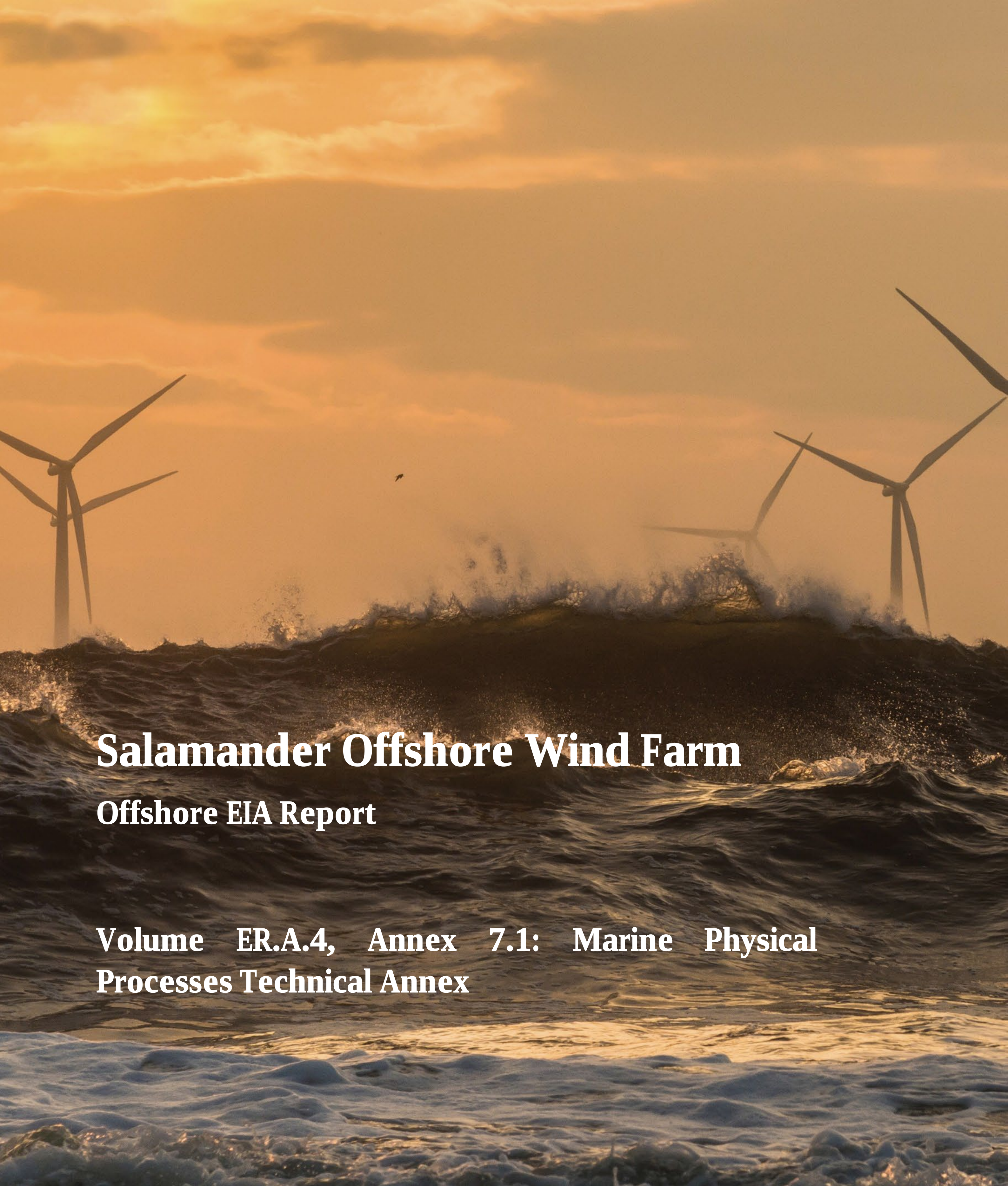

Salamander Offshore Wind Farm

Offshore EIA Report

Volume ER.A.4, Annex 7.1: Marine Physical Processes Technical Annex

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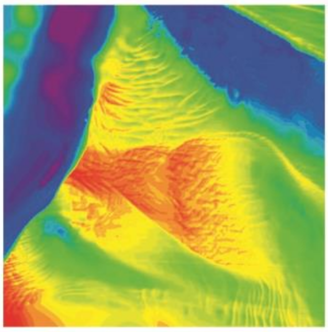
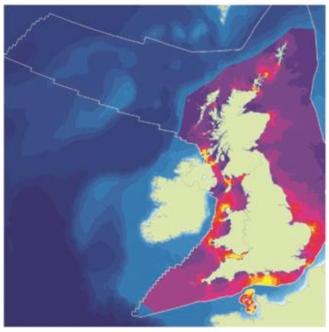
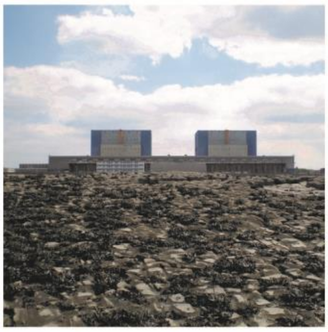
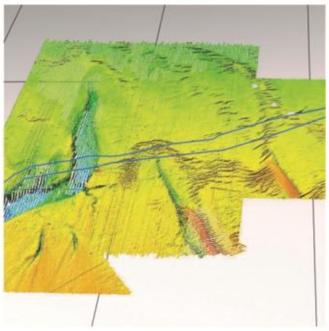
Salamander Offshore Wind Farm Environmental Impact Assessment

Volume ER.A.4, Annex 7.1: Marine Physical Processes Technical Annex

April 2024

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Contributing Authors

David Lambkin, Anthony Brooks.

Notice

ABPmer
Quayside Suite, Medina Chambers, Town Quay, Southampton, Hampshire SO14 2AQ
T: +44 (0) 2380 711844 W: http://www.abpmer.co.uk/

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Acronyms and abbreviations

BERR	Department for Business, Enterprise and Regulatory Reform
BGS	British Geological Survey
BMAPA	British Marine Aggregate Producers Association
CEA	Cumulative Effects Assessment
EIA	Environmental Impact Assessment
HDD	Horizontal Directional Drilling
INTOG	Innovation and Targeted Oil & Gas
MFE	Mass Flow Excavator
OWF	Offshore Wind Farm
SAC	Special Areas of Conservation
SPM	Suspended Particulate Matter
SSC	Suspended Sediment Concentration
TEDA	Thames Estuary Dredging Association
TSHD	Trailing Suction Hopper Dredger
UK	United Kingdom
WCS	Worst Case Scenario

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

1 Introduction

1.1 Overview

ABPmer has been commissioned to undertake the Environmental Impact Assessment (EIA) for the potential impacts of the Salamander Offshore Wind Farm (hereafter referred to as 'the Salamander Project') in relation to marine physical processes, which is a collective term for the following:

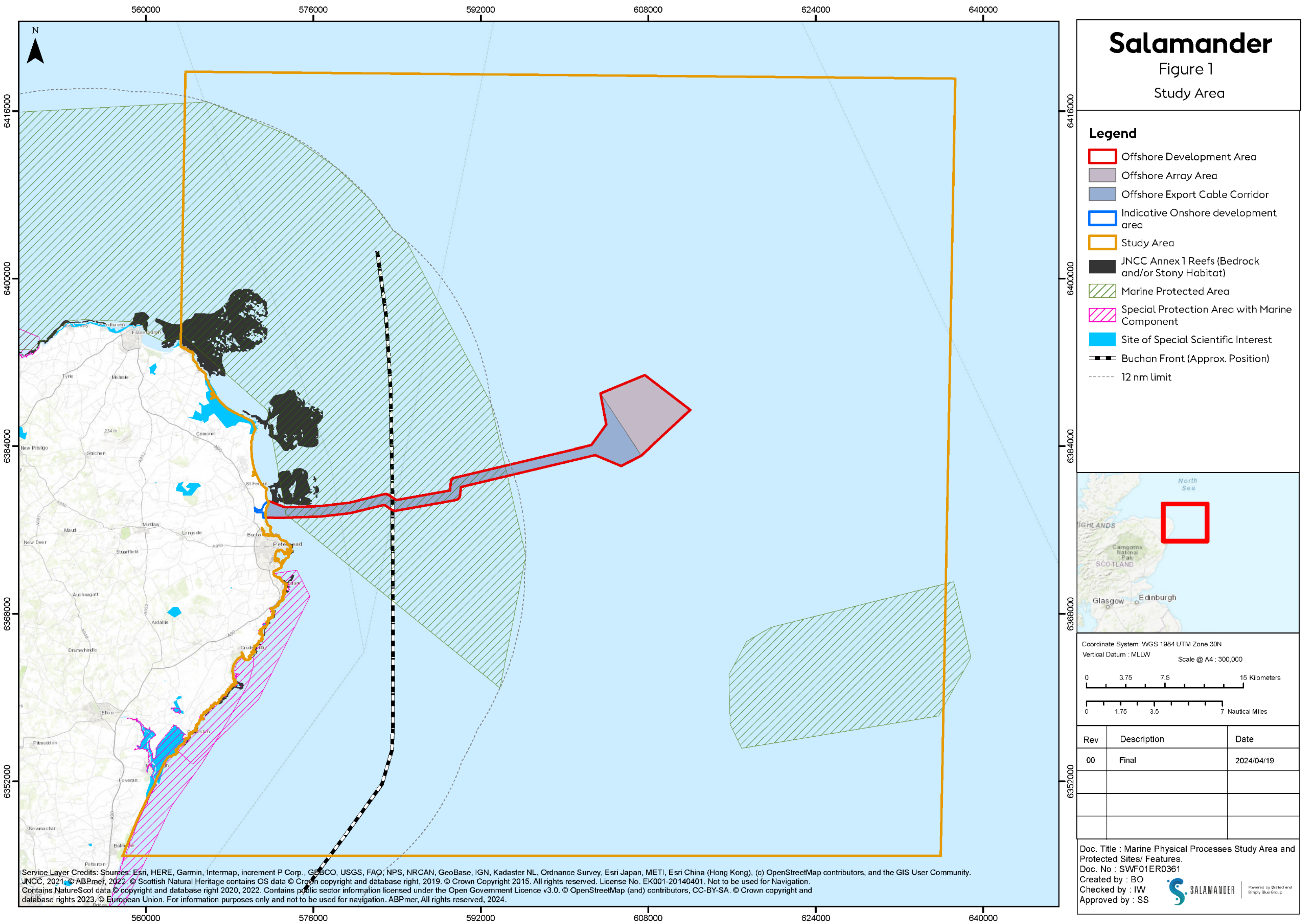
- Water levels;
- Currents;
- Waves (and winds);
- Sediments and geology: (including seabed sediment distribution and sediment transport);
- Seabed geomorphology; and
- Coastal geomorphology.

The Offshore Array Area for the Salamander Project would be located approximately 35 kilometres (km) east of Peterhead (**Error! Reference source not found.**). Electricity generated would be transported to the shore by offshore export cable(s) installed within the Offshore Export Cable Corridor, making landfall approximately 2.5 km to the north of Peterhead. The boundary of the Study Area is also shown in **Error! Reference source not found.**. This covers a wider geographic area than the equivalent boundary shown at Scoping, reflective of a slightly more conservative approach in defining the maximum theoretical extent of change around the Offshore Array Area and the Offshore Export Cable Corridor.

This technical report provides a detailed assessment of the changes to suspended sediment concentrations (SSC), bed levels and sediment type as a consequence of sediment disturbance during the Construction and Decommissioning phases of the Salamander Project. The findings of this report have been summarised in **Volume ER.A.3, Chapter 7: Marine Physical Processes** and are used to inform assessments for other EIA receptor groups which may potentially be sensitive to changes in SSC and deposition.

The effects of scour during operation and maintenance are assessed directly within the main Environmental Impact Assessment Report (EIAR), **Volume ER.A.3, Chapter 7: Marine Physical Processes**. Potential effects on the other marine physical processes elements listed above, i.e. water levels, currents, waves (and winds), seabed geomorphology and coastal morphology are also presented in detail in **Volume ER.A.3, Chapter 7: Marine Physical Processes.**

Figure 1. Study Area and Protected Sites/Features



2 Baseline Conditions

A description of the baseline environment across the marine physical processes Study Area is provided in **Volume ER.A.3, Chapter 7: Marine Physical Processes**, drawing upon the findings of the project-specific survey data and other pre-existing data. Realistic worst-case scenarios used in the assessments presented in this Annex are also set out in **Volume ER.A.3, Chapter 7: Marine Physical Processes**.

A summary of the relevant baseline characteristics within and nearby to the Offshore Development Area - the total area comprising the Offshore Array Area and the Offshore Export Cable Corridor - is provided below, based on the data sources described in **Volume ER.A.3, Chapter 7: Marine Physical Processes**.

- **Tidal current** speeds vary continuously in response to flood/ebb, spring/neap, equinox/solstice and other tidal cycles, as well as with depth and in conjunction with any non-tidal surge influence. Based on the available metocean data, peak depth averaged current speed on a mean spring tide within the Offshore Array Area is **approximately 0.5 to 0.8 m/s**, increasing gradually along the Offshore Export Cable Corridor to between approximately 0.8 and 1.1 m/s at the coast near Peterhead (ABPmer et al. 2008). Peak depth averaged current speed on a mean neap tide is approximately half the spring value.

- **Tidal currents** disperse sediment plumes by advection. The path followed by tidal currents, and the maximum distance that tidal currents might displace water in one flood or ebb cycle from a given location, is a limiting factor in the maximum spatial extent of sediment plume effects. The tidal ellipse's shown in Figure 2 illustrate the approximate elliptical path (length, width and orientation) followed by water in the study area during a mean spring tidal cycle. These tidal ellipses are quite strongly rectilinear throughout the Offshore Export Cable Corridor and Offshore Array Area. During mean spring tidal conditions, the **approximate overall tidal excursion distance is: 8 km in the Offshore Array Area; 12 to 14 km in the middle of the Offshore Export Cable Corridor and up to 17 km** close to the landfall (ABPmer et al. 2008). Tidal excursion distances on a mean neap tide (not shown) are approximately half the corresponding mean spring value. The spring tidal excursion buffer in Figure 2 indicates the maximum extent of water displacement (and therefore any plume effects) arising from any location within the Offshore Array Area or Offshore Export Cable Corridor.

- Monthly averaged satellite imagery of **suspended particulate matter (SPM)** also suggest that average (surface) SPM concentration is generally **very low throughout the Offshore Export Cable Corridor and Offshore Array Area during summer months (1.1 mg/l within the Offshore Array Area, to around 0.7 mg/l** at the landward end of the Offshore Export Cable Corridor) (Cefas, 2016). SPM concentrations increase slightly during winter but are still relatively very low in absolute terms, increasing from around 1.5 mg/l at the Offshore Array Area to approximately 4.5 mg/l in the vicinity of the landfall. In practice, higher values (potentially several tens or hundreds of mg/l) are realistically anticipated in some locations during larger spring tides and storm conditions, with the greatest concentrations encountered closer to the seabed generally, especially where and when wave action penetrates to the seabed.

- **SSC varies with height in the water column**. Sediment is naturally re-suspended by the action of currents and waves at the seabed, so SSC levels are higher, lower in the water column. Sediment grains naturally settle downwards under gravity but are also re-suspended upwards by turbulence, which is greater nearer the seabed. This results in an equilibrium state, and a non-linear profile of SSC (i.e. rapidly decreasing with height above the seabed).

Based on the results of the geophysical survey of the Offshore Export Cable Corridor and Offshore Array Area (Ocean Infinity, 2022a) coupled with existing available data (from the BGS and EMODnet) seabed sediments are characterised as:

- **Eastern half of the Offshore Array Area: sandy sediments** with sandwave features up to approximately 3 m height. Surficial sediment unit up to circa 6 m but absent in places;
- **Western half of the Offshore Array Area and eastern edge of the Offshore Export Cable Corridor: gravelly sand, with sandwave** features up to 3.5 m height.
- **Offshore Export Cable Corridor towards the shore: Gravelly sand and sandy gravels** with localised occurrence of sandwaves. Forth Formation (comprising sands or clays with mixed gravels and sands) found at or near the seabed in nearshore areas.

At the time of writing, project-specific geophysical survey data was not available for nearshore areas. However, existing data from BGS and EMODnet indicates the presence of coarse grained (gravelly sand) sediments as well exposed rock and hard substrate (reef) along the shoreline in close proximity to the landfall. A summary of the sediment types within the Offshore Array Area, Offshore Export Cable Corridor and at the cable landfall is presented in Figure 2.9 of **Volume ER.A.3, Chapter 7: Marine Physical Processes.**

3 Methodology

This section outlines the methodology used to assess potential changes to suspended sediment concentrations, seabed levels and sediment characteristics due to sediment disturbance caused by Construction, Operation and Maintenance (O&M), and Decommissioning related activities.

3.1 Overview

Local increases in SSC may potentially result from the disturbance of sediment by construction, repair and maintenance, related activities, namely due to:

- Drilling for pile anchors;
- Seabed preparation (levelling and/or dredging) prior to installation of suction caisson and gravity anchors;
- Sandwave levelling by dredging and/or Mass Flow Excavation (MFE);
- Cable burial by ploughing, trenching and jetting (including initial installation and any subsequent cable repairs and/or remediation in the Operational phase);
- Release of drilling fluid during trenchless cable installation punch out; and
- Trenching at the landfall.

The following construction/ O&M activities may cause some localised disturbance of sediment but at a rate, scale and duration less than or similar to the activities above and so are not explicitly assessed:

- Installation of anchor/mooring systems;
- Pre-lay grapnel runs (PLGR) (to remove extraneous debris prior to the cable being laid);
- Boulder clearance; and
- Deployment of cable protection.

Likewise, the following decommissioning activities could also potentially give rise to increases in SSC and associated deposition of material within the Offshore Array Area and Offshore Export Cable Corridor but at a rate, scale and duration less than or similar to the activities above and so are not explicitly assessed:

- Removal of Wind Turbine Generator (WTG) mooring/anchoring systems;
- Removal of cable protection; and
- De-burial and removal of inter-array and offshore export cable from the seabed.

The effects of dredging for the creation of temporary floatation pits near to the landfall are similar to those described in this report for seabed preparation and are assessed directly within **Volume ER.A.3, Chapter 7: Marine Physical Processes.**

Any material mobilised by the activities listed above may be transported away from the disturbance location by the local tidal regime. According to the source-pathway-receptor model:

- Disturbance and release of sediment is considered as the source of potential changes to SSC in the water column;
- Tidal currents act as the pathway for transporting the suspended sediment; and
- The receptor is a feature potentially sensitive to any increase in suspended sediments and consequential deposition.

The magnitude, duration, rate of change and frequency of recurrence of changes to SSC and bed level are variable between operation types and in response to natural variability in the controlling environmental parameters. It may also be influenced by in-combination and cumulative activities; the former being associated with multiple simultaneous events occurring within the Salamander Project (e.g. cabling and drilling), the latter being associated with the coincidence of Salamander Project and non-project related activities (e.g. cabling and nearby port dredge disposal operations).

Given that the realistic worst-case scenario is based on the design option (or combination of options) that represents the greatest potential for change, as set out in **Volume ER.A.2, Chapter 4: Project Description**, confidence can be held that development of any alternative options within the project design envelope parameters will give rise to no effects greater, or worse, than those assessed in this impact assessment.

3.2 Approach

This assessment of changes to suspended sediment concentration and associated deposition of sediment as a result of activities related to the Salamander Project is informed by location and project specific numerical (spreadsheet) modelling (described below in Section 3.2.1). Based on previous stakeholder engagement and discussion with other EIA topics using the results of these assessments, the quantitative detail of the modelling results for all individual activities are reported as a descriptive summary and a series of spatial maps.

The theoretical basis for, and the results of, the following assessments are consistent with the results of observational (monitoring) evidence (e.g. BERR, 2008), previous explicit numerical modelling of sediment plumes for analogous activities and environmental settings (e.g. TEDA, 2010; and by ABPmer for East Anglia ONE; Navitus Bay; Hornsea Four; Awel y Môr and Erebus), similar spreadsheet modelling for other wind farms by ABPmer (e.g. for Burbo Bank Extension; Walney Extension; Thanet Extension; Hornsea Three; Five Estuaries), and results from other (various) consultants and wind farm EIAs, which normally also use a similar range of methodologies.

The worst case scenario (WCS) for each activity type is determined using the information contained in the full offshore project description (**Volume ER.A.2, Chapter 4: Project Description**). For each activity, the rate and duration of sediment disturbance and the total sediment volume is calculated for individual occurrences and for all occurrences of the activity, including the range of design permutations (e.g. a smaller number of larger foundations or a larger number of smaller foundations). Scenarios are identified that are likely to correspond to the realistic 'worst case' in terms of instantaneous and overall effects. The effect of all other options in the design envelope are therefore expected to be equal to or less than the results presented in this report.

3.2.1 Spreadsheet based numerical models

In order to inform the assessment of potential changes to SSC and bed levels arising from construction related activities, a number of spreadsheet based numerical models have been developed for use. Similar models were developed and used to inform the EIAs for similar activities at Burbo Bank Extension, Walney Extension, Navitus Bay, Thanet Extension, Hornsea Three and Erebus offshore wind farms (DONG Energy, 2013a,b; Navitus Bay Development Ltd, 2014; Vattenfall, 2018; Ørsted, 2018; and Blue Gem Wind, 2022, respectively).

The spreadsheet based numerical models used here are based upon the following information, assumptions and principles:

- Re-suspended coarser sediments (sands and gravels) will settle relatively rapidly to the seabed and their dispersion can therefore be considered on the basis of a 'snapshot' of the ambient conditions which are unlikely to vary greatly between the times of sediment release and settlement to the seabed. Re-suspended finer sediments may persist in the water column for hours or longer and so their dispersion is considered instead according to the longer-term net tidal current drift rate and direction in the area, which vary both temporally and spatially in speed and direction;

- A representative current speed for the Offshore Array Area is 0.5 m/s[1], which is representative of higher tidal flow conditions occurring on most flood and ebb cycles for a range of spring and neap conditions. Assuming a higher value will increase dispersion, decrease SSC and reduce the thickness of subsequent deposits and *vice versa*. In practice, a range of actual local conditions and outcomes are likely;

- Lateral dispersion of SSC in the plume is controlled by the horizontal eddy dispersion coefficient, Ke, estimated as $Ke = \kappa u^* z$ (Soulsby, 1997), where, z is the height above the seabed (a representative value of half the water depth is used), κ is the von Kármán coefficient ($\kappa = 0.4$) and u^* is the friction velocity ($u^* = \sqrt{(\tau/\rho)}$). Where ρ is the density of seawater ($\rho = 1027$ kg/m³) and τ is the bed shear stress, calculated using the quadratic stress law ($\tau = \rho\ C_d\ U2$, Soulsby, 1997) using a representative current speed for the Offshore Development Area (U = 0.5 m/s) and a drag coefficient value for a rippled sandy seabed ($C_d = 0.006$);

- The interpreted geophysical and grab sample data from the Offshore Array Area and Offshore Export Cable Corridor indicate that in general there are three characteristic surficial sediment types present (Ocean Infinity, 2022a,b), namely:

    - Sand (medium/ fine);
    - Gravelly Sand;
    - Sandy gravel.

- In places these surficial sediment units are thin or absent, with Quaternary units outcropping at the bed (Ocean Infinity, 2022a). These are described in greater detail within **Volume ER.A.3, Chapter 7: Marine Physical Processes**;

- To estimate the time-scale in suspension, sediment is assumed to settle downwards at a calculated (theoretical) settling velocity for each grain size fraction (0.0001 m/s for fines, 0.05 m/s for (medium) sands and 0.5 m/s for gravels and generally coarser sediments, including clastic drill arisings).

The numerical model for SSC resulting from the release of sands and gravels is constructed as follows:

- The time required for sediment to settle at the identified settling velocity through a range of total water depths representative of the site is calculated, to yield the duration for settlement;

[1] Use of a similar representative current speed is consistent with the approach taken to many other similar EIA documents (e.g. Simply Blue Energy (Scotland) Ltd. (2023); RWE (2023). This is necessary because, in any tidally dominated location, current speed will vary continuously in time (slack to peak flow every ebb and flood half-tide, with neap-spring and other cycles of natural variance), and in space (e.g. within the Offshore Array Area and along the Offshore Export Cable Corridor). In practice, there are endless possible permutations of actual sequences of current speeds and directions that might affect a plume from a given activity (start time, location, duration and change of location during the activity).

- The horizontal distance downstream that the plume is advected is found as the product of the representative ambient current speed and the duration for settlement;
- The horizontal footprint area of the plume at different water depths is calculated from the initial dispersion area, increasing at the horizontal dispersion rate over the elapsed time for the plume to reach that depth; and
- The estimate of SSC at different elevations is found by dividing the sediment mass in suspension at a given water depth (the product of the sediment release rate and the duration of the impact, divided by the water depth) by the representative plume volume at that depth (horizontal footprint area at that depth x 1 m).

The numerical model for sediment deposition thickness resulting from the release of sands and gravels is constructed as follows:

- The area over which sediment is deposited depends on the lateral spreading of the sediment plume footprint with depth, but also with tidal variation in current speed and direction, including the possibility of flow reversal. This is an important factor if the release occurs for more than tens of minutes as it affects the distance and direction which the plume is advected from the source;
- The width of the footprint of (instantaneous) deposition onto the seabed is estimated as the square root of the near-bed plume footprint area (calculated using the model for SSC above). When drilling anchor piles, the point of sediment release is likely to be static and so the width of deposition is characterised based on the footprint of release and a small amount of lateral dispersion between surface and seabed prior to deposition;
- The length of the footprint of deposition onto the seabed over multiple tidal cycles is estimated as twice the advected distance of the plume at the representative current speed, representing the maximum length over consecutive flood and ebb tides. If the operation lasts less than 12.4 hours (one full tidal cycle), the length is reduced proportionally;
- The average seabed deposition thickness is calculated as the total volume of sediment released, divided by the footprint area (width times length) of deposition; and
- This model provides a conservative estimate of deposition thickness as it assumes that the whole sediment volume is deposited locally in a relatively narrow corridor. In practice, the deposition footprint on the seabed will probably be normally wider and frequently longer than is assumed, and the proportion of all sediment deposited locally will vary with the distribution in grain size (leading to a greater area but a correspondingly smaller average thickness).

The numerical model for SSC resulting from dispersion of fine sediment is constructed on the basis of the initial dispersion into the receiving waters, and then further dispersion of the plume as a whole, as per the following example for overspill for a trailing suction hopper dredger (TSHD):

- The vessel is likely to be stationary during precision dredging operations so the water movement relative to the vessel is dominantly tidal (at the representative current speed 0.5 m/s);
- Sediment is discharged at a representative rate (e.g. 30 kg/s for dredging over-spill) into a minimum volume of water 100 m^3 = 10 m x 10 m x 1 m deep;

- This volume of water will be refreshed every 20 seconds (10 m / 0.5 m/s);
- The total sediment input is 20 s x 30 kg/s = 600 kg;
- The resulting initial concentration in the receiving water is 600 kg / 100 m^3 = 6 kg/m^3 = 6,000 mg/l;
- The initial concentration plume would then be subject to turbulent dispersion both laterally and vertically. Given the starting mass of sediment and water volume above, levels of SSC will vary rapidly in proportion to the dilution of the same sediment mass as the plume dimensions and volume increase; and
- Assuming a faster current speed, faster vessel motion or larger footprint of release would reduce the mass of sediment introduced to the fixed volume of the receiving waters (and so SSC) at the point of initial dispersion, and *vice versa*.

4 Description of activities causing sediment disturbance

4.1 Drilling of pile anchors

Overview

If used, pile anchors will be installed into the seabed using standard piling techniques. In some locations, the particular geology may present some obstacle to piling, in which case, some or all of the seabed material might be drilled from within the pile volume to assist in the piling process. Other (drilled or micro-pile) pile types may be installed using drilling alone.

The impact of drilling operations mainly relates to the release of drilling spoil, in the worst case at or above the water surface, which will put sediment into suspension and the subsequent re-deposition of that material to the seabed. The nature of this disturbance will be determined by the rate and total volume of material to be drilled, the seabed and subsoil material type, and the drilling method (affecting the texture and grain size distribution of the drill spoil). These changes are quantitatively characterised in this section using the spreadsheet based numerical models described in Section 3.

Evidence base

The evidence-base does not presently include many measurements of SSC resulting from drilling operations for monopile or pin pile installation (including pin pile anchors). This is due to the relatively small number of occasions that such works have been necessary.

Limited evidence, at the Lynn and Inner Dowsing offshore wind farms (CREL, 2008) from the field is provided by the during- and post-construction monitoring of monopile installation using drill-drive methods into chalk. It is recognised that the underlying geology, foundation/anchor dimensions and drilling apparatus differs from the Offshore Array Area of the Salamander Project; it is also not known how the drilled sub-soils would disaggregate.

The installation of steel monopiles at the Lynn and Inner Dowsing offshore wind farms (4.7 m diameter and up to 20 m penetration depth) were assisted in some cases by a drill-drive methodology. The drill arisings were mainly in the form of rock (chalk) chippings that were released onto the seabed a short distance away in a controlled manner using a pumped riser. The particular concern in that case was the possibility of sub-surface chalk arisings leading to high levels of SSC of an atypical sediment type. The result of sediment trap monitoring (located as close as 100 m from the operation) was that the chalk was not observed to collect in significant quantities. However, direct measurements of SSC were not possible at the time of the operation.

The dimensions of the (mainly chalk) drill arisings deposit created was measured by geophysical survey and characterised as a conical mound, approximately 3 m thick at the peak, extending laterally (from the peak to ambient bed level) up to 10 m in what is assumed the downstream direction and 5 m in the other. The volume of the deposit (measured as approximately 290 m^3) was similar to the total volume of the drilled hole (347 m^3) indicating that the majority of the total drill arisings volume had been deposited locally. The difference in volumes might be partially explained by different patterns of settling or transport leading to some material settling away from the main deposit location. It is also possible that the combination of drill and drive did not necessarily release a volume of material equivalent to 100% of the internal volume of the pile, or that the full burial depth may not have been achieved in this example. Seabed photographs indicate that the material in the deposit is clearly horizontally graded, with the largest clasts closer to the centroid of the deposit. It is recognized that the geological setting at Lynn and Inner Dowsing is very different to that of the Salamander Project, with drilling likely to be disturbing Quaternary deposits (rather than chalk). At this stage it is unknown how this material may respond to drilling: it could potential disaggregate and disperse widely or form lager clasts which immediately settle to the bed. The assessment considers this range of possibilities – see Section 5.2.

4.2 Seabed preparation by dredging prior to anchor and cable installation

Overview

To provide a stable footing for suction caisson and gravity base anchors, standard dredging techniques may be used to remove or lower the level of the mobile seabed sediment veneer within a footprint slightly larger than the anchor base. Dredging may also be used to prepare the seabed level for cable burial to locally reduce the crest level of sandwaves where they are present in the planned location of anchors and in a narrow corridor where they are present in the Offshore Array Area and Offshore Export Cable Corridor.

Dredging has the potential to cause elevated SSC by sediment over-spill at the water surface during dredging and by the subsequent release of the dredged material from the dredger during spoil disposal at a nearby location. The subsequent settlement of the sediment disturbed by dredging will lead to sediment accumulation of varying thickness and extent on the seabed. These changes are quantitatively characterised in this report using spreadsheet based numerical models.

Mass Flow Excavator (MFE) tools might also be used as part of the sandwave levelling process, but are potentially less efficient at displacing large sediment volumes over distances more than a few tens of metres. A MFE will also displace sediment through a combination of resuspension and fluidisation of the seabed, causing sediment to be simply dispersed away from the local area or to flow away downslope under gravity. Levels of SSC caused by an MFE when used for cable burial and trenching are described in Section 4.3. The total volume of sediment displaced, and therefore the maximum area and thickness of sediment deposit outside of the levelled area is the same as described for dredging.

Evidence base

Dredging for construction aggregates is a common marine activity in UK waters (although none is presently undertaken in Scotland). The evidence-base with regards to dredging and elevated levels of SSC associated with extraction of sands and gravels (similar in character to those within the Offshore Array Area and Offshore Export Cable Corridor) is broad and well established through a variety of monitoring and numerical modelling studies. The following text from the UK Marine Special Areas of Conservation (SAC) Project is representative of the wider evidence base.

"Dredging activities often generate no more increased suspended sediments than commercial shipping operations, bottom fishing or generated during severe storms (Parr et al., 1998). Furthermore, natural events such as storms, floods and large tides can increase suspended sediments over much larger areas, for longer periods than dredging operations (Environment Canada, 1994). It is therefore often very difficult to distinguish the environmental effects of dredging from those resulting from natural processes or normal navigation activities (Pennekamp et al., 1996).

...In general, the effects of suspended sediments and turbidity are generally short term (<1 week after activity) and near-field (<1 km from activity). There generally only needs to be concern if sensitive species are located in the vicinity of the maintained channel."

Whilst seabed preparation and sandwave levelling represent a potentially large volume of sediment, **Volume ER.A.2, Chapter 4: Project Description** states that dredged material will be returned to the seabed adjacent to the dredged area and therefore retained within the local sedimentary system. This is unlike the case of marine aggregate dredging where the material is deliberately removed.

4.3 Cable burial (ploughing, trenching and jetting)

Overview

The impact of cable burial operations mainly relates to a localised and temporary re-suspension and subsequent settling of sediments (BERR, 2008). The exact nature of this disturbance will be determined by the soil conditions within the footprint of the Offshore Development, the length of installed cable, the burial depth and burial method. These changes are quantitatively characterised in this section for export and inter-array cables.

There are localised areas of sandwaves present, as evidenced in the baseline section of **Volume ER.A.3, Chapter 7: Marine Physical Processes**. Sandwave levelling is potentially required in both the Offshore Array Area and Offshore Export Cable Corridor. The specific requirements (location and dimensions of levelling corridors, volume of sediment affected for each bedform and total) will be confirmed in due course through the completion of a full Cable Burial Risk Assessment (CBRA).

Evidence base

The evidence base with respect to cable burial activities is broad and includes a range of theoretical, numerical modelling and monitoring studies considering a range of installation methodologies, sediment types, water depths and other environmental conditions. The evidence base is widely applicable as the dimensions of the cables, the installation techniques used and the target depths of burial do not vary significantly with the scale of the development (small or large wind farm arrays) or the type of cable being installed (wind farm export or inter-array cables, or non-wind farm electrical and communications cables).

SSC monitoring during cable laying operations has been undertaken at Nysted Wind Farm (ABPmer et al., 2007; BERR, 2008). During the works, both jetting and trenching were used, where the latter method involves pre-trenching and back-filling using back-hoe dredgers. Superficial sediments within the site were predominantly medium sands, approximately 0.5 m to 3 m in thickness, underlain by clay. (These characteristics are similar to many areas of the Offshore Array Area and Offshore Export Cable Corridor). SSC was recorded at a distance of 200 m from jetting and trenching activities and the following values were observed:

- trenching – mean (14 mg/l) and max (75 mg/l); and
- jetting – mean (2 mg/l) and max (18 mg/l).

The higher sediment concentrations from the trenching activities were considered to be a result of the larger volume of seabed strata disturbed during operations and the fact that the material disturbed during trenching was lifted to the surface for inspection. This meant that the sediment was transported through the full water column before being placed alongside the trench (BERR, 2008).

Cable laying monitoring also took place at Kentish Flats where ploughing methods were used to install three export cables (EMU Limited, 2005). Cefas agreed pre-defined threshold limits against which SSC monitoring would be compared. The monitoring 500 m down-tide (where the concentrations would be greatest) of the cable laying activities showed:

- marginal, short-term increases in background levels (approximately nine times increase to the background concentrations); and
- peak concentrations occasionally reaching 140 mg/l (equivalent to peaks in the naturally occurring background concentrations).

The observations at Nysted and Kentish Flats provide confidence that cable laying activities do not create a long-term, significant disruption to the background sediment concentrations. Furthermore, it also illustrates that there is little sediment dispersal, indicating that there is unlikely to be much deposition on the seabed other than immediately adjacent to the cable route.

Reach (2007) describes plume dispersion studies for a cable laying jetting operation in Hong Kong with an assumption that 20% of a trench cross-section of 1.75 m² would be disturbed by the jetting process and the speed of the jetting machine would be 300 m/hour (0.083m/s). ASA (2005) describes similar studies for a cable laying operation near Cape Cod in the USA and assumed that 30% of a trench cross-section of 3 m² would be disturbed by the jetting process and the speed of the jetting machine would be 91 m/hour (0.025m/s). This latter study also assumed that any sand particles would quickly return to the bed and only the fine sediment particles (particles with a diameter less than 63 μm) would form a plume in the water column.

SeaScape Energy (2008) describes cable installation plume dispersion monitoring studies carried out at the Burbo offshore wind farm in Liverpool Bay, UK.

- Three export cables were installed to a target depth of approximately 3 m by vertical injector ploughing while array cables were installed to a similar depth by jetting assisted ploughing.
- The monitoring demonstrated clearly that both cable installation techniques had only small scale impacts on localised SSC. Changes were measurable to a few hundreds of metres only. Suspended sediment levels never approached the threshold level (3,000 mg/l) agreed with regulatory authorities beforehand, even in very close proximity to the works (less than 50 m).
- Local changes in SSC over a relatively fine sediment seabed area (most likely to lead to plume impacts) was in the region of 250 to 300 mg/l within 200 m of the operation, falling to the measured baseline level (100 mg/l) by 700 m downstream. It is assumed, therefore, that coarser sediments were associated with even lower levels.

The post-burial impacts of cable burial on sandy seabed morphology were also considered by BERR (2008) with reference to a wide range of desktop and monitoring studies. The report concludes that impacts will also be limited in terms of both the thickness of re-deposited sediments and the potential for affecting the surficial sediment type:

"The low levels of sediment that are mobilised during cable laying mean that there will be only low levels of deposition around the cable route. The finer material will generally remain in suspension for longer but will settle and remobilise on each tide with no measurable material left in place. Coarser sediments are expected to settle within a few metres of the cable route and following disturbance is likely to recover rapidly, given similar communities in the vicinity." (BERR, 2008).

4.4 Drilling fluid release during trenchless landfall operations

Trenchless cable installation techniques (such as Horizontal Directional Drilling (HDD)) may be used to transition the offshore export cable(s) to the onshore export cables at landfall. Up to two conduits may be required. The drill punch-out locations will be below the lowest astronomical tidal water level. The drill length may be up to approximately 2,500 m per conduit, with a bore diameter of up to approximately 1.3 m.

The release of drilling fluid (a suspension of natural bentonite clay in water) into the coastal waters at the punch-out location may cause a sediment plume in the nearshore area.

Drilling fluid is a composite made of bentonite and 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 HDPE strings during pull back;
- cooling the reamers (cutting tools);
- hole stabilisation; and
- creation of a filter cake against the wall of the hole to minimize the risk of loss of drilling fluid or influx of groundwater penetration into the borehole.

The drilling fluid typically consists of a low concentration bentonite – water mixture. Depending on the formation to be drilled through, the concentration is typically between 13 litres (30 kg) and 35 litres (80 kg) of dry bentonite clay per m^3 of water (30,000 to 80,000 mg/l).

The use of bentonite has limited potential to cause environmental impacts:

- it is a natural material, so has no chemical constituents;
- it is recyclable;
- it is on the OSPAR List of Substances Used and Discharged Offshore which Are Considered to Pose Little or No Risk to the Environment (PLONOR); and
- owing to the large diameter bore and long length, the total volume of fluid used may be relatively large, but, owing to the low concentration, the total amount of bentonite used is limited.

Further assessment of the potential impacts arising from the release of drilling fluid during trenchless cable installation is provided in **Volume ER.A.3, Chapter 9: Benthic and Intertidal Ecology**.

4.5 Activities Potentially Causing Cumulative Changes to Suspended Sediment Concentrations, Bed levels and Sediment Type

Overview

A Cumulative Effects Assessment (CEA) has been undertaken to consider the impact associated with the Salamander Project together with other projects and plans. Each project has been considered on a case-by-case basis for scoping in or out of the coastal processes chapter, based upon development stage, data confidence, effect-receptor pathways and the spatial/temporal scales involved.

In terms of the potential for cumulative changes to SSC, bed levels and sediment type, the screening approach described above was informed using modelled spring tidal excursion ellipses. This is because meaningful sediment plume interaction generally only has the potential to occur if the activities generating the sediment plumes are located within one spring tidal excursion ellipse from one another and occur at the same time. An additional precautionary 5 km was added to the spring tidal excursion ellipse buffer to allow for the potential influence of any extreme events.

Given the length and orientation of tidal excursion ellipses in the vicinity of the Salamander Project, it is the case that the potential for sediment plume interaction will be limited to instances in which Salamander Project construction activities occur simultaneously with those occurring at other developments set out in Table 1.

Table 1. List of projects for consideration in the marine physical processes cumulative effects assessment

Development	Type	Project Phase	Reasons for inclusion
Eastern Green Link 2 (EGL2)	Interconnector	Consented	There is potential for temporal overlap of construction timelines and the EGL2 project is 26.78 km and 2.86 km from the Offshore Array and Offshore ECC.
Green Volt Floating Offshore Wind Farm	Floating Offshore Wind Farm	Consent Application Submitted	The Green Volt project is included as it is scheduled to be operational by 2027. The Green Volt export cable is 0.3 km from the Offshore Array and overlaps the Offshore ECC respectively.
Cenos Floating Offshore Wind Farm Export Cable	Floating Offshore Wind Farm	Scoping Submitted	The Cenos Floating Offshore Wind Farm project is included as it is scheduled to be operational by 2028 and its ECC overlaps with the Offshore Array and Offshore ECC.
Central North Sea Electrification (CNSE) Project	Platform Electrification	Scoping Submitted	The CNSE project is included as it is scheduled to be operational by 2028. The CNSE project's export cable route is 18.1 km and 4.6 km from the Offshore Array and Offshore ECC respectively.
MarramWind Export Cable	Floating Offshore Wind Farm	Scoping Submitted	The MarramWind project is included as its ECC search area is within 1.5 km from the Offshore Array and overlaps with the Offshore ECC.
Muir Mhòr Offshore Wind Farm Export Cable	Floating Offshore Wind Farm	Scoping Submitted	The Muir Mhòr project is included as the construction period could overlap with Salamander. The Muir Mhòr project's ECC is 5.53 km from the Offshore Array and overlaps the Offshore ECC.
Hywind Scotland Pilot Park	Floating Offshore Wind Farm	Operational	The Hywind project's array is located 11.7 km and 8.1 km from the Offshore Array and Offshore ECC respectively. The Hywind project's ECC is located 14.3 km

Development	Type	Project Phase	Reasons for inclusion
			and 0.1 km from the Offshore Array and Offshore ECC respectively.
Buchan Floating Offshore Wind Farm	Floating Offshore Wind Farm	Scoping Submitted	The Buchan project's ECC search area is 1.44 km from the Offshore Array and overlaps with the Offshore ECC.
NorthConnect	Interconnector	Consented	The NorthConnect Project overlaps with the Offshore Array and Offshore ECC respectively.
Peterhead (CR070)	Dredge Spoil Disposal	Operational	Disposal ground located within 3.1 km of the Offshore Array.
North Buchan Ness (CR080)	Dredge Spoil Disposal	Operational	Disposal ground located within 1.7 km of the Offshore Array.

5 Assessment of changes to suspended sediment concentrations, bed levels and sediment type

5.1 Overview

This section provides a description of the realistically possible combinations of magnitude and extent of impact for local increases in SSC and seabed deposition, due to sediment disturbance potentially caused by:

- Drilling of pile anchors;
- Seabed preparation (inc. sandwave levelling) by dredging prior to anchor and cable installation;
- Cable burial (ploughing, trenching and jetting) (including initial installation and any subsequent cable repairs and/or remediation in the Operational phase); and
- Drilling fluid release during trenchless cable installation at the landfall.

As set out in Section 3.2, the results are determined using spreadsheet-based tools, supported by analytical assessments of project-specific data and evidence from analogous projects and activities (including aggregate dredging).

Sediment disturbed and released into the water column during the Construction, Operation (cable repair/remediation events) and Decommissioning phases will settle downwards at a rate depending upon its grain size. During settling, the sediment plume will be advected away from the point of release by any currents that are present and will be dispersed laterally by turbulent diffusion. The horizontal advection distance will be related to the flow speed and the physical properties of the sediment. The maximum near-bed level of SSC is expected to be found where the main body of the settling plume of sediment reaches the seabed.

Coarse grained sediments (i.e. sand/ gravel) will behave differently to fine grained sediments (i.e. silt/ clay) when released into the water column. The disturbance of coarse grained or consolidated material is likely to give rise to high SSCs in the vicinity of the release location, but is also likely to settle out of suspension quickly (e.g. in the order of seconds to minutes) so any sediment plumes are likely to be localised. In contrast, fine grained material will tend to remain in suspension for a longer period of time (in the order of hours to days), potentially resulting in an increase in SSC over a larger area, at a progressively reduced concentration, due to advection and dispersion from the original release location.

Similar differences are expected when considering any resulting changes in bed level due to resettlement of the material in suspension. Coarser material will tend to give rise to thicker but more localised changes in bed levels whereas fine grained material may give rise to smaller changes in bed levels over a wider area. The exact pattern of re-deposition of sediment to the seabed will depend on the actual combination of operational methods (including cumulative operations) and environmental conditions at the time of the event which will be variable. The total volume of sediment disturbed is, however, known with greater certainty and a range of potential combinations of deposit shape, thickness and area (corresponding to the same total volume) can be more reliably provided, as a subset of all possible combinations.

5.2 Results

5.2.1 Project alone (including in-combination changes)

The actual magnitude and extent of impacts will depend in practice on a range of factors, such as the actual total volumes and rates of sediment disturbance, the local water depth and current speed at the time of the activity, the local sediment type and grain size distribution, the local seabed topography and slopes, etc. There will be a wide range of possible combinations of these factors and so it is not possible to predict specific dimensions with complete certainty. To provide a robust assessment, a range of realistic combinations have been considered, based on conservatively representative location (environmental) and project (WCS) specific information, including a range of water depths, heights of sediment ejection/initial resuspension, and sediment types.

This wider range of results can be summarised broadly in terms of four main zones of effect, based on the distance from the activity causing sediment disturbance. These zones are consistent with the results of observational (monitoring) evidence and recent numerical modelling of analogous activities (e.g. BERR, 2008; TEDA, 2010; Navitus Bay Development Ltd, 2014; Awel y Môr Offshore Wind Farm Ltd, 2022) as well as aggregate dredging studies (e.g. TEDA (2012), HR Wallingford (2011); SCDA (2010)):

- 0 to 50 m - Near-field zone:
    - 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 – no change to SSC; no measurable ongoing deposition;

- 50 to 500 m - Intermediary zone:
    - 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 low 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 – no change to SSC; no measurable ongoing deposition;

- 500 m to the tidal excursion buffer distance – Far-field zone:
  - zone of lesser but measurable SSC increase and no measurable thickness of deposition. Spatially variable but approximately 8 km in the Offshore Array Area; 12 to 14 km in the middle of the Offshore Export Cable Corridor and up to 17 km close to the landfall;
  - 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 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 impact or change to SSC nor a measurable sediment deposition.

Figure 2 provides a summary of the maximum spatial extent of these zones in relation to the whole of the Offshore Array Area and Offshore Export Cable Corridor. Figure 3 provides an example schematic illustration of the footprint of effect for a single occurrence of an activity causing local sediment disturbance. In practice the WCS impact will be a limited number of discrete areas of effect (similar to that shown in the example), separated by areas of lesser impact.

If multiple activities causing sediment disturbance (such as dredging, drilling or cable installation) are undertaken simultaneously at two or more locations that are aligned in relation to the ambient tidal streams, then there is potential for overlap between the areas of change in SSC and sediment deposition. The change in SSC in areas of overlap will be additive if the downstream activity occurs within the area of effect from upstream (i.e. sediment is disturbed within the sediment plume from the upstream location). The change in SSC will not be additive (i.e. the effects will be as described for single occurrences only) if the areas of effect only meet or overlap downstream following advection or dispersion of the effects. Effects on sediment deposition will be additive if and where the footprints of the deposits overlap.

Further details of any plumes associated with the release of drilling mud at the landfall are provided below:

- The maximum volume of drilling mud (and other drill cuttings) contained in one conduit is estimated to be up to 3,318 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.

- The realistic worst case considered is a release of drilling mud with a conservative maximum concentration of 80,000 mg/l, up to the total volume of the conduit (3,318 m^3), in a relatively short period of time (minutes to hours), at up to two exit locations for the two export cables.

- At the point of 'punch out' some of the total volume of drilling fluid may be released into the surrounding seawater by residual pressure in the system, and further movement of the equipment. The size of the plume will be initially very small in extent and localised to the end of the drill bit and borehole (order of a few metres diameter); the SSC of the undiluted drilling fluid at this point will be very high (30,000 to 80,000 mg/l). The free end of the plume will be advected (transported passively) at the speed and direction of the ambient tidal current at the time of the release and the narrow plume will gradually grow in length for the (limited) period of time that drilling fluid continues to be released.

- The plume will be subject to turbulent dispersion over time and distance as it is advected. The width and the height of the plume will gradually increase, but the SCC within the plume will rapidly decrease in proportion to the increase in volume.

- Bentonite clay grains are very small and so are likely to stay in suspension for long periods of time (days to weeks or longer) in the relatively turbulent marine environment. As a result, the Bentonite clay in the drilling fluid is expected to become progressively dispersed to very low concentrations (not measurably different from ambient natural turbidity levels) over periods of hours to days, and will therefore not settle or accumulate onto the seabed in measurable thickness in any location more than a few tens of metres from the main point of release.

5.2.2 Cumulative changes to suspended sediment concentrations, bed levels and sediment type

A number of projects and activities associated with the installation and operation of electricity transmission cables have been identified that are within a spring tidal excursion ellipse from the Salamander Project. These could theoretically cause cumulative changes to suspended sediment concentrations, bed levels and sediment type if they were to coincide with construction of the Offshore Development (Table 1).

Cable installation vessels will request a vessel safety zone of at least 500 m when installing or handling cables. The exact distances within which other such vessels can pass typically varies, depending on location and vessel activity type. However, it is reasonable to assume that this zone will be around 500 m typically for any commercial operation.

As set out in Section 5.2.1, at a distance of greater than 500 m from the source of bed disturbance any increases in SSC are expected to be modest (tens to low hundreds of mg/l) and fine sediment is unlikely to deposit in measurable thickness. In addition to direct communications between the ships, this process will likely be managed via vessel management plans and official bulletins, such as Notice to Mariners. Accordingly, whilst plume interaction may still theoretically occur, the potential for much higher concentration and/or more persistent plumes than that previously described in the Project-alone assessments of SSC is small.

Cumulative increases in bed level could also theoretically occur although the potential for this to occur is expected to be very low, given the expected separation distance of the vessels and the fact that seabed sediments are regularly re-worked and transported by tidal currents in this region.

Figure 2. **Spring tidal excursion buffer, 50 m and 500 m buffers outside of the Offshore Export Cable Corridor and Offshore Array Area**

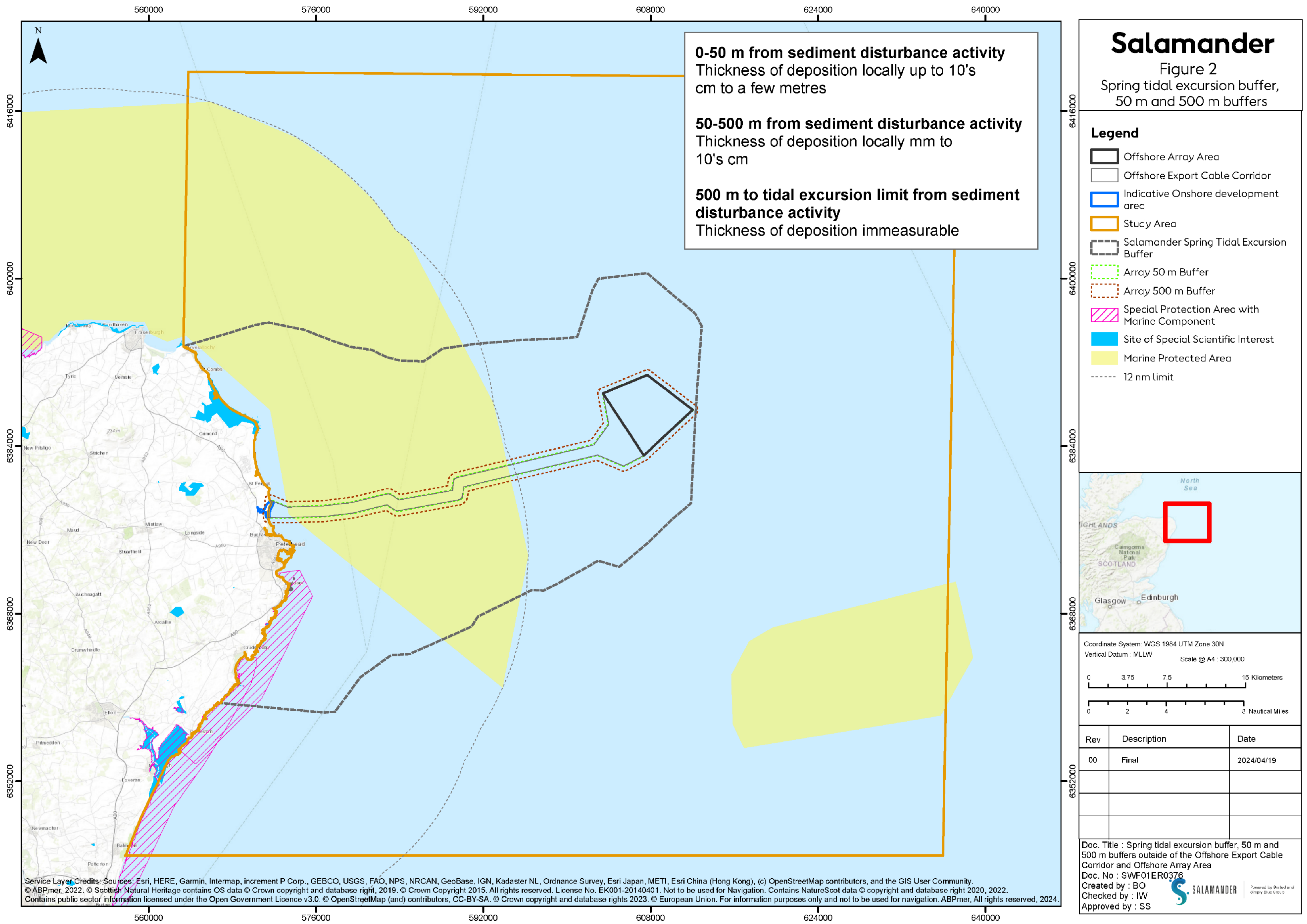


Figure 3. Sediment deposition footprints associated with installation of a single foundation at an example location in the Offshore Array Area

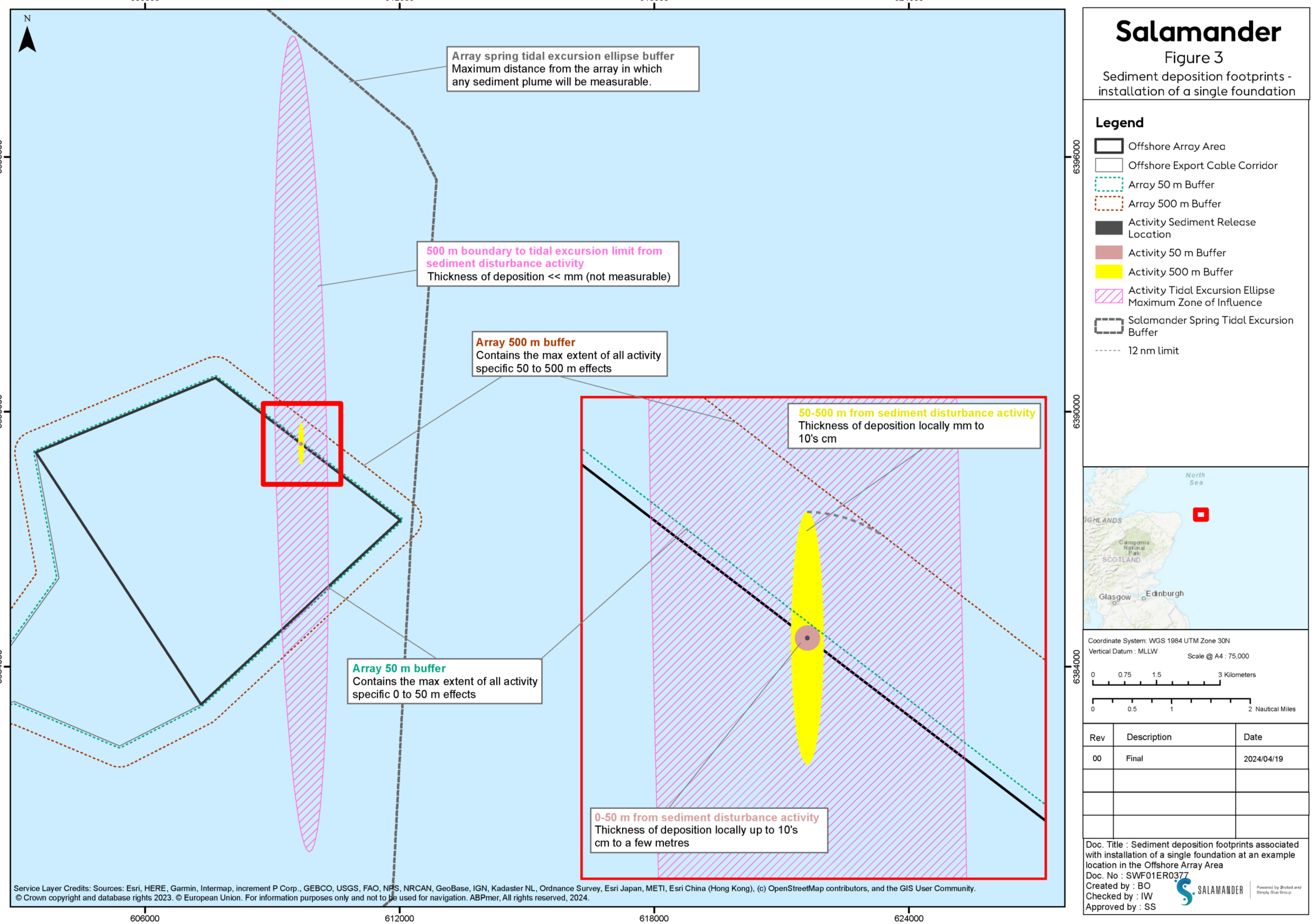
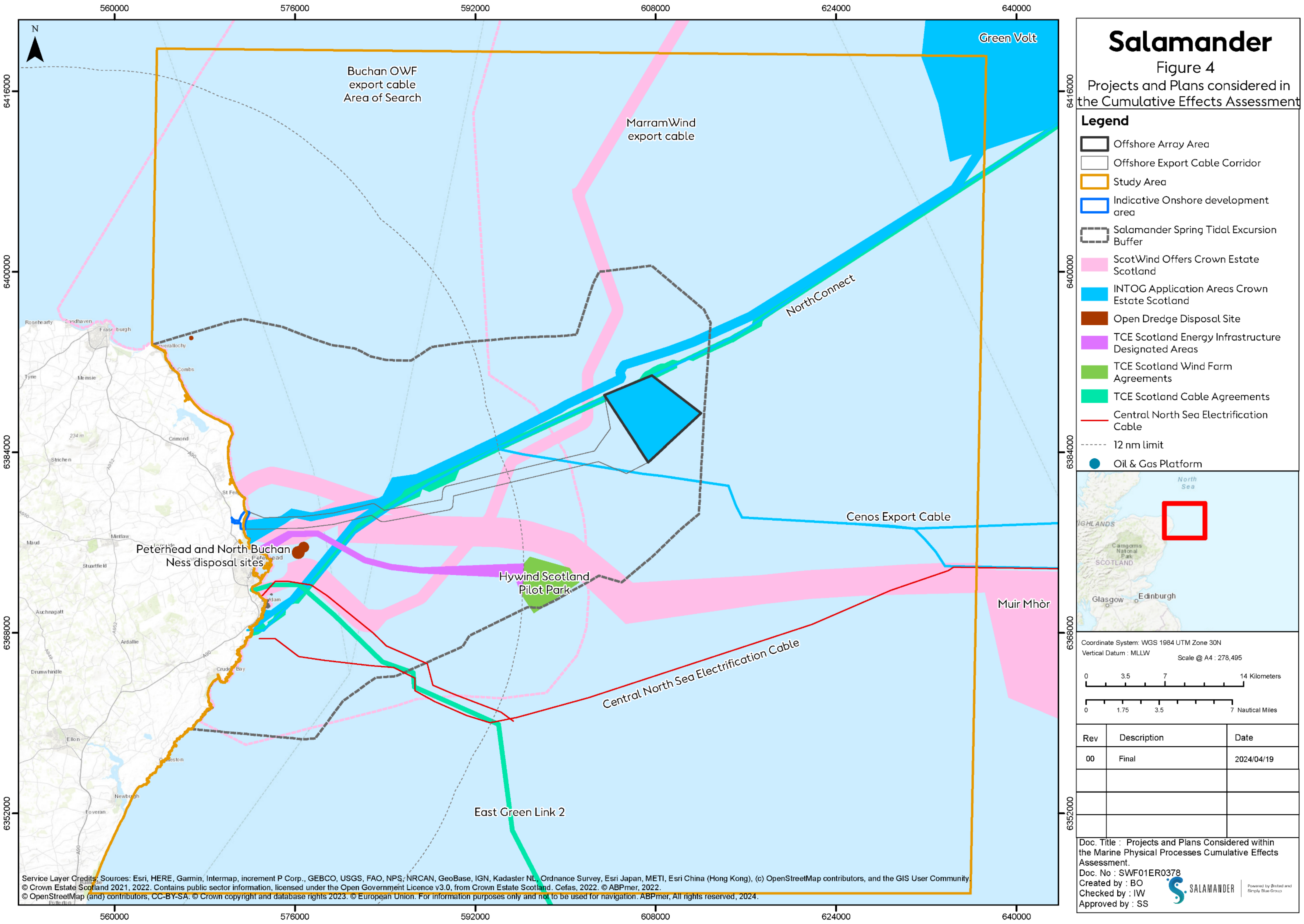


Figure 4. Projects and Plans Considered within the Marine Physical Processes Cumulative Effects Assessment (Includes Locations of Projects and Plans Scoped out of Assessment)



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Contact Us

ABPmer

Quayside Suite,
Medina Chambers
Town Quay, Southampton
SO14 2AQ

T +44 (0) 23 8071 1840
F +44 (0) 23 8071 1841
E enquiries@abpmer.co.uk

www.abpmer.co.uk