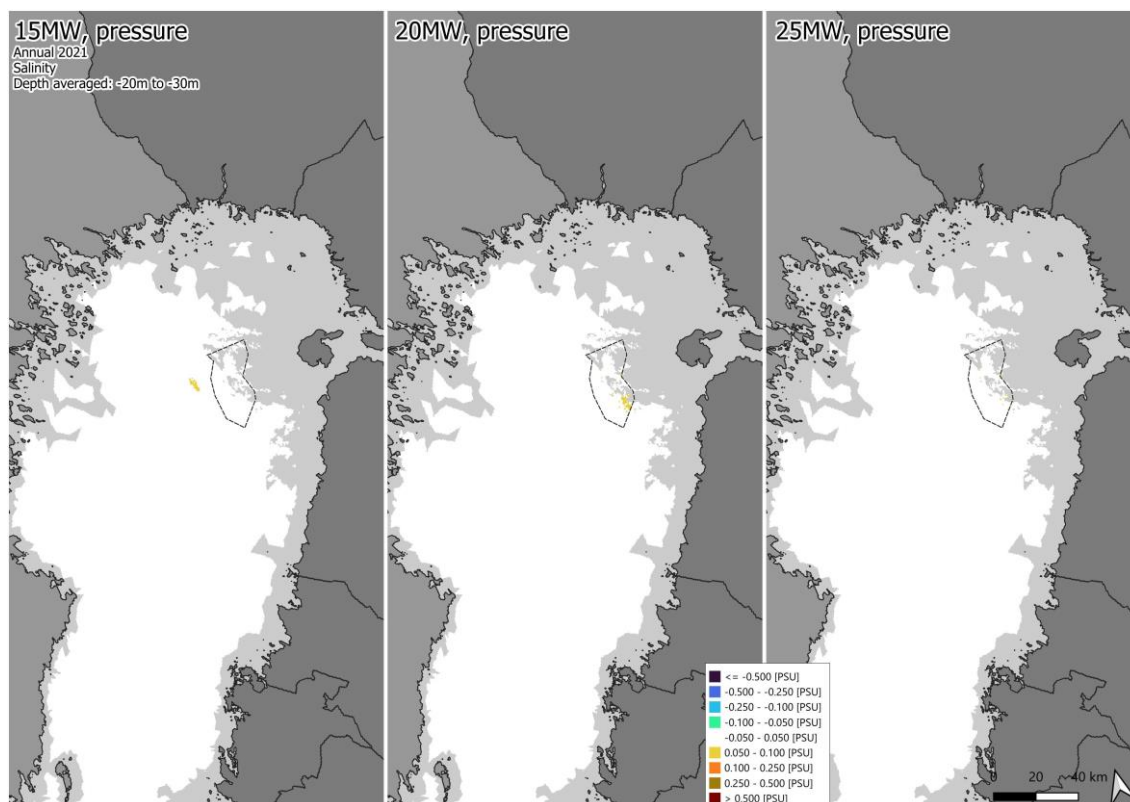


Figure 3.8: Change in annual (2021) average salinity between – 20 m and -30 m due to the 15MW (160 Turbines, left), the 20MW (120 Turbines, centre) and the 25MW (120 Turbines, right).

Table 3.2: Changes in the total salinity flux per month and on annual bases. Left: inner box, Right: outer box.

Month	15MW	20MW	25MW
2021-01-01	-223.52%	-343.64%	-317.16%
2021-02-01	-36.23%	-118.10%	-120.04%
2021-03-01	29.82%	-380.80%	-387.45%
2021-04-01	3.63%	-124.17%	-124.45%
2021-05-01	76.93%	-352.37%	-398.30%
2021-06-01	16.15%	-94.37%	-98.08%
2021-07-01	-6.96%	-62.19%	-59.83%
2021-08-01	-2.05%	-64.81%	-65.86%
2021-09-01	-5.05%	-101.72%	-102.23%
2021-10-01	-1.11%	-145.61%	-147.59%
2021-11-01	-197.25%	-3124.93%	-3065.51%
2021-12-01	-32.83%	-945.69%	-954.65%
2021-2022	-4.43%	-152.53%	-153.75%

Month	15MW	20MW	25MW
2021-01-01	-707.66%	-700.23%	-605.67%
2021-02-01	-10.33%	-22.17%	-24.05%
2021-03-01	-2.89%	-46.27%	-47.84%
2021-04-01	23.56%	-364.06%	-370.09%
2021-05-01	2490.90%	-1901.12%	-2850.10%
2021-06-01	15.29%	-36.07%	-39.73%
2021-07-01	-1.55%	-23.18%	-21.89%
2021-08-01	3.20%	-24.17%	-26.15%
2021-09-01	3.98%	-36.76%	-40.35%
2021-10-01	-7.94%	-58.42%	-57.39%
2021-11-01	-42.40%	-323.15%	-312.06%
2021-12-01	-18.49%	-273.03%	-276.87%
2021-2022	-1.66%	-70.47%	-72.29%

3.4. Temperature

Impact on the temperature is presented in Figure 3.9 to Figure 3.11 in Appendix 7. Table 16 to Table 18 in Appendix 8 summarize the maximum and minimum impact. With regard to the description of the baseline (situation without wind farm), please refer to (NIRAS, 2023-12-20).

Baseline (NIRAS, 2023-12-20): Annual average surface temperature (uppermost 5 m) for the year 2021 generally higher in the south and south-eastern part (accounting to approximately 7.5 °C) and lower along the coast in the northern and north-western parts with values between 5-6 °C. The lowest values occur along the Swedish coast, south of the planned wind farm. Since in summer the water warms up only at the surface to a certain depth, a stratification of the temperature takes place. The annual average temperatures decrease with depth. The thermocline generally lies between 10 to 20 m in summer. At this depth, the annual mean temperature of most of the Bay of Bothnia ranges between 4°C and 6°C, except for some areas south of the wind farm with temperatures above 6°C. Between 20 m and 30 m depth, the average temperature decreases to 3-5 °C over most of the sea area. Temperature conditions present strong seasonal variations with large areas in the northern, north-eastern part of the Bothnian Sea experiencing negative values (indicating ice-coverage) between December and April. In spring, temperatures rise relatively sharply, with this effect being more pronounced along the Finnish coast, resulting in a strong spatial temperature gradient in July with low temperatures of about 4-8°C (between 20 m and the surface) along the northern part of the Swedish coast and high temperatures of more than 12-19°C (between 20 and the surface) along the Finnish coast. Overall water temperature peaks between August and September with values between 14-20°C at the surface and 8 – 13°C at 10 to 20 m depth. Temperatures start to decrease during September.

General Impact of the investigated wind farm cases: Regarding the annual average temperature, there is an increase in the surface temperature to be expected, limited to 0.5°C for a minor area close to the wind farm area. At depths of -10 m to -40 m, an effect of maximum $\pm 1^\circ$ can be observed, whereas a cooling only occurs at depths between -10 m to -20 m within the wind farm area.

In respect to the seasonal variations, the effects can be described as follows:

- Dominant warming of the surface temperature can be observed in most of the months (except of February, July, and October, where only cooling is visible), whereas it is most pronounced in July with differences of up to $> 2.5^\circ\text{C}$. This can be explained, as due to reduced wind speeds less water vapour is transported away and thus, the evaporation (which cools down the water surface) is slowed down.
- Most pronounced effects occur between June and September, whereas the spatial distribution of the warmed and cooled areas vary between the months. While increased warming occurs west of the windfarm in June and July, in August waters north of the windfarm show higher temperatures compared to the baseline and in September that in the east of the windfarm. The cooling effect ($< -2^\circ\text{C}$) east is observable on the respective opposite side of the windfarm.
- As in summer, there is a thermocline between 10 and 20 m. Due to the reduced warming in the southern part of the windfarm in June to September, leading to a shift of the thermocline by up to 10 m (10 m instead of 20 m in July).

Maximum extent of cooled water appears in July August within a depth of 10 – 20 m, > 40 kilometres to the north and south of the windfarm.

Impact of the 25MW: Consistent with observations on salinity and current speed, no case consistently demonstrates the greatest impact. Considering the mean temperature in August (Appendix 9) for example, the induced increase of the temperature is most pronounced in the 25MW Case. In contrast, in September, depending on the depth considered, a different case has the major impact: The greatest impact on the surface temperature is to be attributed to the 15 MW case, between 10 m and 20 m, the effect is greater for the 25MW and 20MW case respectively. The temperature fluxes presented in Table 3.3 offer a more precise understanding of the

impact from the three cases. The data reveal that the 15MW scenario has the lowest impact, while the 25MW scenario exhibits the highest impact. However, it is important to note that the magnitude of impact remains within the same order across all cases.

In general, the comparison of the impact of the 25MW case with that of the 20MW or 15MW reveals an impact the same seasonal and spatial pattern. In addition, the order of magnitude is comparable.

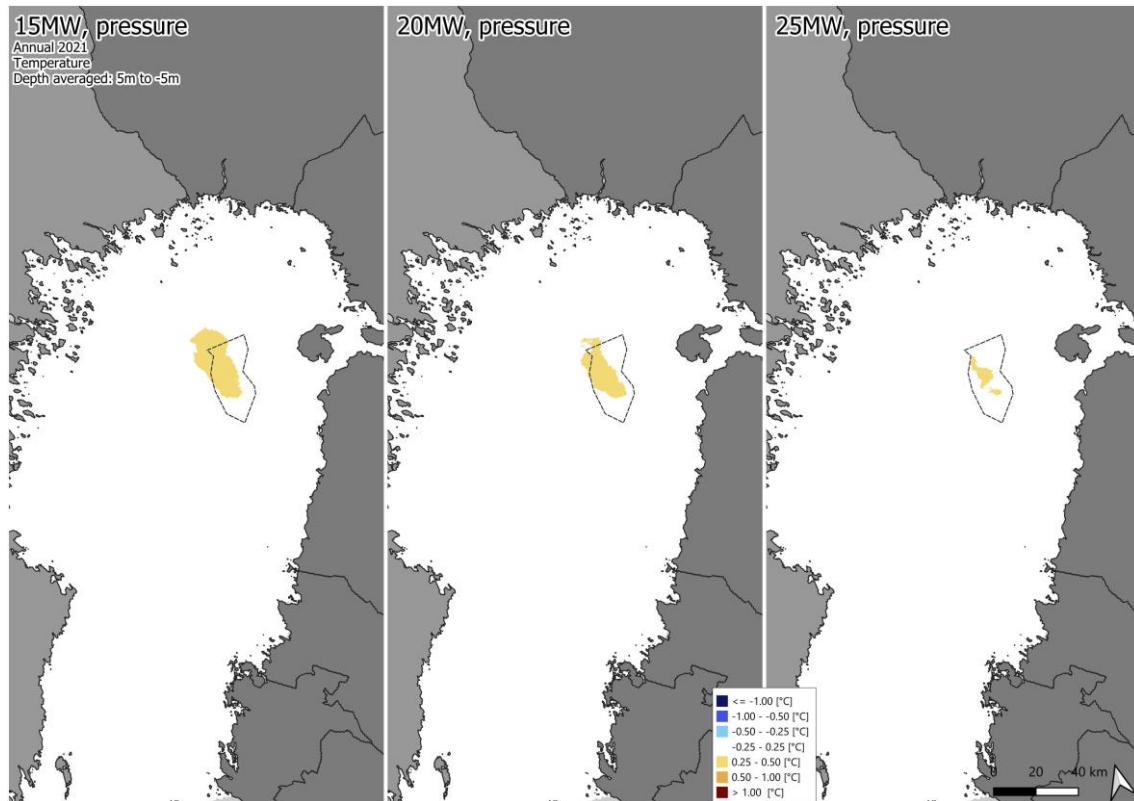


Figure 3.9: Change in annual (2021) average temperature in the upper most 5 m due to the 15MW (160 Turbines, left), the 20MW (120 Turbines, centre) and the 25MW (120 Turbines, right).

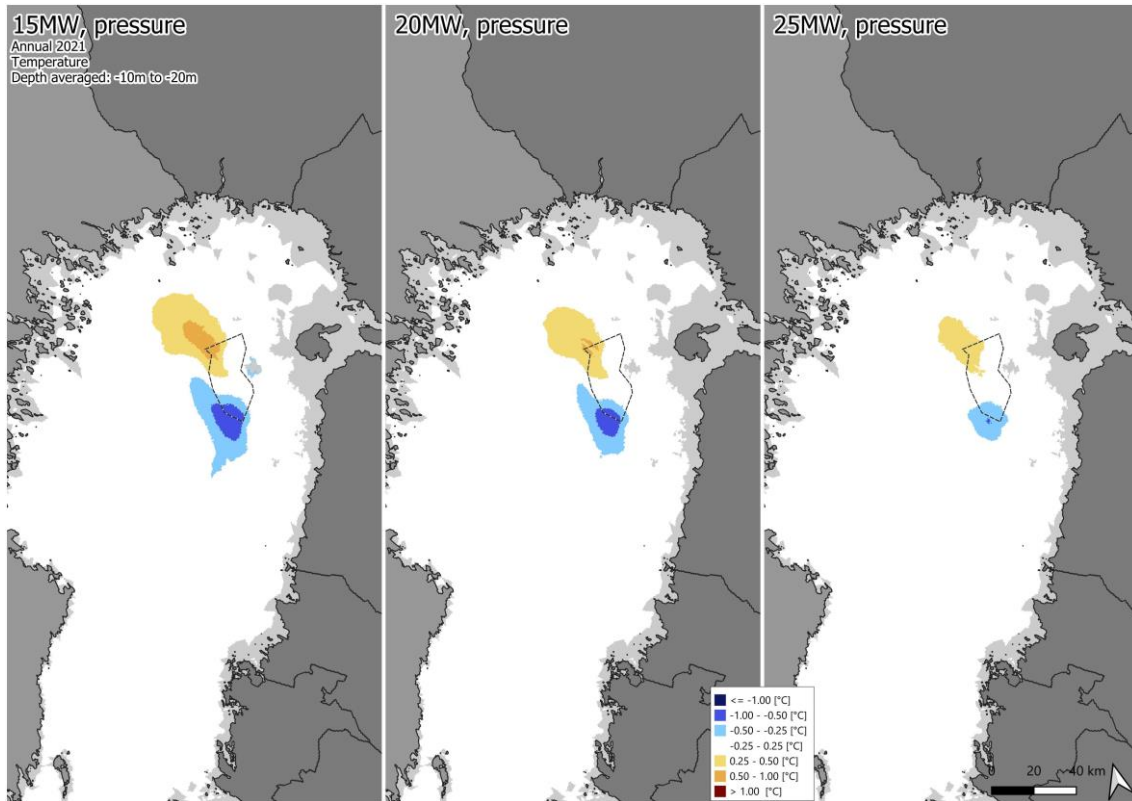


Figure 3.10: Change in annual (2021) average temperature between -10 and -20 m due to the 15MW (160 Turbines, left), the 20MW (120 Turbines, centre) and the 25MW (120 Turbines, right).

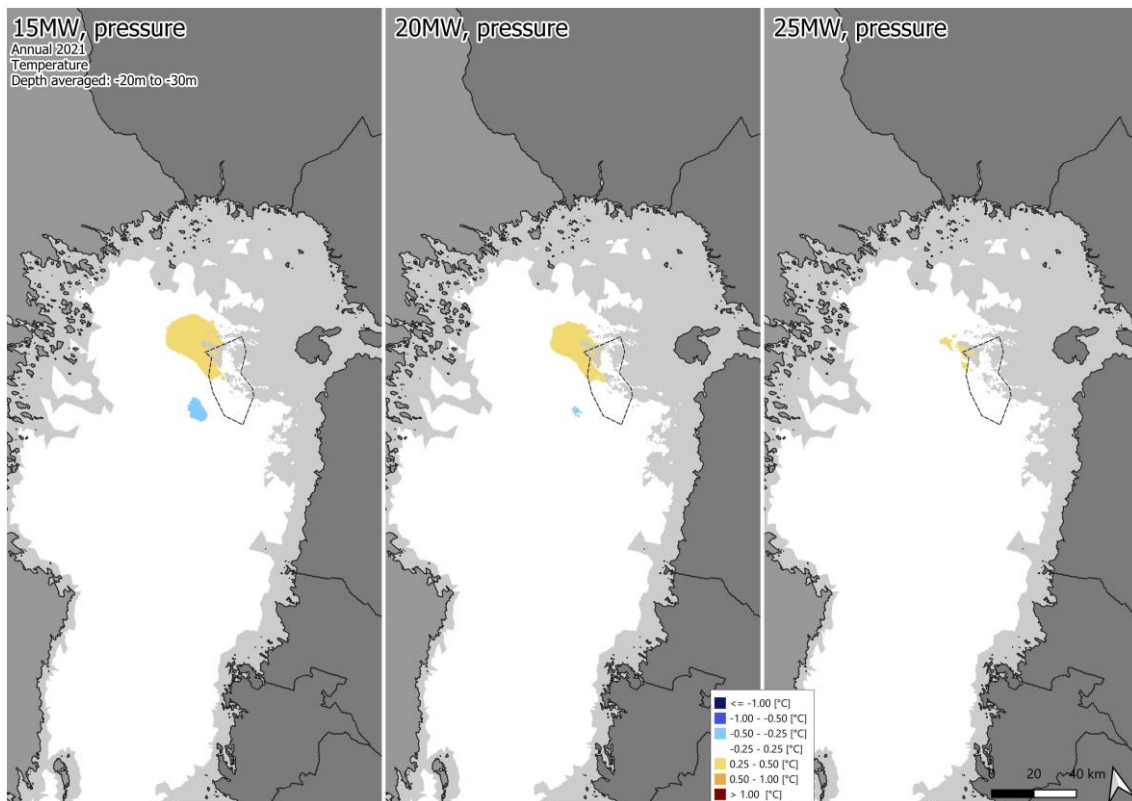


Figure 3.11: Change in annual (2021) average temperature between -20 m and -30 m due to the 15MW (160 Turbines, left), the 20MW (120 Turbines, centre) and the 25MW (120 Turbines, right).

Table 3.3: Changes in the total temperature flux per month and on annual bases. Left: inner box, Right: outer box.

Month	15MW	20MW	25MW
2021-01-01	-19.34%	-24.78%	-20.95%
2021-02-01	-26.05%	-27.64%	-25.08%
2021-03-01	-29.33%	-32.16%	-32.04%
2021-04-01	-26.59%	-35.55%	-35.45%
2021-05-01	-24.27%	-32.88%	-32.58%
2021-06-01	-29.01%	-34.56%	-33.48%
2021-07-01	-17.75%	-20.57%	-21.31%
2021-08-01	-17.55%	-23.46%	-23.19%
2021-09-01	-13.38%	-40.81%	-46.67%
2021-10-01	-244.12%	-400.60%	-401.57%
2021-11-01	-77.81%	-151.45%	-160.46%
2021-12-01	-82.14%	-129.03%	-137.37%
2021-2022	-33.11%	-46.87%	-47.68%

Month	15MW	20MW	25MW
2021-01-01	-37.04%	-37.85%	-31.03%
2021-02-01	-16.82%	-16.73%	-16.14%
2021-03-01	-20.14%	-19.45%	-19.15%
2021-04-01	-16.93%	-19.56%	-19.33%
2021-05-01	-19.13%	-21.50%	-20.39%
2021-06-01	-14.79%	-16.79%	-17.37%
2021-07-01	-5.83%	-5.97%	-7.83%
2021-08-01	-16.32%	-12.72%	-12.36%
2021-09-01	-7.90%	-12.58%	-11.18%
2021-10-01	77.53%	6.27%	-65.53%
2021-11-01	-4.36%	-22.06%	-29.49%
2021-12-01	-28.24%	-41.71%	-47.36%
2021-2022	-16.49%	-19.98%	-21.58%

3.5. Summary

The present documentation analyses the different influence of varying wind farm layouts and turbines on the hydrodynamics (temperature, salinity and current velocity). The following three different layouts (see also Table 2.1 and Table 2.2) were analysed:

- 15MW with 160 Turbines (D: 236 m, Hub height: 150 m),
- 20 MW with 120 Turbines (D: 276 m, Hub height: 170 m),
- 25 MW with 120 Turbines (D: 340 m, Hub height: 200 m).

While the results of the 15 MW and 20 MW cases are already described in detail in (NIRAS, 2023-12-20), the 25MW case was also analysed as part of this study. The results show that - regardless of the parameter considered - the cases analysed (15MW, 20MW and 25MW) have a comparable effect (in terms of impact area and magnitude). In addition, all analysed layouts show the same seasonal variations in respect of spatial occurrence and order of magnitude of the impact.

Based on these results, the impact is judged to be comparable.

4. References

Jensen, N.O. (1983). *A note on wind generator interaction*. DTU.

NIRAS. (2023-12-20). *Halla OWF, hydrodynamics - Sediment & Brine Dispersal modelling*.

REFWIND, IEA Wind Task 55. (n.d.). *IEAWindTask37/IEA-22-280-RWT*. Retrieved from <https://github.com/IEAWindTask37/IEA-22-280-RWT>

Appendix 1 Hydrodynamic Impact: Current 2D-Maps

The results are provided in a separate PDF.

Appendix 2 Hydrodynamic Impact: Current Areal analyses

Table 6: Areal statistics of impact of 15 MW case on the current speed

Maximum Reduction in Current Speed observed in the model area based on the mean over a specific period [m/s]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	-0.03	-0.04	-0.03	-0.02	-0.03	-0.03	-0.03	-0.04	-0.04	-0.05	-0.06	-0.05	-0.05
-5 m to -10 m	-0.02	-0.02	-0.02	-0.01	-0.01	-0.02	-0.02	-0.01	-0.02	-0.03	-0.05	-0.04	-0.03
-10 m to -20 m	-0.01	-0.02	-0.02	0.00	-0.01	-0.02	-0.02	-0.01	-0.02	-0.02	-0.03	-0.03	-0.02
-20 m to -30 m	-0.01	-0.01	-0.01	0.00	-0.01	-0.02	-0.02	-0.02	-0.02	-0.02	-0.03	-0.02	-0.03
-30 m to -40 m	-0.01	-0.01	-0.01	0.00	-0.01	-0.02	-0.02	-0.02	-0.01	-0.01	-0.03	-0.02	-0.03
-40 m to -50 m	-0.01	-0.01	-0.01	0.00	-0.01	-0.02	-0.02	-0.02	-0.01	-0.01	-0.01	-0.02	-0.03
-50 m to -60 m	-0.01	-0.01	-0.01	0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02
-60 m to -70 m	0.00	-0.01	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.01
-70 m to -80 m	0.00	-0.01	-0.01	0.00	0.00	-0.01	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.01

Maximum Increase in Current Speed observed in the model area based on the mean over a specific period [m/s]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	0.01	0.01	0.04	0.02	0.01	0.03	0.01	0.05	0.02	0.04	0.04	0.02	0.02
-5 m to -10 m	0.01	0.02	0.03	0.01	0.01	0.02	0.02	0.05	0.03	0.05	0.04	0.02	0.02
-10 m to -20 m	0.01	0.03	0.02	0.01	0.01	0.01	0.01	0.03	0.01	0.04	0.03	0.02	0.02
-20 m to -30 m	0.01	0.03	0.01	0.00	0.01	0.02	0.01	0.01	0.01	0.03	0.02	0.02	0.02
-30 m to -40 m	0.01	0.03	0.01	0.00	0.01	0.02	0.00	0.01	0.01	0.02	0.01	0.01	0.02
-40 m to -50 m	0.01	0.02	0.01	0.00	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.02
-50 m to -60 m	0.01	0.02	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.02	0.01	0.01	0.02
-60 m to -70 m	0.01	0.02	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.02	0.01	0.01	0.02
-70 m to -80 m	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.00	0.01

5% Percentile Difference (Decrease) in Current Speed observed in the model area based on the mean over a specific period [m/s]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	-0.003	-0.005	-0.003	-0.001	-0.003	-0.004	-0.003	-0.005	-0.005	-0.007	-0.009	-0.006	-0.006
-5 m to -10 m	-0.002	-0.004	-0.002	-0.001	-0.002	-0.004	-0.003	-0.002	-0.003	-0.004	-0.007	-0.005	-0.005
-10 m to -20 m	-0.002	-0.003	-0.002	-0.001	-0.002	-0.003	-0.003	-0.002	-0.005	-0.004	-0.007	-0.004	-0.005
-20 m to -30 m	-0.003	-0.003	-0.002	0.000	-0.001	-0.003	-0.002	-0.001	-0.004	-0.005	-0.007	-0.004	-0.005
-30 m to -40 m	-0.002	-0.003	-0.001	0.000	-0.001	-0.002	-0.002	-0.001	-0.004	-0.004	-0.007	-0.004	-0.005
-40 m to -50 m	-0.002	-0.004	-0.001	0.000	-0.001	-0.001	-0.002	-0.001	-0.003	-0.004	-0.005	-0.003	-0.004
-50 m to -60 m	-0.002	-0.005	-0.001	0.000	-0.001	-0.002	-0.001	-0.001	-0.002	-0.004	-0.005	-0.003	-0.003
-60 m to -70 m	-0.002	-0.005	-0.001	0.000	-0.001	-0.002	-0.001	-0.001	-0.002	-0.003	-0.005	-0.003	-0.003
-70 m to -80 m	-0.002	-0.005	-0.001	0.000	-0.001	-0.002	-0.001	-0.001	-0.003	-0.003	-0.005	-0.003	-0.004

95% Percentile Difference (Increase) in Current Speed observed in the model area based on the mean over a specific period [m/s]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	0.001	0.002	0.002	0.001	0.001	0.003	0.001	0.003	0.003	0.007	0.004	0.003	0.003
-5 m to -10 m	0.001	0.002	0.002	0.001	0.001	0.002	0.000	0.005	0.001	0.007	0.003	0.003	0.002
-10 m to -20 m	0.000	0.002	0.002	0.001	0.000	0.001	0.000	0.004	0.000	0.002	0.002	0.001	0.001
-20 m to -30 m	0.000	0.001	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.002	0.001	0.001	0.001
-30 m to -40 m	0.001	0.001	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.002	0.001	0.001	0.001
-40 m to -50 m	0.001	0.002	0.002	0.000	0.001	0.001	0.000	0.000	0.000	0.003	0.001	0.001	0.002
-50 m to -60 m	0.001	0.002	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.003	0.002	0.001	0.002
-60 m to -70 m	0.001	0.001	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.002	0.002	0.001	0.002
-70 m to -80 m	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.001

Table 5: Areal statistics of impact of 20 MW case on the current speed

Maximum Reduction in Current Speed observed in the model area based on the mean over a specific period [m/s]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	-0.02	-0.03	-0.03	-0.01	-0.02	-0.03	-0.02	-0.03	-0.04	-0.05	-0.05	-0.04	-0.04
-5 m to -10 m	-0.01	-0.02	-0.02	-0.01	-0.01	-0.02	-0.01	-0.01	-0.02	-0.02	-0.04	-0.03	-0.03
-10 m to -20 m	-0.01	-0.02	-0.02	0.00	-0.01	-0.02	-0.01	-0.01	-0.01	-0.02	-0.03	-0.02	-0.02
-20 m to -30 m	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02	-0.02	-0.01	-0.01	-0.02	-0.02	-0.02
-30 m to -40 m	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02	-0.02	-0.01	-0.01	-0.02	-0.02	-0.02
-40 m to -50 m	-0.01	-0.01	-0.01	0.00	-0.01	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02
-50 m to -60 m	-0.01	-0.01	0.00	0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02
-60 m to -70 m	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.01
-70 m to -80 m	0.00	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.01

Maximum Increase in Current Speed observed in the model area based on the mean over a specific period [m/s]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.04	0.02	0.03	0.03	0.01	0.02
-5 m to -10 m	0.01	0.01	0.02	0.01	0.00	0.01	0.01	0.04	0.02	0.03	0.03	0.02	0.01
-10 m to -20 m	0.01	0.02	0.01	0.00	0.01	0.01	0.01	0.02	0.01	0.03	0.02	0.02	0.01
-20 m to -30 m	0.01	0.02	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.02	0.02	0.01	0.02
-30 m to -40 m	0.01	0.02	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.02	0.01	0.01	0.02
-40 m to -50 m	0.01	0.02	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02
-50 m to -60 m	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.02	0.01	0.01	0.02
-60 m to -70 m	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.02
-70 m to -80 m	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01

5% Percentile Difference (Decrease) in Current Speed observed in the model area based on the mean over a specific period [m/s]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	-0.003	-0.004	-0.002	-0.001	-0.002	-0.004	-0.003	-0.004	-0.004	-0.006	-0.007	-0.005	-0.005
-5 m to -10 m	-0.002	-0.003	-0.002	-0.001	-0.002	-0.003	-0.002	-0.002	-0.003	-0.003	-0.006	-0.005	-0.005
-10 m to -20 m	-0.002	-0.002	-0.002	-0.001	-0.002	-0.003	-0.002	-0.002	-0.004	-0.003	-0.006	-0.004	-0.005
-20 m to -30 m	-0.002	-0.002	-0.001	0.000	-0.001	-0.003	-0.002	-0.001	-0.004	-0.004	-0.005	-0.003	-0.005
-30 m to -40 m	-0.002	-0.003	-0.001	0.000	-0.001	-0.002	-0.002	-0.001	-0.003	-0.003	-0.005	-0.003	-0.004
-40 m to -50 m	-0.002	-0.003	-0.001	0.000	-0.001	-0.001	-0.001	-0.001	-0.002	-0.003	-0.004	-0.003	-0.003
-50 m to -60 m	-0.002	-0.004	-0.001	0.000	-0.001	-0.001	-0.001	-0.001	-0.002	-0.003	-0.004	-0.002	-0.003
-60 m to -70 m	-0.002	-0.004	-0.001	0.000	-0.001	-0.001	-0.001	-0.001	-0.002	-0.003	-0.004	-0.002	-0.003
-70 m to -80 m	-0.002	-0.005	-0.001	0.000	-0.001	-0.001	-0.001	-0.001	-0.002	-0.003	-0.004	-0.003	-0.003

95% Percentile Difference (Increase) in Current Speed observed in the model area based on the mean over a specific period [m/s]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.005	0.003	0.003	0.002
-5 m to -10 m	0.001	0.001	0.002	0.000	0.000	0.001	0.000	0.003	0.001	0.005	0.003	0.002	0.002
-10 m to -20 m	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.003	0.000	0.002	0.002	0.001	0.001
-20 m to -30 m	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001
-30 m to -40 m	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001
-40 m to -50 m	0.001	0.001	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.002	0.001	0.001	0.001
-50 m to -60 m	0.001	0.001	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.002	0.001	0.001	0.001
-60 m to -70 m	0.001	0.001	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.002	0.001	0.001	0.001
-70 m to -80 m	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.001

Appendix 3 Hydrodynamic Impact: Comparison of Mean current

Table 7: Differences of mean current speed [m/s] – Part 1

(considering varying extents (Bothnian Bay, innerBox, and outerBox), different depth intervals and different time intervals)

Entire Year		Current Speed								
		Bothnian Bay			innerBox			outerBox		
		25MW	20MW	15MW	25MW	20MW	15MW	25MW	20MW	15MW
	5 - -5m	-0.0004	-0.0004	-0.0003	-0.0084	-0.0096	-0.0101	-0.0043	-0.0043	-0.0042
	-5 - -10m	-0.0002	-0.0002	-0.0002	-0.0029	-0.0031	-0.0021	-0.0015	-0.0012	-0.0005
	-10 - -20m	-0.0003	-0.0004	-0.0004	-0.0024	-0.0025	-0.0015	-0.0012	-0.0012	-0.0004
	-20 - -30m	-0.0003	-0.0004	-0.0004	-0.0027	-0.0033	-0.0028	-0.0014	-0.0018	-0.0014
	-30 - -40m	-0.0003	-0.0003	-0.0004	-0.0024	-0.0030	-0.0025	-0.0010	-0.0012	-0.0009
	-40 - -50m	-0.0002	-0.0002	-0.0002	-0.0017	-0.0018	-0.0012	-0.0004	-0.0003	0.0001
	-50 - -60m	-0.0002	-0.0002	-0.0002	-0.0003	0.0001	0.0011	-0.0001	0.0002	0.0006
	-60 - -70m	-0.0002	-0.0002	-0.0002	0.0016	0.0028	0.0040	-0.0001	0.0003	0.0006
	-70 - -80m	-0.0002	-0.0003	-0.0003	0.0020	0.0026	0.0034	-0.0004	-0.0003	-0.0002

January		Current Speed								
		Bothnian Bay			innerBox			outerBox		
		25MW	20MW	15MW	25MW	20MW	15MW	25MW	20MW	15MW
	5 - -5m	-0.0006	-0.0006	-0.0007	-0.0114	-0.0117	-0.0137	-0.0068	-0.0067	-0.0079
	-5 - -10m	-0.0004	-0.0005	-0.0005	-0.0053	-0.0054	-0.0054	-0.0032	-0.0032	-0.0031
	-10 - -20m	-0.0003	-0.0004	-0.0004	-0.0011	-0.0015	-0.0004	-0.0003	-0.0006	0.0003
	-20 - -30m	-0.0002	-0.0003	-0.0003	0.0017	0.0010	0.0025	0.0019	0.0012	0.0025
	-30 - -40m	-0.0001	-0.0002	-0.0002	0.0038	0.0032	0.0052	0.0029	0.0025	0.0038
	-40 - -50m	-0.0002	-0.0003	-0.0003	0.0056	0.0050	0.0080	0.0025	0.0024	0.0038
	-50 - -60m	-0.0004	-0.0004	-0.0004	0.0080	0.0076	0.0112	0.0014	0.0015	0.0025
	-60 - -70m	-0.0006	-0.0006	-0.0007	0.0096	0.0098	0.0131	0.0001	0.0002	0.0007
	-70 - -80m	-0.0007	-0.0008	-0.0009	0.0099	0.0096	0.0125	-0.0016	-0.0017	-0.0017

February		Current Speed								
		Bothnian Bay			innerBox			outerBox		
		25MW	20MW	15MW	25MW	20MW	15MW	25MW	20MW	15MW
	5 - -5m	-0.0001	-0.0001	-0.0001	-0.0023	-0.0020	-0.0031	-0.0017	-0.0013	-0.0019
	-5 - -10m	-0.0001	0.0000	0.0000	-0.0018	-0.0014	-0.0022	-0.0011	-0.0008	-0.0011
	-10 - -20m	-0.0001	-0.0001	-0.0001	-0.0016	-0.0012	-0.0016	-0.0008	-0.0005	-0.0006
	-20 - -30m	-0.0001	-0.0001	-0.0001	-0.0012	-0.0008	-0.0010	-0.0003	-0.0001	0.0002
	-30 - -40m	0.0000	0.0000	0.0000	-0.0009	-0.0004	-0.0003	0.0004	0.0004	0.0009
	-40 - -50m	0.0001	0.0001	0.0001	-0.0011	-0.0006	-0.0007	0.0006	0.0006	0.0011
	-50 - -60m	0.0000	0.0001	0.0001	-0.0007	0.0000	-0.0002	0.0003	0.0007	0.0009
	-60 - -70m	-0.0001	0.0001	0.0001	0.0005	0.0013	0.0015	0.0001	0.0009	0.0011
	-70 - -80m	-0.0002	0.0000	0.0000	0.0007	0.0010	0.0015	0.0001	0.0011	0.0013

March		Current Speed								
		Bothnian Bay			innerBox			outerBox		
		25MW	20MW	15MW	25MW	20MW	15MW	25MW	20MW	15MW
	5 - -5m	-0.0001	-0.0001	-0.0001	-0.0008	-0.0009	-0.0014	-0.0008	-0.0008	-0.0010
	-5 - -10m	0.0000	-0.0001	-0.0001	-0.0003	-0.0004	-0.0008	-0.0004	-0.0004	-0.0005
	-10 - -20m	0.0000	0.0000	0.0000	-0.0003	-0.0004	-0.0005	-0.0002	-0.0003	-0.0002
	-20 - -30m	0.0000	0.0000	0.0000	-0.0004	-0.0006	-0.0002	-0.0002	-0.0003	0.0000
	-30 - -40m	0.0000	0.0000	0.0000	-0.0002	-0.0004	0.0001	-0.0001	-0.0003	-0.0001
	-40 - -50m	0.0000	0.0000	0.0000	0.0000	-0.0001	0.0002	0.0000	-0.0001	0.0000
	-50 - -60m	0.0000	0.0000	0.0000	0.0002	0.0003	0.0004	0.0002	0.0002	0.0002
	-60 - -70m	0.0000	0.0000	0.0000	0.0004	0.0005	0.0007	0.0002	0.0003	0.0004
	-70 - -80m	-0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0003	0.0005

Table 8: Differences of mean current speed [m/s] – Part 2
(considering varying extents (Bothnian Bay, innerBox, and outerBox), different depth intervals and different time intervals)

		Current Speed								
		Bothnian Bay			innerBox			outerBox		
		25MW	20MW	15MW	25MW	20MW	15MW	25MW	20MW	15MW
April	5 - -5m	-0.0002	-0.0003	-0.0003	-0.0048	-0.0063	-0.0072	-0.0029	-0.0036	-0.0040
	-5 - -10m	-0.0002	-0.0002	-0.0002	-0.0024	-0.0033	-0.0035	-0.0017	-0.0021	-0.0021
	-10 - -20m	-0.0002	-0.0003	-0.0003	-0.0016	-0.0025	-0.0027	-0.0013	-0.0018	-0.0019
	-20 - -30m	-0.0001	-0.0002	-0.0002	-0.0023	-0.0036	-0.0035	-0.0013	-0.0020	-0.0019
	-30 - -40m	-0.0001	-0.0001	-0.0001	-0.0020	-0.0030	-0.0028	-0.0007	-0.0010	-0.0008
	-40 - -50m	0.0000	0.0000	0.0000	-0.0009	-0.0011	-0.0009	-0.0001	0.0000	0.0001
	-50 - -60m	0.0000	0.0000	0.0000	0.0002	0.0009	0.0016	0.0002	0.0005	0.0007
	-60 - -70m	0.0000	0.0000	0.0000	0.0015	0.0029	0.0036	0.0002	0.0005	0.0006
	-70 - -80m	0.0000	-0.0001	-0.0001	0.0009	0.0017	0.0020	-0.0002	-0.0002	-0.0003
May	5 - -5m	-0.0003	-0.0003	-0.0003	-0.0081	-0.0102	-0.0117	-0.0033	-0.0039	-0.0044
	-5 - -10m	-0.0002	-0.0003	-0.0002	-0.0037	-0.0045	-0.0043	-0.0015	-0.0018	-0.0016
	-10 - -20m	-0.0004	-0.0005	-0.0006	-0.0045	-0.0056	-0.0051	-0.0027	-0.0033	-0.0029
	-20 - -30m	-0.0004	-0.0005	-0.0004	-0.0056	-0.0074	-0.0072	-0.0030	-0.0036	-0.0031
	-30 - -40m	-0.0003	-0.0003	-0.0003	-0.0059	-0.0070	-0.0064	-0.0022	-0.0020	-0.0013
	-40 - -50m	-0.0002	-0.0001	-0.0001	-0.0044	-0.0042	-0.0032	-0.0010	-0.0002	0.0006
	-50 - -60m	-0.0001	-0.0001	-0.0001	-0.0018	-0.0005	0.0007	-0.0003	0.0004	0.0010
	-60 - -70m	-0.0001	-0.0001	-0.0001	0.0010	0.0030	0.0042	-0.0003	0.0001	0.0004
	-70 - -80m	-0.0002	-0.0002	-0.0002	0.0018	0.0029	0.0030	-0.0009	-0.0009	-0.0009
June	5 - -5m	-0.0007	-0.0006	-0.0007	-0.0093	-0.0093	-0.0102	-0.0057	-0.0057	-0.0065
	-5 - -10m	-0.0005	-0.0004	-0.0005	-0.0032	-0.0029	-0.0018	-0.0024	-0.0024	-0.0023
	-10 - -20m	-0.0004	-0.0004	-0.0005	-0.0044	-0.0049	-0.0043	-0.0020	-0.0020	-0.0016
	-20 - -30m	-0.0004	-0.0004	-0.0005	-0.0053	-0.0063	-0.0066	-0.0029	-0.0033	-0.0036
	-30 - -40m	-0.0004	-0.0005	-0.0005	-0.0046	-0.0057	-0.0061	-0.0025	-0.0031	-0.0035
	-40 - -50m	-0.0003	-0.0004	-0.0004	-0.0041	-0.0052	-0.0056	-0.0017	-0.0021	-0.0023
	-50 - -60m	-0.0002	-0.0003	-0.0003	-0.0037	-0.0045	-0.0045	-0.0013	-0.0015	-0.0015
	-60 - -70m	-0.0002	-0.0002	-0.0002	-0.0016	-0.0016	-0.0012	-0.0009	-0.0010	-0.0009
	-70 - -80m	-0.0001	-0.0002	-0.0002	0.0002	0.0001	0.0000	-0.0007	-0.0009	-0.0009
July	5 - -5m	-0.0004	-0.0002	0.0000	-0.0020	-0.0001	0.0050	-0.0017	0.0001	0.0036
	-5 - -10m	0.0002	0.0003	0.0005	0.0102	0.0118	0.0165	0.0059	0.0072	0.0103
	-10 - -20m	0.0001	0.0001	0.0002	0.0007	0.0014	0.0035	0.0021	0.0028	0.0045
	-20 - -30m	-0.0002	-0.0002	-0.0002	-0.0030	-0.0030	-0.0029	-0.0011	-0.0011	-0.0007
	-30 - -40m	-0.0002	-0.0002	-0.0002	-0.0030	-0.0028	-0.0029	-0.0010	-0.0009	-0.0006
	-40 - -50m	-0.0002	-0.0002	-0.0002	-0.0027	-0.0025	-0.0023	-0.0006	-0.0004	0.0001
	-50 - -60m	-0.0002	-0.0001	-0.0001	-0.0018	-0.0016	-0.0009	-0.0005	-0.0003	0.0003
	-60 - -70m	-0.0002	-0.0001	-0.0001	-0.0001	0.0003	0.0016	-0.0005	-0.0003	0.0003
	-70 - -80m	-0.0002	-0.0002	-0.0002	0.0009	0.0010	0.0017	-0.0007	-0.0006	-0.0003
August	5 - -5m	-0.0006	-0.0006	-0.0005	-0.0119	-0.0114	-0.0098	-0.0055	-0.0042	-0.0023
	-5 - -10m	-0.0005	-0.0004	-0.0004	-0.0036	-0.0024	0.0000	-0.0019	-0.0007	0.0007
	-10 - -20m	-0.0008	-0.0010	-0.0010	-0.0030	-0.0036	-0.0019	-0.0025	-0.0029	-0.0018
	-20 - -30m	-0.0006	-0.0007	-0.0008	-0.0043	-0.0062	-0.0061	-0.0031	-0.0041	-0.0041
	-30 - -40m	-0.0006	-0.0007	-0.0008	-0.0036	-0.0050	-0.0047	-0.0028	-0.0033	-0.0032
	-40 - -50m	-0.0005	-0.0005	-0.0006	-0.0028	-0.0036	-0.0028	-0.0022	-0.0021	-0.0019
	-50 - -60m	-0.0004	-0.0004	-0.0005	-0.0015	-0.0014	-0.0003	-0.0014	-0.0010	-0.0008
	-60 - -70m	-0.0004	-0.0003	-0.0004	0.0007	0.0016	0.0030	-0.0009	-0.0003	-0.0002
	-70 - -80m	-0.0003	-0.0003	-0.0004	0.0014	0.0020	0.0034	-0.0008	-0.0006	-0.0006

Table 9: Differences of mean current speed [m/s]– Part 3

(considering varying extents (Bothnian Bay, innerBox, and outerBox), different depth intervals and different time intervals)

		Current Speed								
		Bothnian Bay			innerBox			outerBox		
		25MW	20MW	15MW	25MW	20MW	15MW	25MW	20MW	15MW
September	5 - -5m	-0.0003	0.0000	0.0003	-0.0121	-0.0127	-0.0121	-0.0056	-0.0037	-0.0024
	-5 - -10m	0.0000	0.0004	0.0008	-0.0035	-0.0012	0.0017	-0.0015	0.0012	0.0033
	-10 - -20m	-0.0002	0.0000	0.0002	-0.0005	0.0021	0.0055	-0.0006	0.0010	0.0030
	-20 - -30m	-0.0003	-0.0004	-0.0003	-0.0021	-0.0010	0.0013	-0.0009	-0.0001	0.0014
	-30 - -40m	-0.0002	-0.0002	-0.0001	-0.0014	-0.0002	0.0017	-0.0001	0.0007	0.0017
	-40 - -50m	-0.0001	0.0000	0.0000	0.0006	0.0026	0.0046	0.0009	0.0021	0.0030
	-50 - -60m	0.0000	0.0000	0.0001	0.0025	0.0050	0.0072	0.0014	0.0028	0.0036
	-60 - -70m	0.0000	0.0000	0.0000	0.0042	0.0069	0.0093	0.0015	0.0027	0.0034
	-70 - -80m	-0.0001	-0.0001	-0.0001	0.0020	0.0036	0.0043	0.0007	0.0015	0.0019
October	5 - -5m	-0.0005	-0.0006	-0.0005	-0.0135	-0.0180	-0.0185	-0.0057	-0.0072	-0.0068
	-5 - -10m	-0.0004	-0.0005	-0.0003	-0.0084	-0.0096	-0.0074	-0.0034	-0.0036	-0.0020
	-10 - -20m	-0.0005	-0.0006	-0.0005	-0.0052	-0.0046	-0.0019	-0.0021	-0.0018	-0.0001
	-20 - -30m	-0.0006	-0.0009	-0.0010	-0.0032	-0.0023	-0.0001	-0.0022	-0.0025	-0.0017
	-30 - -40m	-0.0006	-0.0008	-0.0010	-0.0036	-0.0042	-0.0033	-0.0023	-0.0031	-0.0030
	-40 - -50m	-0.0004	-0.0006	-0.0007	-0.0035	-0.0041	-0.0041	-0.0011	-0.0013	-0.0013
	-50 - -60m	-0.0003	-0.0004	-0.0005	-0.0024	-0.0021	-0.0022	-0.0003	0.0001	0.0004
	-60 - -70m	-0.0002	-0.0004	-0.0004	0.0004	0.0019	0.0028	0.0002	0.0008	0.0013
	-70 - -80m	-0.0002	-0.0004	-0.0005	0.0012	0.0025	0.0030	0.0004	0.0010	0.0017
November	5 - -5m	-0.0006	-0.0006	-0.0006	-0.0120	-0.0149	-0.0169	-0.0057	-0.0069	-0.0073
	-5 - -10m	-0.0005	-0.0005	-0.0004	-0.0070	-0.0084	-0.0083	-0.0031	-0.0037	-0.0032
	-10 - -20m	-0.0004	-0.0005	-0.0004	-0.0039	-0.0045	-0.0036	-0.0016	-0.0016	-0.0007
	-20 - -30m	-0.0003	-0.0004	-0.0003	-0.0022	-0.0020	-0.0012	-0.0013	-0.0011	-0.0006
	-30 - -40m	-0.0003	-0.0003	-0.0003	-0.0028	-0.0023	-0.0017	-0.0012	-0.0011	-0.0007
	-40 - -50m	-0.0002	-0.0003	-0.0003	-0.0029	-0.0024	-0.0020	-0.0011	-0.0011	-0.0010
	-50 - -60m	-0.0002	-0.0003	-0.0003	-0.0017	-0.0010	-0.0008	-0.0009	-0.0011	-0.0011
	-60 - -70m	-0.0002	-0.0003	-0.0004	0.0005	0.0015	0.0018	-0.0008	-0.0010	-0.0011
	-70 - -80m	-0.0003	-0.0004	-0.0004	0.0008	0.0014	0.0016	-0.0011	-0.0015	-0.0017
December	5 - -5m	-0.0005	-0.0006	-0.0007	-0.0125	-0.0176	-0.0208	-0.0063	-0.0081	-0.0095
	-5 - -10m	-0.0004	-0.0005	-0.0006	-0.0063	-0.0095	-0.0101	-0.0031	-0.0046	-0.0048
	-10 - -20m	-0.0005	-0.0007	-0.0009	-0.0034	-0.0050	-0.0047	-0.0020	-0.0031	-0.0029
	-20 - -30m	-0.0005	-0.0007	-0.0008	-0.0042	-0.0071	-0.0078	-0.0025	-0.0042	-0.0045
	-30 - -40m	-0.0004	-0.0006	-0.0007	-0.0048	-0.0082	-0.0086	-0.0019	-0.0034	-0.0035
	-40 - -50m	-0.0003	-0.0004	-0.0004	-0.0037	-0.0055	-0.0051	-0.0009	-0.0013	-0.0010
	-50 - -60m	-0.0002	-0.0002	-0.0002	-0.0015	-0.0012	0.0003	-0.0002	0.0000	0.0005
	-60 - -70m	-0.0002	-0.0002	-0.0002	0.0022	0.0052	0.0073	0.0000	0.0004	0.0008
	-70 - -80m	-0.0002	-0.0004	-0.0004	0.0045	0.0053	0.0068	-0.0007	-0.0010	-0.0010

Appendix 4 Hydrodynamic Impact: Salinity – 2D-Maps

The results are provided in a separate PDF.

Appendix 5 Hydrodynamic Impact: Salinity Areal analyses

Table 10: Areal statistics of impact of 15 MW case on the salinity

Maximum Reduction in Salinity observed in the model area based on the mean over a specific period [PSU]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	-0.06	-0.07	-0.13	-0.07	-0.09	-0.10	-0.28	-0.28	-0.13	-0.12	-0.13	-0.18	-0.14
-5 m to -10 m	-0.06	-0.06	-0.12	-0.05	-0.05	-0.10	-0.19	-0.27	-0.13	-0.18	-0.11	-0.17	-0.14
-10 m to -20 m	-0.05	-0.06	-0.13	-0.04	-0.04	-0.11	-0.14	-0.23	-0.12	-0.24	-0.09	-0.14	-0.11
-20 m to -30 m	-0.05	-0.08	-0.13	-0.04	-0.02	-0.12	-0.10	-0.18	-0.11	-0.27	-0.07	-0.12	-0.09
-30 m to -40 m	-0.02	-0.11	-0.12	-0.03	-0.02	-0.05	-0.04	-0.10	-0.04	-0.09	-0.10	-0.10	-0.07
-40 m to -50 m	-0.01	-0.11	-0.09	-0.03	-0.02	-0.02	-0.02	-0.04	-0.02	-0.01	-0.11	-0.07	-0.05
-50 m to -60 m	-0.01	-0.12	-0.06	-0.02	-0.02	-0.03	-0.02	-0.03	-0.01	-0.01	-0.10	-0.07	-0.05
-60 m to -70 m	-0.01	-0.11	-0.04	-0.02	-0.02	-0.03	-0.02	-0.01	0.00	-0.01	-0.06	-0.06	-0.04
-70 m to -80 m	-0.01	-0.11	-0.04	-0.02	-0.02	-0.02	-0.02	-0.01	0.00	-0.01	-0.03	-0.04	-0.06

Maximum Increase in Salinity observed in the model area based on the mean over a specific period [PSU]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	0.02	0.06	0.14	0.12	0.05	0.13	0.11	0.21	0.12	0.08	0.08	0.08	0.05
-5 m to -10 m	0.05	0.06	0.12	0.06	0.05	0.19	0.16	0.16	0.08	0.14	0.08	0.08	0.07
-10 m to -20 m	0.07	0.06	0.12	0.04	0.05	0.20	0.25	0.19	0.16	0.29	0.07	0.08	0.07
-20 m to -30 m	0.05	0.06	0.11	0.04	0.04	0.18	0.16	0.15	0.14	0.24	0.11	0.07	0.05
-30 m to -40 m	0.03	0.06	0.10	0.03	0.03	0.11	0.14	0.11	0.08	0.13	0.12	0.07	0.04
-40 m to -50 m	0.03	0.07	0.10	0.03	0.02	0.09	0.09	0.06	0.05	0.09	0.13	0.05	0.04
-50 m to -60 m	0.03	0.10	0.10	0.04	0.03	0.07	0.04	0.05	0.03	0.03	0.13	0.12	0.04
-60 m to -70 m	0.02	0.12	0.06	0.01	0.01	0.06	0.04	0.04	0.04	0.03	0.10	0.03	0.03
-70 m to -80 m	0.03	0.14	0.07	0.02	0.01	0.05	0.05	0.04	0.04	0.04	0.09	0.03	0.02

5% Percentile Difference (Decrease) in Salinity observed in the model area based on the mean over a specific period [PSU]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	-0.02	-0.03	-0.03	-0.02	-0.02	-0.03	-0.06	-0.08	-0.06	-0.06	-0.05	-0.08	-0.07
-5 m to -10 m	-0.03	-0.03	-0.04	-0.02	-0.01	-0.03	-0.04	-0.06	-0.05	-0.06	-0.05	-0.08	-0.06
-10 m to -20 m	-0.03	-0.03	-0.04	-0.01	-0.01	-0.03	-0.04	-0.05	-0.03	-0.06	-0.04	-0.07	-0.05
-20 m to -30 m	-0.02	-0.04	-0.04	-0.01	-0.01	-0.02	-0.02	-0.05	-0.02	-0.02	-0.04	-0.05	-0.03
-30 m to -40 m	-0.01	-0.04	-0.03	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.03	-0.03	-0.02
-40 m to -50 m	0.00	-0.05	-0.03	-0.02	-0.01	-0.01	0.00	-0.01	0.00	-0.01	-0.03	-0.02	-0.01
-50 m to -60 m	0.00	-0.05	-0.03	-0.02	-0.01	-0.01	0.00	0.00	0.00	0.00	-0.02	-0.01	-0.01
-60 m to -70 m	0.00	-0.05	-0.03	-0.02	-0.01	-0.01	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01
-70 m to -80 m	0.00	-0.03	-0.03	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01

95% Percentile Difference (Increase) in Salinity observed in the model area based on the mean over a specific period [PSU]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	0.01	0.02	0.02	0.02	0.01	0.01	0.04	0.07	0.04	0.03	0.02	0.05	0.03
-5 m to -10 m	0.01	0.02	0.02	0.01	0.01	0.02	0.03	0.05	0.04	0.03	0.02	0.04	0.02
-10 m to -20 m	0.01	0.02	0.02	0.01	0.01	0.02	0.03	0.03	0.03	0.05	0.02	0.04	0.03
-20 m to -30 m	0.01	0.02	0.02	0.01	0.00	0.03	0.03	0.04	0.03	0.04	0.03	0.04	0.03
-30 m to -40 m	0.01	0.02	0.01	0.01	0.00	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.02
-40 m to -50 m	0.01	0.02	0.01	0.01	0.01	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02
-50 m to -60 m	0.01	0.03	0.01	0.01	0.01	0.02	0.03	0.02	0.02	0.02	0.03	0.02	0.02
-60 m to -70 m	0.01	0.06	0.02	0.01	0.01	0.02	0.03	0.03	0.02	0.02	0.03	0.02	0.01
-70 m to -80 m	0.01	0.06	0.02	0.01	0.01	0.02	0.03	0.03	0.02	0.02	0.03	0.01	0.01

Table 11: Areal statistics of impact of 20 MW case on the salinity

Maximum Reduction in Salinity observed in the model area based on the mean over a specific period [PSU]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	-0.05	-0.05	-0.09	-0.05	-0.10	-0.07	-0.22	-0.23	-0.10	-0.10	-0.10	-0.12	-0.10
-5 m to -10 m	-0.04	-0.05	-0.09	-0.04	-0.06	-0.09	-0.15	-0.23	-0.11	-0.13	-0.09	-0.12	-0.10
-10 m to -20 m	-0.04	-0.05	-0.10	-0.03	-0.02	-0.12	-0.10	-0.20	-0.09	-0.19	-0.07	-0.10	-0.07
-20 m to -30 m	-0.03	-0.07	-0.11	-0.02	-0.01	-0.07	-0.07	-0.13	-0.07	-0.21	-0.05	-0.08	-0.06
-30 m to -40 m	-0.01	-0.08	-0.09	-0.02	-0.01	-0.02	-0.03	-0.06	-0.02	-0.06	-0.08	-0.07	-0.04
-40 m to -50 m	-0.01	-0.09	-0.06	-0.02	-0.01	-0.01	-0.01	-0.03	-0.01	-0.01	-0.07	-0.05	-0.04
-50 m to -60 m	-0.01	-0.10	-0.04	-0.01	-0.01	-0.02	-0.01	-0.02	0.00	-0.01	-0.06	-0.05	-0.04
-60 m to -70 m	-0.01	-0.08	-0.03	-0.01	-0.01	-0.02	-0.01	-0.01	0.00	-0.01	-0.04	-0.04	-0.03
-70 m to -80 m	0.00	-0.08	-0.03	-0.01	-0.01	-0.01	-0.01	-0.01	0.00	-0.01	-0.02	-0.03	-0.02

Maximum Increase in Salinity observed in the model area based on the mean over a specific period [PSU]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	0.02	0.05	0.10	0.09	0.10	0.11	0.09	0.16	0.09	0.06	0.07	0.07	0.04
-5 m to -10 m	0.04	0.05	0.08	0.06	0.07	0.16	0.12	0.14	0.07	0.10	0.07	0.07	0.06
-10 m to -20 m	0.06	0.05	0.09	0.07	0.07	0.17	0.22	0.15	0.15	0.24	0.06	0.07	0.06
-20 m to -30 m	0.09	0.08	0.16	0.17	0.13	0.17	0.17	0.14	0.13	0.22	0.10	0.06	0.06
-30 m to -40 m	0.08	0.10	0.10	0.08	0.10	0.11	0.16	0.13	0.09	0.14	0.10	0.05	0.06
-40 m to -50 m	0.06	0.07	0.09	0.05	0.05	0.10	0.10	0.08	0.06	0.09	0.11	0.04	0.04
-50 m to -60 m	0.03	0.08	0.08	0.03	0.02	0.05	0.06	0.05	0.05	0.04	0.10	0.03	0.04
-60 m to -70 m	0.02	0.09	0.04	0.01	0.01	0.05	0.04	0.04	0.03	0.03	0.08	0.03	0.02
-70 m to -80 m	0.02	0.11	0.05	0.01	0.01	0.04	0.04	0.03	0.03	0.03	0.08	0.03	0.02

5% Percentile Difference (Decrease) in Salinity observed in the model area based on the mean over a specific period [PSU]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	-0.02	-0.02	-0.02	-0.01	-0.01	-0.02	-0.05	-0.07	-0.05	-0.04	-0.03	-0.06	-0.05
-5 m to -10 m	-0.02	-0.02	-0.03	-0.01	-0.01	-0.02	-0.03	-0.05	-0.05	-0.05	-0.03	-0.06	-0.04
-10 m to -20 m	-0.02	-0.02	-0.03	-0.01	0.00	-0.02	-0.03	-0.04	-0.03	-0.05	-0.03	-0.05	-0.04
-20 m to -30 m	-0.01	-0.03	-0.02	-0.01	0.00	-0.01	-0.02	-0.03	-0.01	-0.01	-0.02	-0.03	-0.02
-30 m to -40 m	0.00	-0.03	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	0.00	-0.02	-0.02	-0.01
-40 m to -50 m	0.00	-0.04	-0.02	-0.01	-0.01	-0.01	0.00	0.00	0.00	0.00	-0.02	-0.01	0.00
-50 m to -60 m	0.00	-0.04	-0.02	-0.01	-0.01	-0.01	0.00	0.00	0.00	0.00	-0.01	-0.01	0.00
-60 m to -70 m	0.00	-0.03	-0.02	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	0.00
-70 m to -80 m	0.00	-0.02	-0.02	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01

95% Percentile Difference (Increase) in Salinity observed in the model area based on the mean over a specific period [PSU]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	0.01	0.02	0.02	0.01	0.01	0.01	0.03	0.06	0.04	0.03	0.02	0.04	0.02
-5 m to -10 m	0.01	0.02	0.02	0.01	0.01	0.02	0.03	0.04	0.04	0.03	0.02	0.04	0.02
-10 m to -20 m	0.01	0.02	0.02	0.01	0.01	0.02	0.03	0.04	0.03	0.04	0.02	0.03	0.03
-20 m to -30 m	0.02	0.02	0.01	0.01	0.01	0.02	0.03	0.05	0.03	0.05	0.03	0.03	0.03
-30 m to -40 m	0.01	0.01	0.01	0.01	0.00	0.02	0.02	0.04	0.03	0.03	0.03	0.02	0.02
-40 m to -50 m	0.01	0.01	0.01	0.01	0.00	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
-50 m to -60 m	0.01	0.03	0.01	0.01	0.00	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02
-60 m to -70 m	0.01	0.05	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.01
-70 m to -80 m	0.01	0.05	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.01	0.01

Table 12: Areal statistics of impact of 25 MW case on the salinity

Maximum Reduction in Salinity observed in the model area based on the mean over a specific period [PSU]														
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December	
5 m to -5 m	-0.04	-0.04	-0.11	-0.05	-0.08	-0.08	-0.14	-0.19	-0.09	-0.07	-0.05	-0.07	-0.05	
-5 m to -10 m	-0.03	-0.05	-0.10	-0.03	-0.05	-0.10	-0.10	-0.21	-0.09	-0.07	-0.04	-0.06	-0.05	
-10 m to -20 m	-0.02	-0.04	-0.11	-0.03	-0.02	-0.10	-0.08	-0.19	-0.07	-0.12	-0.03	-0.05	-0.05	
-20 m to -30 m	-0.01	-0.06	-0.11	-0.02	-0.01	-0.06	-0.06	-0.13	-0.03	-0.12	-0.03	-0.04	-0.04	
-30 m to -40 m	-0.01	-0.08	-0.10	-0.02	-0.01	-0.02	-0.03	-0.07	-0.02	-0.03	-0.04	-0.04	-0.03	
-40 m to -50 m	0.00	-0.08	-0.08	-0.02	-0.01	-0.01	-0.02	-0.03	-0.01	-0.01	-0.04	-0.03	-0.02	
-50 m to -60 m	0.00	-0.09	-0.07	-0.02	-0.01	-0.02	-0.02	-0.02	-0.01	-0.01	-0.03	-0.03	-0.02	
-60 m to -70 m	0.00	-0.09	-0.04	-0.02	-0.01	-0.02	-0.01	-0.01	0.00	0.00	-0.02	-0.03	-0.01	
-70 m to -80 m	0.00	-0.08	-0.03	-0.02	-0.01	-0.01	-0.01	-0.01	0.00	0.00	-0.01	-0.01	-0.01	

Maximum Increase in Salinity observed in the model area based on the mean over a specific period [PSU]														
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December	
5 m to -5 m	0.02	0.05	0.12	0.09	0.09	0.07	0.07	0.14	0.09	0.04	0.03	0.04	0.02	
-5 m to -10 m	0.02	0.05	0.10	0.06	0.05	0.10	0.09	0.13	0.08	0.04	0.03	0.04	0.02	
-10 m to -20 m	0.04	0.04	0.10	0.07	0.06	0.13	0.18	0.13	0.14	0.11	0.03	0.04	0.04	
-20 m to -30 m	0.08	0.08	0.16	0.18	0.13	0.13	0.15	0.14	0.12	0.14	0.07	0.06	0.05	
-30 m to -40 m	0.07	0.10	0.11	0.08	0.10	0.09	0.14	0.12	0.11	0.10	0.06	0.04	0.05	
-40 m to -50 m	0.05	0.08	0.10	0.04	0.05	0.06	0.07	0.08	0.08	0.08	0.07	0.03	0.04	
-50 m to -60 m	0.02	0.09	0.10	0.03	0.02	0.04	0.05	0.05	0.04	0.03	0.07	0.02	0.03	
-60 m to -70 m	0.02	0.10	0.06	0.01	0.01	0.02	0.03	0.03	0.02	0.02	0.05	0.02	0.02	
-70 m to -80 m	0.02	0.10	0.06	0.01	0.01	0.02	0.03	0.02	0.02	0.02	0.05	0.02	0.01	

5% Percentile Difference (Decrease) in Salinity observed in the model area based on the mean over a specific period [PSU]														
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December	
5 m to -5 m	-0.01	-0.02	-0.02	-0.02	-0.01	-0.02	-0.03	-0.06	-0.05	-0.03	-0.02	-0.03	-0.02	
-5 m to -10 m	-0.01	-0.02	-0.03	-0.01	-0.01	-0.02	-0.02	-0.04	-0.04	-0.04	-0.02	-0.03	-0.02	
-10 m to -20 m	-0.01	-0.02	-0.03	-0.01	-0.01	-0.01	-0.02	-0.04	-0.03	-0.03	-0.01	-0.02	-0.02	
-20 m to -30 m	0.00	-0.03	-0.03	-0.01	0.00	-0.01	-0.02	-0.03	-0.01	-0.01	-0.01	-0.01	-0.01	
-30 m to -40 m	0.00	-0.03	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	0.00	0.00	-0.01	-0.01	-0.01	
-40 m to -50 m	0.00	-0.04	-0.02	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	0.00	
-50 m to -60 m	0.00	-0.04	-0.02	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	
-60 m to -70 m	0.00	-0.03	-0.02	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
-70 m to -80 m	0.00	-0.02	-0.02	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

95% Percentile Difference (Increase) in Salinity observed in the model area based on the mean over a specific period [PSU]														
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December	
5 m to -5 m	0.01	0.01	0.02	0.01	0.01	0.02	0.03	0.06	0.04	0.02	0.01	0.02	0.01	
-5 m to -10 m	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.04	0.04	0.02	0.01	0.02	0.01	
-10 m to -20 m	0.01	0.01	0.02	0.01	0.01	0.02	0.03	0.04	0.03	0.02	0.01	0.02	0.01	
-20 m to -30 m	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.05	0.03	0.03	0.01	0.02	0.02	
-30 m to -40 m	0.01	0.01	0.01	0.01	0.00	0.02	0.02	0.03	0.02	0.03	0.02	0.01	0.02	
-40 m to -50 m	0.01	0.01	0.01	0.01	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	
-50 m to -60 m	0.01	0.03	0.01	0.01	0.00	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.01	
-60 m to -70 m	0.01	0.05	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	
-70 m to -80 m	0.01	0.06	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01	

Appendix 6 Hydrodynamic Impact: Comparison of Mean Salinity

Table 13: Differences of mean Salinity [PSU] – Part 1

(considering varying extents (Bothnian Bay, innerBox, and outerBox), different depth intervals and different time intervals)

Entire Year		Salinity								
		Bothnian Bay			innerBox			outerBox		
		25MW	20MW	15MW	25MW	20MW	15MW	25MW	20MW	15MW
	5 - -5m	-0.0011	-0.0017	-0.0047	-0.015	-0.019	-0.028	-0.010	-0.013	-0.020
	-5 - -10m	-0.0008	-0.0014	-0.0043	-0.009	-0.010	-0.015	-0.006	-0.007	-0.011
	-10 - -20m	0.0003	-0.0001	-0.0029	0.009	0.010	0.002	0.007	0.008	0.002
	-20 - -30m	0.0020	0.0023	0.0003	0.020	0.024	0.011	0.015	0.019	0.011
	-30 - -40m	0.0025	0.0029	0.0018	0.014	0.018	0.007	0.009	0.012	0.007
	-40 - -50m	0.0028	0.0032	0.0026	0.006	0.010	0.002	0.004	0.006	0.001
	-50 - -60m	0.0029	0.0032	0.0030	0.001	0.004	0.000	0.001	0.002	-0.002
	-60 - -70m	0.0031	0.0033	0.0035	0.000	0.003	0.000	0.001	0.001	-0.001
	-70 - -80m	0.0032	0.0033	0.0038	-0.002	0.002	0.000	0.001	0.002	0.000
January		Salinity								
		Bothnian Bay			innerBox			outerBox		
		25MW	20MW	15MW	25MW	20MW	15MW	25MW	20MW	15MW
	5 - -5m	-0.0010	-0.0007	-0.0012	-0.007	-0.007	-0.015	-0.007	-0.007	-0.013
	-5 - -10m	-0.0013	-0.0011	-0.0017	-0.009	-0.009	-0.018	-0.007	-0.008	-0.014
	-10 - -20m	-0.0013	-0.0010	-0.0017	-0.006	-0.007	-0.017	-0.007	-0.008	-0.014
	-20 - -30m	-0.0016	-0.0013	-0.0019	0.001	-0.002	-0.010	-0.008	-0.010	-0.016
	-30 - -40m	-0.0018	-0.0017	-0.0022	-0.012	-0.018	-0.026	-0.012	-0.017	-0.022
	-40 - -50m	-0.0002	-0.0005	-0.0006	-0.037	-0.044	-0.057	-0.019	-0.025	-0.032
	-50 - -60m	0.0022	0.0014	0.0017	-0.057	-0.062	-0.081	-0.024	-0.032	-0.042
	-60 - -70m	0.0057	0.0047	0.0056	-0.058	-0.063	-0.083	-0.022	-0.028	-0.040
	-70 - -80m	0.0078	0.0070	0.0084	-0.077	-0.075	-0.099	-0.021	-0.024	-0.035
February		Salinity								
		Bothnian Bay			innerBox			outerBox		
		25MW	20MW	15MW	25MW	20MW	15MW	25MW	20MW	15MW
	5 - -5m	-0.0020	-0.0014	-0.0022	0.014	0.012	0.011	0.011	0.009	0.009
	-5 - -10m	-0.0025	-0.0019	-0.0031	0.005	0.004	-0.001	0.006	0.005	0.002
	-10 - -20m	-0.0019	-0.0015	-0.0031	0.004	0.004	-0.011	0.005	0.005	-0.003
	-20 - -30m	-0.0008	-0.0004	-0.0017	-0.005	-0.005	-0.027	-0.003	-0.001	-0.012
	-30 - -40m	0.0006	0.0005	0.0001	-0.028	-0.023	-0.043	-0.011	-0.008	-0.017
	-40 - -50m	0.0015	0.0009	0.0008	-0.030	-0.022	-0.037	-0.014	-0.011	-0.018
	-50 - -60m	0.0023	0.0014	0.0016	-0.025	-0.016	-0.025	-0.017	-0.013	-0.019
	-60 - -70m	0.0037	0.0026	0.0032	-0.021	-0.012	-0.019	-0.015	-0.012	-0.017
	-70 - -80m	0.0055	0.0045	0.0058	-0.019	-0.012	-0.018	-0.012	-0.010	-0.014
March		Salinity								
		Bothnian Bay			innerBox			outerBox		
		25MW	20MW	15MW	25MW	20MW	15MW	25MW	20MW	15MW
	5 - -5m	-0.0019	-0.0012	-0.0023	0.018	0.018	0.022	0.009	0.010	0.012
	-5 - -10m	-0.0011	-0.0008	-0.0021	0.015	0.014	0.011	0.007	0.007	0.004
	-10 - -20m	0.0004	0.0004	-0.0013	0.018	0.018	0.005	0.008	0.008	-0.001
	-20 - -30m	0.0007	0.0006	-0.0007	0.013	0.015	-0.004	0.004	0.005	-0.005
	-30 - -40m	0.0003	0.0001	-0.0008	0.006	0.008	-0.002	-0.001	0.001	-0.005
	-40 - -50m	0.0003	0.0000	-0.0007	0.003	0.004	0.000	-0.003	-0.001	-0.005
	-50 - -60m	0.0008	0.0006	0.0002	0.001	0.001	-0.001	-0.002	-0.002	-0.005
	-60 - -70m	0.0016	0.0013	0.0013	-0.001	-0.002	-0.003	-0.002	-0.003	-0.005
	-70 - -80m	0.0027	0.0023	0.0027	-0.001	-0.002	-0.004	-0.002	-0.004	-0.007

Table 14: Differences of mean mean Salinity [PSU] – Part 2

(considering varying extents (Bothnian Bay, innerBox, and outerBox), different depth intervals and different time intervals)

		Salinity								
		Bothnian Bay			innerBox			outerBox		
		25MW	20MW	15MW	25MW	20MW	15MW	25MW	20MW	15MW
April	5 - -5m	-0.0006	-0.0010	-0.0027	0.002	-0.006	-0.014	0.002	-0.003	-0.007
	-5 - -10m	0.0001	-0.0001	-0.0019	0.011	0.009	0.005	0.006	0.004	0.001
	-10 - -20m	0.0005	0.0007	-0.0013	0.017	0.019	0.009	0.010	0.012	0.005
	-20 - -30m	0.0003	0.0007	-0.0010	0.021	0.024	0.006	0.011	0.015	0.006
	-30 - -40m	0.0003	0.0005	-0.0008	0.014	0.017	0.005	0.007	0.010	0.004
	-40 - -50m	0.0009	0.0008	0.0001	0.009	0.009	0.003	0.004	0.005	0.002
	-50 - -60m	0.0012	0.0010	0.0007	0.003	0.002	0.000	0.001	0.001	-0.001
	-60 - -70m	0.0017	0.0014	0.0014	0.001	0.000	-0.001	-0.001	-0.002	-0.003
	-70 - -80m	0.0024	0.0019	0.0022	-0.002	-0.003	-0.005	-0.001	-0.003	-0.004
May	5 - -5m	-0.0017	-0.0033	-0.0070	-0.017	-0.006	-0.013	-0.005	0.001	-0.005
	-5 - -10m	-0.0008	-0.0022	-0.0054	-0.002	0.013	0.013	0.005	0.013	0.011
	-10 - -20m	0.0002	-0.0005	-0.0030	0.021	0.036	0.032	0.022	0.030	0.026
	-20 - -30m	0.0011	0.0017	0.0005	0.034	0.047	0.038	0.029	0.040	0.037
	-30 - -40m	0.0015	0.0024	0.0018	0.027	0.036	0.027	0.023	0.032	0.031
	-40 - -50m	0.0020	0.0030	0.0028	0.019	0.024	0.018	0.016	0.023	0.024
	-50 - -60m	0.0023	0.0029	0.0030	0.014	0.016	0.012	0.012	0.018	0.019
	-60 - -70m	0.0031	0.0036	0.0039	0.011	0.014	0.012	0.010	0.017	0.018
	-70 - -80m	0.0038	0.0043	0.0050	0.017	0.020	0.020	0.012	0.020	0.023
June	5 - -5m	-0.0018	-0.0041	-0.0080	-0.036	-0.051	-0.061	-0.024	-0.035	-0.042
	-5 - -10m	-0.0013	-0.0025	-0.0057	-0.016	-0.018	-0.016	-0.012	-0.015	-0.016
	-10 - -20m	0.0005	0.0000	-0.0037	0.037	0.048	0.049	0.021	0.023	0.019
	-20 - -30m	0.0015	0.0016	-0.0004	0.063	0.078	0.068	0.041	0.050	0.045
	-30 - -40m	0.0022	0.0028	0.0025	0.046	0.055	0.043	0.029	0.039	0.037
	-40 - -50m	0.0035	0.0046	0.0051	0.031	0.038	0.030	0.018	0.027	0.028
	-50 - -60m	0.0037	0.0049	0.0056	0.019	0.026	0.026	0.012	0.019	0.020
	-60 - -70m	0.0038	0.0049	0.0057	0.014	0.023	0.026	0.009	0.014	0.016
	-70 - -80m	0.0034	0.0045	0.0052	0.020	0.033	0.040	0.008	0.014	0.017
July	5 - -5m	0.0002	-0.0005	-0.0033	-0.059	-0.074	-0.087	-0.026	-0.040	-0.053
	-5 - -10m	-0.0001	-0.0007	-0.0030	-0.036	-0.050	-0.047	-0.012	-0.022	-0.023
	-10 - -20m	-0.0009	-0.0018	-0.0057	-0.002	-0.011	-0.023	0.003	-0.004	-0.015
	-20 - -30m	0.0016	0.0014	-0.0024	0.037	0.034	0.008	0.027	0.026	0.008
	-30 - -40m	0.0027	0.0031	0.0016	0.046	0.049	0.034	0.027	0.032	0.023
	-40 - -50m	0.0038	0.0048	0.0049	0.038	0.044	0.038	0.019	0.026	0.023
	-50 - -60m	0.0042	0.0054	0.0061	0.027	0.032	0.032	0.014	0.020	0.020
	-60 - -70m	0.0042	0.0054	0.0062	0.018	0.022	0.024	0.011	0.015	0.017
	-70 - -80m	0.0035	0.0046	0.0053	0.017	0.023	0.026	0.009	0.015	0.016
August	5 - -5m	-0.0023	-0.0024	-0.0064	-0.053	-0.051	-0.060	-0.046	-0.045	-0.053
	-5 - -10m	-0.0023	-0.0026	-0.0062	-0.038	-0.034	-0.035	-0.034	-0.031	-0.033
	-10 - -20m	0.0007	-0.0002	-0.0038	0.011	0.010	0.003	0.014	0.015	0.011
	-20 - -30m	0.0045	0.0041	0.0013	0.036	0.039	0.023	0.039	0.046	0.037
	-30 - -40m	0.0044	0.0047	0.0035	0.028	0.037	0.026	0.030	0.039	0.035
	-40 - -50m	0.0040	0.0046	0.0043	0.020	0.030	0.024	0.021	0.027	0.026
	-50 - -60m	0.0037	0.0044	0.0046	0.014	0.021	0.019	0.013	0.018	0.018
	-60 - -70m	0.0034	0.0042	0.0047	0.012	0.018	0.017	0.010	0.013	0.014
	-70 - -80m	0.0029	0.0037	0.0042	0.014	0.020	0.021	0.009	0.013	0.014

Table 15: Differences of mean mean Salinity [PSU] – Part 3

(considering varying extents (Bothnian Bay, innerBox, and outerBox), different depth intervals and different time intervals)

		Salinity								
		Bothnian Bay			innerBox			outerBox		
		25MW	20MW	15MW	25MW	20MW	15MW	25MW	20MW	15MW
September	5 - -5m	-0.0021	-0.0038	-0.0086	-0.026	-0.037	-0.049	-0.020	-0.028	-0.038
	-5 - -10m	-0.0015	-0.0032	-0.0076	-0.023	-0.029	-0.037	-0.018	-0.021	-0.026
	-10 - -20m	0.0012	0.0007	-0.0029	0.003	0.006	-0.003	0.007	0.019	0.015
	-20 - -30m	0.0058	0.0068	0.0042	0.022	0.027	0.010	0.027	0.039	0.028
	-30 - -40m	0.0052	0.0061	0.0049	0.019	0.027	0.013	0.020	0.029	0.022
	-40 - -50m	0.0039	0.0047	0.0042	0.015	0.023	0.016	0.014	0.019	0.016
	-50 - -60m	0.0027	0.0033	0.0034	0.013	0.021	0.020	0.009	0.013	0.012
	-60 - -70m	0.0021	0.0027	0.0029	0.011	0.020	0.022	0.006	0.009	0.010
	-70 - -80m	0.0016	0.0019	0.0023	0.009	0.019	0.021	0.004	0.006	0.008
October	5 - -5m	0.0007	0.0001	-0.0034	0.001	0.000	-0.006	-0.001	0.001	-0.005
	-5 - -10m	0.0008	0.0001	-0.0033	0.002	0.003	-0.003	0.000	0.002	-0.003
	-10 - -20m	0.0014	0.0009	-0.0020	0.005	0.012	0.013	0.002	0.006	0.004
	-20 - -30m	0.0029	0.0037	0.0018	0.004	0.016	0.018	0.000	0.005	0.003
	-30 - -40m	0.0040	0.0048	0.0024	-0.008	-0.006	-0.016	-0.008	-0.014	-0.027
	-40 - -50m	0.0040	0.0039	0.0013	-0.011	-0.018	-0.035	-0.010	-0.026	-0.045
	-50 - -60m	0.0040	0.0045	0.0029	-0.006	-0.013	-0.028	-0.007	-0.020	-0.036
	-60 - -70m	0.0036	0.0046	0.0039	-0.004	-0.012	-0.024	-0.003	-0.012	-0.022
	-70 - -80m	0.0028	0.0036	0.0033	-0.006	-0.011	-0.020	-0.002	-0.006	-0.012
November	5 - -5m	0.0009	0.0009	-0.0036	-0.003	-0.013	-0.033	-0.003	-0.008	-0.021
	-5 - -10m	0.0010	0.0005	-0.0041	-0.003	-0.012	-0.031	-0.003	-0.007	-0.020
	-10 - -20m	0.0015	0.0006	-0.0035	0.000	-0.009	-0.025	-0.002	-0.007	-0.019
	-20 - -30m	0.0033	0.0034	0.0012	0.009	0.007	-0.004	0.004	0.001	-0.006
	-30 - -40m	0.0044	0.0057	0.0045	0.012	0.014	0.010	0.004	0.003	-0.001
	-40 - -50m	0.0046	0.0059	0.0049	0.008	0.012	0.010	0.001	-0.001	-0.007
	-50 - -60m	0.0033	0.0040	0.0030	0.006	0.011	0.011	0.000	-0.002	-0.008
	-60 - -70m	0.0021	0.0023	0.0013	0.007	0.011	0.011	0.002	0.000	-0.005
	-70 - -80m	0.0010	0.0007	-0.0002	0.007	0.013	0.015	0.003	0.003	0.000
December	5 - -5m	-0.0019	-0.0025	-0.0077	-0.014	-0.015	-0.030	-0.011	-0.009	-0.021
	-5 - -10m	-0.0011	-0.0019	-0.0069	-0.011	-0.009	-0.022	-0.008	-0.005	-0.015
	-10 - -20m	0.0011	0.0011	-0.0029	-0.004	-0.001	-0.012	-0.003	0.000	-0.008
	-20 - -30m	0.0045	0.0055	0.0032	0.007	0.011	0.003	0.003	0.006	0.000
	-30 - -40m	0.0055	0.0062	0.0043	0.009	0.013	0.009	0.004	0.003	-0.001
	-40 - -50m	0.0054	0.0056	0.0038	0.009	0.014	0.011	0.004	0.001	-0.003
	-50 - -60m	0.0041	0.0041	0.0030	0.005	0.013	0.012	0.003	0.001	-0.002
	-60 - -70m	0.0024	0.0022	0.0017	0.005	0.014	0.014	0.002	0.002	-0.001
	-70 - -80m	0.0014	0.0010	0.0009	-0.002	0.006	0.005	0.000	0.001	-0.001

Appendix 7 Hydrodynamic Impact: Temperature 2D-Maps

The results are provided in a separate PDF.

Appendix 8 Hydrodynamic Impact: Temperature Areal analyses

Table 16: Areal statistics of impact of 15 MW case on the temperature

Maximum Reduction in Temperature observed in the model area based on the mean over a specific period [°C]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	-0.13	-0.33	-0.87	-0.42	-0.19	-0.12	-0.57	-1.04	-0.35	-0.24	-0.34	-0.32	-0.28
-5 m to -10 m	-0.53	-0.25	-1.22	-0.37	-0.15	-0.39	-2.22	-3.15	-2.17	-1.18	-0.47	-0.29	-0.32
-10 m to -20 m	-0.87	-0.30	-1.13	-0.35	-0.12	-0.70	-2.13	-4.49	-3.36	-3.09	-0.99	-0.24	-0.35
-20 m to -30 m	-0.30	-0.41	-1.07	-0.30	-0.10	-0.44	-1.68	-2.09	-1.24	-2.84	-1.40	-0.19	-0.33
-30 m to -40 m	-0.20	-0.53	-0.54	-0.13	-0.09	-0.36	-1.12	-1.45	-0.56	-1.10	-1.52	-0.40	-0.32
-40 m to -50 m	-0.17	-0.55	-0.38	-0.13	-0.03	-0.35	-0.78	-0.67	-0.47	-0.41	-1.41	-0.41	-0.40
-50 m to -60 m	-0.06	-0.46	-0.21	-0.04	-0.04	-0.39	-0.32	-0.22	-0.07	-0.15	-1.03	-0.30	-0.38
-60 m to -70 m	-0.05	-0.43	-0.21	-0.03	-0.04	-0.40	-0.20	-0.08	-0.05	-0.13	-0.47	-0.25	-0.37
-70 m to -80 m	-0.03	-0.34	-0.18	-0.03	-0.04	-0.18	-0.16	-0.10	-0.06	-0.07	-0.42	-0.23	-0.34

Maximum Increase in Temperature observed in the model area based on the mean over a specific period [°C]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	0.39	0.51	0.58	0.29	0.13	0.48	1.01	1.16	0.76	0.81	0.48	0.46	0.55
-5 m to -10 m	0.57	0.76	0.82	0.33	0.21	0.46	1.47	2.32	0.93	1.08	0.45	0.46	0.71
-10 m to -20 m	0.68	0.88	1.17	0.27	0.33	0.64	2.20	3.21	1.37	1.51	0.44	0.50	0.76
-20 m to -30 m	0.53	0.93	1.20	0.25	0.31	0.48	1.52	2.55	1.24	1.76	0.78	0.52	0.71
-30 m to -40 m	0.38	0.78	1.20	0.26	0.18	0.66	0.51	1.32	0.67	1.01	1.25	0.52	0.73
-40 m to -50 m	0.38	0.78	1.30	0.34	0.18	0.59	0.58	0.88	0.45	0.45	1.20	0.54	0.74
-50 m to -60 m	0.34	0.58	1.07	0.46	0.34	0.45	0.53	0.62	0.40	0.41	1.10	0.62	0.66
-60 m to -70 m	0.18	0.57	0.47	0.09	0.06	0.37	0.51	0.35	0.34	0.24	0.72	0.56	0.34
-70 m to -80 m	0.17	0.53	0.48	0.07	0.06	0.35	0.49	0.38	0.25	0.20	0.41	0.52	0.32

5% Percentile Difference (Decrease) in Temperature observed in the model area based on the mean over a specific period [°C]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	-0.03	-0.09	-0.10	-0.10	-0.06	-0.04	-0.05	-0.12	-0.15	-0.11	-0.19	-0.16	-0.11
-5 m to -10 m	-0.05	-0.09	-0.13	-0.10	-0.05	-0.07	-0.18	-0.44	-0.31	-0.13	-0.21	-0.15	-0.10
-10 m to -20 m	-0.16	-0.11	-0.17	-0.08	-0.04	-0.10	-0.30	-0.78	-1.05	-0.38	-0.23	-0.14	-0.10
-20 m to -30 m	-0.10	-0.14	-0.14	-0.06	-0.03	-0.06	-0.23	-0.48	-0.50	-0.67	-0.27	-0.14	-0.11
-30 m to -40 m	-0.05	-0.11	-0.09	-0.03	-0.02	-0.04	-0.09	-0.15	-0.13	-0.36	-0.29	-0.26	-0.13
-40 m to -50 m	-0.04	-0.11	-0.07	-0.02	-0.01	-0.02	-0.05	-0.06	-0.05	-0.16	-0.21	-0.26	-0.17
-50 m to -60 m	-0.03	-0.12	-0.04	-0.01	-0.01	-0.01	-0.02	-0.03	-0.03	-0.06	-0.20	-0.18	-0.19
-60 m to -70 m	-0.03	-0.09	-0.02	-0.01	-0.01	0.00	-0.01	-0.02	-0.03	-0.04	-0.17	-0.14	-0.19
-70 m to -80 m	-0.02	-0.06	-0.01	0.00	-0.01	0.00	0.00	-0.02	-0.03	-0.03	-0.14	-0.11	-0.16

95% Percentile Difference (Increase) in Temperature observed in the model area based on the mean over a specific period [°C]													
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December
5 m to -5 m	0.12	0.05	0.16	0.11	0.05	0.18	0.26	0.42	0.43	0.39	0.17	0.19	0.16
-5 m to -10 m	0.14	0.10	0.20	0.13	0.08	0.15	0.20	0.54	0.51	0.49	0.18	0.21	0.19
-10 m to -20 m	0.18	0.15	0.20	0.15	0.11	0.14	0.22	0.78	0.64	0.55	0.20	0.23	0.26
-20 m to -30 m	0.16	0.15	0.23	0.16	0.11	0.12	0.15	0.48	0.42	0.29	0.26	0.26	0.30
-30 m to -40 m	0.16	0.12	0.27	0.12	0.09	0.17	0.15	0.30	0.21	0.17	0.43	0.29	0.31
-40 m to -50 m	0.16	0.14	0.28	0.08	0.07	0.19	0.14	0.20	0.13	0.09	0.44	0.36	0.28
-50 m to -60 m	0.15	0.23	0.25	0.04	0.05	0.17	0.16	0.16	0.14	0.08	0.32	0.39	0.26
-60 m to -70 m	0.14	0.31	0.16	0.03	0.04	0.18	0.21	0.19	0.16	0.09	0.23	0.35	0.24
-70 m to -80 m	0.13	0.23	0.10	0.03	0.03	0.21	0.28	0.23	0.18	0.12	0.17	0.27	0.24

Table 17: Areal statistics of impact of 20 MW case on the temperature

Maximum Reduction in Temperature observed in the model area based on the mean over a specific period [°C]														
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December	
5 m to -5 m	-0.04	-0.23	-0.71	-0.28	-0.16	-0.10	-0.29	-0.56	-0.19	-0.16	-0.24	-0.27	-0.26	
-5 m to -10 m	-0.32	-0.20	-0.96	-0.26	-0.13	-0.38	-1.73	-2.15	-1.24	-0.69	-0.28	-0.25	-0.26	
-10 m to -20 m	-0.75	-0.24	-0.90	-0.22	-0.07	-0.69	-1.73	-3.49	-2.81	-2.45	-0.63	-0.21	-0.25	
-20 m to -30 m	-0.26	-0.37	-0.93	-0.16	-0.07	-0.40	-1.37	-1.69	-1.00	-2.56	-0.81	-0.16	-0.24	
-30 m to -40 m	-0.15	-0.45	-0.46	-0.08	-0.05	-0.25	-0.72	-1.23	-0.28	-0.99	-0.96	-0.40	-0.27	
-40 m to -50 m	-0.08	-0.42	-0.22	-0.05	-0.05	-0.33	-0.47	-0.58	-0.19	-0.36	-1.03	-0.40	-0.32	
-50 m to -60 m	-0.05	-0.37	-0.17	-0.05	-0.07	-0.37	-0.28	-0.16	-0.06	-0.14	-0.92	-0.30	-0.33	
-60 m to -70 m	-0.04	-0.35	-0.17	-0.01	-0.06	-0.36	-0.11	-0.06	-0.04	-0.11	-0.42	-0.26	-0.31	
-70 m to -80 m	-0.02	-0.23	-0.15	-0.01	-0.03	-0.12	-0.07	-0.07	-0.05	-0.06	-0.38	-0.24	-0.29	

Maximum Increase in Temperature observed in the model area based on the mean over a specific period [°C]														
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December	
5 m to -5 m	0.34	0.34	0.51	0.20	0.11	0.39	0.87	1.02	0.69	0.66	0.38	0.38	0.42	
-5 m to -10 m	0.48	0.52	0.62	0.22	0.20	0.40	1.22	2.04	0.85	0.89	0.36	0.41	0.54	
-10 m to -20 m	0.56	0.61	0.87	0.22	0.37	0.45	1.74	2.58	1.20	1.29	0.40	0.45	0.61	
-20 m to -30 m	0.42	0.75	0.98	0.48	0.46	0.40	1.19	1.72	1.17	1.48	0.75	0.52	0.57	
-30 m to -40 m	0.35	0.78	0.90	0.26	0.31	0.53	0.47	0.93	0.67	0.78	1.12	0.47	0.62	
-40 m to -50 m	0.31	0.65	1.03	0.33	0.19	0.44	0.51	0.61	0.45	0.45	1.08	0.43	0.61	
-50 m to -60 m	0.28	0.50	0.82	0.39	0.29	0.36	0.44	0.44	0.39	0.39	0.92	0.51	0.54	
-60 m to -70 m	0.17	0.47	0.35	0.08	0.07	0.30	0.40	0.29	0.36	0.24	0.59	0.44	0.25	
-70 m to -80 m	0.14	0.41	0.37	0.06	0.06	0.29	0.42	0.32	0.21	0.19	0.35	0.39	0.23	

5% Percentile Difference (Decrease) in Temperature observed in the model area based on the mean over a specific period [°C]														
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December	
5 m to -5 m	-0.03	-0.07	-0.08	-0.06	-0.04	-0.03	-0.04	-0.10	-0.11	-0.05	-0.15	-0.13	-0.08	
-5 m to -10 m	-0.03	-0.07	-0.09	-0.07	-0.03	-0.05	-0.14	-0.30	-0.23	-0.06	-0.17	-0.12	-0.08	
-10 m to -20 m	-0.12	-0.09	-0.13	-0.05	-0.02	-0.07	-0.27	-0.62	-0.86	-0.29	-0.19	-0.12	-0.08	
-20 m to -30 m	-0.09	-0.11	-0.10	-0.04	-0.02	-0.05	-0.22	-0.41	-0.43	-0.58	-0.22	-0.12	-0.09	
-30 m to -40 m	-0.04	-0.08	-0.06	-0.03	-0.01	-0.03	-0.08	-0.14	-0.11	-0.32	-0.25	-0.22	-0.11	
-40 m to -50 m	-0.03	-0.08	-0.05	-0.02	-0.01	-0.01	-0.05	-0.05	-0.04	-0.14	-0.19	-0.23	-0.15	
-50 m to -60 m	-0.03	-0.09	-0.03	-0.01	-0.01	-0.01	-0.01	-0.03	-0.03	-0.06	-0.18	-0.16	-0.16	
-60 m to -70 m	-0.02	-0.07	-0.01	0.00	-0.01	0.00	0.00	-0.01	-0.03	-0.04	-0.16	-0.12	-0.16	
-70 m to -80 m	-0.02	-0.04	-0.01	0.00	0.00	0.00	0.00	-0.02	-0.02	-0.03	-0.13	-0.10	-0.14	

95% Percentile Difference (Increase) in Temperature observed in the model area based on the mean over a specific period [°C]														
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December	
5 m to -5 m	0.11	0.05	0.12	0.08	0.05	0.16	0.26	0.33	0.36	0.33	0.14	0.17	0.13	
-5 m to -10 m	0.12	0.08	0.15	0.10	0.08	0.13	0.20	0.39	0.46	0.41	0.15	0.18	0.16	
-10 m to -20 m	0.14	0.12	0.16	0.12	0.11	0.12	0.19	0.60	0.56	0.47	0.16	0.20	0.21	
-20 m to -30 m	0.12	0.12	0.19	0.14	0.11	0.10	0.15	0.35	0.32	0.22	0.22	0.22	0.23	
-30 m to -40 m	0.12	0.09	0.21	0.11	0.08	0.15	0.13	0.22	0.15	0.11	0.34	0.24	0.24	
-40 m to -50 m	0.13	0.11	0.22	0.08	0.06	0.17	0.12	0.17	0.11	0.06	0.31	0.29	0.20	
-50 m to -60 m	0.12	0.18	0.20	0.04	0.05	0.15	0.13	0.15	0.11	0.05	0.22	0.30	0.18	
-60 m to -70 m	0.11	0.24	0.14	0.03	0.04	0.16	0.18	0.17	0.14	0.07	0.16	0.26	0.17	
-70 m to -80 m	0.11	0.20	0.07	0.03	0.04	0.18	0.23	0.20	0.16	0.09	0.11	0.19	0.17	

Table 18: Areal statistics of impact of 25 MW case on the temperature

Maximum Reduction in Temperature observed in the model area based on the mean over a specific period [°C]														
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December	
5 m to -5 m	-0.04	-0.21	-0.67	-0.26	-0.16	-0.08	-0.24	-0.48	-0.16	-0.24	-0.17	-0.16	-0.30	
-5 m to -10 m	-0.21	-0.18	-0.94	-0.25	-0.11	-0.28	-1.43	-1.50	-0.48	-0.31	-0.17	-0.14	-0.27	
-10 m to -20 m	-0.51	-0.29	-0.85	-0.21	-0.04	-0.59	-1.68	-3.47	-1.60	-1.00	-0.17	-0.11	-0.16	
-20 m to -30 m	-0.19	-0.40	-0.84	-0.16	-0.04	-0.29	-1.14	-1.78	-0.97	-1.73	-0.31	-0.11	-0.18	
-30 m to -40 m	-0.11	-0.43	-0.43	-0.08	-0.03	-0.22	-0.72	-1.43	-0.63	-0.68	-0.46	-0.29	-0.18	
-40 m to -50 m	-0.06	-0.44	-0.20	-0.05	-0.03	-0.25	-0.27	-0.37	-0.54	-0.22	-0.50	-0.30	-0.25	
-50 m to -60 m	-0.03	-0.38	-0.12	-0.03	-0.04	-0.27	-0.14	-0.18	-0.05	-0.09	-0.60	-0.23	-0.31	
-60 m to -70 m	-0.02	-0.35	-0.12	-0.01	-0.04	-0.22	-0.02	-0.05	-0.05	-0.05	-0.26	-0.20	-0.30	
-70 m to -80 m	-0.02	-0.24	-0.10	0.00	-0.01	-0.02	-0.02	-0.06	-0.04	-0.05	-0.25	-0.18	-0.28	

Maximum Increase in Temperature observed in the model area based on the mean over a specific period [°C]														
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December	
5 m to -5 m	0.29	0.38	0.65	0.22	0.11	0.38	0.80	1.06	0.62	0.46	0.27	0.32	0.36	
-5 m to -10 m	0.41	0.59	0.59	0.23	0.17	0.35	1.15	1.90	0.68	0.55	0.25	0.33	0.43	
-10 m to -20 m	0.49	0.72	0.87	0.25	0.32	0.31	1.47	2.58	0.78	0.89	0.31	0.35	0.46	
-20 m to -30 m	0.38	0.85	1.09	0.51	0.45	0.26	0.96	1.78	0.60	0.97	0.55	0.40	0.46	
-30 m to -40 m	0.30	0.84	0.98	0.27	0.27	0.31	0.37	0.84	0.53	0.52	0.71	0.36	0.56	
-40 m to -50 m	0.23	0.67	0.98	0.24	0.17	0.26	0.24	0.59	0.28	0.26	0.66	0.27	0.43	
-50 m to -60 m	0.22	0.57	0.91	0.35	0.26	0.21	0.19	0.42	0.24	0.17	0.47	0.26	0.31	
-60 m to -70 m	0.14	0.51	0.44	0.08	0.06	0.17	0.20	0.19	0.21	0.10	0.31	0.20	0.16	
-70 m to -80 m	0.11	0.41	0.46	0.07	0.05	0.17	0.21	0.15	0.11	0.07	0.14	0.16	0.18	

5% Percentile Difference (Decrease) in Temperature observed in the model area based on the mean over a specific period [°C]														
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December	
5 m to -5 m	-0.02	-0.07	-0.09	-0.06	-0.03	-0.02	-0.02	-0.09	-0.08	-0.05	-0.11	-0.08	-0.05	
-5 m to -10 m	-0.03	-0.07	-0.10	-0.06	-0.02	-0.02	-0.08	-0.31	-0.15	-0.07	-0.12	-0.08	-0.05	
-10 m to -20 m	-0.06	-0.08	-0.12	-0.05	-0.02	-0.03	-0.22	-0.56	-0.54	-0.20	-0.13	-0.08	-0.05	
-20 m to -30 m	-0.06	-0.08	-0.10	-0.04	-0.01	-0.03	-0.19	-0.31	-0.29	-0.52	-0.15	-0.07	-0.04	
-30 m to -40 m	-0.03	-0.07	-0.06	-0.02	-0.01	-0.03	-0.10	-0.11	-0.08	-0.27	-0.16	-0.12	-0.05	
-40 m to -50 m	-0.02	-0.06	-0.04	-0.02	-0.01	-0.01	-0.05	-0.05	-0.04	-0.12	-0.13	-0.13	-0.07	
-50 m to -60 m	-0.02	-0.06	-0.02	-0.01	-0.01	0.00	-0.02	-0.02	-0.03	-0.05	-0.13	-0.10	-0.08	
-60 m to -70 m	-0.01	-0.05	0.00	0.00	-0.01	0.00	-0.01	-0.01	-0.02	-0.03	-0.12	-0.08	-0.08	
-70 m to -80 m	-0.01	-0.03	0.00	0.01	0.00	0.00	0.00	-0.02	-0.02	-0.03	-0.10	-0.07	-0.08	

95% Percentile Difference (Increase) in Temperature observed in the model area based on the mean over a specific period [°C]														
Depth	2021	January	February	March	April	May	June	July	August	September	October	November	December	
5 m to -5 m	0.10	0.04	0.09	0.07	0.06	0.15	0.23	0.36	0.31	0.24	0.09	0.11	0.07	
-5 m to -10 m	0.10	0.06	0.13	0.10	0.09	0.13	0.19	0.39	0.35	0.26	0.10	0.12	0.10	
-10 m to -20 m	0.11	0.11	0.15	0.13	0.11	0.10	0.18	0.55	0.34	0.27	0.10	0.13	0.14	
-20 m to -30 m	0.09	0.11	0.19	0.15	0.12	0.09	0.11	0.31	0.20	0.12	0.13	0.14	0.16	
-30 m to -40 m	0.09	0.09	0.24	0.12	0.09	0.12	0.09	0.16	0.10	0.05	0.16	0.14	0.15	
-40 m to -50 m	0.08	0.12	0.25	0.09	0.07	0.12	0.09	0.10	0.05	0.03	0.13	0.15	0.12	
-50 m to -60 m	0.07	0.18	0.22	0.05	0.06	0.11	0.09	0.09	0.05	0.03	0.08	0.13	0.09	
-60 m to -70 m	0.07	0.26	0.17	0.03	0.04	0.10	0.11	0.10	0.07	0.03	0.06	0.10	0.07	
-70 m to -80 m	0.07	0.24	0.09	0.03	0.04	0.10	0.14	0.11	0.08	0.03	0.04	0.06	0.06	

Appendix 9 Hydrodynamic Impact: Comparison of temperature

Table 19: Differences of mean temperature [°C] – Part 1

(considering varying extents (Bothnian Bay, innerBox, and outerBox), different depth intervals and different time intervals)

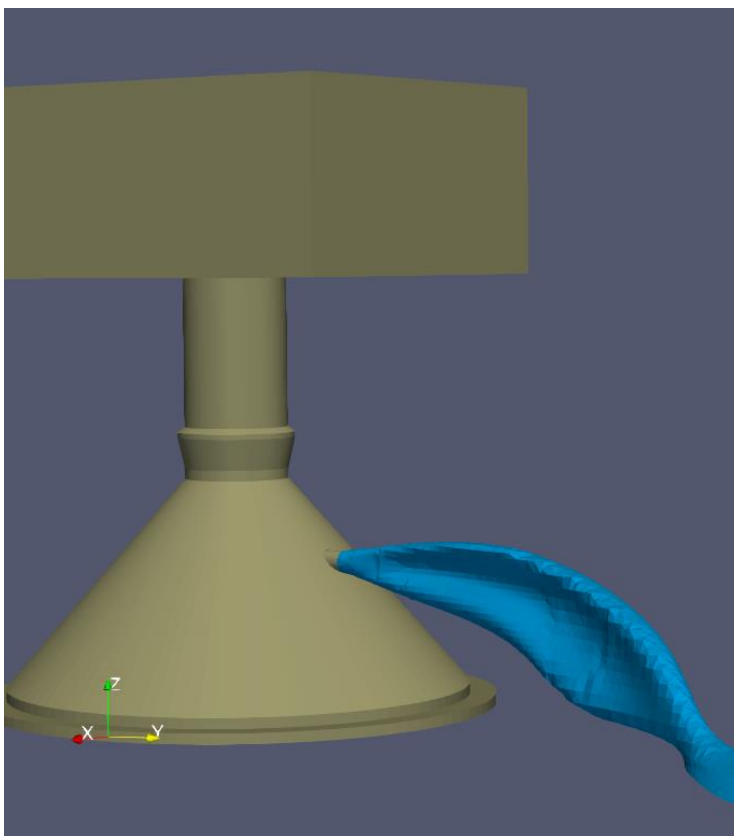
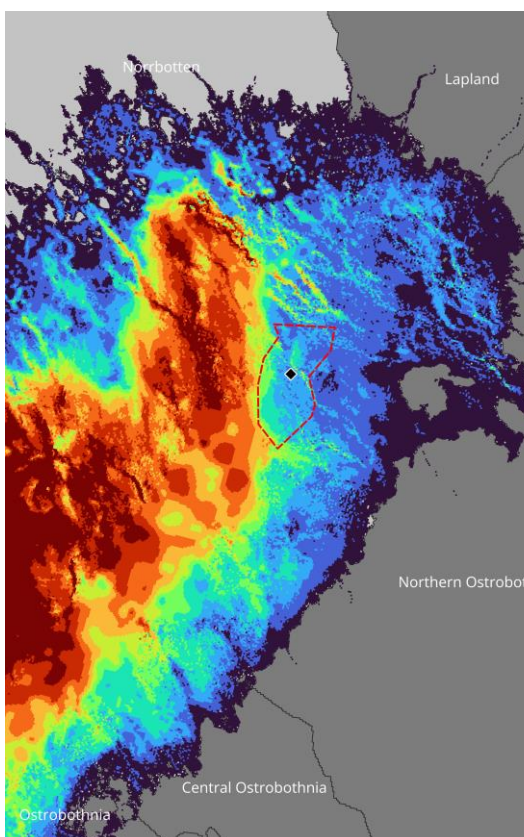
Entire Year		Temperature								
		Bothnian Bay			innerBox			outerBox		
		25MW	20MW	15MW	25MW	20MW	15MW	25MW	20MW	15MW
	5 - -5m	0.018	0.018	0.018	0.172	0.183	0.170	0.13	0.13	0.12
	-5 - -10m	0.052	0.051	0.048	0.086	0.080	0.026	0.08	0.07	0.03
	-10 - -20m	0.033	0.029	0.025	0.002	-0.009	-0.057	0.00	-0.01	-0.04
	-20 - -30m	0.014	0.012	0.011	0.041	0.035	-0.006	0.03	0.03	0.02
	-30 - -40m	0.011	0.010	0.013	0.056	0.054	0.028	0.05	0.07	0.07
	-40 - -50m	0.009	0.010	0.014	0.042	0.045	0.029	0.04	0.07	0.08
	-50 - -60m	0.008	0.010	0.015	0.023	0.026	0.018	0.03	0.05	0.06
	-60 - -70m	0.008	0.011	0.015	0.017	0.021	0.016	0.02	0.04	0.05
	-70 - -80m	0.007	0.010	0.014	-0.009	-0.017	-0.021	0.01	0.03	0.04
January		Temperature								
		Bothnian Bay			innerBox			outerBox		
		25MW	20MW	15MW	25MW	20MW	15MW	25MW	20MW	15MW
	5 - -5m	-0.006	-0.005	-0.006	0.001	0.002	0.002	0.01	0.01	0.01
	-5 - -10m	-0.002	0.001	0.002	0.082	0.075	0.101	0.06	0.06	0.08
	-10 - -20m	0.004	0.006	0.008	0.160	0.142	0.185	0.08	0.08	0.11
	-20 - -30m	0.007	0.007	0.009	0.239	0.200	0.258	0.11	0.10	0.13
	-30 - -40m	0.009	0.008	0.010	0.115	0.080	0.115	0.05	0.03	0.05
	-40 - -50m	0.020	0.016	0.020	-0.076	-0.098	-0.115	0.00	-0.02	-0.03
	-50 - -60m	0.028	0.023	0.029	-0.170	-0.181	-0.229	-0.01	-0.03	-0.05
	-60 - -70m	0.031	0.027	0.033	-0.155	-0.156	-0.205	0.00	-0.01	-0.02
	-70 - -80m	0.022	0.018	0.022	-0.216	-0.209	-0.287	0.00	0.00	-0.02
February		Temperature								
		Bothnian Bay			innerBox			outerBox		
		25MW	20MW	15MW	25MW	20MW	15MW	25MW	20MW	15MW
	5 - -5m	-0.008	0.000	0.001	0.045	0.032	0.010	0.01	0.00	0.00
	-5 - -10m	-0.005	0.001	0.002	0.068	0.047	0.053	0.03	0.03	0.04
	-10 - -20m	0.004	0.004	0.002	0.131	0.083	0.101	0.08	0.07	0.09
	-20 - -30m	0.025	0.022	0.023	0.128	0.062	0.077	0.10	0.08	0.10
	-30 - -40m	0.036	0.031	0.037	-0.002	-0.034	-0.054	0.08	0.07	0.07
	-40 - -50m	0.034	0.028	0.034	-0.024	-0.037	-0.076	0.06	0.05	0.05
	-50 - -60m	0.032	0.026	0.032	0.005	-0.003	-0.020	0.03	0.03	0.02
	-60 - -70m	0.033	0.026	0.032	0.015	0.006	-0.003	0.02	0.01	0.01
	-70 - -80m	0.029	0.024	0.029	0.019	0.008	0.010	0.01	0.01	0.01
March		Temperature								
		Bothnian Bay			innerBox			outerBox		
		25MW	20MW	15MW	25MW	20MW	15MW	25MW	20MW	15MW
	5 - -5m	0.003	0.007	0.006	0.023	0.015	-0.028	0.01	0.00	-0.01
	-5 - -10m	0.012	0.013	0.014	0.025	0.017	-0.016	0.02	0.01	-0.01
	-10 - -20m	0.023	0.022	0.023	0.058	0.050	0.003	0.04	0.03	0.01
	-20 - -30m	0.028	0.025	0.028	0.057	0.056	0.009	0.06	0.05	0.03
	-30 - -40m	0.024	0.021	0.023	0.042	0.044	0.021	0.04	0.04	0.03
	-40 - -50m	0.021	0.017	0.018	0.028	0.029	0.019	0.03	0.03	0.02
	-50 - -60m	0.018	0.014	0.015	0.020	0.018	0.017	0.02	0.02	0.01
	-60 - -70m	0.017	0.014	0.015	0.016	0.012	0.013	0.02	0.01	0.01
	-70 - -80m	0.017	0.015	0.016	0.014	0.013	0.012	0.02	0.01	0.01

Table 20: Differences of mean temperature [°C] – Part 2
(considering varying extents (Bothnian Bay, innerBox, and outerBox), different depth intervals and different time intervals)

		Temperature								
		Bothnian Bay			innerBox			outerBox		
		25MW	20MW	15MW	25MW	20MW	15MW	25MW	20MW	15MW
April	5 - -5m	0.009	0.006	0.004	0.023	0.005	-0.018	0.02	0.00	-0.01
	-5 - -10m	0.017	0.014	0.014	0.044	0.033	0.032	0.04	0.03	0.03
	-10 - -20m	0.027	0.026	0.026	0.096	0.096	0.079	0.09	0.09	0.08
	-20 - -30m	0.026	0.025	0.026	0.106	0.111	0.064	0.10	0.10	0.09
	-30 - -40m	0.022	0.020	0.021	0.064	0.069	0.047	0.07	0.07	0.06
	-40 - -50m	0.020	0.018	0.019	0.042	0.041	0.032	0.04	0.04	0.04
	-50 - -60m	0.016	0.014	0.014	0.030	0.027	0.027	0.02	0.02	0.02
	-60 - -70m	0.015	0.013	0.013	0.024	0.021	0.022	0.02	0.01	0.01
	-70 - -80m	0.017	0.015	0.015	0.010	0.002	-0.004	0.01	0.01	0.00
May	5 - -5m	0.031	0.026	0.027	0.163	0.170	0.186	0.14	0.15	0.15
	-5 - -10m	0.026	0.019	0.016	0.053	0.042	0.008	0.08	0.06	0.03
	-10 - -20m	0.017	0.009	0.005	-0.034	-0.054	-0.084	-0.01	-0.04	-0.07
	-20 - -30m	0.011	0.010	0.010	0.023	0.026	0.000	0.01	0.00	-0.02
	-30 - -40m	0.014	0.016	0.018	0.075	0.088	0.066	0.06	0.05	0.05
	-40 - -50m	0.018	0.022	0.024	0.086	0.086	0.070	0.06	0.05	0.05
	-50 - -60m	0.018	0.022	0.025	0.077	0.059	0.042	0.05	0.05	0.04
	-60 - -70m	0.021	0.026	0.028	0.074	0.054	0.040	0.06	0.06	0.06
	-70 - -80m	0.023	0.030	0.033	0.047	0.020	0.012	0.06	0.09	0.11
June	5 - -5m	0.041	0.038	0.039	0.434	0.473	0.480	0.29	0.31	0.32
	-5 - -10m	0.015	0.005	-0.005	-0.112	-0.165	-0.346	-0.01	-0.03	-0.11
	-10 - -20m	0.000	-0.011	-0.016	-0.400	-0.474	-0.582	-0.17	-0.16	-0.17
	-20 - -30m	-0.003	-0.004	-0.006	-0.226	-0.274	-0.367	-0.10	-0.11	-0.13
	-30 - -40m	0.002	0.005	0.007	-0.059	-0.080	-0.140	0.00	-0.01	-0.05
	-40 - -50m	0.009	0.015	0.019	-0.004	-0.013	-0.041	0.03	0.03	0.01
	-50 - -60m	0.016	0.024	0.028	0.024	0.024	0.017	0.04	0.04	0.03
	-60 - -70m	0.022	0.032	0.037	0.036	0.043	0.045	0.05	0.05	0.04
	-70 - -80m	0.026	0.039	0.043	0.032	0.049	0.063	0.06	0.08	0.09
July	5 - -5m	0.034	0.027	0.031	0.532	0.467	0.387	0.39	0.33	0.30
	-5 - -10m	0.009	-0.001	-0.010	0.016	-0.069	-0.353	0.07	-0.01	-0.18
	-10 - -20m	-0.021	-0.031	-0.041	-0.533	-0.516	-0.656	-0.27	-0.24	-0.33
	-20 - -30m	-0.009	-0.011	-0.013	-0.379	-0.332	-0.417	-0.09	0.01	0.00
	-30 - -40m	0.008	0.010	0.013	-0.154	-0.117	-0.218	0.05	0.12	0.11
	-40 - -50m	0.011	0.018	0.022	-0.049	-0.024	-0.105	0.07	0.13	0.12
	-50 - -60m	0.014	0.023	0.028	-0.006	0.006	-0.031	0.06	0.11	0.10
	-60 - -70m	0.019	0.031	0.036	0.033	0.048	0.035	0.06	0.10	0.10
	-70 - -80m	0.021	0.036	0.040	0.029	0.045	0.049	0.06	0.10	0.11
August	5 - -5m	0.040	0.039	0.039	0.337	0.318	0.287	0.24	0.21	0.16
	-5 - -10m	0.032	0.026	0.016	0.268	0.219	0.082	0.15	0.07	-0.09
	-10 - -20m	-0.030	-0.044	-0.059	0.034	0.028	-0.139	-0.18	-0.22	-0.40
	-20 - -30m	-0.018	-0.016	-0.014	0.019	0.040	-0.122	-0.04	0.00	-0.11
	-30 - -40m	-0.001	0.006	0.012	0.103	0.075	-0.034	0.04	0.08	0.03
	-40 - -50m	0.004	0.014	0.020	0.093	0.054	0.000	0.04	0.08	0.07
	-50 - -60m	0.008	0.019	0.024	0.051	0.026	0.010	0.03	0.07	0.07
	-60 - -70m	0.012	0.024	0.028	0.037	0.027	0.017	0.02	0.06	0.06
	-70 - -80m	0.010	0.024	0.028	-0.004	-0.024	-0.033	0.01	0.04	0.05

Table 21: Differences of mean temperature [°C] – Part 3
(considering varying extents (Bothnian Bay, innerBox, and outerBox), different depth intervals and different time intervals)

		Temperature								
		Bothnian Bay			innerBox			outerBox		
		25MW	20MW	15MW	25MW	20MW	15MW	25MW	20MW	15MW
September	5 - -5m	0.050	0.062	0.064	0.313	0.450	0.526	0.23	0.32	0.37
	-5 - -10m	0.052	0.063	0.062	0.310	0.410	0.445	0.24	0.29	0.30
	-10 - -20m	0.017	0.005	-0.005	0.176	0.178	0.156	0.07	-0.03	-0.09
	-20 - -30m	-0.068	-0.084	-0.090	0.092	0.121	0.105	-0.12	-0.18	-0.17
	-30 - -40m	-0.051	-0.048	-0.044	0.048	0.025	0.029	-0.05	-0.05	-0.03
	-40 - -50m	-0.028	-0.020	-0.015	0.019	-0.025	-0.031	0.00	0.00	0.00
	-50 - -60m	-0.012	-0.002	0.003	0.000	-0.053	-0.070	0.01	0.02	0.01
	-60 - -70m	-0.004	0.006	0.011	-0.011	-0.056	-0.080	0.02	0.02	0.01
	-70 - -80m	-0.002	0.008	0.013	-0.007	-0.050	-0.062	0.02	0.02	0.02
October	5 - -5m	0.006	0.006	0.002	0.110	0.095	0.048	0.09	0.08	0.06
	-5 - -10m	0.006	0.005	-0.001	0.104	0.076	0.010	0.08	0.07	0.04
	-10 - -20m	0.004	-0.002	-0.012	0.084	-0.008	-0.157	0.08	0.04	-0.04
	-20 - -30m	-0.008	-0.022	-0.034	0.142	0.052	-0.103	0.12	0.10	0.04
	-30 - -40m	-0.018	-0.022	-0.017	0.266	0.314	0.281	0.19	0.32	0.36
	-40 - -50m	-0.023	-0.012	0.005	0.279	0.429	0.482	0.18	0.40	0.52
	-50 - -60m	-0.026	-0.019	-0.005	0.210	0.356	0.415	0.13	0.32	0.43
	-60 - -70m	-0.025	-0.021	-0.011	0.144	0.284	0.340	0.08	0.21	0.29
	-70 - -80m	-0.024	-0.022	-0.017	0.122	0.235	0.310	0.05	0.14	0.19
November	5 - -5m	0.008	0.007	0.004	0.132	0.152	0.137	0.10	0.11	0.11
	-5 - -10m	0.011	0.011	0.009	0.146	0.171	0.166	0.11	0.13	0.12
	-10 - -20m	0.014	0.015	0.014	0.162	0.195	0.198	0.11	0.13	0.13
	-20 - -30m	0.006	0.008	0.011	0.160	0.208	0.232	0.10	0.12	0.14
	-30 - -40m	-0.014	-0.019	-0.018	0.092	0.130	0.157	0.05	0.08	0.10
	-40 - -50m	-0.030	-0.036	-0.034	0.056	0.093	0.113	0.03	0.07	0.11
	-50 - -60m	-0.032	-0.033	-0.027	0.036	0.081	0.108	0.01	0.08	0.13
	-60 - -70m	-0.031	-0.030	-0.022	0.013	0.057	0.079	-0.01	0.04	0.09
	-70 - -80m	-0.028	-0.026	-0.019	-0.016	-0.012	0.005	-0.04	-0.01	0.03
December	5 - -5m	0.003	0.005	0.004	-0.052	0.017	0.019	0.00	0.04	0.05
	-5 - -10m	0.012	0.016	0.019	0.027	0.105	0.141	0.05	0.10	0.14
	-10 - -20m	0.024	0.034	0.042	0.108	0.179	0.230	0.09	0.14	0.19
	-20 - -30m	0.023	0.026	0.034	0.135	0.157	0.201	0.09	0.10	0.14
	-30 - -40m	0.010	0.003	0.007	0.073	0.048	0.057	0.04	0.02	0.03
	-40 - -50m	-0.008	-0.019	-0.017	0.045	0.000	-0.006	-0.01	-0.05	-0.05
	-50 - -60m	-0.020	-0.031	-0.029	0.003	-0.053	-0.071	-0.05	-0.09	-0.10
	-60 - -70m	-0.029	-0.036	-0.034	-0.023	-0.090	-0.114	-0.07	-0.09	-0.10
	-70 - -80m	-0.033	-0.034	-0.031	-0.137	-0.274	-0.322	-0.09	-0.09	-0.09



Halla OWF

H₂ wastewater, impact to the physical environment

Halla Offshore Wind Oy

Date: 29 November 2024

Rev.no.	Date	Description	Prepared by	Verified by	Approved by
01	20241031	Rev. 1	TEB	AWNI	TEB
02	20241104	Rev. 2 – Client’s comments	TEB	AWNI	TEB
03	20241129	Rev. 3 – Table 4.1 corrected	TEB	AWNI	TEB

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1. Introduction

NIRAS has by Halla Offshore Wind Oy been requested to investigate the alternations to the salinity and water temperature due to the outlet of wastewater from the hydrogen production (CTR03 dated 2024-10-01). The hydrogen production facility will be offshore within the wind farm with an input of 4 TWh electricity production (1/3 of the total wind farm production capacity of 12 TWh). The production facility platform will be installed at 22 mMSL.

This represent the worst-case scenario being the shallowest platform location and nearest to Swedish border to demonstrate possible border crossing impacts. The other two hydrogen platforms would have similar type but lower actual impact due to greater water depth.

The modelling used a maximum impact approach to assess the highest heat and salt load for each production site. Given the localised nature of the impact, the modelling focused on a single centralised hydrogen production location. This site was chosen as it represented the most sensitive option, taking into account nearby sensitive areas and water depth.

NIRAS has previously examined the effects of decentralised hydrogen production as well as the influences of substructures and wind wake (NIRAS, 2023-12-20).

2. Scope of Work

To quantify the dispersal of discharged wastewater from the hydrogen production in the form of reject water with excess salinity and cooling water with excess temperature from a platform inside the wind farm area at 22 m water depth, Figure 2-1.

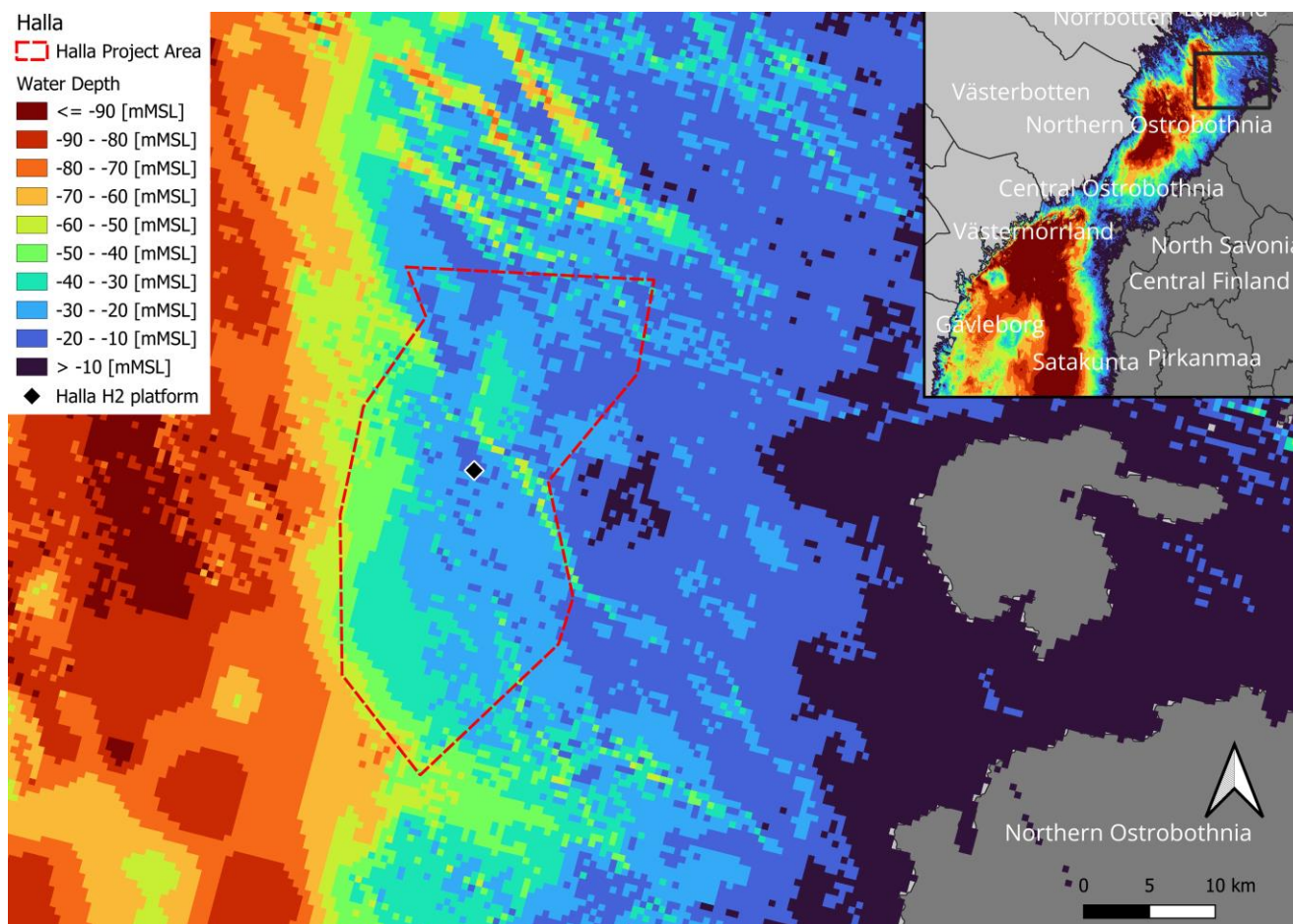


Figure 2-1: Halla Offshore Wind Farm, location of H₂ production platform.

3. Methodology

The wastewater effluent from the cooling and clean water production is a rather small source in volume with an excess of temperature and salinity that can potentially affect the local environment. To explore this further, a detailed CFD model of the GBS and nearby waters was created using OpenFOAM's Multicomponent solver to manage density and temperature variations in a low ambient flow.

To address the two fundamental temperature scenarios (winter and summer), simulations were conducted for both stratified and non-stratified conditions. In the stratified scenario, a thermocline was incorporated into the model.

4. Model setup

4.1. Data

The requirement for reject water and cooling water is based on the assumptions that only 1/3 of the overall wind farm capacity (2200 GW) are converted to hydrogen as illustrated in Table 4.1.

Table 4.1: In- and output for the hydrogen production.

Item	Unit	Value
Input	MWh	4000
Efficiency		60%
Hydrogen yield	MWh	2400
Reject, salt water	m ³ /s	0.085
Salt, excess	PSU	9.96
Cooling water	m ³ /s	2.16
Temp, excess	°C	15.0
Diameter pipe	m	1
Area pipe	m ²	0.79
V outlet, cooling+salt water	m/s	2.80

4.1.1. GBS model

Based on the available information it assumes that the GBS for the platform at 22 m water with the outlet at 10 m below the mean surface level.

The overall dimensions for the GBS conical shape are:

- a base slab with a diameter of 71.5 m.
- a cone with a diameter of 45 m at the bottom on top of the base slab.
- A cone with a diameter of 10 m at the top.
- A cone 20 m high.
- An outlet at 10 m below mean sea level.
- An ice cone at mean sea level and
- for illustration a top side has been added to the drawing.

Only the part below mean sea level influence the model results. The structure used in the model is depicted in Figure 4-1.

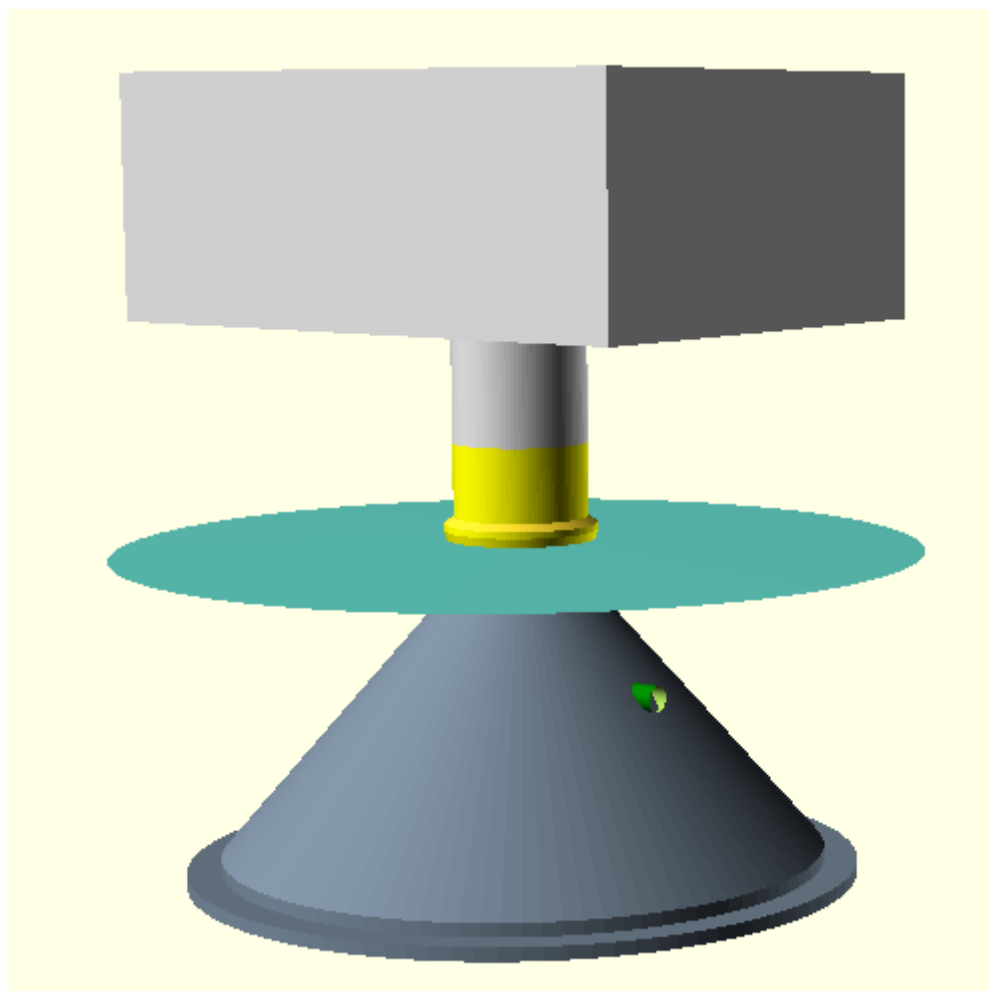


Figure 4-1: Sketch of the GBS with an indicative topside (only for illustration). Mean sea level is marked with a turquoise circle.

4.1.2. Flow and stratification cases

To investigate the difference between a case with a clear thermocline and one without 2 cases are simulated:

- 1) A well mixed situation with a constant temperature and salinity over the water column
- 2) A stratified situation with a clear thermocline but constant salinity.

The two scenarios are simulated for one hour using a constant background current speed, direction, density, and temperature—conditions that do not occur in reality and are therefore seen as conservative. This means the modelled plume's extent is larger, and there is less mixing with surrounding water than would naturally be the case. A natural scenario would include influences such as:

- Shifting current directions, the plume will be spread not only in one direction but in several increasing the mixing and reducing the extent.
- Shifting current speeds will increase the turbulence and thus altering the shape of the plume and thereby increase the mixing.
- Shifting densities (temperature & salinities) will affect the shape of the plume and thereby the mixing.

The hydrodynamics (NIRAS, 2023-12-20) at the location of the platform is picturized in Appendix 1 as profiles time series for density, temperature, salinity, current speed and current direction for the year 2022 and summarized below:

- Density: For most of the year density over the depth is found to be constant around 1003 kg/m^3 except for mid April (day 100) where the density down to around 10 m becomes slightly lower (probably to run-off from the catchment) and again for a longer period starting in June, peaking mid July and to in October. At the peak the surface water has a density of 1001 kg/m^3 and the bottom 1003 kg/m^3 .
- Temperature: in January the bottom water is around 4°C and the surface just above 0°C to both to become below 0°C for a few days end of February whereafter the temperature again becomes positive at the bottom but staying below 0°C at the surface to end of April. Here the sun kicks in at slowly start to warm up the surface water peaking mid July at 19°C . In the same period the bottom water increases to 5°C to peak mid August where the water column is total mixed at 16°C . From here a thermocline starts to form until the surface water is cooled down to the same temperature as the bottom water mid September at around 8 to 9°C staying well mixed to the beginning of December where the surface water starts to cool.
- Current Speed: In general, the varies over the year and the water depth between 0 to 0.3 m/s with no clear seasonal pattern.
- Current Direction: in most of the time the current direction is not constant over the depth running either in the same or opposite direction at the surface compared to the bottom or when the thermocline is present running in the same direction at the surface and bottom but in another direction at the thermocline.

4.1.2.1. *Well mixed*

List of inputs to the model:

- 1) The background current is 5 cm/s ,
- 2) The density and temperature of the water 1002 kg/m^3 and 2°C .
- 3) The reject water has a density of 1008 kg/m^3 (10 PSU) and a temperature of 2°C .
- 4) The cooling water has a density of 999.7 kg/m^3 and temperature of 17°C ($2^\circ\text{C}+15^\circ\text{C}$).
- 5) The resulting wastewater has then a density of 999.7 kg/m^3 .

4.1.2.2. *Stratified - thermocline*

List of inputs to the model:

- 1) Stratified flow with a thermocline at 10 m .
- 2) The intake for the reject and cooling water is placed below the thermocline, deeper than 10 m .
- 3) The background current in the top layer is 5 cm/s and at the bottom 3 cm/s .
- 4) The density and temperature are 1001.3 kg/m^3 (2 PSU) and 10°C in bottom layer and 1001.4 kg/m^3 (3 PSU) and 15°C in the top layer.
- 5) The reject water has a density of 1007.5 kg/m^3 (10 PSU) and a temperature of 10°C .
- 6) The cooling water has a density of 999.6 kg/m^3 and temperature of 25°C ($10^\circ\text{C}+15^\circ\text{C}$).
- 7) The resulting wastewater has then a density of 999.7 kg/m^3 .

4.1.3. Boundaries and Mesh

The main purpose of the numerical flume on Figure 4-2 is to contain the surrounding water and the patches for definition of the boundary conditions.

For this low background current case (see chapter 4.1.2.1 and 4.1.2.2) the extent of the flume in the current direction is -50 m to 250 m, perpendicular to -50 m/+150m with a depth of 20 m. This to have sufficient space for the current to initiate upstream, having no influence from the downstream to avoid eventual blocking and for the plume from the outlet to develop freely. Because the outlet is located 90° relative to the substructure's current, its discharge will be at a right angle to the main flow.

The base mesh is 1x1x1 m, which is reduced to 0.25x0.25x0.25 m near the GBS within a 10 m range and further refined to 0.03125 m near the outlet over a distance of 2 m.

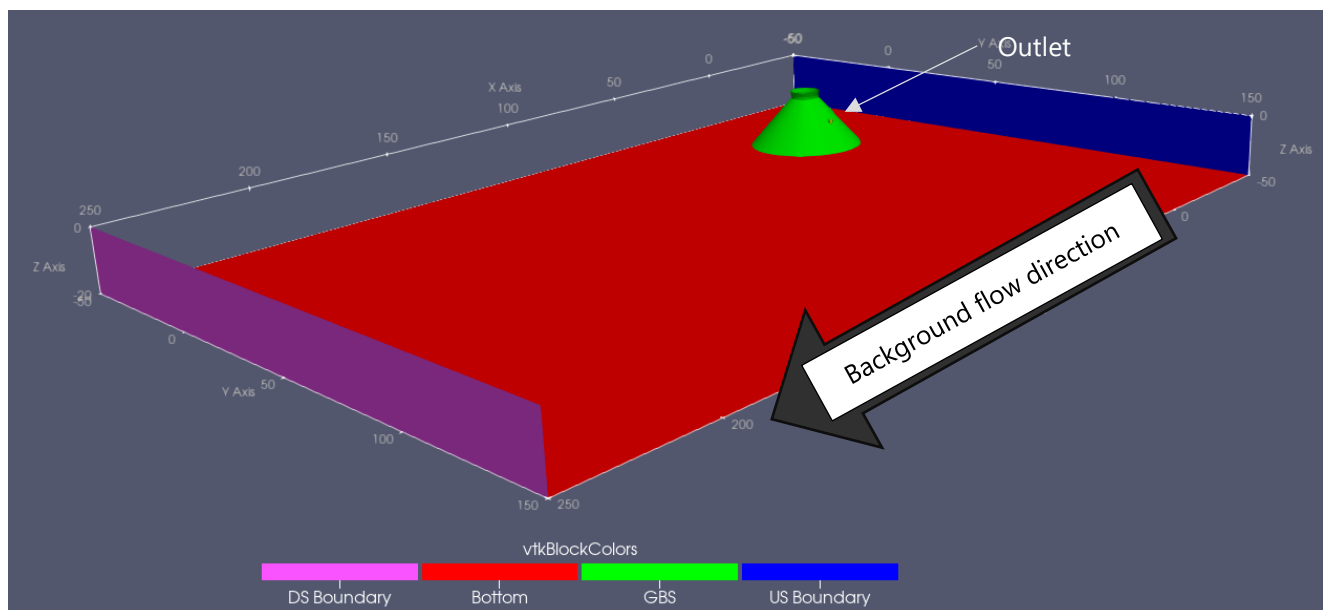


Figure 4-2: CFD domain for the GBS together with up and downstream boundary seabed. DS: downstream, US: upstream.

For the well-mixed scenario, the upstream boundary is governed by the condition described in chapter 4.1.2.1. In contrast, for the stratified scenario, the upstream boundary is divided at the thermocline level and driven by the values specified in chapter 4.1.2.2.

4.2. Solver

OpenFOAM (Open Field Operation and Manipulation (OpenFOAM, n.d.)) is an open-source computational fluid dynamics (CFD) software that allows users to simulate and analyse complex fluid flow problems. One of the capabilities of OpenFOAM is the modelling of multicomponent fluids e.g. mixing of water with different densities where the density is a function of the temperature using the Boussinesq approximation to describe the density as function of the temperature.

Multicomponent fluids refer to mixtures that consist of multiple distinct chemical species. Examples include gas mixtures, liquid solutions, and multiphase flows. OpenFOAM provides a framework for simulating the behaviour of such fluids by employing various mathematical models and numerical techniques.

In OpenFOAM, the modelling of multicomponent fluids involves considering the transport and interaction of individual components within the mixture. This includes accounting for mass transfer, species diffusion, and chemical reactions inclusive the properties and behaviour of each component, such as density, viscosity, diffusivity, and reaction kinetics.

5. Results

When reviewing the figure in the following subchapters, please take note of the following:

- The wastewater plume is illustrated for specific dilutions indicated as percentages, with 100% representing the concentration found solely at the outlet where no dilution has occurred.
- The plot illustrates the extent of the plume, indicating where the surface dilution reaches the specified percentage. Consequently, volumes with less dilution are found within this boundary.
- As the excess salinity is 9.96 PSU a dilution to 0.1% means an excess salinity of 0.01 PSU.
- Excess temperature refers to the temperature exceeding the ambient water temperature.

5.1. Well mixed flow

Figure 5-1 and Figure 5.2 illustrate the wastewater plume's extent diluted to 0.1% after 1 hour, as seen from the side, above and below. The maximum extent happens at the surface, as the discharged wastewater has slightly lower density than the surrounding water. The plume stretches 80 meters across, 230 meters parallel, and is for the 100 metre 18 m thick whereafter it becomes more diffuse having a thickness of 9 to 0 m for an excess temperature of up to 1°C.

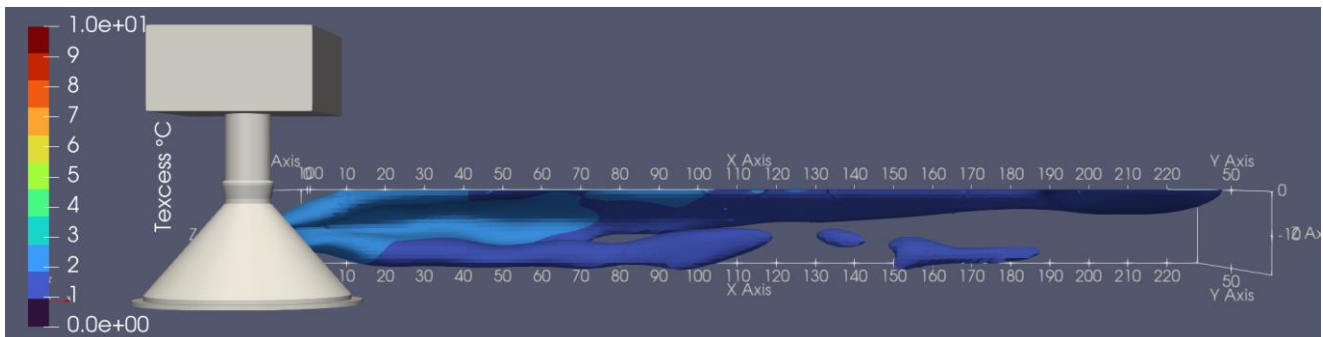


Figure 5-1: Well-mixed, extent of wastewater plume diluted to 0.1% after 1 hour. View: Vertical with the background current running from left to right. Axis units are in meters.

However, the excess temperature above 1°C only covers a small area at the surface of about 200m by 20m but does not reach the seabed.

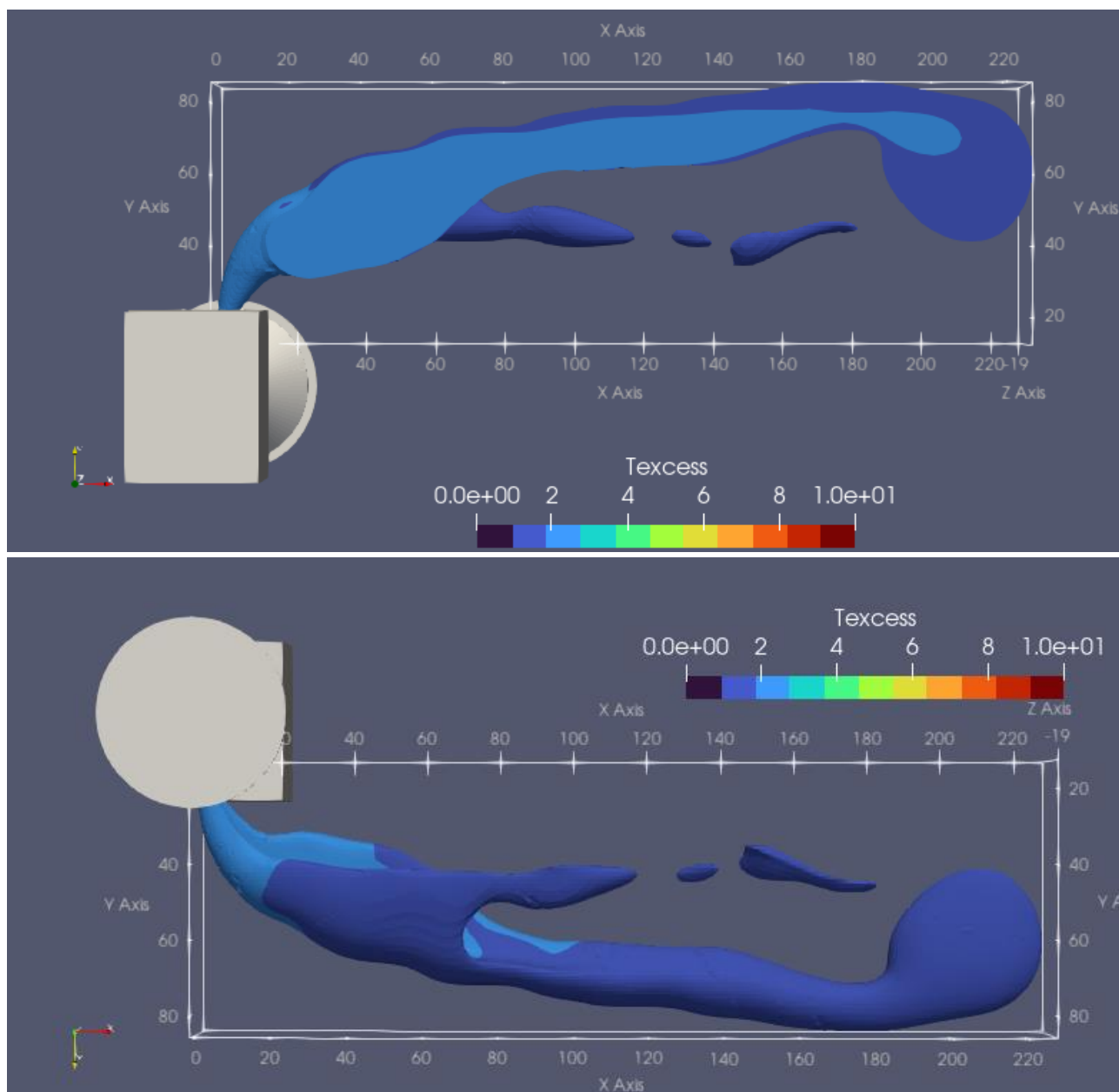


Figure 5.2: Well-mixed, extent of wastewater plume diluted to 0.1% after 1 hour. Top: from above, Bottom: from below. The background current running from left to right. Axis units are in meters.

For further illustration of plume dilution, Figure 5.3 demonstrates how the plume dilutes to concentrations of 0.1%, 0.25%, and 0.5% after one hour. This shows that the wastewater rapidly mixes with the surrounding water once it exits the pipe.

Figure 5.4 illustrates the excess temperature for six cross sections along the plume one hour after it leaves the outlet pipe, measured at the pipe and at distances of 60 m, 140 m, and 210 m. The results indicate that excess temperatures above 1°C are observed along the wastewater plume for an extent of 230 m.

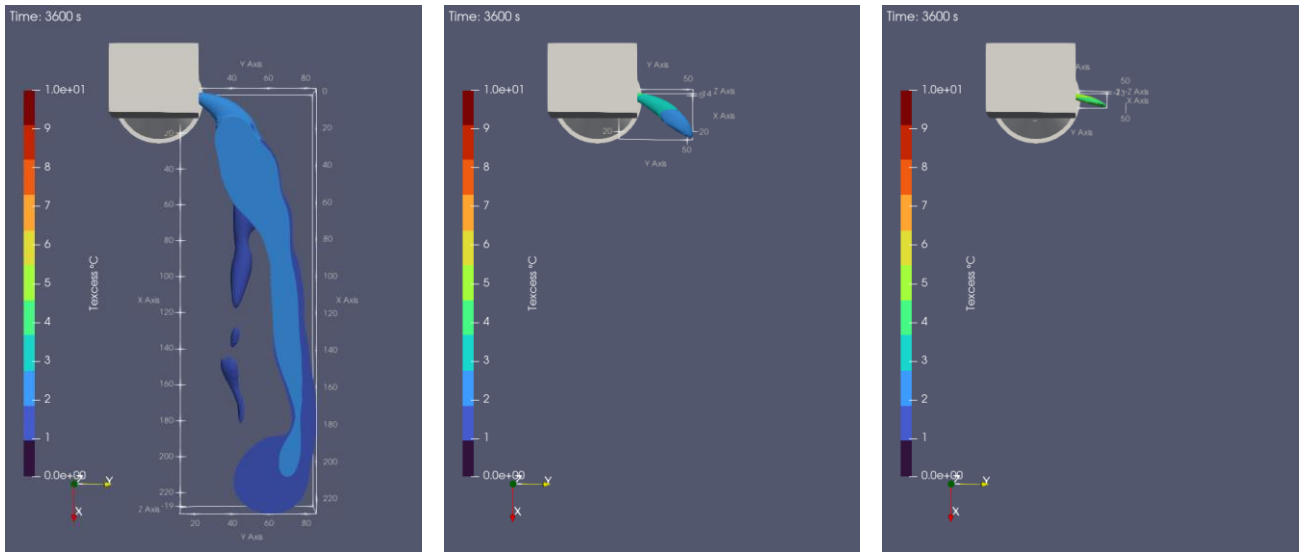


Figure 5-3: Well-mixed, extent of wastewater plume diluted to 0.1% (left), 0.25% (mid) and 0.5% (right) after 1 hour. View: from above against the current. Axis units are in meters.

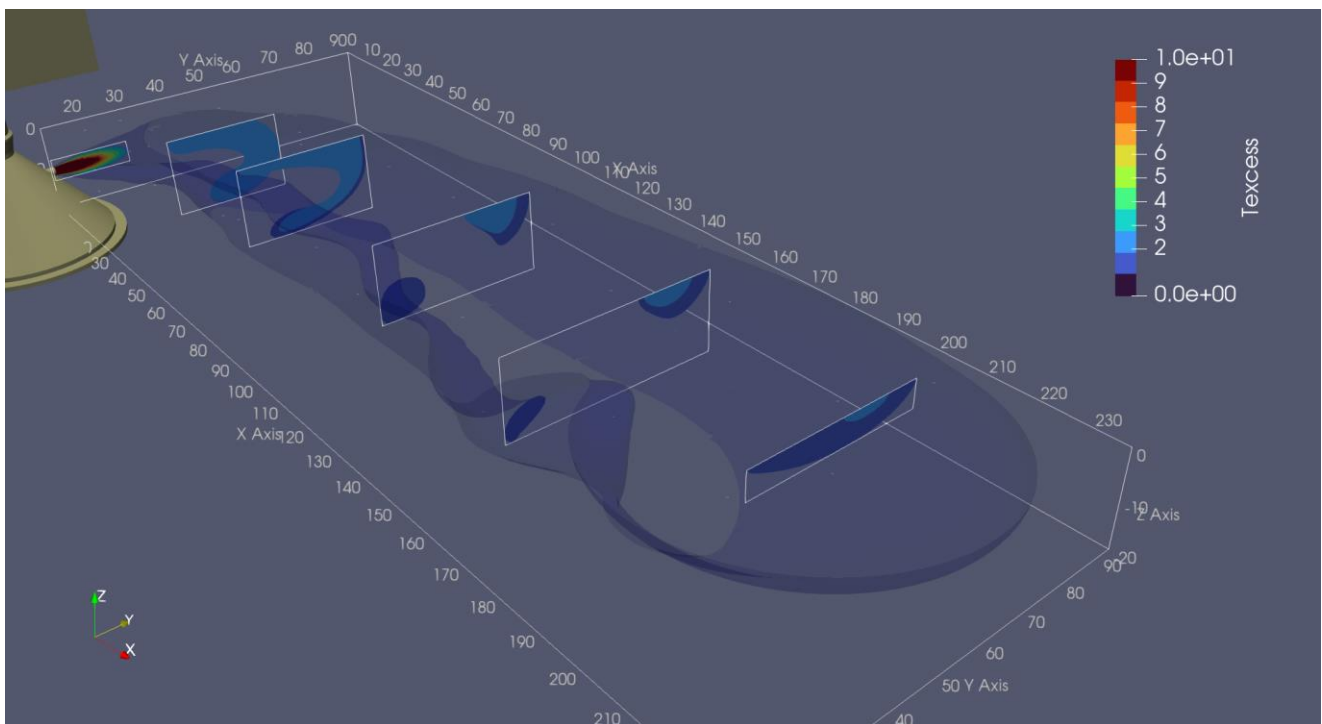


Figure 5-4: Well-mixed, cross section along the wastewater plume (0.1% diluted) showing excess temperature. View: from above against the current. Axis units are in meters.

5.2. Stratified flow

To illustrate the propagation of the wastewater plume, Figure 5.5 depicts the plume and the thermocline one hour after the release of the lighter wastewater. The plume is observed close to the surface shortly after it exits the outlet. The asymmetric disruption of the thermocline is partly caused by the substructure's presence but also due to the wastewater outlet.

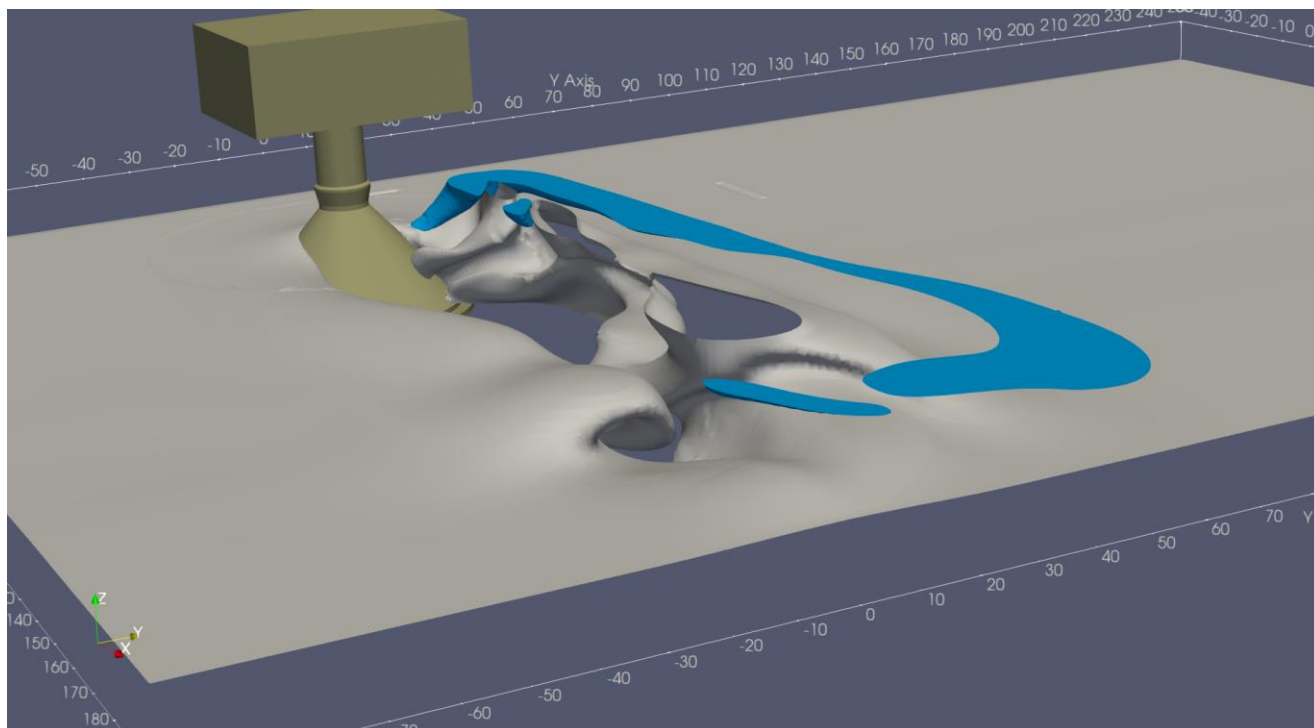


Figure 5.5: Stratified, extent of wastewater plume (light blue) diluted to 0.1% and the thermocline (grey) after 1 hour. View: from above against the current. Axis units are in meters.

Figure 5-6 and Figure 5-7 depict the extent of the plume diluted to 0.1% after one hour, viewed from both above and below. At the surface, the 0.1 % plume extends up to 70 meters perpendicular to the current, stretches 200 meters parallel to it, and has a thickness of a few meters, where the temperature exceeds by 1°C.

As the intake of the cooling water is assumed to be below the thermocline the excess temperature in the surface layer reaches less than 1°C shortly after the wastewater has left the outlet.

Dilution begins as soon as the reject/cooling water exits the pipe, achieving levels of 0.1%, 0.25%, and 0.5% as illustrated in Figure 5.3. For a 0.5% dilution, the plume extends to just 20 meters perpendicular to the flow and 15 meters parallel to it.

Figure 5.8 illustrates the excess temperature along the plume from the pipe extending to approximately 200 meters downstream. Near the surface and towards the substructure, an excess temperature of 1°C is sustained up to about 20 meters downstream, after which the excess temperature drops to between 1°C.

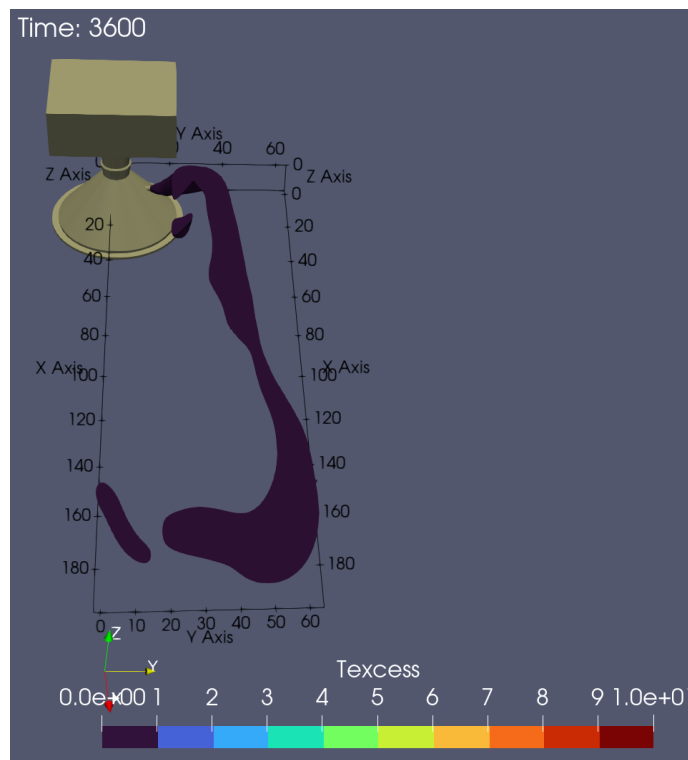


Figure 5-6: Stratified, extent of wastewater plume diluted to 0.1% after 1 hour. View: from above against the current. Excess temperature according to the temperature in the top layer. Axis units are in meters.

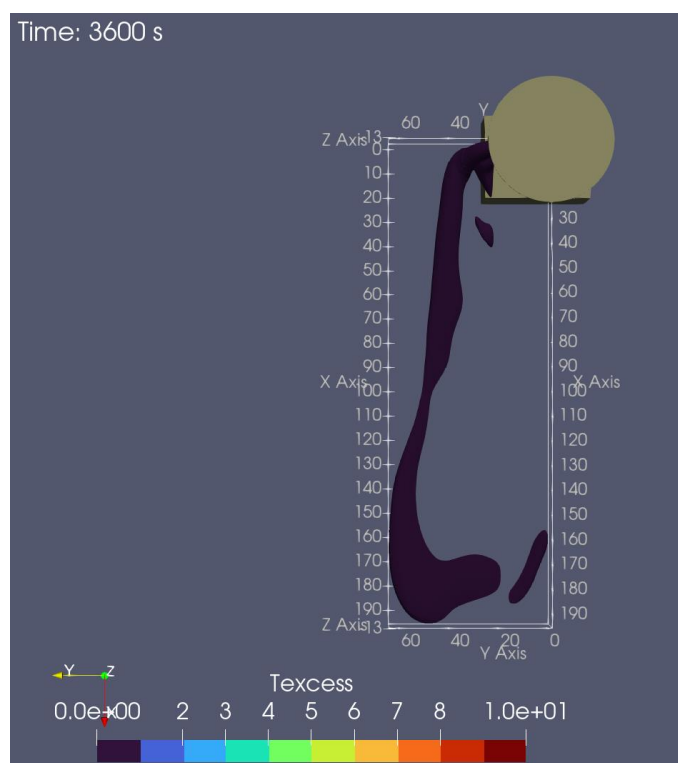


Figure 5-7: Stratified, extent of wastewater plume diluted to 0.1% after 1 hour. View: from below against the current. Excess temperature according to the temperature in the top layer. Axis units are in meters.

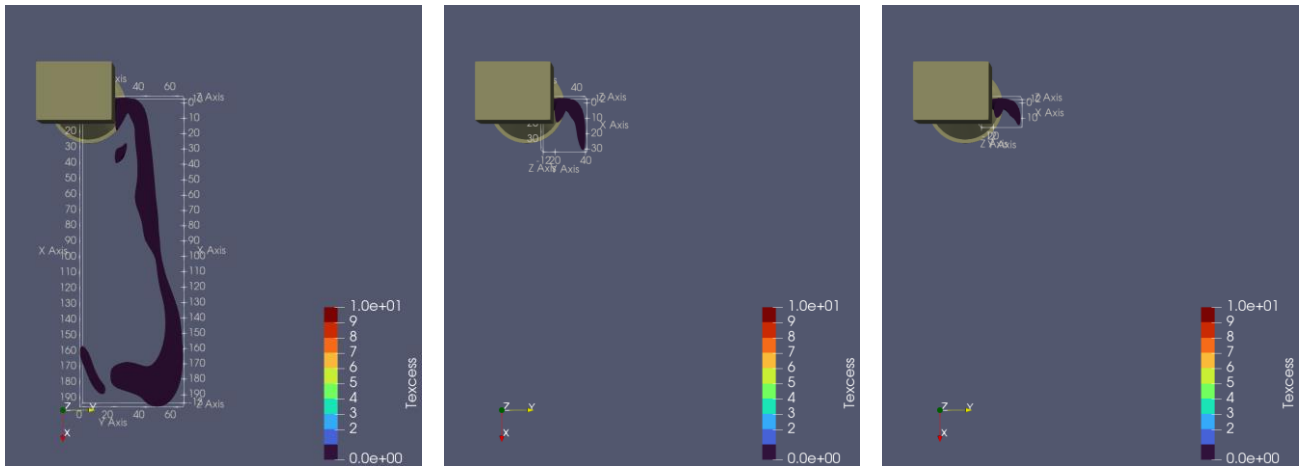


Figure 5-8: Stratified, extent of wastewater plume diluted to 0.1% (left), 0.25% (mid) and 0.5% (right) after 1 hour. View: from above against the current. Excess temperature according to the temperature in the bottom layer. Axis units are in meters.

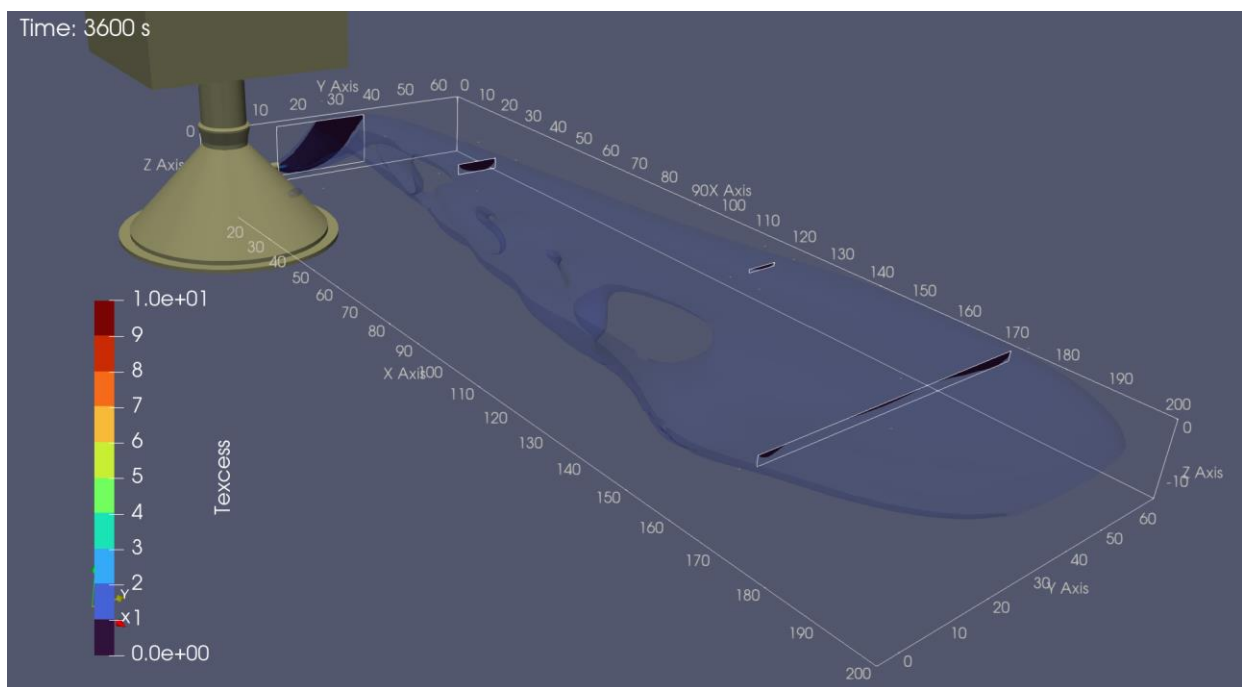


Figure 5-9: Stratified, wastewater plume cross section showing excess temperatures. View: from above against the current. Excess temperature according to the temperature in the bottom layer. Axis units are in meters.

6. References

NIRAS. (2023-12-20). *Halla OWF, hydrodynamics - Sediment & B rine Dispersal modelling*.

OpenFOAM. (n.d.). *OpenFOAM*. Retrieved from <https://www.openfoam.com/>: <https://www.openfoam.com/>

Appendix 1 Profiles over time of Density, Temperature, Salinity and Current speed.

The presented profile time series show the baseline conditions (the situation before the installation of the platform) at the location for the of the modelled platform (NIRAS, 2023-12-20).

Day 0 corresponds to 2022-01-01.

