



Morven Hawthorn Pit Grid Connection Project

Preliminary Environmental Information Report

Volume 2, Annex 1.2: Model Design, Validation and
Results

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Glossary

Term	Meaning
Bathymetry	The measurement of water depth in oceans, seas and lakes.
Harmonic Constituents	Individual sinusoidal components of a complex tidal signal, each characterised by a specific amplitude, phase, and frequency.
Highly Protected Marine Area (HMPA)	Areas of the sea (including the shoreline) that allow the protection and full recovery of marine ecosystems. HPMAs protect all species and habitats and associated ecosystem processes within the site boundary, including the seabed and water column.
Impact	A change caused by an action that occurs during a project's lifetime.
Landfall	The area in which the offshore export cables make landfall (come onshore) and the transitional area between the offshore cabling and the onshore cabling. This term applies to the entire landfall area between the trenchless technique exit pits and the transition joint bay inclusive of all construction works.
Lowest Astronomical Tide (LAT)	The lowest tide level that can be expected to occur under average meteorological conditions and under any combination of astronomical conditions.
Marine Conservation Zone (MCZ)	An area designated under the Marine and Coastal Access Act 2009 for the purpose of conserving marine flora, fauna, habitats, or features of geological or geomorphological interest.
Marine Directorate Licensing Operations Team (MD-LOT)	The part of the Scottish Government's Marine Directorate responsible for assessing and administering applications for marine licences for Scottish waters and Section 36 consent (offshore) in Scotland.
Marine Management Organisation (MMO)	The MMO, as a UK government body, is responsible for licensing, regulating and overseeing activities in the marine environment for English waters. For a DCO and deemed marine licence, the MMO acts as a statutory consultee, advising on marine planning, environmental impacts, habitats and compliance with marine licensing regulations.
Marine Protected Areas (MPA)	Areas within the United Kingdom's seas designated for the protection of marine life and habitats against damage caused by human activities.
Maximum Design Scenario (MDS)	The realistic worst case scenario, selected on a topic-specific and impact specific basis, from a range of potential parameters for the MHPGC Project.

Term	Meaning
MHPGC Project Scoping Opinions	Separate scoping opinions received from PINS (on behalf of the Secretary of State) and MD-LOT (on behalf of the Scottish Ministers) in response to the MHPGC Scoping Report. The MHPGC Project Scoping Opinions contain the range of issues that PINS, and MD-LOT in consultation with statutory stakeholders, have identified should be considered within the EIA process.
MHPGC Project Scoping Report	A Scoping Report for the MHPGC Project, scoping the likely significant effects of the project on the environment, was submitted and accepted by Planning Inspectorate (PINS) and submitted to the Scottish Ministers, via the Marine Directorate – Licencing Operations Team (MD-LOT) in February 2025.
Morven Hawthorn Pit Grid Connection Project	The MHPGC Project is comprised of the offshore export cables in Scottish and English waters from the Morven North or the Morven South offshore substation platform(s) (OSP), landfall, onshore export cables, the onshore land substation (LSS) and AC connection cables. Also referred to in this report as the MHPGC Project, for ease of reading.
Morven North Offshore Wind Array Project and Morven South Offshore Wind Array Project	Morven North and Morven South comprises the Morven North Offshore Wind Array Project and Morven South Offshore Wind Array Project, collectively.
Offshore Export Cable Corridor	The proposed offshore area in which the offshore export cables will be laid, from either the Morven North offshore substation platform or Morven South offshore substation platform to the transition joint bay (TJB) at landfall.
Offshore Export Cables	HVDC cables which bring electricity from either the Morven North or Morven South offshore substation platform to the TJB at landfall.
Physical Processes	The collective term for the following: hydrodynamics (water levels and currents); winds and waves; stratification and frontal systems; geology and seabed sediments (including sediment transport); seabed geomorphology; and coastal geomorphology.
Planning Inspectorate (PINS)	The PINS is an executive agency of the UK Government responsible for administering and examining DCO applications for NSIPs in England. PINS manages the application process, oversees consultation and examination, and makes a recommendation to the relevant Secretary of State on whether consent should be granted.
MHPGC Project Preliminary Environmental Information Report (PEIR)	A report that provides preliminary environmental information in accordance with the Infrastructure Planning (Environmental Impact Assessment) Regulations 2017. This is information that enables consultees to understand the likely significant environmental effects of a project and which helps to inform consultation responses.

Term	Meaning
Scour Protection	Protective materials installed to avoid sediment being eroded away from the base of the foundations and/or buried subsea cable due to the flow of water.
Sites of Special Scientific Interest (SSSI)	Designated areas which feature rare flora or fauna or are host to important features (physiological or geological) which are of scientific interest, designated under the Wildlife and Countryside Act 1981 (as amended).
Special Areas of Conservation (SAC)	A site designation specified in the Habitats Directive (Council Directive 92/43/EEC) and protected in the UK under the Conservation of Habitats and Species Regulations 2017 and the Conservation of Offshore Marine Habitats and Species Regulations 2017 in England. Each site is designated for one or more of the habitats and species listed in the Directive. The Directive requires that a management plan be prepared and implemented for each SAC to ensure the Favourable Conservation Status of the habitats or species for which it was designated.
Special Protection Areas (SPA)	Locations within the UK designated to conserve rare, vulnerable, and migratory bird species of European importance, as classified by the Conservation (Natural Habitats, &c.) Regulations 1994 (in Scotland), the Conservation of Habitats and Species Regulations 2017 (in England) and Conservation of Offshore Marine Habitats and Species Regulations 2017 (in Scotland and England).
Spring Tidal Excursion	The distance suspended sediment is transported prior to being carried back on the returning tide.
the Study Area	For each environmental topic, the baseline environment will be characterised, and the likely significant effect will be described within a topic-specific Study Area. Specific Study Areas are defined for each topic and are based on the maximum spatial extent across which likely significant effects of the MHPGC Project may be experienced by the relevant receptors (i.e. Zone of Influence (Zoi)).
Tidal cycle	One high tide plus a successive low tide.
Tidal Ellipse	The illustration of the variance of tidal currents in horizontal space.
Trenchless Techniques	Construction methods used to install underground or sub-surface infrastructure without the need for continuous open trench excavation, thereby avoiding or minimising disturbance to surface features, habitats and existing land users.

Acronyms

Acronym	Meaning
ABPmer	Associated British Ports, Marine Environmental Research
ADCP	Acoustic Doppler Current Profiler
CFE	Controlled Flow Excavator
DCO	Development Consent Order
DHI	Danish Hydraulic Institute
DTU	Technical University of Denmark
EMODnet	European Marine Observation and Data Network
FLiDAR	Floating Light Detection and Ranging
FM	Flexible Mesh
HD	Hydrodynamic
HDD	Horizontal Directional Drill
HMPA	Highly Protected Marine Area
HW	High Water
LAT	Lowest Astronomical Tide
LW	Low Water
MCZ	Marine Conservation Zone
MD-LOT	Marine Directorate Licensing Operations Team
MDS	Maximum Design Scenario
MFE	Mass Flow Excavator
MHPGC	Morven Hawthorn Pit Grid Connection
MMO	Marine Management Organisation
MPA	Marine Protected Area
MSL	Mean Sea Level
OSP	Offshore Substation Platforms
PEIR	Preliminary Environmental Information Report
PLONOR	Poses little or no risk
PSA	Particle Size Analysis
PT	Particle Tracking
SAC	Special Area of Conservation
SPA	Special Protection Area
SSC	Suspended Sediment Concentration
SSSI	Site of Special Scientific Importance
ST	Sand Transport
TSHD	Trailer Suction Hopper Dredger

Acronym	Meaning
UCL	University College London
UKHO	United Kingdom Hydrographic Office
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator
VORF	Vertical Offshore Reference Frame
WL	Water Level

Units

Unit	Meaning
kg	Kilogram
kg/m ³	kg/m ³
kg/s	Kilograms per second
km	Kilometre
km ²	Square kilometre
m	Metre
mm	Millimetre
m ²	Square Metre
m/hr	Metres per hour
mMSL	Metres below Mean Sea Level
m/s	Metres per second
m ² /s	Square metre per second
mg/l	Milligrams per litre
nm	Nautical mile
s	Second
°	Degree
%	Percent
µm	Micrometre

Executive summary

This Technical Report presents the modelling methodology and results to inform the technical assessment of effects on physical processes for the Morven Hawthorn Pit Grid Connection Project (hereafter 'the MHPGC Project'). The Technical Report integrates baseline data analysis with advanced numerical modelling, including hydrodynamic (HD) and particle tracking (PT) simulations, to characterise tidal dynamics and sediment behaviour both within the MHPGC Project Preliminary Environmental Information Report (PEIR) Red Line Boundary and across the Physical Processes Study Area.

HD modelling confirms that tidal currents and sediment transport rates vary significantly between neap and spring conditions. Neap tides are characterised by low current speeds and minimal sediment movement, whereas spring tides exhibit substantially higher flows and associated transport rates. These findings provide a robust understanding of the baseline regime and inform predictions of construction phase effects.

PT modelling, supported by conservative spreadsheet-based calculations, evaluates the extent, duration and magnitude of changes in suspended sediment concentration (SSC) and deposition patterns resulting from sediment disturbance. Model outputs indicate that sediment plumes generated during construction are spatially limited and short term, aligning with the tidal axis. Overall, predicted changes in SSC and seabed deposition are confined to the immediate vicinity of construction activities, with negligible overlap into designated conservation sites.

1 Introduction

1.1 Overview

- 1.1.1.1 This Technical Report presents the Model Design, Validation and Results for the Morven Hawthorn Pit Grid Connection Project (hereafter 'the MHPGC Project'). It forms **Volume 2, Annex 1.2: Model Design, Validation and Results, of the Preliminary Environmental Information Report (PEIR)** prepared for the MHPGC Project and supports **Volume 2, Chapter 1: Physical Processes, of the PEIR**.
- 1.1.1.2 Specifically, the report details the results of modelling the construction phase of the MHPGC Project along with detailing the methods and validation used to produce said results. The MHPGC Project will connect the offshore substation platform(s) (OSP) of Morven North Offshore Wind Array Project or Morven South Offshore Wind Array Project (hereafter 'Morven North or Morven South'), located approximately 61 kilometres (km) at its closest point from the Aberdeenshire coast in Scottish waters, to the National Grid Hawthorn Pit Substation, South of Seaham along the Northumberland Coastline. The proposed offshore export cables are up to 326.40 km, extending from the Morven North or Morven South OSP to Mean High Water Springs (MHWS).
- 1.1.1.3 A range of numerical models have been developed to address the following aims:
- Hydrodynamics: Characterise the HD regime (tidal currents and water levels) during the construction phase of the MHPGC Project;
 - Sediment plumes: Characterise the patterns of elevated SSC and sediment deposition resulting from sediment disturbance during the construction phase.
- 1.1.1.4 The report presented is informed by the following technical chapter:
- **Volume 1, Chapter 2: Project Description, of the PEIR;**
- 1.1.1.5 The report also draws on baseline physical processes information contained within the following annex:
- **Volume 2, Annex 1.1: Physical Processes Technical Report, of the PEIR.**

1.2 Study area

- 1.2.1.1 The Physical Processes Study Area is located off the northeast coast of England and southeast coast of Scotland and represents the area across which baseline data collation and characterisation has been undertaken for the purposes of informing the physical processes assessment [**Figure 1.1**]. A Zone of Influence (ZOI) has also been defined: this is the area within which the MHPGC project may cause direct or indirect changes to HDs, sediments, morphology, or the water column. It has been defined on the basis of:
- The distance away from the MHPGC Project that suspended sediment plumes may be advected (and interact with potentially sensitive receptors). This has been defined by a spring tidal excursion ellipse buffer around the MHPGC Project PEIR Red Line Boundary;
 - The distance up/down drift from the landfall, that littoral processes could theoretically be affected by infrastructure associated with the MHPGC Project.
- 1.2.1.2 The Physical Processes Study Area is shown on **Figure 1.1**. The study area is larger than the ZOI and encompasses a nominal wider region within which greater detail of baseline understanding is required to inform assessments of potential indirect changes (e.g.) to sediment transport pathways. The study area does not indicate an expectation of measurable change or impact within this extent.

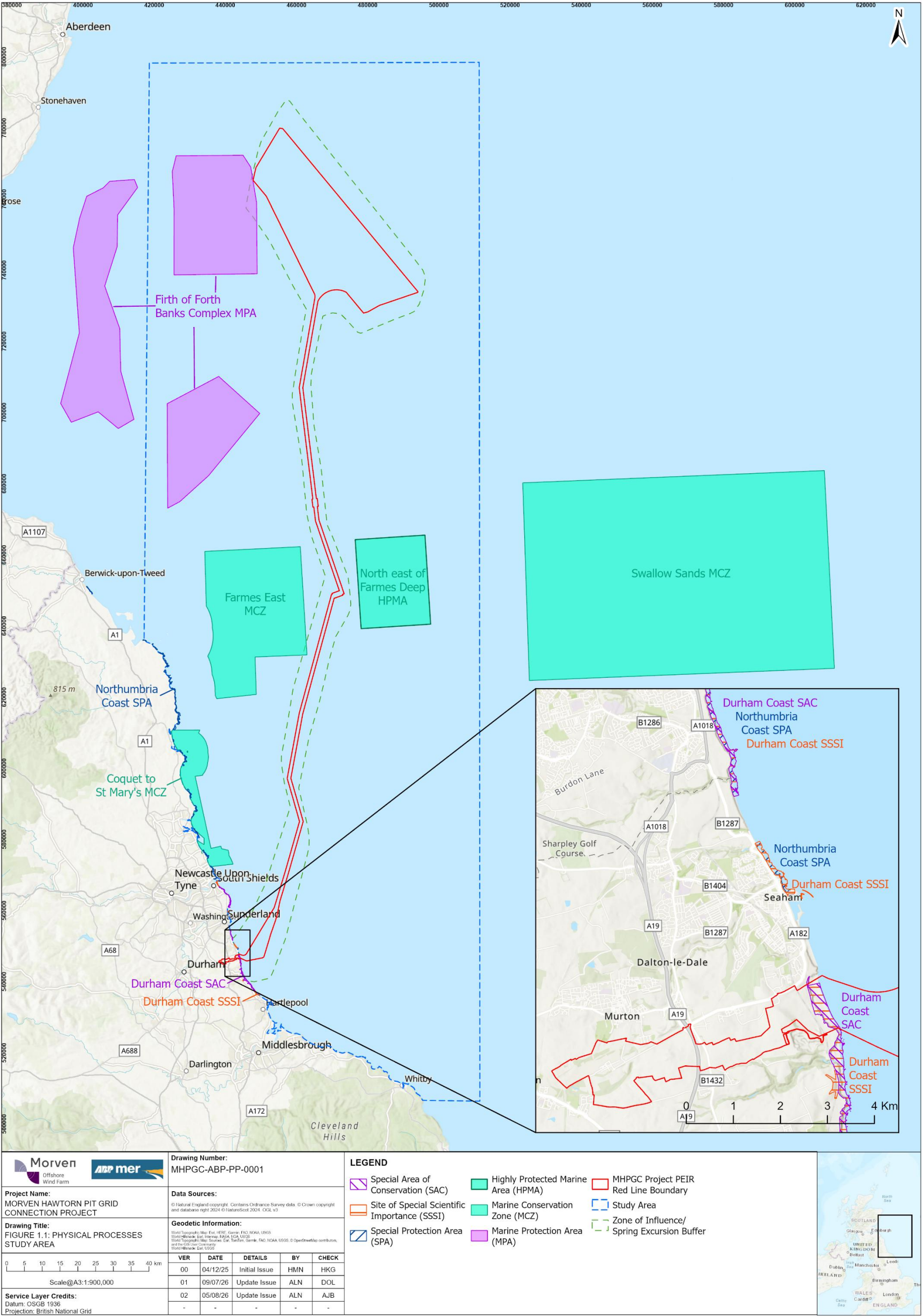


Figure 1.1: Physical Processes Study Area

2 Methodology

2.1 Overview

- 2.1.1.1 The numerical modelling for this study has been undertaken using the MIKE21FM software package from the Danish Hydraulic Institute (DHI), which has been developed specifically for application in oceanographic, coastal and estuarine environments.
- 2.1.1.2 When used by an experienced modeller, and in conjunction with suitable data inputs, these models provide reliable and realistic representations of both baseline environmental conditions, and the potential effects of offshore wind farm infrastructure and other construction phase activities.
- 2.1.1.3 The HD modelling described in this report is undertaken using a two-dimensional (depth averaged) HD model, utilising a flexible mesh (FM) with high resolution in the Physical Processes Study Area. The model is run in a tide only mode (no effect of winds or air pressure) to simulate a continuous timeseries of tidally varying water levels and currents over a representative spring-neap period.
- 2.1.1.4 The sediment plume modelling described in this technical report is undertaken using a PT approach, whereby particles representing discrete amounts of sediment are released and subject to advection and dispersion within the simulated flow fields from the HD model.

2.2 Hydrodynamic model

2.2.1 Hydrodynamic model design

- 2.2.1.1 The HD model is built using the MIKE21FM HD module, which simulates the propagation of the tidal wave and associated movements of water volume in offshore and coastal settings.
- 2.2.1.2 The HD model creates a timeseries simulation of tidal water levels and depth averaged current speed and direction throughout the model domain.
- 2.2.1.3 The HD model is based on the ABPmer SEASTATES validated regional scale European Shelf Tide and Surge model, used in a tide only mode, with locally enhanced resolution in the Physical Processes Study Area. The design and performance of the regional model are described in 'ABPmer SEASTATES North West European Continental Shelf Tide and Surge Hindcast Database, Model validation report' (ABPmer, 2017).

Model mesh

- 2.2.1.4 The HD model mesh is based on that used by the ABPmer SEASTATES European Shelf Tide and Surge model (ABPmer, 2017). The extent of the model mesh and the distribution of mesh resolution is shown in **Figure 2.1**. An FM design is used (interlocking triangular "elements" of varying shape and orientation), providing tailored spatially variable resolution within a single model mesh (**Figure 2.2**).
- 2.2.1.5 The (variable) resolution of the mesh outside of the Physical Processes Study Area (as shown in **Figure 2.1**) is sufficient and suitable to simulate the general progression of the tidal wave and associated movement of water volume around the European continental shelf, up to the edges of the local Physical Processes Study Area.
- 2.2.1.6 Resolution is increased throughout the Physical Processes Study Area from south of Peterhead in Scotland to Flamborough Head in England (**Figure 2.2**). The highest mesh resolution is approximately 100m covering the MHPGC Project PEIR Red Line Boundary and extending from north of Blyth to south of Redcar (covering approximately 85km of coastline), fully encompassing the Zol. The higher resolution provides a more detailed description of the key bathymetric and coastal features affecting flow patterns in these areas.

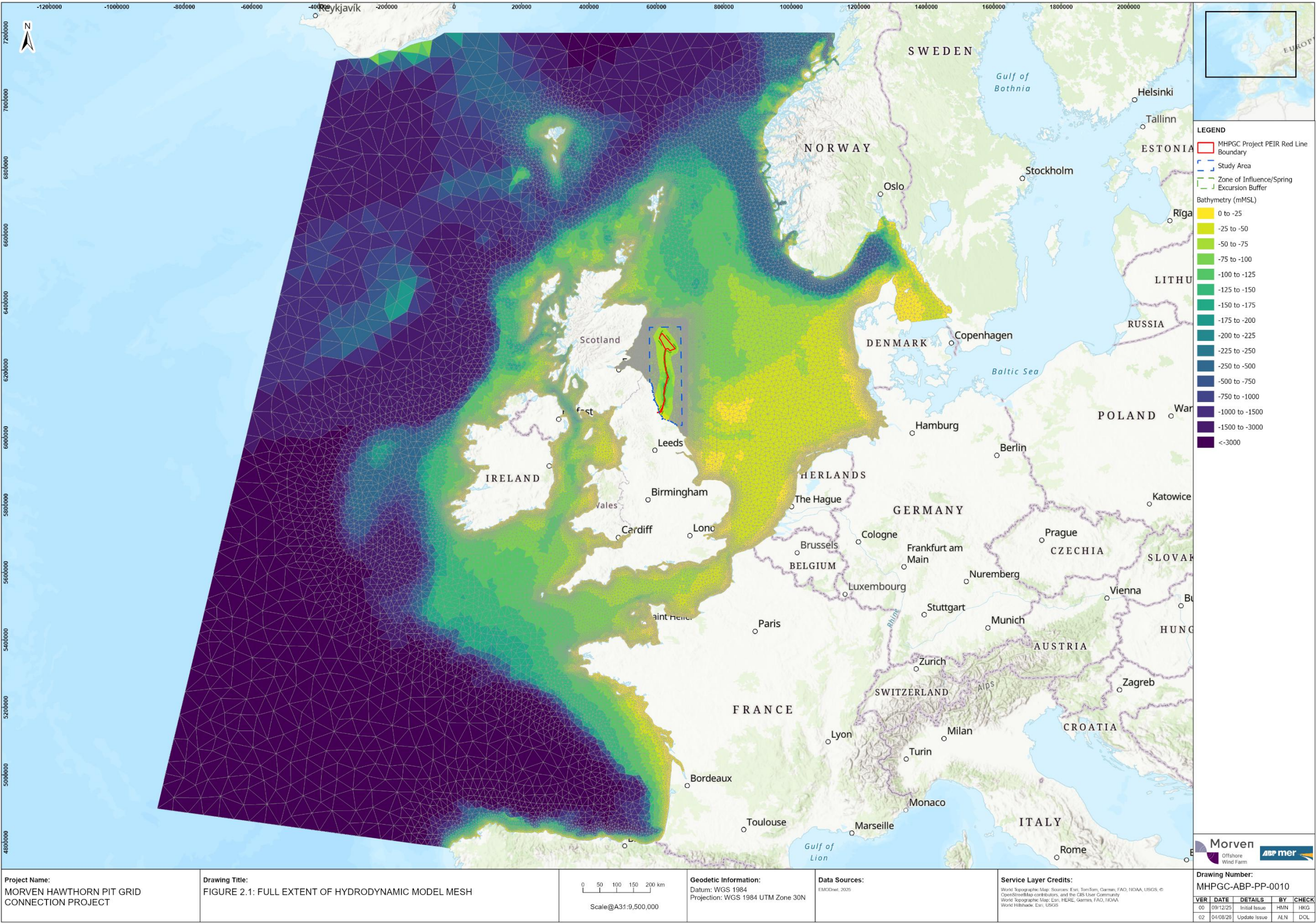


Figure 2.1: Full extent of HD model mesh

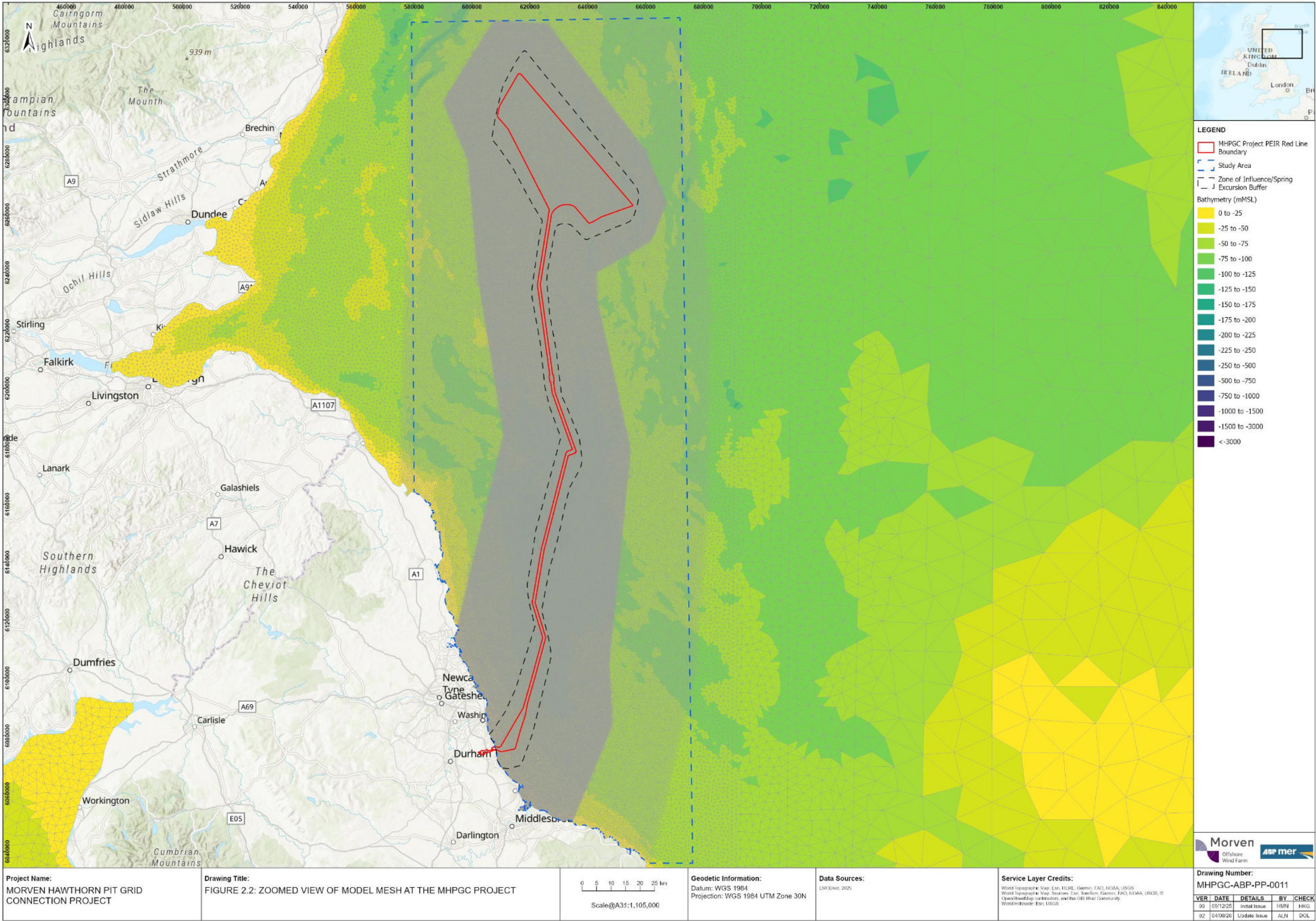


Figure 2.2: Zoomed view of the model mesh at the MHPGC Project.

Model bathymetry

- 2.2.1.7 The HD model bathymetry is sourced from EMODnet (EMODnet, 2025), which is a freely available and generally reliable data source. Depth values from EMODnet across the MHPGC Project were compared with those obtained from the 2024 MHPGC Project geophysical survey (XOCEAN Ltd., 2024). The comparison shows a very strong correlation between the two data sets. The good level of validation achieved by the regional model with respect to water levels and currents (ABPmer, 2017) also provides indirect validation of the bathymetry data source across the rest of the domain.
- 2.2.1.8 Spatially varying adjustments are made to convert the bathymetry data from the standard Lowest Astronomical Tide (LAT) datum at source, to Mean Sea Level (MSL), as is required for use in the model. Adjustments are made using a combination of Vertical Offshore Reference Frames (VORF) (University College London (UCL) and United Kingdom Hydrographic Office (UKHO), 2005) and tidal water level statistics from tide gauges for locations elsewhere in Europe outside of the VORF data extent.

Model boundary conditions

- 2.2.1.9 The HD model has four open water level boundaries, shown in **Figure 2.3**.
- 2.2.1.10 Temporally and spatially varying tidal water levels are applied at these boundaries, representing the passage of the deep ocean tidal wave from the North Atlantic onto the European shelf (and smaller exchanges with the Baltic Sea). Tidal boundary data are obtained using the DTU10 (DTU, 2010) database of harmonic constituents. The good level of validation achieved by the model with respect to water levels and currents (ABPmer, 2017) also provides indirect validation of the tidal boundary data source.
- 2.2.1.11 The effect of winds and air pressure (for non-tidal surge related influences) are not included in this (tide only) model.

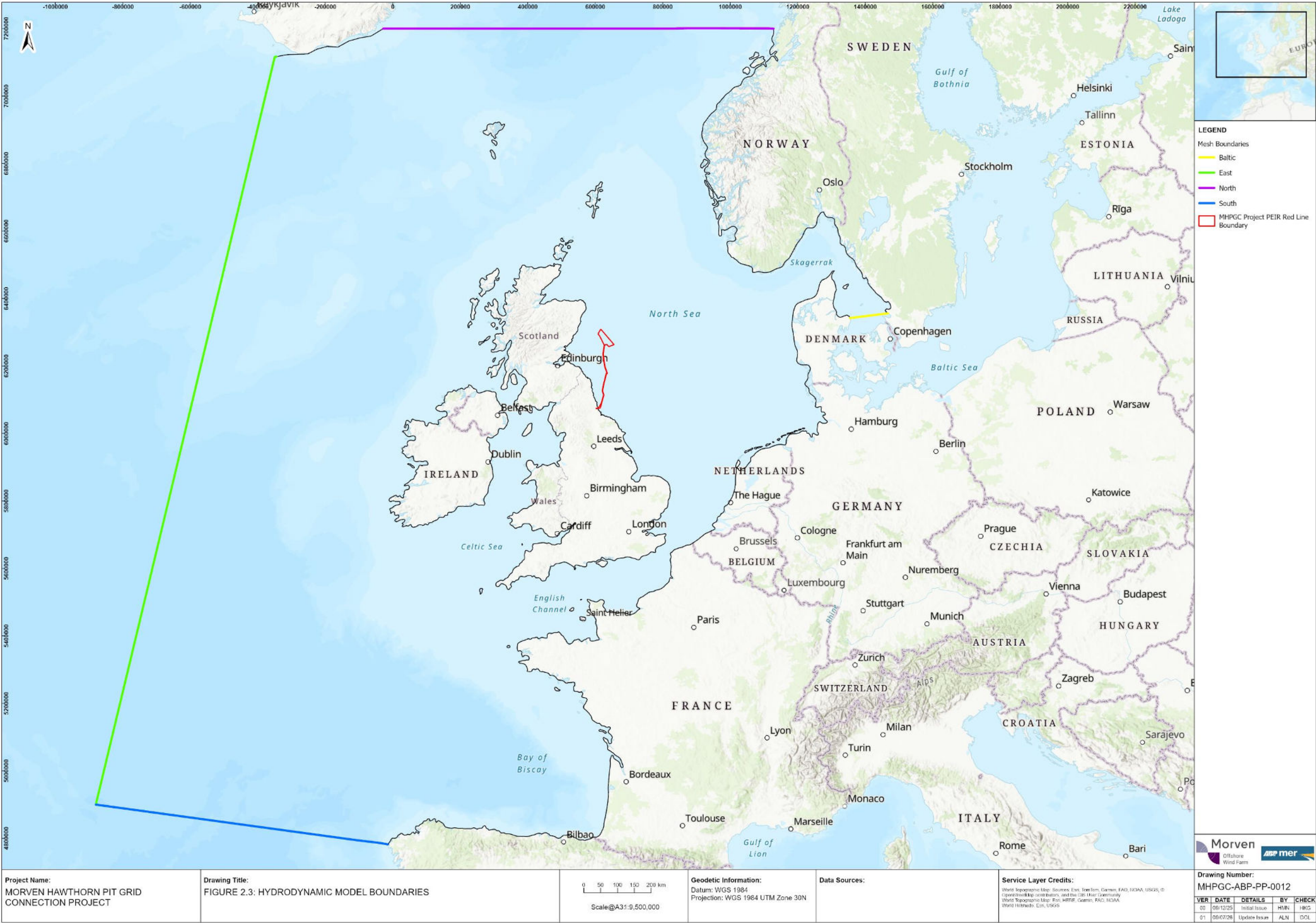


Figure 2.3: HD model boundaries

Bed roughness

- 2.2.1.12 Bed roughness in the model describes the friction from the seabed 'felt' by moving water. Changing the magnitude of bed roughness locally effects the rate at which water moves in that area and so can affect both tidal range and phasing, and (mainly the speed of) tidal currents. As such, bed roughness is a key variable in the model that can be varied to optimise the model performance in comparison to coincident measured data.
- 2.2.1.13 The ABPmer SEASTATES European Shelf Tide and Surge model utilises a bespoke spatially varying map of bed roughness, created by combining information about the distribution of seabed and sediment type, and water depth. The good level of validation achieved by the model with respect to regional scale patterns of water levels and currents (ABPmer, 2017) also provides indirect validation of the bed roughness values.
- 2.2.1.14 The same validated spatially variable bed roughness distribution is applied in the technical report, with no adjustments made.

Hydrodynamic model validation

- 2.2.1.15 The regional SEASTATES tide model largely controls the timing, magnitude and direction of water levels and currents entering and propagating through the Physical Processes Study Area. The regional model has been separately validated against the tide gauge and current meter data in numerous locations around the European continental shelf, including national tide gauges at North Shields, Whitby and Immingham (ABPmer, 2017).
- 2.2.1.16 The HD model has also been locally validated against water level data at the North Shields and Whitby tide gauges. Model current speed and direction is validated against one of the deployed Floating Light Detection and Ranging (FLiDAR) Acoustic Doppler Current Profiler (ADCP) measurements. The location of these points is displayed in **Figure 2.4**.

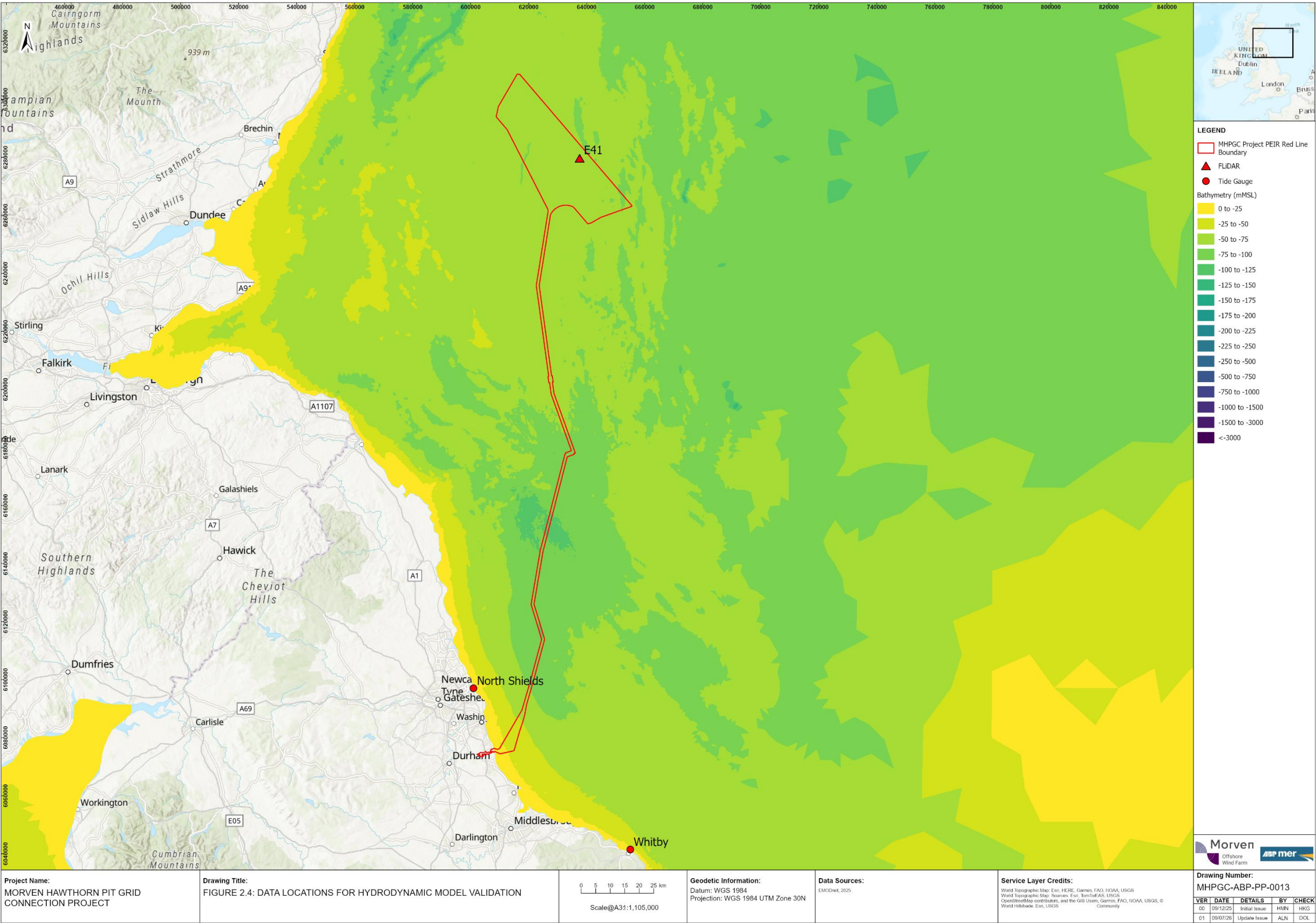


Figure 2.4: Data locations for HD model validation

Water levels

North Shields

- 2.2.1.17 Water level model predictions against concurrent tide gauge observations over a representative 14 day period (07 July 2024 to 21 July 2024) have been analysed both visually and statistically. The HD model validation process has focused on this representative spring-neap tidal cycle, identified and selected from a longer time-series of modelled water level data.
- 2.2.1.18 Water levels at the location of the North Shields tide gauge were extracted from the model and compared to the water level measured at the North Shields tide gauge for the same period.
- 2.2.1.19 **Figure 2.5** and **Figure 2.6** show timeseries and scatter comparison plots of the modelled water levels and measured water levels. The visual comparison shows the general levels, shape and phasing of the tide is reproduced well. A review of validation metrics indicates the model results reproduce the measured water levels well within the vicinity of the North Shields tide gauge.

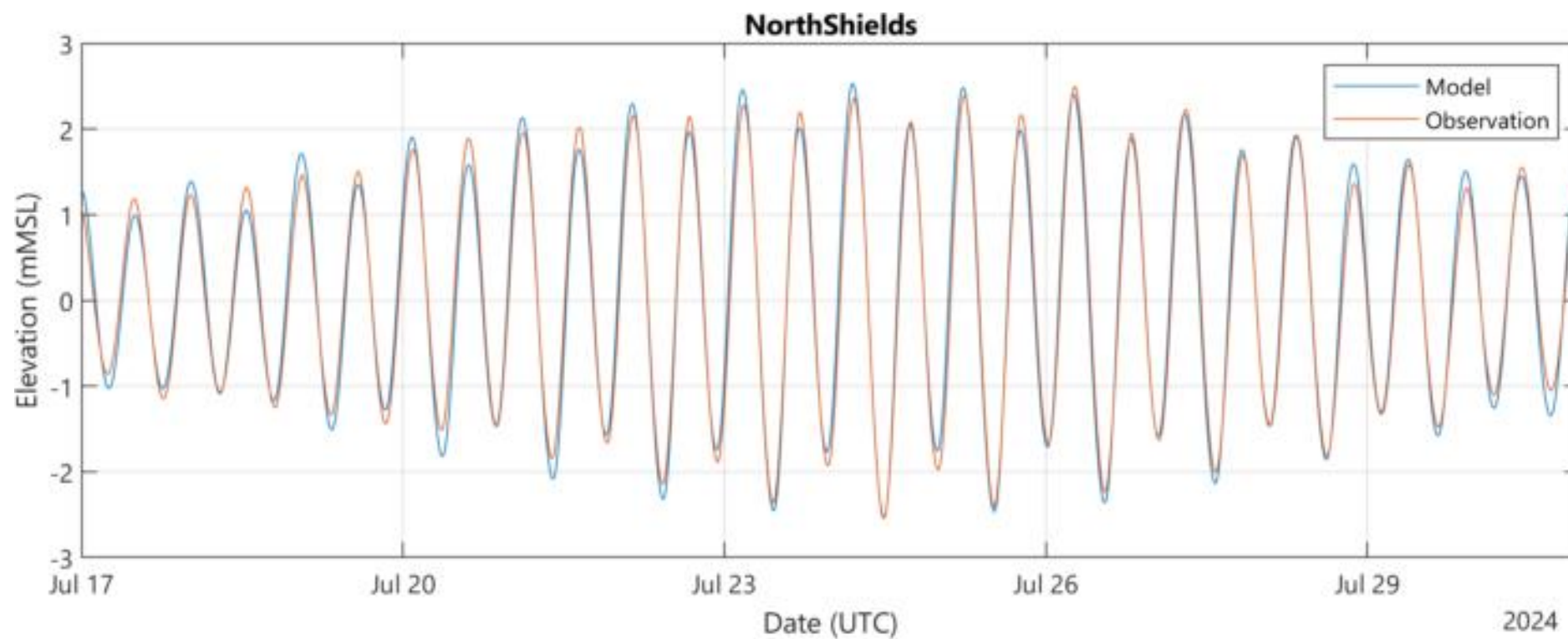


Figure 2.5: Comparison of measured and modelled water levels at North Shields tide gauge

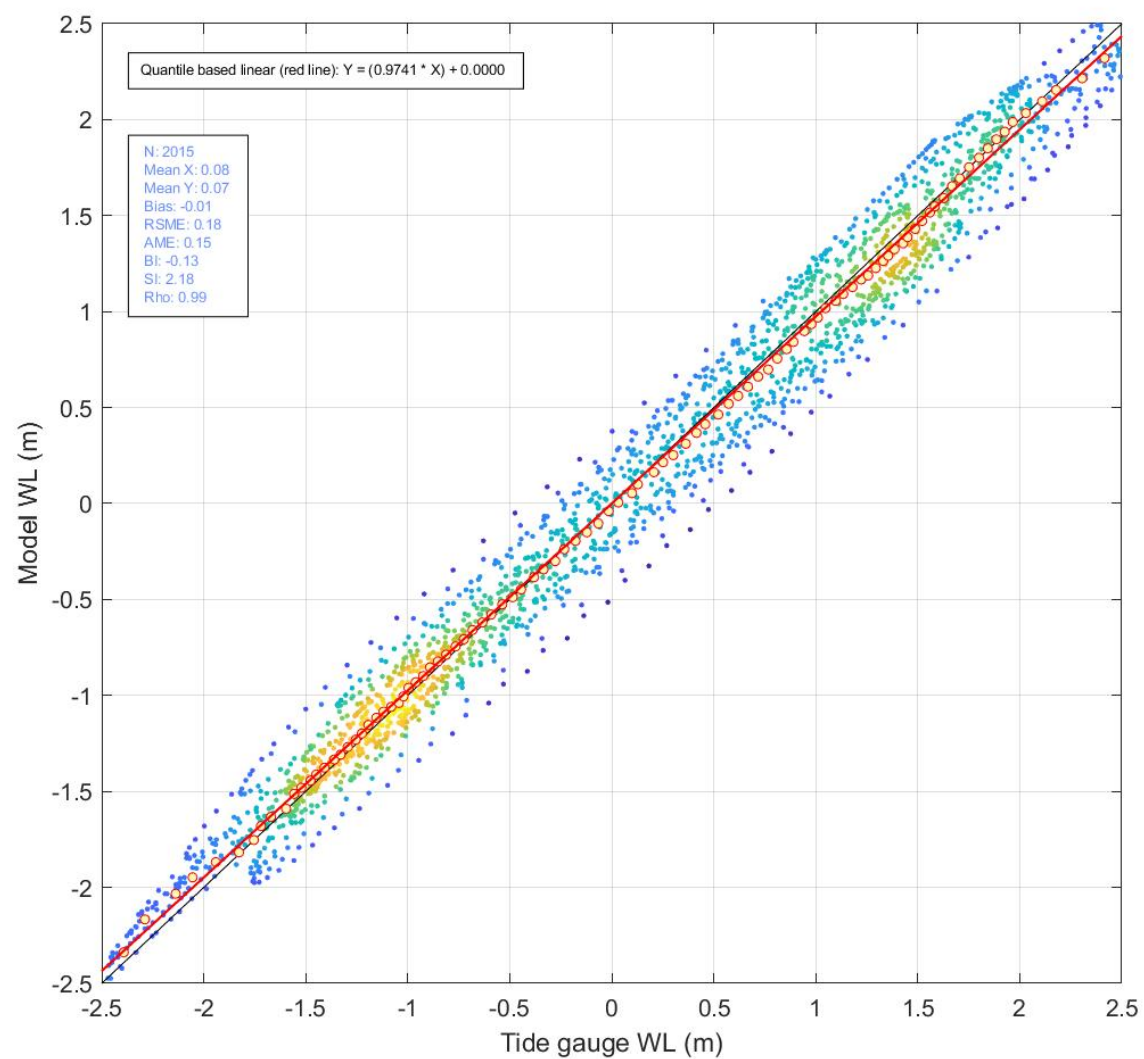


Figure 2.6: Quantile-quantile density scatter plot of North Shields tide gauge water levels (WL) vs. modelled water levels

Whitby

- 2.2.1.20 Water levels at the location of Whitby tide gauge were extracted from the model and compared to the harmonically extracted tide only water level measured at the Whitby tide gauge for the same period.
- 2.2.1.21 **Figure 2.7** and **Figure 2.8** show timeseries and scatter comparison plots of the modelled water levels and measured water levels. The visual comparison shows the general levels, shape and phasing of the tide is reproduced well. A review of validation metrics indicates the model results reproduce the measured water levels well within the vicinity of the Whitby tide gauge.
- 2.2.1.22 Paired with the results from the North Shields tide gauge, the model is likely to reproduce observed water levels equally as well, if not better, within the MHPGC Project.

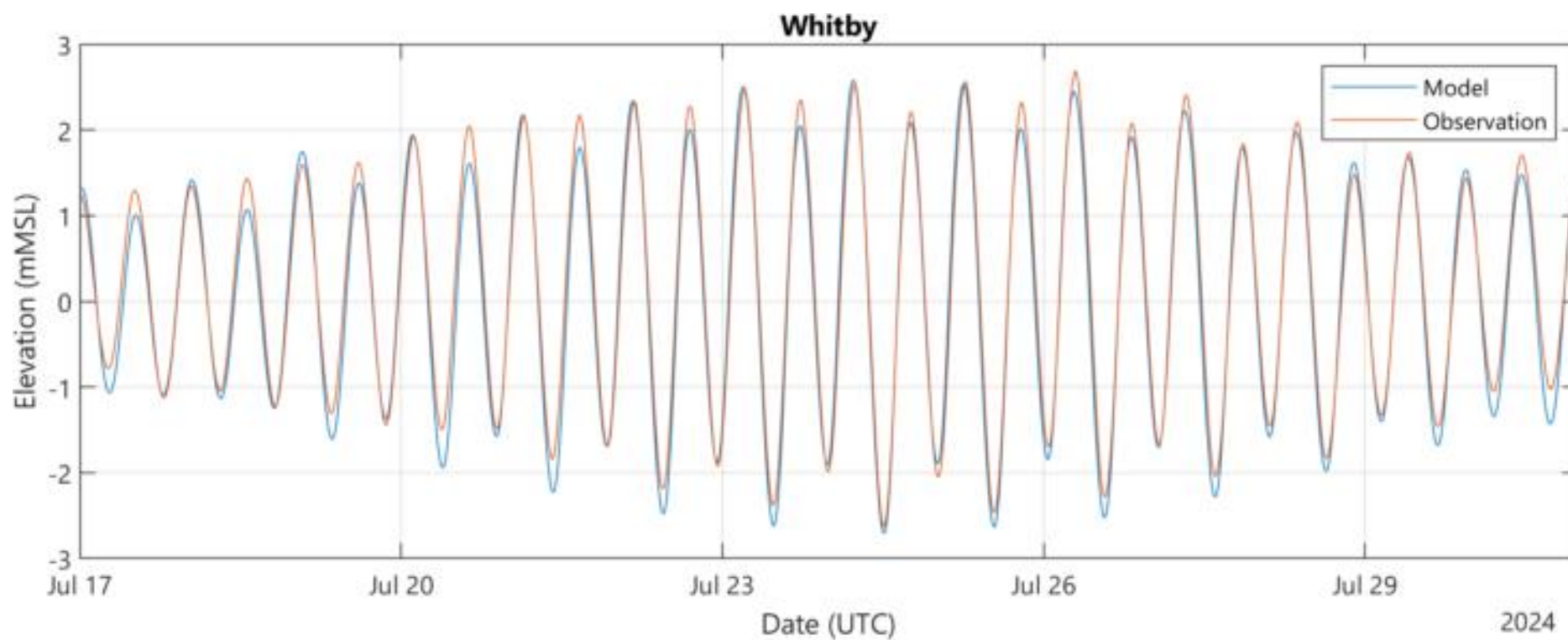


Figure 2.7: Comparison of measured and modelled water levels at Whitby tide gauge

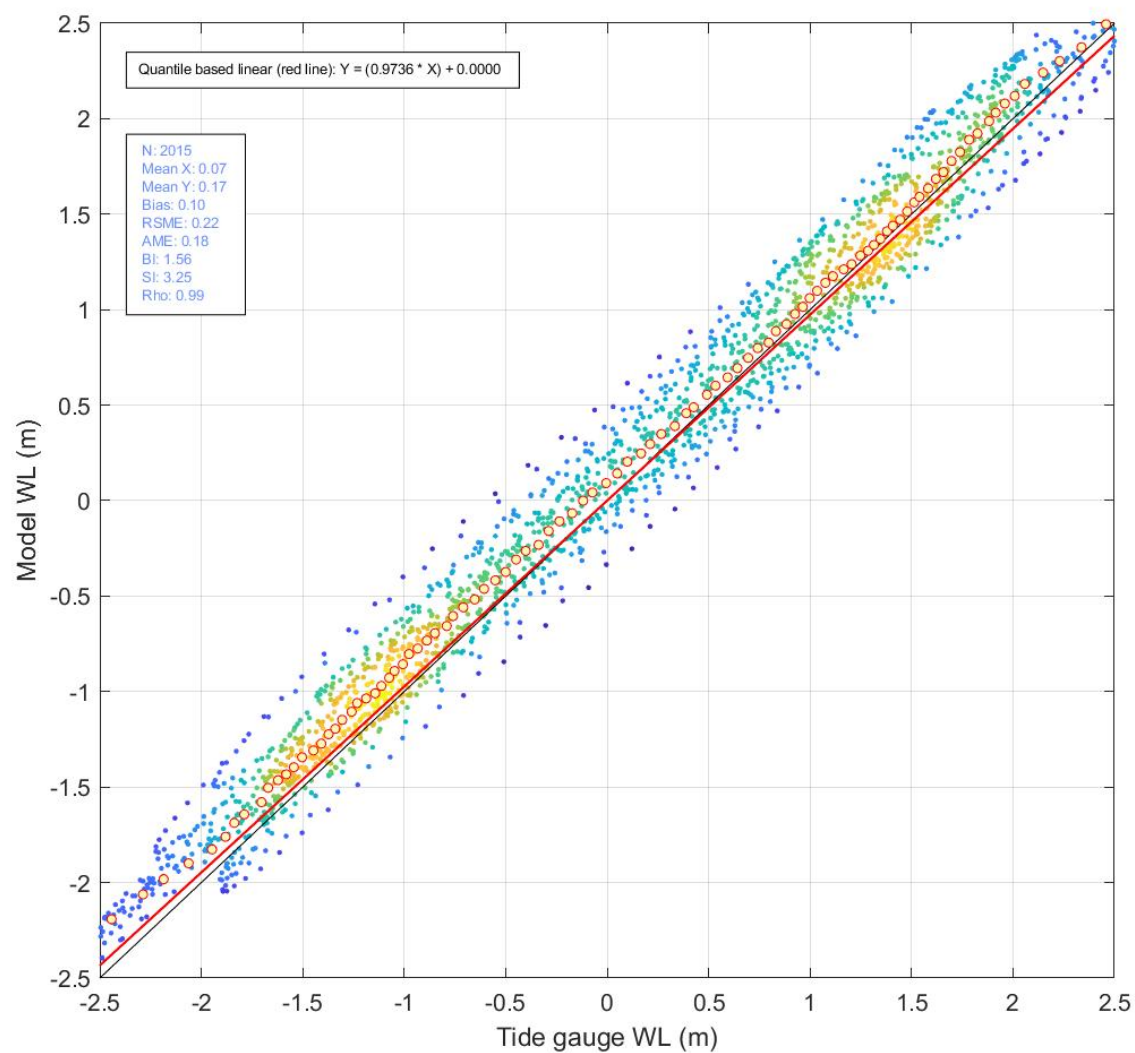


Figure 2.8: Quantile-quantile density scatter plot of Whitby tide gauge water levels (WL) vs. modelled water levels

Current speed and direction

2.2.1.23 **Figure 2.9** and **Figure 2.10** show timeseries and scatter comparison plots of the modelled tidal current speed and direction to depth-averaged ADCP data for E41 FLiDAR buoy throughout a mean neap and mean spring tide. The model shows good agreement with the measured data, satisfactorily replicating both the general current speed and direction.

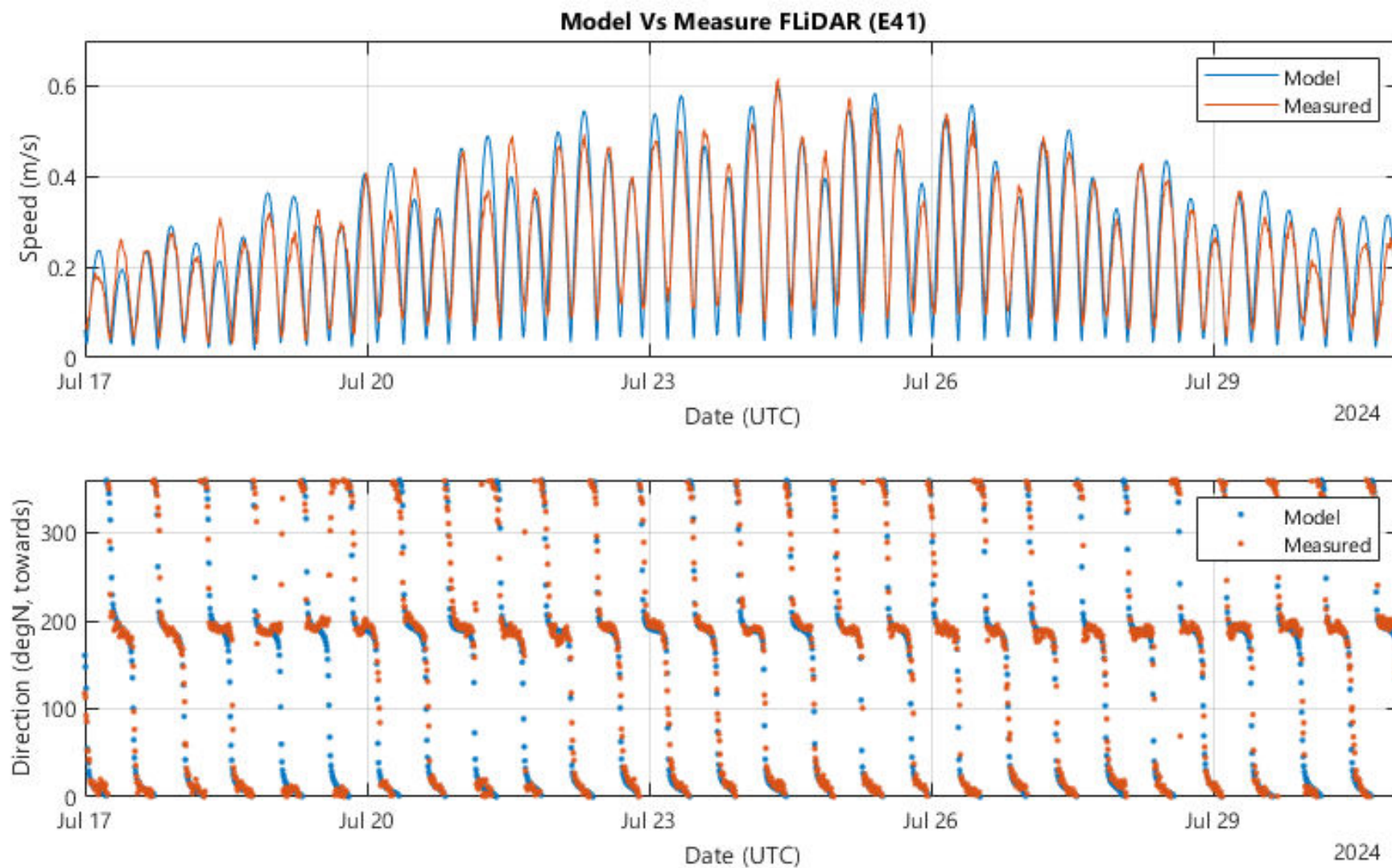


Figure 2.9: Comparison of modelled current speed and direction and the measured FLiDAR E41 data

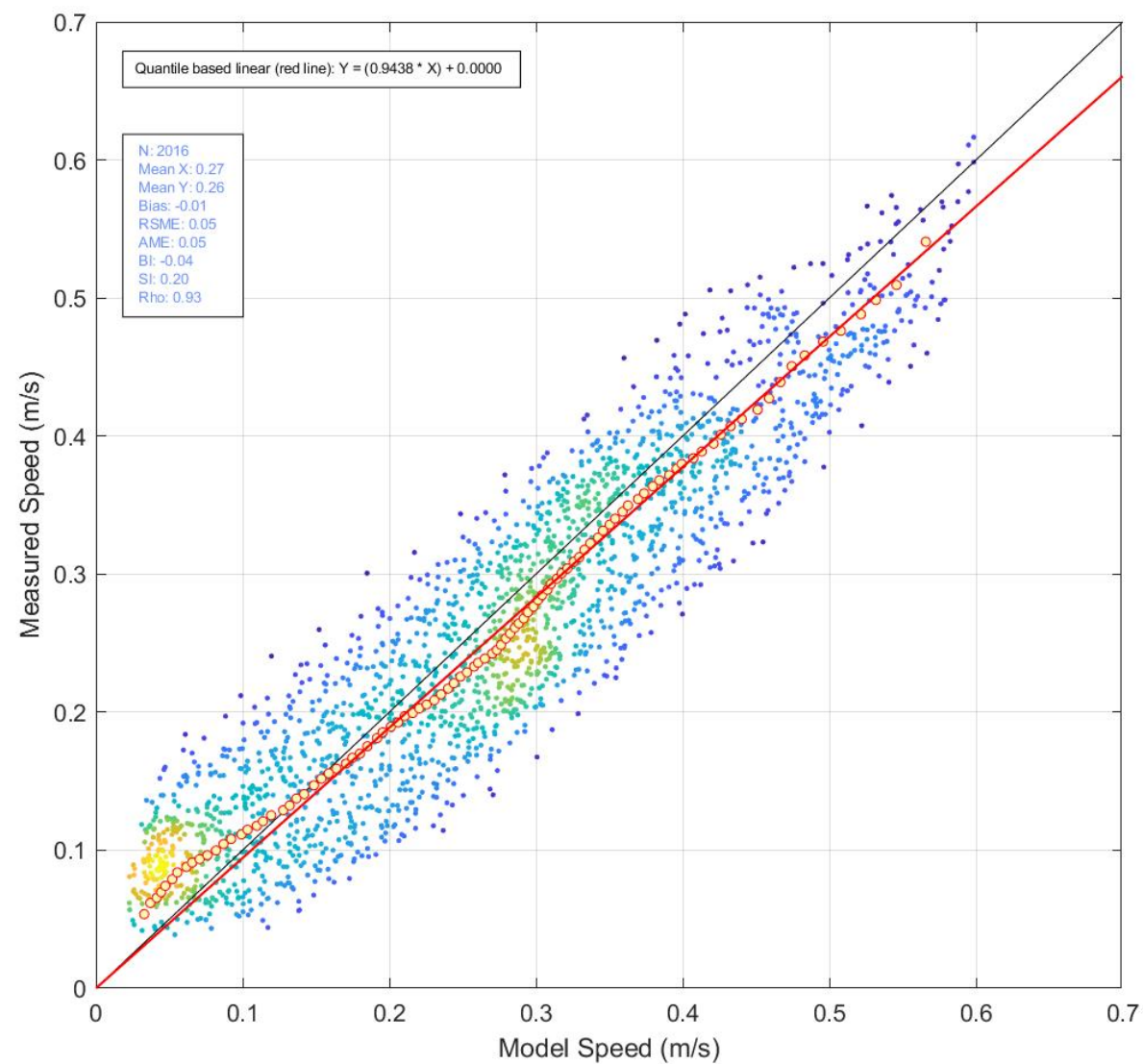


Figure 2.10: Quantile-quantile density scatter plot of FLiDAR E41 vs. modelled current speed

2.3 Sediment disturbance

2.3.1 Overview

- 2.3.1.1 This section describes the design and inputs to a sediment plume model simulating patterns of SSC and resulting sediment deposition thickness in the Physical Processes Study Area. The model will be used to simulate the effect of various activities that may disturb sediment from the MHPGC Project.
- 2.3.1.2 Scenario specific information and model inputs are described in subsequent sections, this includes:
- Disturbance activity type;
 - Release location;
 - Rate of movement of the source or static release;
 - Height of sediment release in the water column;
 - Rate of sediment release;
 - Proportion of sediment in each grainsize category.
- 2.3.1.3 Scenario specific results are also provided in **Section 3.2**, including:
- Distribution of SSC at the end of active disturbance and one and three days thereafter;
 - Distribution of maximum instantaneous SSC at any time during and up to three days after the end of active disturbance;
 - Timeseries of SSC at the site of active disturbance and at nearby observation points during and after the end of active disturbance;
 - Distribution of resulting sediment deposition thickness.

2.3.2 Sediment plume model design

General design

- 2.3.2.1 The sediment plume model provides a timeseries simulation of SSC and settled sediment thickness in response to sediment release, advection and dispersion within the model domain. The sediment plume model is built using the MIKE21FM PT module which simulates the horizontal and vertical advection and dispersion of sediment, represented as numerous discrete particles, within a temporally and spatially varying flow field.

Set up

- 2.3.2.2 The sediment plume model utilises the same forcing, roughness, bathymetry and model grid extent as the validated HD model described in **Section 2.2.1**, however with slightly reduced mesh resolution across the Physical Processes Study Area (c. 200m) compared to c. 100m compared to the HD model) in order to keep output file size manageable. The model is therefore able to consider a range of representative (e.g. spring and neap) tidal conditions.

Input sediment types, settling, dispersion and erosion rates

- 2.3.2.3 Five different sediment grain size fractions are considered in the plume dispersion modelling, although only certain grades may be relevant to specific scenarios. The sediment grain size fractions considered and their associated settling rates (Soulsby, 1997) are summarised in **Table 2.1**.

Table 2.1: Sediment grain size fractions

Sediment fraction name	Representative grain size (micrometres (µm))	Representative settling velocity (m/s)
Gravel	c.8,000	0.5
Coarse sand	c.1,000	0.1

Sediment fraction name	Representative grain size (micrometres (µm))	Representative settling velocity (m/s)
Medium sand	c.250	0.03
Fine sand	c.150	0.01
Silt	c.10	0.0001

- 2.3.2.4 A higher than default horizontal dispersion rate of $1.0\text{m}^2/\text{s}$ is applied to all sediment grain size fractions. Smaller values ($0.1\text{m}^2/\text{s}$ and $0.01\text{m}^2/\text{s}$) were also considered but resulted in very narrow plumes with a very limited footprint of effect that did not appear to measurably disperse over the model simulation period. The value used is within the (relatively wide) range of generally reported values based on observations of this parameter. As a result, the rate of increase in plume width with time is (slightly) increased, which provides a more conservative indication of area of effect. The corresponding SSC values are (slightly) reduced but are still realistically elevated in comparison to typical baseline values. A vertical dispersion rate of $0.01\text{m}^2/\text{s}$ is applied to all sediment grain size fractions.
- 2.3.2.5 Once deposited to the seabed, sediment in the model cannot be eroded and will remain in place. In practice, sediment in a plume that has been deposited to the seabed will immediately rejoin the natural sedimentary environment and will thereafter be naturally eroded at the same time and rate as all other naturally present similar sediment grains in that location. By restricting re-erosion, the area and thickness of initial deposition from the sediment plume (prior to further natural erosion and dispersion) can be observed in more detail.

2.3.3 Sediment plume model scenarios

- 2.3.3.1 **Table 2.2** provides a summary of the sediment plume scenarios modelled, the location of each release, the mass of sediment and the type of sediment at each site. The cable route has been split up into sections with different sediment grain size fractions is displayed in **Figure 2.11**.

Table 2.2: Sediment disturbance scenarios

Scenario number	Mean tidal condition	Activity	Release location (Universal Transverse Mercator (UTM) 30)	Rate and duration of release	Grain size fractions (% of total)
Scottish Waters					
1	Neap	Sandwave clearance (Mass Flow Excavator (MFE))	Closest point in the MHPGC PEIR Red Line Boundary (i.e., western corner) to the Firth of Forth Banks Complex Marine Protected Area (MPA) (56° 46.4640'N, 1° 13.1460'W)	1,000 kilograms per second (kg/s) for c.12.5 hours, static at 3m above bed	0% gravel, 7% coarse sand, 25% medium sand, 48% fine sand and 20% silt
2	Spring				
3	Neap	Dredge spoil disposal	Closest point in the MHPGC PEIR Red Line Boundary (i.e., western to the Firth of Forth Banks Complex MPA (56° 46.4640'N, 1° 13.1460'W)	1,749,000kg, sudden release, static, at water surface	0% gravel, 7% coarse sand, 25% medium sand, 48% fine sand and 20% silt
4	Spring				
5	Neap	Sandwave clearance (MFE)	Central point of the MHPGC PEIR Red Line Boundary within Scottish waters (56° 26.9400'N, 0° 56.7360'W)	1,000kg/s for c.12.5 hours, static at 3m above bed.	0% gravel, 7% coarse sand, 25% medium sand, 48% fine sand and 20% silt
6	Spring				
7	Neap	Dredge spoil disposal	Central point of the MHPGC PEIR Red Line Boundary within Scottish waters (56° 26.9400'N, 0° 56.7360'W)	1,749,000kg, sudden release, static, at water surface	0% gravel, 7% coarse sand, 25% medium sand, 48% fine sand and 20% silt
8	Spring				
Whole length of MHPGC Project PEIR Red Line Boundary					

Scenario number	Mean tidal condition	Activity	Release location (Universal Transverse Mercator (UTM) 30)	Rate and duration of release	Grain size fractions (% of total)
9	Neap/Spring	Pre-lay Trenching (Controlled Flow Excavator (CFE))	Whole length of MHPGC PEIR Red Line Boundary (from the trenchless drill exit pits I, English waters and full extent in Scottish waters)	1113kg/s for 26.1 days, 400m/hr, at 3m above bed. Rate assumes 100% release of material from the trench	<u>Section 1</u> 0% gravel, 10% coarse sand, 10% medium sand, 15% fine sand and 65% silt
					<u>Section 2</u> 0% gravel, 7% coarse sand, 25% medium sand, 23% fine sand and 45% silt
					<u>Section 3</u> 0% gravel, 7% coarse sand, 25% medium sand, 48% fine sand and 20% silt
English offshore waters					
10	Neap	Sandwave clearance MFE	Point along the MHPGC PEIR Red Line Boundary in English waters closest to Farnes East Marine Conservation Zone (MCZ) (55° 31.8480'N, 0° 58.8900'W)	1000kg/s for c.12.5 hours, static at 3m above bed	0% gravel, 7% coarse sand, 25% medium sand, 23% fine sand and 45% silt
11	Spring				
12	Neap	Dredge spoil disposal	Point along the MHPGC PEIR Red Line Boundary in English waters closest to Farnes East MCZ.	1,749,000kg, sudden release, static, at water surface	0% gravel, 7% coarse sand, 25% medium sand, 23% fine sand and 45% silt
13	Spring				

Scenario number	Mean tidal condition	Activity	Release location (Universal Transverse Mercator (UTM) 30)	Rate and duration of release	Grain size fractions (% of total)
			(55° 31.8480'N, 0° 58.8900'W)		
English nearshore waters					
14	Neap	Sandwave clearance (MFE)	Point in the MHPGC PEIR Red Line Boundary that is c.2.5km from the trenchless drill exit pits (54° 49.3200'N, 1° 15.6180'W)	1,000kg/s for 12 hours 20 minutes, static, at 3m above bed	0% gravel, 10% coarse sand, 10% medium sand, 15% fine sand and 65% silt
15	Spring				
16	Neap	Dredge spoil disposal	Point in the MHPGC PEIR Red Line Boundary that is c.2.5km from the trenchless drill exit pits (54° 49.3200'N, 1° 15.6180'W)	1,749,000kg, sudden release, static, at water surface	0% gravel, 10% coarse sand, 10% medium sand, 15% fine sand and 65% silt
17	Spring				
18	Neap	Landfall punch-out	Point representing the indicative trenchless drill exit pit locations (the exact trenchless drill exit pit locations will be confirmed as part of detailed design post consent). (54° 48.9900'N, 1° 18.6660'W)	670.2kg/s, for 10 minutes (instantaneous) hour, static, at 5m above bed	100% Silt
19	Spring				

Scenario assumptions

Release location assumptions

- 2.3.3.2 The location of the static releases in Scenarios 1 to 4 (local sandwave clearance and dredge spoil disposal) is within MHPGC Project PEIR Red Line Boundary, in Scottish Waters, at the closest point to the Firth of Forth Banks Complex MPA.
- 2.3.3.3 The location of the static releases in Scenarios 5 to 8 (local sandwave clearance and dredge spoil disposal) is the central point of the MHPGC Project PEIR Red Line Boundary, within Scottish waters.
- 2.3.3.4 The pre-lay trenching in Scenario 9 is represented as a moving source over a 26.1 day period (i.e. approximately 50 full tidal cycles), moving from the landfall, through English and Scottish waters then along the western boundary of the MHPGC Project PEIR Red Line Boundary, closest to the Firth of Forth Bank Complex MPA, at a constant (maximum) rate of 400m/hr (covering approximately 250km during the simulation period).
- 2.3.3.5 The location of the static releases in Scenarios 10 to 13 (local sandwave clearance and dredge spoil disposal) are in English waters and were chosen as the closest point, aligned with the tidal axis to the Farnes East MCZ, ensuring the maximum effect to the closest designated feature was captured in the model results.
- 2.3.3.6 The location of the static releases in Scenarios 14 to 17 (local sandwave clearance and dredge spoil disposal) is in the nearshore area, approximately 2.5km offshore of the trenchless drill exit pits for MHPGC Project. The location of the static releases in Scenarios 18 and 19 (landfall punch-out) is representative of the indicative trenchless drill exit pit locations (the exact trenchless drill exit pit locations will be confirmed as part of detailed design post consent)..

Sandwave clearance (mass flow excavator) assumptions

- 2.3.3.7 The rate of sediment disturbance (1,000kg/s) by an active MFE tool was conservatively estimated based on the speed of progress of the tool, and the bulk density of the local sediment type at each of the locations. This estimate is conservative in comparison to the working rate of the device (1,000m³/hr, which corresponds to approximately 440kg/s).
- 2.3.3.8 All of the disturbed sediment is initially released at 3m above the local seabed level. In practice, an MFE will also displace some proportion of sediment from the trench to the adjacent seabed through liquefaction and near-bed gravity flow (rather than necessarily putting sediment into suspension higher into the water column). This scenario therefore provides a conservative representation of the near-field effect of the MFE process.

Dredge Spoil Release Assumptions

- 2.3.3.9 Dredge spoil disposal is represented as a surface release from a Trailing Suction Hopper Dredger (TSHD). The mass of sediment placed into suspension by a spoil release scenario is estimated as follows:
- A representative large TSHD hopper sediment volume of 11,000m³ is released suddenly (within a single 10 minute timestep in the model);
 - The total mass of sediment released is estimated as 11,000m³ sediment x 0.6 solidity ratio x 2,650kg/m³ solid density = 17,490,000kg;
 - The majority (90%) of the sediment volume is realistically assumed to descend directly to the bed in the “active phase” of the plume as a single mass of sediment, which does not contribute to the more diffuse SSC effects considered by the plume model;
 - The remaining 10% of sediment (10% of 17,490,000kg = 1,749,000kg) is assumed to be dispersed into the water column at the point of release, allowing sediment grains to remain in suspension for longer, forming the “passive phase” of the plume;
 - It is assumed that the sediment is sufficiently mixed by the dredging process that the proportion of sediment fractions in the active and passive phases are the same as the original seabed sediment.

2.3.3.10 The proportion of sediment assumed to be in the passive and active phases is a conservatively representative value that may vary in practice. The chosen value (up to 10% in the passive phase) is consistent with studies by Becker *et al.* (2015).

Pre-lay trenching assumptions

2.3.3.11 The mass of sediment placed into suspension by pre-lay cable trenching was estimated as follows:

- The amount of material removed from a U-shaped trench (2.1m wide and 3m deep) is calculated as 6.3m^3 of sediment per one metre trenched;
- This is converted to a mass of sediment removed by applying a dry bulk density of $1,590\text{kg/m}^3$ (0.6 solidity ratio $\times 2,650\text{kg/m}^3$ solid density) for uniform sand ($6.3\text{m}^3 \times 1,590\text{kg/m}^3 = 10,017\text{kg}$);
- The rate of trenching is assumed to be 400 m/hr , resulting in a sediment release rate of $1,113\text{kg/s}$ ($(10,017\text{kg} \times 400)/(60 \times 60) = 1,113\text{kg/s}$);
- It is conservatively assumed that 100% of the material in the trench is fluidised and displaced.

Landfall punch-out assumptions

2.3.3.12 A trenchless technique, such as HDD or direct pipe, will be adopted to transition the offshore export cables to the onshore export cables at landfall. The usage of drilling fluid as part of the trenchless technique installation could cause a sediment plume in the nearshore area.

2.3.3.13 Drilling fluid or drilling mud is a suspension of mainly bentonite clay in water, with the following functions:

- To remove cuttings from in front of the drill bit;
- Power the mud motor;
- To transport cuttings from the drill face through the annular space towards the surface;
- Lubricate the drill string during drilling phases and any conduit liners or cables during pull back;
- Cooling the reamers (cutting tools);
- Hole stabilisation;
- Creation of a filter cake against the wall of the hole to minimise the risk of loss of drilling fluid or influx of groundwater penetration into the borehole.

2.3.3.14 The drilling fluid typically consists of a low concentration bentonite and water mixture. Depending on the formation to be drilled through, the concentration is typically between 30kg and 100kg of dry bentonite clay per m^3 of water ($30,000$ to $100,000\text{mg/l}$).

2.3.3.15 The use of bentonite has several benefits:

- It is a natural material;
- It is recyclable;
- It is on the poses little or no risk to the environment (PLONOR) list, so its discharge is not a danger to the environment;
- Owing to the large diameter pipe and long length, the total volume of fluid used may be relatively large, but, owing to the low concentration, the total amount of bentonite is limited.

2.3.3.16 Based on the range of expected duct lengths ($2,000\text{m}$) and maximum diameter (1.6m), the maximum volume of drilling mud (and other drill cuttings) contained in one conduit is estimated to be up to $4,021\text{m}^3$. Several stages of drilling (pilot hole drilling and stages of reaming) may result in smaller release events separated in time. The installation of the duct may result in a larger release of fluid from the conduit (up to the total volume); however, in practice, the fluid present at this stage may have been replaced or otherwise reduced to a concentration lower than required for drilling.

2.3.3.17 The realistic maximum design scenario (MDS) considered is a release of drilling mud with a conservative representative concentration of $100,000\text{mg/l}$, up to the total volume of a single conduit ($4,021\text{m}^3$). Therefore, the mass of bentonite released per port is calculated as $4,021\text{m}^3 \times 100\text{kg/m}^3 = 402,100\text{kg}$. It is conservatively assumed the total volume is released over a conservatively short timescale of 10 minutes from punch out (i.e. an effectively instantaneous release). This gives a rate of release of $402,100\text{kg}/600\text{s} = 670.2\text{kg/s}$.

2.3.3.18 All of the disturbed sediment is initially released at 5m above the local seabed level. Moreover, bentonite is represented within the model by 100% silt sediment type.

- 2.3.3.19 Because of the time required to drill and finalise each conduit, it is assumed that the six bentonite releases that will occur during the whole construction phase will not happen simultaneously, and with a sufficiently long-time gap between punch out events that no overlapping or cumulative changes to SSC are expected. The punch-out release scenario therefore considers the change caused during the creation of a single borehole.

Sediment Type Assumptions

- 2.3.3.20 The assumed sediment type within the MHPGC Project PEIR Red Line Boundary, is informed by Particle Size Analysis (PSA) results for 49 grab samples collected along the length of the offshore export cable corridor (Gardline Ltd., 2023; 2024). Along the offshore export cable corridor, sediments were heterogenous. Of the 49 stations, all stations had negligible gravel content, except for the two outlier stations. Sediments in the northern area of the MHPGC Project PEIR Red Line Boundary, contain higher proportions of sand whereas those in the southern area of the MHPGC Project PEIR Red Line Boundary, exhibited higher proportions of fines, likely due to the proximity to the coastline and major riverine systems.
- 2.3.3.21 The proportion of each grain size fraction (gravel, coarse sand, medium sand, fine sand and silt) was therefore chosen as 0%, 7%, 25%, 48% and 20%, respectively for plume releases originating from the northern boundary of the MHPGC Project PEIR Red Line Boundary (approximately the northern boundary of MHPGC Project PEIR Red Line Boundary to KP100), in Scottish waters. For releases originating from the offshore export cable corridor in offshore English waters (approximately KP100 to KP40), 0% gravel, 7% coarse sand, 25% medium sand, 23% fine sand, 45% silt was used. For nearshore release locations (approximately KP40 to KP0), typically showing a higher proportion of fine sediments, 0% gravel, 10% coarse sand, 10% medium sand, 15% fine sand, 65% silt was used.
- 2.3.3.22 To represent the changing general sediment type for moving releases across the full MHPGC Project PEIR Red Line Boundary length (Scenario 9), sediment type was broadly grouped into three sections, based on sediment grab sample and interpreted backscatter information from the MHPGC Project surveys [see **Figure 2.11**]. Section 1 was represented by 0% gravel, 10% coarse sand, 10% medium sand, 15% fine sand, 65% silt; Section 2 was represented by 0% gravel, 7% coarse sand, 25% medium sand, 23% fine sand, 45% silt; and Section 3 was represented by 0% gravel, 7% coarse sand, 25% medium sand, 48% fine sand, 20% silt.

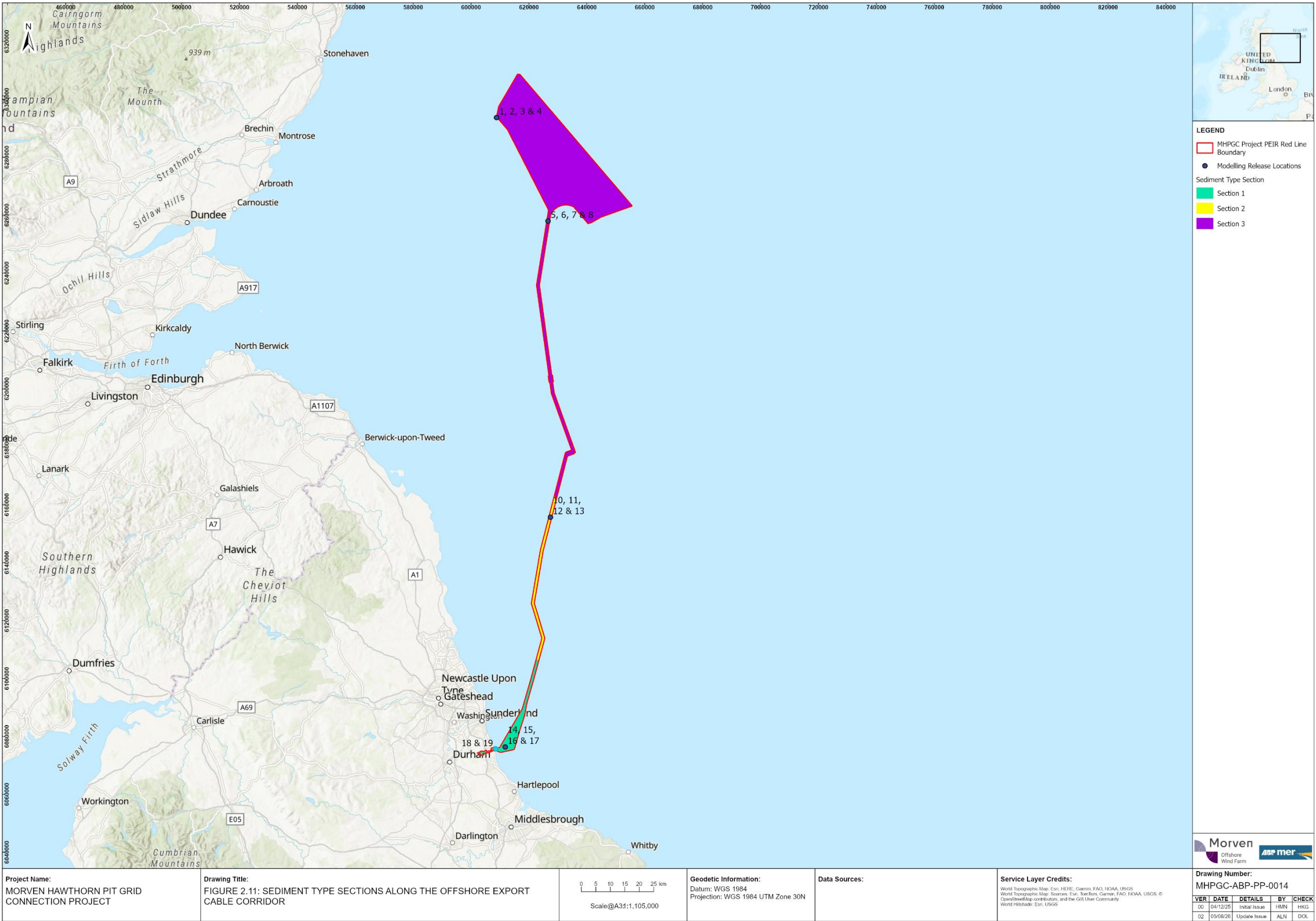


Figure 2.11: Sediment type sections along the offshore export cable corridor

2.3.3.23 The proportion of sediment mass in each grain size fraction is accounted for in the number and mass of the individual particles released at each timestep within the models.

Model validation

2.3.3.24 Predictive location specific plume models are not normally validated, as location specific observations of the activities being simulated are rarely available. However, this type of modelling approach, in conjunction with validated HD inputs, is generally accepted to provide a realistic description of sediment plumes in the marine environment, as found in numerous similar recent offshore wind farm modelling studies undertaken by ABPmer (e.g. Awel y Môr Offshore Wind Farm Limited (ABPmer, 2021); Five Estuaries Offshore Wind Farm Limited (ABPmer, 2024)).

2.3.3.25 The following additional points also support confidence in the modelling process and results:

- **Section 2.2** validates the accuracy and representativeness of the water level, current speed and direction data that control the rate and direction of sediment plume advection in the PT model;
- The representative rate of dispersion is controlled by the model settings but can be variable in practice depending on other environmental conditions (e.g. wave conditions);
- The inputs and settings used in the model and the definitions of the sediment disturbance activities are considered to be conservatively realistic;
- The modelling process and analysis of the results are undertaken by an experienced coastal processes modeller.

3 Results

3.1 Tidal regime

3.1.1 Overview

- 3.1.1.1 This section sets out the assessment of the tidal regime within the Physical Processes Study Area. The HD model has been built using the MIKE21FM HD module, which simulates the development, propagation and dispersion of the tidal wave, and associated movements of water, throughout the model domain. Detailed information about the design and validation of the HD model has been previously stated in **Section 2.2** of this technical report.
- 3.1.1.2 The HD model creates a continuous simulation of tidal water level, depth-average current speed and current direction throughout the domain, for a representative spring-neap cycle (approximately mean neap and mean spring conditions).

3.1.2 Baseline conditions

- 3.1.2.1 Plots showing the spatial distribution of current speed and direction for representative neap and spring conditions, during slack waters and peak flows are shown in **Appendix A** [see **Figure A.1** to **Figure A.3**].
- 3.1.2.2 HD modelling indicates distinct differences in current speed between neap and spring tidal conditions across the Physical Processes Study Area. During neap tides, peak currents reach approximately 0.3m/s to 0.4m/s, with slack water phases showing low flow (<0.1m/s). In contrast, spring tides exhibit stronger currents across the Physical Process Study Area, peaking at 0.5m/s to 0.6m/s. Slack periods during spring tides still maintain flows of around 0.2m/s.
- 3.1.2.3 Current speed is relatively uniform in space across the MHPGC Project PEIR Red Line Boundary , with Scottish and English regions of the offshore export cable corridor showing similar current speed values. During peak flows associated with close to local low water (LW), current direction is approximately northwards in Scottish waters and north-northwesterly in English waters. During peak flows coinciding with close to local high water (HW), flow directions are reversed, respectively. During slack water periods flow directions in Scottish and English waters diverge and converge as the tide exits and enters the Firth of Forth.
- 3.1.2.4 The timeseries of current speed and direction throughout the model domain was also used to determine the residual current speed and direction (the long-term drift rate and direction of water over one spring-neap cycle). This is shown in **Figure A.4** of **Appendix A**. Residual current speeds are typically low throughout the MHPGC Project PEIR Red Line Boundary (<0.02m/s).
- 3.1.2.5 The timeseries of current speed and direction throughout the model domain was also used in conjunction with a simple sediment transport model (using the MIKE21FM Sand Transport (ST) module). The model simulates a time series of total load transport rate and direction for 250µm diameter quartz sand in response to the shear stress caused by the tidal currents described by the HD model. These results were also used to determine the residual ST rate and direction (the long-term transport rate and direction for representative medium to fine sand over one spring-neap cycle). Plots showing the spatial distribution of instantaneous sediment transport rate and direction for selected tidal conditions, and the residual sediment transport rate and direction over a representative spring-neap cycle, are shown in **Appendix A** [see **Figure A.5** to **Figure A.7**].
- 3.1.2.6 Sediment transport rates are markedly lower across the study area during neap tides ($<1 \times 10^{-12} \text{m}^3/\text{s}/\text{m}$), reflecting the weaker tidal currents at this stage. In contrast, spring tides, particularly during peak flows when current speeds are greatest, show higher transport rates, reaching approximately $1 \times 10^{-6} \text{m}^3/\text{s}/\text{m}$ along the offshore export cable corridor. The residual sediment transport pattern across the offshore export cable corridor generally trends from south to north.

3.2 Sediment plume model results

3.2.1 Overview

3.2.1.1 The following results are provided as figures in **Appendix B**:

- Maps of SSC at the end of sediment disturbance, and one and three days later;
- Maps of instantaneous maximum SSC at any time throughout the model simulation period;
- Timeseries of SSC at a central location in the area of sediment disturbance (centre of the route for a moving release or at the location of a fixed release).

3.2.1.2 The following results are provided as images in **Appendix C**:

- Maps of settled sediment thickness at the end of the model simulation period.

3.2.1.3 Results for SSC describe an increase in SSC relative to the ambient naturally occurring condition.

3.2.1.4 To help identify the potential extent of plume interaction with designated sites, MCZ, Site of Special Scientific Interest (SSSI), MPA, Highly Protected Marine Area (HMPA), Special Protection Area (SPA) and Special Area of Conservation (SAC) boundaries have been overlaid on the plume modelling results.

3.2.2 Sediment plume suspended sediment concentration results

Plumes from extended release periods over multiple flood/ebb cycles (i.e. sandwave clearance and pre-lay trenching)

Overview

3.2.2.1 Maps of the increase in SSC as a result of local sandwave clearance using a MFE (static near-bed source) within the MHPGC Project PEIR Red Line Boundary are provided by Scenarios 1 and 2 for the western extent in Scottish waters, Scenarios 5 and 6 for the MHPGC Project PEIR Red Line Boundary corridor in Scottish waters, Scenarios 10 and 11 for the MHPGC Project PEIR Red Line Boundary in offshore English waters, and Scenarios 14 and 15 for the MHPGC Project PEIR Red Line Boundary in nearshore (release locations up to 2.5km from the coast) English waters. All sandwave clearance using a MFE scenarios were ran for both neap and spring tidal conditions. All maps are included in **Appendix B**.

3.2.2.2 Maps of the increase in SSC as a result of pre-lay cable trenching using a CFE (moving near-bed source) is provided by Scenario 9 for the whole length of the MHPGC Project PEIR Red Line Boundary, with the modelled trenching route running from the landfall, along the offshore export cable corridor and along the western boundary, spanning both English and Scottish waters. All maps are included in **Appendix B**.

3.2.2.3 The following paragraphs provide a general description and characterisation of the more detailed results shown in the scenario images listed above. See the individual figures in **Appendix B** for site and scenario specific details of SSC and plume dimensions.

3.2.2.4 The plume feature resulting from continuous sediment disturbance activities is characterised as a long, relatively thin plume extending along the tidal axis and to the limit of the tidal excursion distance from the point of active disturbance. Where the source is moving in the pre-lay trenching scenario, the path of active disturbance in the simulation period is visible in the results images as a line of higher maximum instantaneous SSC, with elevated SSC regions extending from this aligned with the tidal axis.

3.2.2.5 The combined SSC from all sediment types is expected to be very high within 5m of the release location during active sediment disturbance (millions of mg/l within 5m of the activity, i.e. more sediment than water in the local plume). This level of detail is not resolved directly by the sediment plume model, which indicates a more dispersed initial concentration of 1,000 to 10,000mg/l. This initial elevated SSC effect is highly localised and will persist only while the disturbance continues in that specific area. As the sediment plume settles and disperses both vertically and horizontally over time and distance downstream, the SSC is anticipated to decrease to less than 1,000mg/l within tens of metres.

- 3.2.2.6 Gravels and sands will settle relatively quickly to the seabed [see **Table 2.1**]. At a representative higher current speed of approximately 0.6m/s during spring tides, these sediment types will settle from the maximum anticipated height of initial suspension (3m above the bed) to the seabed within the following approximate distances from the release point: 4m for gravels, 18m for coarse sand, 60m for medium sand and 180m for finer sands. This distance will be proportionally reduced during periods of lower current speed, such as times outside peak flow and generally around neap tides.
- 3.2.2.7 During spring tidal conditions, the disturbed sediment is carried away from the working area at a faster rate, dispersing the sediment mass over a larger area and water volume, and so the resulting SSC in the plume is relatively lower than on a comparable neap tide.
- 3.2.2.8 During slack water (on both neap and spring tides), water is not moving sediment away from the area of disturbance, resulting in suspended sediment accumulating in a local area of relatively higher SSC. This local area of higher SSC is subsequently advected by the tide and may take longer to reduce to background levels than other parts of the plume generated during non-slack water conditions.
- 3.2.2.9 The extended release scenarios (pre-lay trenching (CFE) and sandwave clearance (MFE)) all exhibit the same general plume characteristics discussed here, but the SSC and size of the plume scales with the sediment release rate used to characterise each disturbance mechanism.
- 3.2.2.10 For all release scenarios discussed in this section (Scenarios 1, 2, 5, 6, 9, 10, 11, 14 and 15), SSC is less than 5mg/l everywhere within three days after the disturbance activity has ended.
- 3.2.2.11 In all cases where plumes intersect a designated site, the plume remains spatially constrained, with a limited footprint that effects the designated sites. Consequently, only a small part of the designated site is likely to be affected, and only for a short duration. The tidal ellipse path also varies between tides, making it unlikely that the same seabed area will experience elevated SSC for more than one or two consecutive tides.

Scottish waters

- 3.2.2.12 Sediment released by pre-lay trenching and sandwave clearance activities within the western extent of the MHPGC Project PEIR Red Line Boundary, within Scottish waters (Scenario 1, 2 and 9) has the potential to reach northeastern region of the Firth of Forth Banks Complex MPA. The MPA lies very close to the MHPGC Project PEIR Red Line Boundary (<100m), so high SSC values (>500mg/l) are predicted within this designated site. However, the region of most intense maximum instantaneous SSC is small, and SSC reduces quickly with distance into the MPA from the release location. Additionally, these very high SSC values are only present during the active release and for a very short time afterwards. Several hours after the release has ended maximum SSC concentration within the MPA reduce to <20mg/l, and one day after the release has ended plume concentrations have reduced to less than 5mg/l throughout the Physical Processes Study Area.
- 3.2.2.13 Plumes generated by pre-lay trenching and sandwave clearance activities within the MHPGC Project PEIR Red Line Boundary in Scottish waters do not reach, or directly effect, any designated sites.

English waters

- 3.2.2.14 Sediment released by pre-lay trenching and sandwave clearance activities within the MHPGC Project PEIR Red Line Boundary in English waters (Scenario 9, 10 and 11) has the potential to reach the Farnes East MCZ, when the release location is at the closest point in the MHPGC Project Red Line Boundary aligned with the tidal axis to the designated site. When release coincides with spring tides, a larger portion of the MCZ may experience elevated SSC, as stronger currents during spring tides transport the plume further than during neap tides. The MCZ lies approximately 4.5km northwest from the nearest point of the MHPGC Project PEIR Red Line Boundary (approximately KP82), so SSC will have significantly reduced due to sediment resettlement before reaching the area. The maximum predicted instantaneous SSC within the MCZ is less than 100mg/l during pre-lay trenching and less than 30mg/l during sandwave clearance. One day after disposal ends, the plume will have dispersed, and no elevated SSC is expected within the designated site.
- 3.2.2.15 Results from pre-lay trenching along the whole length of the MHPGC Project PEIR Red Line Boundary (Scenario 9) indicate that the North East Farnes Deep HMPA could potentially be affected by a plume originating from CFE activities within English waters if the release point aligns with the closest

location along the tidal axis in the MHPGC Project PEIR Red Line Boundary (approximately KP113) and coincides with large spring tides. However, the HMPA lies to the east/southeast and just outside the mean spring tidal excursion ellipse, so any plume overlap is predicted to be minimal and short-lived, occurring only during large spring tides and extending only slightly into the designated site and with very low SSC (less than 5mg/l).

Spreadsheet model estimates

- 3.2.2.16 The sediment plume model results provide a more reliable description of SSC in the far-field (i.e. for sediments that are subject to advection and dispersion over timescales greater than one hour and distances greater than 1,000m).
- 3.2.2.17 The near-field spreadsheet model provides a more generalised but demonstrably realistic range of potential plume SSC/area combination estimates in the near-field (i.e. for sediment of any type that is deposited more rapidly to the seabed in timescales less than one hour and distances less than 1,000m). Such estimates can provide a more reliable description of details in the near-field that are not resolved spatially or temporally by the sediment plume model.
- 3.2.2.18 The volume of sediment displaced from the trench is finite and directly related to the trench cross-sectional area (up to 6.3m³). This allows for an estimation of the maximum average SSC across a range of realistic plume areas, determined by the distance of displacement and ejection height. Results are summarised in **Table 3.1**. The calculation takes a conservative approach, assuming that 100% of the trench material is fluidised and displaced, and that none of it settles out of the plume with increasing time/distance from the disturbance activity.
- 3.2.2.19 It is important to note that the values in **Table 3.1** represent the maximum average SSC for the plume and will not be uniform throughout the plume area. In practice, as indicated by the spatial results from plume modelling, extremely high SSCs (tens to hundreds of thousands of mg/l, meaning more sediment than water) will occur very close to the disturbance, with concentrations decreasing as the distance from the source increases.

Table 3.1: Maximum average SSC for a 6.3m³ trench for a range of realistic ejection heights

Distance of displacement (m)	Average SSC of plume (mg/l) for ejection height		
	3m	5m	10m
5	1,335,600	801,360	400,680
10	667,800	400,680	200,340
25	267,120	160,272	80,136
50	133,560	80,136	40,068
100	66,780	40,068	20,034
150	44,520	26,712	13,356
200	33,390	20,034	10,017
250	26,712	16,027	8,014
300	22,260	13,356	6,678
400	16,695	10,017	5,009
500	13,356	8,014	4,007

Plumes from spoil disposal

Overview

- 3.2.2.20 Maps of the increase in SSC as a result of spoil disposal at the water surface from a TSHD within the MHPGC Project PEIR Red Line Boundary are provided by Scenarios 3 and 4 for the western extent of the MHPGC Project PEIR Red Line Boundary in Scottish waters, Scenarios 7 and 8 for the MHPGC Project PEIR Red Line Boundary in Scottish waters, Scenarios 12 and 13 for the MHPGC Project PEIR Red Line Boundary in offshore English waters (beyond 2.5km from the coast), and Scenarios 16 and 17 for the MHPGC Project PEIR Red Line Boundary in nearshore English waters (within 2.5km of the coast). All spoil disposal scenarios were run for both neap and spring tidal conditions. All maps are included in **Appendix B**.
- 3.2.2.21 The following paragraphs provide a general description and characterisation of the more detailed results for each location shown in the figures listed above. See the individual figures in **Appendix B** for site and scenario specific details of SSC and plume dimensions.
- 3.2.2.22 The passive phase plume feature (defined previously in **Paragraph 2.3.3.9**) resulting from a spoil disposal event is characterised by an ellipsoidal plume, where elevated SSC closely follows the path of the tidal ellipse with higher concentrations towards the release location, and decreasing concentration with increasing time and distance.
- 3.2.2.23 Gravels and sands will settle relatively quickly towards the seabed [see **Table 2.1**]. From the maximum expected height of initial suspension (approximately 105m above the bed), these sediments are likely to resettle on the seabed, ceasing to increase SSC, within approximately three minutes to 180 minutes. At a representative higher current speed of 0.6m/s during spring tides, these sediments will settle to the bed within approximately 126m for gravel, 630m for coarse sand, 2,100m for medium sand, and 6,300m for finer sands from the release point. This distance will be proportionally shorter during periods of lower current speed, such as outside peak flow times and generally around neap tides. Fine sand and silt-sized sediments persist in suspension for longer than relatively coarser sediment grain sizes (i.e. medium sand, coarse sand and gravels) and so control the majority of the effect on SSC beyond these durations/distances.
- 3.2.2.24 The level of SSC associated with all sediment fractions is expected to be locally very high at the location of the spoil release (millions of mg/l within 5m of the activity (i.e. more sediment than water in the local plume). This level of detail is not resolved directly by the sediment plume model, which indicates a more dispersed initial concentration of 1,000mg/l to 10,000mg/l.
- 3.2.2.25 Due to ongoing dispersion and the settlement of non-silt sediment to the seabed during the first half tidal cycle, the level of SSC within the spoil plume reduces rapidly with time to less than 25mg/l after one day, and to less than 5mg/l after three days.
- 3.2.2.26 For all release locations, the plume remains spatially constrained, with only a limited footprint that effects designated sites. Consequently, only a small part of the designated site is likely to be affected, and only for a short duration. The tidal ellipse path varies between tides, making it unlikely that the same seabed area will experience elevated SSC for more than one or two consecutive tides.

Scottish waters

- 3.2.2.27 Sediment released by spoil disposal activities along the western extent of the MHPGC Project PEIR Red Line Boundary in Scottish waters (Scenario 3 and 4) has the potential to reach the northeastern region of the Firth of Forth Banks Complex MPA. The MPA is very close to the MHPGC Project PEIR Red Line Boundary (<100m), so high SSC values (>500mg/l) are predicted within the designated site, however the region of most intense maximum instantaneous SSC is small, and SSC reduces quickly with distance into the MPA from the release location. Additionally, these very high SSC values are only present during the active release and for a very short time afterwards. Several hours after the release has ended maximum SSC concentration within the MPA reduce to <50mg/l, and one day after the release has ended plume concentrations have reduced to less the 5mg/l throughout the study area.
- 3.2.2.28 Plumes generated by spoil disposal activities within the southern extent of the MHPGC Project PEIR Red Line Boundary in Scottish waters do not reach, or directly effect, any designated sites.

English waters

- 3.2.2.29 Sediment released by spoil disposal activities within the MHPGC Project PEIR Red Line Boundary in offshore English waters has the potential to reach the Farnes East MCZ, when the release location is at the closest point in the MHPGC Project PEIR Red Line Boundary aligned with the tidal axis to the designated site. When disposal coincides with spring tides, a larger portion of the MCZ may experience elevated SSC, as stronger currents during spring tides transport the plume further than during neap tides. The MCZ lies approximately 4.5km northwest from the nearest point of the offshore export cable corridor (approximately KP82) aligned with the tidal axis, so SSC will have significantly reduced due to sediment resettlement before reaching the MCZ. The maximum predicted instantaneous SSC within the MCZ is less than 50mg/l. One day after disposal ends, the plume will have dispersed, and no elevated SSC is expected within the designated site.
- 3.2.2.30 The North East Farnes Deep HMPA could potentially be affected by spoil disposal activities within offshore English waters if the release point aligns with the closest location along the tidal axis in the MHPGC Project PEIR Red Line Boundary (approximately KP113) and the timing coincides with large spring tides. However, the HMPA lies just outside the mean spring tidal excursion ellipse, so any plume overlap is expected to be minimal, extending only a relatively small distance (<1km) into the designated site and with very low SSC of less than 5mg/l.

Plumes from bentonite release

- 3.2.2.31 Maps of the increase in SSC as a result of punch out via trenchless techniques drilling mud release within the MHPGC Project PEIR Red Line Boundary are provided by Scenarios 18 and 19 for the nearshore sections of the MHPGC Project PEIR Red Line Boundary in English waters, for both neap and spring tidal conditions in **Appendix B**.
- 3.2.2.32 The following paragraphs provide a general description and characterisation of the more detailed results for each location shown in the figures listed above. See the individual figures in **Appendix B** for site and scenario specific details of SSC and plume dimensions.
- 3.2.2.33 At temporal and spatial scales smaller than that captured by the model resolution, the initial plume will have a very high local SSC of bentonite (up to the concentration of the drilling fluid itself) but will have a correspondingly small footprint (hundreds of thousands of mg/l within 5m of the activity). This level of detail is not resolved directly by the sediment plume model, which indicates a more dispersed initial concentration of >1,000mg/l. The plume is subsequently advected in the general direction, and at the speed of, the ambient currents at the time of the release, and gradually becomes dispersed, both horizontally and vertically, by the natural process of diffusion.
- 3.2.2.34 Due to the small particle size and low settling velocities [see **Table 2.1**], all of the bentonite released is held in suspension for days or longer before settling. In this time, the individual grains become dispersed widely over large areas, meaning SSC reduces to <5mg/l everywhere within one day of the release.
- 3.2.2.35 The bentonite plume does not reach, or directly affect, any designated sites.

3.2.3 Seabed sediment deposition results

Bed level changes associated with plumes from pre-lay trenching and sandwave clearance (Controlled Flow Excavator)

- 3.2.3.1 Estimates of the footprint and thickness of sediment deposition from trenching are provided based on:
- The results of the sediment plume model;
 - Near-field spreadsheet model estimates (for all sediment types).
- 3.2.3.2 The sediment plume model results provide a more reliable description of settlement thickness in the far-field (i.e. for sediments that are subject to advection and dispersion over timescales greater than one hour and distances greater than 1,000m).
- 3.2.3.3 The near-field spreadsheet model provides a more generalised but demonstrably realistic range of potential deposition area/thickness combination estimates in the near-field, i.e. for sediment of any

type that is deposited more rapidly to the seabed in timescales less than one hour and distances less than 1,000m. Such estimates can provide a more reliable description of details in the near-field that are not resolved spatially or temporally by the sediment plume model.

Far-field plume model estimates

Overview

- 3.2.3.4 Maps of settlement thickness as a result of localised sandwave clearance using an MFE (static near-bed source) within the MHPGC Project PEIR Red Line Boundary are provided by Scenarios 1 and 2 for western extent of the MHPGC Project PEIR Red Line Boundary in Scottish waters, Scenarios 5 and 6 for the southern extent of the MHPGC Project PEIR Red Line Boundary in Scottish waters, Scenarios 10 and 11 for the MHPGC Project PEIR Red Line Boundary in offshore English waters, and Scenarios 14 and 15 for the MHPGC Project PEIR Red Line Boundary in nearshore English waters. All sandwave clearance using a MFE scenarios were ran for both neap and spring tidal conditions. All maps are included in **Appendix C**.
- 3.2.3.5 Maps of settlement thickness as a result of pre-lay cable trenching (moving near-bed source) are provided by Scenario 9 for the whole length of the MHPGC Project Red Line Boundary, with the modelled trenching route running from the landfall, along the full extent of the boundary to the northern extent in Scottish offshore waters. Due to the length of the modelled trenching route, release spans both neap and spring tidal conditions. All maps are included in **Appendix C**.
- 3.2.3.6 The following paragraphs provide a general description and characterisation of the more detailed results for each location shown in the figures listed above. See the individual figures in **Appendix C** for site and scenario-specific details of settlement thickness and extent.
- 3.2.3.7 The results show the thickness of sediment following initial deposition. The same sediment may be subsequently re-eroded and resettled elsewhere as part of the ongoing natural sediment transport regime.
- 3.2.3.8 The predicted thickness of settlement is limited. The coarser sand fractions at each site settle to the seabed within a limited time of release (from seconds up to five minutes, i.e. within the ten minute timestep of the sediment plume model) and so tend to be deposited within a relatively small footprint (from metres up to 100m), resulting in a relatively greater local average thickness of <100mm. The predicted thickness of settlement for only the finer sediments is very limited, in the order of <2 millimetres (mm) for all release locations.
- 3.2.3.9 Sediment accumulation of this magnitude will not cause a measurable change in bed level or sediment type in practice, particularly considering the mobile nature of the seabed under baseline conditions. Fine sediments that do settle are also likely to experience further erosion and dispersion during subsequent tides.

Scottish waters

- 3.2.3.10 For sandwave clearance releases along the western extent of the MHPGC Project PEIR Red Line Boundary in Scottish waters, some deposition within the Firth of Forth Bank Complex MPA is possible. The deposition footprint is small, aligned with the tidal axis, and extends approximately 100m either side of the release location for deposits greater than 50mm, and around 500m either side for deposits greater than 10mm. During spring tides, higher current speeds result in a slightly larger spatial footprint (extending 20% further from the release location during springs than neaps), although overall thickness values are lower (P95 during springs is 192mm, compared to 301mm during neaps) compared to equivalent activity at the same location during neap tides as the same amount of material is being spread over a greater area.

English waters

- 3.2.3.11 There is no deposition due to sandwave clearance predicted within any of the surrounding designated sites for releases originating within English waters.

Near-field spreadsheet model estimates

- 3.2.3.12 Coarser sediments (gravels and sands) will settle from the maximum height of disturbance (3m above the bed) relatively rapidly towards the seabed and so the distance of advection and dispersion is realistically limited to distances within 4m (gravel) to 200m (finer sands) downstream from the

trench during representative stronger tidal current conditions (0.6m/s). Distances will be proportionally less at times of lower current speed. The plume model does not resolve spatial details less than the resolution of the model mesh (<200m) and tidal current speed varies widely over flood and ebb, and spring and neap cycles. The following method provides a range of realistic estimates of deposition thickness within the near-field.

- 3.2.3.13 The volume of sediment displaced from the trench is finite and proportional to the trench cross section (up to 6.3m²) and so it is possible to estimate the maximum average sediment thickness for a range of realistic downstream dispersion distances. Results are presented in **Table 3.2**. This calculation conservatively assumes that 100% of the material in the trench is fluidised and displaced, with the downstream dispersion occurring perpendicular to the trench axis. Where the current direction is more oblique to the trench, the perpendicular distance from the trench to the edge of the deposit will be reduced, with a proportional increase in average thickness. In all cases, a larger footprint or extent of effect for any reason will result in a proportionally smaller average thickness of deposition, and vice versa.

Table 3.2: Maximum average sediment deposit thickness for a 6.3m³ trench for a range of realistic downstream dispersion distances

Distance of displacement (m)	Average thickness of deposit (mm) for trench cross section area
	6.3m ²
5	1,260
10	630
25	252
50	126
100	63
150	42
200	32
250	25
300	21
400	16
500	13

Bed level changes associated with plumes from spoil disposal

- 3.2.3.14 Estimates of the footprint and thickness of sediment deposition from dredge spoil disposal are provided based on:
- Sediment plume model predictions for the passive phase of the plume only;
 - Near-field spreadsheet model estimates for the passive phase of the plume only (for all sediment types);
 - Near-field spreadsheet model estimates for the active phase of the plume only (for all sediment types).
- 3.2.3.15 The sediment plume model results provide a more reliable description of settlement thickness in the far-field (i.e. for sediments that are subject to advection and dispersion over timescales greater than one hour and distances greater than 500m to 1,000m).

- 3.2.3.16 The near-field spreadsheet plume model provides a more generalised but demonstrably realistic range of potential deposition area/thickness combination estimates in the near-field, (i.e. for sediment of any type that is deposited more rapidly to the seabed in timescales less than one hour and distances less than 1,000m). Such estimates provide a more reliable description of details in the near-field that are not resolved spatially or temporally by the sediment plume model.
- 3.2.3.17 The results from the plume model relate only to the sediment in the passive phase of the plume (i.e. 10% of the total sediment volume/mass being deposited). Results for the passive and active phases of the plume should be considered together in order to describe the full effect on bed level change of the dredge spoil release.

Passive phase: far-field plume model estimates

Overview

- 3.2.3.18 Maps of settlement thickness resulting from the passive phase of the plume (approximately 10% of the sediment volume) during dredge spoil disposal within the MHPGC Project PEIR Red Line Boundary are provided by Scenarios 3 and 4 for the western extent of the MHPGC Project PEIR Red Line Boundary in Scottish Waters, Scenarios 7 and 8 for the MHPGC Project PEIR Red Line Boundary for the southern extent in Scottish waters, Scenarios 12 and 13 for the MHPGC Project PEIR Red Line Boundary in offshore English waters, and Scenarios 16 and 17 for the MHPGC Project PEIR Red Line Boundary in nearshore English waters. All spoil release scenarios were run for both neap and spring tidal conditions. All maps are included in **Appendix C**. The settlement thickness resulting from the active phase of the plume (approximately 90% of the sediment volume) is considered separately in another section below [see **Paragraph 3.2.3.29**].
- 3.2.3.19 The following paragraphs provide a general description and characterisation of the more detailed results for each location and activity shown in the figures. See the individual figures in **Appendix C** for site and scenario specific details of settlement thickness and extent.
- 3.2.3.20 The results show the thickness of sediment following initial deposition. The same sediment is expected to immediately rejoin the natural sedimentary environment and will be subsequently re-eroded and resettled elsewhere as part of the ongoing natural sediment transport regime.
- 3.2.3.21 The predicted thickness of settlement accounting for all sediment types in the passive phase plume is limited. The coarser sand and gravel fractions at each site settle to the seabed within a limited time of release (from minutes to one hour) and so tend to be deposited within a relatively small footprint.
- 3.2.3.22 For releases within the MHPGC Project PEIR Red Line Boundary within offshore Scottish waters, the deposit is within 4km of the release location, with a maximum thickness of 6mm occurring within 200m of the release location, and thickness of less than 5mm predicted elsewhere. In offshore English waters the deposit remains within 3km of the release location. The maximum deposited thickness is 5mm. In nearshore English waters the deposit remains within 3km with a maximum thickness of 12mm. The predicted average thickness of settlement for the finer sediments in the passive phase plume is dispersed more widely and the magnitude of deposition is very limited, in the order of <2mm for all sites.
- 3.2.3.23 During spring tides, due to higher current speeds the deposits are dispersed more between the surface and the seabed, typically forming larger footprint deposits with proportionally smaller average local thickness.
- 3.2.3.24 Sediment accumulation of this magnitude will not cause a measurable change in bed level or sediment type in practice, particularly considering the mobile nature of the seabed under baseline conditions. Fine sediments that do settle are also likely to experience further erosion and dispersion during subsequent tides.
- Scottish waters
- 3.2.3.25 For spoil disposal in western extent of the MHPGC Project PEIR Red Line Boundary in Scottish waters some deposition within the Firth of Forth Bank Complex MPA is possible. The deposition footprint is small, aligned with the tidal axis, and extends approximately 200m either side of the release location for deposits greater than 10mm, and around 3km for deposits less than 5mm.

English waters

- 3.2.3.26 There is no deposition due to spoil disposal release predicted within any of the surrounding designated sites for releases within English offshore and nearshore waters.

Passive phase: near-field spreadsheet model estimates

- 3.2.3.27 Coarser sediments (gravels and sands) in the passive plume will settle from the water surface (105m (maximum water depth along the offshore export cable corridor) above the seabed) relatively rapidly towards the seabed and so the distance of advection and dispersion is realistically limited to distances within 126m (gravel) to approximately 6,000m (finer sands) downstream from the disposal site during representative stronger tidal current conditions (0.6m/s on spring tides). Distances will be proportionally less at times of lower current speed (and during neap tides). The plume model does not resolve spatial details less than the resolution of the model mesh (approximately 200m) and tidal current speed varies widely over flood and ebb, and spring and neap cycles. The following method provides a range of realistic estimates for sediment thickness in the near-field.
- 3.2.3.28 The total volume of sediment in the passive phase of the plume is limited (10% of $11,000\text{m}^3 = 1,100\text{m}^3$) and so it is possible to estimate the maximum average sediment thickness for a range of realistic dispersion footprint dimensions. Results are presented in **Table 3.3**. These estimates conservatively assume that all sediment in the passive phase is deposited to the seabed, however, the silt fraction (comprising up to 20% of the sediment mass in the passive phase, depending on the location, see **Table 2.2**) will remain in suspension for longer (as described by the plume model results above [see **Paragraph 3.2.3.18**] and will not contribute to these estimates.

Table 3.3: Maximum average sediment deposit thickness as a result of the passive plume for a range of realistic downstream dispersion distances

Downstream dispersion distance (m)	Maximum average thickness of sediment accumulation (mm) for varying dispersion widths		
	50m	100m	200m
100	220	110	55
250	88	44	22
500	44	22	11
750	29	15	7
1,000	22	11	6
2,000	11	6	3
3,000	7	4	2
4,000	6	3	1
5,000	4	2	1

Active phase: near-field spreadsheet model estimates

- 3.2.3.29 The active phase of the plume will descend rapidly and directly to the seabed, where it will spread laterally, initially with the force of impact and then under gravity. The final shape or dimensions of the deposit therefore cannot be predicted in detail. The volume of sediment in the active phase of the plume is also limited (90% of $11,000\text{m}^3 = 9,900\text{m}^3$) and so it is also possible to estimate the maximum average sediment thickness for a range of realistic dispersion footprint areas. Results are presented in **Table 3.4**.

Table 3.4: Maximum average sediment deposit thickness for a range of realistic active phase deposit dimensions and areas

Deposit length scale (m)	Deposit footprint area (m ²)*	Maximum average thickness of sediment accumulation (mm)
50	2,500	3,960
100	10,000	990
150	22,500	440
200	40,000	248
222	49,500	200
315	99,000	100
445	198,000	50

*Deposit footprint area = Deposit length scale²

Bed level changes associated with plumes from bentonite release

- 3.2.3.30 Due to the small particle size and low settling velocities [see **Table 2.2**], most of the bentonite released is held in suspension for days or longer before settling. In this time, the individual grains become dispersed widely over large areas and so does not result in any measurable thickness of bentonite deposition.
- 3.2.3.31 Sediment deposition thickness across the Physical Processes Study Area is predicted to be <5mm in all release cases, which is not measurable in practice and will be, at most, comparable to normally occurring patterns as a result of natural processes and other vessel movement related disturbances.

Tidal excursion distance and plume advection

- 3.2.3.32 The tidal excursion distance is the approximate distance over which a package of water (or a section of plume with elevated SSC) is advected during one flood or ebb tide.
- 3.2.3.33 The local extent of the sediment plume at any given time describes the instantaneous local magnitude and extent of elevated SSC. The plume is being almost continuously moved (advected) by the ambient currents. This section considers the distances and directions that the plume might be displaced from the source before it is dissipated to near background concentrations, and therefore the overall spatial extent that any local plume effects might be (temporarily) experienced.
- 3.2.3.34 The sediment plume is mainly advected from the source of the sediment disturbance by the ambient tidal currents. The relative motion (local speed and direction) of the plume at any given time in the tidal cycle will vary depending not only on the relative time in the flood ebb cycle, but also the spatially varying flow characteristics along the path of advection.
- 3.2.3.35 In open water, plume advection typically describes an elliptical path, which may or may not be closed, (i.e. returning to approximately the same position at the end of the tidal cycle). In areas of more complex flow, the path may be more complex (e.g. following coastline or bathymetric features), and the path may not be necessarily closed. The distance that the plume is advected from the disturbance source (both along the tidal axis and laterally across it) describes the area over which any effects on SSC are likely to occur. Conversely, areas beyond the tidal excursion distance and footprint are unlikely to experience any effect on SSC from the plume.
- 3.2.3.36 A summary map of idealised tidal excursion ellipses, calculated using ABPmer's North West European Continental Shelf Tide and Surge Hindcast Model (ABPmer, 2017), is shown in **Figure 3.1**.

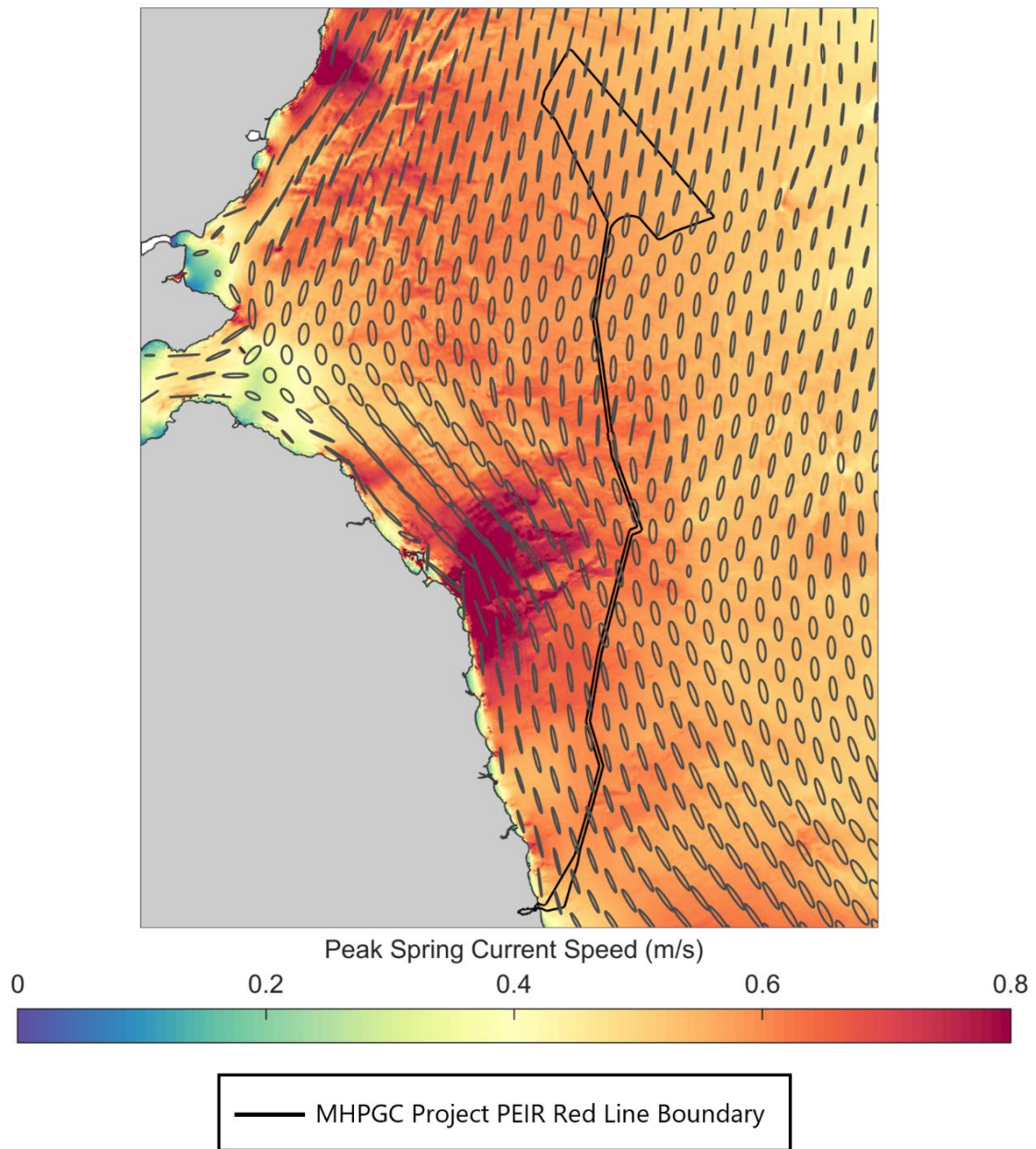


Figure 3.1: Peak current speed on a mean spring tide and associated tidal excursion ellipses

- 3.2.3.37 The tidal axis is indicated by the orientation of the long axis of the ellipse. The tidal axis is generally parallel to the adjacent coastlines in offshore areas but varies closer to headlands and estuaries. Across the MHPGC Project PEIR Red Line Boundary, the ellipses are relatively long and thin, suggesting a rectilinear pattern of tidal currents (well defined ebb and flood directions with minimal rotation of the tide through the tidal cycle). In practice, patterns of tidal flow are complex, and the path taken by water will be affected by detailed patterns of flow over distances less than one (idealised) tidal excursion in some areas.
- 3.2.3.38 Across the Physical Processes Study Area, the tidal axis is oriented approximately north-northwest to south-southeast, shifting to a more north south alignment further north along the MHPGC Project PEIR Red Line Boundary in Scottish waters. The MHPGC Project PEIR Red Line Boundary itself runs roughly south-southwest to north-northeast in English waters and south to north in Scottish waters. Because the cable corridor and tidal axis are not perpendicular, particularly in Scottish waters where they are almost parallel, the plume extent remains tightly constrained within or very close to the offshore export cable corridor boundaries. This significantly reduces the spatial effect of elevated SSC and bed deposition.
- 3.2.3.39 The displacement of the plume features by tidal currents also provides a proxy measure of the tidal excursion distance from each of the release locations for representative neap and spring range conditions. The path of the plume (including changes in flow speed and direction elsewhere in the model domain) provides a Lagrangian estimate. In areas of more complex flow (e.g. near to headlands and estuaries), this can provide a more realistic measure than the alternative Eulerian estimate (based on the net displacement of water past a particular location).
- 3.2.3.40 The tidal excursion distance is the approximate distance over which a package of water (or a section of plume with elevated SSC) is advected during one flood or ebb tide.
- 3.2.3.41 The values presented were determined based on the observed advection of the plume features in the sediment plume model results, over multiple flood and ebb cycles, during representative mean neap and mean spring tidal range conditions. There can be variation in the peak current speed between consecutive flood and ebb tides, therefore, a small range of tidal excursion distances are presented for tidal ranges representative of mean neap and mean spring conditions.
- 3.2.3.42 The tidal excursion distance varies in proportion to the peak current speed during particular flood or ebb cycles. As such, the distance may also be smaller than the mean neap conditions (on smaller than mean neap tidal ranges) and occasionally larger than the mean spring condition (on larger than mean spring tidal ranges).
- 3.2.3.43 In offshore Scottish waters:
- On neap tides, the tidal excursion distance is approximately 3km to 4km;
 - On spring tides, the tidal excursion distance is approximately 5km to 7km.
- 3.2.3.44 In offshore English waters:
- On neap tides, the tidal excursion distance is approximately 3km to 4km;
 - On spring tides, the tidal excursion distance is approximately 5km to 6km.
- 3.2.3.45 In nearshore English waters:
- On neap tides, the tidal excursion distance is approximately 5km to 6km;
 - On spring tides, the tidal excursion distance is approximately 8km to 9km.
- 3.2.3.46 The spatial variation in Lagrangian tidal excursion provides a more generalised basis for the description of the extent of potential effect on SSC and sediment deposition.
- 3.2.3.47 The tidal excursion distances quoted above are estimated based on the sediment plume advection distances from the PT model results (maximum distance of advection in either the flood or ebb direction from the location of release), these values are consistent with the tidal current speed predictions in both the bespoke project-specific HD model [Section 2.2], ABPmer's SEASTATES European Shelf Tide and Surge model (ABPmer, 2017) and tidal ellipses illustrated in the UK Marine Renewables Atlas (<https://www.renewables-atlas.info>). Interim sediment plume modelling for Morven North and Morven South (Morvern Offshore Wind Farm, 2025) shows similar extents. However, a higher tidal excursion distance value of 13.5km is quoted in that report, which may have

resulted from conservative upward rounding of these distances, or by using the overall length of plumes from longer duration releases (that may be present in both the flood and ebb directions, i.e. representing two excursion lengths).

4 Summary

- 4.1.1.1 The assessments presented in this technical report inform the technical analysis and the assessment of potential environmental impacts of the MHPGC Project on physical processes. This assessment has been informed by a combination of analysis of baseline information and numerical modelling (HD and PT) results.
- 4.1.1.2 The HD modelling allows an analysis of the baseline tidal regime and tidally driven sediment transport regime. Model results show low current speeds and associated low sediment transport rates throughout the offshore MHPGC Project PEIR Red Line Boundary during neap tides. In contrast, current speeds and sediment transport rates are significantly higher during spring tides.
- 4.1.1.3 PT modelling results, alongside conservative spreadsheet-based methods allow an analysis of the local extent, duration and magnitude of change to SSC, and sediment deposition patterns, as the result of activities causing sediment disturbance. Sediment plumes released across the MHPGC Project are characterised as spatially constrained and transient, aligned with the tidal axis. The coarser sand and gravel fractions at each site settle to the seabed within a limited time of release (from seconds up to minutes) and so tend to be deposited within a relatively small footprint (from metres up to 500m from the activity site), resulting in a locally measurable settled sediment layer. Finer sediments will remain in suspension for longer, becoming relatively more dispersed over time, resulting in a locally limited or an immeasurable thickness settled sediment layer. The predicted effect of plumes (measurable changes in SSC and sediment deposition) is largely confined to the near vicinity of construction phase activities, with minimal overlap into designated sites.
- 4.1.1.4 The wider range of results can be summarised broadly in terms of four main zones of effect, based on the distance along the tidal axis from the activity causing sediment disturbance.
- 0m to 50m: zone of highest SSC increase and greatest likely thickness of deposition. All gravel sized sediment likely deposited in this zone, also a large proportion of sands that are not resuspended high into the water column, and also most or all dredge spoil in the active phase. Plume dimensions and SSC, and deposit extent and thickness, are primarily controlled by the volume of sediment released and the manner in which the deposit settles:
 - At the time of active disturbance: very high SSC increase (tens to hundreds of thousands of mg/l) lasting for the duration of active disturbance plus up to 30 minutes following end of disturbance; sands and gravels may deposit in local thicknesses of tens of centimetres to several metres; fine sediment is unlikely to deposit in measurable thickness;
 - More than one hour after the end of active disturbance: SSC is <50mg/l; no measurable ongoing deposition.
 - 50m to 500m: zone of measurable SSC increase and measurable but lesser thickness of deposition. Mainly sands that are released or resuspended higher in the water column and resettling to the seabed whilst being advected by ambient tidal currents. Plume dimensions and SSC, and deposit extent and thickness, are primarily controlled by the volume of sediment released, the height of resuspension or release above the seabed, and the ambient current speed and direction at the time:
 - At the time of active disturbance: high SSC increase (hundreds to thousands of mg/l) lasting for the duration of active disturbance plus up to 30 minutes following end of disturbance; sands and gravels may deposit in local thicknesses of up to tens of centimetres; fine sediment is unlikely to deposit in measurable thickness;
 - More than one hour after end of active disturbance: SSC is <10mg/l; fine sediment is unlikely to deposit in measurable thickness;
 - Deposition thicknesses of 5 cm or more may occur (will be limited to) up to approximately 100m from activities causing sediment disturbance;
 - Deposition thicknesses of 1 cm or more may occur (will be limited to) up to approximately 200m from activities causing sediment disturbance;
 - Measurably higher SSC of [hundreds]mg/l or more may occur (will be limited to) up to approximately 200m from activities causing sediment disturbance (the distance within

which most sand and gravel will have resettled and only finer sediment remains in suspension).

- 500m to the tidal excursion buffer distance: zone of lesser but measurable SSC increase and no measurable thickness of deposition. Mainly fines that are maintained in suspension for more than one tidal cycle and are advected by ambient tidal currents. Plume dimensions and SSC are primarily controlled by the volume of sediment released, the patterns of current speed and direction at the place and time of release and where the plume moves to over the following 24 hours:
 - At the time of active disturbance: low to intermediate SSC increase (tens to low hundreds of mg/l) as a result of any remaining fines in suspension, only within a narrow plume (tens to a few hundreds of metres wide, SSC decreasing rapidly by dispersion to ambient values within one day after the end of active disturbance; fine sediment is unlikely to deposit in measurable thickness;
 - One to six hours after end of active disturbance: decreasing to low SSC increase (tens of mg/l); fine sediment is unlikely to deposit in measurable thickness;
 - Six to 24 hours after end of active disturbance: decreasing gradually through dispersion to background SSC (no measurable local increase); fine sediment is unlikely to deposit in measurable thickness. No measurable change from baseline SSC after 24 hours to 48 hours following cessation of activities.
- Beyond the tidal excursion buffer distance (or anywhere not tidally aligned to the active sediment disturbance activity): there is no expected effect or change to SSC nor a measurable sediment deposition.

4.1.1.5 The active phase (main body) of sediment discharged during spoil disposal will result in a localised area of potentially thicker deposition. The shape and local thickness of the deposit cannot be predicted with any certainty, however, the volume of sediment in each deposit is limited and so the area and average thickness will be proportionally related (i.e. thicker deposits will be of smaller extent, and vice versa).

5 References

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Appendix A Tidal Model Figures

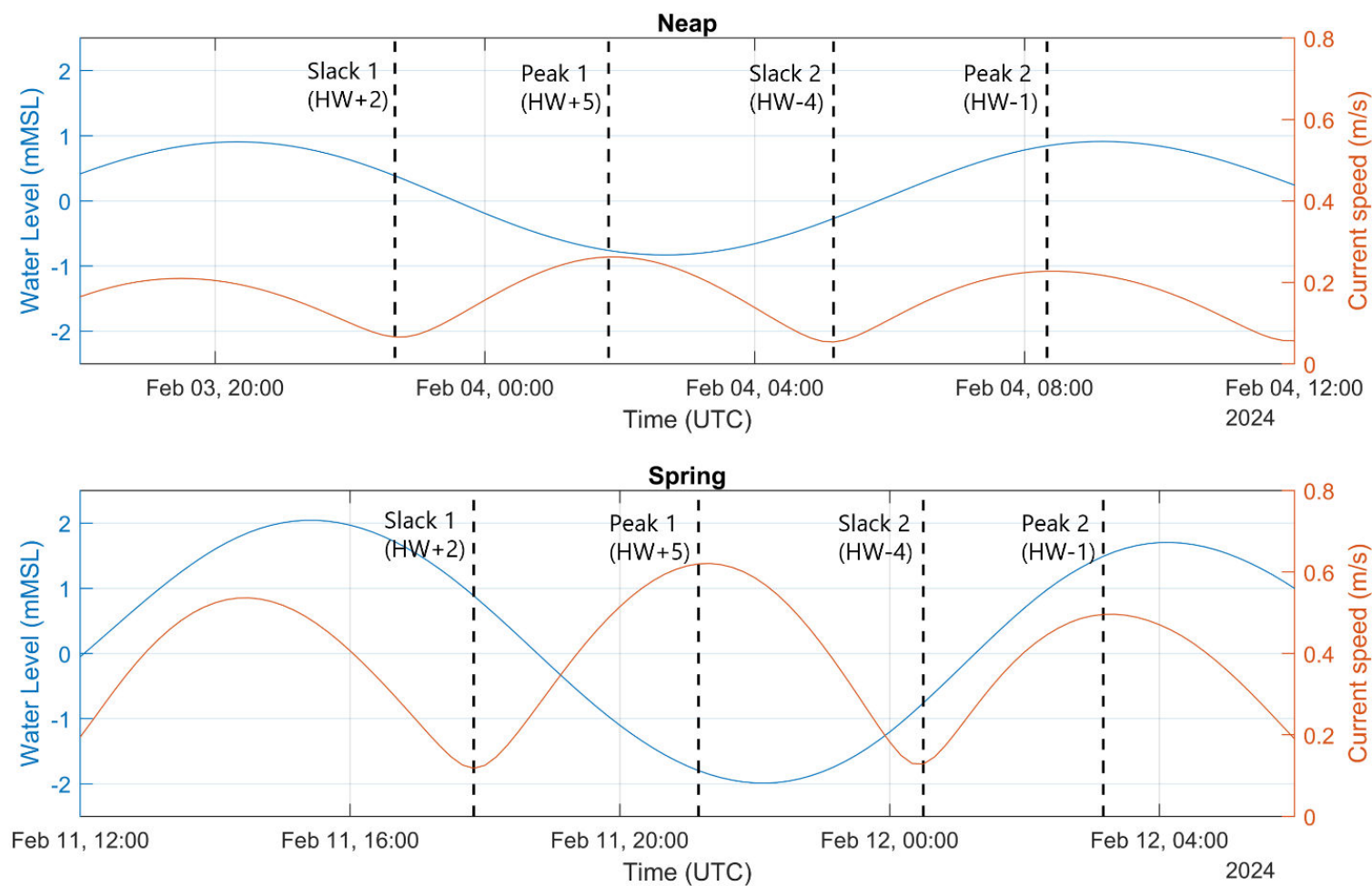


Figure A.1: Water level and current speed timeseries for a central point along the offshore export cable corridor during representative neap (top) and spring (bottom) tides. Times of slack waters and peak flows are shown by dashed lines.

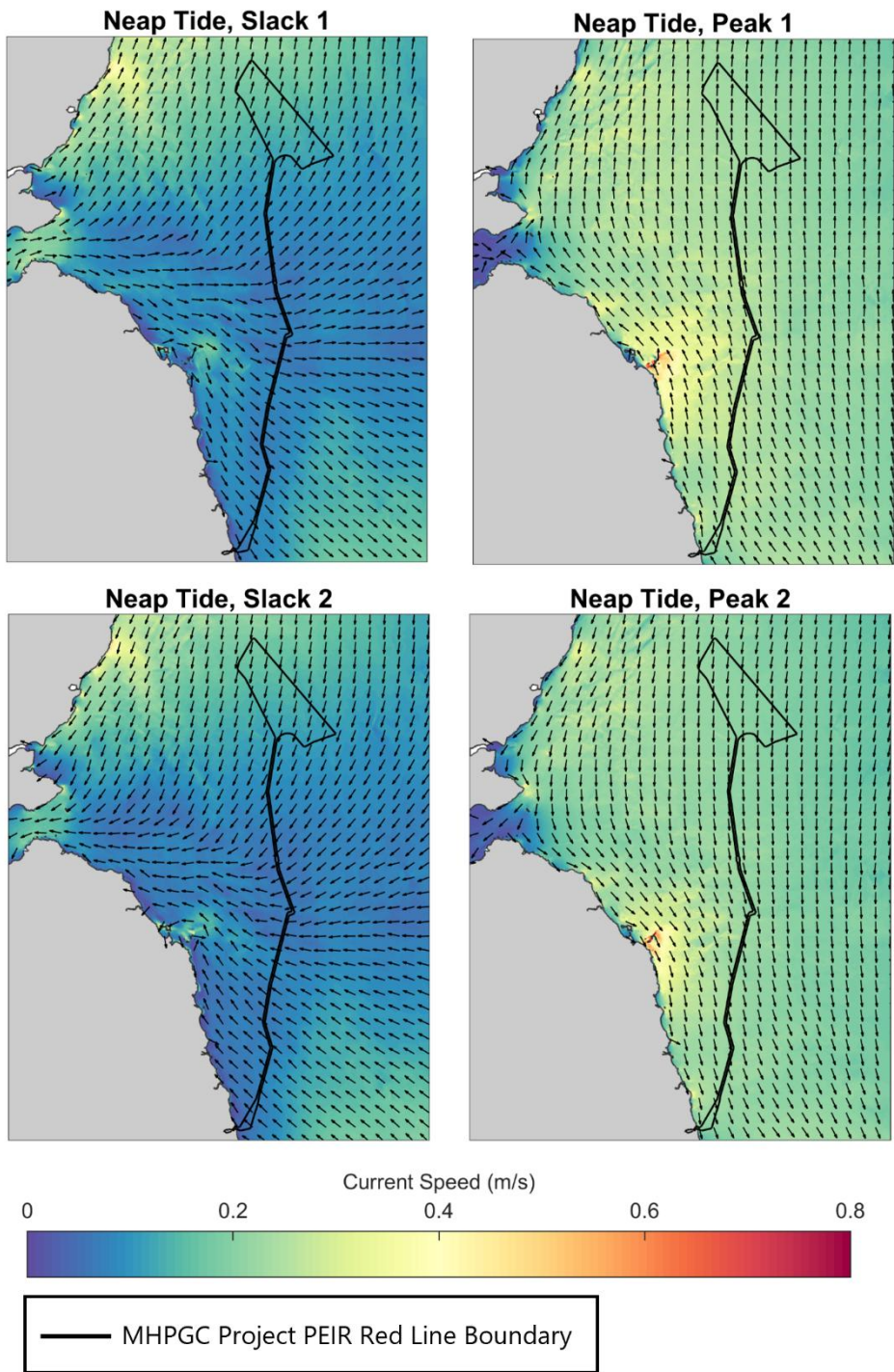


Figure A.2: Baseline tidal current speed and direction during a representative neap tidal condition

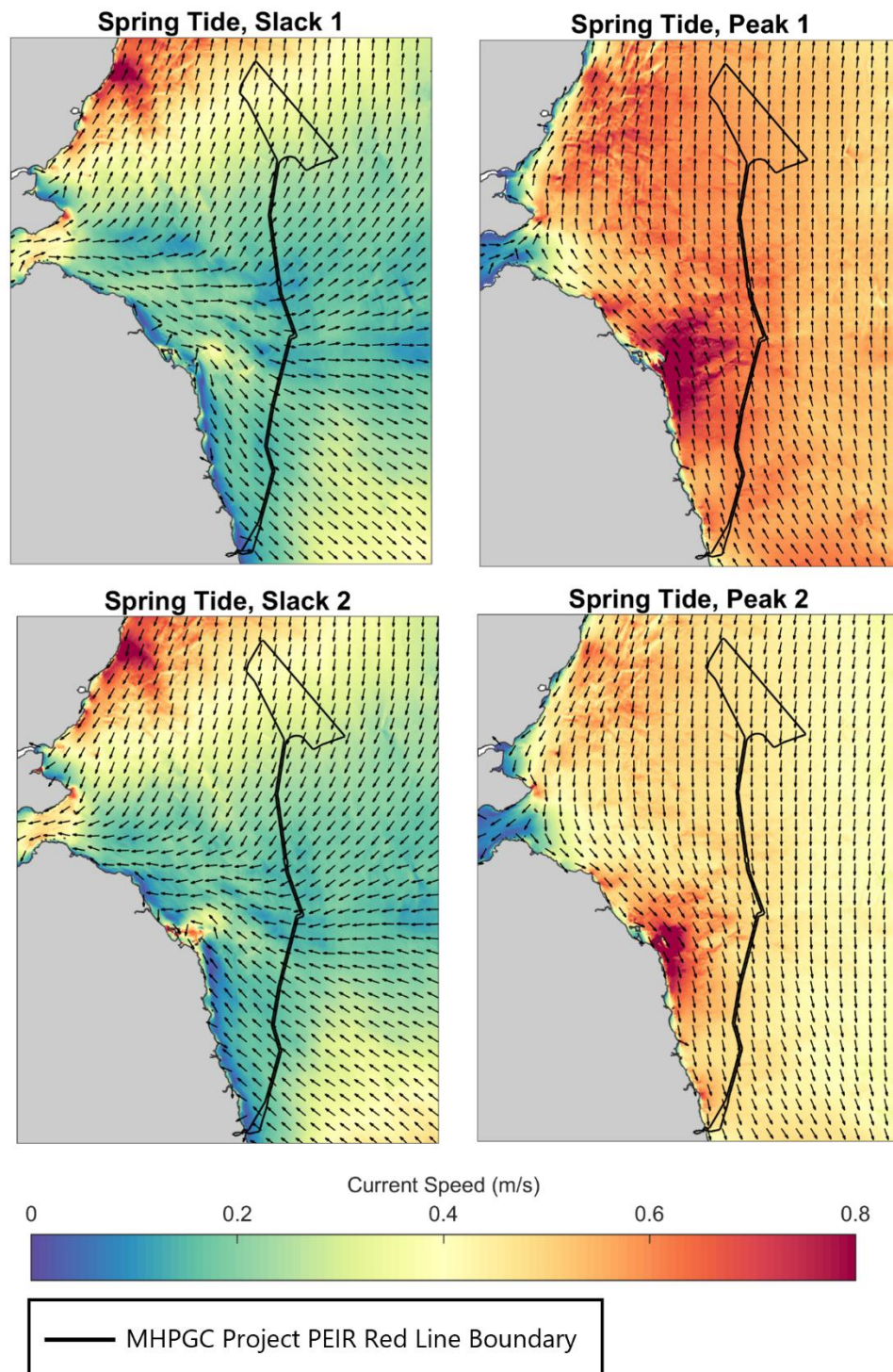


Figure A.3: Baseline tidal current speed and direction during a representative spring tidal condition

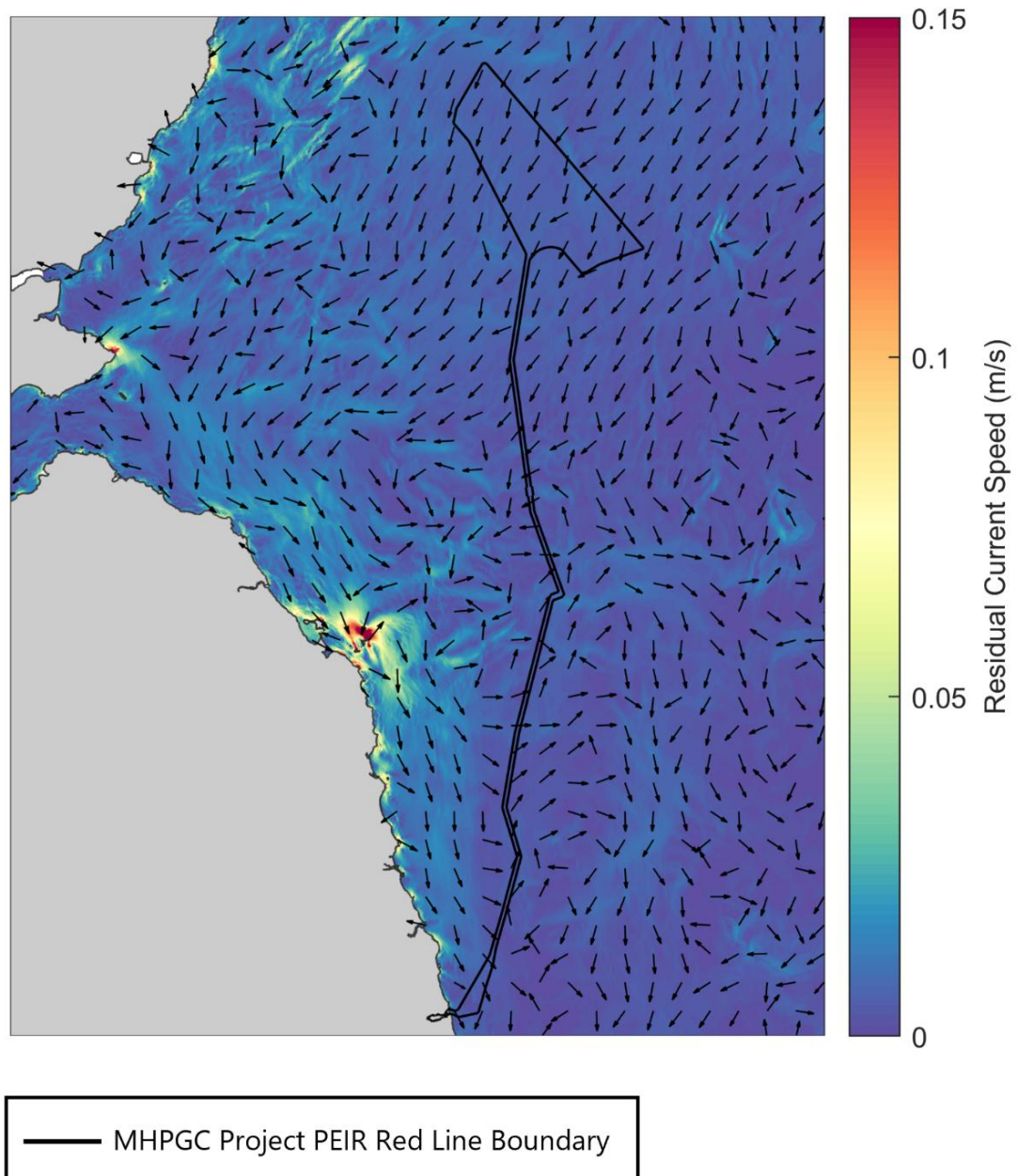


Figure A.4: Baseline residual tidal current speed and direction over a representative spring-neap tidal period

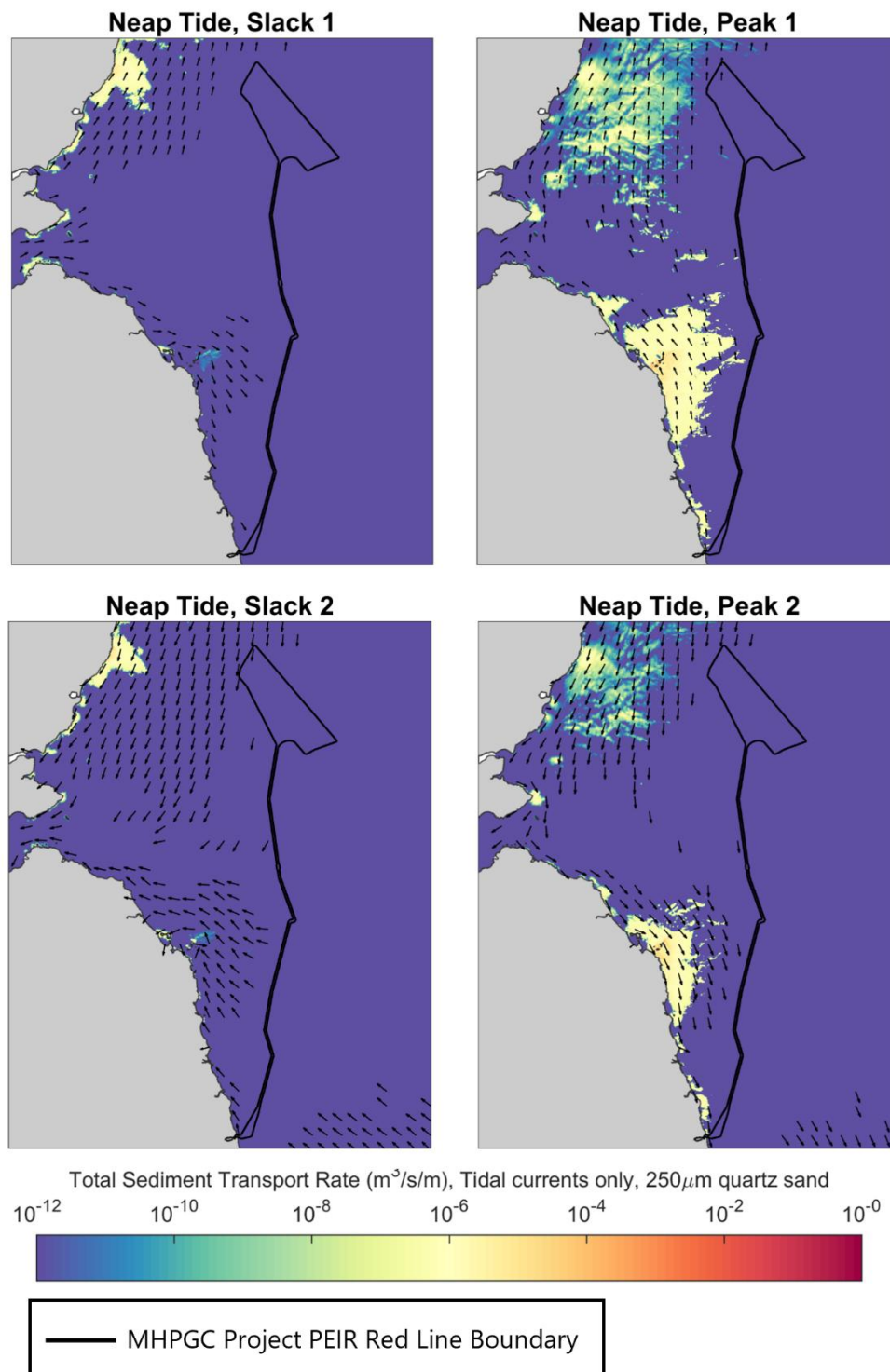


Figure A.5: Baseline sediment transport rate and direction, for $250\mu\text{m}$ quartz sand, during a representative neap tidal condition

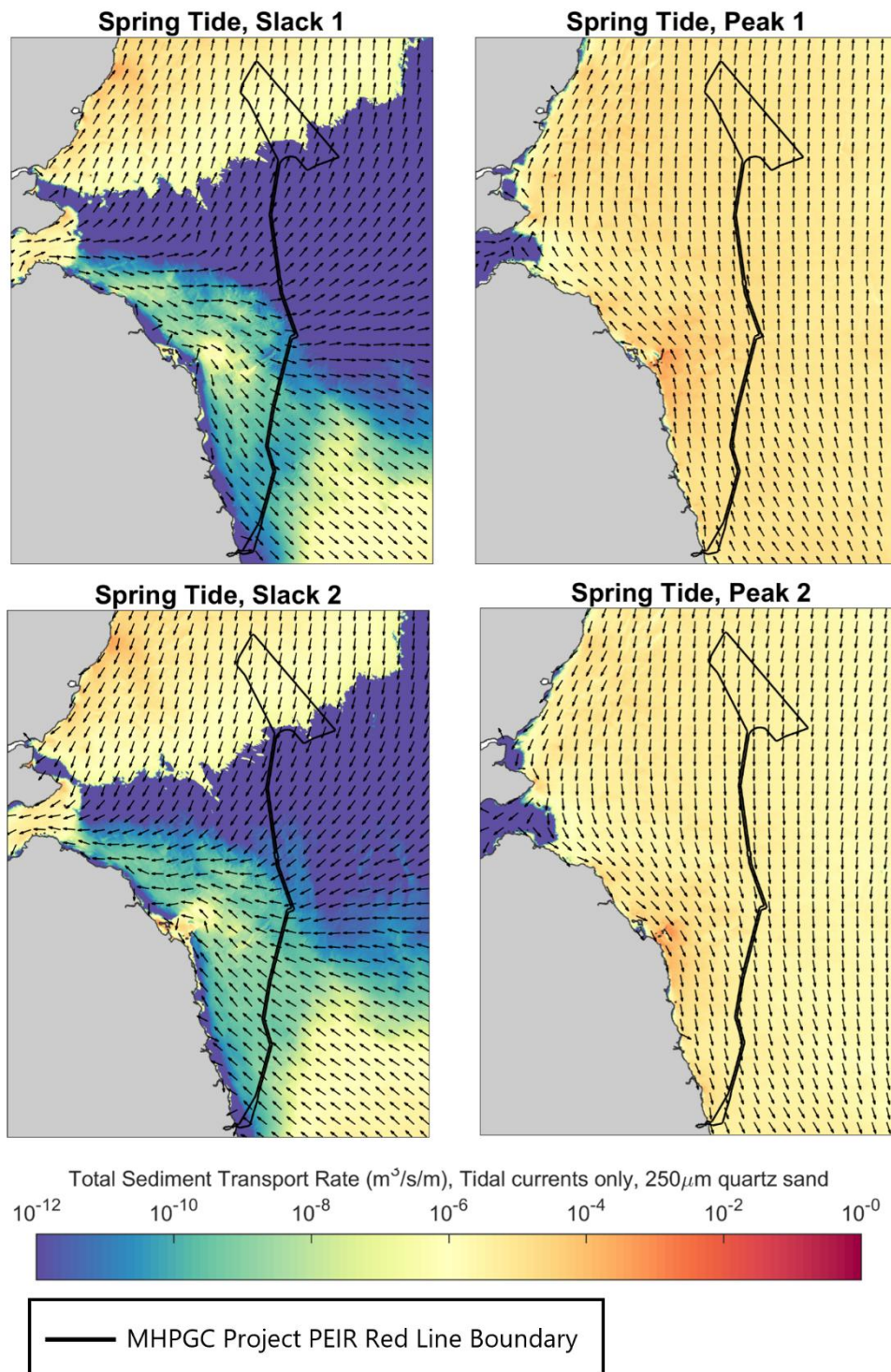


Figure A.6: Baseline sediment transport rate and direction, for $250\mu\text{m}$ quartz sand, during a representative spring tidal condition

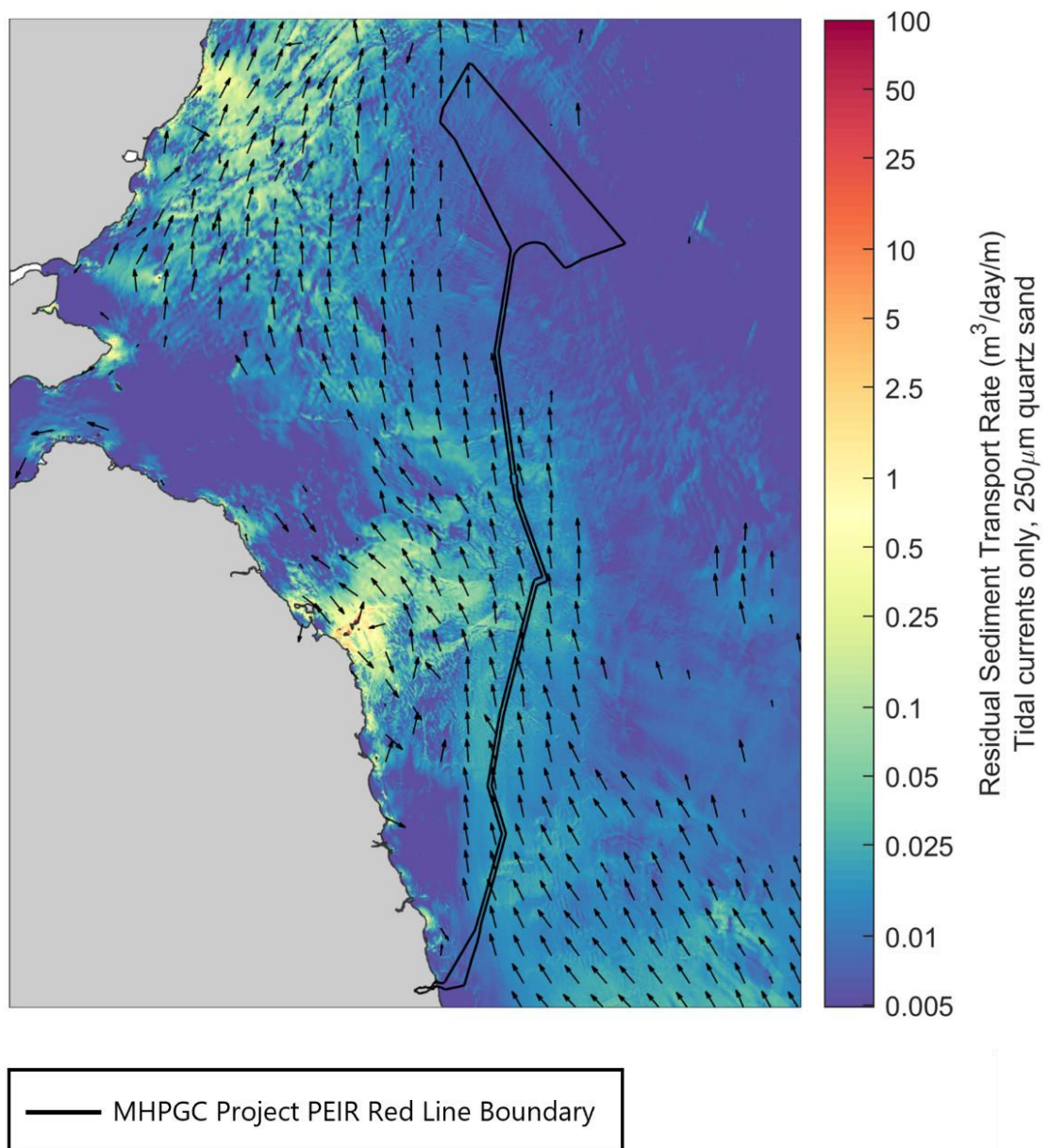


Figure A.7: Baseline residual sediment transport rate and direction, for 250µm quartz sand, predicted over a representative spring-neap tidal period

Appendix B Suspended Sediment Concentration Figures

B.1 Scottish waters

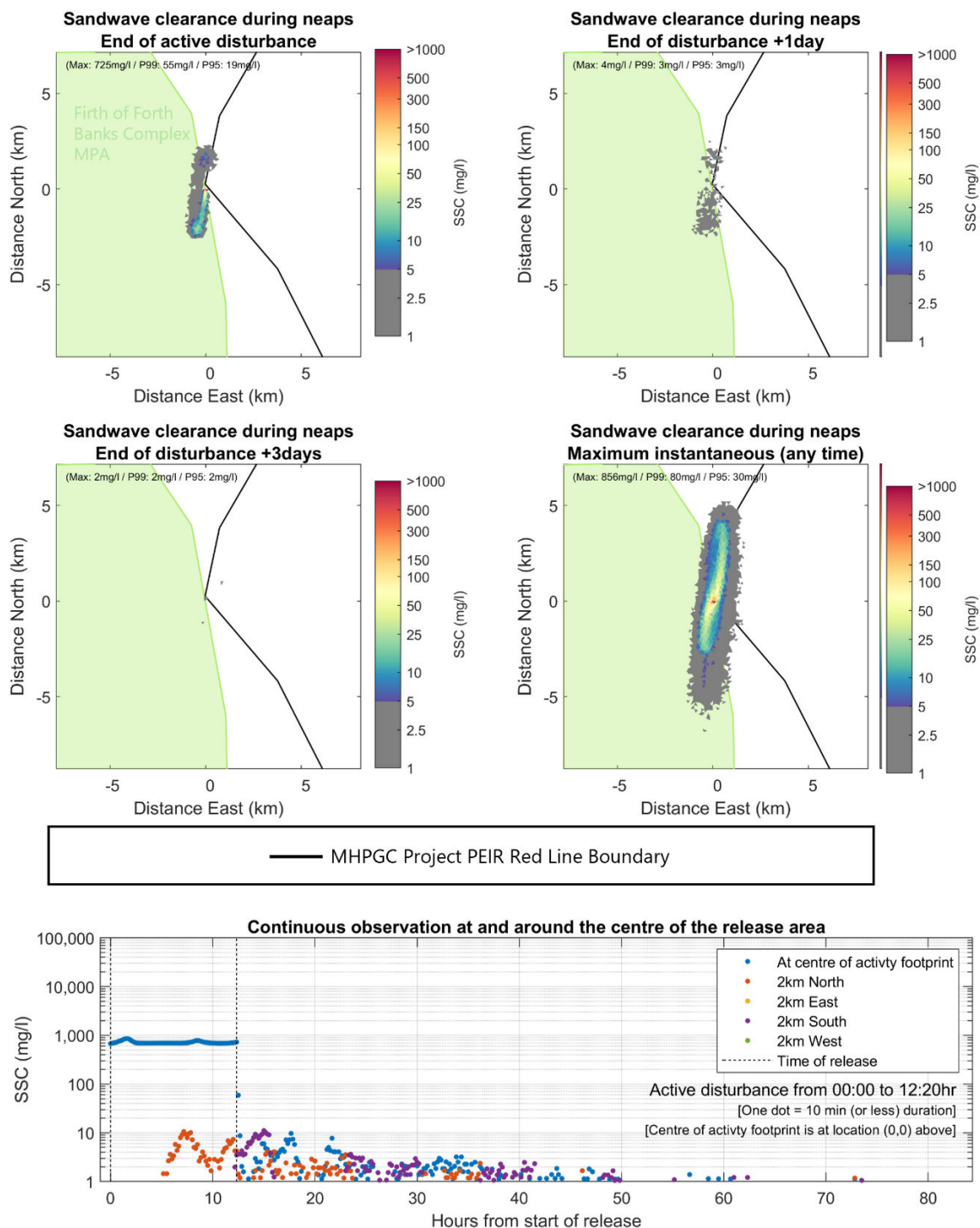


Figure B.1: Increase in SSC as a result of Scenario 1: sandwave clearance using a MFE during a mean neap tide, in offshore Scottish waters, along the western extent of the MHPGC Project PEIR Red Line Boundary

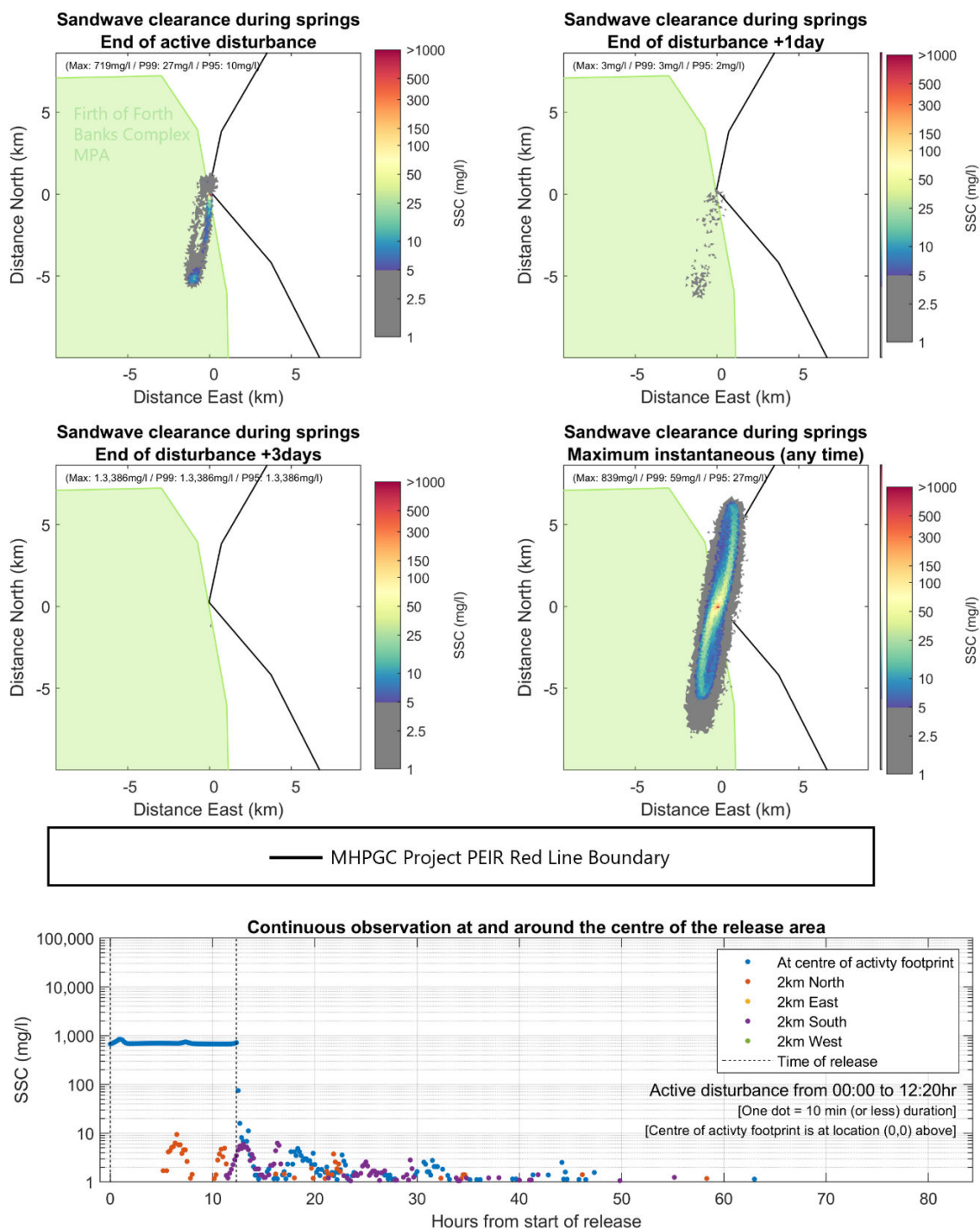


Figure B.2: Increase in SSC as a result of Scenario 2: sandwave clearance using a MFE during a mean spring tide, in offshore Scottish waters, along the western extent of the MHPGC Project PEIR Red Line Boundary

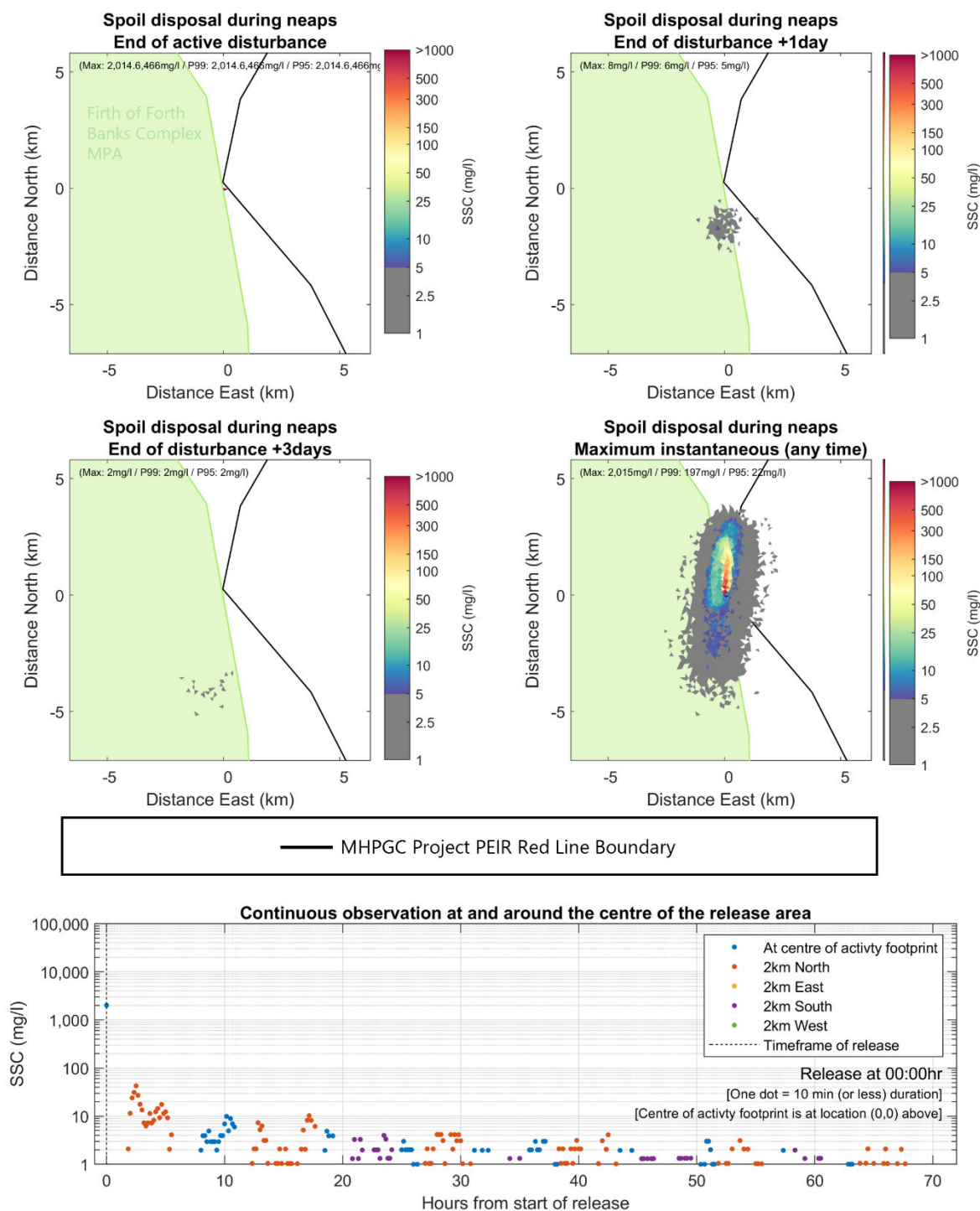


Figure B.3: Increase in SSC as a result of Scenario 3: dredge spoil disposal during a mean neap tide, in offshore Scottish waters, along the western extent of the MHPGC Project PEIR Red Line Boundary

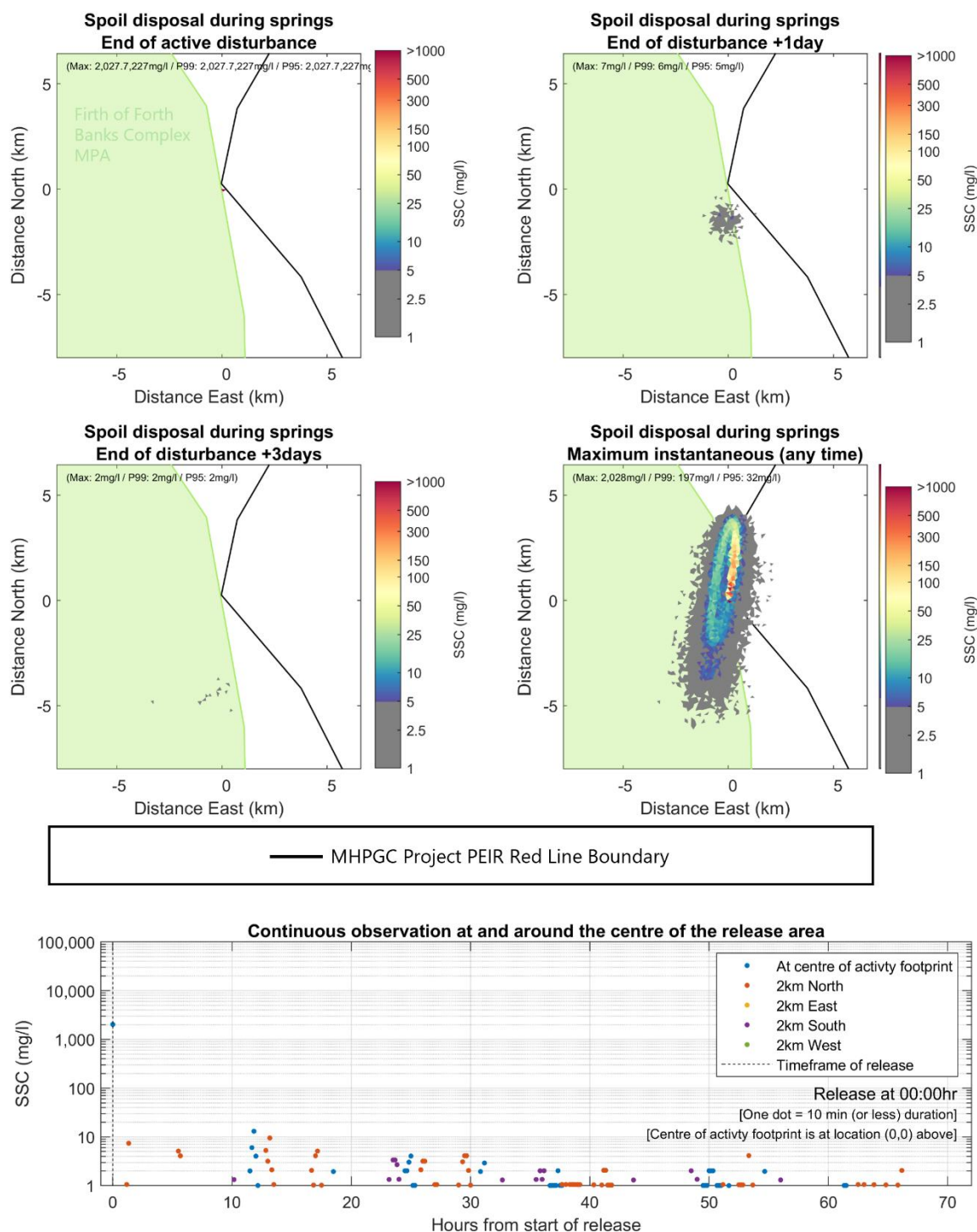


Figure B.4: Increase in SSC as a result of Scenario 4: dredge spoil disposal during a mean spring tide, in offshore Scottish waters, along the western extent of the MHPGC Project PEIR Red Line Boundary

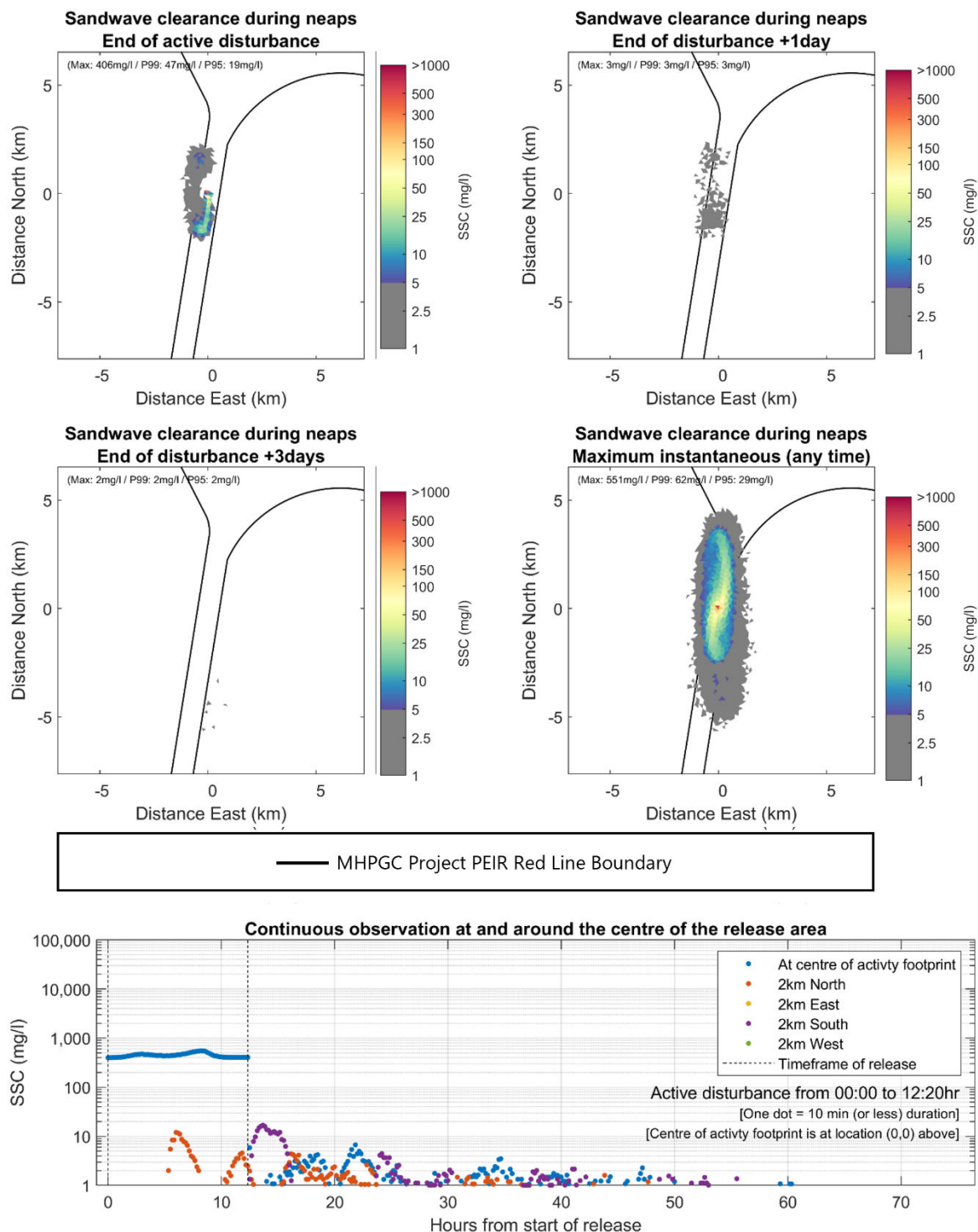


Figure B.5: Increase in SSC as a result of Scenario 5: sandwave clearance using a MFE during a mean neap tide, in offshore Scottish waters in the MHPGC Project PEIR Red Line Boundary

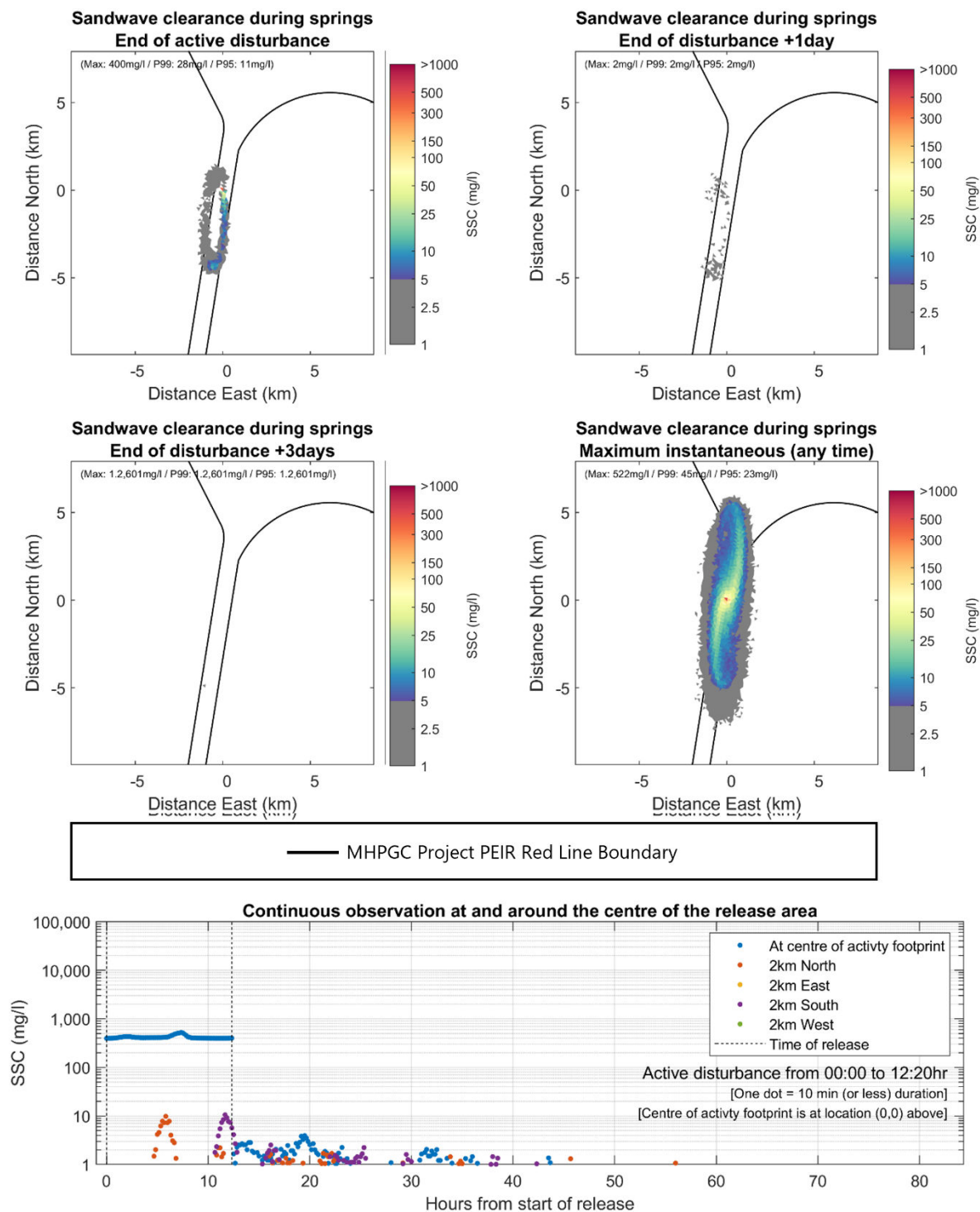


Figure B.6: Increase in SSC as a result of Scenario 6: sandwave clearance using a MFE during a mean spring tide, in offshore Scottish waters, in the MHPGC Project PEIR Red Line Boundary

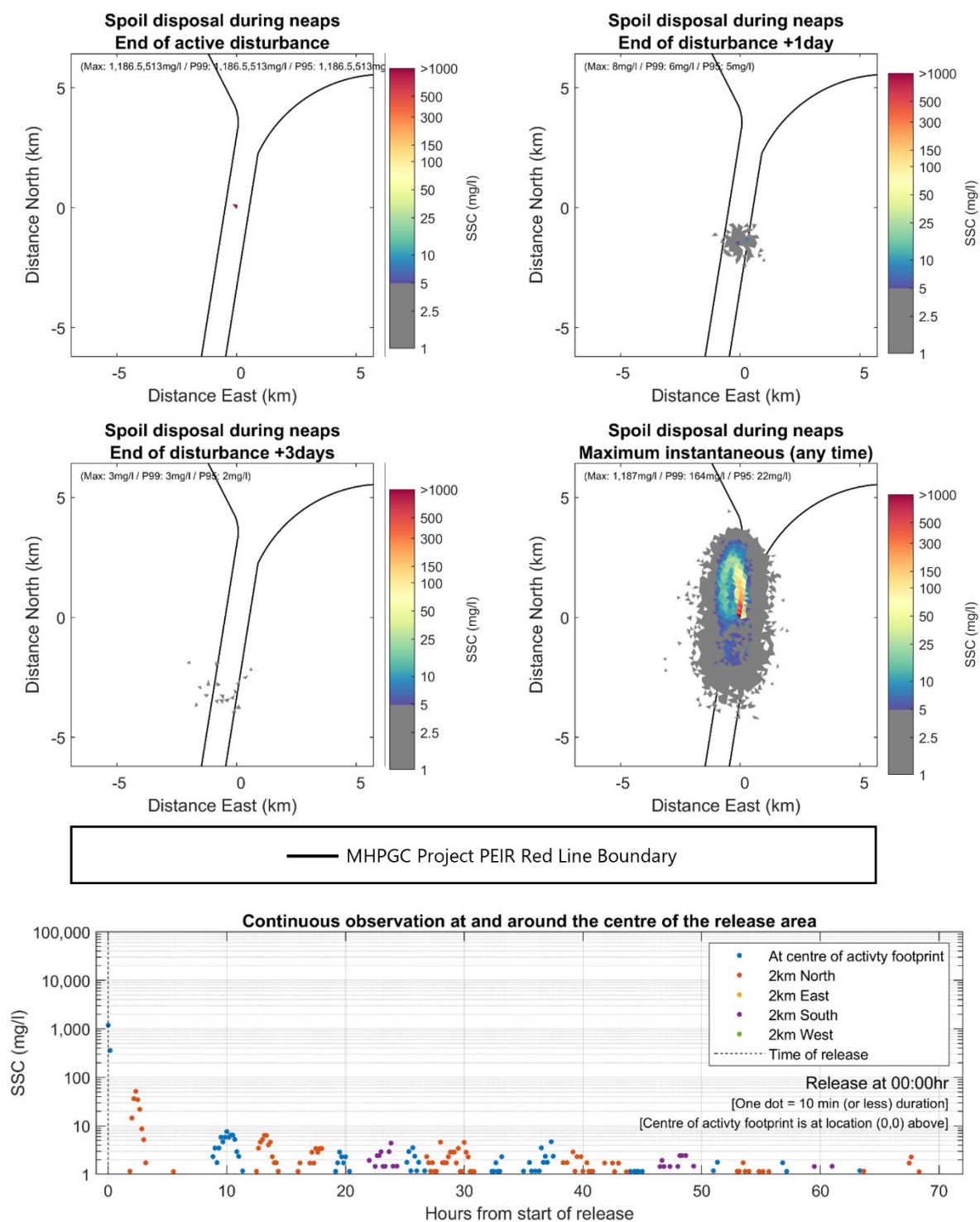


Figure B.7: Increase in SSC as a Result of Scenario 7: dredge spoil disposal during a mean neap tide, in offshore Scottish waters, in the MHPGC Project PEIR Red Line Boundary

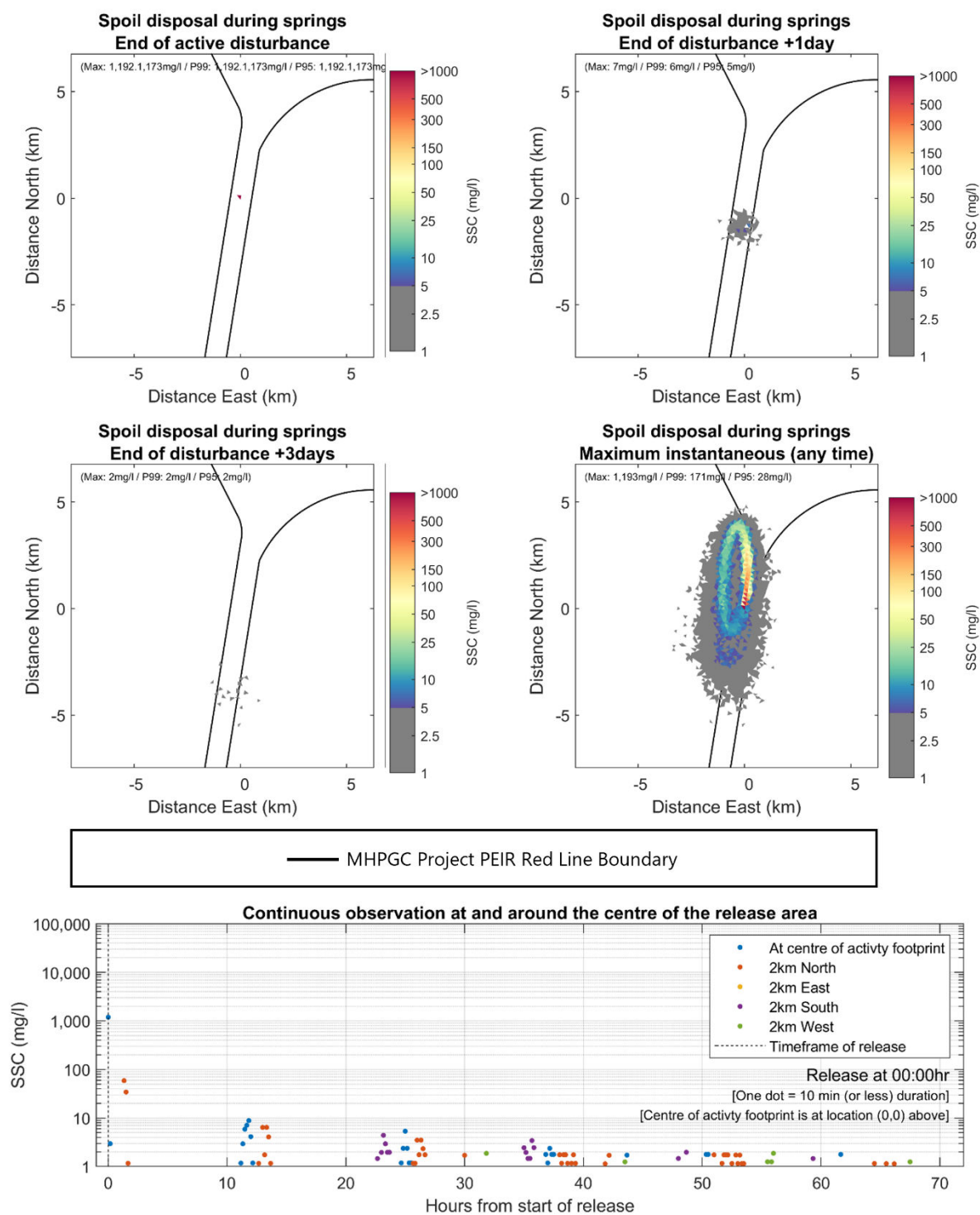


Figure B.8: Increase in SSC as a result of Scenario 8: dredge spoil disposal during a mean spring tide, in offshore Scottish waters, in the MHPGC Project PEIR Red Line Boundary

B.2 Whole length of MHPGC Project PEIR Red Line Boundary

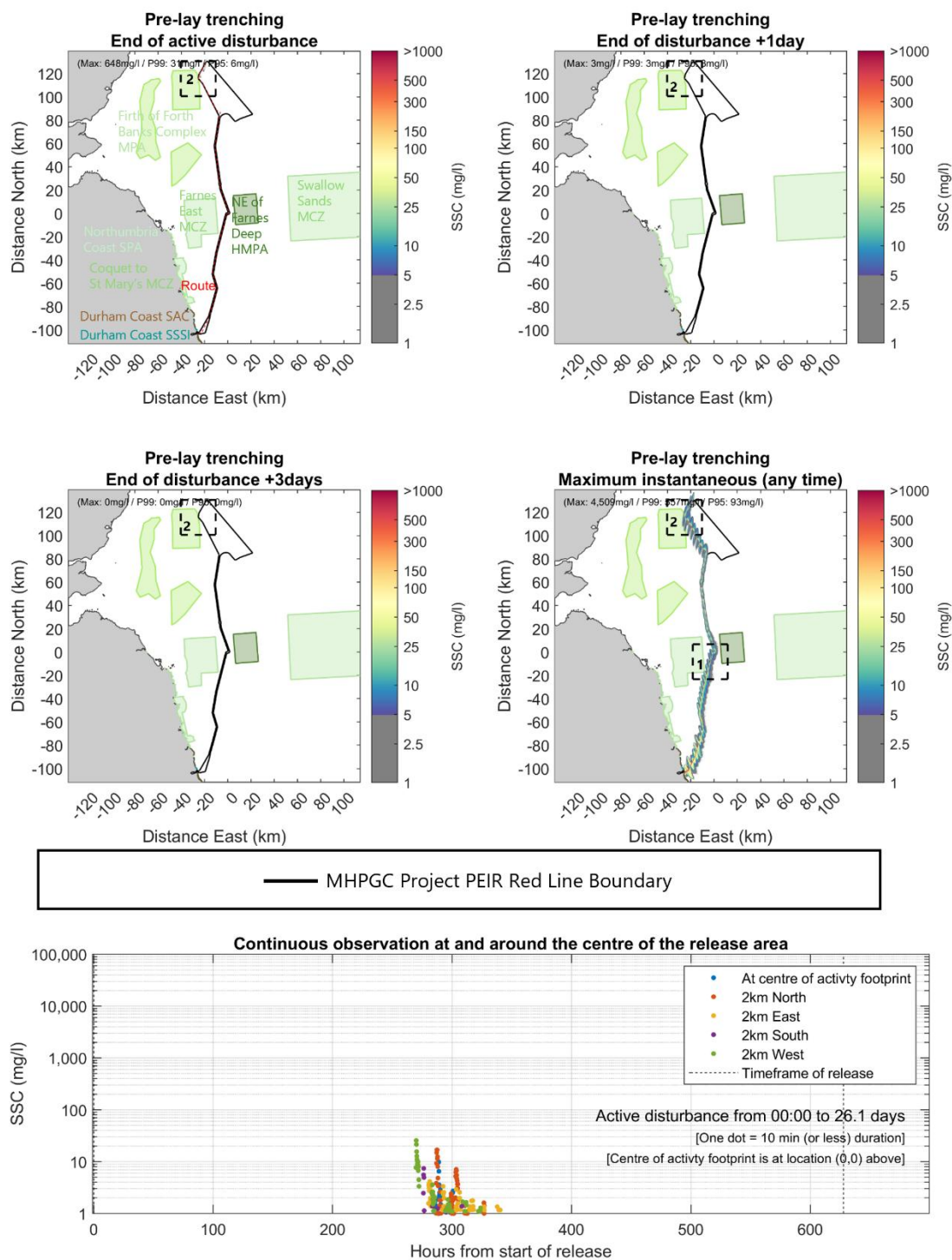


Figure B.9: Increase in SSC as a result of Scenario 9: pre-lay trenching along the length of the MHPGC Project PEIR Red Line Boundary

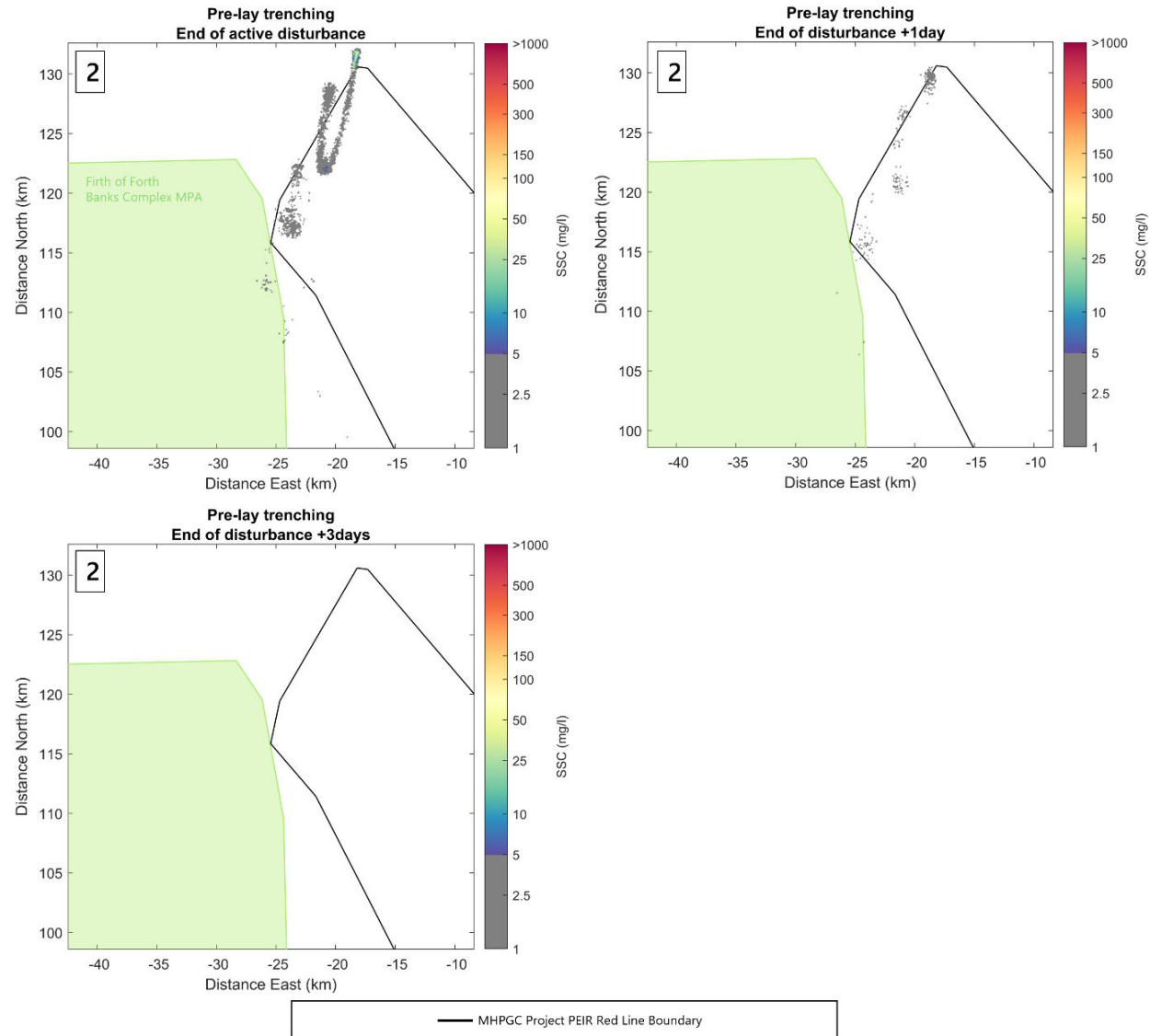


Figure B.10: Increase in SSC as a result of Scenario 9: pre-lay trenching along the length of the MHPGC Project PEIR Red Line Boundary, zoomed view 2.

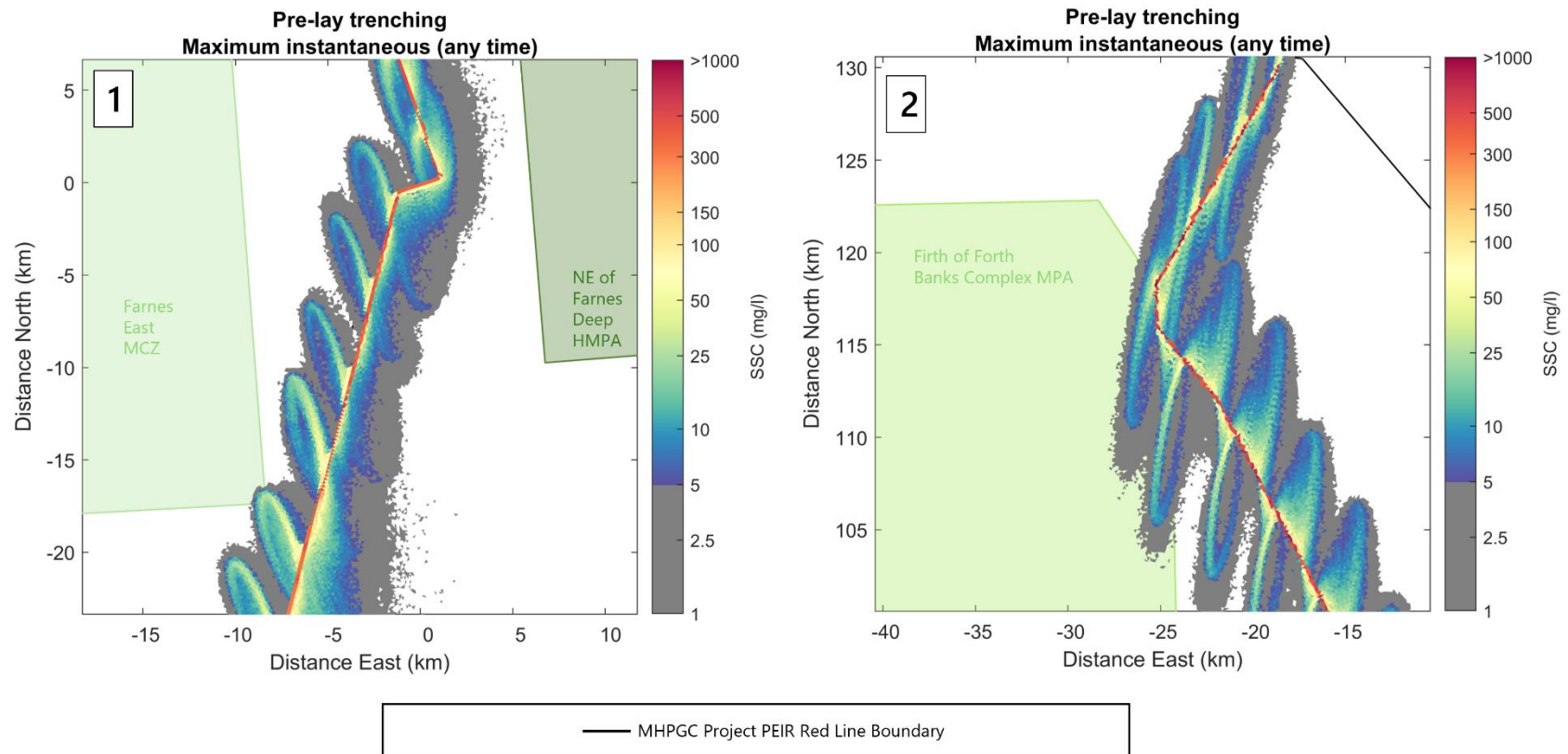


Figure B.11: Maximum instantaneous increase in SSC as a result of Scenario 9: pre-lay trenching along the length of the MHPGC Project PEIR Red Line Boundary , zoomed view 1 (left) and zoomed view 2 (right)

B.3 English waters

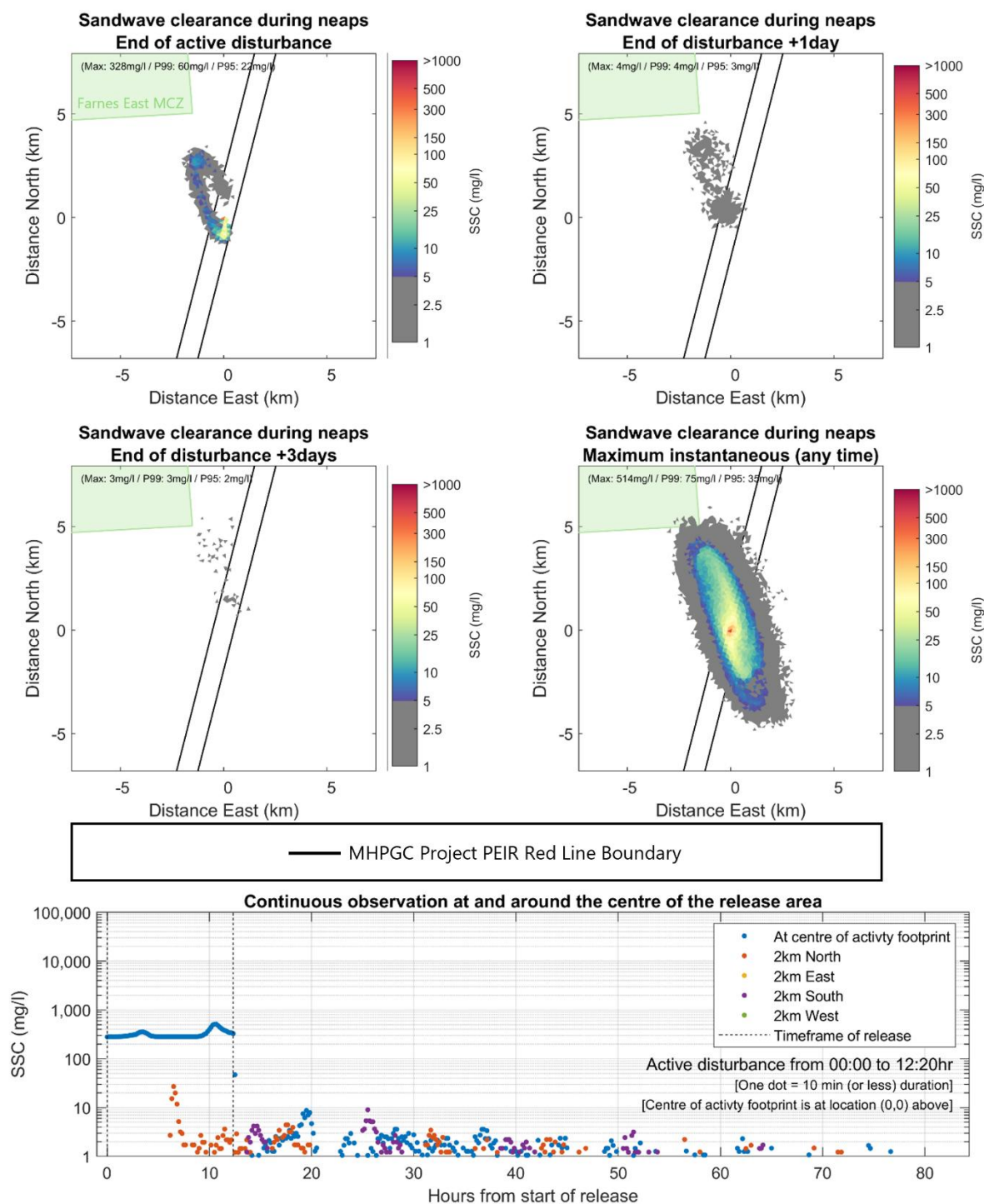


Figure B.12: Increase in SSC as a result of Scenario 10: sandwave clearance using a MFE during a mean neap tide, in offshore English waters, in the MHPGC Project PEIR Red Line Boundary

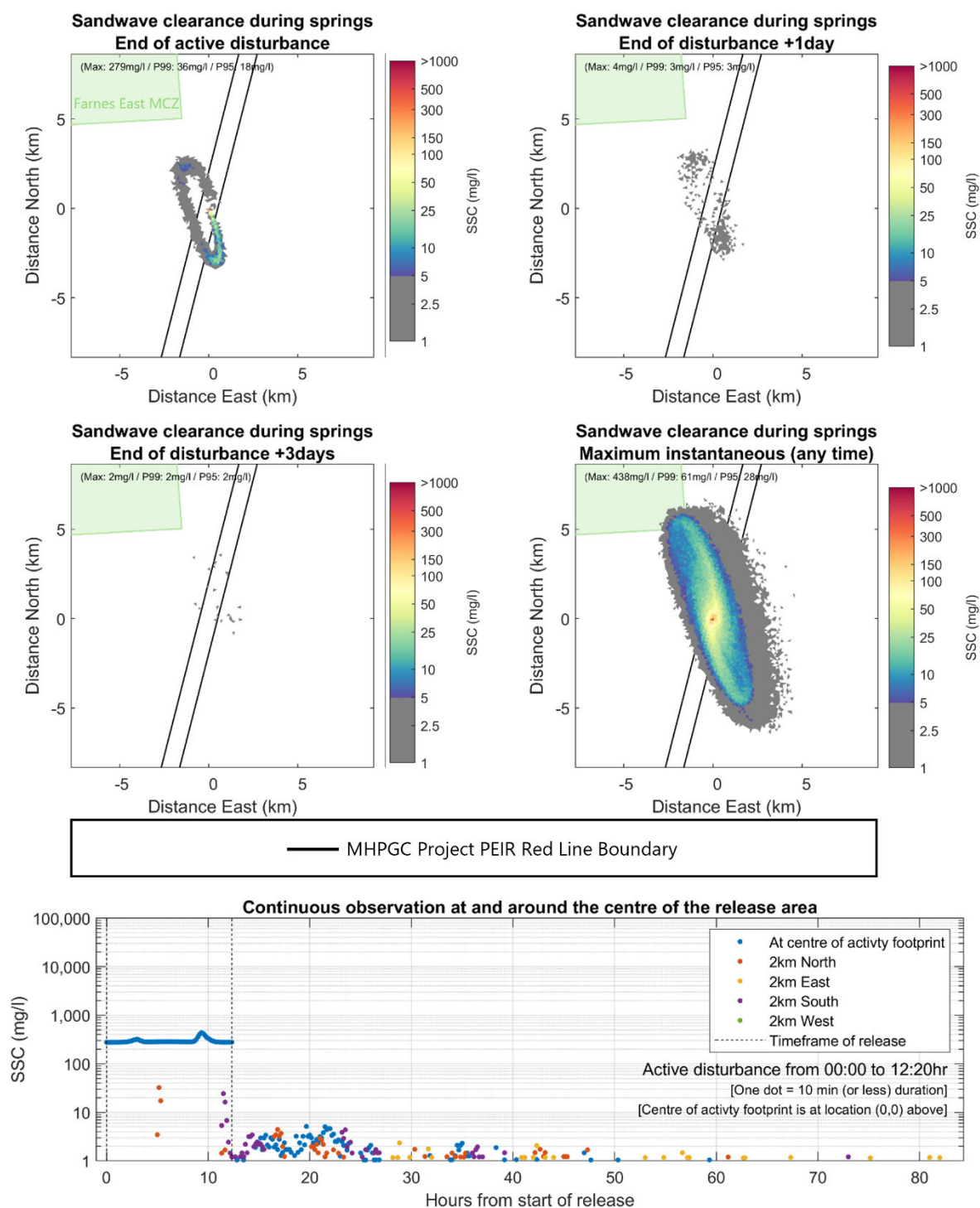


Figure B.13: Increase in SSC as a result of Scenario 11: sandwave clearance using a MFE during a mean spring tide, in offshore English waters, in the MHPGC Project PEIR Red Line Boundary

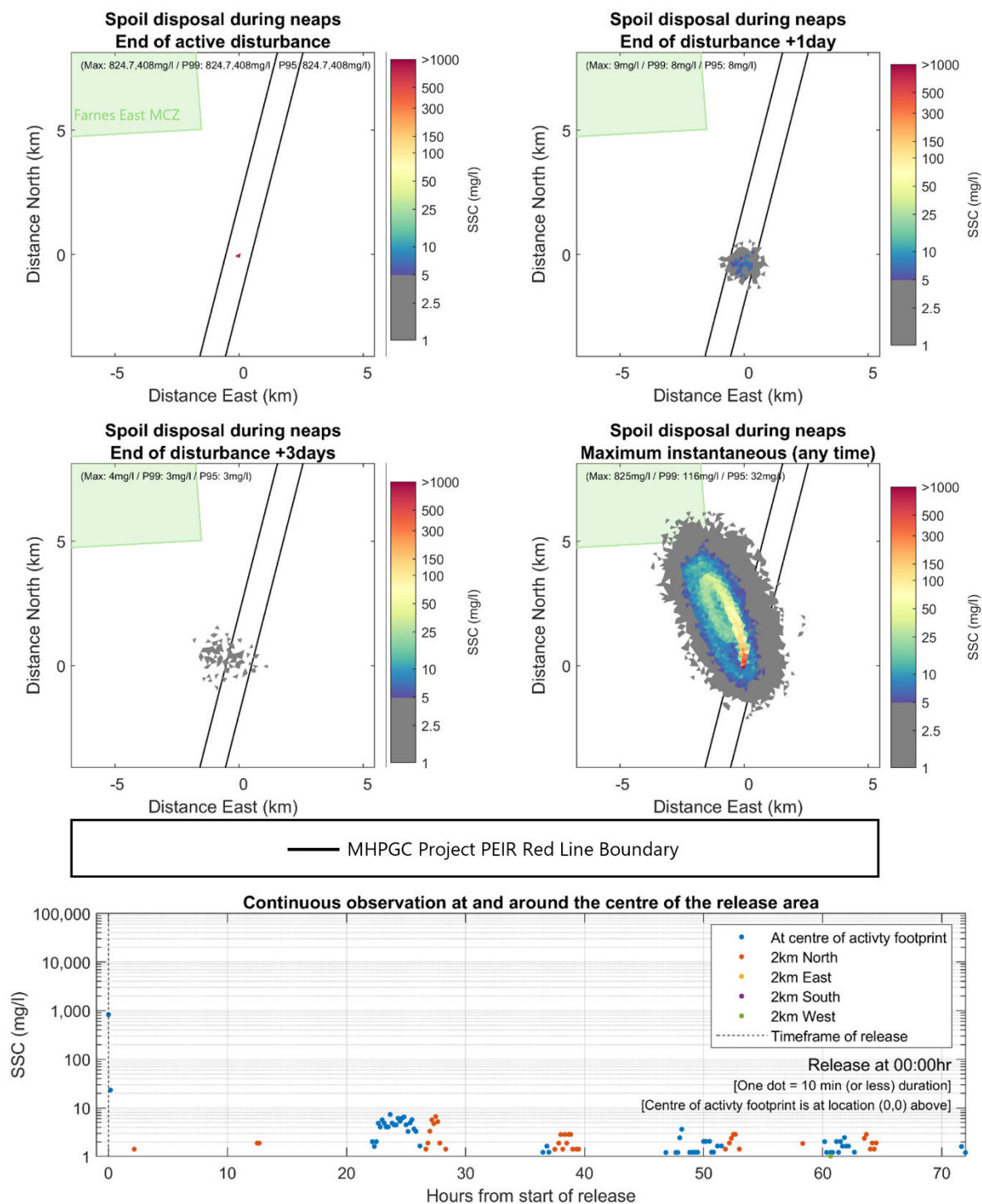


Figure B.14: Increase in SSC as a result of Scenario 12: dredge spoil disposal during a mean neap tide, in offshore English waters in the MHPGC Project PEIR Red Line Boundary

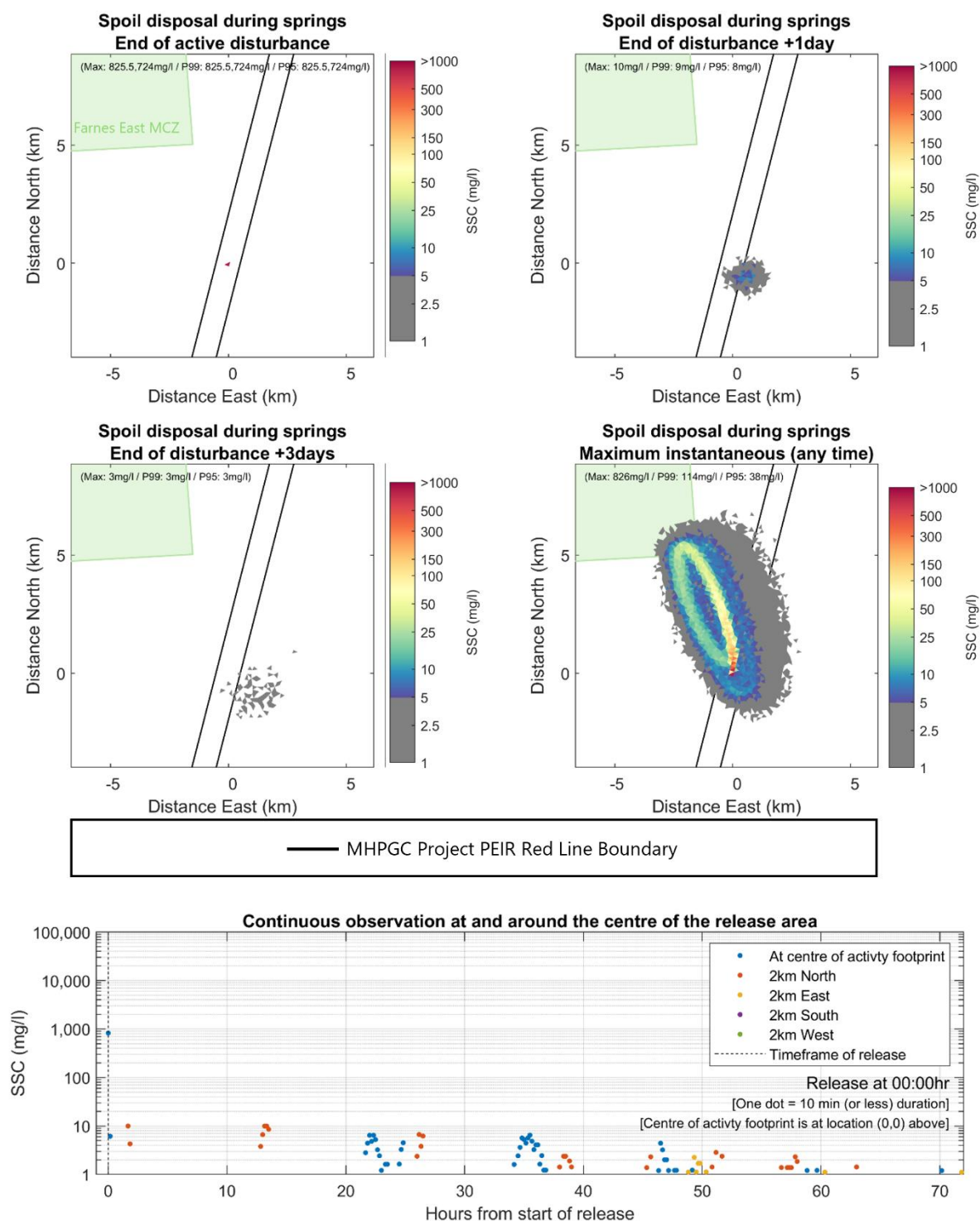


Figure B.15: Increase in SSC as a result of Scenario 13: dredge spoil disposal during a mean spring tide, in offshore English waters, in the MHPGC Project PEIR Red Line Boundary

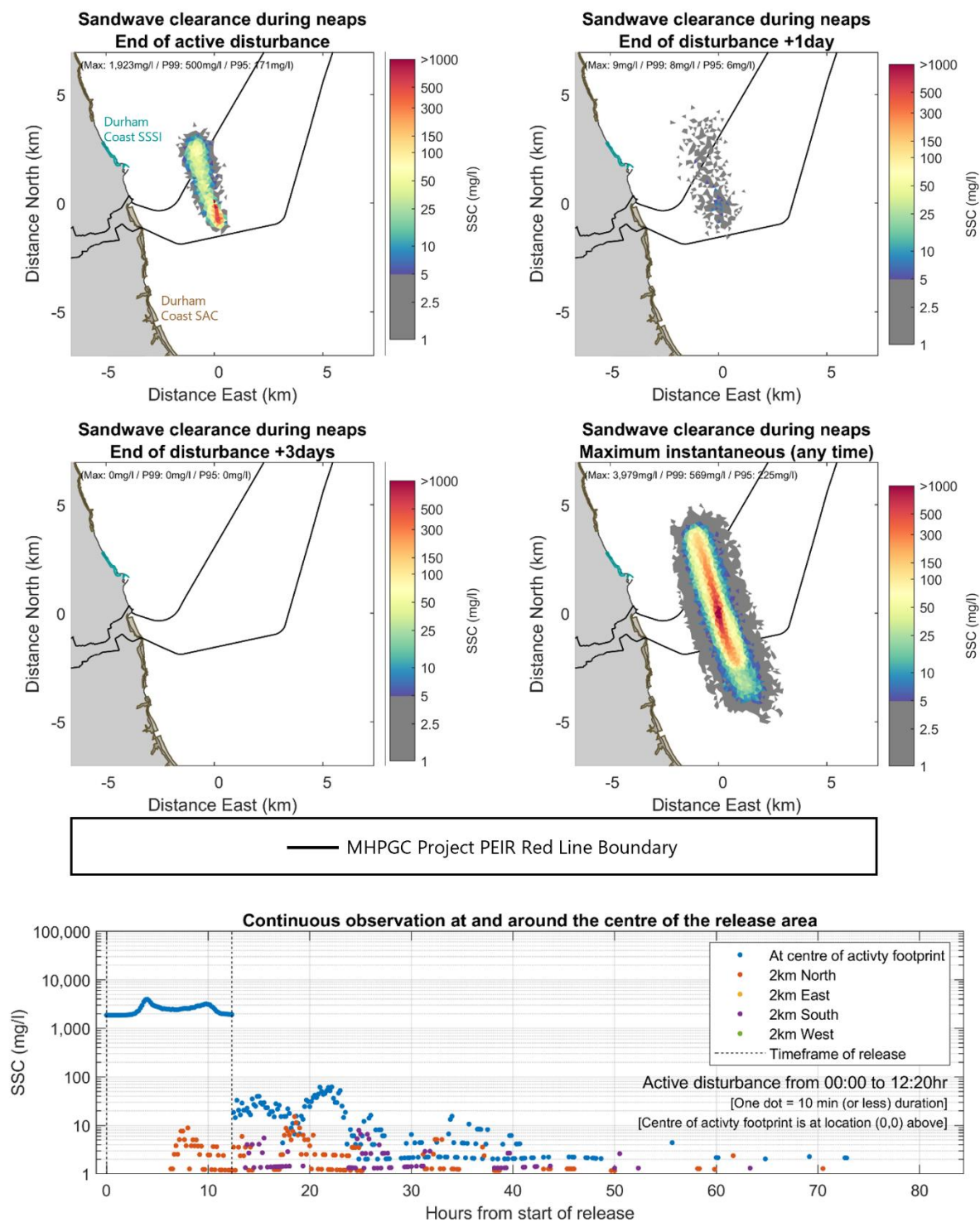


Figure B.16: Increase in SSC as a result of Scenario 14: sandwave clearance using a MFE during a mean neap tide, in nearshore English waters, in the MHPGC Project PEIR Red Line Boundary

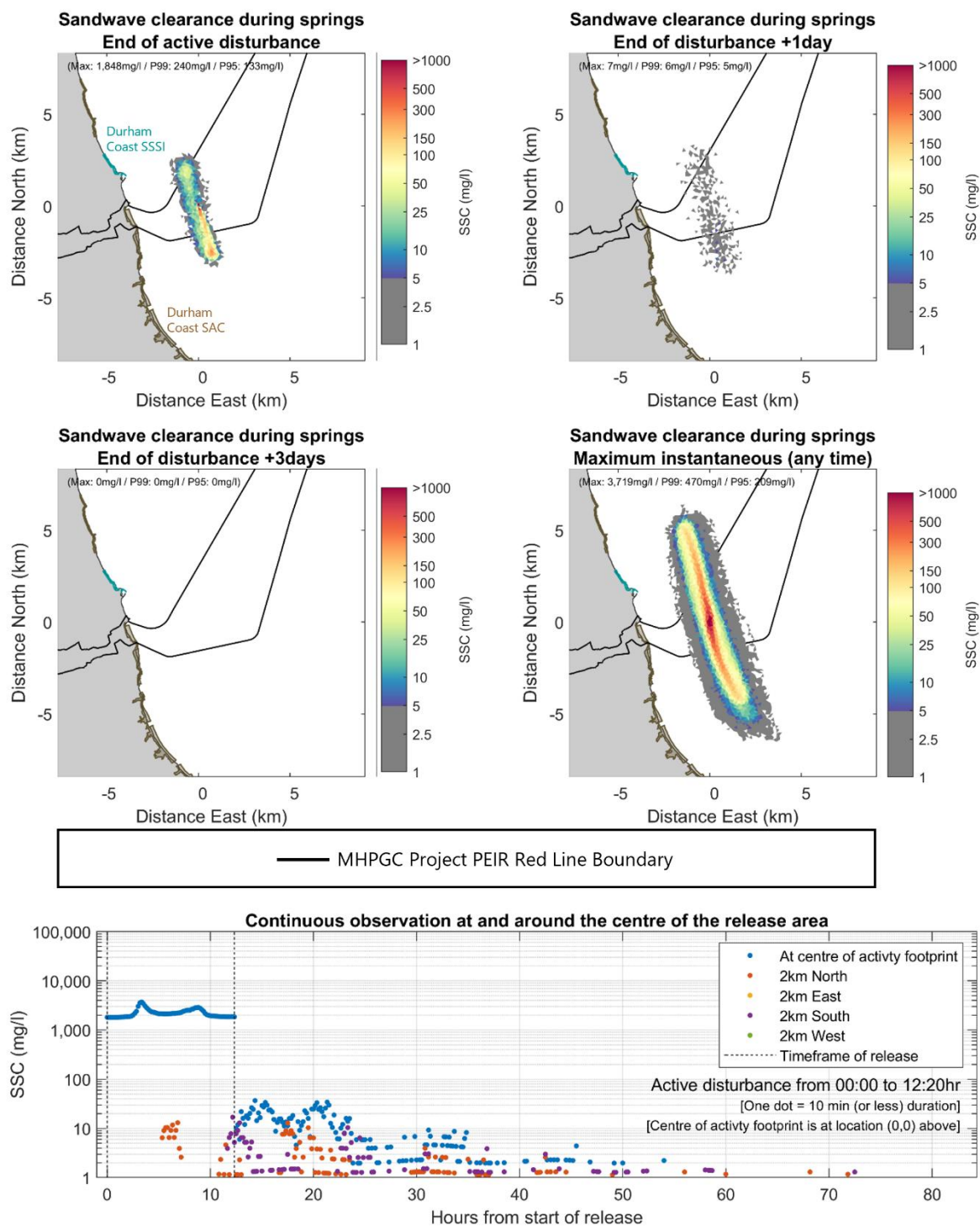


Figure B.17: Increase in SSC as a result of Scenario 15: sandwave clearance using a MFE during a mean spring tide, in nearshore English waters, in the MHPGC Project PEIR Red Line Boundary

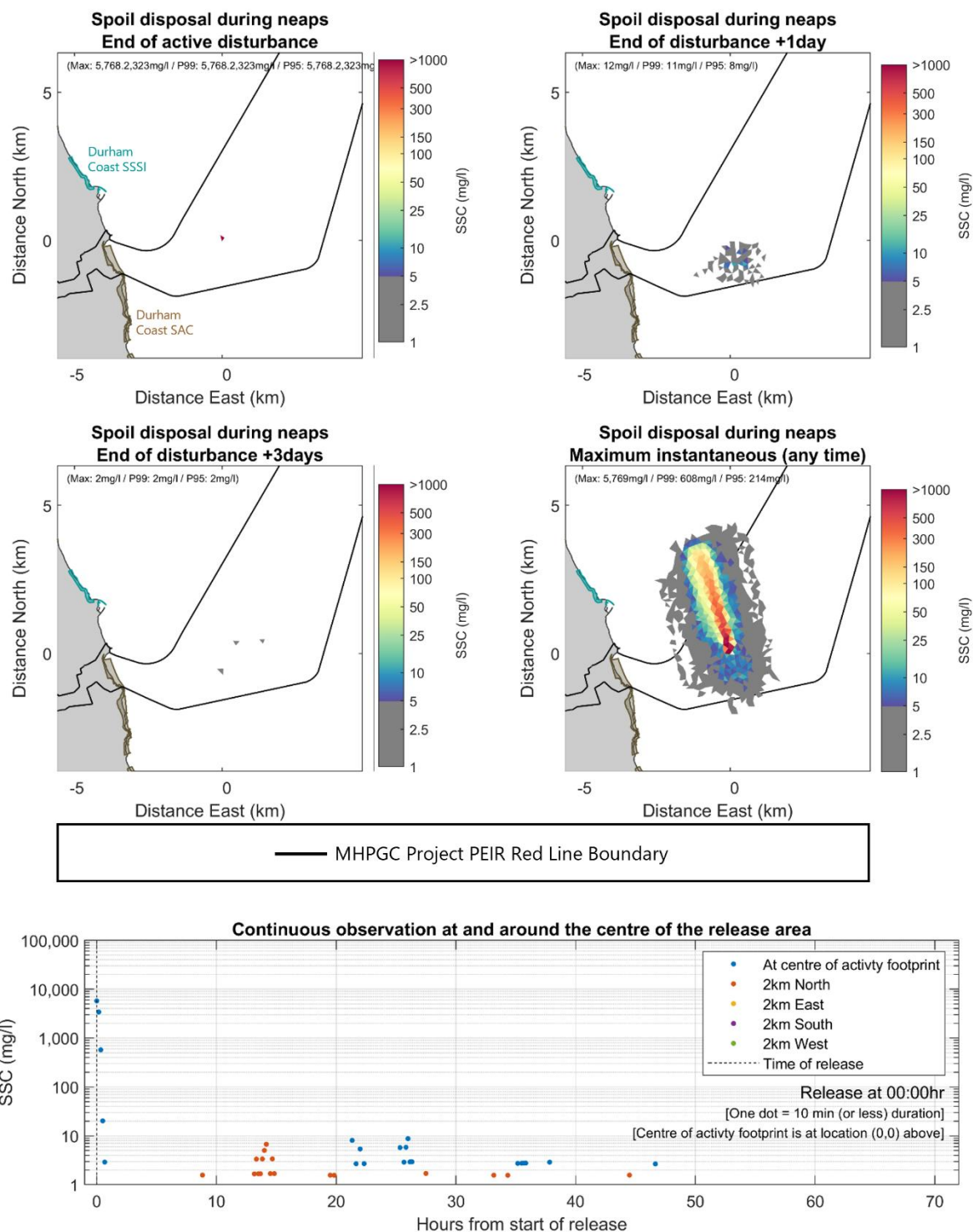


Figure B.18: Increase in SSC as a result of Scenario 16: dredge spoil disposal during a mean neap tide, in nearshore English waters, in the MHPGC Project PEIR Red Line Boundary

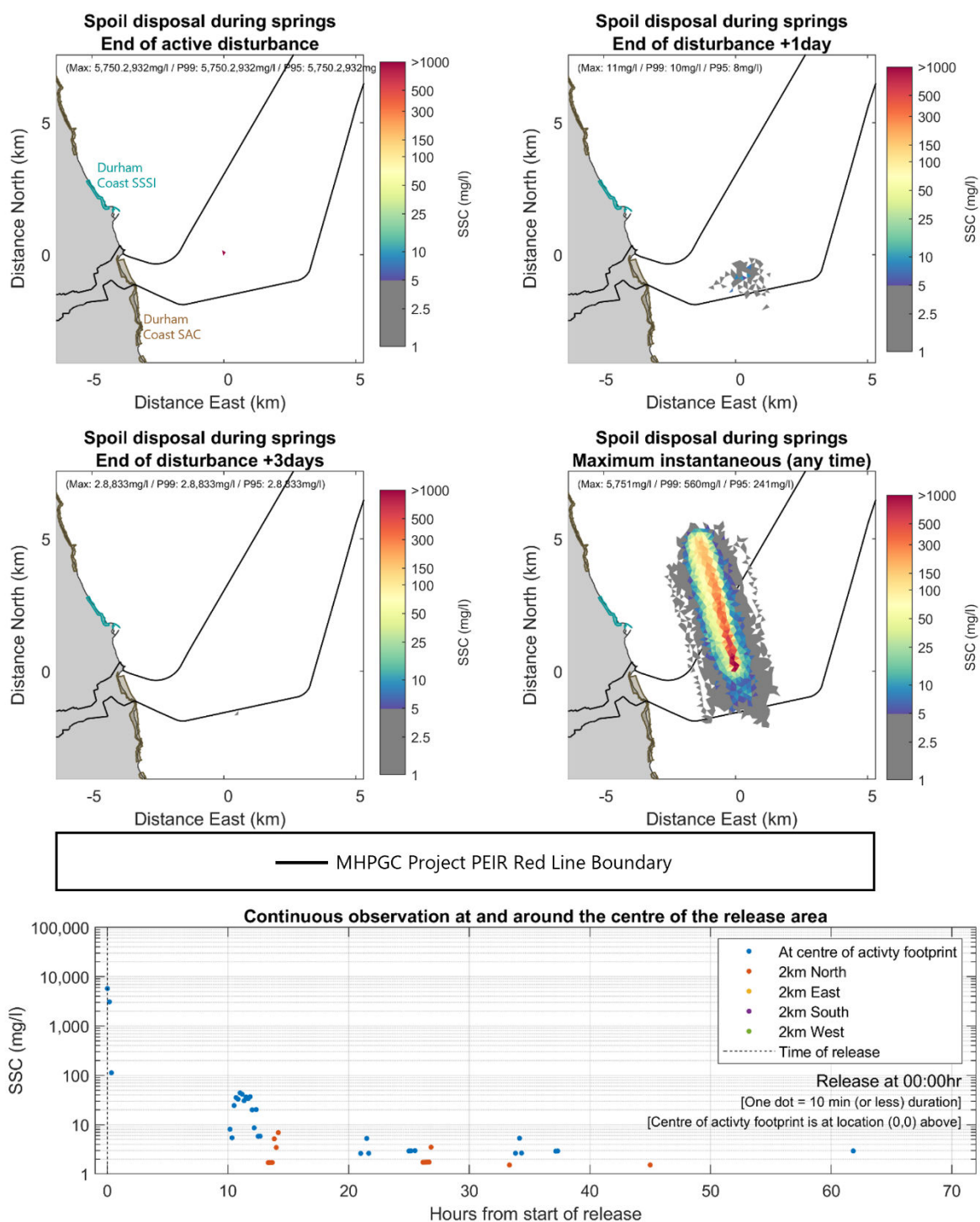


Figure B.19: Increase in SSC as a result of Scenario 17: dredge spoil disposal during a mean spring tide, in nearshore English waters, in the MHPGC Project PEIR Red Line Boundary

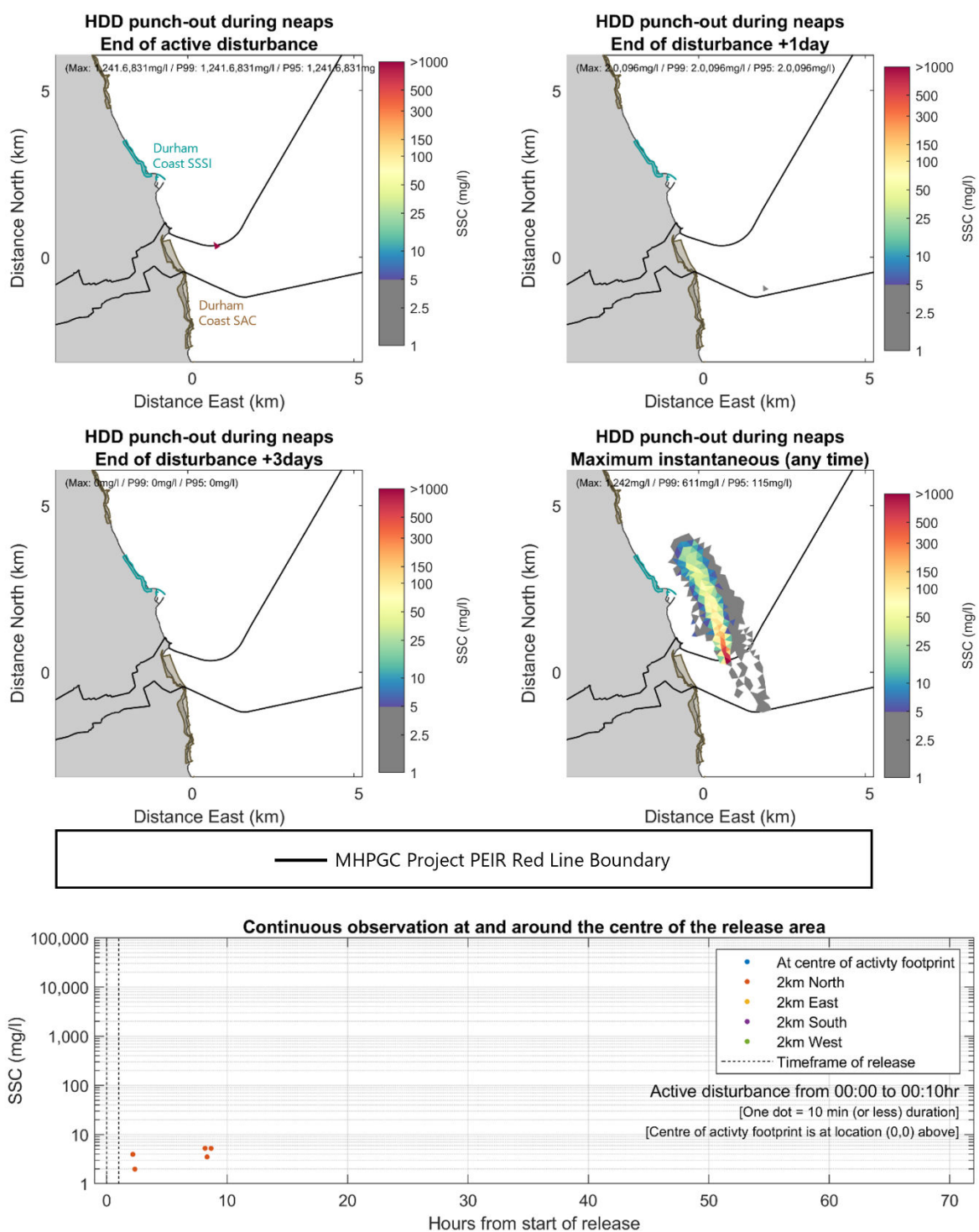


Figure B.20: Increase in SSC as a result of Scenario 18: landfall punch out bentonite release during a mean neap tide, in nearshore English waters, in the MHPGC Project PEIR Red Line Boundary

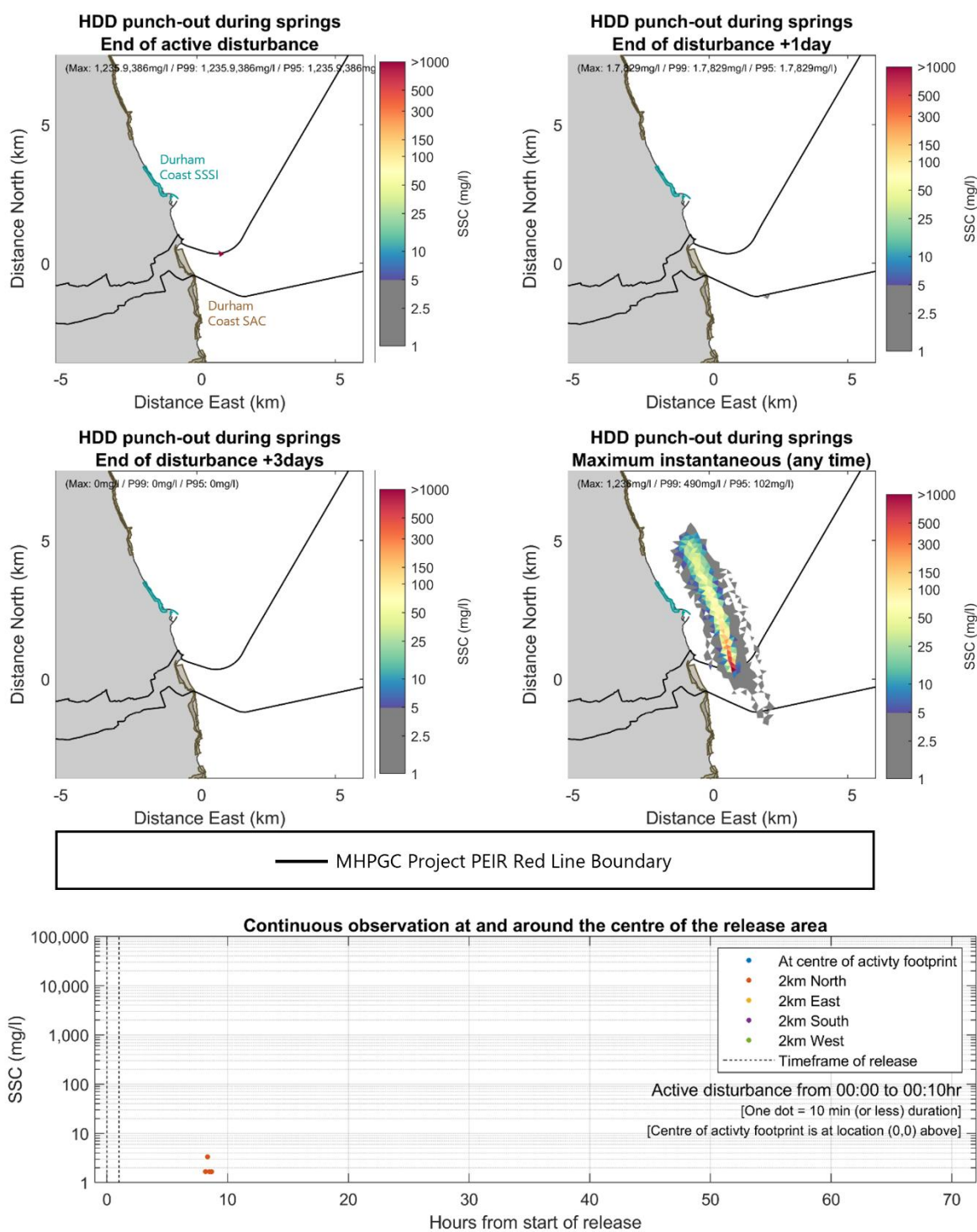


Figure B.21: Increase in SSC as a result of Scenario 19: landfall punch out bentonite release during a mean spring tide, in nearshore English waters, in the MHPGC Project PEIR Red Line Boundary

Appendix C Seabed Deposition Thickness Figures

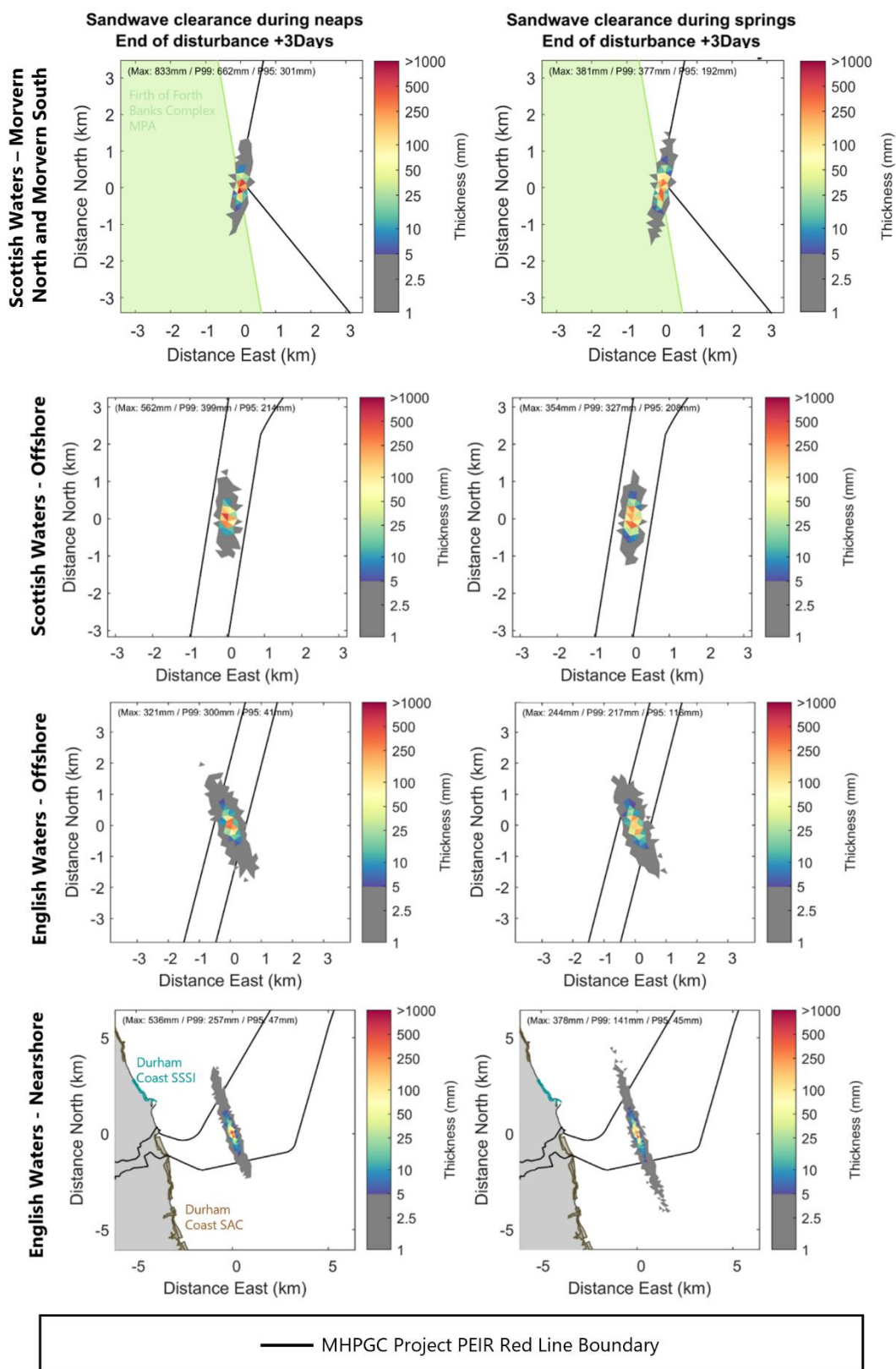


Figure C.1: Sediment settlement thickness as a result of sandwave clearance using a MFE during mean neap (left) and spring (right) tides, in offshore English waters (top), nearshore English waters (middle) and offshore Scottish waters (middle and bottom)

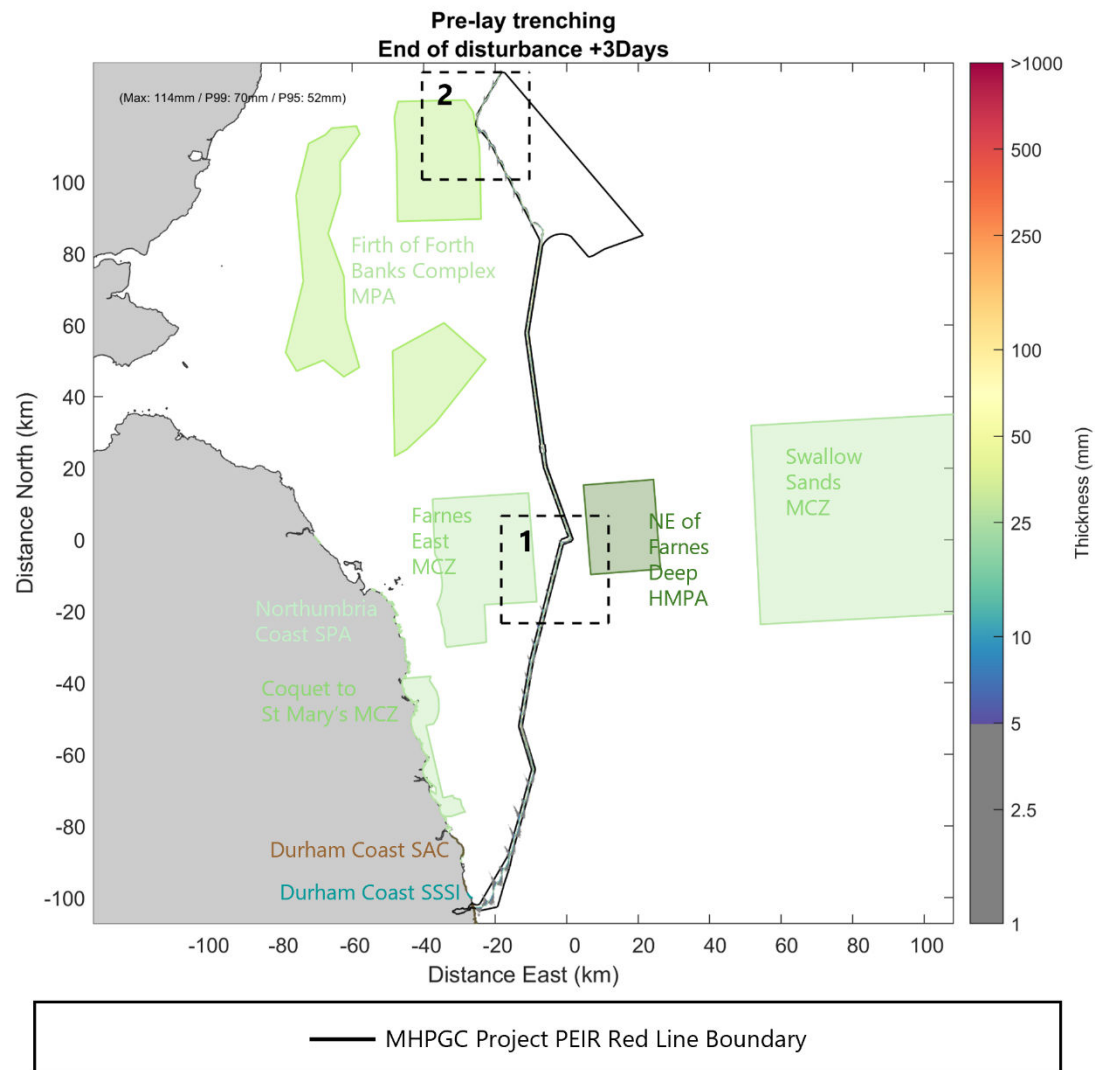


Figure C.2: Sediment settlement thickness as a result of pre-lay trenching along the MHPGC Project PEIR Red Line Boundary

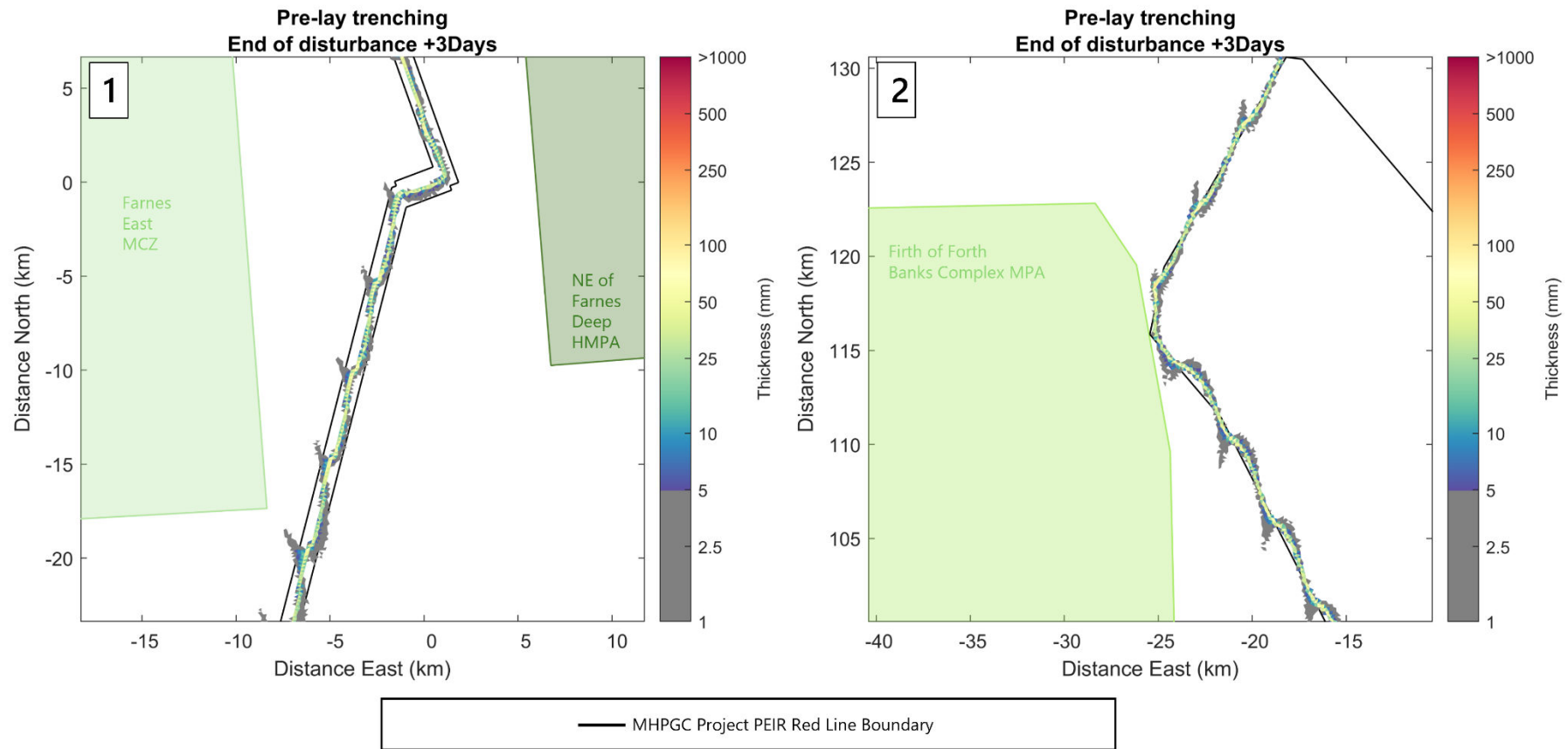


Figure C.3: Sediment settlement thickness as a result of pre-lay trenching using an CFE along the MHPGC Project PEIR Red Line Boundary , zoomed view 1 (left) and zoomed view 2 (right)

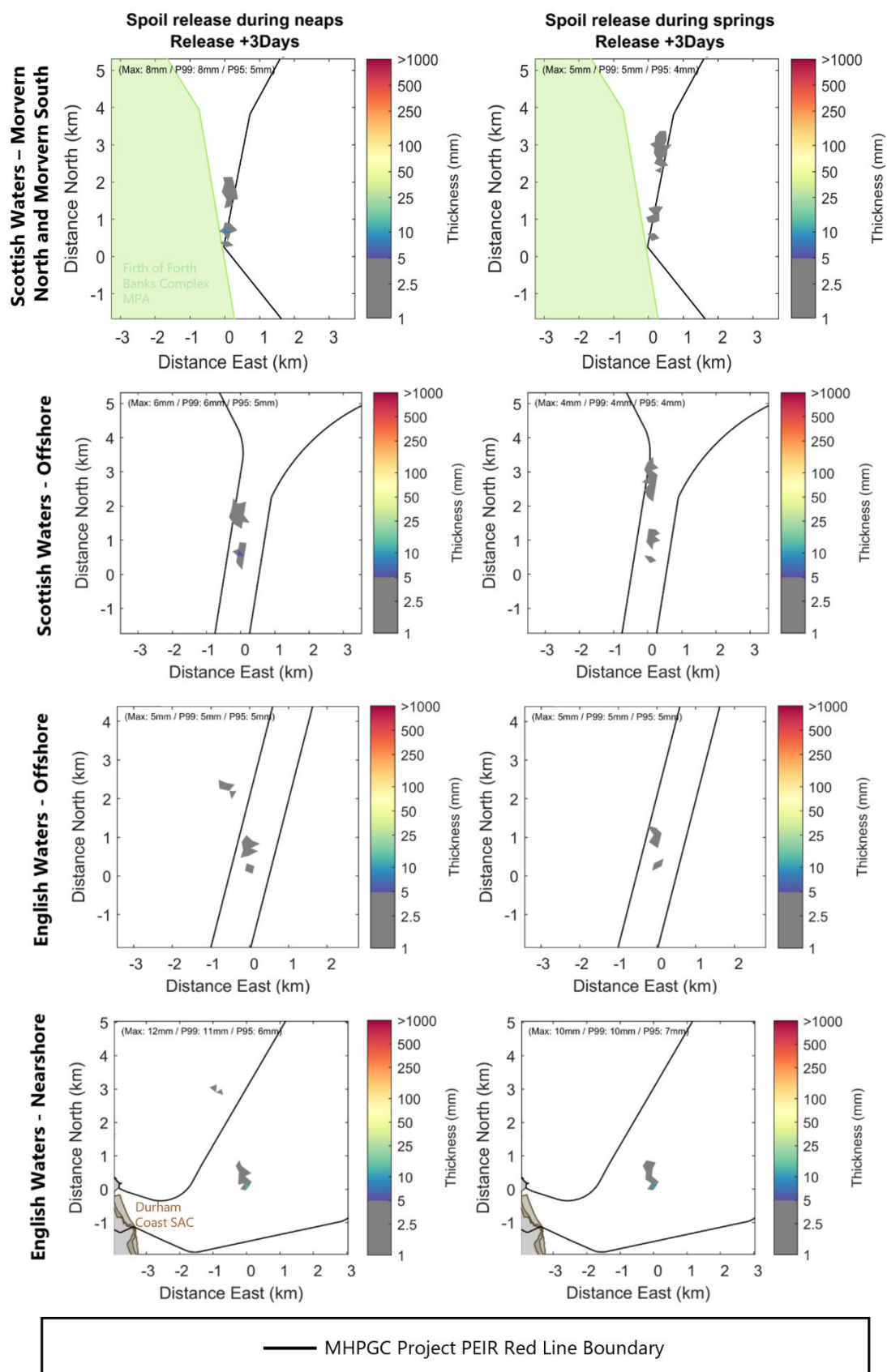


Figure C.4: Sediment settlement thickness as a result of the passive phase plume from dredge spoil disposal during mean neap (left) and spring (right) tides, in offshore English waters (top), nearshore English waters (middle) and offshore Scottish waters (middle and bottom)

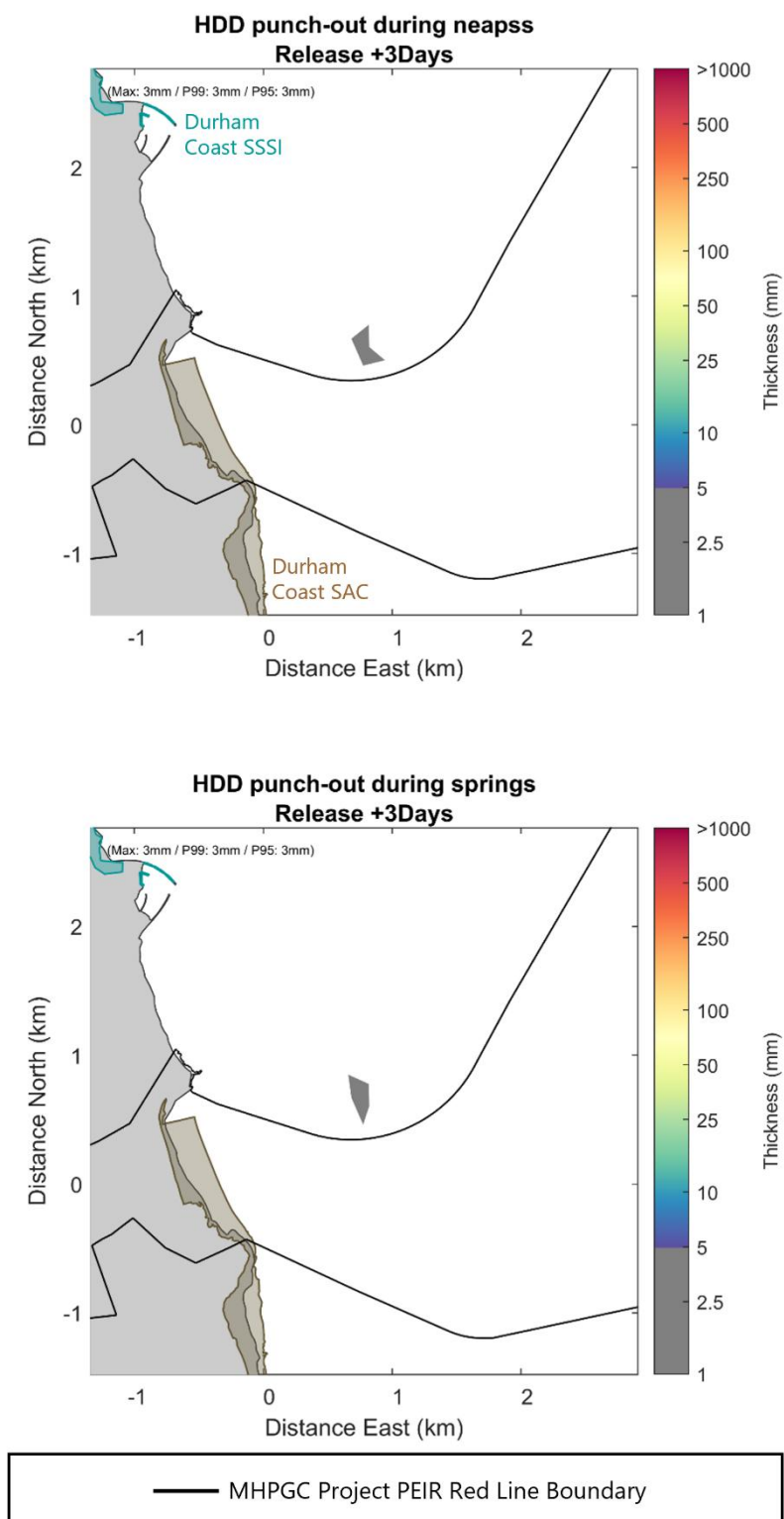


Figure C.5: Sediment settlement thickness as a result of trenchless techniques punch out during a mean neap (top) and spring (bottom) tide, in nearshore English waters, in the MHPGC Project PEIR Red Line Boundary