The Sizewell C Project

6.3 Volume 2 Main Development Site

Chapter 22 Marine Ecology and Fisheries

Appendix 22J - Modelling of Sediment Dispersion of Dredge Material for SZC Construction and Operation

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BRITISH EDF ESTUARINE & MARINE STUDIES

Technical Report Series:	TR480: Modelling of Sediment Dispersion of Dredge Material from SZC Construction and Operation.
Sub-Contract Report Original Title:	Sizewell, Sediment dispersion modelling, Report No. R.3022 August 2018.

Summary of Purpose & Value to BEEMS

The BEEMS Delft3d model of Sizewell with its accompanying particle tracking module has been used to estimate the distribution of sediment, resulting from a range of potential dredge and sediment disposal scenarios planned for the construction and operation of Sizewell C. The Delft3d model has previously been used at Sizewell for thermal plume assessments and has been validated for tidal currents and elevations and been shown to reproduce the hydrodynamics of Sizewell Bay (BEEMS Technical report TR132). This model is therefore considered a reliable basis for modelling mobilized sediment from dredging and drilling activities associated with construction and operation of Sizewell C.

The modelled sediment dispersion scenarios are based upon Sizewell C engineering design assumptions as of 1 June 2018 and some of these designs are subject to possible change as EDF Energy refines designs and construction sequencing.

The activities that produce sediment plumes and are simulated in this report are:
Dredging and drilling for the intake and outfall structures;
Dredging for the Combined Drainage Outfall (CDO) and Fish Recovery and Return (FRR) outfalls; and
Dredging associated with access to the beach landing facility (BLF).

The report assumes local disposal as this represents the worst-case scenario for local effects. The Marine Management Organisation would be consulted in relation to all dredging options and disposal routes, which would be subject to licencing requirements.

This report supersedes the previous dredge assessment associated with construction options that are no longer considered (BEEMS Technical Report TR334). However, the predictions for drilling of the intake and outfall structures have not changed and are copied across to this report for completeness.

New to Edition 2:

Results have been updated for all model scenarios. In Edition1 of this report, the dredging associated with all intakes and outfalls was considered consecutively. Due to the length of time of activity and the construction schedule, this was considered an unlikely representation. As such, the dredging associated with a single intake and outfall were modelled separately. Equally, for the CDO and FRRs, a single structure (FFR1) was modelled to represent the scenario for all three structures, rather than the CDO and both FRRs considered consecutively. For the BLF access channel, an additional model run was implemented to supplement the full capital dredge of the BLF access channel. This additional run represented the maintenance dredge volume (10% of the full capital dredge). Whilst in-combination effects of the multiple cooling water structures (CWS) and the CDO and FRRs were considered unlikely, there is potential for temporal overlap between the maintenance dredge with either a CWS or the CDO/FRR. As such, these results have been included. In addition to analysis of the SSC and sedimentation plumes, intersections with bird foraging areas have also been considered.

Results

Dredging for the cooling water infrastructure results in the largest dredge areas, increases in suspended sediment concentration (SSC) and siltation rates. The modelled sediment plume is predicted to be transported by the tide and has an elongated area extending approximately 13 km to the north, 22 km to the south with increases in SSC of more than 100 mg/l. There is a limited east-west extent and no discernible contact with the coastline. SSCs within the plume, associated with disposal, peak at more than 2,000 mg/l above background but these elevated concentrations are highly localized and short lived. Whilst the 100^{th} percentile produces typical values of approximately 100 mg/l above background, the 95^{th} percentile produces values typically of 20 mg/l, highlighting again the very short nature of the plume. Plumes with instantaneous SSC of >100 mg/l above daily maximum background levels are expected to form over an instantaneous depth averaged area of up to 373 ha (291 ha at the sea surface). A smaller area of up to 14 ha is expected to experience a depth averaged instantaneous SSC of >1,000 mg/l above background levels (34 ha at the sea surface). The elevated concentrations are shown to decay to background levels within *circa* two days on both spring and neap tides after the completion of the disposal operations. Elevated SSC are not expected to occur for more than about eight days for the dredge scenarios. Increase of SSC and sedimentation due to CWS dredging at the SZB intakes was zero.

Dredge scenarios for the cooling water infrastructure consider the location of the outfall and the southerly intake to represent a range of volumes and sediment characteristics. However, as the disposal point would be consistent for all cooling water dredge activities differences between intake headworks would be minor. Furthermore, the dredge scenarios consider a highly conservative assumption of removal of 6 m of surficial sediment overlying bedrock.

Since the completion of this report, preliminary findings of the 2019 geotechnical investigations (in preparation) suggest the sediment thickness at the intake and outfall locations are considerably less than 6 m. As such, the reported SSC plumes and sedimentation rates presented in the report are considered conservative estimates.

The SSC plume is considered in relation to breeding colonies of designated birds to allow Habitats Regulations Assessments and the Environmental Statement to assess the potential for indirect effects, whereby marine feeding birds may have reduced ability to capture fish prey. The largest intersection between the CWS dredge plume and bird foraging areas is at the Little Tern Slaughden colony, with a peak instantaneous intersection of 7%. This plume is very short lived with a plume greater than 1% of the Little Tern foraging range at Slaughden lasting 5 hours per day for two days from the start of dredging. The plume was defined as the instantaneous surface SSC contour greater than 100 mg/l. The Little Tern Dingle and Minsmere colonies were unaffected. The intersection with Common Tern colonies (Minsmere & Orfordness) is 1% or less.

During the drilling of the bedrock at the intake and outfall structures, a very diffuse plume with concentrations of around 5-10 mg/l relative to background develops. Concentrations at this level will not be discernible above background values. Course sediments from the drilling will settle locally, whereas fine sediments will settle intermittently on neap tides and be re-suspended on spring tides.

The sediment plume associated with dredging and local disposal of the FRR and CDO outfalls extends north-south along the coast, with maximum SSC >100 mg/l confined to within 6.5 km to the north and 5.5 km south. Plumes with instantaneous SSC of >100 mg/labove daily maximum background levels are expected to form over instantaneous areas of up to 89 ha at the surface (28 ha depth averaged). A small area of 1 ha is expected to experience an instantaneous SSC of >1,000 mg/l above background at the sea surface. Following the completion of the dredge the plume quickly disperses. On spring tides material in suspension is at concentrations of less 20 mg/l within two days of the completion of the dredge. Some of the dredge sedimentation close to the shore may interact with beach sediment at certain locations due to flows being insufficient to resuspend deposited material. The maximum instantaneous increase in SSC and siltation at the SZB intakes, due to the FRR and CSD dredging, was 164 mg/l and 1.1 mm respectively.

The largest intersection between the CDO & FRR dredge plume and bird foraging areas is at the Little Tern Dingle colony, with a peak instantaneous intersection of 4%. This plume is very short lived with a plume greater than 1% lasting 4 hours for one day from the start of dredging. The Little Tern Minsmere and Slaughden colonies had intersections of 2%. The intersection with Common Tern colonies (Minsmere & Orfordness) is less than 1%.

The area effected by plough dredging, associated with the full capital dredge for the BLF, is close inshore where tidal flows are weaker, and the plume is reduced. Concentrations of more than 50 mg/l above background confined to within 6.5 km to the north and south of the dredge area on spring tides and to within 5 km on neap tides extends north-south along the coast. The maximum SSC values are typically around 200 mg/l above background. Following the initial capital dredging event, an instantaneous plume with SSC concentrations >100 mg/l above daily maximum background levels is expected to form inshore over an area of up to 108 ha at the sea surface and 83 ha as a depth averaged plume. A small area of up to 7 ha would experience an instantaneous SSC of >1,000 mg/l above background levels. Following the completion of the dredge the plume quickly disperses. On spring tides material in suspension is at concentrations of less than 20 mg/l above background within three days. Due to the proximity to the shore, deposits may be detectable on the beach, but are likely to be further redistributed and mixed with beach sediment by wave activity. The maximum instantaneous increase in SSC and siltation at the SZB intakes, due to the BLF dredging, was 86 mg/l and 1.4 mm respectively. The effect of maintenance dredging is similar is shape to the full capital dredge, but on a smaller spatial scale and results in smaller concentrations of SSC and siltation. Maintenance dredging, occurring at approximately monthly intervals would result in up to 28 ha of sea surface expected to experience >100 mg/l, and 1ha expected to experience >1,000 mg/l above background SSC on each occasion.

The largest intersection between the BLF access channel dredge plume and bird foraging areas is at the Little Tern Minsmere colony, with a peak instantaneous intersection of 6%. This plume is very short lived with a plume greater than 1% lasting 3 hours or less each tidal cycle for three days from the start of dredging. The Little Tern Dingle and Slaughden colonies had intersections of 3% & 1%, respectively. The intersection with Common Tern colonies (Minsmere & Orfordness) is less than 1%. For the maintenance dredge, the intersection Is 1% or less for all colonies.

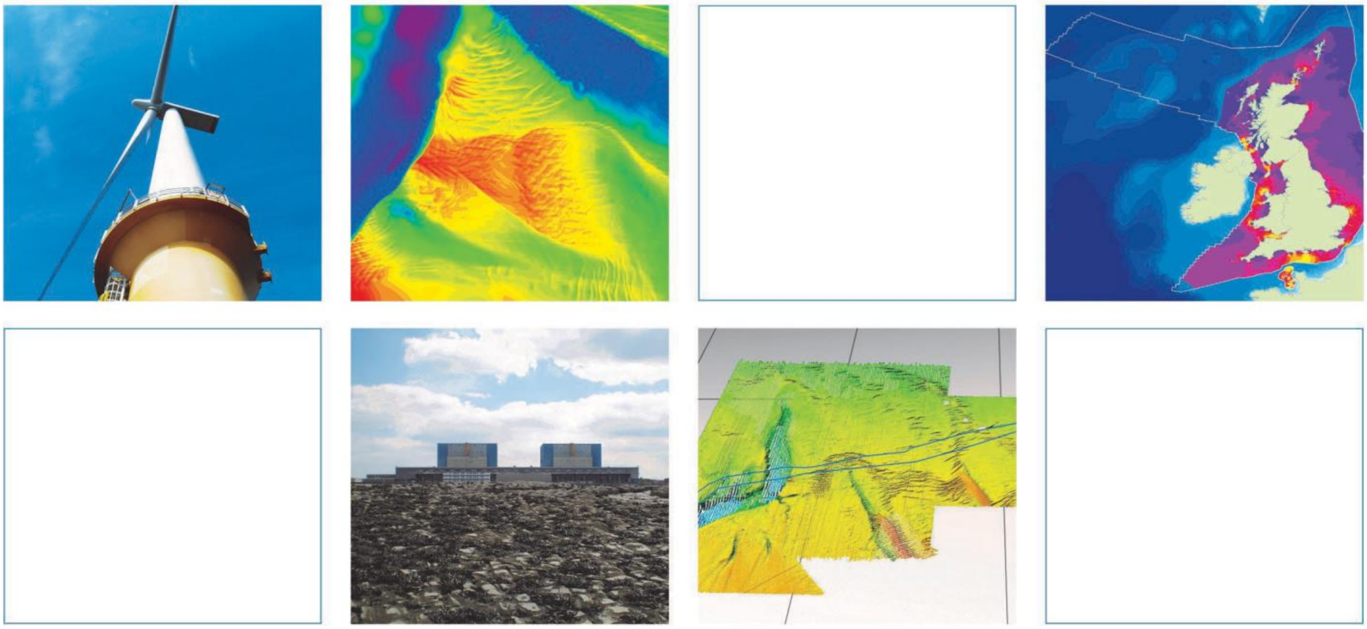
The in-combination assessment for dredging the CWS structure simultaneously with the maintenance dredging of the BLF approach channel, shows the potential for any additional in-combination effects are limited with no interaction of the two plumes expected to occur and with any potential effects within bird foraging areas to be minimal. However, the in-combination assessment for dredging the additional outfall structures simultaneously with the maintenance dredging of the BLF approach channel, shows the plume areas intersecting. The maximum area of instantaneous depth averaged SSC greater than 100 mg/l above background increases from 28 ha for the FRR or CDO on its own to 42 ha for the in-combination effect. At higher concentrations the increased area of impact is much smaller. At concentrations above 500 mg/l the area increases from 2 ha to 3 ha. The maximum area of instantaneous siltation greater than 10 mm increases from 2 ha to 3 ha.

The maximum instantaneous plume intersection of the Little Tern Dingle and Slaughden colonies increases by 1% to 5% and 3%, respectively, as a result of the combined dredging activity. However, the plume intersection is very short lived, with the plume intersection greater than 1% lasting no more than two hours.

Sizewell

Sediment dispersion modelling

June 2019



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Sizewell

Sediment dispersion modelling

June 2019

Summary

An existing detailed three dimensional (3D) hydrodynamic model of the Suffolk coast has been used to investigate the dispersion of sediments from construction related activities at the Sizewell Nuclear New Build (NNB) site. The sediment releases associated with the drilling of the intake and outfall structures and the dredging activities required for installing offshore structures and site accessibility have been modelled. Three different activities have been considered:

- The installation of the Cooling Water System (CWS) intake and outfall structures which requires i) the dredging of surficial sediments, followed by ii) drilling through bed rock;
- The dredging of surficial sediments at the location of additional operational structures (the Fish Return and Recovery (FRR) and Combined Drainage Outfall (CDO) structures); and
- The bed levelling of an area to provide access to a Beach Landing Facility (BLF). Both capital and maintenance dredge requirements have been assessed.

Additionally, the coincident occurrence of a maintenance dredge at the BLF with the dredge associated with the installation of the CWS and additional operational structures has been considered.

Details of the proposed activities, the model setup and results from the modelling are presented in this report. No assessment of the environmental impacts related to the sediment plumes is undertaken since this lies outside of the scope of the present study. Rather, model results are presented in a range of plot formats and as tabulated values to facilitate the environmental assessment, which is to be carried out separately.

The most extensive plume was found to develop as a result of the dredging (and associated local disposal) of the surficial sediments for the installation of the CWS structures. An elongate plume with depth average Suspended Sediment Concentration (SSC) of more than 100 mg/l covered a maximum instantaneous area of around 370 hectares. The plume associated with the disposal of this dredged material is likely to be discernible from background concentrations, although the plume is typically located offshore and is not expected to expose coastal areas to notable increases in SSC or sedimentation. Further, the plume is short lived with elevated SSCs not expected to occur for more than about eight days for the dredge scenarios modelled. There is some intersect of the plume area (defined by increased surface SSC of more than 100 mg/l) into identified bird foraging areas, although this typically accounts for 1 % or less of the foraging area, except for the Little Tern Colony at Slaughden, where 7 % of the foraging area is intersected by the plume.

During drilling at the CWS structures, a very diffuse plume with concentrations of around 5 mg/l relative to background concentrations develops. Concentrations at this level will not be discernible above background values. Drill arisings are expected to deposit close to the drill site. The footprint area of the deposit is expected to extend less than 200 m from the drill site. The mean thickness of deposits local to the drill site are expected to be of the order of 0.05 m to 0.5 m. Beyond the extent of the initial deposit, the thickness of deposits on the seabed from drill arisings is less than 0.2 mm.

The sediment plume associated with dredging (and associated local disposal) of the FRR and CDO structures extends north-south along the coast, with limited offshore extent. The maximum instantaneous plume area with a depth average SSC of more than 100 mg/l are confined to an area of around 30 hectares. Maximum sedimentation is highest close to the disposal site, where values of more than 20 mm occur, although this sedimentation is transient, occurring only at periods of slack flow. Away

from the disposal site, sedimentation is more typically of the order of millimetres. Some of the sedimentation occurs in shallow coastal areas where flows are not sufficient to resuspend material deposited on the bed. These deposits may interact with beach sediment at certain locations. As for the dredging at the CWS structures, following the completion of the dredge the plume quickly disperses and the plume is unlikely to be detectable above background concentrations within a day. There is some intersect of the plume area (defined by increased surface SSC of more than 100 mg/l) into identified bird foraging areas. The area of intersect is small, being 4 % or less of the foraging areas.

In comparison to the plumes associated with the other construction related activities, the plume associated with dredging of the BLF access channel is confined closer inshore where flows are slightly reduced. The maximum instantaneous plume area with depth average SSC above 100 mg/l covers an area of 83 ha when the capital dredge occurs on spring tides. This area is reduced to around 20 hectares for the maintenance dredge. The slower flows inshore result in an increase in sedimentation along the coastal areas and there is some potential for this material to interact with the beach sediments. The plume area (defined as surface SSC of more than 100 mg/l) intersects with small parts of the bird foraging areas. The area of increase accounts for a relatively low proportion of the overall foraging areas (typically 3% or less except for the Little Tern Minsmere colony foraging area which has increases of more than 100 mg/l in surface SSC across 6% of its area).

The modelling results indicate that the potential for in-combination effects for the dredging for CWS structures occurring coincidentally with the maintenance dredge of the BLF approach channel is limited. Should the dredging for the additional outfall structures occur simultaneously with the maintenance dredge for the BLF approach channel there is the potential for some in-combination effects, with the plume areas intersecting. However, the resultant in-combination plume area above 100 mg/l in surface SSC within the bird foraging areas remains small as a percentage of the total foraging area.

The dispersion of any sediment plumes are not expected to be significantly affected by the wave conditions which could occur during the dredging or drilling activities.

Contents

Tables

Figures

Please note that the red line boundary was amended after this document was finalised, therefore figures in this document do not reflect the boundaries in respect of which development consent has been sought in this application. However, amendments to the red line boundary does not have any impact on the findings set out in this document and all other information remains correct.

1 Introduction

ABPmer has been commissioned by Cefas to undertake a number of modelling studies on the Suffolk coast, associated with the existing Sizewell B power station and the proposed Nuclear New Build (NNB), Sizewell C. This work contributes to an on-going study as part of the British Energy Estuarine and Marine Studies (BEEMS) programme, funded by EDF Energy (formerly British Energy) to provide authoritative scientific information on the marine and transitional waters in the vicinity of potential new-build nuclear power stations in the UK.

Previous modelling work carried out by ABPmer has included the development and calibration of a hydrodynamic and thermal model of the Suffolk coast (ABPmer, 2014). The model was used to assess thermal dispersion from the proposed NNB (ABPmer, 2011 and ABPmer, 2015a) and the dispersion of sediments associated with the proposed construction and maintenance activities associated with the NNB (ABPmer, 2015b).

The present study provides an update to the sediment dispersion modelling previously undertaken. This was required to provide an assessment of the effects relating to proposed changes in the construction methods and to extend the assessment to consider the effect of waves. The results presented in ABPmer (2015b) are therefore superseded. Any results which remain valid have been copied into the present report for completeness. The present study applies ABPmer's existing calibrated hydrodynamic model of the Suffolk coast to simulate the sediment dispersion associated with three main activities including:

1. Excavation for the Cooling Water System (CWS) intake and outfall structures;
2. Excavation for the Fish Recovery and Return (FRR) and Combined Drainage Outfall (CDO) structures; and
3. Excavation of the Beach Landing Facility (BLF) approach channel for both capital and maintenance dredge.

These activities are described along with the applied modelling approach in Section 2. A plot indicating the locations of the main activities and sampling locations with respect to the bathymetry is shown in Figure 1.

The report is structured as follows:

Section 2: Model Setup;

Section 3: Results;

Section 5: Wave Sensitivity; and

Section 6: Conclusions.

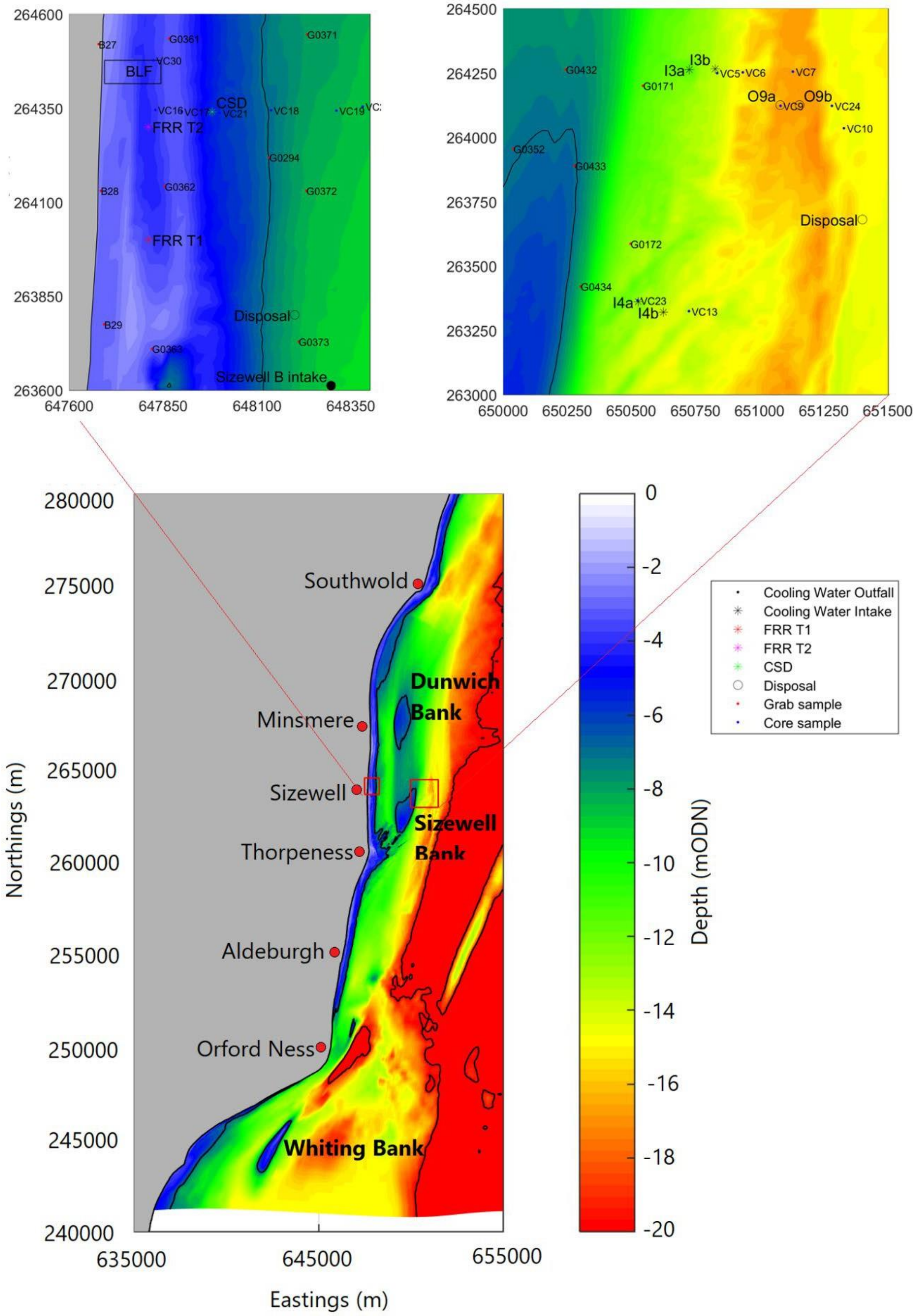


Figure 1. **Location plot**

2 Model Setup

ABPmer's existing Delft3D hydrodynamic (FLOW) model of the Suffolk coast (ABPmer, 2014a) is coupled with a particle tracking model (PART) to simulate the dispersion of sediment disturbed and deposited during construction and maintenance activities at the Sizewell C NNB. The hydrodynamic grid horizontal resolution varies from approximately 25 m x 25 m at the locations of the intakes and outfalls to 100 m x 100 m within approximately 1 km. The hydrodynamic model is 3 Dimensional (3D) with eight layers through the vertical representing 2, 3, 5, 7, 10, 15, 23 and 35 % of the water column from surface to bed. The configuration of these layers is unchanged from the calibrated thermal plume model (ABPmer, 2014a).

The hydrodynamic model was developed in 2010 and is based on bathymetry data provided by Cefas at the time. No consideration is given to any morphological changes, or their associated effect on tidal flows, that could have occurred since the model was setup and calibrated. Version 4.03 (released November 2017) of the Delft3D software was used in this study.

Hydrodynamics are saved at 30 minute intervals and used to drive the PART model, which saves output on a 50 m x 50 m regular horizontal grid at hourly intervals, with the same distribution of layers through the vertical as the FLOW model. The spatially uniform output grid reduces the numerical/artificial mixing of sediment concentrations associated with changes in volume between neighbouring cells (although small volume changes between neighbouring cells exist due to the variations in bathymetry).

The PART module of Delft3D simulates transport and simple water quality processes by means of a particle tracking method using the 3D flow data from the FLOW module. The tracks are followed in three dimensions over time, whereby a dynamic concentration distribution is obtained by calculating the mass of particles in the model grid cells. The processes are assumed to be deterministic except for a random displacement of the particle at each time step. The particle tracking method is based on a random-walk method.

Settling and sedimentation/erosion processes are included in the PART model. Each grain size is attributed a settling velocity and critical thresholds for sedimentation and erosion. When the shear stress is less than the sedimentation threshold the material settles out of suspension at the defined settling velocity. Any material which reaches the bed will remain on the bed until bed shear stresses exceed the critical erosion threshold, at which time all material on the bed is instantaneously placed back into suspension. In reality the erosion of deposited material will be at a more gradual rate than this representation of the process in the model and as such the model will over predict the amount of material in suspension.

To assess the effect of wave driven flows on sediment dispersion, the Delft3D SWAN module has been coupled with the FLOW model via a two-way coupling. This two-way coupling provides an output of the combined tide-wave driven flows which have then been used to drive the PART model. It should be noted that the effect of sediment movement resulting from stirring induced by wave breaking is not accounted for; only the effect of the wave driven flow is included.

Three model scenarios have been defined which simulate the dispersion of sediments associated with the required drilling and dredging activities. Where assumptions are required in defining the characteristics of sediments or the scheme of dredging works, an element of conservatism has been introduced. The definition of these scenarios has drawn upon information from the following sources:

- Client supplied information on the likely activities to be carried out;
- Sediment characteristics from more than 500 grab samples (Kenneth Pye Associates, 2011);
- Beach profile data at Sizewell (Environment Agency, 2011);
- Borehole data collected across the study site to characterise sub-surface material (EDF, 2015);
- Existing scientific literature on sediment plumes from dredging (CIRIA, 2000; Kirby and Land, 1991), sediment plumes from drilling (CREL, 2007) and sediment characteristics and geotechnical data in the study region (Osiris, 2010); and
- Existing studies of a similar nature undertaken by ABPmer. This includes dredge dispersion studies (ABPmer, 2014b and 2014c) and drilling studies (ABPmer, 2012 and 2013a).

In the following sections the model setup pertaining to each of the three scenarios is defined. In each case, the required activity is first described, followed by details on the model scenario including any assumptions made.

2.1 Scenario 1. Installation of the CWS intake and outfall structures

2.1.1 Overview

This scenario considers releases of sediment associated with three different aspects of sediment excavation for the construction of the CWS intake and outfall structures:

a) Dredging of surficial sediments. Cefas has provided calculations of excavated volumes *in situ* of 17,400 m^3 per intake head and 11,750 m^3 per outfall head. These calculations are based on a frustum pyramid and a worst-case surficial sediment depth of 6 m. The dimensions for the dredge areas are shown in Figure 2. Based on the water depths at the intake and outfall structures (*circa* 12-17 mODN) and the sediment type (predominantly sand), it is likely that dredging will be via a Cutter Suction Dredger. The route of disposal has not yet been confirmed and therefore a worst case assumption of local disposal has been assumed (see item b). On this basis, only the sediment disturbed at the seabed by the dredger has been simulated;

b) Disposal of the dredged surficial sediments. Cefas has indicated that local disposal presents the worst-case scenario for this element. For this assessment it is assumed that a Cutter Suction Dredger would discharge dredge material through a pipe approximately 500 m from the dredge site; and

c) Vertical drilling through the bed rock layer to connect the intake and outfall structures to the main power station shafts (which will be connected via tunnel boring). The drilled vertical tunnel is to have a diameter of 9 m, extending to a depth of 15 m below the bed.

For the purposes of modelling these forms of sediment disturbance have been considered as two discrete activities:

i) The removal of the surficial sediments via dredging (with simultaneous release at the disposal location and at the cutter head); and

ii) The vertical drilling through the bed rock.

The CWS intake and outfall locations are provided in Table 1 and are shown in Figure 1.

Table 1. CWS intake and outfall locations

Structure	Eastings (m)	Northings (m)	Depth (mODN)	
			Pre-dredge	Post-dredge
O9a	651080	264125	16.4	22.4
O9b	651155	264125	16.8	22.8
I4a	650526	263360	12.7	18.7
I4b	650624	263341	13.6	19.6
I3a	650726	264262	11.7	17.7
I3b	650826	264264	13.6	19.6

Geophysical surveys within the Galloper Wind Farm Corridor (which lies within 1 km to the south of the proposed Sizewell cooling water structures) report the surficial sediment layer to vary in the region of 0.5 m to 6 m thick (Osiris, 2010). To ensure a conservative assessment, the surface layer is assumed to be 6 m deep when considering the dredging of surficial sediment and 2 m deep when considering the drilling of the underlying bed rock (so that the 15 m of drilling, is through 2 m of sediment and then 13 m of bedrock material).

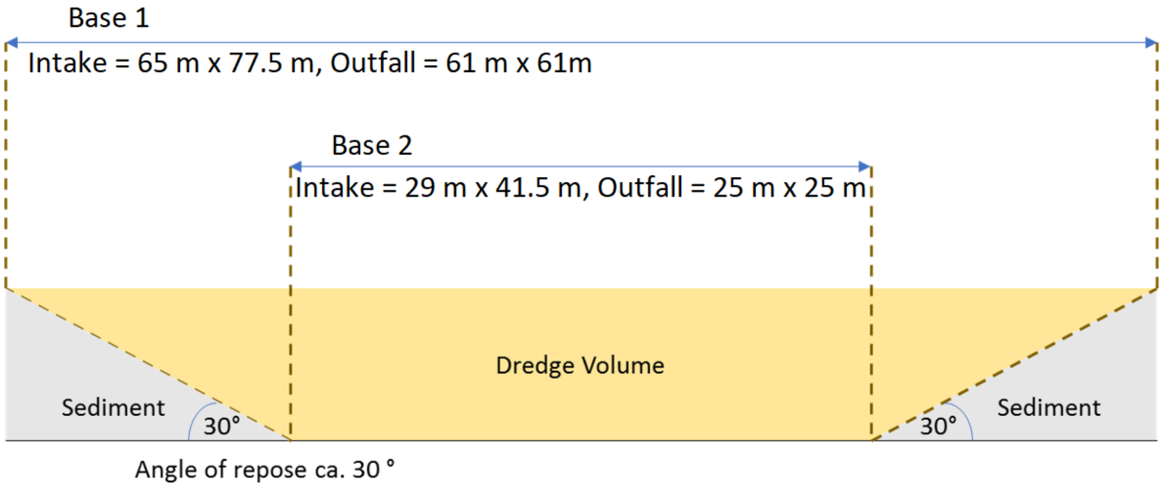


Figure 2. Dredge volume calculations

2.1.2 Characteristics of surficial sediments

Details of the surficial sediments local to the intake and outfall structures are provided by a study undertaken by Kenneth Pye Associates, (2011). The study reports and characterises over 500 grab samples local to Sizewell, with three located in the region of the proposed CWS intakes and outfalls (G0433, G0171 and G0172; see Figure 1). These three samples comprise a muddy sand, with the maximum fraction of fines (below 63 µm) being 5%, and the median grain size (d50) of 210 µm, within the fine sand fraction.

Borehole data collected by EDF (2015) provides information on the characteristics of the sub surface material (see locations on Figure 1). The results from the boreholes at the locations closest to the CWS intake and outfall structures are summarised in Table 2. Note that Outfall 9b is actually slightly closer to Core 9 than Core 24, results for Core 24 are also provided to show the spatial variability in the sediments. Similarly, Intake 3b is closer to Core 5 than to Core 6.

Table 2. Summary of borehole data

Depth (m)	Intake 3a	Intake 3b	Intake 4a	Intake 4b	Outfall 9a	Outfall 9b
	Core 5	Core 6	Core 23	Core 13	Core 9	Core 24
0-1	Silty fine to medium sand	Silty fine to medium sand	Silty fine to medium sand	Silty fine to medium sand	Slightly sandy silty clay	Slightly sandy silty clay
1-2	Slightly silty fine to medium sand	Silty fine sand	Silty medium to coarse sand	Slightly silty medium to coarse sand	Clay	Silty fine sand
2-3	Very silty/clayey fine sand	Medium to coarse sand	Silty medium to coarse sand	Slightly silty medium to coarse sand	Silty fine sand	Very silty fine sand
3-4	Very silty fine sand	Coarse sand	Silty medium to coarse sand	Slightly silty medium to coarse sand	Fine sand	Silty medium to coarse sand
4-5	Silty medium to coarse sand	Silty medium to coarse sand	Silty medium to coarse sand	Medium to coarse sand	Slightly silty medium to coarse sand	Slightly silty coarse sand
5-6	Coarse sand	No info	Silty medium to coarse sand	Coarse sand	Silty sand (fine, medium and coarse)	Slightly silty, sandy gravel

The borehole data was analysed to determine the grain size distribution of the dredge material (see Table 3). Three representative grain sizes were defined; 63 µm (fines), 210 µm (fine to medium sand) and 420 µm (medium to coarse sand). The percentages of each sediment fraction applied in the modelling for the dredging at the CWS intakes and outfalls are provided in Table 3.

Table 3. Representative sediment grain size distribution of surficial sediments at the CWS intakes and outfalls

Location	Percentage of Dredge Material (%)		
	63 µm	210 µm	420 µm
Intake	5	75	20
Outfall	30	60	10

During modelling of the dredge phase, sediments released by the action of the cutter are all assumed to be 210 µm since the suction pipe is expected to remove the majority of the fines, while coarser material will rapidly settle on the bed. Sediments released at the disposal site are assumed to have the sediment distribution of the dredge material.

2.1.3 Sediment release rates for removal of surficial sediments

During the dredging process sediment is released in the marine environment, where it will be dispersed by the hydrodynamics. The main causes of sediment release during dredging of surficial sediment at the cooling water intake/outfall locations are as follows:

- Sediment release near the bed due to the action of the cutter and incomplete removal of disturbed sediment via the suction pipe; and
- Sediment release near the surface due to either discharge from the pipe (if spoil pumped direct to the disposal site) or direct release from the keel of the split hopper (if spoil removed by barge). The worst case for sediment dispersion will arise from the pipe discharge of sediment at the surface, therefore this method of disposal has been modelled at a location approximately 500 m southeast of the dredge location (see Figure 1).

With normal dredger overflow and bottom release from barges, the sediment release associated with the disposal has two components; a dynamic phase where the sediment rapidly falls to the bed and a passive phase where the sediment plume dispersion is controlled by the hydrodynamics and the settling velocities for the individual particles. When the sediment is discharged from a pipe, the release initially has a momentum in the direction of orientation of the pipe, which reduces away from the outlet and eventually the dynamic and passive plume phases take over due to the effect of gravity. The release rates associated with these different components of the dredging processes informed the source terms for the plume modelling.

The 'S-factor' method for defining the approximate release rates (losses to the water column) during a dredge was devised by Blokland (1988), in which the quantity of sediment released in the immediate vicinity of the dredger is determined in kilogramme of dry solid per cubic metre of material dredged. The method is based on *in situ* measurements of suspended sediment concentrations and provides a useful estimate of the magnitude of sediment losses where there is no site-specific information. The S-factor will vary with the dredger size and the sediment type. Kirby and Land (1991) defined S- factors for different types of dredging operation in muddy sediment. A value of approximately 6 kg of dry solids per cubic metre was defined as a disturbance rate at the cutter head for Cutter Suction Dredgers, although this was reduced to 3 kg/m^3 when reduced swing and rotation speeds are applied. The S-factor would be expected to be lower than the quoted values for the dredging of coarser sediments due to the greater settling velocity of coarser material. To provide a conservative approach, an S-factor of 6 kg of dry solid per cubic metre dredged is considered applicable to represent losses associated with the action of the cutter head at the seabed.

The dredging rate will depend on the vessel used. A summary of dredger statistics is provided in Table 4.

Table 4. Summary of cutter suction dredgers

Dredger	Min Dredging Depth[1] (m)	Max Dredging Depth (m)	Discharge Pipe Diameter (m)
Beaver 300 SE	(1.88)	6	0.26
John M	(2)	12.5	0.29
Beaver 40	(2.1)	8	0.39
Beaver 45	(2.4)	10	0.45
Beaver 50	(2.45)	14	0.5
Beaver St Lawrence	(2.54)	14	0.55
Seine	2.9	18	0.65
Beaver B65 DDSP	(2.95)	18	0.65
Edax	6.5	27.5	0.75
Cyrus II	(5.85)	25	0.85
Castor	(5.04)	25.7	0.85
Phoenix	7	31.5	0.9
Helios	6.35	35	1
Taurus II	6.6	30	1
Artemis	(7.6)	31.1	1

[1] Where this is not stated on dredger datasheets, this is assumed to be 1 m more than the max. draught (value shown in brackets).

The smaller Cutter Suction Dredgers may be constrained by the depths, with maximum dredging depths of 12.5 m for the Humber Workboats' 'John M' and maximum dredging depths of 18 m for Boskallis' 'Seine' for example. The water depth at Outfall O9b pre-dredge is 16.8 m ODN (yielding depths of up to 18 m at high water and 15.6 m at low water during larger range spring tides), post-dredge depths are expected to be between two and six metres deeper than this (see Table 1). It may be possible to extend the standard maximum dredging depths by modifying the dredger setup, however since the dredger to be used has not been identified, a conservative approach using a larger dredger has been assumed. A dredger such as Boskalis' 'Cyrus II' or Van Oord's 'Castor' would not be constrained by the depths. The *in situ* solid dredging rates for sands with a 500 m length discharge pipe are likely to be of the order 3,850 m^3 per hour, based on available vessel specification productivity curves.

Based on the volumes to be dredged at the intakes and outfalls, it would take *circa* 4.5 hours and 3 hours of continuous operation to dredge the surficial sediment at each CWS intake and outfall structure, respectively. In reality however, the dredging will not be continuous since the dredger spuds (legs) will need repositioning at intervals. Allowing for nine repositioning's of the spuds and assuming a 30 minute duration for each repositioning, the dredge will take approximately 8.5 hours to complete the dredging of surficial sediments at each intake structure (with 9 cycles of 30 minutes of dredging, followed by a 30 minute interval for repositioning). The time will be slightly less to complete the dredging of surficial sediments (approximately 7 hours) at each CWS outfall structure due to the smaller volume of sediments to be removed (with 9 cycles of 20 minutes of dredging, followed by a 30 minute interval for repositioning). Note that the dredge period at each position will vary due to the frustum pyramid shape of the dredge with longer durations of continuous dredging where the sediment depths to be dredged are deepest (i.e. in the centre of the dredge area) and shorter durations around the edges where depths of sediment to be dredged are thinnest.

The sediment release rates applied in the model were derived as follows;

- The material properties of quartz were used to calculate the *in situ* mass of sediment, specifically a sediment density of 2,650 kg/m^3 was assumed;
- The total volume of sediment to be dredged at the CWS structure locations is 93,100 m^3, with 17,400 m^3 to be dredged at each of the four intake heads and 11,750 m^3 to be dredged at each of the two outfall heads;
- The assumed *in situ* dredge rate was 3,850 m^3 per hour giving a release rate for disposal of 1,352 kg/s based on a dry bed density of 1,264 kg/m^3 (equivalent to a wet density of 1,800 kg/m^3). This bed density is representative of compacted material;
- The total mass released in the model due to cutterhead disturbance = 6 kg x 3,850 m^3 per hour, yielding a release rate of 6.4 kg/s;
- The sediment release associated with the action of the cutter was distributed over nine cells (with each cell being 25 m x 25 m) for each structure, centred on the intake and outfall locations;
- Sediment disturbed by the action of the cutter was input into Layer 8 (the bottom 35 % of the water column);
- The sediment release associated with the disposal material was from a single location at 651400, 263680. This is approximately 500 m southeast of Outfall O9b. The distance from the Intakes is slightly greater, being around 825 m for I3b and I4b and 900 m for I3a and I4a;
- Sediment released at the disposal site was equally split between Layer 1 (top 2% of the water column) and Layer 8. The input into Layer 1 reflects the level of input from the discharge pipe for the passive plume, while the input into Layer 8 takes some account of the dynamic plume (although the dynamic phase is not directly represented in the modelling);

- The disposal from the pipe will be at a velocity sufficient to avoid sediment settling and blocking the pipe, the discharge velocity at the end of the pipe is therefore expected to be around 5 m/s. The momentum at the outfall would induce some turbulent mixing; this process is not included in the PART model, however to account for some of this spreading the sediment has been input over a 10 m radial area;
- For the dredging at the intake structures, each dredger cycle comprised of 30 minutes of dredging, followed by a 30 minute gap when the dredger was repositioned. Assuming nine repositioning's, it therefore takes approximately 8.5 hours to complete the dredging of each CWS intake structure;
- For the dredging at the outfall structures, each dredger cycle comprised of 20 minutes of dredging, followed by a 30 minute gap when the dredger was repositioned. Assuming nine repositioning's, it therefore takes approximately 7 hours to complete the dredging of each outfall structure;
- The sediment releases begin at the time of low water so that the sediment plume is initially carried southwards, towards the key coastal receptor of Thorpeness; i.e. the potential worst case;
- The construction sequence is such that there will be a sufficient gap between the dredging at each individual CWS structure so that any disturbed sediment will have fully dispersed before the subsequent structure is dredged. The model therefore simulates the sediment dispersion associated with the dredging of one single CWS intake structure (which has the larger sediment release volume) and the dredging of one single CWS outfall structure (which has the higher percentage of fines);
- The sediment plumes arising from dredging either of the two outfall locations will not differ significantly, with the majority of the sediment plume resulting from disposal (which is assumed to be at a single location for all CWS structures) and with only a small sediment disturbance at the dredger itself. Similarly, the sediment plume will not differ significantly between the dredging of each intake structure. The dredging of the most inshore outfall (O9a) and the most southerly and inshore intake (I4a) was simulated in the model; and
- The pre-dredge bathymetry was used in the model and therefore no adjustments for deepening as a result of the dredge have been included.

The model was set up to examine dredging starting on spring and neap conditions (i.e. two separate model runs). Each model run simulated the dispersion of sediment over a 15 day spring neap period, with the intermittent sediment release to represent the dredge occurring for the first 7-8.5 hours and with the model run on for 14.5 days following the completion of the dredge to determine the on- going dispersion of the released sediment.

2.1.4 Characteristics of drill arisings

Following the dredging of the surficial sand layer, vertical drilling through the underlying Coralline Crag bed rock will be conducted to connect intake and outfall structures to the main power station shafts (which will be constructed via tunnel boring). During the drilling process, sediment, in the form of cuttings, is released in the marine environment.

The sediment grain size distribution for the drill arising from the bedrock is essentially unknown and will depend on the drilling method and the 'bit weight' used. A monitoring study undertaken during and after monopole installation in chalk bedrock at the Lynn and Inner Dowsing windfarm (CREL, 2007) has been considered to identify how the material may break up. The hydrodynamics and sediment properties (both chalk and Coralline Crag being types of limestone) at the Lynn and Inner

Dowsing site are broadly similar to those at the Sizewell CWS intakes and outfalls, and the monitoring study therefore offers a reasonable analogue for the present study (details are provided in Table 5).

During the monitoring study at the Lynn and Inner Dowsing wind farm site, diver surveys of drill arisings directly around the drill site were undertaken. The majority of bed material around the drill site was comprised of coarse clumps of between 2 cm and 10 cm, with these clumps deposited up to 8 m from the drill site in an elongated cone shape with a height of 3 m (CREL, 2007). The material deposited within this area is calculated to account for around 45% of the drilled material volume (assuming a void ratio of 0.45). During the monitoring study, samples of drill arisings were also analysed to identify the grain size distribution. These samples were obtained through a 50 mm diameter pipe and as such will not include the coarser clumps described above. A total of 40 samples during drilling at four different monopile locations were obtained. The particle size analysis indicated a large amount of variability in the particle size distribution with an average of approximately 50% of fines (less than 63 μm). The drill arisings in this study have been modelled with a representative grain size of 63 μm.

Table 5. Comparison of hydrodynamic and sediment properties at the Lyn and Inner Dowsing Wind Farm and Sizewell

Property	Lynn and Inner Dowsing	Sizewell Intakes and Outfalls
Water depth (mODN)	18	11.7-16.8
Peak flows on spring tide (m/s)	1.3	1.2-1.3
Excavation volume (m^3)	350	754-954
Bedrock type	Chalk	Limestone (Coralline Crag)

2.1.5 Sediment release rates for drilling through bed rock

Based on the information provided in Section 2.1.4, the following assumptions have been made to derive realistic worst case release rates to apply in the model:

- Surficial sediments are 2 m thick and will be removed by dredging;
- Half of the drill arisings from drilling through the bedrock will settle in close proximity to the drill site, most of which will comprise coarse clumps. This material is not included in the model; the depth and area of the spoil heap will be considered conceptually, drawing on the results of the Lynn and Inner Dowsing monitoring study (CREL, 2007);
- Half of the drill arisings from drilling through the bedrock will comprise fine sediment (63 μm). In reality some of this material could include some coarser fractions. However results from the Lynn and Inner Dowsing study indicate a highly variable grain size distribution and the assumption of fines represents a worst case with regards to the extent of the area of impact;
- The material properties of a 'medium strength limestone' (BGS, 1993) have been used to calculate the *in situ* mass of sediment, specifically a sediment density of 2,160 kg/m^3 has been assumed;
- The duration of drilling was condensed from 15 consecutive 12 hour shifts, to a continuous 180 hour period (7.5 days). This provides a higher intensity of release and avoids any constraints being placed on drilling times. It is assumed that it will take 176 hours of continuous operation to drill through the 13 m bedrock layer;
- For drilling through the bedrock, release rates are 1.9 kg/s and 2.4 kg/s for the intake and outfall, respectively; and

- Drill cuttings (fines) are released in the surface layer (Layer 1) of the model (the top 2% of the water column). The actual position of discharge is unknown, and could be at the bed or surface depending on drilling method. A surface release is assumed as this represents a worst case, as sediment will persist in the water column for longer and provide a larger extent of effect.

The model was set up to examine drilling commencing on spring and neap conditions (i.e. two separate model runs). In both model runs sediment releases begin at the time of low water so that the sediment plume is initially carried southwards, towards the key coastal receptor of Thorpeness. Each model run was 15 days, with the model run on for 7.5 days following the completion of the drilling.

Modelling considers the drilling of one intake and one outfall structure, with the most inshore of the outfall structures being selected (O9a), and the most southerly and inshore of the intakes (I4a) selected. These locations were chosen so as to simulate the impacts of Suspended Sediment Concentrations (SSC) above background concentrations and thicknesses of bed deposition closest to the shore.

2.2 Scenario 2. Installation of additional structures

This scenario comprises the release of sediments associated with the excavation of additional outfall structures, which includes two Fish Recovery and Return (FRR) outfalls and one Combined Drainage Outfall (CDO). These structures are located inshore of the CWS structures in much shallower water depths (see Figure 1). Surficial sediments will be removed by dredging and the FRR and CDO structures would rest within the sand surface (i.e. no drilling is required). This scenario therefore considers releases of sediment associated with:

a) Dredging of surficial sediments. Cefas has provided calculations of excavated volumes *in situ* of 1,845 m^3 per outfall (with each outfall structure having the same dimensions). This sediment volume is based on a frustum pyramid (as for the CWS intakes and outfalls, see Figure 2) and a conservative estimate with dredging to a depth of 2 m. The dredge area is 44 x 30 m at each outfall. The dredge is expected to be conducted by a Cutter Suction Dredger with local disposal. Thus, only the sediment disturbed at the seabed by the dredger was simulated in the model for this aspect; and

b) Disposal of the dredged surficial sediments. Cefas has indicated that local disposal presents the worst-case scenario for this element. For this assessment, it is assumed that a Cutter Suction Dredger would discharge to a pipe approximately 500 m to the southeast of dredge site.

The dredging and disposal have been considered as one discrete activity, since they will occur simultaneously.

2.2.1 Characteristics of sediments

Details of the surficial sediments local to the FRR and CDO structures are provided by a study undertaken by Kenneth Pye Associates, (2011). The grab samples located in the region of the proposed FRR and CDO structures indicate fine sand with a median grain size of around 270 µm (Samples G0361 and G0362 – see Figure 1). No mud was present in these samples. Borehole data collected by EDF (2015) from three cores in relatively close proximity to the structures is also available; this data is summarised in Table 6.

Table 6. **Summary of borehole data close to the FRR and CDO structures**

Depth Below Surface	Core 16	Core 17	Core 21
0-1 m	Silty fine to med sand	Fine to medium sand	Fine to medium sand
1-2 m	Silty fine to med sand	Medium to coarse sand	Slightly Silty fine to medium sand

For the purposes of modelling it is assumed that 5% of the dredge material comprises silts with a representative grain size of 20 µm and 95% is fine sand with a representative grain size of 210 µm.

2.2.2 Sediment release rates

The sources of sediment release are similar to those for the dredging of the CWS structures (see Section 2.1.3) being local bed disturbance at the cutter head and disposal of material from the end of the discharge pipe.

As for Scenario 1, the 'S-factor' method was applied to calculate the sediment releases associated with the action of the cutter; a value of 6 kg per cubic metre of dry solid was applied.

The FRR and CDO structures lie further inshore than the intake and outfall structures for the cooling water system, in an area where present day water depths are between 3.65 to 5.35 m ODN (see Table 7). On this basis, the larger dredger assumed for the dredging for the cooling water intake and outfall head construction would be too large to be used for the dredging of the FRR and CDO structures. A more suitable dredger would be the Humber Work Boats' 'John M'; this has a pipe diameter of 0.29 m and a much lower dredging rate of around 480 m^3 *in situ* per hour.

Table 7. **Water depth at FRR and CDO structures pre- and post-dredge**

Structure	Location		Depth (mODN)	
	Eastings (m)	Northings (m)	Pre-dredge	Post-dredge
FRR T1	647810	264000	3.65	5.65
FRR T2	647810	264300	4.19	6.19
CDO	647980	264340	5.35	7.35

Note that an intermediate sized dredger could be used to complete the dredging at both the deeper CWS structures and at the shallower FRR and CDO structures. However, this would require a modified setup to the dredger to allow the deeper locations to be dredged and would place a tidal constraint on the period of dredging operations at the shallower structure locations and as such the use of such a dredger was considered unlikely.

Based on the volumes to be dredged at the FRR and CDO structures, it would take approximately four hours of continuous dredging to complete each structure using the 'John M'. The dredging will not be continuous, with repositioning of the spuds required at intermittent periods. Allowing for 12 repositioning's of the spuds and assuming a 30 minute duration for each repositioning, the dredge will take approximately 9.5 hours to complete the dredging of surficial sediments at each outfall structure (with 12 cycles of 19 minutes of dredging, followed by a 30 minute interval for repositioning).

The proposed dredge approach, with local disposal approximately 500 m from the dredge location, requires the consenting of an alternative disposal site to that used for Scenario 1 (the dredging associated with the CWS structures). Alternative disposal methods could be considered which would enable disposal at one single location for all dredge material. For example, material could be pumped to barges and these could transit to the disposal location for material dredged from the CWS structures.

The sediment release rates applied in the model were derived as follows:

- The material properties of quartz were used to calculate the *in situ* mass of sediment, specifically a sediment density of 2,650 kg/m^3 was assumed;
- The total volume of sediment to be dredged at the FRR and CDO structure locations is 5,535 m^3, with 1,845 m^3 to be dredged at each of the structure locations;
- The assumed *in situ* dredge rate was 480 m^3 per hour giving a release rate for disposal of 125 kg/s, based on a dry bed density of 938 kg/m^3 (equivalent to a wet density of 1,600 kg/m^3). This bed density is representative of near surface bed material which is affected by tidal flows;
- The total mass released in the model due to cutter head disturbance = 6 kg x 480 m^3 per hour, yielding a release rate of 0.8 kg/s;
- The sediment release associated with the action of the cutter was distributed equally over four cells for each structure, centred on the outfall locations;
- Sediment disturbed by the action of the cutter was input into Layer 8 (the bottom 35 % of the water column);
- The sediment release associated with the disposal material was from a single location at 648200, 263800. This is approximately 500 m southeast of FRR T1. The distance from the other structures is slightly longer, being 585 m and 635 m from the CDO and FRR T2, respectively;
- Sediment released at the disposal site was equally split between Layer 1 (top 2% of the water column) and Layer 8. The input into Layer 1 reflects the level of input from the discharge pipe for the passive plume, while the input into Layer 8 takes some account of the dynamic plume (although the dynamic phase is not directly represented in the modelling);
- The disposal from the pipe will be at a velocity sufficient to avoid sediment settling and blocking the pipe, the discharge velocity at the end of the pipe is therefore expected to be around 5 m/s. The momentum at the outfall would induce some turbulent mixing; this process is not included in the PART model, however to account for some of this spreading the sediment has been be input over a 10 m radial area;
- For the dredging of the outfall structures, each dredger cycle comprised of 19 minutes of dredging, followed by a 30 minute gap when the dredger was repositioned. It therefore takes approximately 9.5 hours to complete the dredging of each outfall structure;
- The construction sequence is such that there will be a sufficient gap between the dredging at each individual outfall structure so that any disturbed sediment will have fully dispersed before the subsequent structure is dredged. The model therefore simulates the sediment dispersion associated with the dredging of one single structure;
- The sediment plumes arising from dredging either of the three outfall locations will not differ significantly, with the majority of the sediment plume resulting from disposal (which is assumed to be at a single location) and with only a small sediment disturbance at the dredger itself. The dredging at FRR1 (the most southerly and inshore structure) was simulated in the model; and

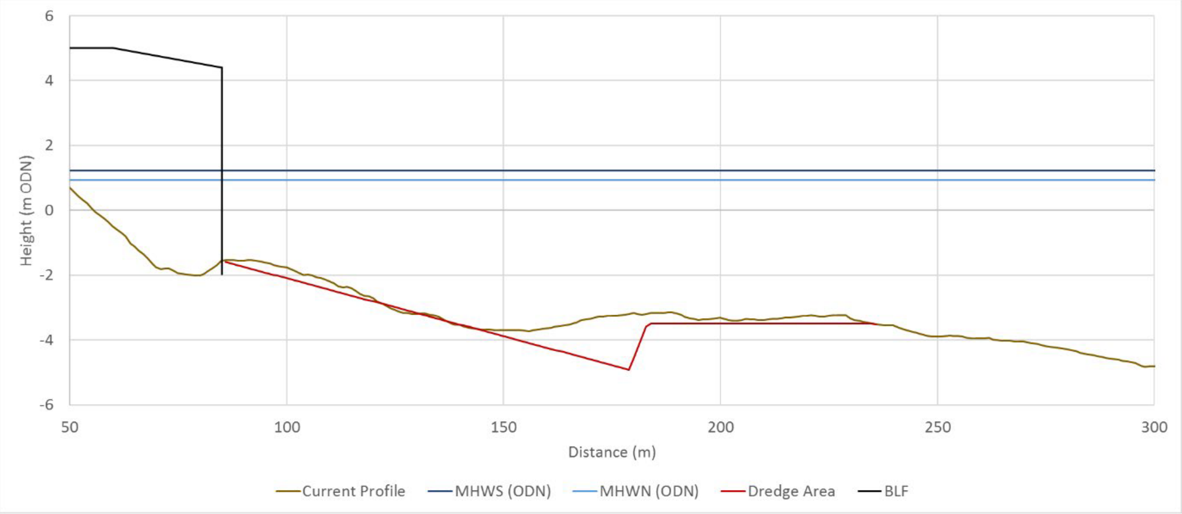
- The pre-dredge bathymetry was used in the model and therefore no adjustments for deepening as a result of the dredge have been included.

The model was set up to examine dredging starting on spring and neap conditions (i.e. two separate model runs). Each model run simulated the dispersion of sediment over a 15 day spring-neap period, with intermittent sediment release during the first 9.5 hours and with the model run on for 14.5 days following the completion of the dredge.

2.3 Scenario 3. Dredging of the BLF approach channel

This scenario comprises the dredging for a Beach Landing Facility (BLF) so that North Sea Barges, which will be used to deliver freight, can gain access to shore. A plough or a scraper method will be used to provide clearance over the outer longshore bar and to flatten the inner bar so that barges can come safely aground. The desired profile will require the movement of an estimated 3,850 m^3 of sediment *in situ*. However, the inner and outer bar are mobile and are likely to be different for each dredge and a conservative estimate of the dredge volume has been obtained by allowing for an additional 750 m^3 of sediment *in situ*. A total dredge volume of 4,600 m^3 *in situ* has therefore been modelled. The location of the BLF is shown in Figure 1. A cross section of the required reprofiled seabed is shown in Figure 3.

For this Scenario, both a capital dredge and a maintenance dredge (which is likely to be required at routine intervals to ensure that vessel access to the BLF is maintained) have been considered. The former is based on the total dredge volume, while the latter simulates the removal of 10 % of the total capital dredge volume.



Source: Cefas

Figure 3. Required reprofiled seabed for the BLF

2.3.1 Characteristics of sediments

Vibrocore survey data from the vicinity of the proposed BLF channel (VC30) indicates surficial sediments of fine to medium sands (top metre) overlaying a metre of coarse to medium sand and a subsequent layer of silty to medium sand. This is consistent with the closest grab samples to the area of excavation (G0361) which indicates sand with a median grain size of 266 µm. Only the upper two metres will be reprofiled and therefore only the dispersion of sand fractions are considered in the model for this scenario. A sediment grain size of 210 µm was applied to represent the fine to medium sand. While there is some coarser sand within the sediment to be removed this material is likely to re-settle on the bed within the dredge area and therefore unlikely to disperse to the wider marine environment.

2.3.2 Sediment release rates

For modelling of the dispersion of sediment from the plough dredging it is necessary to calculate a disturbance rate (kg/s dry solid) to be input to the model during the plough operation. Plough dredging involves the mechanical agitation of the bed with the ambient flows removing the sediment in suspension away from the dredge area. The rates of dredging using this method are therefore highly variable throughout the tide, with higher rates of sediment removal expected during periods of faster tidal flows. Rates of removal will also vary considerably with the sediment type (grain size and bed density) being dredged.

To determine suitable input parameters to represent the sediment release in the model a number of assumptions were made. Unless stated otherwise, these assumptions apply to both the capital and maintenance dredge:

- The material properties of quartz were used to calculate the *in situ* mass of sediment, specifically a sediment density of 2,650 kg/m^3 was assumed;
- A total dredge volume of 4,600 m^3 *in situ* has been modelled for the capital dredge;
- A total dredge volume of 460 m^3 *in situ* has been modelled for the maintenance dredge;
- It was assumed that the vessel would dredge in a shore parallel direction, in the same direction as the tidal flow. Following the completion of the dredge along one pass of the dredge area, it was assumed that the dredger would transit round in a loop, back to the start position;
- The assumed vessel speed during dredging was 1.95 knots (1 m/s) so that each 62 m length to be dredged takes about 1 minute, the turning time to reposition back at the start was assumed to be 3 minutes;
- The plough width was assumed to be 10 m, this is consistent with the UKD dredgers the Sealion and the Seahorse, which have a maximum draught of 2.55 m and can work in depths of more than 20 m. The use of these plough vessels would be depth constrained around low water with pre-dredge water depths of 1.4 m to 3.5 m. Depth constraints are not considered in defining the sediment release rates for modelling;
- The average sediment moved by the plough on one pass through the dredge area was assumed to be of the order of 0.1 to 0.3 m deep. However, a large proportion of this material is likely to resettle within the BLF dredge area on each pass. Assuming that 10 % of the material is moved outside of the dredge area in suspension each pass, yields a sediment release of 0.1 x 0.1 m depth x 10 m width x 62 m length = 6.2 m^3 in 1 minute (or 372 m^3 per hour);
- The dry bed density was assumed to be 938 kg/m^3 (equivalent to a bulk density of 1,600 kg/m^3), therefore the sediment disturbance release rate during dredging was taken to be 97 kg/s. As noted above, these rates are expected to be highly variable depending on the local flow speeds during the dredge;
- The sediment release associated with the plough was distributed over five cells to the south of the BLF footprint, with different proportions released in different cells to account for the different depths of sediment to be removed. In reality, the release location would be likely to vary between the north and south of the BLF with the plough working in the same direction as the tidal flow. The modelled release to the south considers a worst case with respect to the key coastal receptor at Thorpeness;

- Sediment disturbed by the action of the plough was input into Layer 8 of the model (the bottom 35 % of the water column);
- Assuming dredging operations would occur around the clock, the reprofiling for the capital dredge would take approximately 2.1 days to complete with 742 cycles of 1 minute of dredging, followed by 3 minutes of transit;
- Assuming dredging operations would occur around the clock, the reprofiling for the maintenance dredge would take approximately 5 hours to complete with 74 cycles of 1 minute of dredging, followed by 3 minutes of transit.
- Sediment releases begin at the time of low water so that the sediment plume is initially carried southwards, towards the key coastal receptor of Thorpeness; and
- The pre-dredge bathymetry has been used in the model as the effect of any deepening on flows is expected to be minimal and highly localised so that the changes will be mainly constrained within the dredged area.

The model was set up to examine dredging starting on spring and neap conditions (i.e. two separate model runs). Each model run simulated the dispersion of sediment over a 15 day spring-neap period, with the dredge occurring during the first 2.1 days (5 hours for the maintenance dredge) and with the model run on for a further 13 days (15 days for the maintenance dredge) following the completion of the dredge.

2.4 In-combination assessment

There is a possibility that the dredging of surficial sediments for the installation of the CWS and additional outfall structures could occur coincident with a maintenance dredge of the BLF approach channel. To provide an assessment of any potential in-combination effects, the model results from the different model simulations have been combined. Two in-combination scenarios have been considered:

1) maintenance dredging of the BLF approach channel with dredging of surficial sediments at intake I4a; and
2) maintenance dredging of the BLF approach channel with dredging of surficial sediments at the FRR1 structure.

To consider a worst case with respect to maximum plume areas, it is assumed that the dredging for each individual activity starts concurrently at the time of low water.

3 Results

The outputs from the model are selected to show the overall extent of effect from the proposed dredging and drilling activities, with plan view plots of the maximum plume dispersion. The maximum values are referred to in the following as location maxima as they are not for an individual timestep but rather a maximum value at each individual gird cell or location. While the location maximum plots are useful for informing the potential impact of the sediment dispersion on receptors on the bed (since they indicate areas where smothering could occur), they do not reflect the transient nature of the plume in suspension, which receptors are unlikely to be sensitive to. To demonstrate the transient nature of the plume, plan view plots of the 95th percentile (P95) of SSC are also included. The P95 values are calculated over the spring-neap model simulation period. Suspended Sediment Concentrations (SSC) have been averaged over all model layers to provide equivalent depth average values. Results for the surface layer of the model are also provided.

The results also show the plume dispersion patterns at specific times during the spring and neap tides. SSC have been averaged over all model layers to provide equivalent depth average values. Time- series plots at selected locations along the main axis of the plume are also included to illustrate the variability over the time of the model scenario. All results shown are values above background.

For all scenarios, sedimentation on the seabed has been calculated assuming a density on the bed of 285 kg/m^3. This corresponds to a wet density of 1,200 kg/m^3, representative of freshly deposited material, which is loosely consolidated on the bed. Over time, if deposits are not re-eroded by tidal flows, they will gradually compact and the thickness of deposits will reduce. Scaling can be applied to the presented values to determine thickness of deposits at different *in situ* densities if required.

A detailed impact assessment is beyond the scope of this study, however it is useful to understand how the modelled SSC and sedimentation values, which are quoted above background levels relate to background levels. Survey work at Sizewell carried out as part of the BEEMS project in 2009 and 2010 show that the inshore daily maximum background SSC is in the range 357 to 609 mg/l at 0.3 m above the seabed and 266 to 459 mg/l at 1 m above the seabed (BEEMS Report TR098). The background SSC at the surface ranges between 9 to 436 mg/l inshore and between 28 and 246 mg/l offshore (close to the planned intake and outfall structures, BEEMS Report TR189). While a detailed impact assessment is not included in this report, the model outputs have been presented to facilitate such an assessment (being undertaken Cefas).

Instantaneous plume areas have been quantified, with a focus on maximum areas of intersect with bird foraging areas. The plume areas are defined as depth average or surface SSC above 100 mg/l, with surface values being most relevant to assessing the impact to Terns and Gulls and depth average values being most relevant to red throated divers.

Cefas has identified multiple bird foraging areas (relating to different bird species and colonies, where relevant) that could be affected by any sediment plumes arising from the proposed dredging activities. The extent of the bird foraging areas are tabulated in Table 8, with values given in hectares (Ha), and the location in relation to the infrastructure are shown in Figure 4. The foraging areas for the Sandwich Tern colonies and the Lesser Black Backed Gull extends across the model domain and as such the total plume areas can be considered for the assessment of effect on these bird species.

Table 8. Bird foraging areas

Bird species	Colony	Area (Ha)
Little Tern	Dingle	1,851
	Minsmere	1,638
	Slaughden	1,788
Common Tern	Minsmere	51,148
	Orfordness	63,663
Sandwich Tern	Northern	161,870
	Central	172,060
	Southern	188,360
Lesser Black Backed Gull	Not Applicable	3,873,400

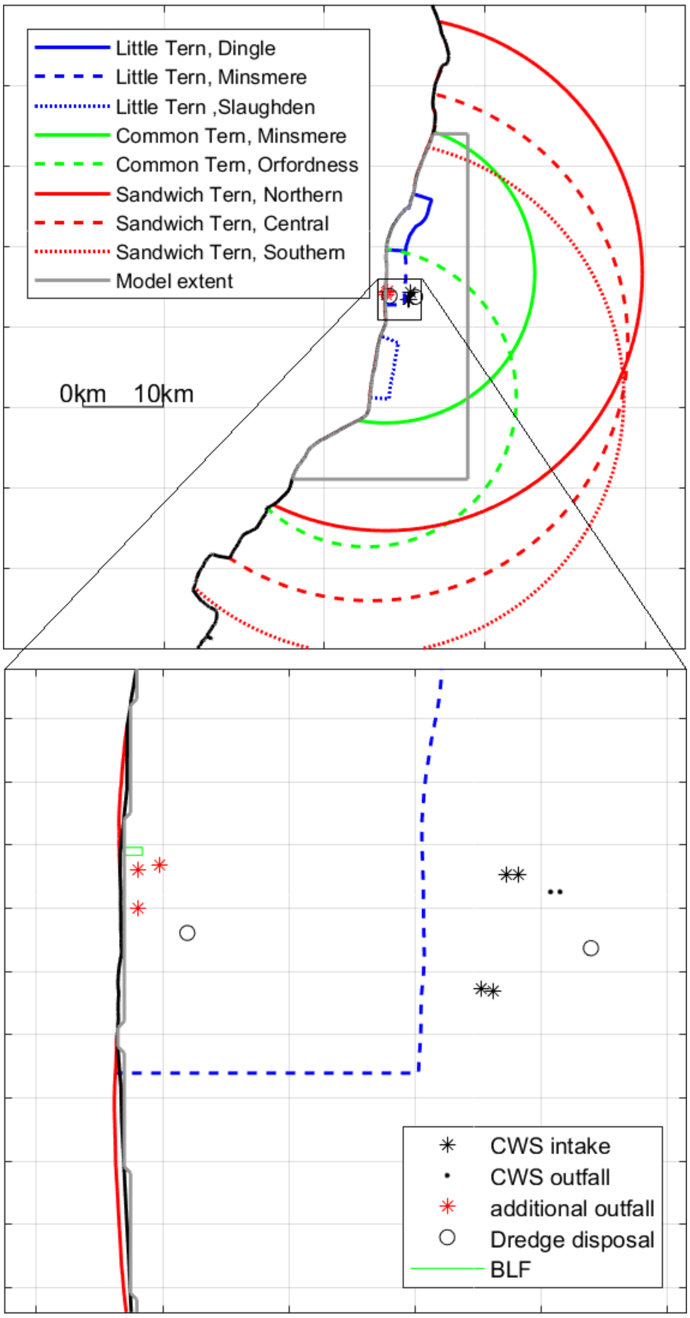


Figure 4. Bird foraging areas

3.1 Scenario 1. Installation of the CWS intake and outfall structures

3.1.1 Dredging of surficial sediments at the CWS structures

Plan plots of the location maximum depth average SSC associated with the dredging of surficial sediments at the CWS intake structure (I4a) and outfall structure (O9a) are shown for spring and neap tides in Figure 5. Equivalent plots of location maximum SSC for the surface layer of the model are provided in Figure 6. These plots show the maxima recorded at any time over the length of the model scenario and they do not take into account the length of time or how frequently these conditions occur.

Highest depth average location maximum SSC's occur for the dredging of Intake I4a. The resultant plume extends along the main flow axis, with values of more than 100 mg/l above background from approximately 13 km to the north and 22 km to the south of the disposal location on spring tides (Figure 5). The northern extent of the sediment plume is slightly reduced (to around 7 km) on neap tides. The maximum plume concentrations reduce rapidly in a direction perpendicular to the flow, with depth average SSC returning to background concentrations within approximately one kilometre to the east and one kilometre to the west of the disposal site. Due to the offshore location of the sediment release, the coastal areas are not expected to be affected by the plume with only low concentrations in suspension and minimal settling occurring on the bed in the inshore region.

To quantify the extent of the plume, the areas of location maximum SSC above different threshold values have been calculated. Results are presented for the dredging at Intake I4a and Outfall O9a, as both depth average and surface SSC in Table 9 to Table 12. Areas are given in Ha.

An area of 3,757 Ha is affected by increases in depth average SSC of more than 100 mg/l as a result of the dredge at Intake I4a, when the dredge is started on spring tides (Table 9). This area is reduced to 2,950 when the dredge is started on neap tides. Areas of elevated surface SSC are generally less than the depth average values as can be seen by comparing Table 9 and Table 10 with Table 11 and Table 12.

To provide some indication of how long the conditions prevail, the plume areas have been calculated for different threshold values and durations (Table 13). No area is affected by increases of more than 50 mg/l for a continuous duration of more than six hours.

Table 9. Areas of location maximum depth average SSC resulting from dredging of the surficial sediments at Intake I4a

SSC > mg/l	Spring Tides		Neap Tides	
	Area (Ha)	% of Plume Area	Area (Ha)	% of Plume Area
0	20,824	100	16,297	100
20	8,920	43	7,126	44
50	6,422	31	5,268	32
100	3,757	18	2,950	18
200	1,092	5	1,242	8
300	467	2	574	4
500	150	1	216	1
1000	39	<1	52	<1
2000	12	<1	13	<1

Table 10. Areas of location maximum depth average SSC resulting from dredging of the surficial sediments at Outfall O9a

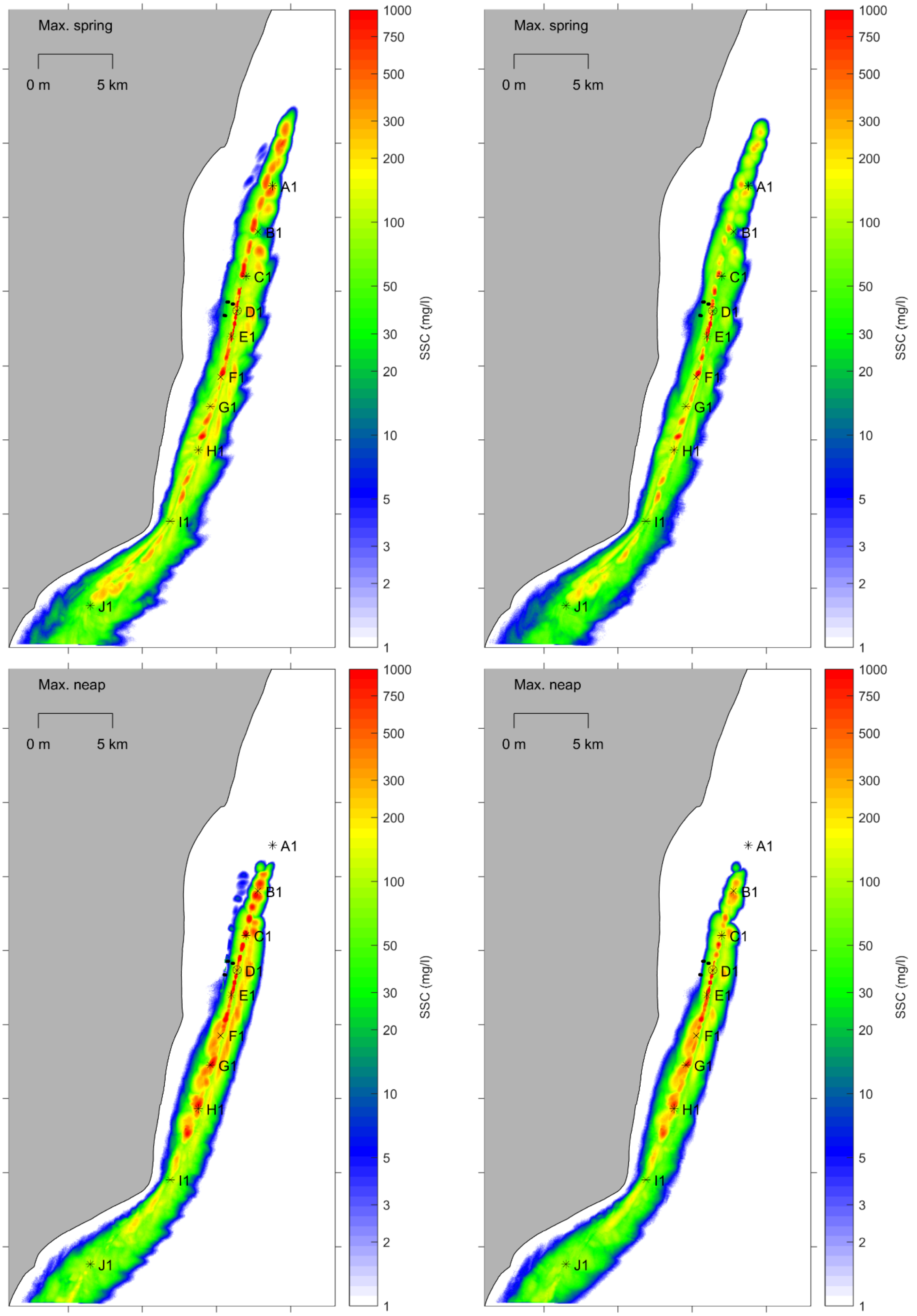
SSC > mg/l	Spring Tides		Neap Tides	
	Area (Ha)	% of Plume Area	Area (Ha)	% of Plume Area
0	20,014	100	15,719	100
20	7,714	39	6,656	42
50	4,840	24	4,405	28
100	1,787	9	2,098	13
200	369	2	764	5
300	150	1	300	2
500	66	<1	79	<1
1000	19	<1	15	<1
2000	4	<1	6	<1

Table 11. Areas of location maximum SSC in the surface layer of the model resulting from dredging of the surficial sediments at Intake I4a

SSC > mg/l	Spring Tides		Neap Tides	
	Area (Ha)	% of Plume Area	Area (Ha)	% of Plume Area
0	13,928	100	11,399	100
20	6,899	50	5,411	47
50	4,281	31	3,839	34
100	2,226	16	2,383	21
200	858	6	1,128	10
300	442	3	594	5
500	220	2	205	2
1000	63	<1	22	<1
2000	7	<1	4	<1

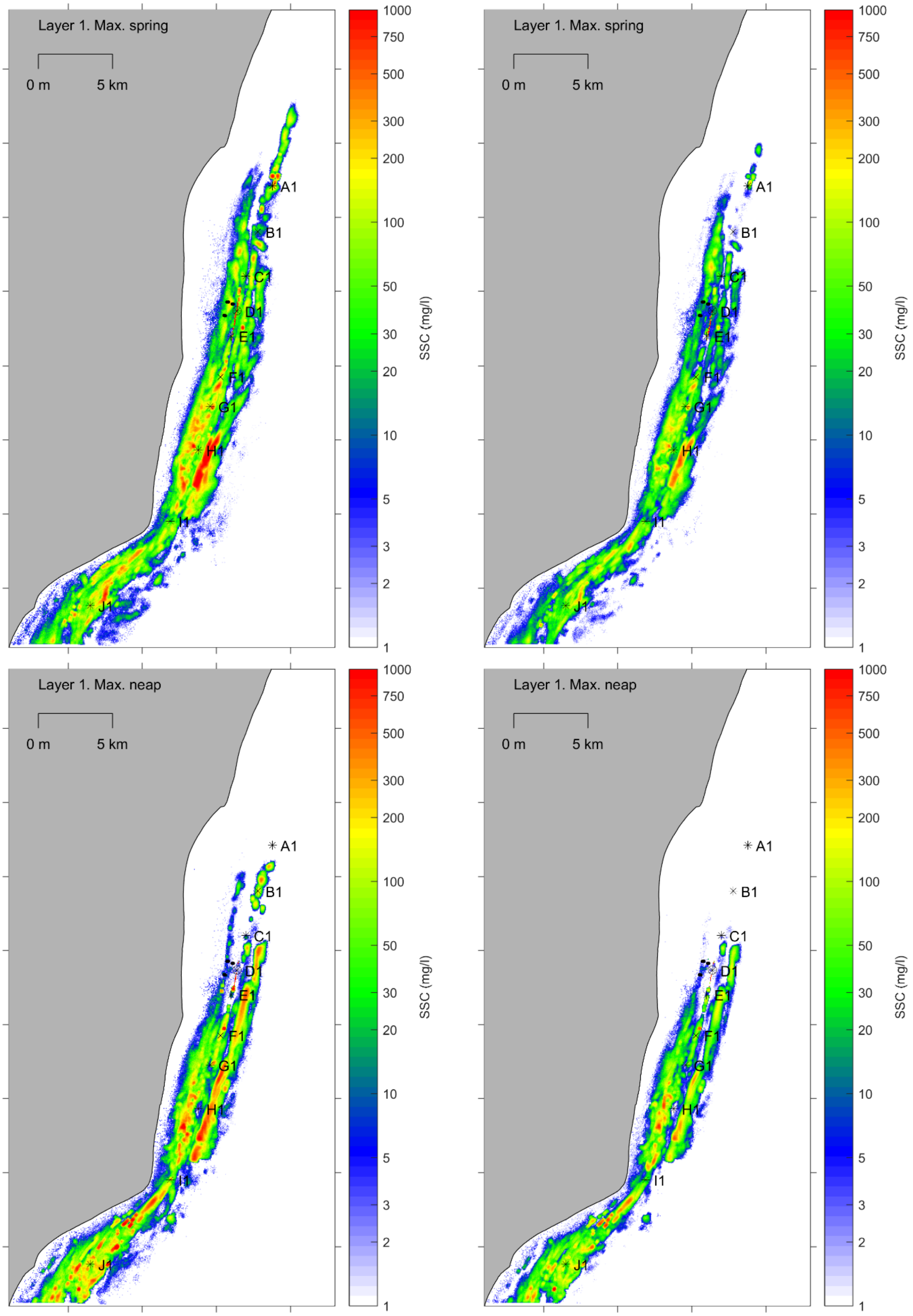
Table 12. Areas of location maximum SSC in the surface layer of the model resulting from dredging of the surficial sediments at Outfall O9a

SSC > mg/l	Spring Tides		Neap Tides	
	Area (Ha)	% of Plume Area	Area (Ha)	% of Plume Area
0	12,911	100	9,199	100
20	4,206	33	4,096	45
50	2,008	16	2,405	26
100	835	6	1,086	12
200	251	2	354	4
300	106	1	153	2
500	15	<1	33	<1
1000	6	<1	3	<1
2000	4	<1	1	<1



Disposal is at D1. Black dots show CWS structures. Other locations (A1 to J1) show time series extraction points

Figure 5. Location maximum depth average SSC associated with dredging at Intake I4a (left hand panels) and Outfall O9a (right hand panels) on spring and neap tides



Disposal is at D1. Black dots show CWS structures. Other locations (A1 to J1) show time series extraction points

Figure 6. Location maximum surface SSC associated with dredging at Intake I4a (left hand panels) and Outfall O9a (right hand panels) on spring and neap tides

Table 13. Areas of location maximum SSC in the surface layer of the model for different continuous durations resulting from dredging at Intake I4a

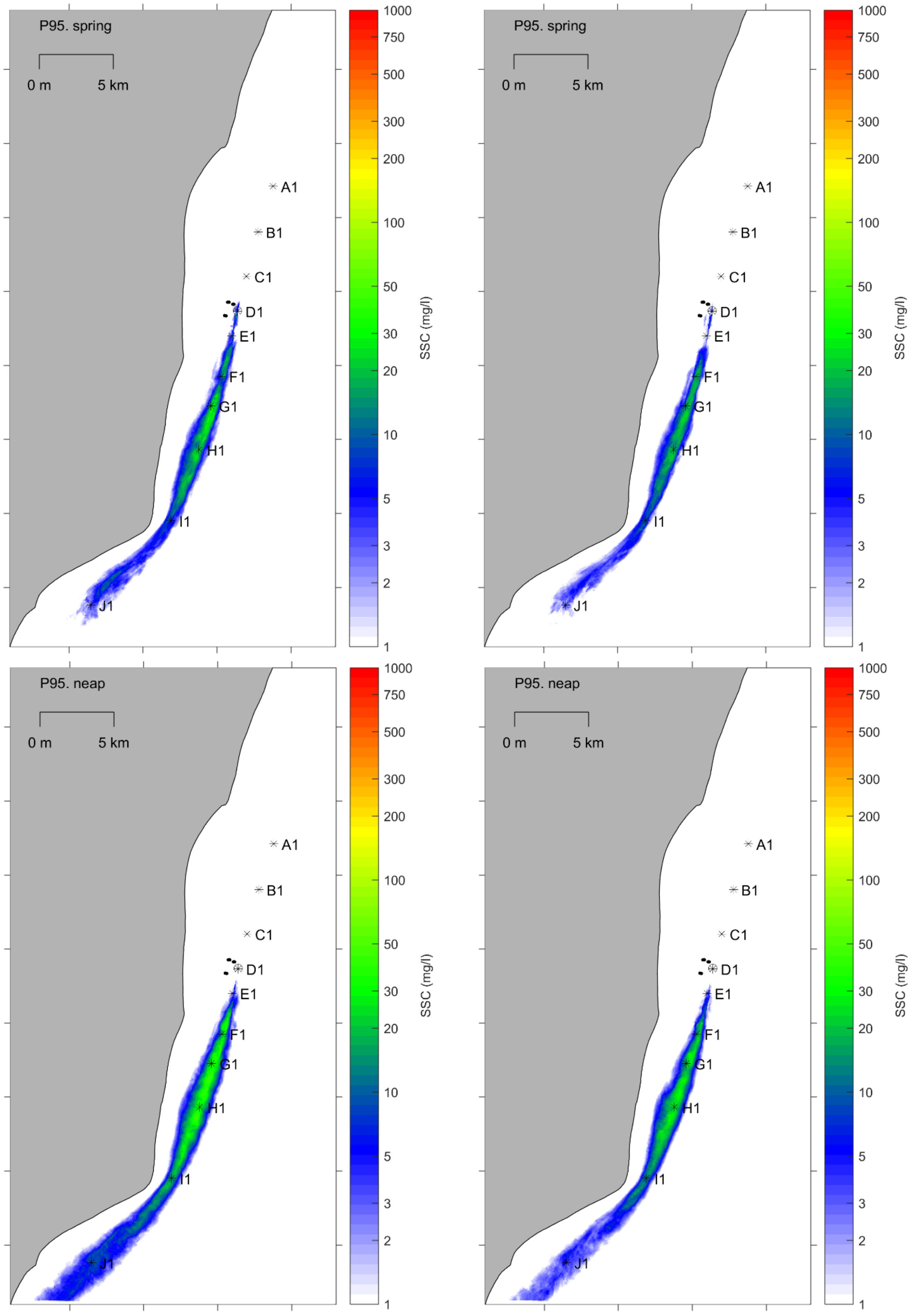
SSC > mg/l	Duration (>= hours)	Area (Ha)	
		Spring Tides	Neap Tides
50	1	4,281	3,839
50	3	51	106
50	6	0	0
50	12	0	0
100	1	2,226	2,383
100	3	145	95
100	6	0	0
100	12	0	0
300	1	443	594
300	3	<1	1
300	6	0	0
300	12	0	0

Plan plots of P95 SSC associated with the dredging of surficial sediments at the CWS intake structure I4a and outfall structure (O9a) are shown as depth average values in Figure 7 and as surface values in Figure 8. The large reduction in P95 SSC in comparison to the location maximum values shown in Figure 5 and Figure 6, demonstrate the transient and short lived nature of the plume.

As for the maximum SSC, the highest P95 SSC's occur along the main flow axis. Values of more than 20 mg/l above background extending over an area of approximately 0.65 km in lateral extent on spring tides, centred on a point around 0.8 km southwest of the disposal site (Figure 7).

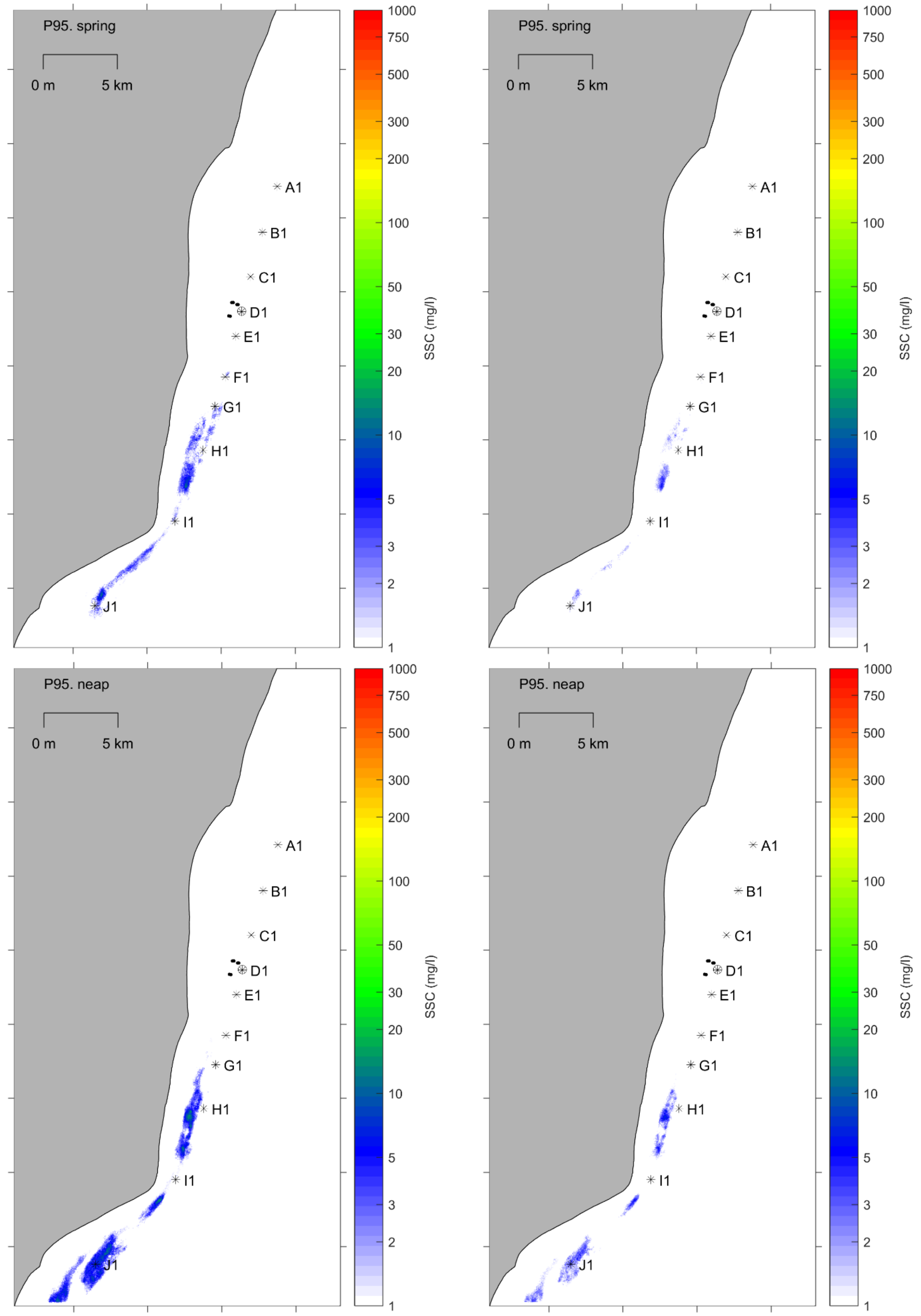
For the dredge occurring on neap tides, the lower flows result in a slightly less transient plume and subsequently P95 SSC above 20 mg/l extend over a larger area with a lateral extent of around 1.2 km. To the north of the disposal site, P95 values are not increased more than 10 mg/l above background indicating that any increase in SSC that does occur is at low concentrations and/or is short lived. The displacement of the plume to the south of the disposal location results from the release of the sediment on the flood tide when flows are southwards and also from the dominance of the southward flows. If the dredge were started at the time of high water, the plume centroid would likely be shifted northwards.

The location maximum sedimentation is plotted in Figure 9. Maximum sedimentation is highest in the immediate vicinity of the disposal site, where very localised sedimentation of more than 1,000 mm (1 m) occurs. Deposits of more than 1000 mm thickness only occur in two of the 50 m x 50 m model grid cells when the dredge is started on neap tides (i.e. over an area of 0.5 Ha). When the dredge is started on spring tides, the maximum thickness of deposit does not exceed 1000 mm in any model grid cell. The location maximum sedimentation rapidly reduces to more typical values of 10 mm at distances of *circa* 1 km from the disposal site. Sedimentation is highest on the neap tides, with discrete areas of maximum sedimentation of more than 10 mm extending 23 km to the south and 7 km to the north of the disposal site. Comparatively, maximum sedimentation on a spring tide is more typically less than 5 mm, with the faster spring tidal flows maintaining the material in suspension for longer periods than the relatively slower neap flows.



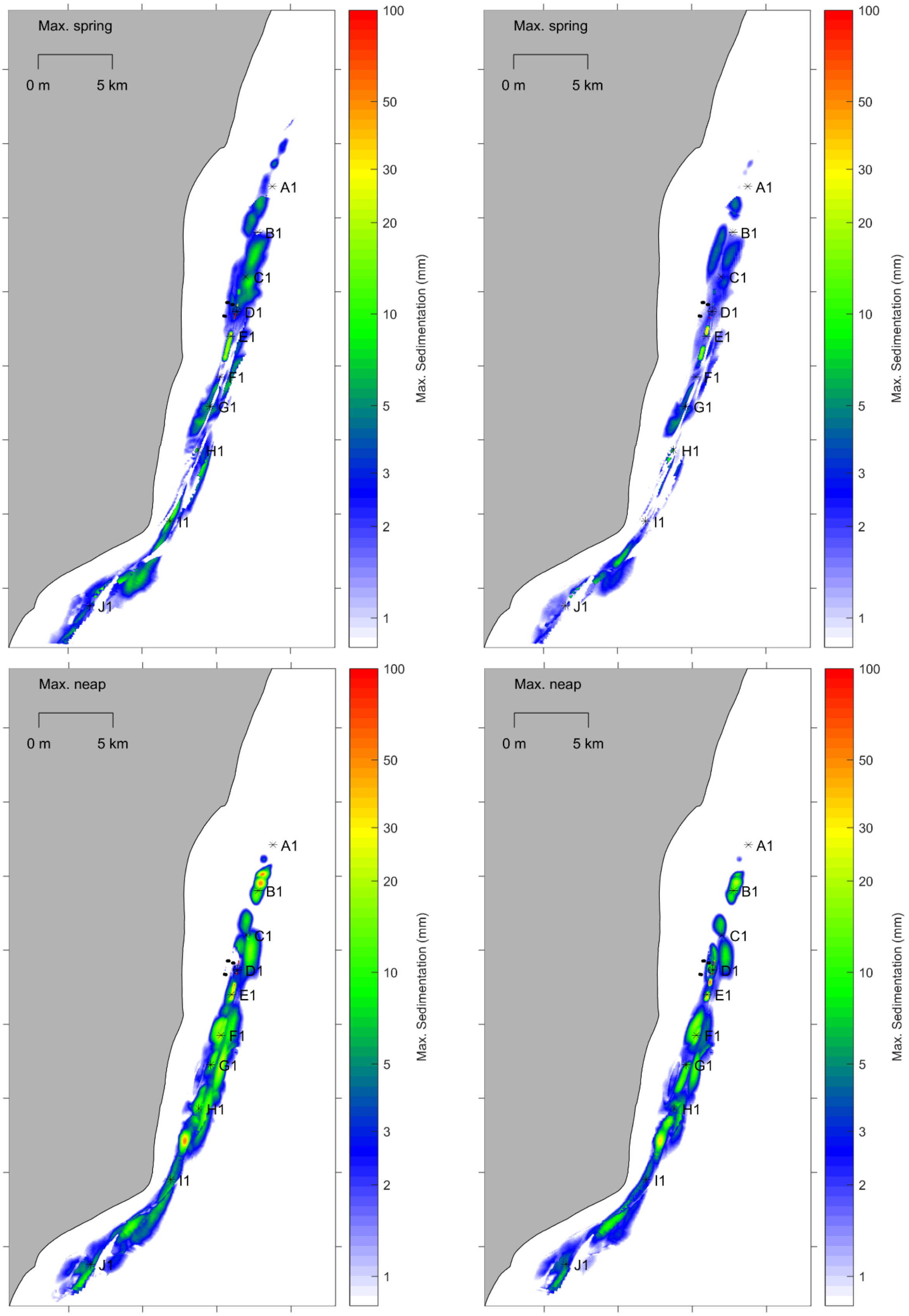
Disposal is at D1. Black dots show CWS structures. Other locations (A1 to J1) show time series extraction points

Figure 7. 95th Percentile depth average SSC associated with dredging at Intake I4a (left hand panels) and Outfall O9a (right hand panels) on spring and neap tides



Disposal is at D1. Black dots show CWS structures. Other locations (A1 to J1) show time series extraction points

Figure 8. 95th Percentile surface SSC associated with dredging at Intake I4a (left hand panels) and Outfall O9a (right hand panels) on spring and neap tides



Disposal is at D1. Black dots show CWS structures. Other locations (A1 to J1) show time series extraction points

Figure 9. Location maximum sedimentation associated with dredging at Intake I4a (left hand panels) and Outfall O9a (right hand panels) on spring and neap tides

Location maximum sedimentation on the bed covers an area of approximately 15,000 Ha, but at very low thicknesses (Table 14 and

Table 15). Areas affected by sedimentation of more than 2 mm thickness are constrained to 3,000 Ha when the dredge occurs on spring tides and to just over 4,000 Ha when the dredge occurs on neap tides. As noted previously, the location maximum values provide no indication of the duration of the periods of settling on the bed. To provide some indication of how long the conditions prevail, the sedimentation areas on the bed have been calculated for different threshold values and durations (see

Table 16). When the dredge occurs on spring tides, the sedimentation is typically short lived, with re-erosion occurring within one tidal cycle. When the dredge occurs on neap tides the time for which sediment remains on the bed is more prolonged.

Table 14. Areas of location maximum sediment thickness resulting from dredging of the surficial sediments at Intake I4a

Sediment Thickness > mm	Spring Tides		Neap Tides	
	Area (Ha)	% of Plume Area	Area (Ha)	% of Plume Area
0	15,224	100	14,315	100
2	2,997	20	4,006	28
5	698	5	1,737	12
10	65	<1	561	4
20	15	<1	106	1
50	4	<1	7	<1
100	3	<1	4	<1
300	1	<1	2	<1
500	0	0	1	<1
1000	0	0	1	<1

Table 15. Areas of location maximum sediment thickness resulting from dredging of the surficial sediments at Outfall O9a

Sediment Thickness > mm	Spring Tides		Neap Tides	
	Area (Ha)	% of Plume Area	Area (Ha)	% of Plume Area
0	14,521	100	13,457	100
2	1,582	11	3,205	24
5	119	1	1,017	8
10	32	<1	292	2
20	11	<1	40	<1
50	1	<1	4	<1
100	1	<1	2	<1
300	1	<1	1	<1
500	1	<1	1	<1
1000	0	0	1	<1

Table 16. Areas of location maximum sediment thickness for different continuous durations resulting from dredging at Intake I4a

Sediment Thickness > mm	Duration (>= hours)	Area (Ha)	
		Spring Tides	Neap Tides
5	1	698	1,737

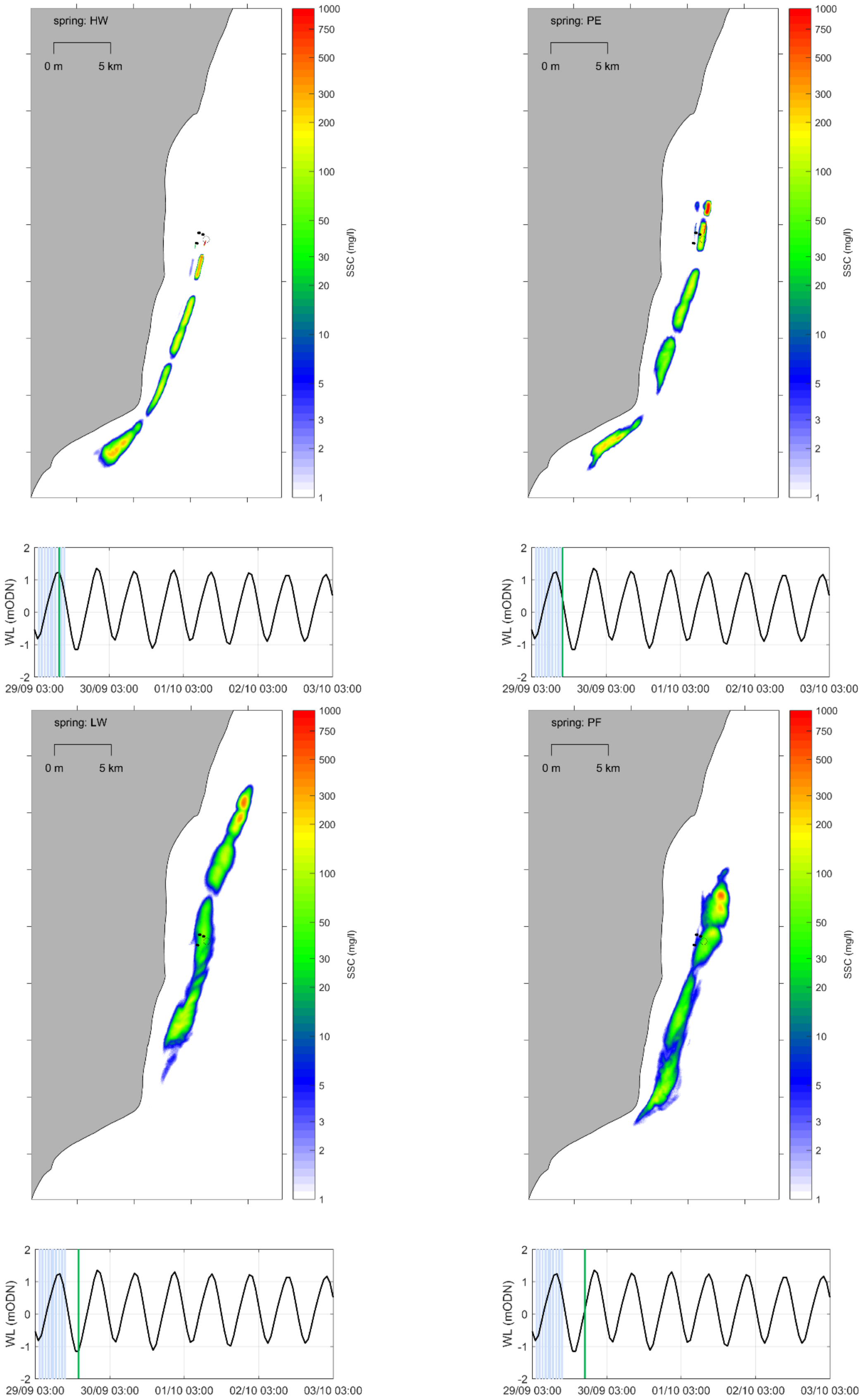
Sediment Thickness > mm	Duration (>= hours)	Area (Ha)	
		Spring Tides	Neap Tides
5	3	8	116
5	6	8	101
5	12	0	30
10	1	65	561
10	3	0	10
10	6	0	7
10	12	0	4
20	1	15	106
20	3	0	4
20	6	0	4
20	12	0	4
50	1	4	7
50	3	0	3
50	6	0	3
50	12	0	3
300	1	1	2
300	3	0	1
300	6	0	1
300	12	0	1

The coastal areas are not expected to be affected by the plume with only low concentrations in suspension and minimal settling occurring on the bed in the inshore region.

The location maximum and P95 SSC values and the location maximum sedimentation values are higher for the dredging at the intake structure than for the dredging at the outfall structure. This is due to the larger volumes of sediment released during the dredge of the intake structure. While there is a larger percentage of fines released at the outfall structure, the flows are typically at a magnitude which maintains not only the finest material in suspension, but also the fine sand. The discussion of results is therefore focussed on the results for dredging at the CWS intake.

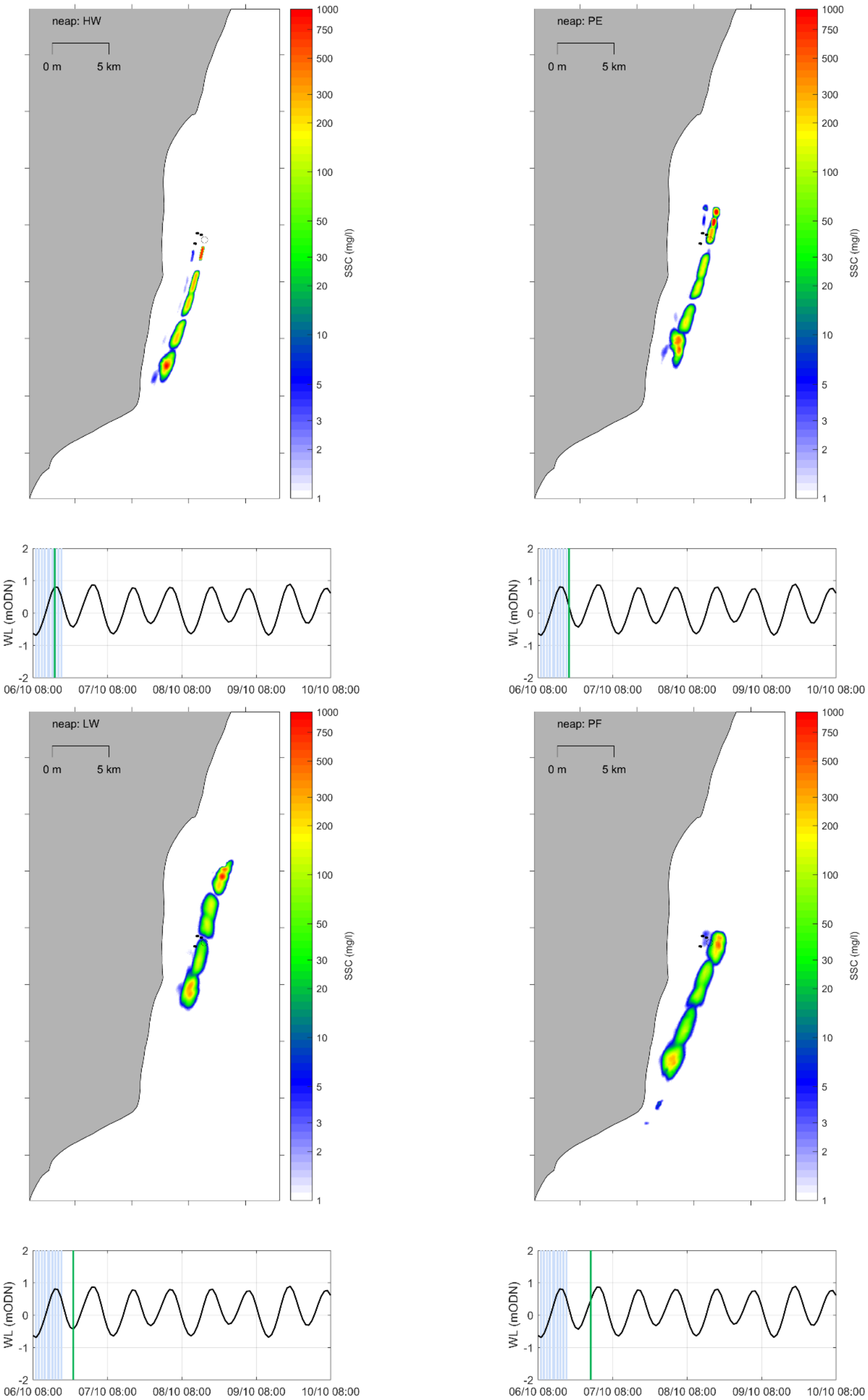
To show how the sediment plume evolves spatially throughout a semi-diurnal tide, plan plots of depth average SSC are shown at discrete tidal states on a mean spring tide and a mean neap tide in Figure 10 and Figure 11, respectively. The plots are shown for the dredging at the intake structure I4a. The timesteps shown correspond to the first High Water (HW) after the start of the dredging (which is approximately six hours after the first sediment release and is around two and a half hours before the final sediment release) and the times of the subsequent Peak Ebb (PE), Low Water (LW) and Peak Flood (PF). The plots demonstrate the transient nature of the plume, with the plume transported 15 km to the north and 20 km to the south on a spring tide and around 5 km to the north and 10 km to the south on a neap tide (Figure 11). The plume initially consists of discrete areas (high concentrations) of material in suspension, resulting from the intermittent nature of the sediment release; over time as the plume is transported with the tidal flows these discrete 'blobs' start to disperse and become less distinct. The main plume with highest concentrations is associated with the disposal of dredged material. A separate, smaller plume is evident slightly inshore of the main plume, this is associated with the sediment disturbed at the cutterhead.

Plan plots of sedimentation are presented throughout the same spring tidal period as shown for SSC (Figure 10) in Figure 12. These show the settling and subsequent re-erosion of sediment from the bed during the tide.



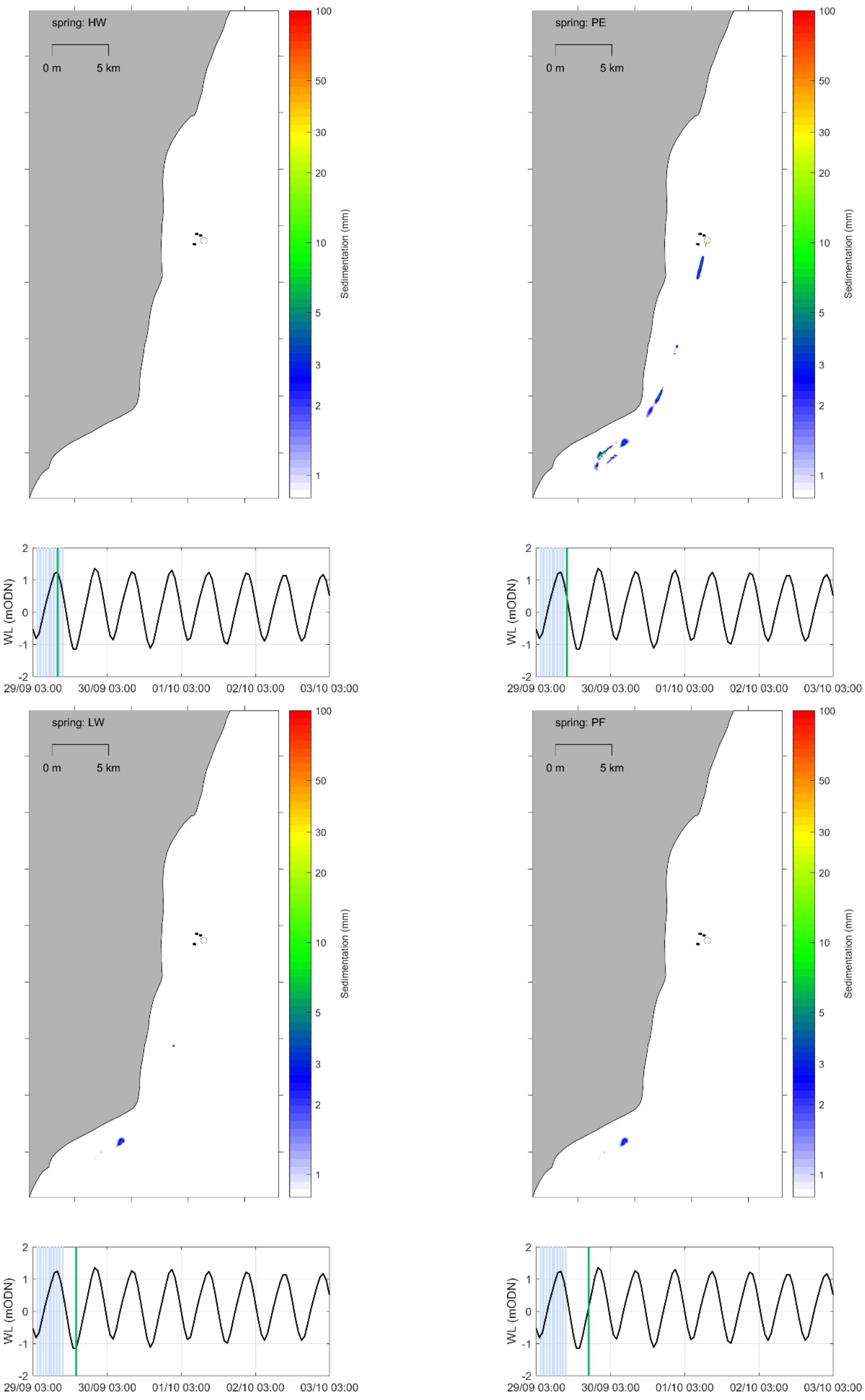
The pale blue shading on the time series plots indicate periods of sediment release.

Figure 10. Depth average SSC at HW, PE, LW and PF during dredging at Intake I4a on a spring tide



The pale blue shading on the time series plots indicate periods of sediment release.

Figure 11. Depth average SSC at HW, PE, LW and PF during dredging at Intake I4a on a neap tide



The pale blue shading on the time series plots indicate periods of sediment release.

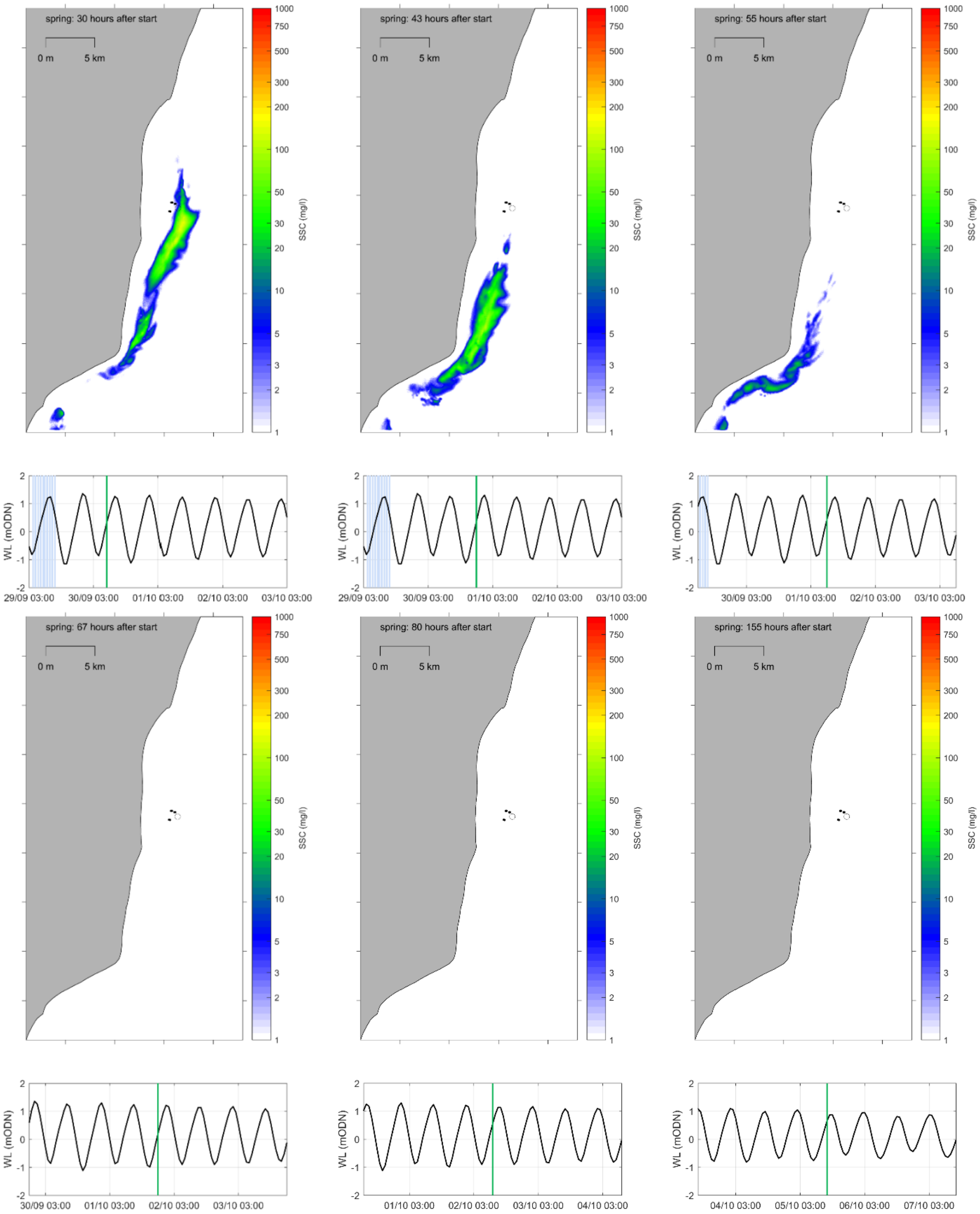
Figure 12. Sedimentation at HW, PE, LW and PF during dredging at Intake I4a on a spring tide

To show how the sediment plumes disperse over a longer duration, map plots of depth average SSC are shown at discrete timesteps on spring tides in Figure 13 and on neap tides in Figure 14. These are shown for the sediment release associated with the dredging at the intake structure I4a. These indicate that following the completion of the dredge, the plume quickly dissipates when the dredge occurs on spring tides. When the dredge occurs on neap tides the plume concentrations initially dissipate following the completion of the dredge and then increase. This increase is due to the faster spring tides resuspending sediment which has been deposited on the bed during the neap tides; once the sediment is back in suspension, it is rapidly dispersed.

There is some material remaining on the bed within the model area at the end of the model simulation, this accounts for approximately 7 % of the material released during the dredge at Intake I4a. As a result of a higher percentage of finer sediments, this is reduced to around 3% of the material released during the dredge at Outfall O9a. The areas of sedimentation on the bed above different threshold thicknesses at the end of the model simulation of the dredge at I4a are provided in Table 17. The area of deposited material at the end of the spring and neap run is shown in Figure 15, the deposits are very localised being constrained predominantly to a sheltered area located inshore of Whiting Bank (see location on Figure 1), close to the southern boundary of the model. The material deposited mainly comprises medium sands which require faster flows for resuspension to occur than the fine sands. The thickness of deposited material is 2-3 mm, although this is likely to reduce over time either by resuspension from storm waves or as settling occurs and the bed density increases.

Table 17. Areas of sediment thickness resulting from dredging of the surficial sediments at Intake I4a at the end of the model simulation

Sediment Thickness > mm	Area (Ha)	
	Spring Tide	Neap Tide
0	2,861	1,813
2	8	16
5	0	0



The pale blue shading on the time series plots indicate periods of sediment release.

Figure 13. Depth average SSC at stages during dredging at Intake I4a on a spring tide

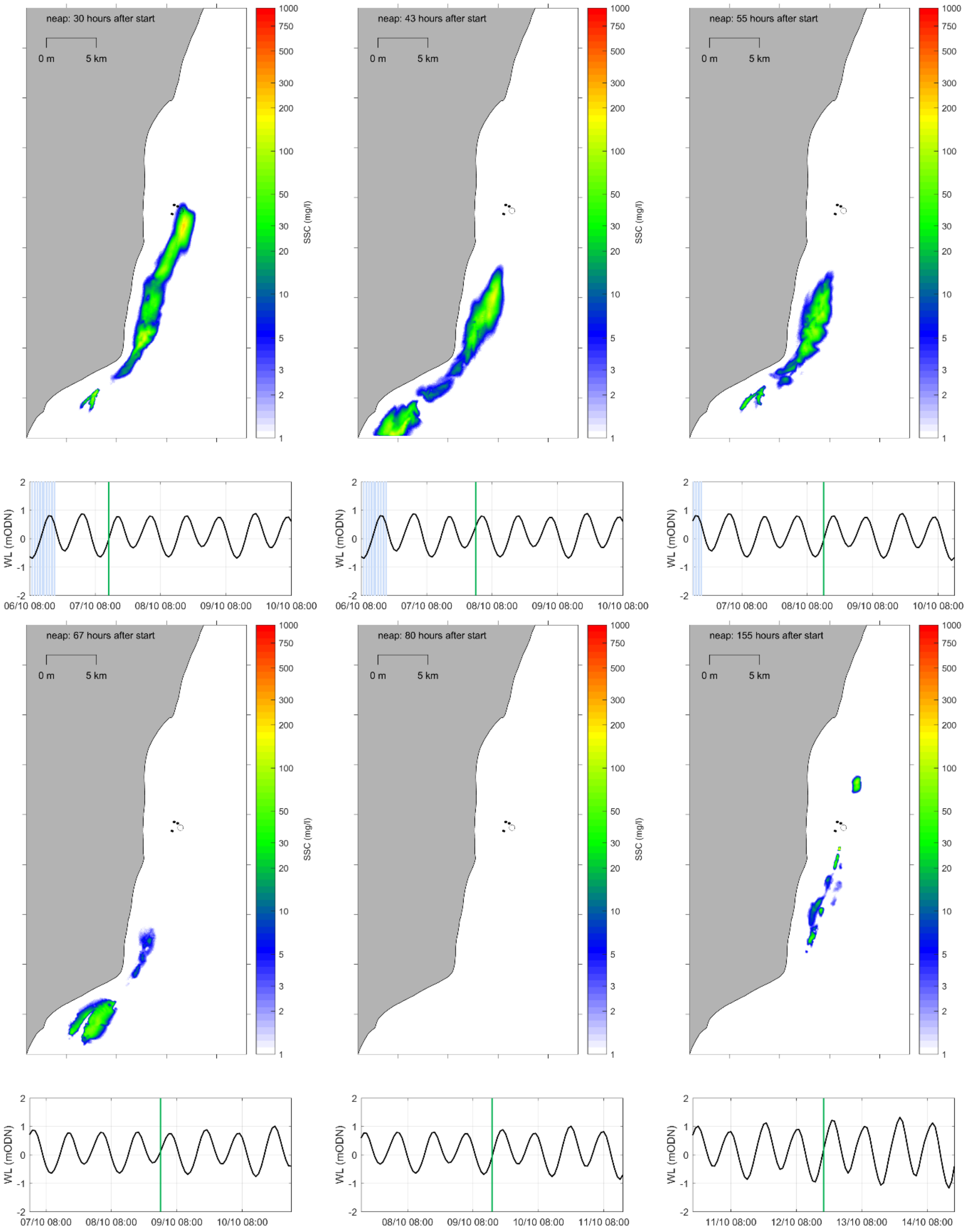


Figure 14. Depth average SSC at stages during dredging at Intake I4a on a neap tide

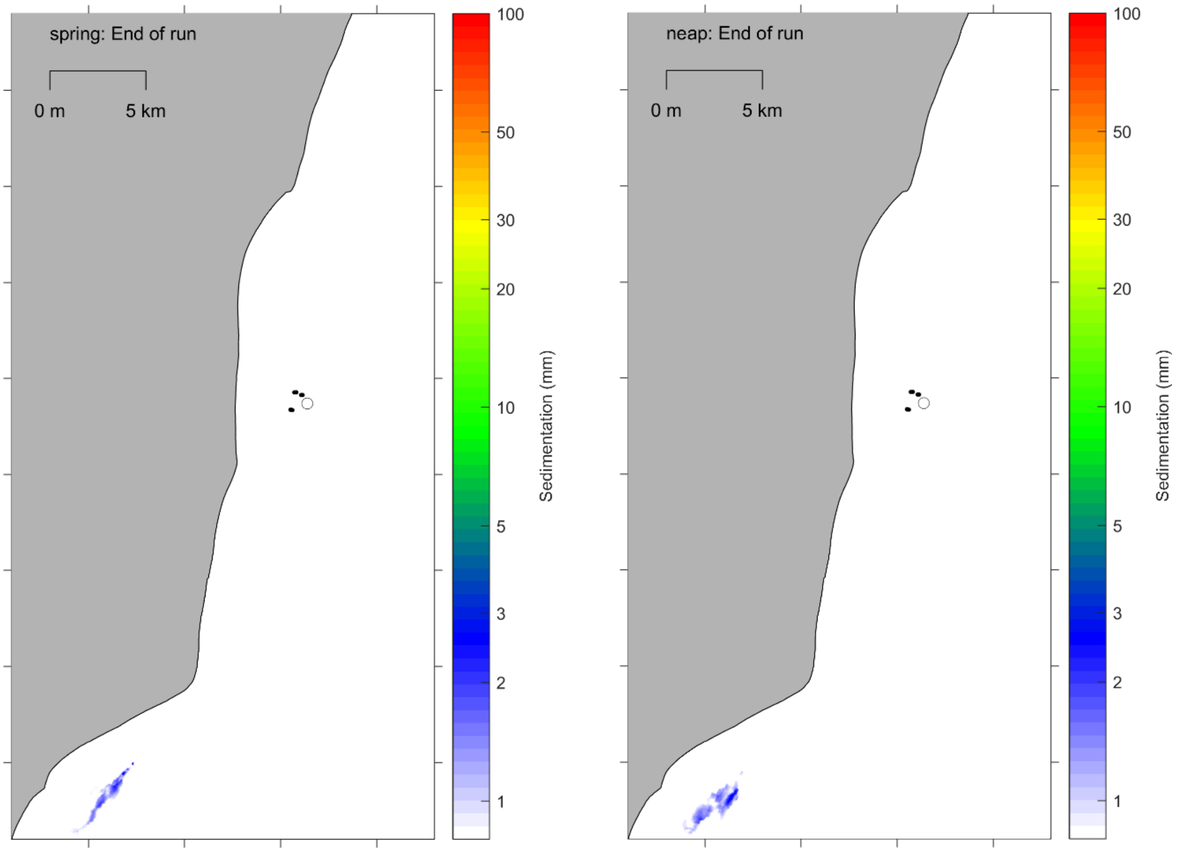
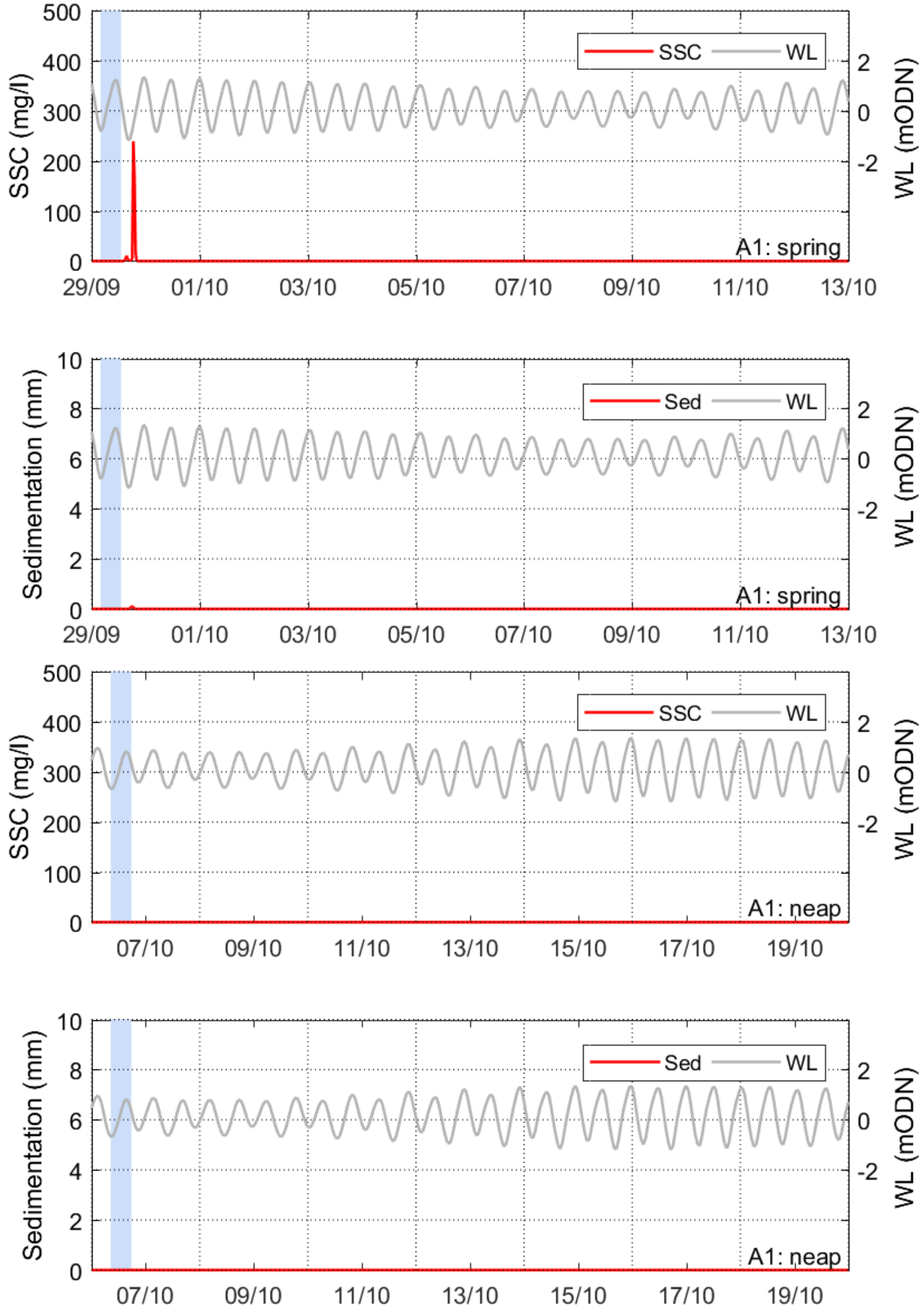


Figure 15. Sedimentation on the bed at the end of the model run for dredging at Intake I4a on a spring and neap tide

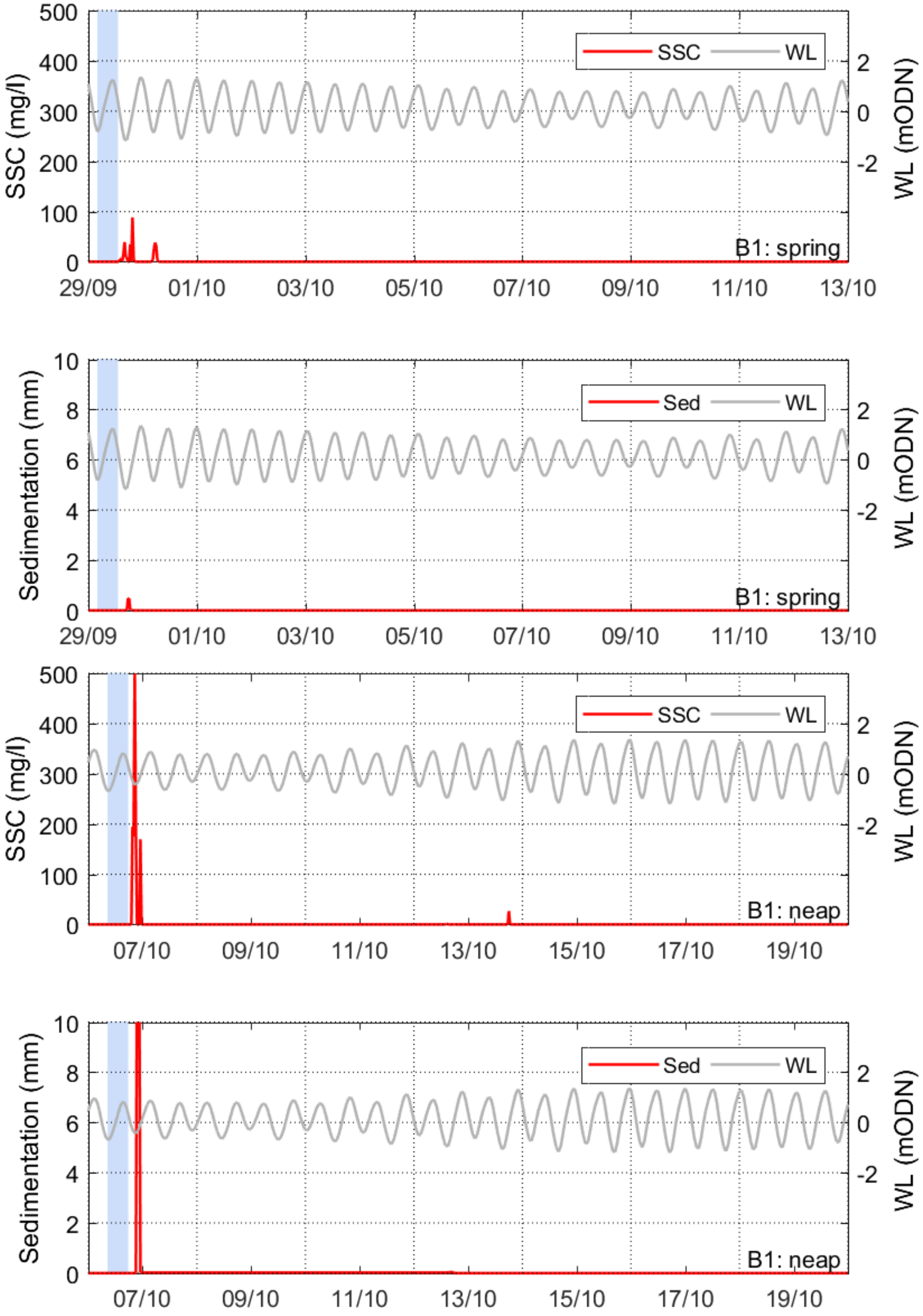
The plume dispersion at individual locations is shown as time series plots at discrete locations (Figure 5) in Figure 16 to Figure 21. Results are shown for the dredging at the intake structure I4a. These plots show that, with the exception of Location J1, (Figure 21) settling on the bed is intermittent, occurring mainly on neap tides and at periods of slack water on spring tides. J1 is located slightly inshore of Whiting Bank in an area of deeper water and slower tidal flows (peaking at around 0.8 m/s on spring tides compared to peaks of 1.2 m/s to the north of Orford Ness), which reduce the potential for resuspension. It should be noted that in the model, when the bed shear stress exceeds the critical value for resuspension, all material on the bed is instantaneously resuspended in the water column (see for example time series of sedimentation at D1 on a neap tide in Figure 18). In reality, the resuspension of sediments would be a more gradual process and as such the resultant 'spikes' in SSC are expected to provide a significant over prediction of the actual SSC values which would occur.

To consider the potential for the dredging to result in entrainment of sediment into the intake of the existing power station (Sizewell B), the near bed SSC and sedimentation at the Sizewell B intake location (shown in Figure 1) have been considered. The sedimentation and SSC at the Sizewell B intake were zero throughout the model simulation for the dredging of both the intake and the outfall, therefor the results have not been shown.



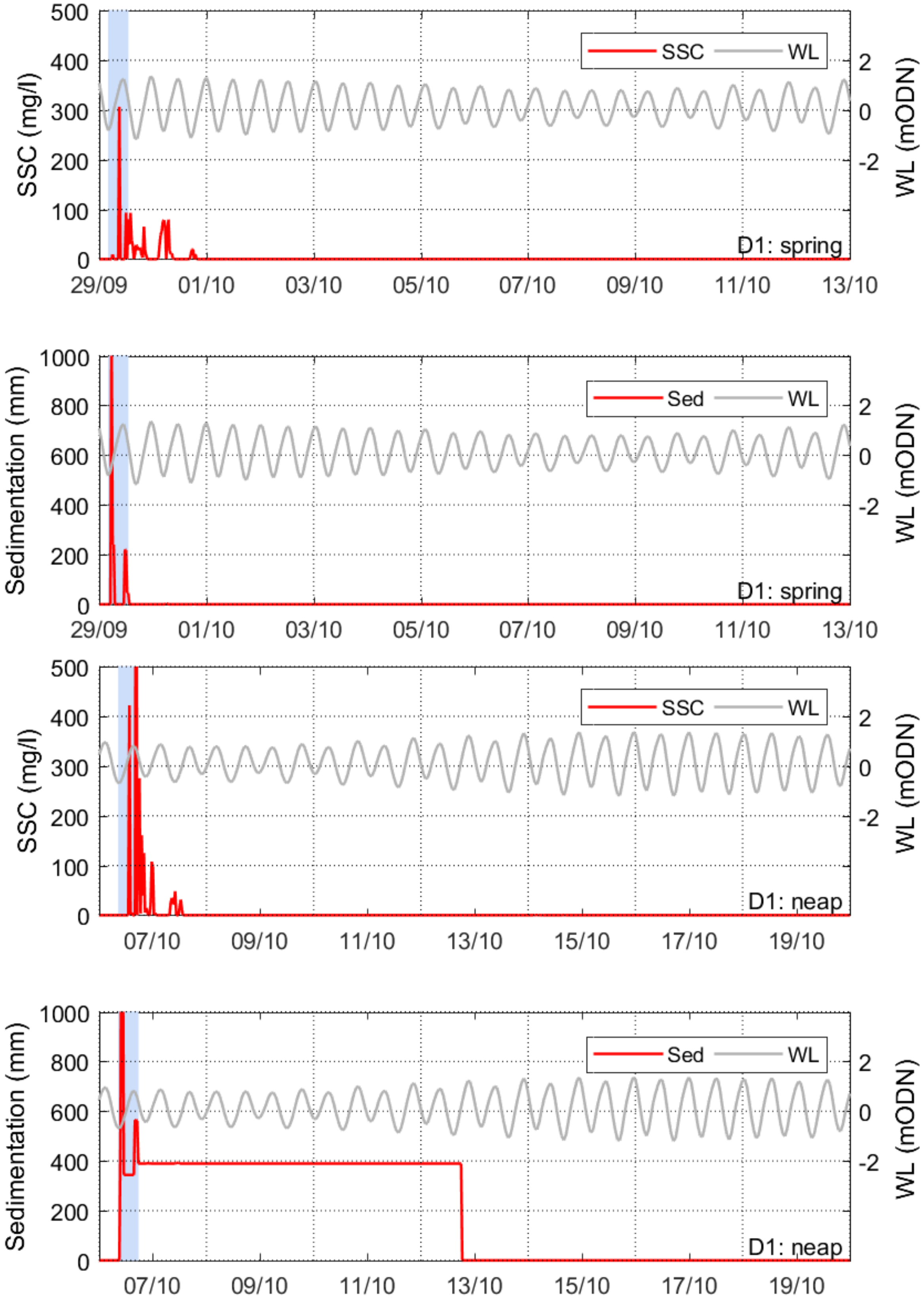
Blue shading shows periods of sediment release.

Figure 16. Time series of depth average SSC and sedimentation at Location A1 on spring (upper two panels) and neap tides (lower two panels) during and after dredging at Intake I4a



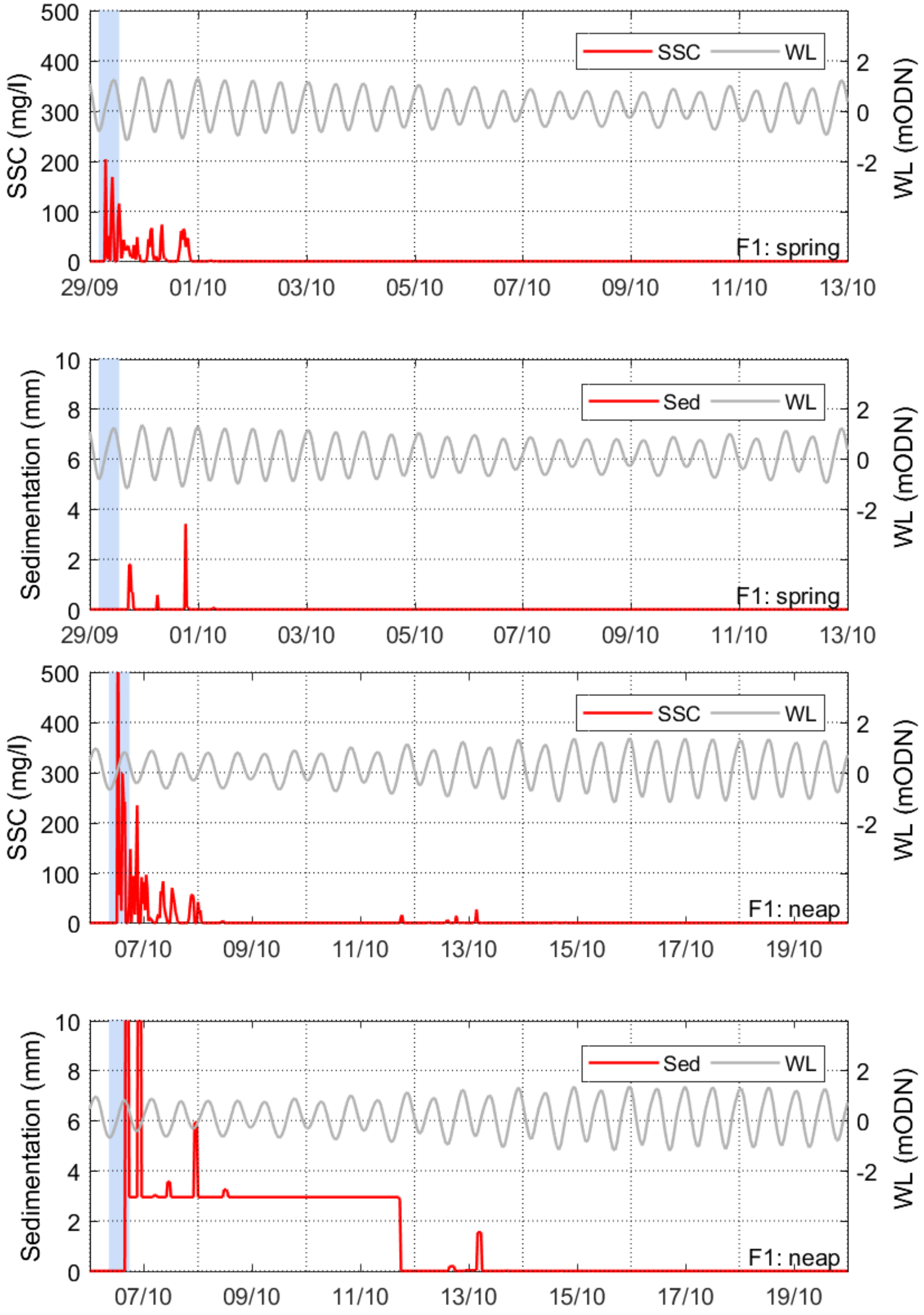
Blue shading shows periods of sediment release.

Figure 17. Time series of depth average SSC and sedimentation at Location B1 on spring (upper two panels) and neap tides (lower two panels) during and after dredging at Intake I4a



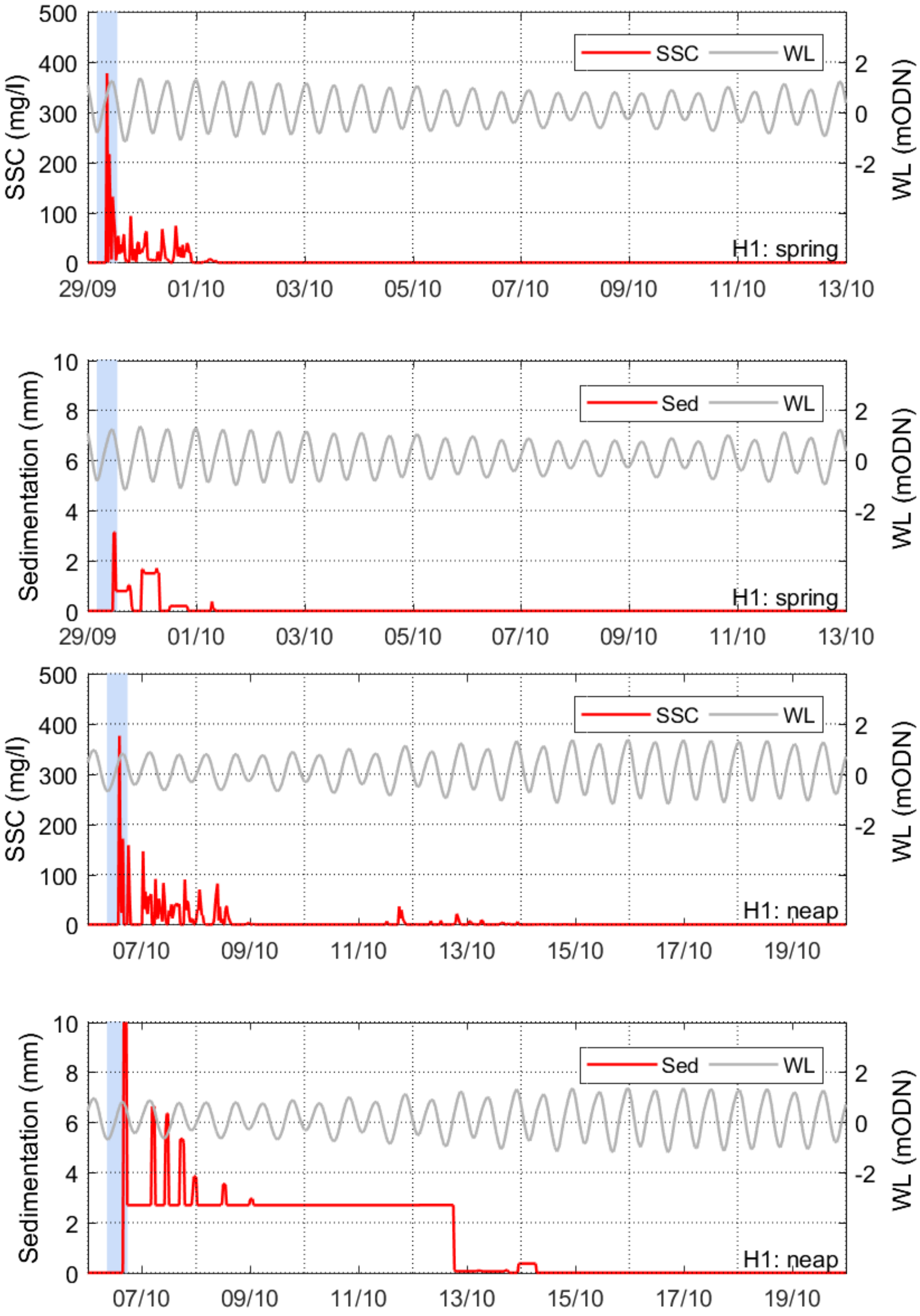
Blue shading shows periods of sediment release.

Figure 18. Time series of depth average SSC and sedimentation at Location D1 (disposal location) on spring (upper two panels) and neap tides (lower two panels) during and after dredging at Intake I4a



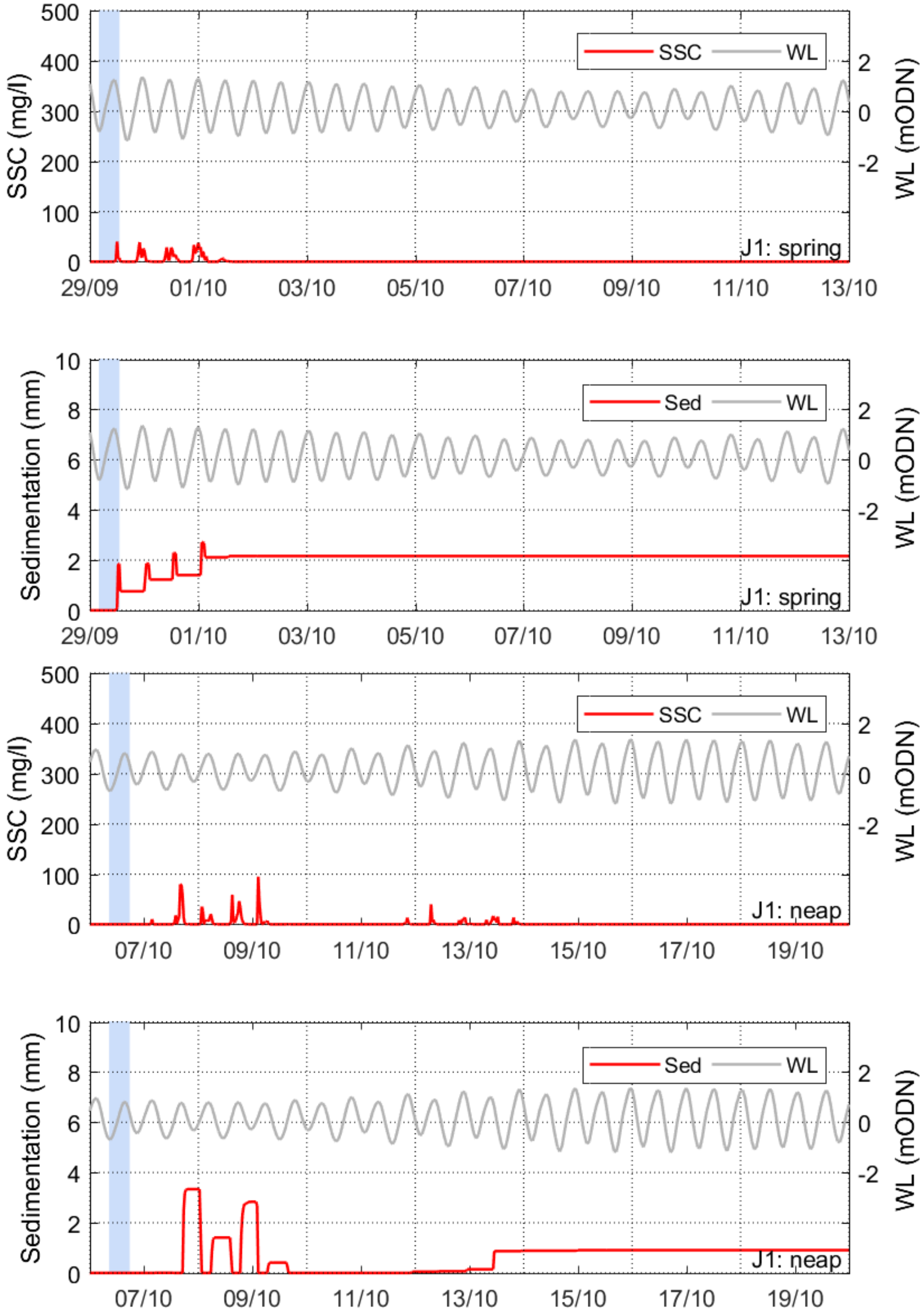
Blue shading shows periods of sediment release.

Figure 19. Time series of depth average SSC and sedimentation at Location F1 on spring (upper two panels) and neap tides (lower two panels) during and after dredging at Intake I4a



Blue shading shows periods of sediment release.

Figure 20. Time series of depth average SSC and sedimentation at Location H1 on spring (upper two panels) and neap tides (lower two panels) during and after dredging at Intake I4a



Blue shading shows periods of sediment release.

Figure 21. Time series of depth average SSC and sedimentation at Location J1 on spring (upper two panels) and neap tides (lower two panels) during and after dredging at Intake I4a

To quantify the plume extent and dispersion in more detail, time series of instantaneous plume areas in suspension (both as depth average and in the surface layer) and sedimentation areas on the bed are shown in Figure 22 and Figure 23. Maximum instantaneous plume areas are tabulated in Table 18 to Table 20. The plots show that on spring tides within two days of the completion of the dredge there is no plume area with depth average concentrations above 20 mg/l. Furthermore, the plume concentrations are less than 200 mg/l above background values within one day of the dredge completion and as such may be difficult to detect from the background given the natural variability in SSC recorded in 2009 (EMU, 2009), noted in Section 3. Highest SSCs within the plume peak at more than 2000 mg/l above background, but these are confined to a small area (up to 6 Ha when the dredge occurs on neap tides) and duration (less than 12 hours).

Table 18. Maximum area of instantaneous depth average SSC resulting from dredging of the surficial sediments at Intake I4a

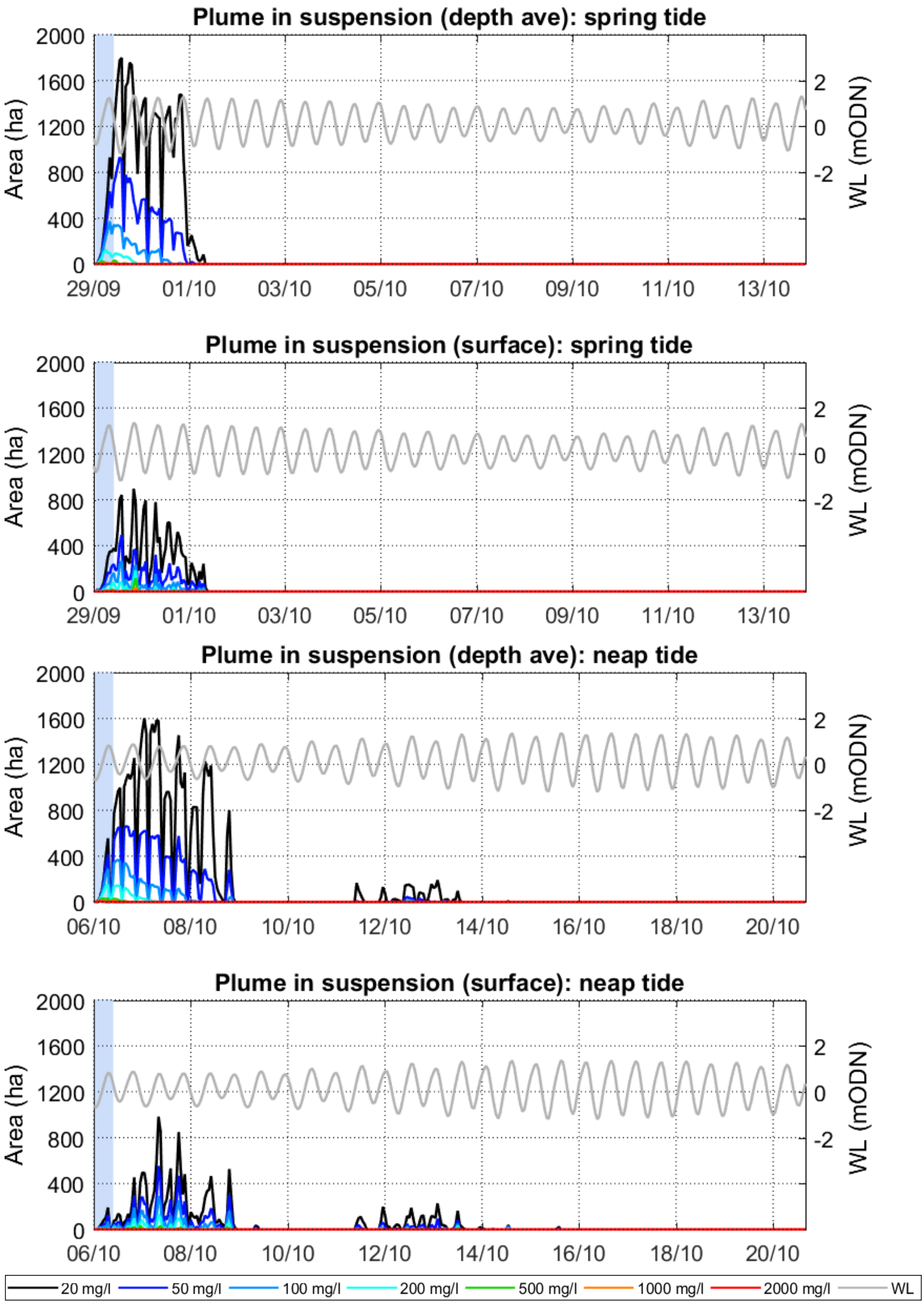
SSC > mg/l	Area (Ha)	
	Spring Tides	Neap Tides
20	1,798	1,603
50	932	660
100	373	368
200	124	150
500	30	33
1000	11	14
2000	3	6

Table 19. Maximum area of instantaneous surface SSC resulting from dredging of the surficial sediments at Intake I4a

SSC > mg/l	Area (Ha)	
	Spring Tides	Neap Tides
20	896	982
50	492	553
100	265	291
200	185	130
500	115	32
1000	34	5
2000	2	2

Table 20. Maximum area of instantaneous sedimentation resulting from dredging of the surficial sediments at Intake I4a

Sediment Thickness > mm	Area (Ha)	
	Spring Tides	Neap Tides
2	849	1,235
5	200	441
10	58	199
20	14	53
50	3	5
100	3	2
500	0	1



Blue shading shows periods of sediment release

Figure 22. Plume areas in suspension (as depth average and in the surface layer) during and after the dredging at Intake I4a

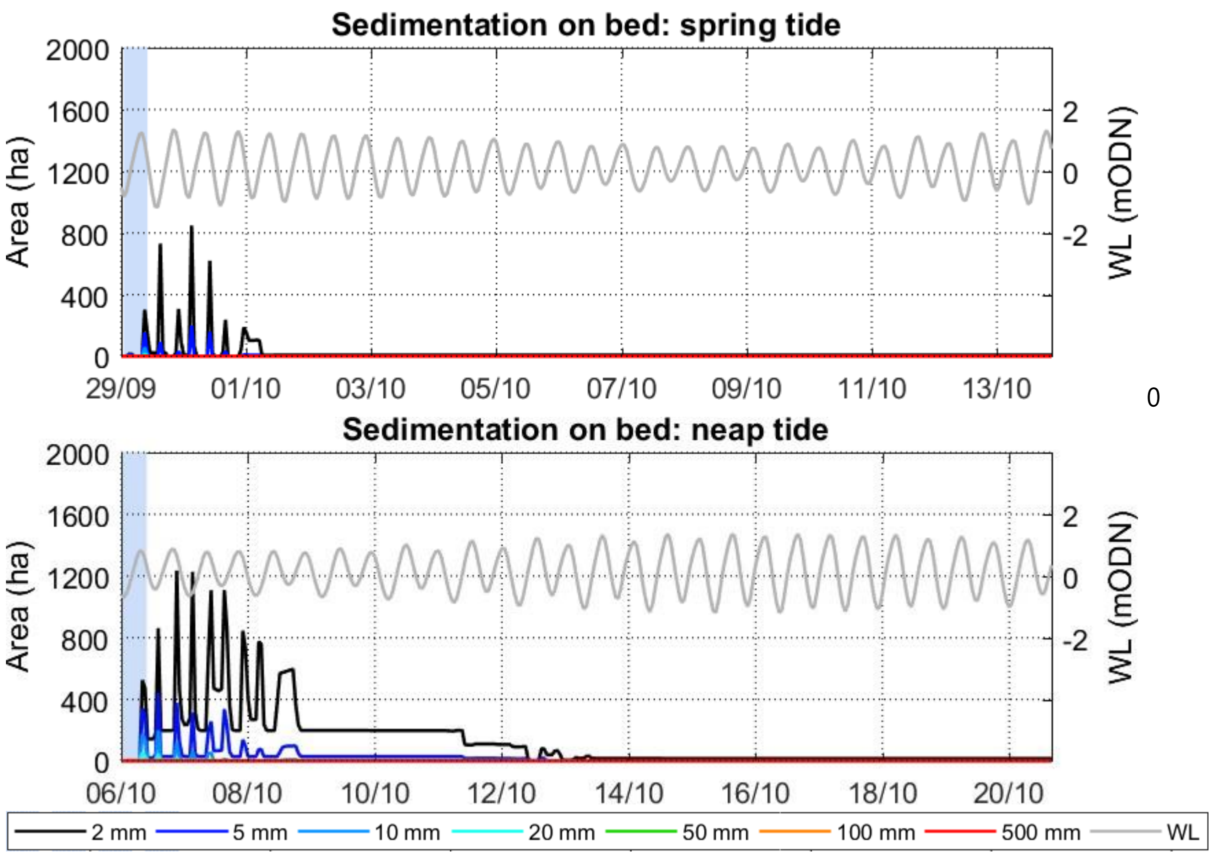


Figure 23. Plume areas on the bed during and after the dredging at Intake I4a

3.1.2 Bird foraging

To aid an assessment of plume effects on bird foraging, time series plots of the percentage of bird foraging areas intersected by the plume (defined as areas with a surface SSC of more than 100 mg/l) are plotted in Figure 24. Maximum areas of plume intersect with bird foraging areas are summarised in Table 21.

Table 21. Maximum area of plume intersect with habitat/bird foraging areas resulting from dredging of surficial sediments at Intake I4a. Plume defined as surface SSC above 100 mg/l.

Receptor	Spring Tides		Neap Tides	
	Area (Ha)	% of Foraging Area	Area (Ha)	% of Foraging Area
Little Tern Dingle Colony	0	0	0	0
Little Tern Minsmere Colony	0	0	0	0
Little Tern Slaughden Colony	124	7	68	4
Common Tern (Minsmere Colony)	265	1	206	<1
Common Tern (Orfordness Colony)	238	<1	291	<1

Within the bird foraging areas (see Figure 4 for locations), the surface SSC exceeds 100 mg/l across small parts of the Little Tern Slaughden Colony and parts of both the Common Tern colonies (Table 21). The maximum plume areas exceeding 100 mg/l covers approximately 7 % of the Little Tern Slaughden Colony and 1 % or less of the Common Tern colonies.

The timeseries plot (Figure 24) indicates that the duration of these maximum values is short lived (typically a few hours and overall less than approximately 2 days). For the Sandwich Terns and the Lesser Black Backed Gull, all of the plume is contained within the foraging areas identified in Figure 4. The maximum plume extent accounts for less than 1 % of the foraging areas for these bird species.

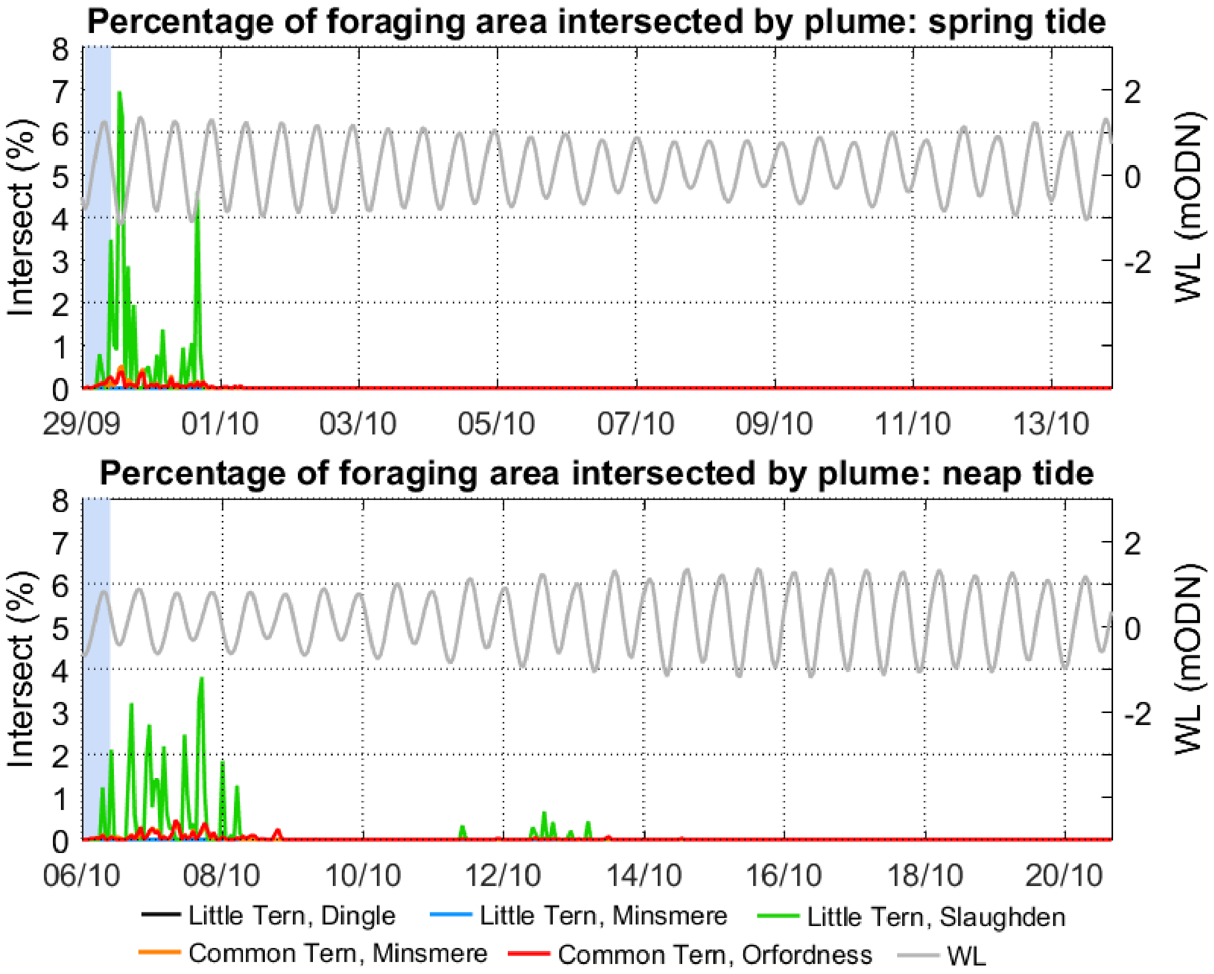


Figure 24. Plume areas in suspension (defined as surface SSC of more than 100 mg/l), intersecting with bird foraging areas during and after the dredging of the of surficial sediments at Intake I4a

3.1.3 Drilling of the bedrock

Plan plots of the location maximum depth average SSC and sedimentation and associated with the drilling of the intake structure (I4a) on spring and neap tides are shown in Figure 25. For this scenario, where SSC is very low, the plan plots of P95 do not capture the plume and hence are not included.

The plume concentrations (and sedimentation) associated with drilling are several orders of magnitude less than the concentrations associated with the dredging and the colour bar scales in Figure 25 have been modified accordingly. Maximum depth average SSC's are typically less than 10 mg/l above background concentrations and as such will not be detectable against the background variability. Maximum sedimentation is also insignificant, being fractions of a millimetre.

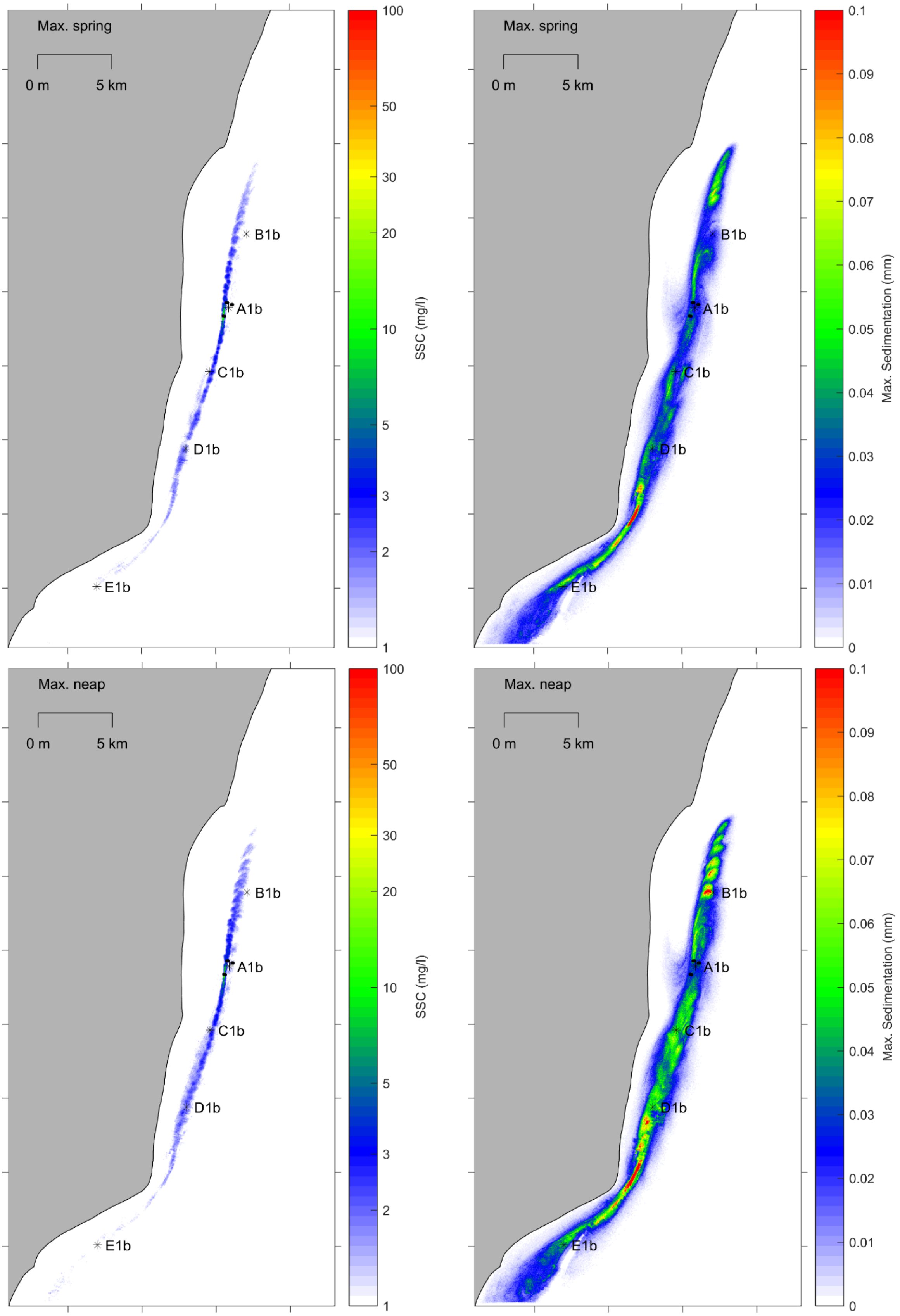
The sedimentation on the seabed close to the drill site will actually be far more than the model predicts since coarser material (not included in the model) will settle around the discharge site creating a spoil pile as observed during the Lynn and Inner Dowsing monitoring study (CREL, 2007). The extent of the spoil will depend on the depth at which the drill arisings are released, the size of the arisings and the tidal conditions during drilling. Assuming a release at the surface, given the local flow conditions and water depths, the coarsest fractions of sediment (>10,000 µm) are expected to settle within 60 m of the disposal site, while the less coarse sediment (around 1,000 µm) will settle within 200 m. Based on the drill volume, and assuming that 50% of the drill arisings settle adjacent to the drill site with an elliptical shape, the mean deposit depth for this coarser material will be of the order of 0.05 m to 0.5 m. As at Lyn and Inner Dowsing the depth of deposit will vary with distance from the drill site resulting in a conical shaped deposit with deeper deposits of more than several metres thickness close to the drill site. It is likely that the spoil pile will reduce in size over time with sediment eroded on stronger spring flows and during stormy periods.

While the plume concentrations associated with the drilling are low and undetectable, for completeness plan plots showing how the sediment plume evolves throughout a mean range spring and neap tide are provided in Figure 27 and Figure 28, respectively. Results are shown for the drilling of the outfall structure (which yields slightly higher SSCs than the drilling of the intake). The time- steps shown correspond to the first HW after the start of the drilling (i.e. approximately six hours after the start of drilling) and the times of the subsequent PE, LW and PF. Concentrations in the drill arising sediment plume typically peak at 5-10 mg/l, constrained to within a couple of kilometres of the release location.

Plan plots of sedimentation associated with the drilling of the intake structure are presented throughout the same spring tidal period as shown for SSC in Figure 29. These show a small area of sedimentation occurring at the LW slack period, which is subsequently resuspended by the subsequent flood tide. As noted above the model does not include the coarser sediment fractions which will settle in close proximity to the drill site.

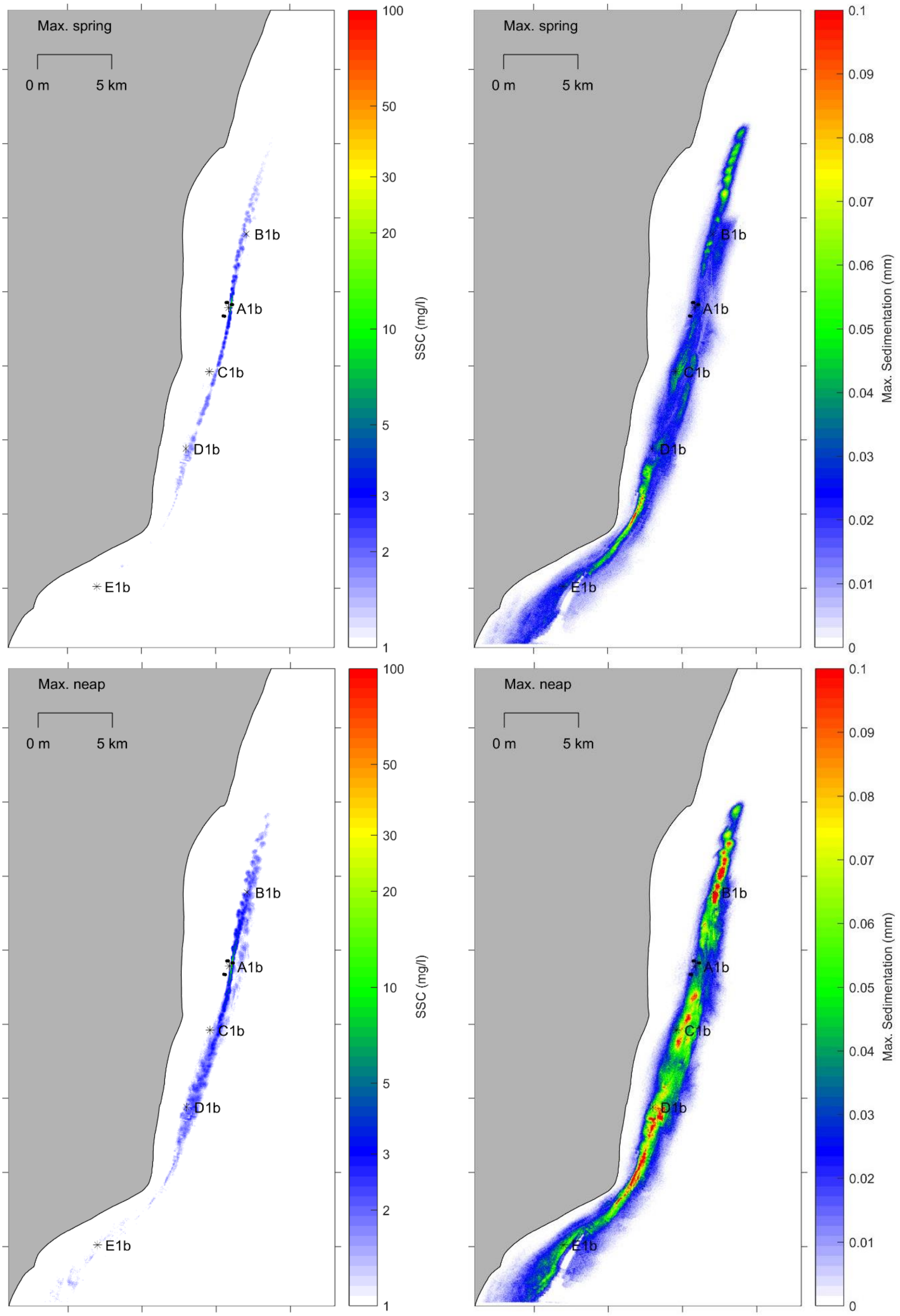
To show how the sediment plumes evolve during and after the drilling of O9a, map plots of depth average SSC are shown at the time of PE on a range of tides (Figure 30). Results are shown for the scenario where drilling begins on spring tides. The plume extent remains small spatially and low in concentrations for the duration of the drilling operation. Following the completion of the drilling, the drill arising plume rapidly disperses, with no plume evident 197 hours after the start of the drill (17 hours after the completion of the drill).

Time series plots at the locations shown on Figure 25 are presented in Figure 31 to Figure 35. These plots show variations in depth average SSC and sedimentation throughout the model run for the drilling of the CWS outfall structure, for runs starting on spring and neap tidal conditions. The plots show that the plume dispersion is insensitive to whether the drill operation starts on a mean neap or a mean spring tide. The time series plots further demonstrate the transient nature of the plume, with short lived 'spikes' in both SSC and sedimentation with material dropping out of suspension and depositing on the bed at LW. The 'spikes' in SSC are typically less than 2 mg/l and will not be detectable, with respect to the background natural variability.



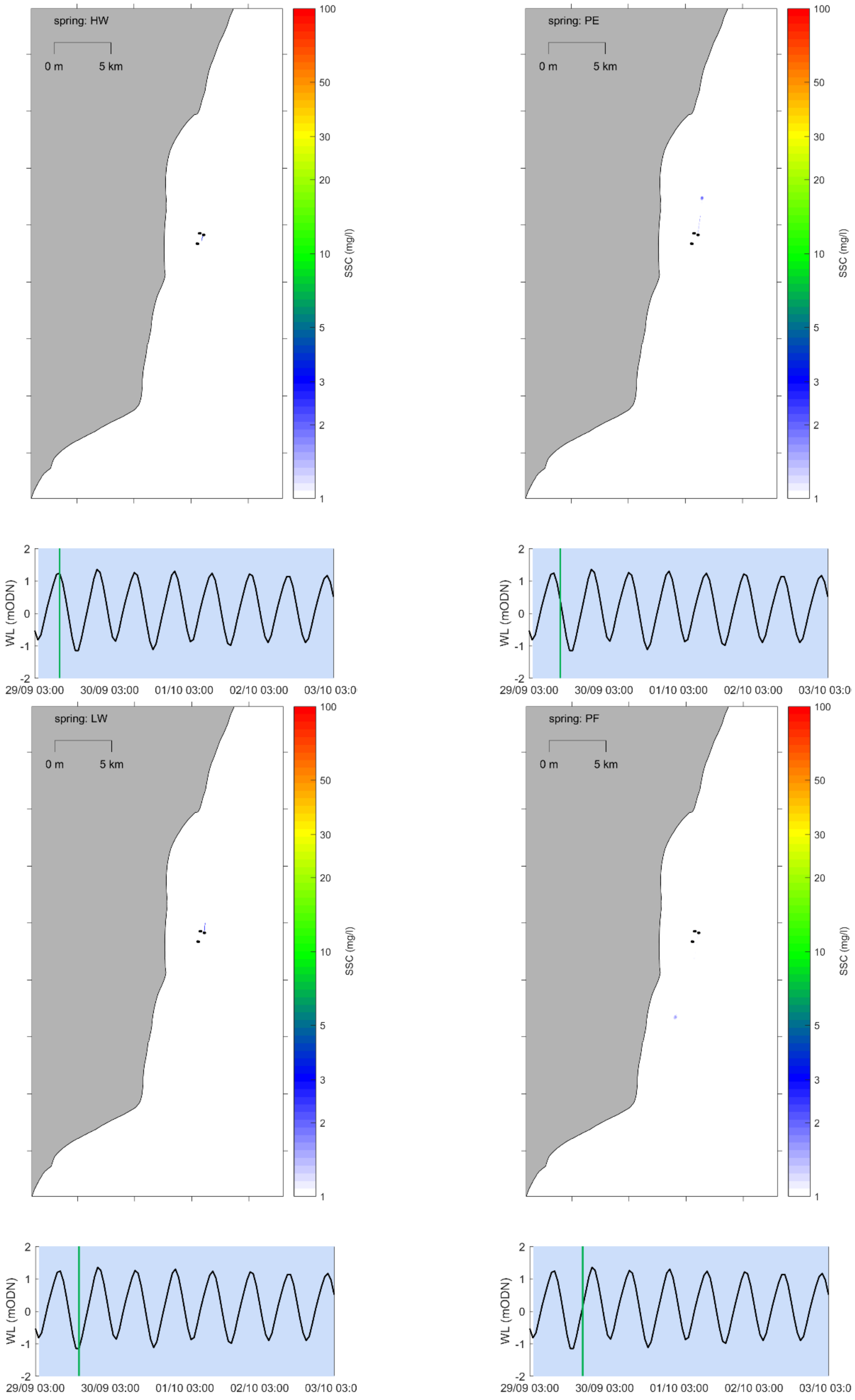
Black dots show CWS structures. Disposal is at D1. Other locations (A1b to E1b) show time series extraction points

Figure 25. Maximum depth average SSC and sedimentation associated with the drilling of Intake I4a on spring and neap tides.



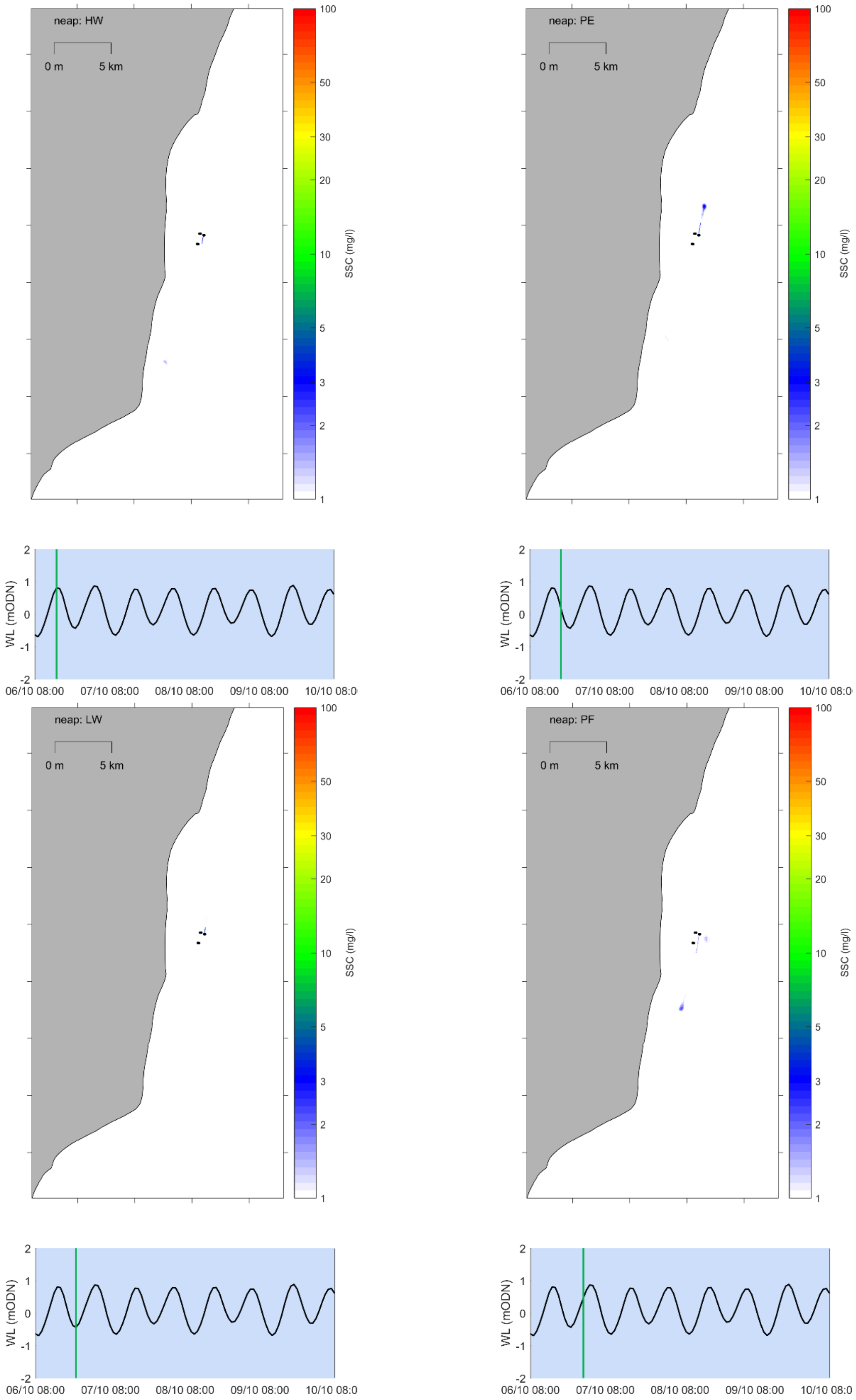
Black dots show CWS structures. Other locations (A1b to E1b) show time series extraction points

Figure 26. Maximum depth average SSC and sedimentation associated with the drilling of Outfall O9a on spring and neap tides



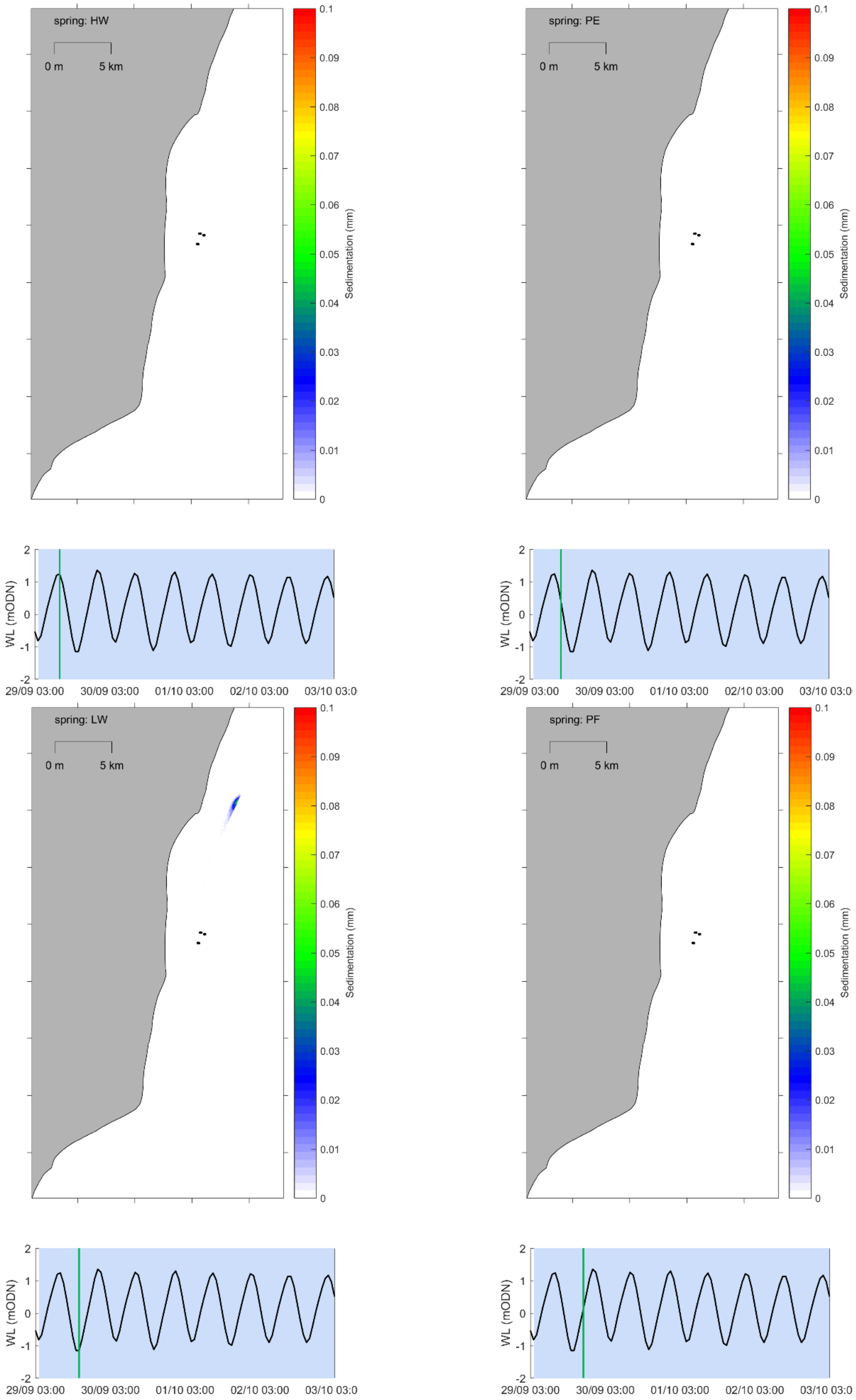
The pale blue shading on the time series plots indicate periods of sediment release.

Figure 27. Depth average SSC at HW, PE, LW and PF during the drilling of Outfall O9a on a spring tide



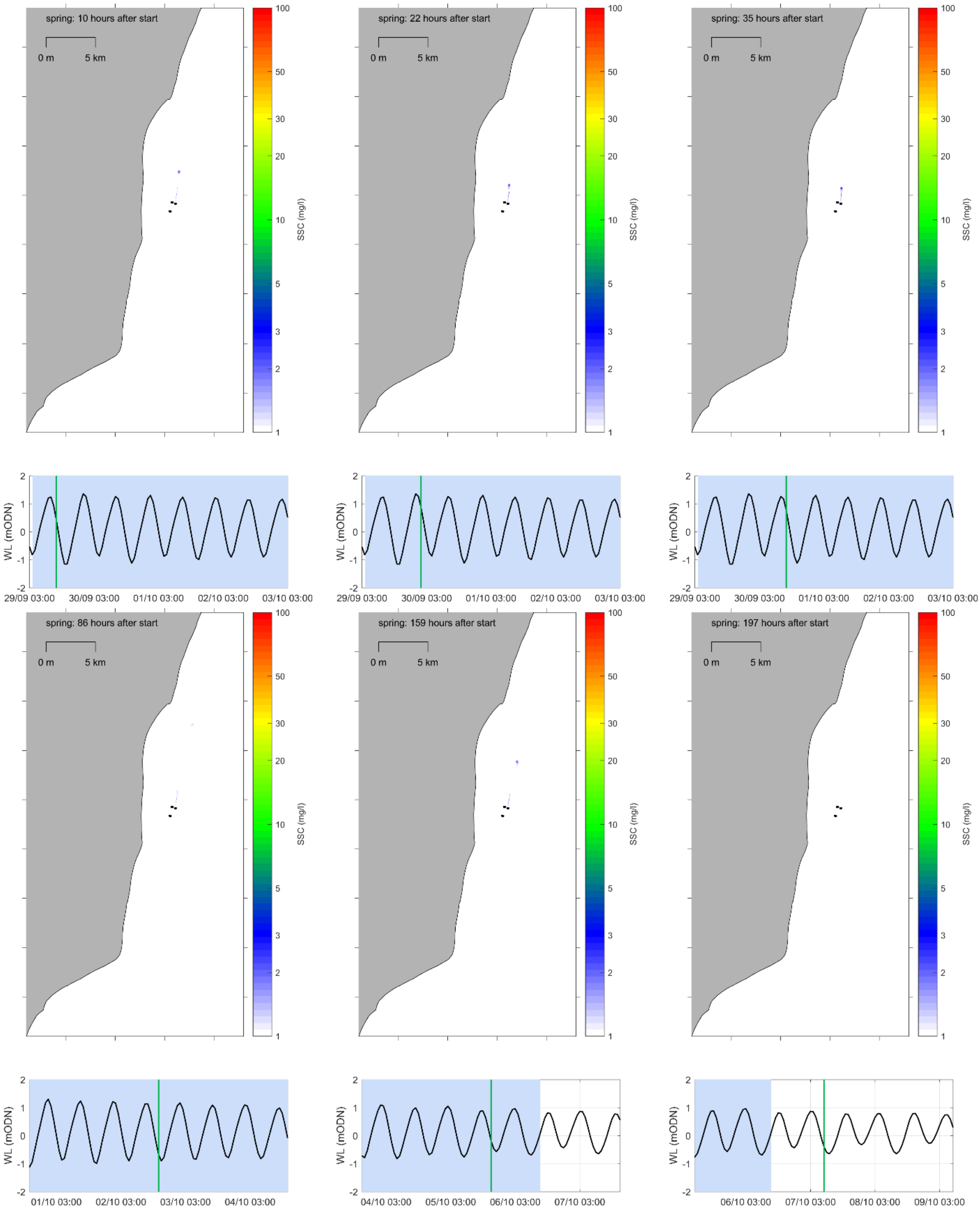
The pale blue shading on the time series plots indicate periods of sediment release.

Figure 28. Depth average SSC at HW, PE, LW and PF during the drilling of Outfall O9a on a neap tide



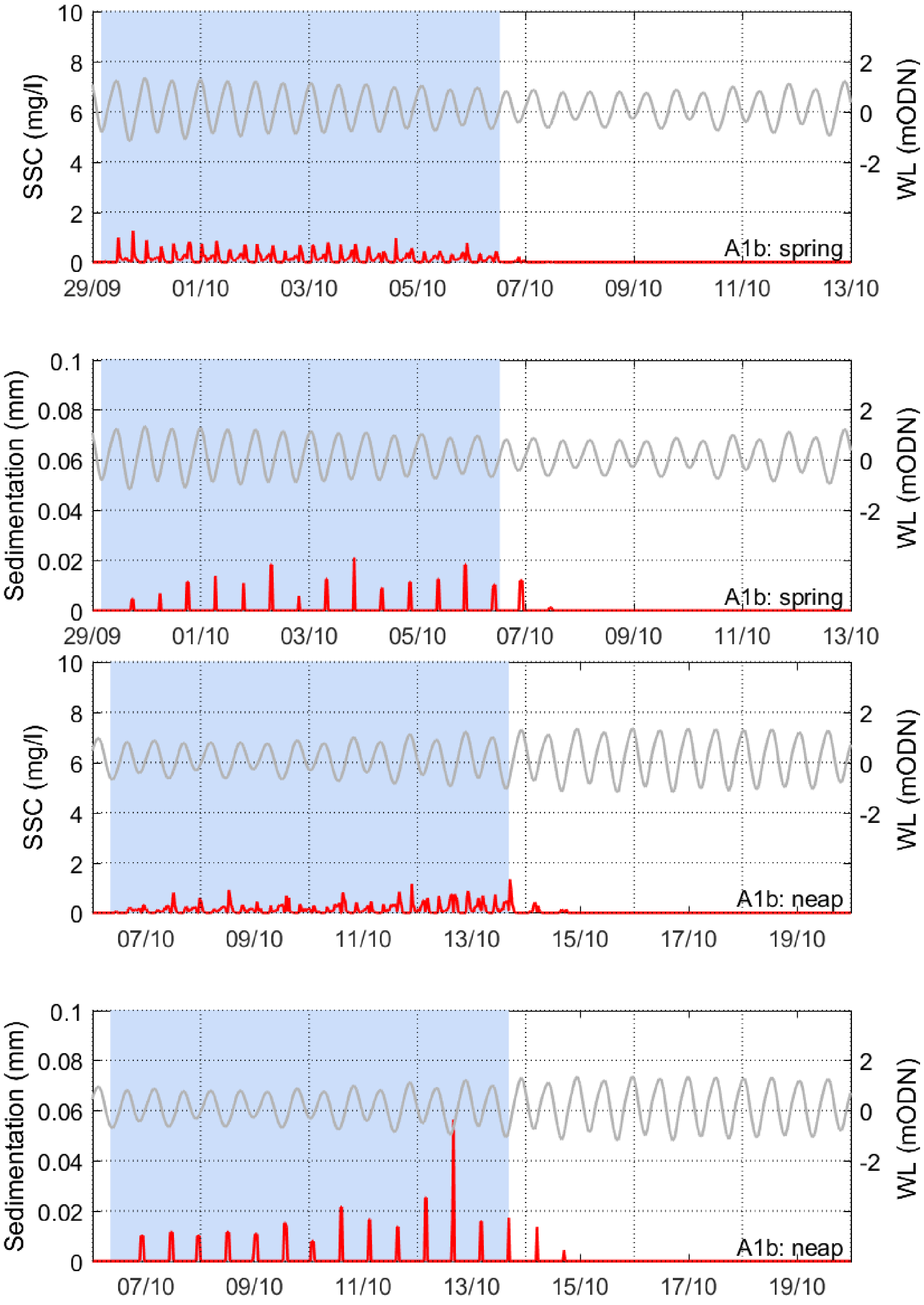
The pale blue shading on the time series plots indicate periods of sediment release.

Figure 29. Sedimentation at HW, PE, LW and PF during the drilling of Outfall O9a on a spring tide



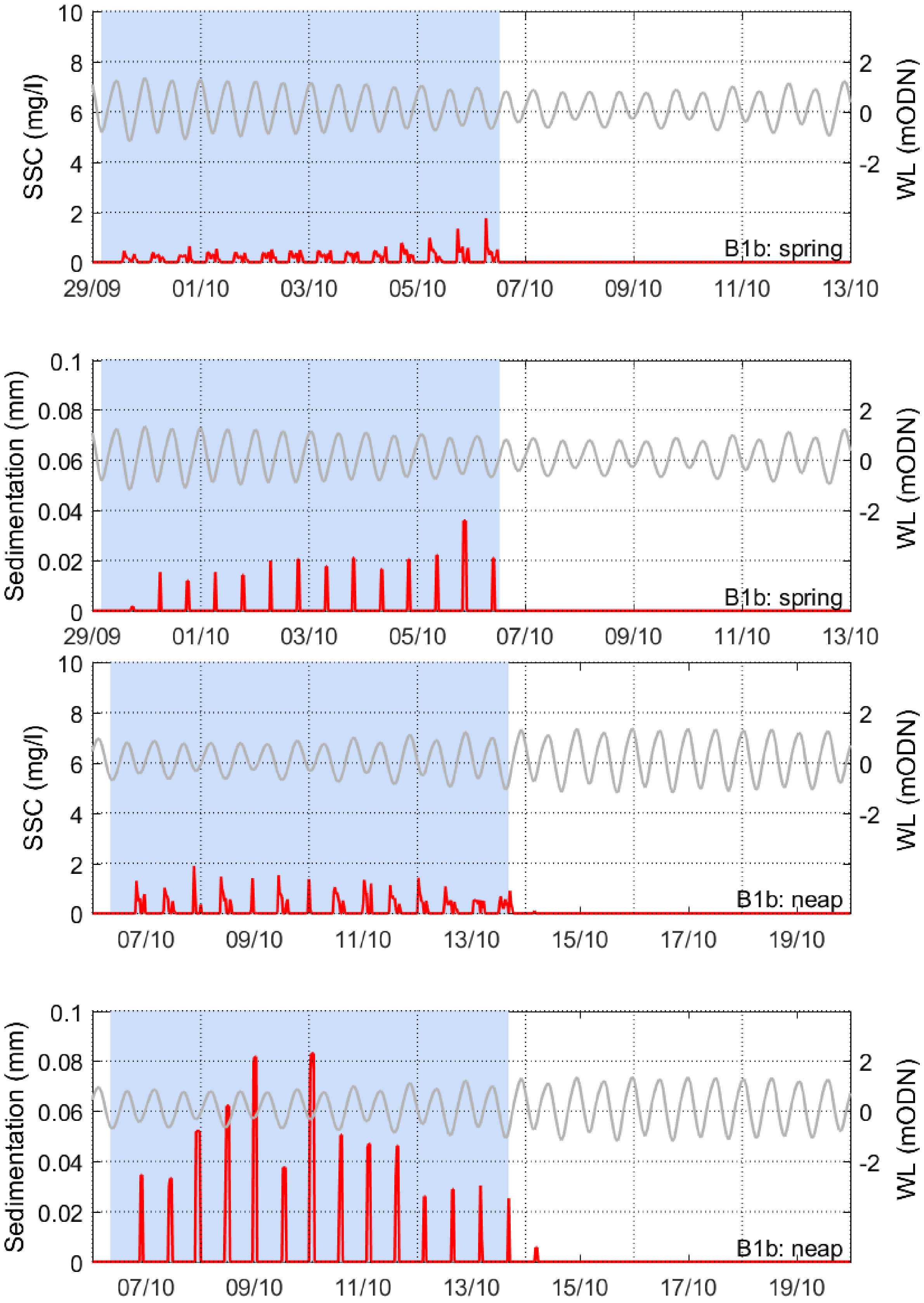
The pale blue shading on the time series plots indicate periods of sediment release.

Figure 30. Depth average SSC at stages during the drilling of Outfall O9a on a spring tide



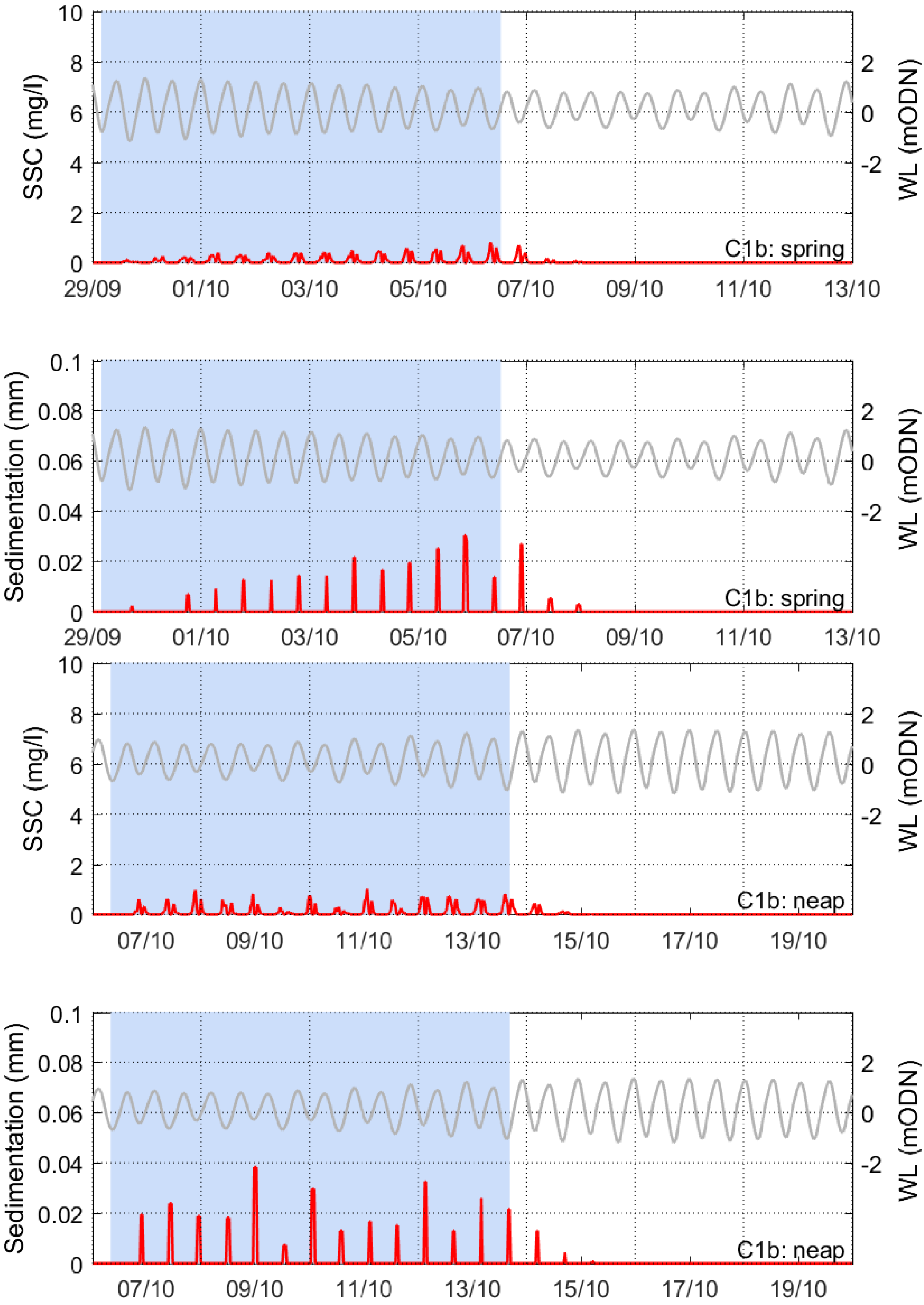
Blue shading shows period of sediment release.

Figure 31. Time series of depth average SSC and sedimentation at Location A1b on spring (upper two panels) and neap tides (lower two panels) during and after drilling the CWS Outfall O9a



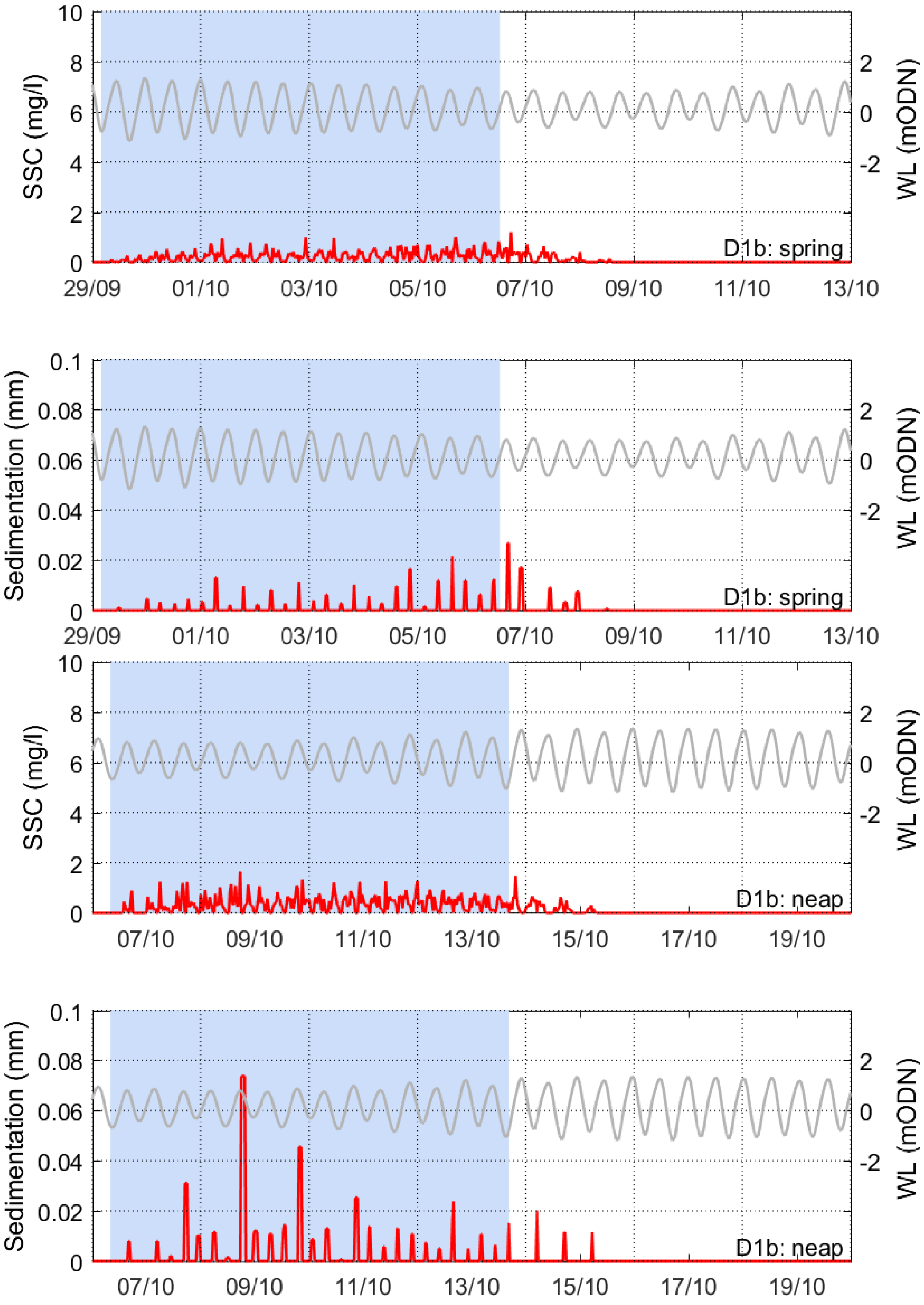
Blue shading shows period of sediment release.

Figure 32. Time series of depth average SSC and sedimentation at Location B1b on spring (upper two panels) and neap tides (lower two panels) during and after drilling the CWS Outfall O9a



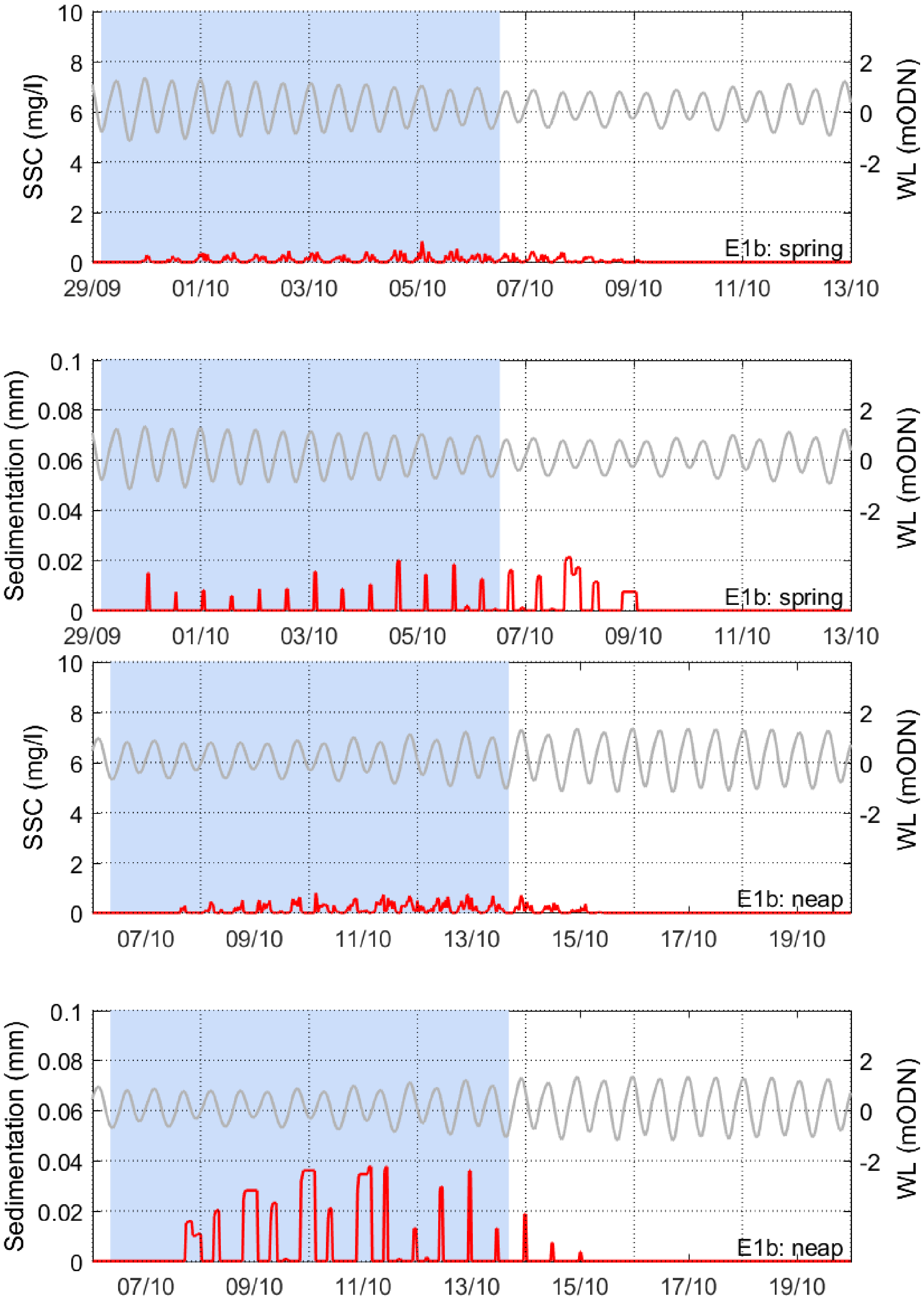
Blue shading shows period of sediment release.

Figure 33. Time series of depth average SSC and sedimentation at Location C1b on spring (upper two panels) and neap tides (lower two panels) during and after drilling the CWS Outfall O9a



Blue shading shows period of sediment release.

Figure 34. Time series of depth average SSC and sedimentation at Location D1b on spring (upper two panels) and neap tides (lower two panels) during and after drilling the CWS Outfall O9a



Blue shading shows period of sediment release.

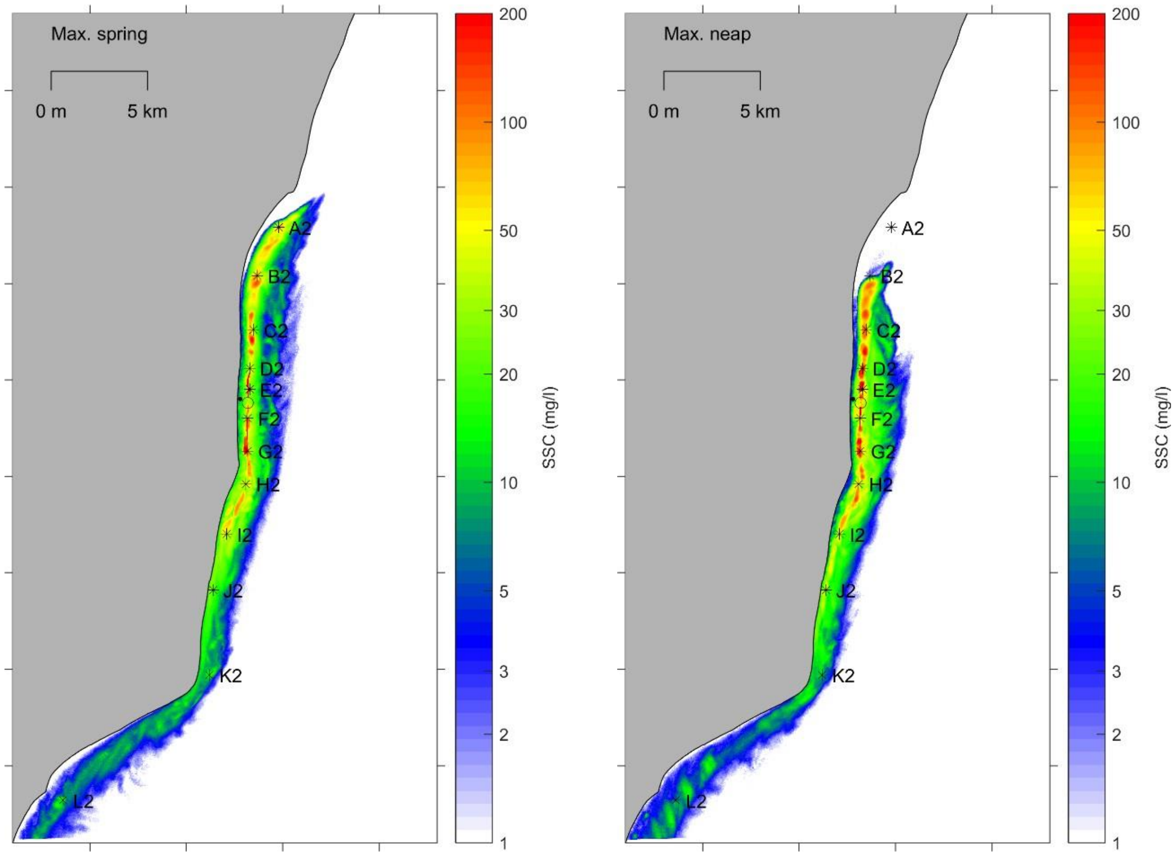
Figure 35. Time series of depth average SSC and sedimentation at Location E1b on spring (upper two panels) and neap tides (lower two panels) during and after drilling the CWS Outfall O9a

3.2 Scenario 2. Dredging of surficial sediments at the FRR and CDO structures

Plan plots of the location maximum SSC associated with the dredging of surficial sediments at the additional structures are shown in for the dredge starting on spring and neap tides in Figure 36 and Figure 37 ,for depth average and surface SSC, respectively.

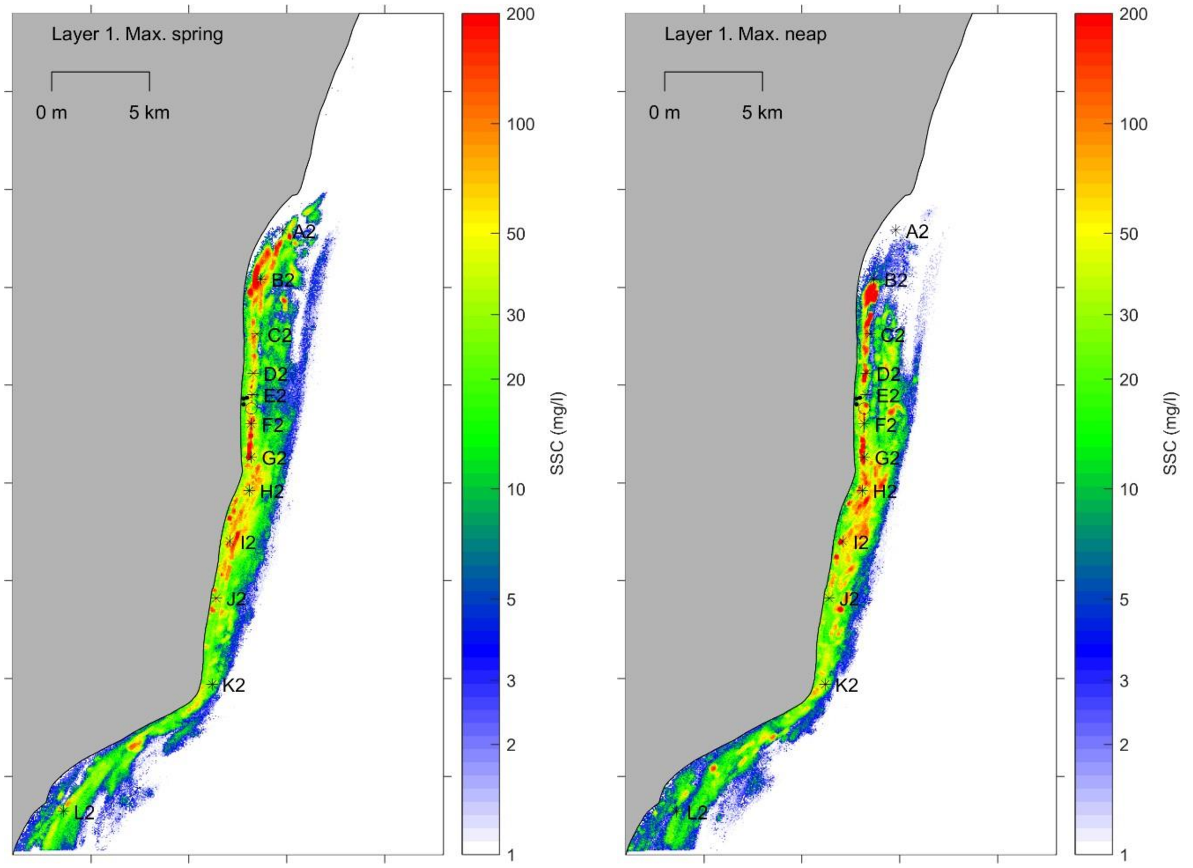
As for the CWS dredge scenario, the plume is elongate in shape, extending north-south along the coast and with limited east-west extent. Despite this similarity, there are some notable differences between the plume characteristics associated with the dredging at these different structures. In particular:

- The plume concentrations are lower for the dredge at the additional structure, by approximately a factor of five; and
- the plume is confined closer inshore and sediments are predicted to disperse to the shoreline where it is likely that the arisings will accumulate on the beaches and mix with the beach sediments.



Black dots show the outfalls, disposal is at the black unfilled circle. Locations (A2 to L2) show time series extraction points

Figure 36, Location maximum depth average SSC associated with dredging at the FRR1 outfall on spring and neap tides



Black dots show the outfalls, disposal is at the black unfilled circle. Locations (A2 to L2) show time series extraction points

Figure 37. Location maximum surface SSC associated with dredging at the FRR1 outfall on spring and neap tides

Location maximum depth average SSC of more than 100 mg/l are constrained to within 6.5 km to the north and 5.5 km to the south of the sediment release locations.

To further quantify the extent of the plume, the areas of location maximum SSC above different threshold values have been calculated. Results are presented for depth average and surface SSC in Table 22 and Table 23, respectively.

An area of 66 Ha is affected by increases in depth average SSC of more than 100 mg/l as a result of the dredge at FRR1, when the dredge is started on spring tides. This area is increased to 115 Ha when the dredge is started on neap tides. Unlike for the dredge at I4a, areas of elevated surface SSC are slightly higher than the depth average values (compare Table 22 and Table 23).

To provide some indication of how long the conditions prevail, the plume areas have been calculated for different threshold values and durations (Table 24). The results indicate that the plume is very short lived with plume areas rapidly decreasing as the threshold duration is increased. Further, no areas are subjected to increased surface SSC of more than 50 mg/l for more than six hours.

Plan plots of P95 SSC associated with the dredging of surficial sediments at the additional outfalls are shown as depth average values Figure 38 and as surface values in Figure 39. These P95 SSC values are significantly lower than the location maximum values, demonstrating the short-lived nature of the plume. Unlike the P95 SSC values for the dredging at I4a (Figure 7), the P95 SSC plume associated with dredging at FRR1 extends both north and south of the dredge disposal location resulting from disposal occurring both on the flood tide when flows are southwards and on the ebb tide when flows are northwards.

Table 22. **Areas of location maximum depth average SSC resulting from dredging of the surficial sediments at the FRR1 outfall**

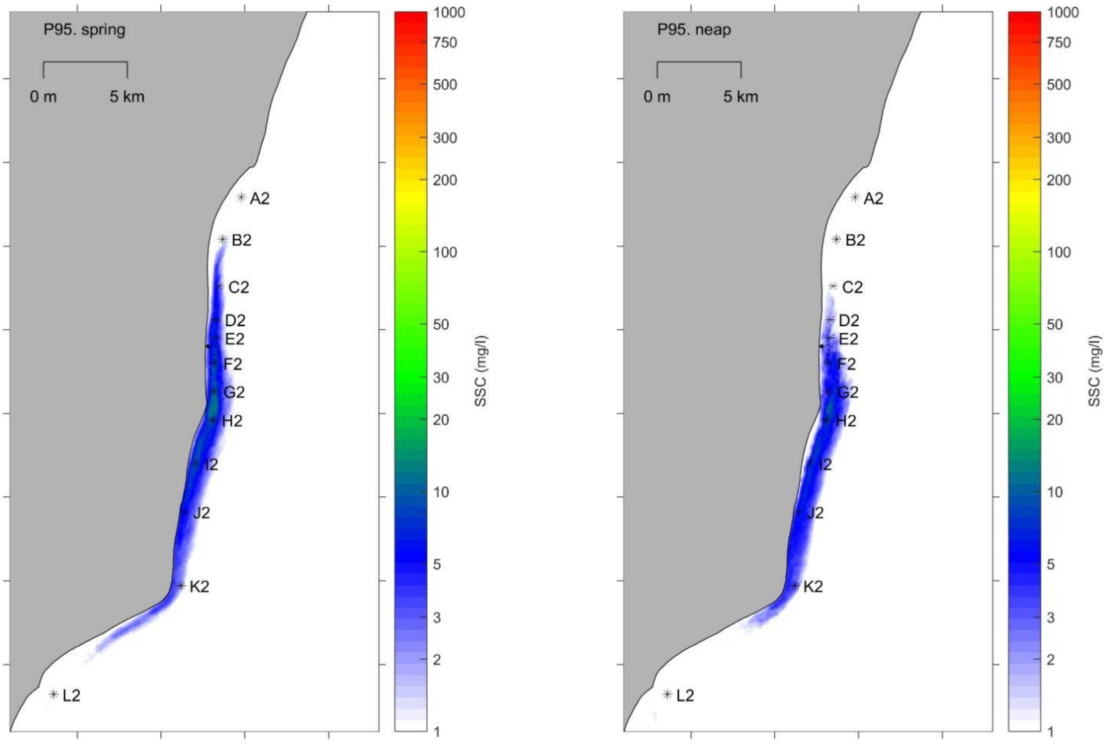
SSC > mg/l	Spring Tides		Neap Tides	
	Area (Ha)	% of Plume Area		% of Plume Area
0	14,973	100	13,551	100
20	1,559	10	1,436	11
50	343	2	413	3
100	66	<1	115	1
200	21	<1	18	<1
300	11	<1	9	<1
500	3	<1	6	<1
1000	1	<1	0	0
2000	0	0	0	0

Table 23. **Areas of location maximum SSC in the surface layer of the model resulting from dredging of the surficial sediments at the FRR1 outfall**

SSC > mg/l	Spring Tides		Neap Tides	
	Area (Ha)	% of Plume Area	Area (Ha)	% of Plume Area
0	9,774	100	8,904	100
20	3,082	32	2,901	33
50	956	10	1,025	12
100	257	3	294	3
200	71	1	91	1
300	40	<1	36	<1
500	13	<1	10	<1
1000	3	<1	3	<1
2000	<1	<1	<1	<1

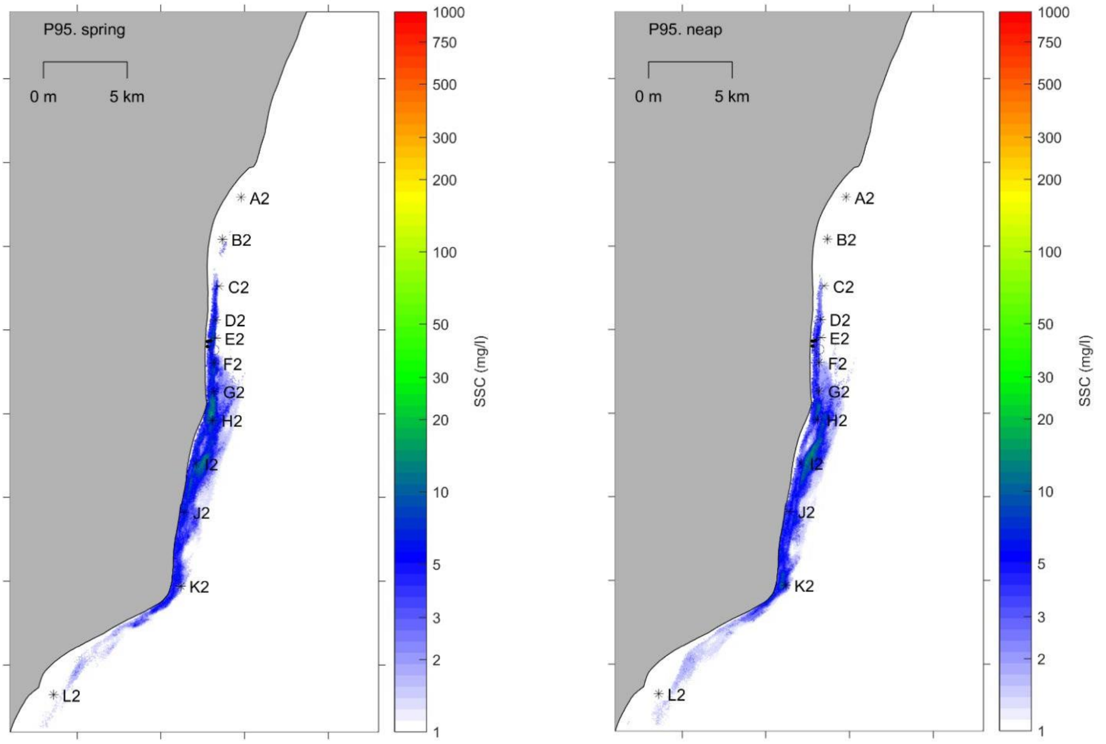
Table 24. **Areas of location maximum SSC in the surface layer of the model for different continuous durations resulting from dredging at the FRR1 outfall**

SSC > mg/l	Duration (>= hours)	Area (Ha)	
		Spring Tides	Neap Tides
50	1	956	1,025
50	3	1	13
50	6	0	0
50	12	0	0
100	1	257	294
100	3	1	0
100	6	0	0
100	12	0	0
300	1	40	36
300	3	<1	0
300	6	0	0
300	12	0	0



Black dots show the outfalls, disposal is at the black unfilled circle. Locations (A2 to L2) show time series extraction points

Figure 38. 95th Percentile in depth average SSC associated with dredging at the FRR1 outfall on spring and neap tides

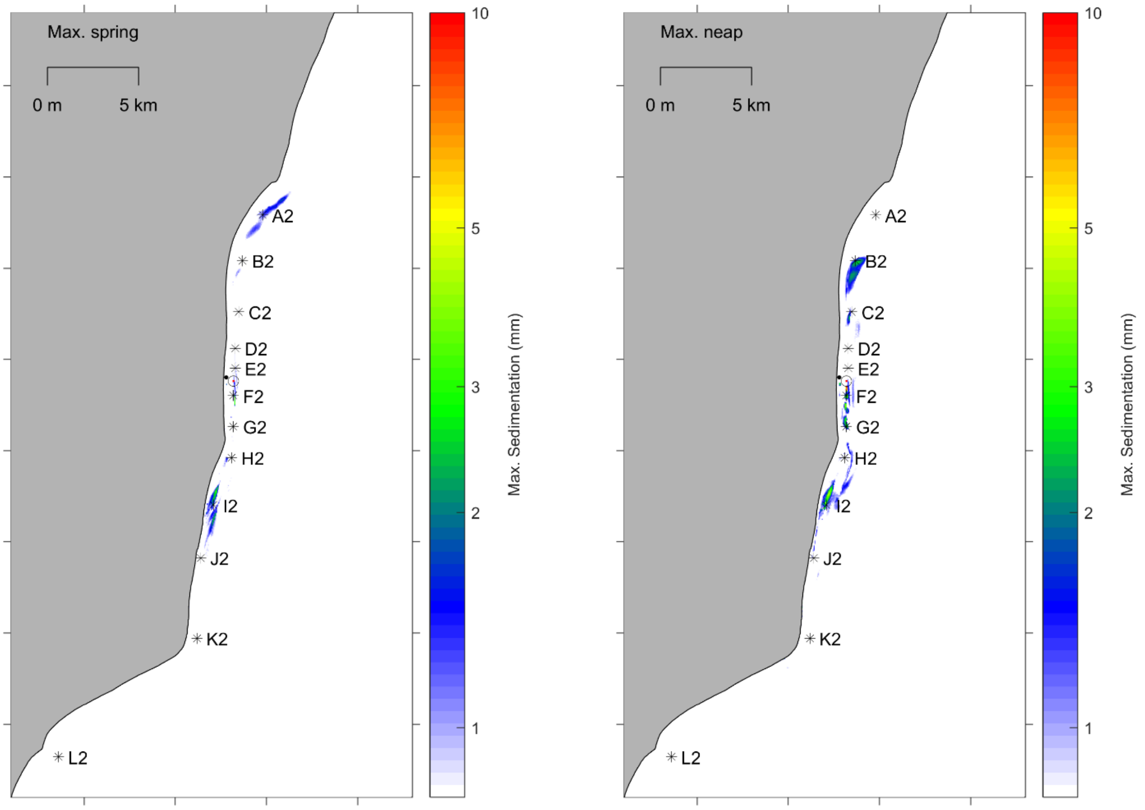


Black dots show the outfalls, disposal is at the black unfilled circle. Locations (A2 to L2) show time series extraction points

Figure 39. 95th Percentile in surface SSC associated with dredging at the FRR1 outfall on spring and neap tides

Location maximum sedimentation on the bed is shown in Figure 40. The maximum sedimentation is highest close to the disposal site, where values of more than 20 mm occur. Maximum sedimentation over the wider area is typically highest on the neap tides, with maximum values of more than 2 mm occurring in localised patches over an area between 7 km to the north and 8 km to the south of the disposal location. These patches correspond to the location of the plume in suspension at the time of slack water (when material settles onto the bed). Areas of location maximum sedimentation above different thresholds are provided in Table 25.

To provide an indication of how long the maximum sedimentation prevails, areas of sedimentation have been calculated for different threshold durations and these are presented in
Table 26.



Black dots show the outfalls, disposal is at the black unfilled circle. Locations (A2 to L2) show time series extraction points

Figure 40. Location maximum sedimentation associated with dredging at the FRR1 outfall on spring and neap tides

Table 25. **Areas of location maximum sediment thickness resulting from dredging of the surficial sediments at the FRR1 outfall**

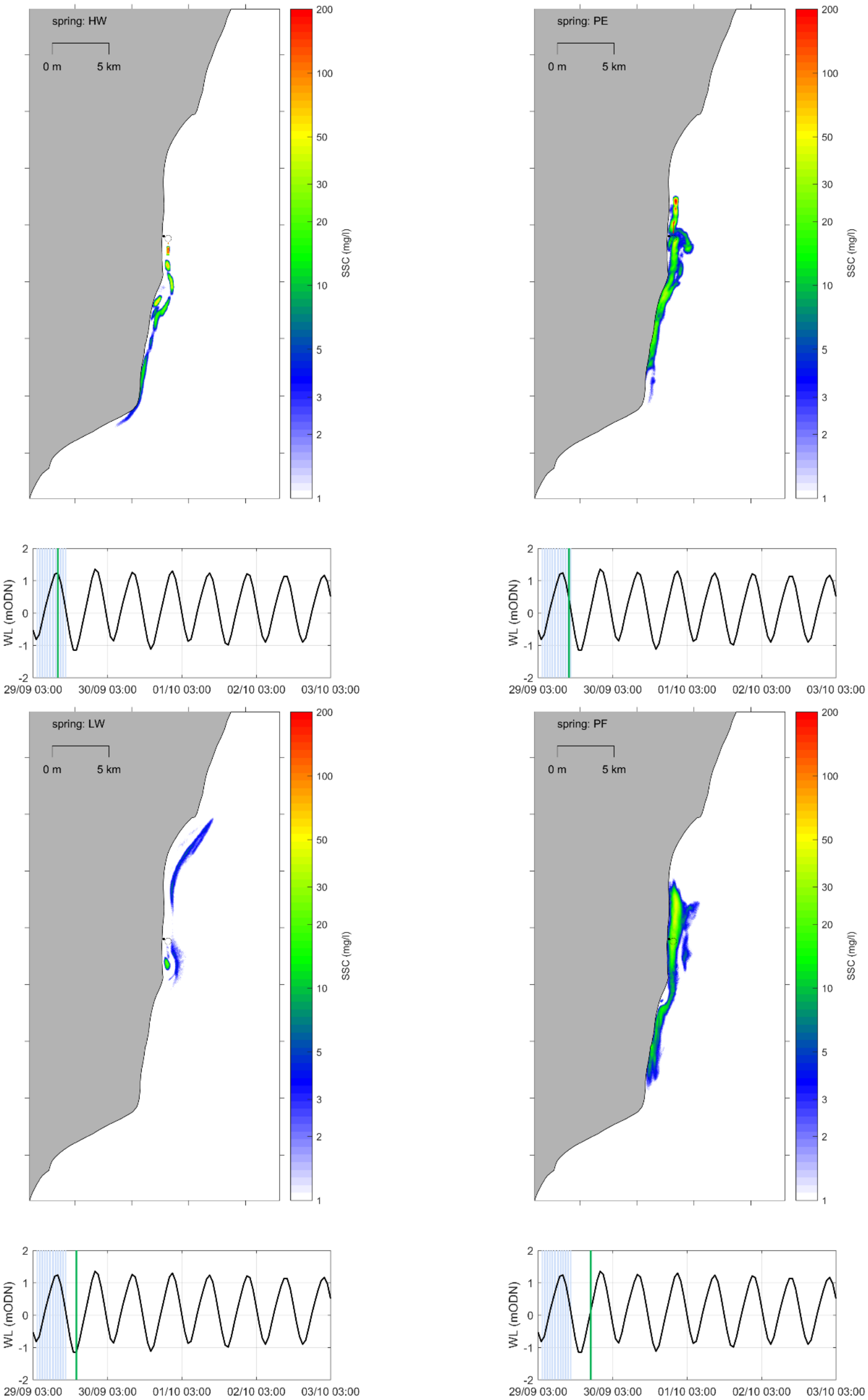
Sediment Thickness > mm	Spring Tides		Neap Tides	
	Area (Ha)	% of Plume Area	Area (Ha)	% of Plume Area
0	11,972	100	11,662	100
2	28	<1	77	1
5	3	<1	9	<1
10	1	<1	3	<1
20	1	<1	1	<1
50	0	0	0	0
100	0	0	0	0
300	0	0	0	0
500	0	0	0	0

Table 26. **Areas of location maximum sediment thickness for different continuous durations resulting from dredging of the surficial sediments at the FRR1 outfall**

Sediment Thickness > mm	Duration (>= hours)	Area (Ha)	
		Spring Tides	Neap Tides
5	1	3	9
5	3	2	6
5	6	2	6
5	12	2	6
10	1	1	3
10	3	0	1
10	6	0	1
10	12	0	1
20	1	1	1
20	3	0	0
20	6	0	0
20	12	0	0

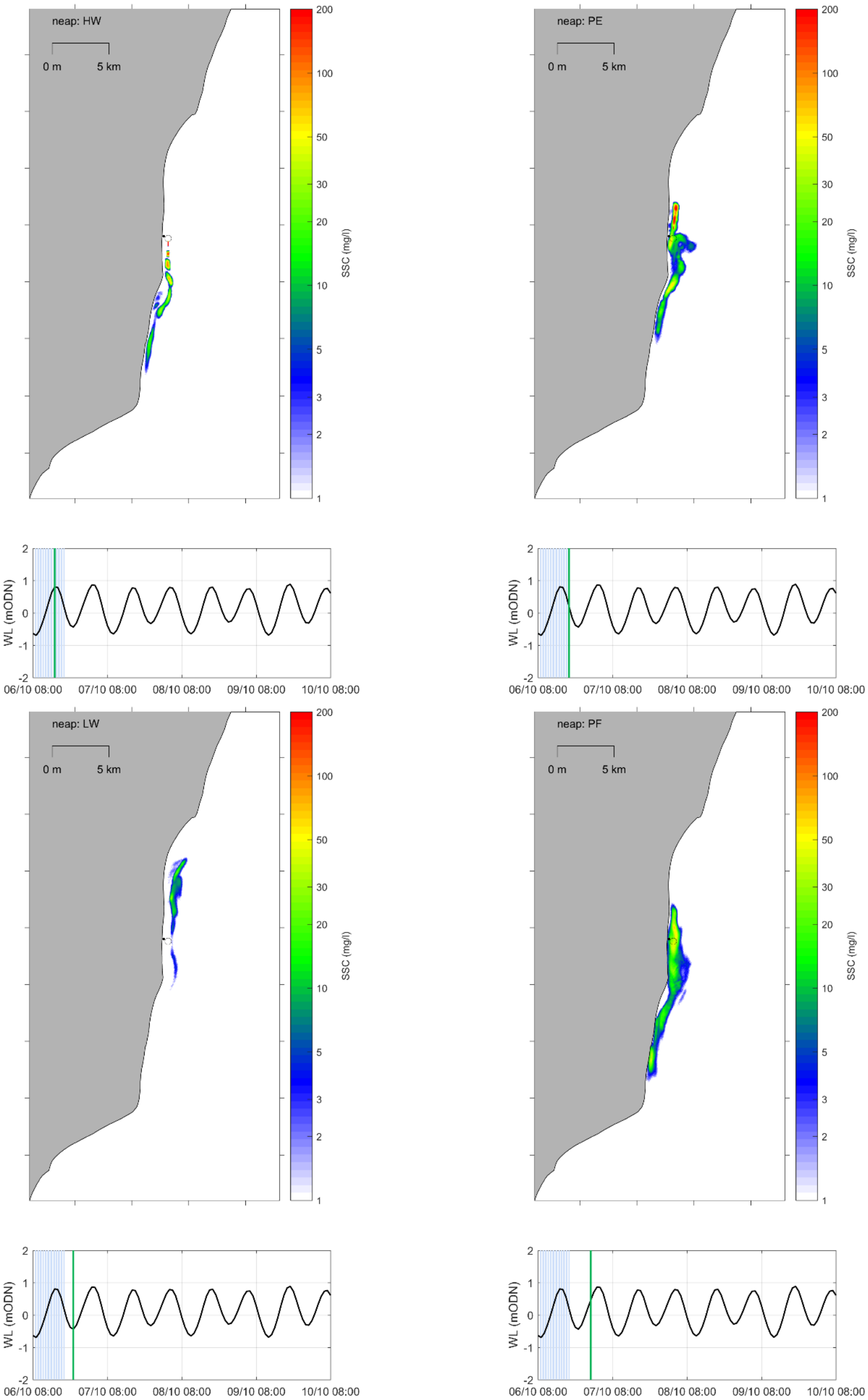
The evolution of the sediment plume throughout a semi-diurnal tide is shown in the plan plots of SSC at discrete tidal states on a mean spring and a mean neap tide in Figure 41 and Figure 42, respectively. The timesteps shown correspond to the first HW after the start of the dredging (which is approximately six hours after the first sediment release) and the times of the subsequent PE, LW and PF. The plots show the transient nature of the plume, with the plume transported 12 km to the north and 17 km to the south on a spring tide and around 8 km to the north and 13 km to the south on a neap tide.

Plan plots of sedimentation are presented throughout the same spring tidal period as shown for SSC (Figure 41) in Figure 43. These show the settling of sediment on the bed at the slack water periods and subsequent re-erosion of sediment during the periods of faster flows. The amount of sediment settling on the bed is localised and the deposits are thin (less than 2 mm). These plots indicate that the location maximum values shown (Figure 40) are short lived.



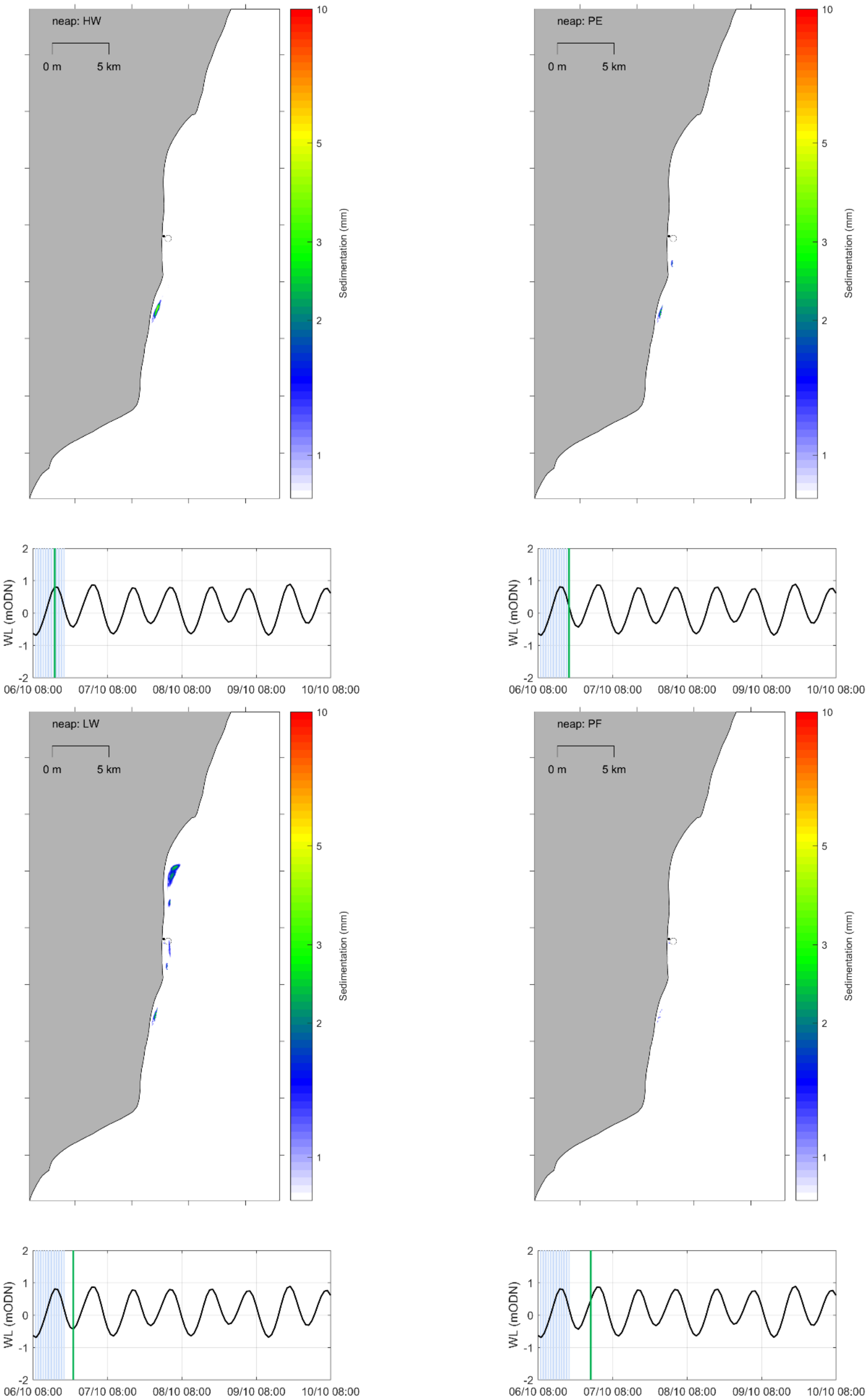
Black dots show the outfalls, disposal is at the black unfilled circle.
The pale blue shading on the time series plots indicate periods of sediment release.

Figure 41. Depth average SSC at HW, PE, LW and PF during dredging at the FRR1 outfall on a spring tide



Black dots show the outfalls, disposal is at the black unfilled circle.
The pale blue shading on the time series plots indicate periods of sediment release.

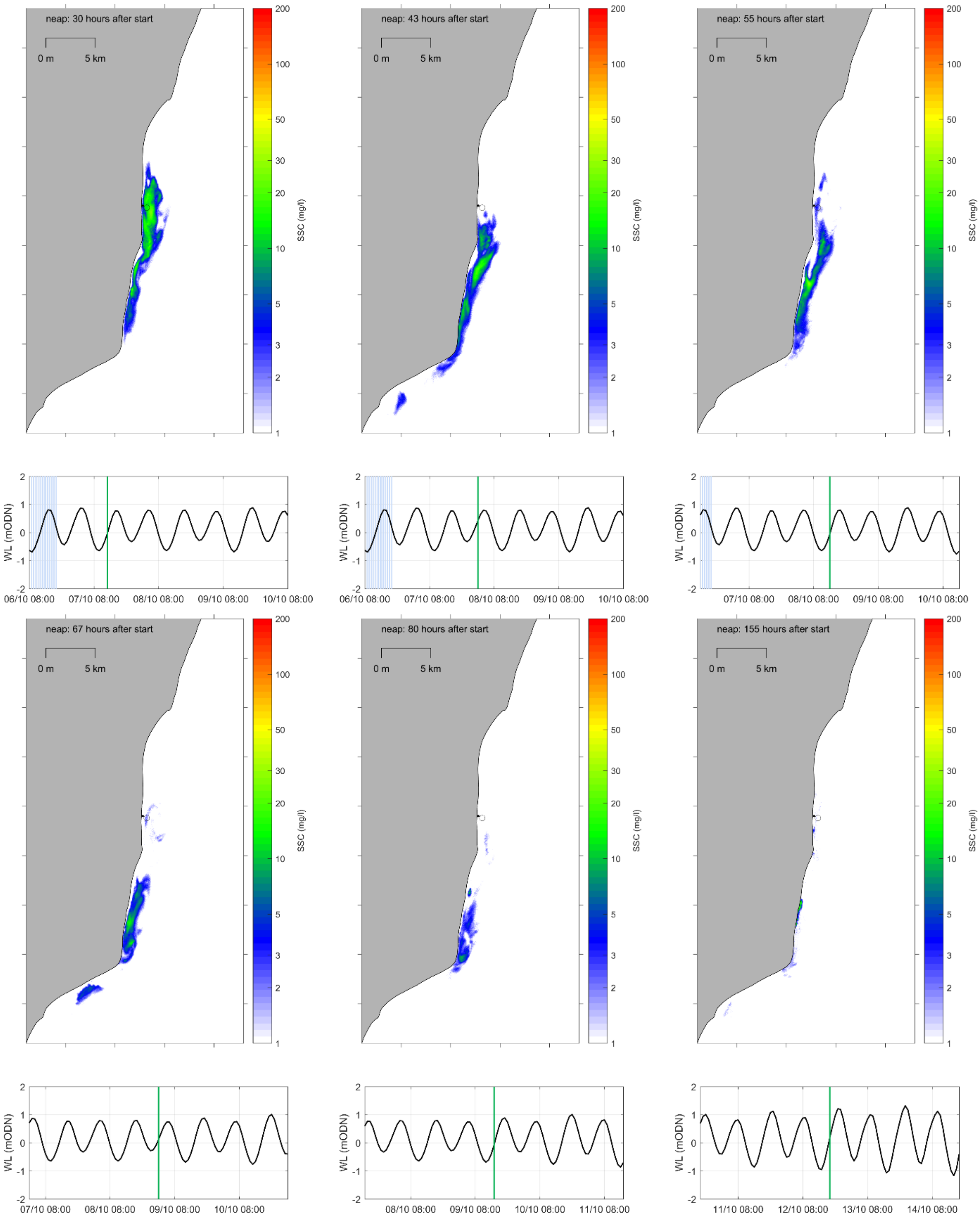
Figure 42. Depth average SSC at HW, PE, LW and PF during dredging at the FRR1 outfall on a neap tide



Black dots show the outfalls, disposal is at the black unfilled circle.
The pale blue shading on the time series plots indicate periods of sediment release.

Figure 43. Sedimentation at HW, PE, LW and PF during dredging at the FRR1 outfall on a neap tide

To show how the sediment plumes disperse after the dredging, map plots are shown at discrete timesteps in Figure 44. These show the results for dredging on a neap tide (when higher concentrations occur along the coast). These indicate that following the completion of the dredge the plume quickly disperses.



Black dots show the outfalls, disposal is at the black unfilled circle.
The pale blue shading on the time series plots indicate periods of sediment release.

Figure 44. Depth average SSC at stages during dredging at the FRR1 outfall on a neap tide

There is some material remaining on the bed within the model area at the end of the dredge which accounts for approximately 15 % of the material released. Material on the bed is moved to localised areas close inshore making them difficult to identify (see Figure 45). Areas (in Ha) of sediment thickness on the bed at the end of the model simulation are provided in Table 27.

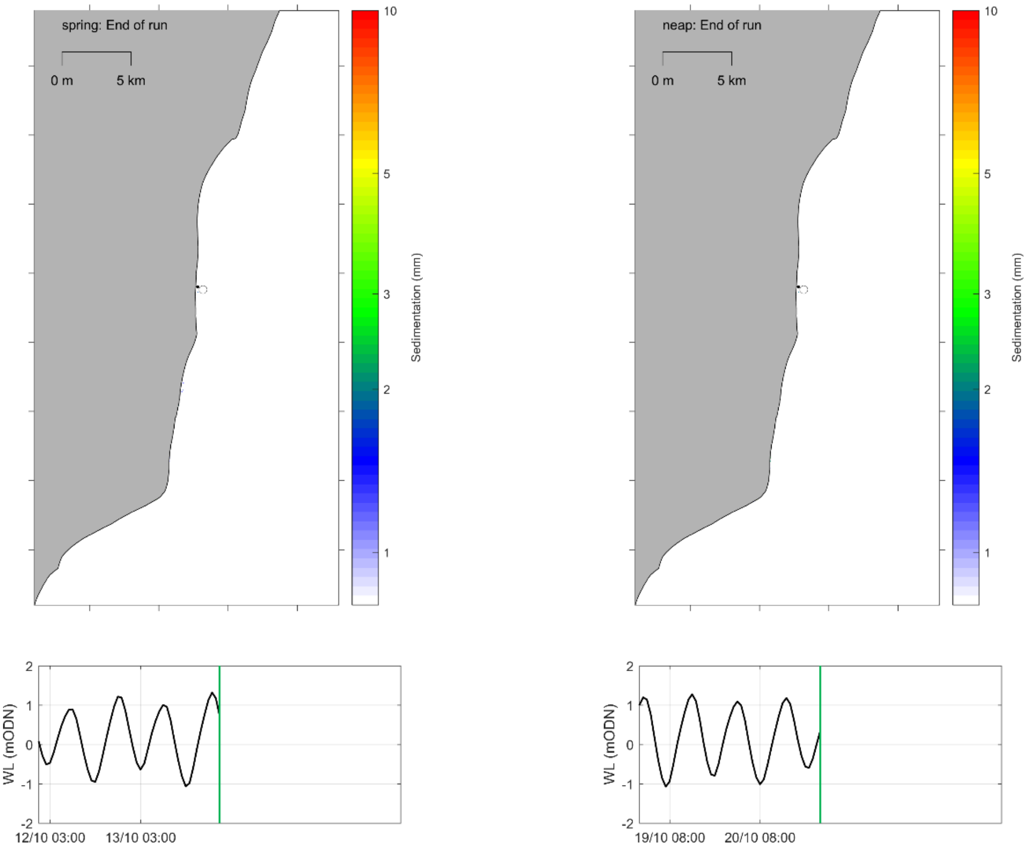
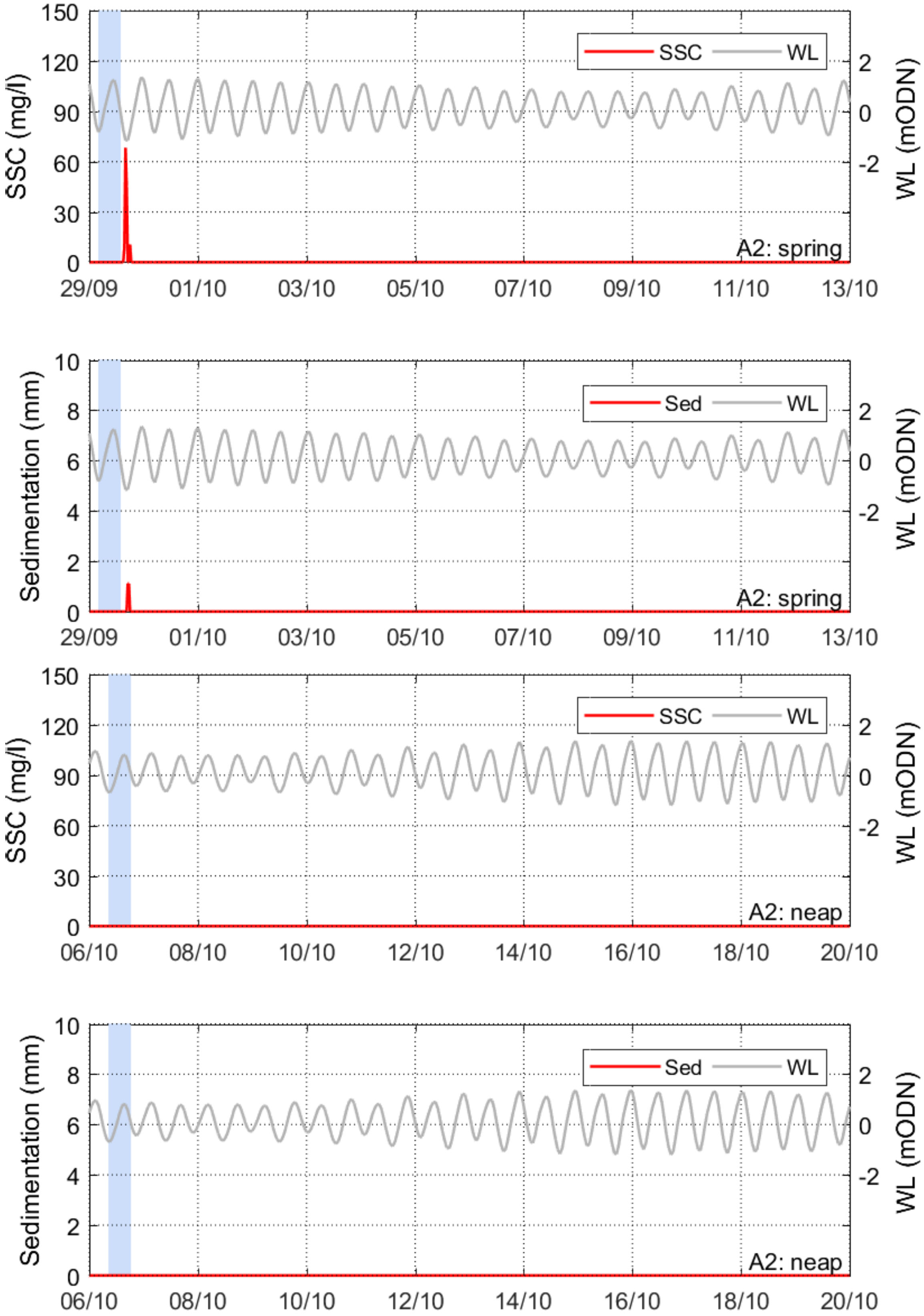


Figure 45. **Sedimentation on the bed at the end of the model run for dredging at the FRR1 outfall on a spring and neap tide**

Table 27. **Areas of sediment thickness at the end of the model simulation resulting from dredging of the surficial sediments at the FRR1 outfall**

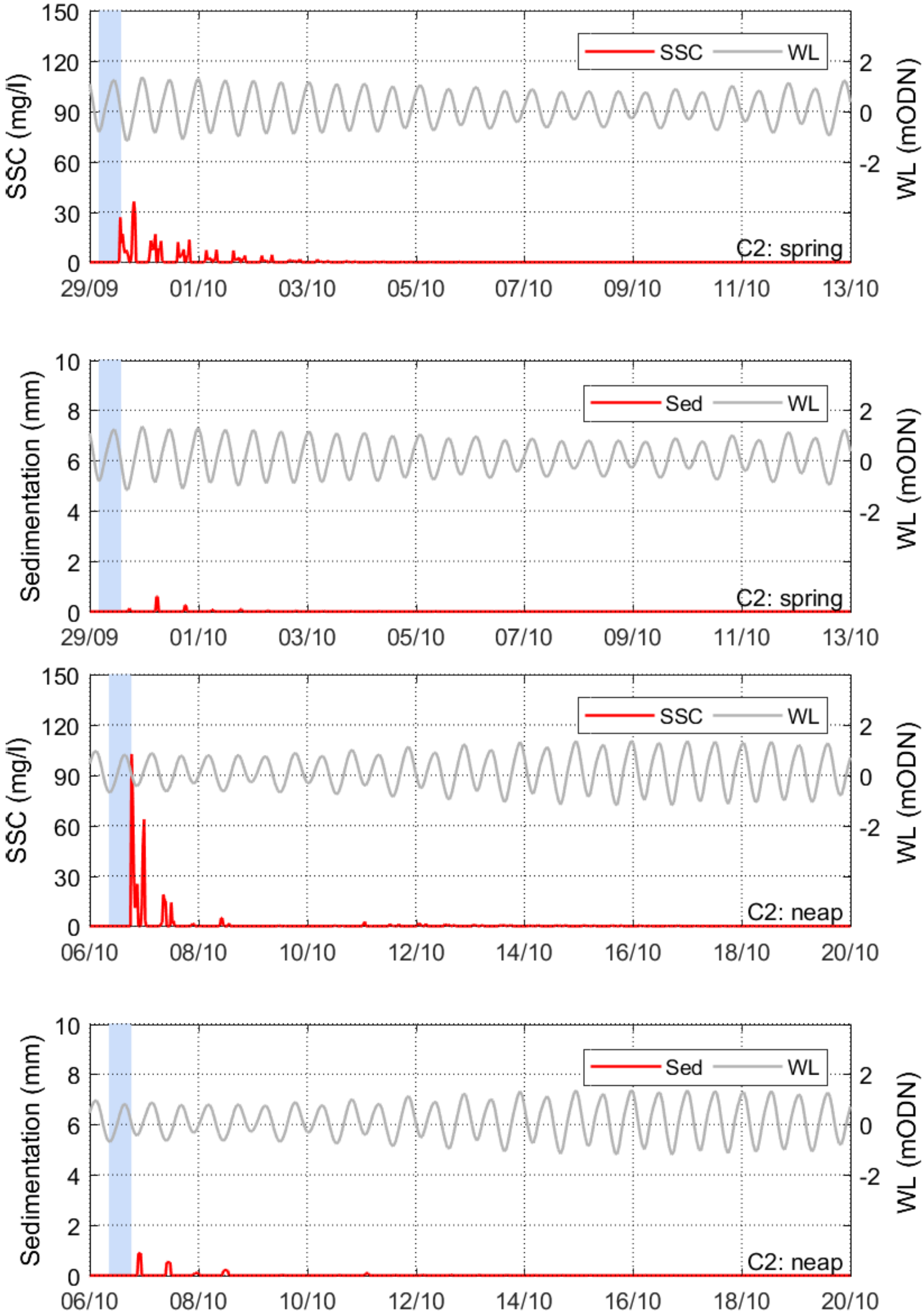
Sediment Thickness > mm	Area (Ha)	
	Spring Tides	Neap Tides
0	480	285
2	11	14
5	2	5
10	0	1

Time series plots of SSC and sedimentation during and after the dredge are shown at discrete locations (see Figure 38 for locations) in Figure 46 to Figure 51 . The greatest change is shown at Location E2 (approximately 500 m north of the disposal location), peaks in concentration of around 200 mg/l occur during the dredge period shortly after HW (Figure 48). These peaks are short lived, with more typical SSCs of 30 mg/l. Sedimentation at E2 peaks around the slack flow period at low water with deposits of up to 1 mm. Deposited sediment is re-eroded on the subsequent tide.



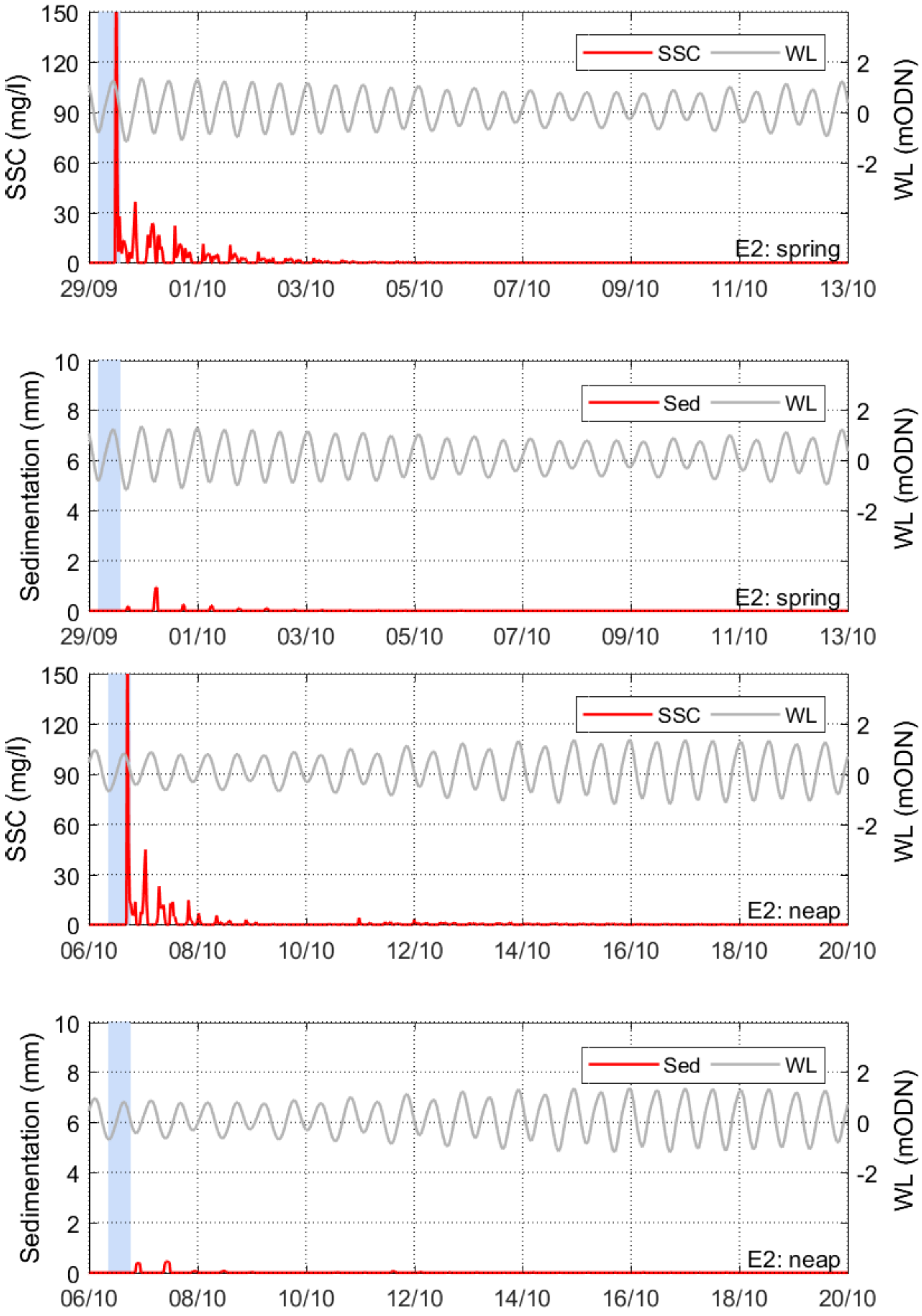
Blue shading shows periods of sediment release.

Figure 46. Time series of depth average SSC and sedimentation at Location A2 on spring (upper two panels) and neap tides (lower two panels) during and after dredging at the FRR1 outfall



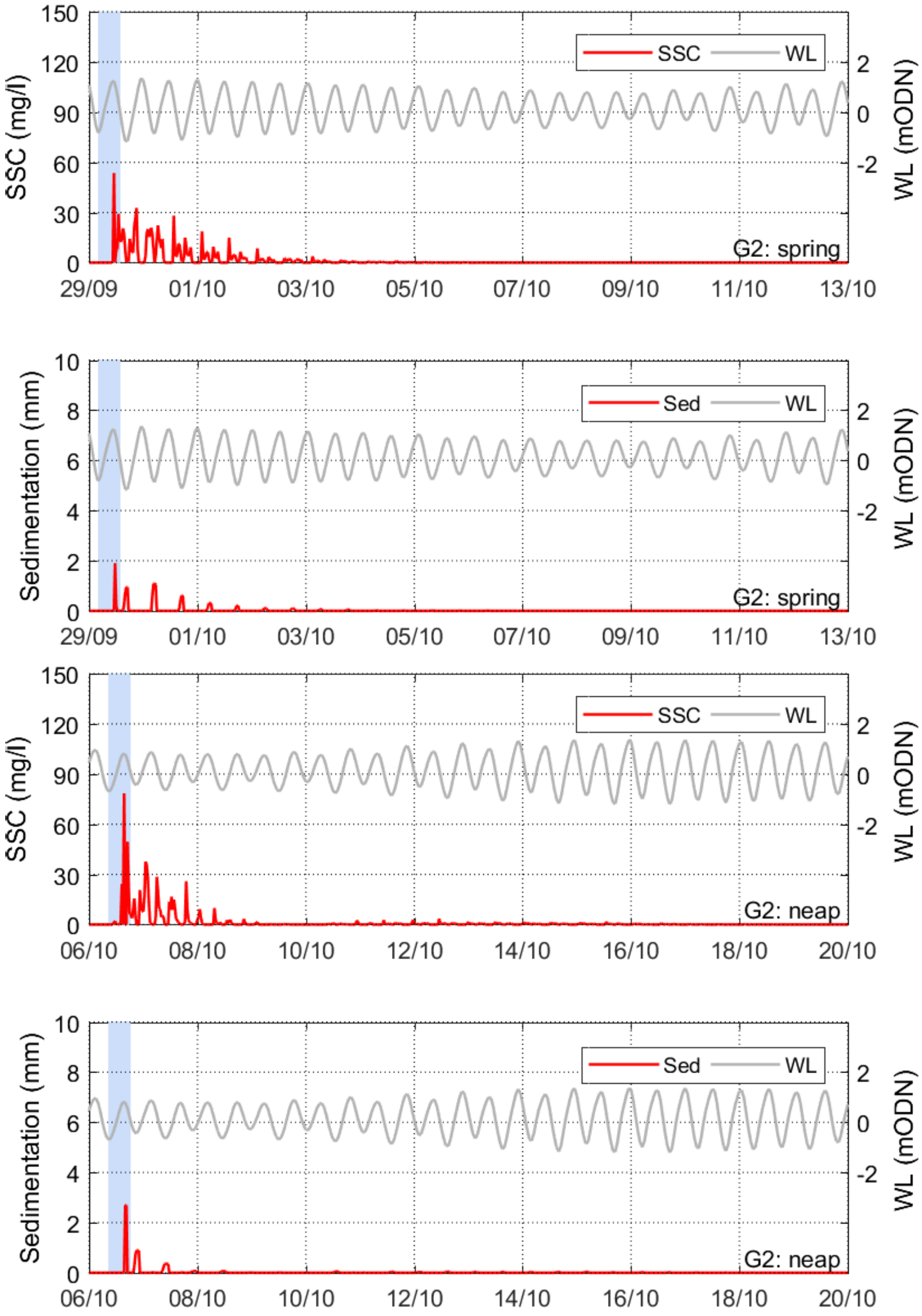
Blue shading shows periods of sediment release.

Figure 47. Time series of depth average SSC and sedimentation at Location C2 on spring (upper two panels) and neap tides (lower two panels) during and after dredging at the FRR1 outfall



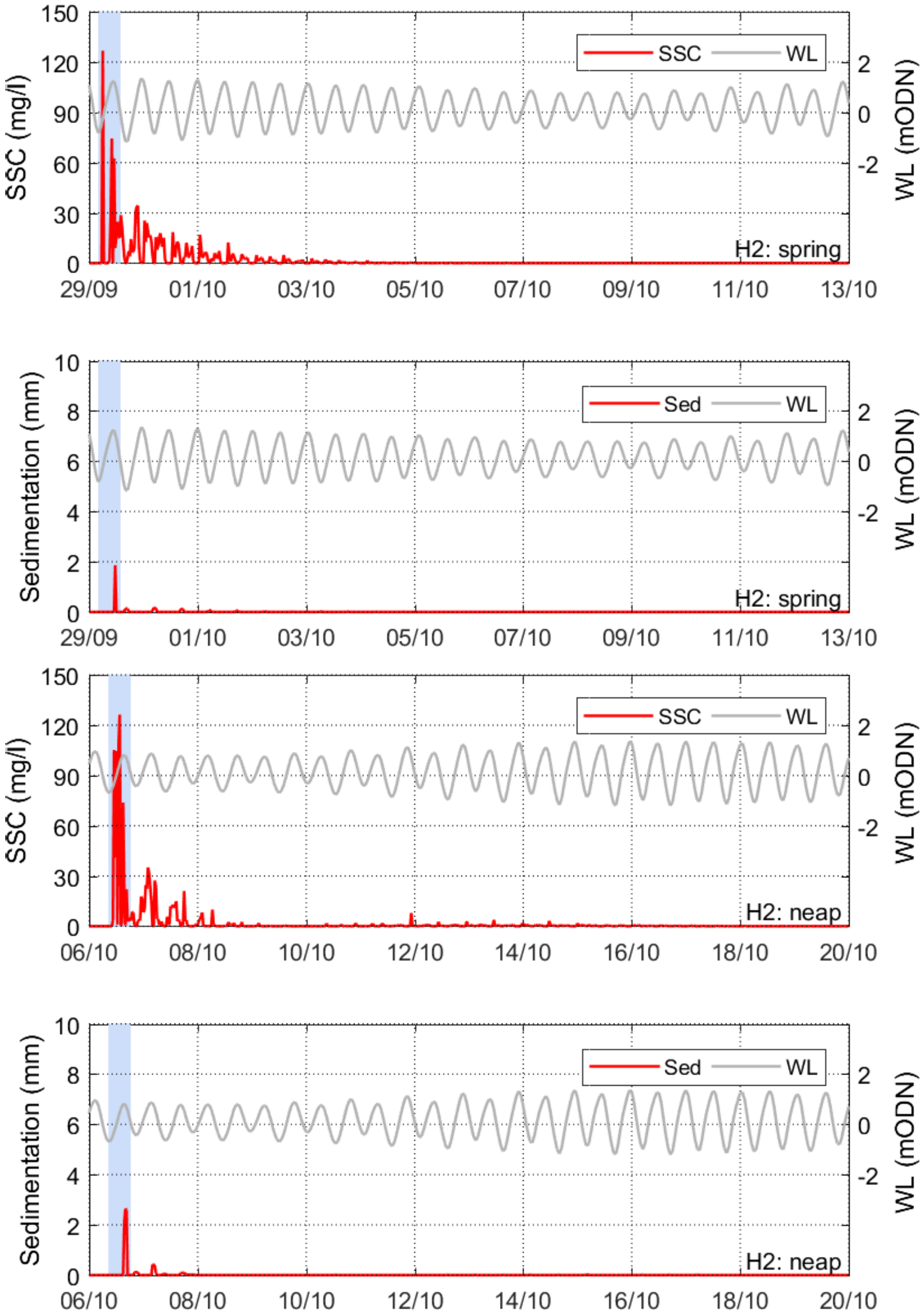
Blue shading shows periods of sediment release.

Figure 48. Time series of depth average SSC and sedimentation at Location E2 on spring (upper two panels) and neap tides (lower two panels) during and after dredging at the FRR1 outfall



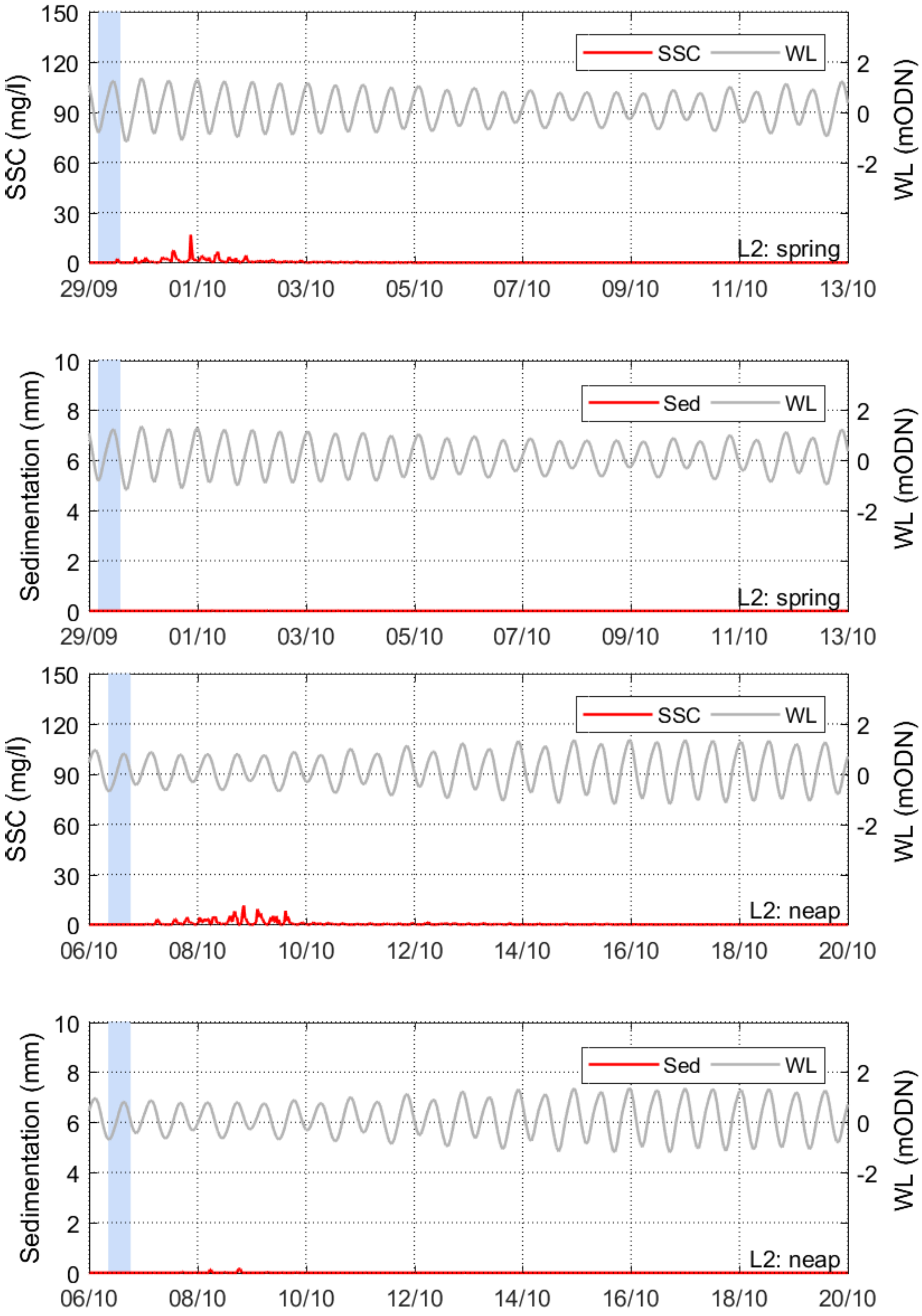
Blue shading shows periods of sediment release.

Figure 49. Time series of depth average SSC and sedimentation at Location G2 on spring



Blue shading shows periods of sediment release.

Figure 50. Time series of depth average SSC and sedimentation at Location H2 on spring (upper two panels) and neap tides (lower two panels) during and after dredging at the FRR1 outfall



Blue shading shows periods of sediment release.

Figure 51. **Time series of depth average SSC and sedimentation at Location L2 on spring (upper two panels) and neap tides (lower two panels) during and after dredging at the FRR1 outfall**

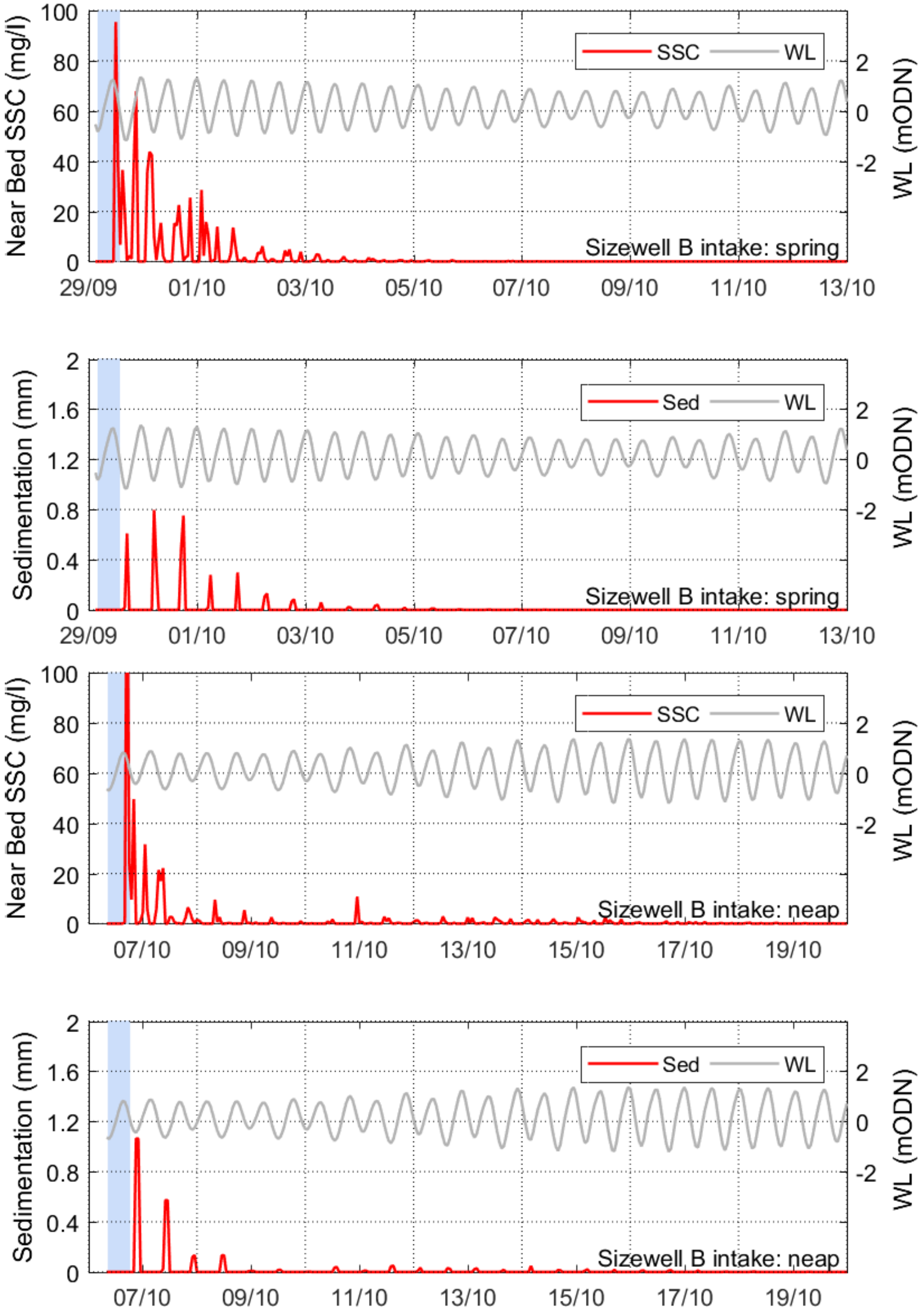


Figure 52. Time series of the near bed SSC and sedimentation at the Sizewell B intake on spring (upper two panels) and neap tides (lower two panels) during and after dredging at the FRR1 outfall

A time series of the sedimentation and near bed SSC during and after the dredge are shown at the Sizewell B intake in Figure 52. The maximum instantaneous sedimentation and near bed SSC at the intake are provided in Table 28.

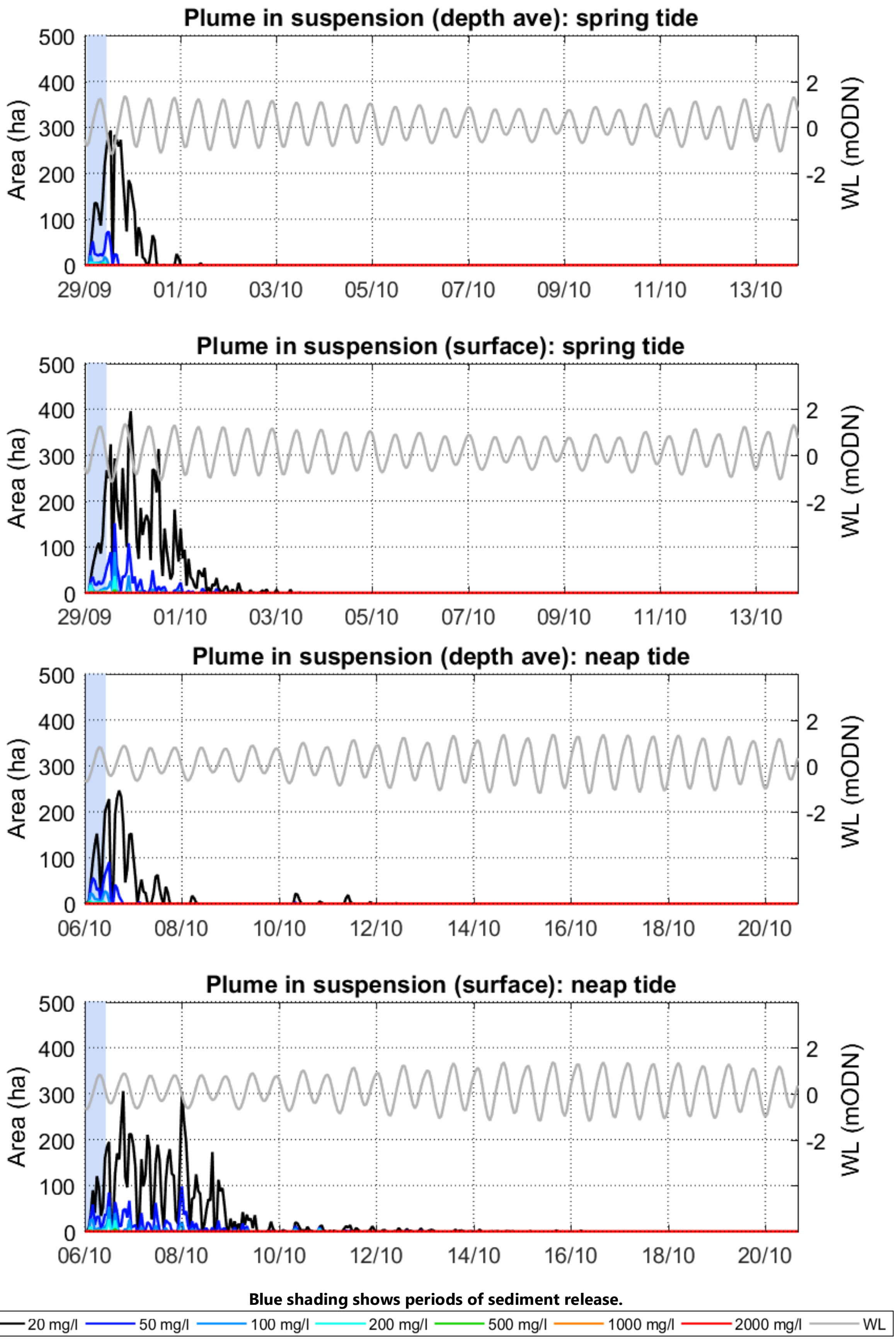
Table 28. Maximum instantaneous sedimentation and near bed SSC at the Sizewell B intake, resulting from dredging of surficial sediments at the FRR1 outfall

Tide	Instantaneous Maximum	
	SSC (mg/l)	Sedimentation (mm)
Spring Tide	95	0.8
Neap Tide	164	1.1

To examine the plume dispersion in more detail, time series of plume areas in suspension and on the bed are shown in Figure 53 and Figure 54 and maximum instantaneous areas are quantified in Table 29 to Table 31.

The plots show that on spring tides material in suspension is at concentrations of less than 20 mg/l within two days of the completion of the dredge, further the plume concentrations are less than 200 mg/l above background values within hours of the dredge completion and as such may be difficult to detect. On neap tides, the plume concentrations in suspension also quickly return to values which are close to background. However, the model predicts some resuspension of material once the larger range spring tides occur, which could result in SSC of more than 20 mg/l in some localised areas. These increases in SSC are expected to be short lived (of the order of days). Further the peaks in SSC are likely to be overestimated in the model since not all material on the bed will instantaneously be suspended and it is considered likely that in reality, any freshly deposited material eroded from the bed will be indiscernible from the background SSC.

Areas of sedimentation are smaller than the plume areas in suspension, since flows are fast enough to maintain material in suspension except in the areas of slowest flows where material settles on the bed. However, once the material has settled, further erosion is not evident (see Figure 54) and accumulations up to 10 mm is likely to be permanent in these areas.



Plume in suspension (depth ave): spring tide

Plume in suspension (surface): spring tide

Plume in suspension (depth ave): neap tide

Plume in suspension (surface): neap tide

Blue shading shows periods of sediment release.

Figure 53. **Plume areas in suspension (as depth average and in the surface layer) during and after the dredging at the FRR1 outfall**

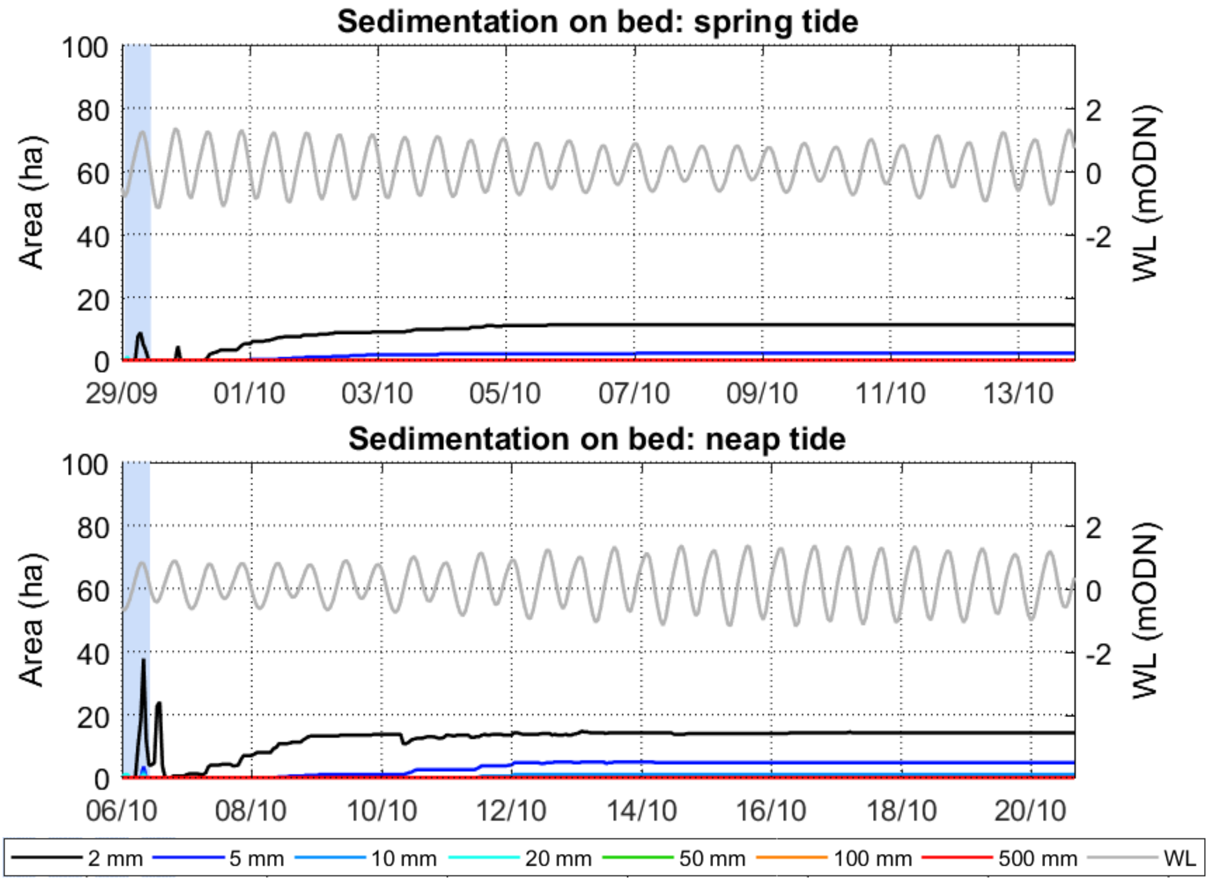


Figure 54. Plume areas on the bed during and after the dredging at the FRR1 outfall

Table 29. Maximum area of instantaneous depth average SSC resulting from dredging of the surficial sediments at the FRR1 outfall

SSC > mg/l	Area (Ha)	
	Spring Tides	Neap Tides
20	293	246
50	73	91
100	21	28
200	7	6
500	2	2
1000	1	0
2000	0	0

Table 30. Maximum area of instantaneous surface SSC resulting from dredging of the surficial sediments at the FRR1 outfall

SSC > mg/l	Area (Ha)	
	Spring Tides	Neap Tides
20	396	305
50	152	98
100	89	54
200	37	27
500	7	6
1000	1	1
2000	0	0

Table 31. Maximum area of instantaneous sedimentation resulting from dredging of the surficial sediments at the FRR1 outfall

Sediment Thickness > mm	Area (Ha)	
	Spring Tides	Neap Tides
2	11	38
5	2	5
10	1	2
20	1	1
50	0	0
100	0	0
500	0	0

3.2.1 Bird Foraging

As with dredging of the CWS structures, the dredging of the additional outfall structures is likely to result in small parts of the bird foraging areas experiencing instantaneous surface SSC of more than 100 mg/l (Table 32). The area of increase above 100 mg/l accounts for 4 % of the total foraging area for Little Terns in the Dingle colony when the dredge occurs on spring tides and less than this for all other species and colonies. A time series of percentage of the foraging areas intersected by the plume is shown in Figure 55.

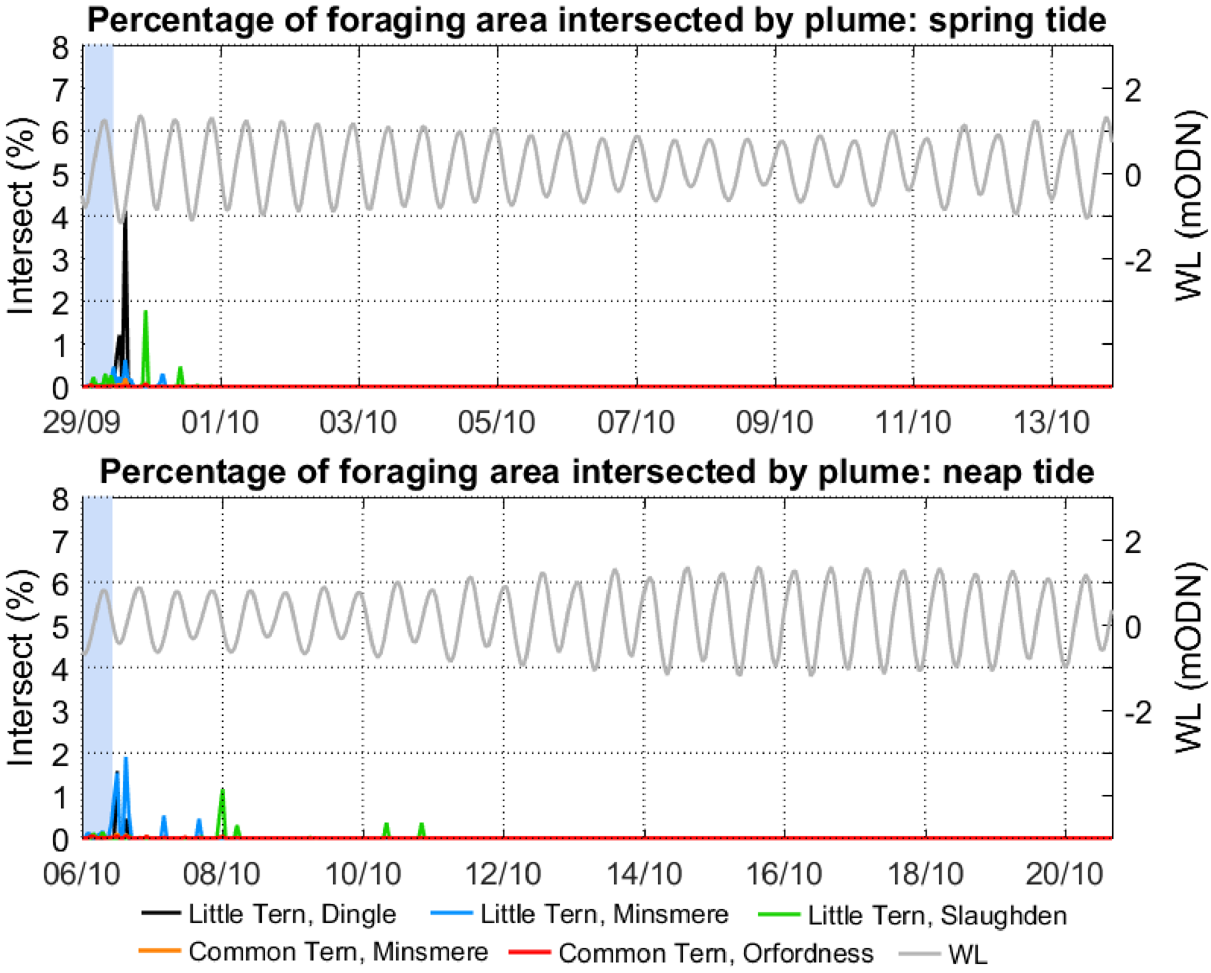


Figure 55. Plume areas in suspension (defined as surface SSC of more than 100 mg/l), intersecting with bird foraging areas during and after the dredging at the FRR1 outfall

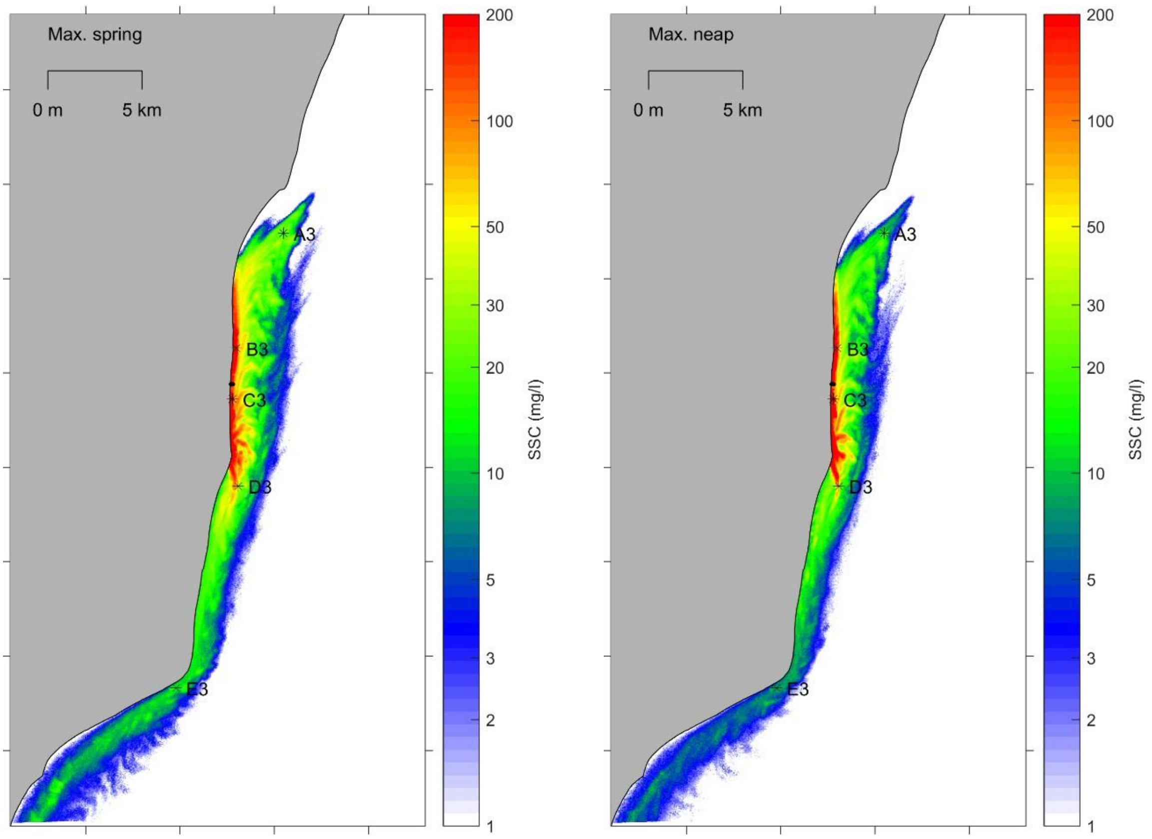
The time series indicate the short loved nature of any areas of intersect. As noted in Section 3.1.1, for the Sandwich Terns and the Lesser Black Backed Gull, all of the plume is contained within the foraging areas identified in Figure 4. The plume extent accounts for less than 1 % of the foraging areas for these bird species.

Table 32. Maximum area of plume intersect with habitat/bird foraging areas resulting from dredging of surficial sediments at the FRR1 outfall. Plume defined as surface SSC above 100 mg/l.

Receptor	Spring Tides		Neap Tides	
	Area (Ha)	% Of Foraging Area	Area (Ha)	% of Foraging Area
Little Tern Dingle Colony	76	4	29	2
Little Tern Minsmere Colony	10	1	31	2
Little Tern Slaughden Colony	32	2	21	1
Common Tern (Minsmere Colony)	89	<1	54	<1
Common Tern (Orfordness Colony)	38	<1	32	<1

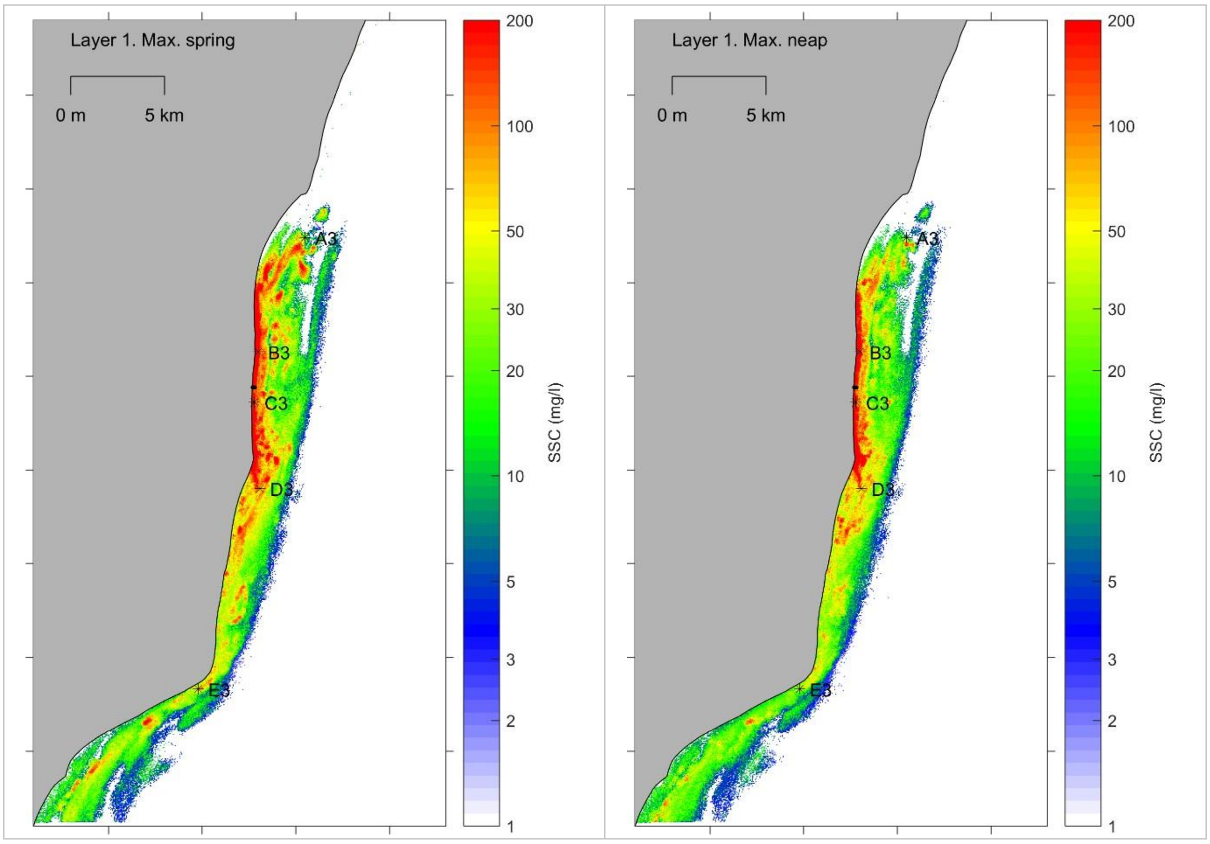
3.3 Scenario 3. Capital dredging of the BLF approach channel

Plan plots of the location maximum SSC associated with the capital dredging to allow access to the BLF are shown for the dredge starting on spring and neap tides in Figure 56 and Figure 57 , for depth average and surface SSC, respectively.



Black dots show the sediment release locations, Locations (A3 to E3) show time series extraction points

Figure 56. Location maximum depth average SSC associated with capital dredging the BLF approach channel on spring and neap tides



Black dots show the sediment release locations, Locations (A3 to E3) show time series extraction points

Figure 57. Location maximum surface SSC associated with capital dredging the BLF approach channel on spring and neap tides

Highest plume concentrations extend directly along the coast, resulting from the inshore sediment release location. Depth average location maximum SSC of more than 100 mg/l above background extend approximately 5 km north and south of the dredge area.

To further quantify the extent of the location maximum plume, areas above different threshold concentrations are provided in Table 33 (depth average SSC) and Table 34 (surface layer SSC). An area of around 300 Ha is affected by increases in depth average SSC of more than 100 mg/l as a result of the capital dredge at the BLF approach channel. As for the dredging at the additional structures, this area is increased when the surface SSC is considered. To provide an indication of how long the location maximum may occur, the plume areas have been calculated for different threshold values and durations in Table 35.

Table 33. Areas of location maximum depth average SSC resulting from capital dredging of the BLF approach channel

SSC > mg/l	Spring Tides		Neap Tides	
	Area (Ha)	% of Plume Area		% of Plume Area
0	14,780	100	14,153	100
20	2,407	16	1,500	11
50	804	5	539	4
100	332	2	300	2
200	138	1	159	1
300	75	1	99	1
500	34	<1	44	<1
1000	16	<1	17	<1
2000	8	<1	6	<1

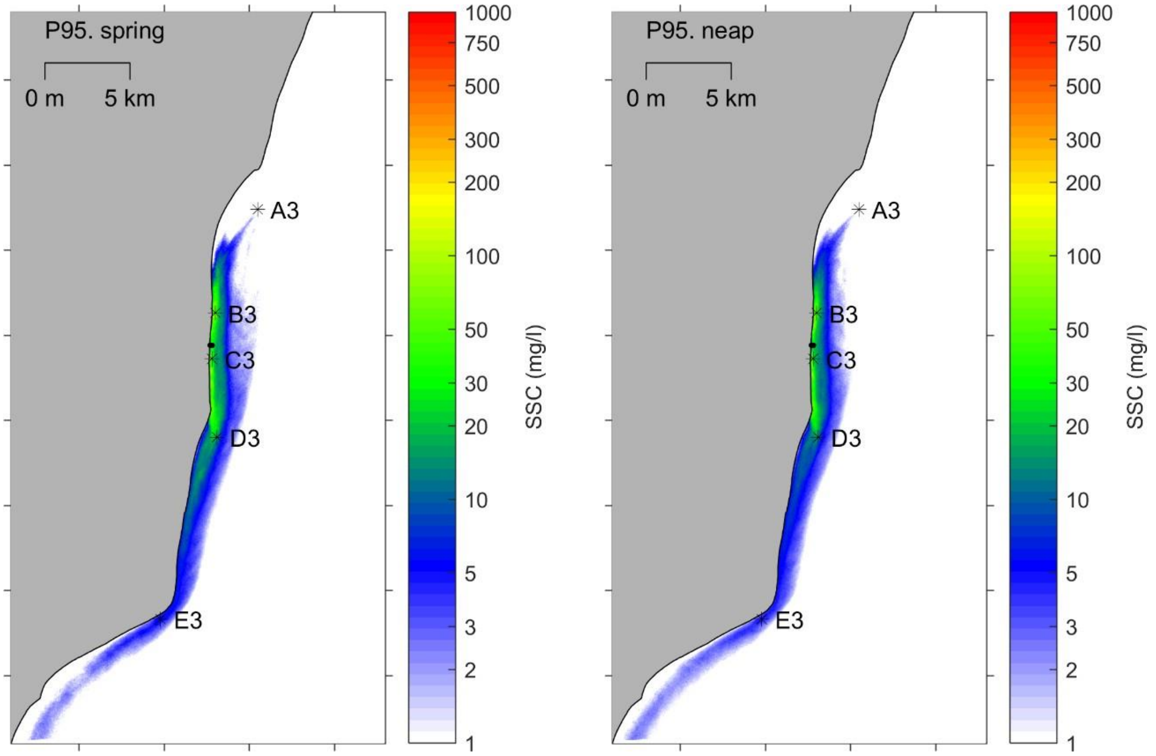
Table 34. Areas of location maximum SSC in the surface layer of the model resulting from capital dredging of the BLF approach channel

SSC > mg/l	Spring Tides		Neap Tides	
	Area (Ha)	% of Plume Area	Area (Ha)	% of Plume Area
0	9,460	100	9,292	100
20	5,221	55	4,464	48
50	2,350	25	1,660	18
100	866	9	551	6
200	314	3	233	3
300	159	2	141	2
500	70	1	71	1
1000	27	<1	18	<1
2000	9	<1	9	<1

Table 35. Areas of location maximum SSC in the surface layer of the model for different continuous durations resulting from capital dredging of the BLF approach channel

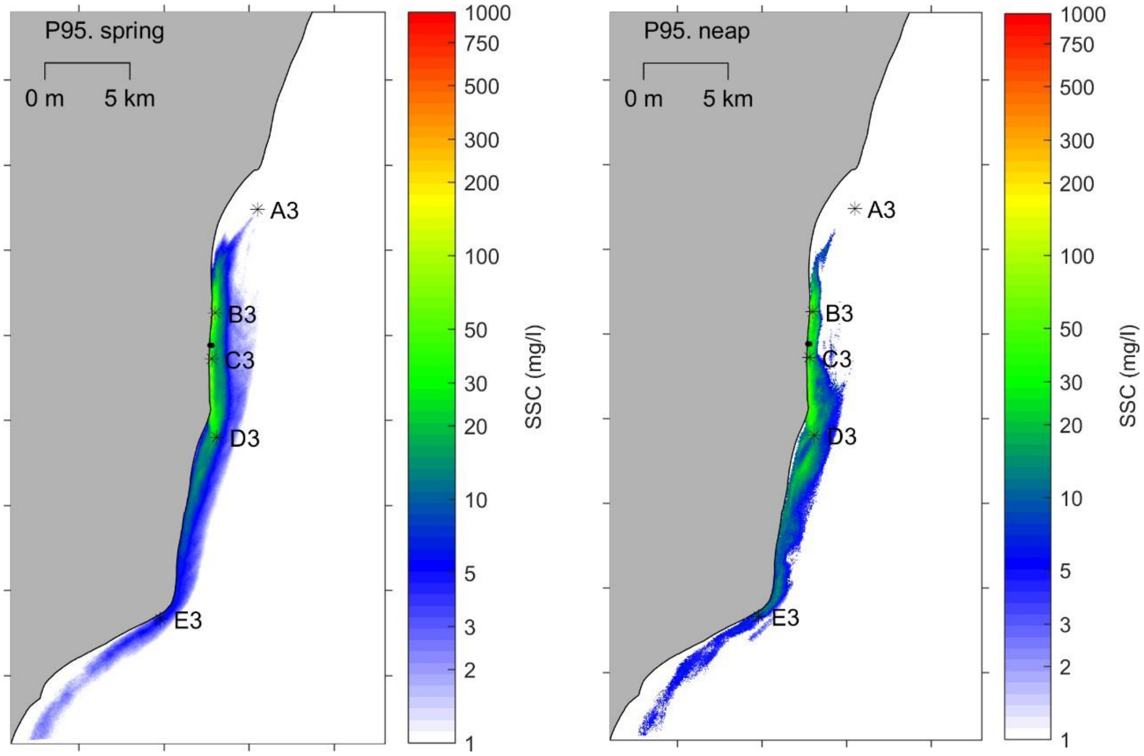
SSC > mg/l	Duration (>= hours)	Area (Ha)	
		Spring Tides	Neap Tides
50	1	2,350	1,660
50	3	172	62
50	6	3	0
50	12	0	0
100	1	866	551
100	3	43	13
100	6	0	0
100	12	0	0
300	1	159	141
300	3	2	0
300	6	0	0
300	12	0	0

Plan plots of the P95 SSC (depth average and surface) associated with the dredging to allow access to the BLF are shown for the dredge starting on spring and neap tides in Figure 58 and Figure 59. As for the other dredging activities, the P95 SSC values show a marked decrease compared to location maximum SSC, highlighting the short-lived duration of the plume. The P95 SSC is slightly higher than occurred for the dredging at the additional outfalls. This is a result of the reduced lateral advection at the release location and the longer duration of sediment release.



Black dots show the sediment release locations, Locations (A3 to E3) show time series extraction points

Figure 58. **95th Percentile in depth average SSC associated with capital dredging the BLF approach channel on spring and neap tides**



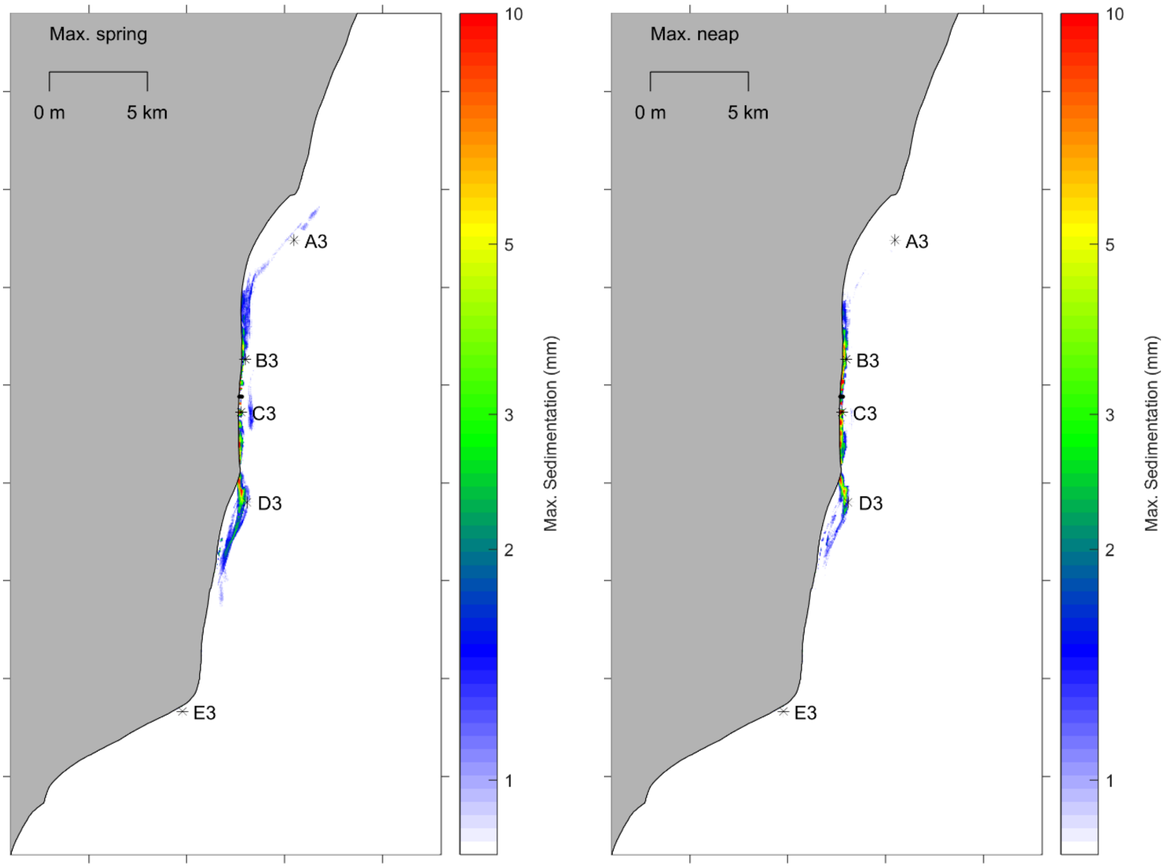
Black dots show the sediment release locations, Locations (A3 to E3) show time series extraction points

Figure 59. 95th Percentile in surface SSC associated with capital dredging the BLF approach channel on spring and neap tides

Plan plots of the location maximum sedimentation are shown for the dredge starting on a spring and neap tide in Figure 60. On both spring and neap tides the sediment only settles on the bed over a relatively small area close inshore. The location maximum sedimentation areas are quantified in Table 36. To provide an indication of how long the conditions prevail, the sedimentation areas have been calculated for different threshold durations (see Table 37).

Table 36. **Areas of location maximum sediment thickness resulting from capital dredging of the BLF approach channel**

Sediment Thickness > mm	Spring Tides		Neap Tides	
	Area (Ha)	% of Plume Area	Area (Ha)	% of Plume Area
0	11,889		11,698	
2	164	1	185	2
5	46	<1	73	1
10	16	<1	23	<1
20	5	<1	6	<1
50	1	<1	3	<1
100	1	<1	2	<1
300	0	0	1	<1
500	0	0	0	0



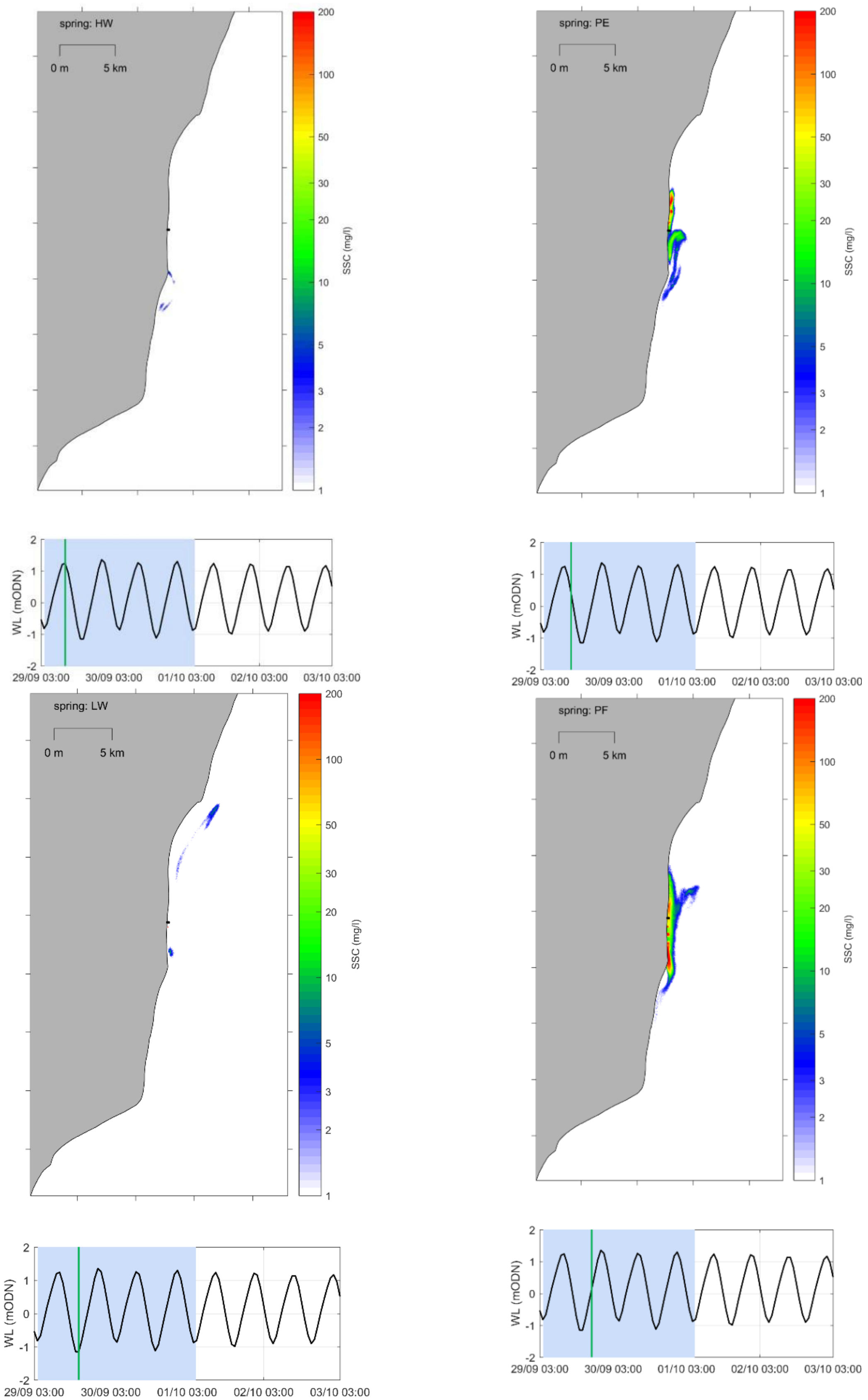
Black dots show the sediment release locations, Locations (A3 to E3) show time series extraction points

Figure 60. **Location maximum sedimentation associated with capital dredging of the BLF approach channel on spring and neap tides**

Table 37. Areas of location maximum sediment thickness for different continuous durations resulting from capital dredging of the BLF approach channel

Sediment Thickness > mm	Duration (>= hours)	Area (Ha)	
		Spring Tides	Neap Tides
5	1	46	73
5	3	38	64
5	6	29	60
5	12	27	59
10	1	16	23
10	3	14	22
10	6	13	22
10	12	12	21
20	1	5	6
20	3	5	6
20	6	4	6
20	12	3	6
50	1	2	3
50	3	1	3
50	6	1	3
50	12	0	3
300	1	0	1
300	3	0	1
300	6	0	1
300	12	0	1

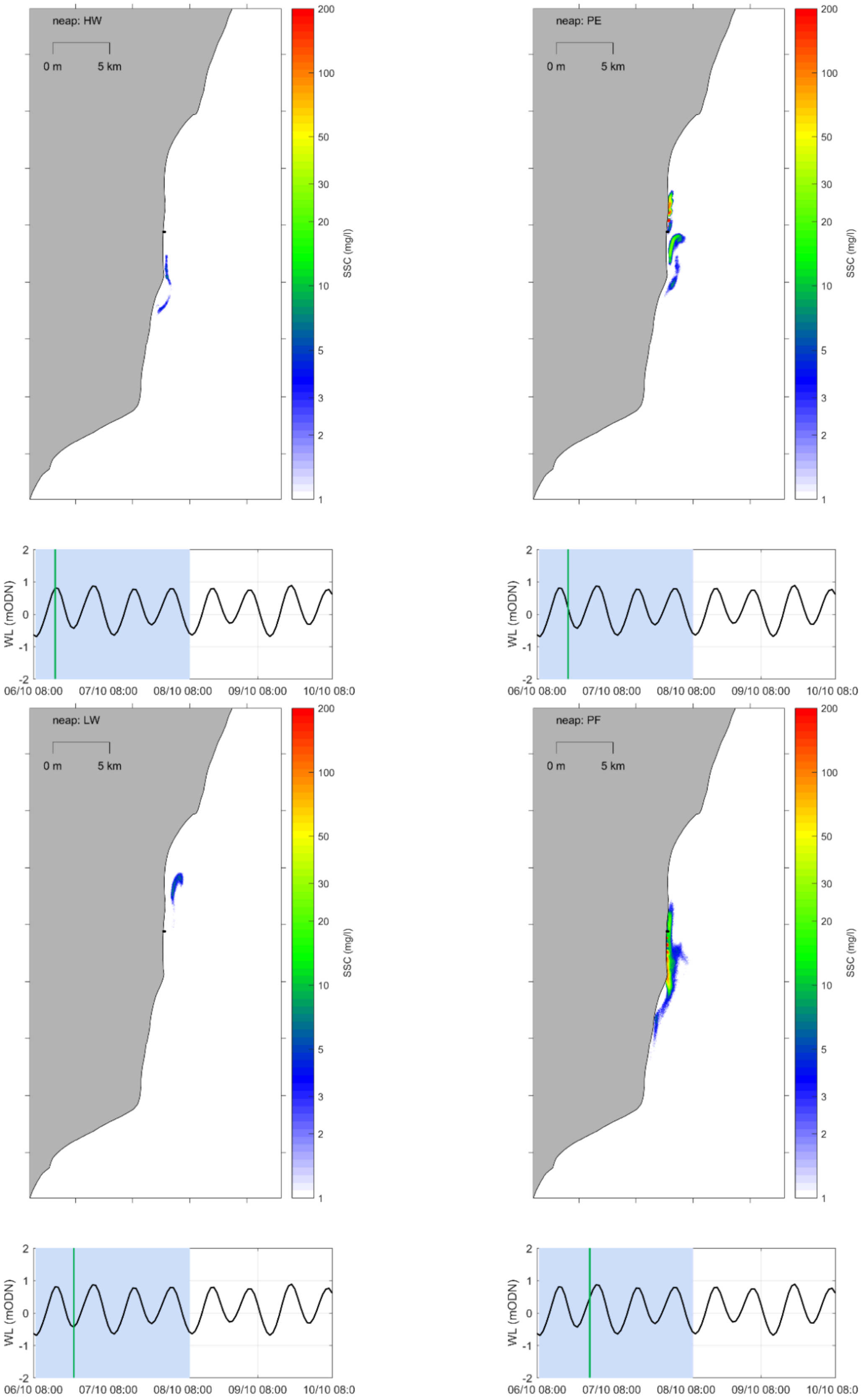
To show how the sediment plume evolves throughout a semi-diurnal tide, plan plots of depth average SSC are shown at HW, PE, LW and PF on a mean spring and a mean neap tide in Figure 61 and Figure 62, respectively. The plume extents are largest at the time of peak flows, and smallest at slack water periods. During slack water periods material settles on the bed in a thin band along the coast (see plan plots of sedimentation on neap tides in Figure 63.



Black dots show the sediment release locations

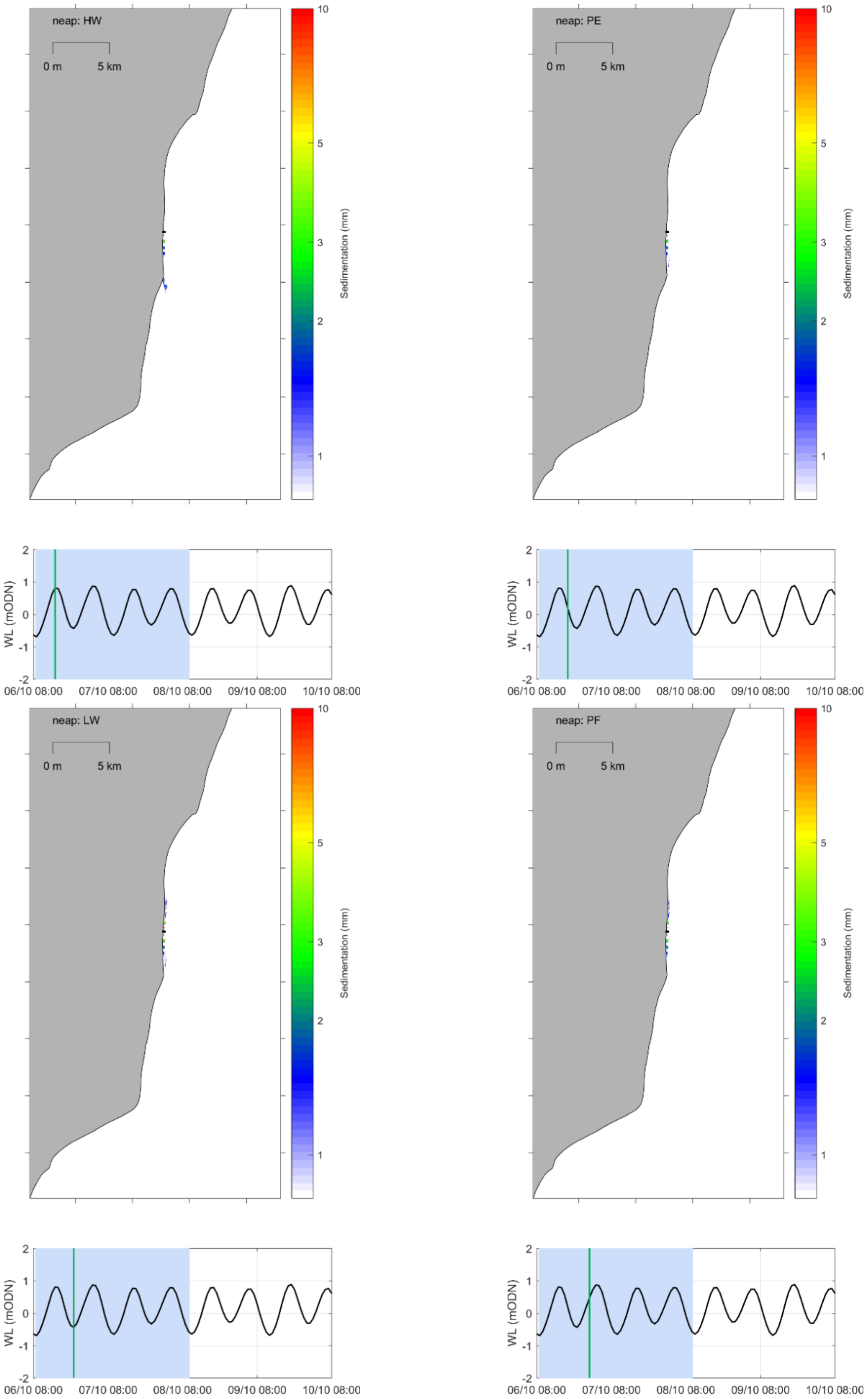
The pale blue shading on the time series plots indicate periods of sediment release.

Figure 61. Depth average SSC at HW, PE, LW and PF during capital dredging of the BLF approach channel on a spring tide



Black dots show the sediment release locations.
The pale blue shading on the time series plots indicate periods of sediment release.

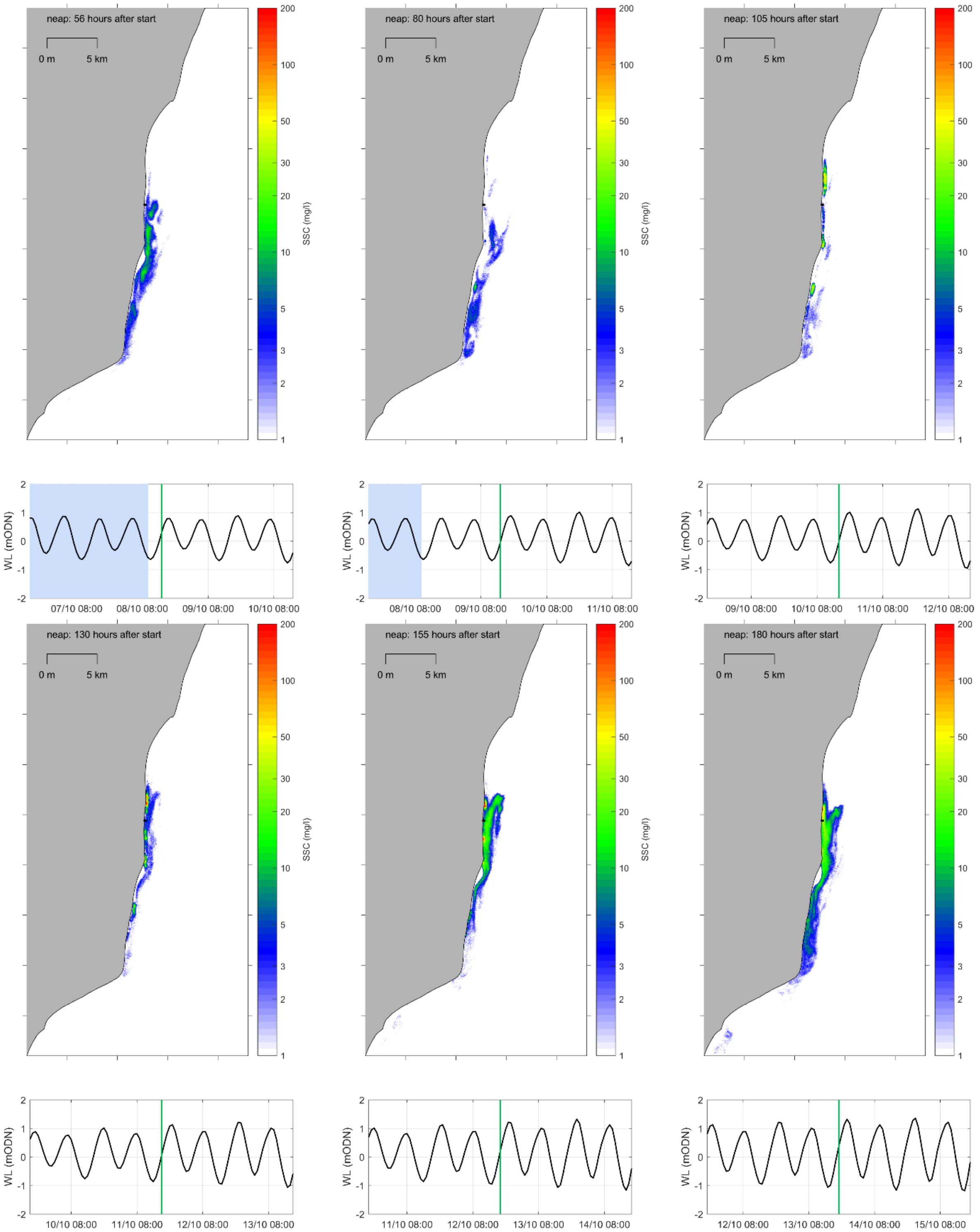
Figure 62. Depth average SSC at HW, PE, LW and PF during capital dredging of the BLF approach channel on a neap tide



Black dots show the sediment release locations.
The pale blue shading on the time series plots indicate periods of sediment release.

Figure 63. Sedimentation at HW, PE, LW and PF during capital dredging of the BLF approach channel on a neap tide

The evolution of the plume after the dredge is completed is shown by a series of plan plots of depth average SSC at discrete model time steps in Figure 64. Results are shown for dredging on neap tides. The plume extents are similar to those for the dredging of the FRR and CDO structures, albeit with slightly higher plume concentrations (due to the longer period and greater volume of sediment release).



Black dots show the sediment release locations.
The pale blue shading on the time series plots indicate periods of sediment release.

Figure 64. Depth average SSC at stages during capital dredging of the BLF approach channel

Areas of sediment thickness (in Ha) on the bed at the end of the model simulation are provided Table 38. The material on the bed at the end of the simulation accounts for approximately 32 % of the total release volume when the capital dredge is started on spring tides. this is slightly reduced to 26 % when the dredge starts on neap tides.

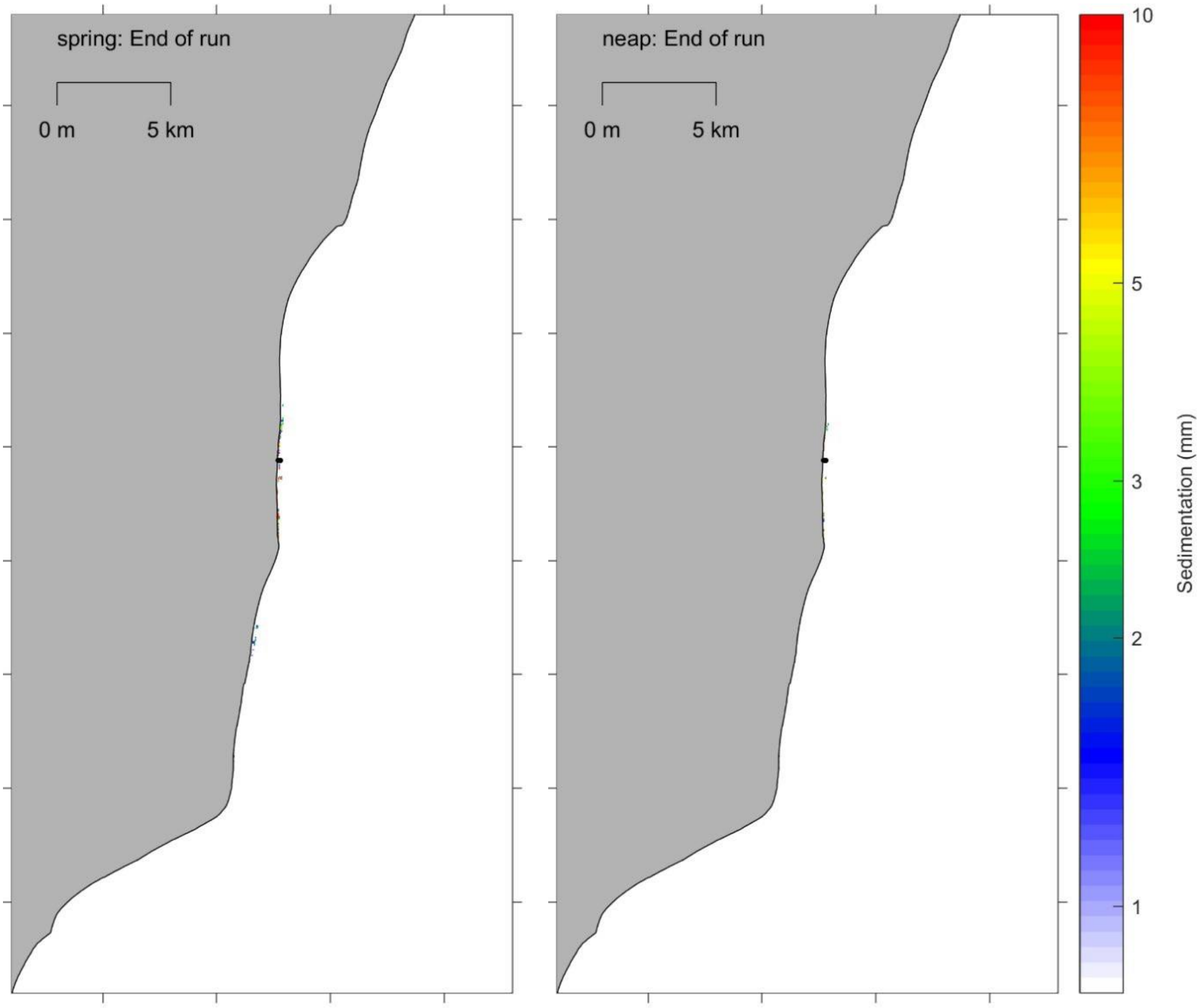


Figure 65. **Sedimentation on the bed at the end of the model run resulting from capital dredging of the BLF approach channel (confined to thin band along the coast)**

Table 38. Areas of sediment thickness resulting from capital dredging of the BLF approach channel at the end of the model simulation

Sediment Thickness > mm	Area (Ha)	
	Spring Tide	Neap Tide
0	629	495
2	56	41
5	27	23
10	12	10
20	3	3
50	0	0

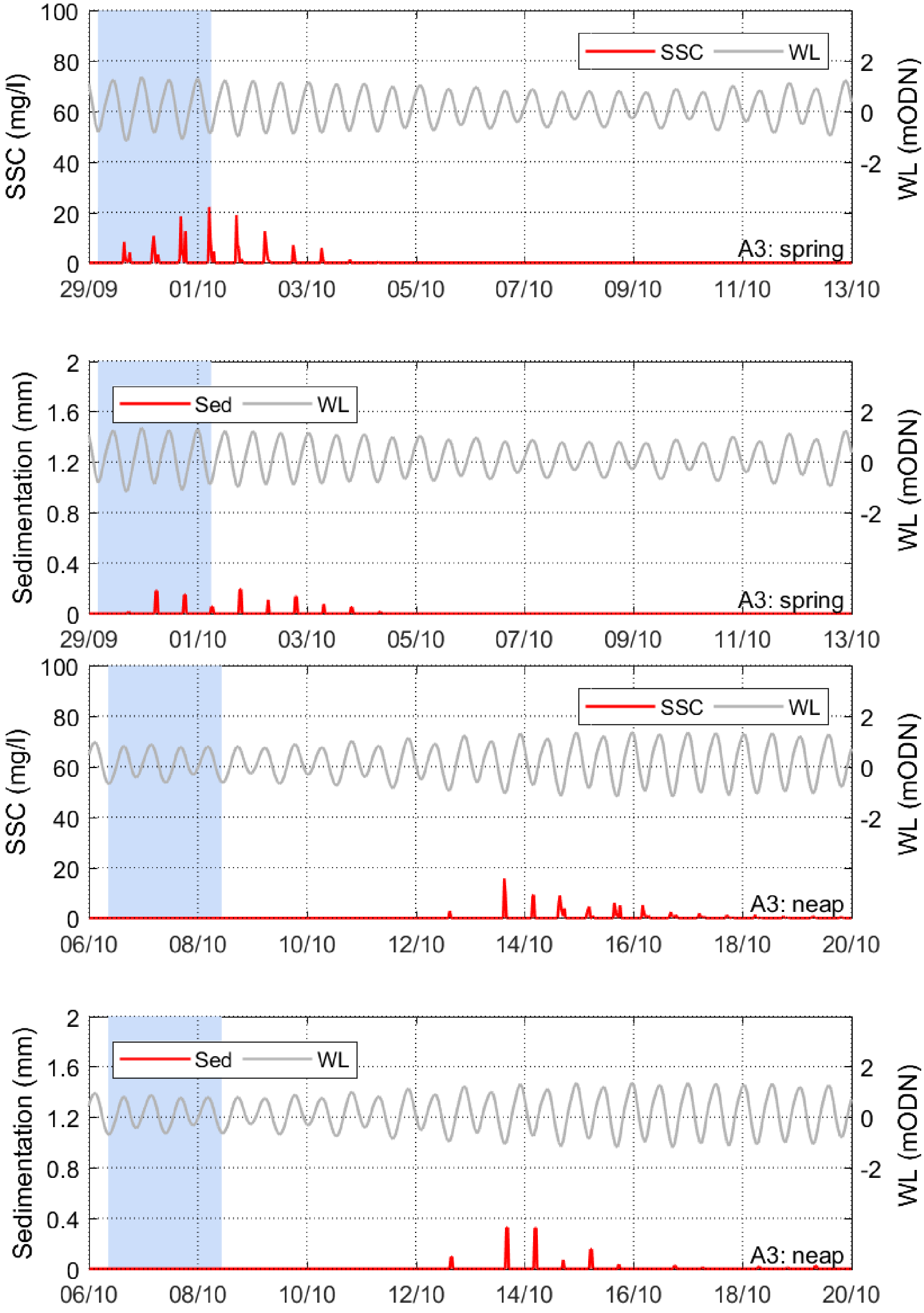
Time series of depth average SSC and sedimentation at discrete locations are presented in Figure 66 to Figure 70. SSC at Location B3, which lies approximately 2 km to the north of the sediment release location, is typically less than 100 mg/l, although short lived peaks of more than 200 mg/l are evident.

Time series of sedimentation at B3 indicates that on spring tides material is deposited at slack water and then re-eroded on the subsequent tide. On neap tides sedimentation builds up over a period of several tides and remains on the bed until the period of faster spring tidal flows. The thickness of deposits on the bed at B3 during both spring and neap tides is only of the order of 1-2 mm. Thicker deposits (of 10-20 mm) occur at Location C3, with sediment accreting throughout the tide except during peak flood when flows are sufficient to maintain material in suspension (and on spring tides, resuspend the finer sediment). C3 is located less than 1 km to the south of the sediment release location in shallow water near the coast, therefore a small amount of re-disturbed sediment will create higher concentrations than further offshore. Overall, the location is one of dominant sedimentation for the sediment released from this scenario. At the other time series sites the sedimentation over LW is re-eroded on the following flood tide.

A time series of the near bed SSC and sedimentation during and after the dredge are shown at the Sizewell B in take in Figure 71. The maxima occur at the lower states of the tide during periods of shallower water. The maximum instantaneous near bed SSC and sedimentation at the intake are provided in Table 39.

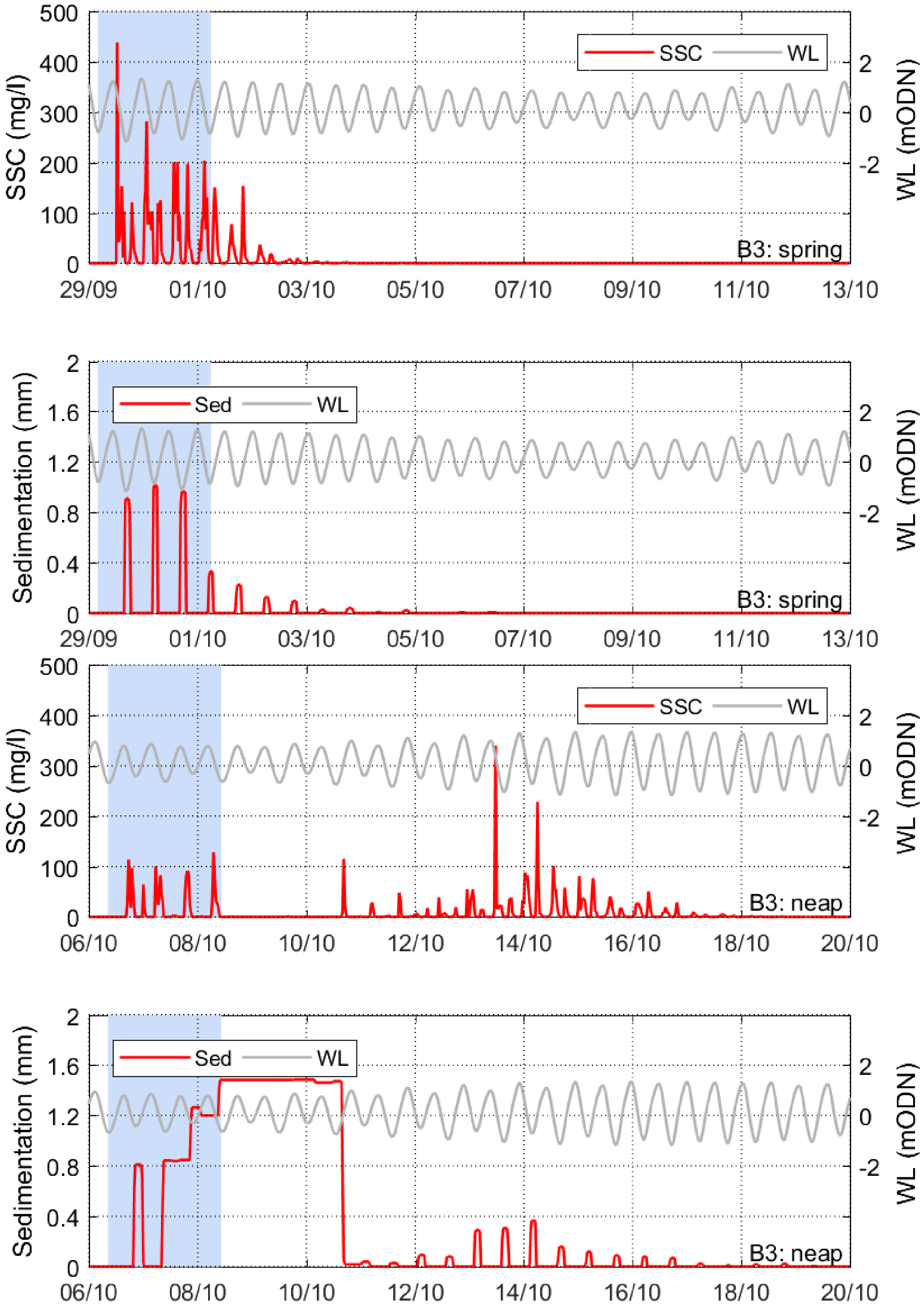
Table 39. Maximum instantaneous near bed SSC and sedimentation at the Sizewell B intake, resulting from capital dredging of the BLF approach channel

Tide	Instantaneous Maximum	
	SSC (mg/l)	Sedimentation (mm)
Spring Tide	86	1.4
Neap Tide	62	0.8



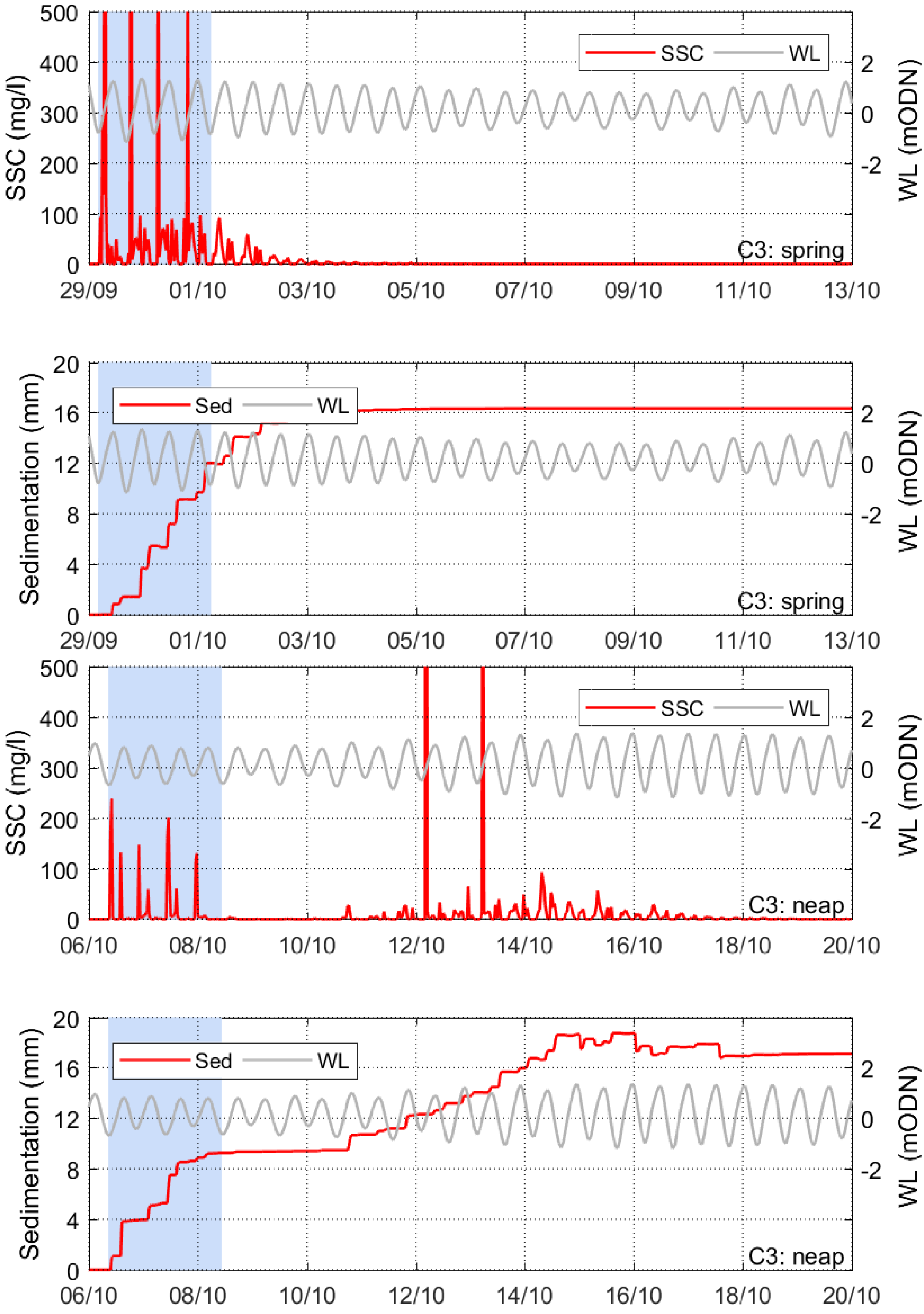
Blue shading shows periods of sediment release.

Figure 66. Time series of depth average SSC and sedimentation at Location A3 on spring (upper two panels) and neap tides (lower two panels) during and after dredging of the BLF approach channel



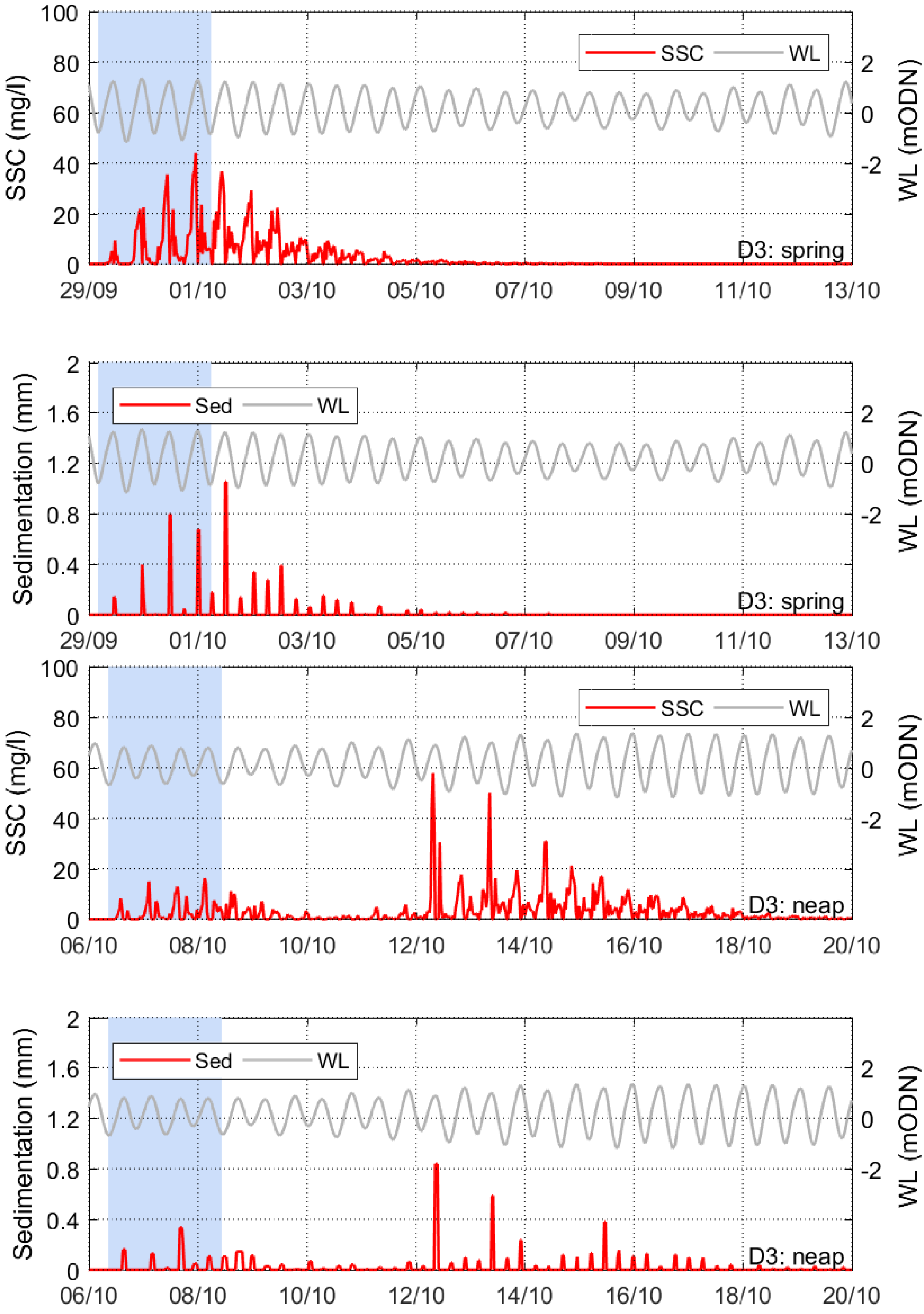
Blue shading shows periods of sediment release.

Figure 67. Time series of depth average SSC and sedimentation at Location B3 on spring (upper two panels) and neap tides (lower two panels) during and after dredging of the BLF approach channel



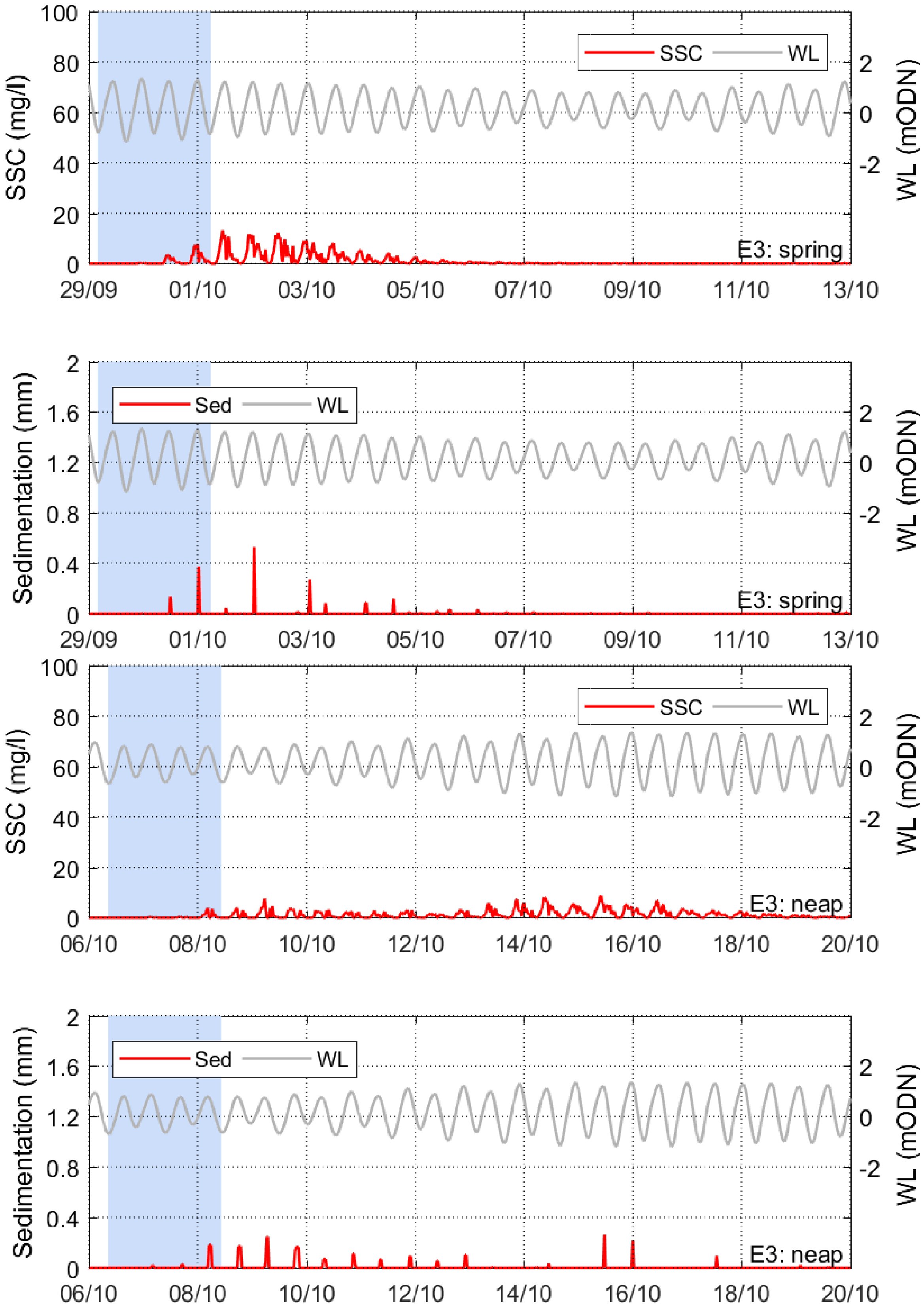
Blue shading shows periods of sediment release.

Figure 68. Time series of depth average SSC and sedimentation at Location C3 on spring (upper two panels) and neap tides (lower two panels) during and after dredging of the BLF approach channel



Blue shading shows periods of sediment release.

Figure 69. Time series of depth average SSC and sedimentation at Location D3 on spring (upper two panels) and neap tides (lower two panels) during and after dredging of the BLF approach channel



Blue shading shows periods of sediment release.

Figure 70. Time series of depth average SSC and sedimentation at Location E3 on spring (upper two panels) and neap tides (lower two panels) during and after dredging of the BLF approach channel

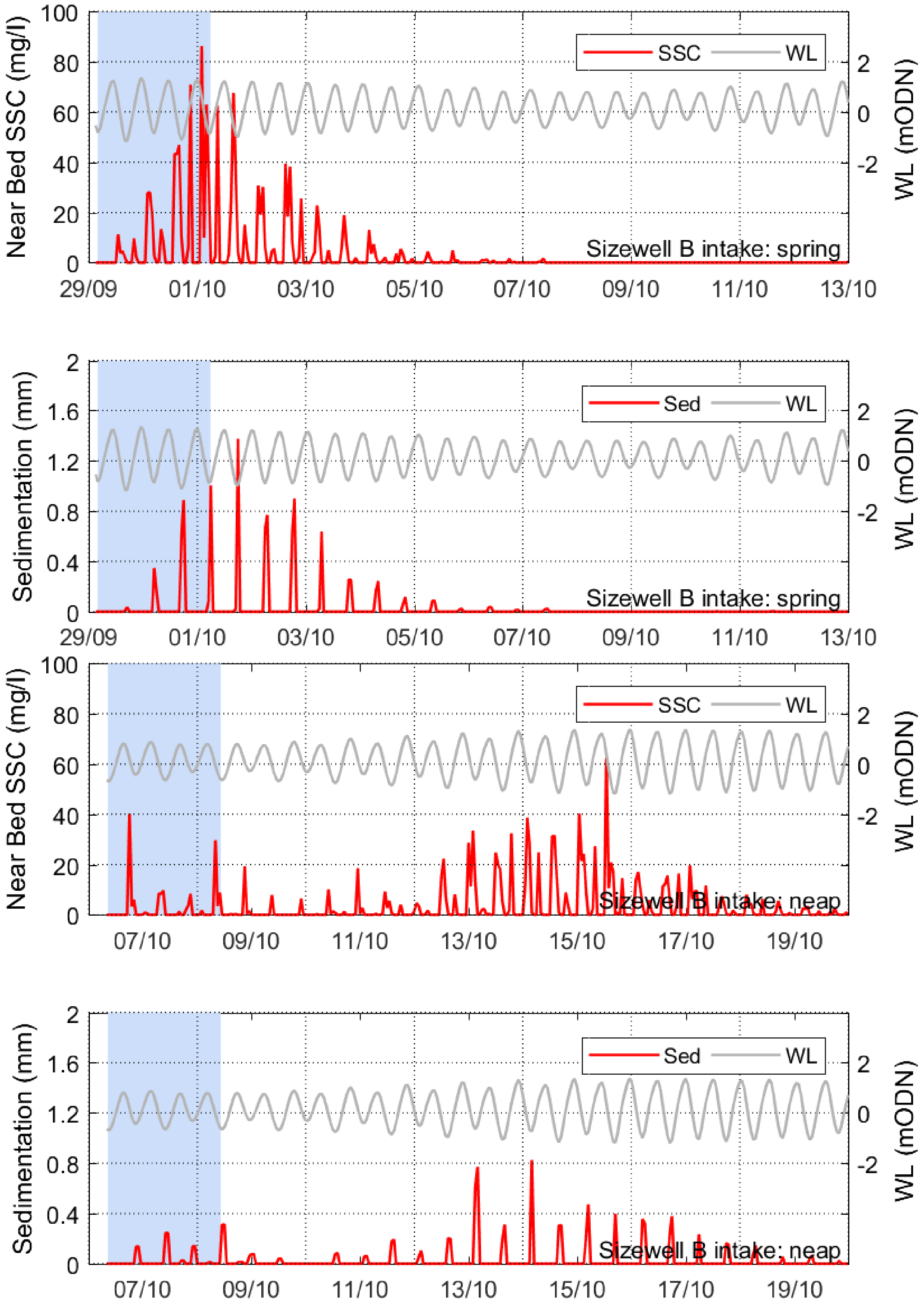
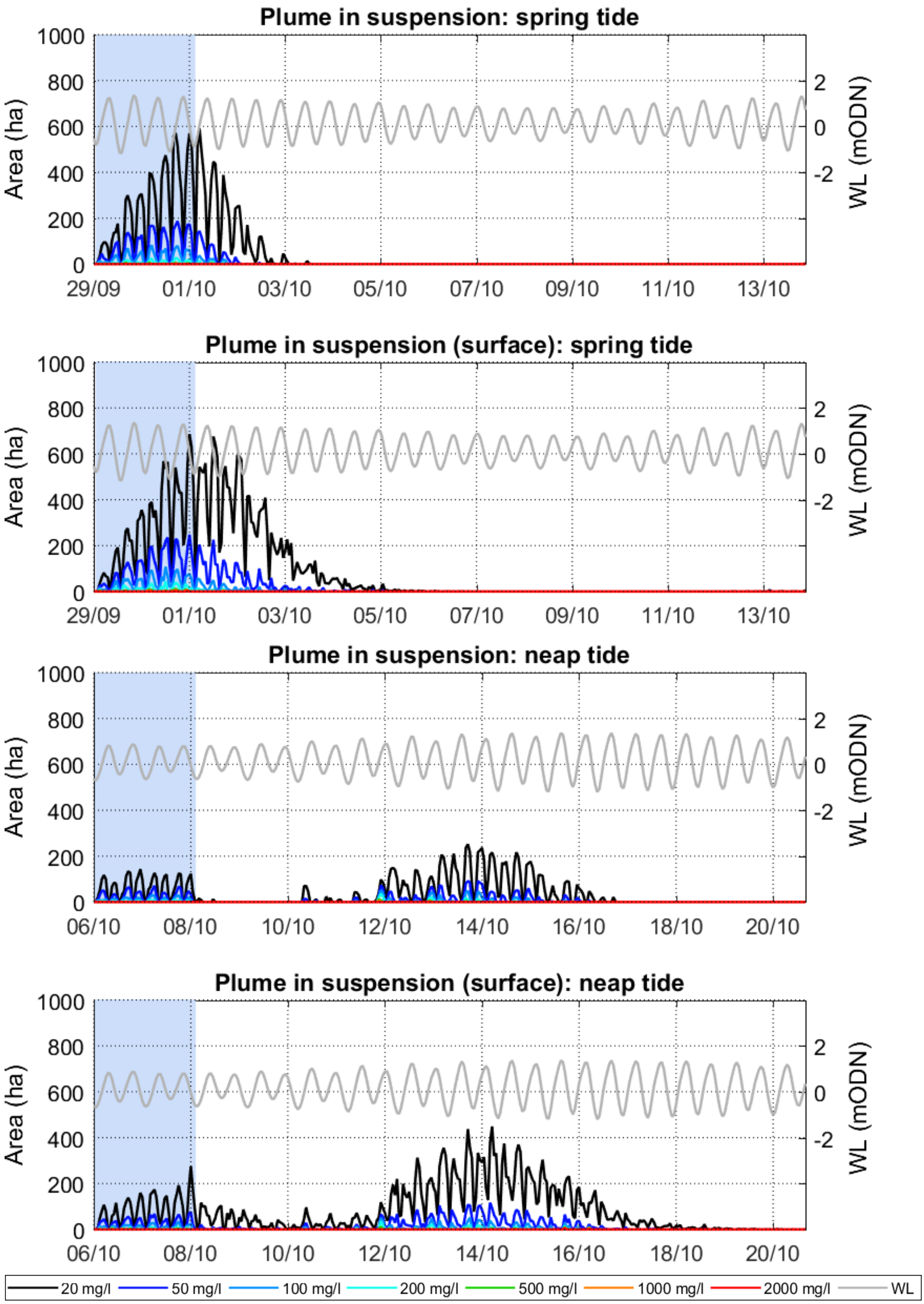


Figure 71. Time series of the near bed SSC and sedimentation at the Sizewell B intake on spring (upper two panels) and neap tides (lower two panels) during and after dredging of the BLF approach channel

To examine the plume dispersion in more detail, time series of plume areas in suspension (depth average and for the surface layer) are shown in Figure 72. Areas of sedimentation are shown in Figure 73. The plots show that on spring tides material in suspension is at concentrations of less than 20 mg/l within four days of the completion of the dredge. On neap tides, the plume concentrations in suspension also quickly return to values which are close to background. However, the model predicts resuspension of material once the larger range spring tides occur, which could result in SSC of more than 100 mg/l before dispersing to background concentrations *circa* 10 days following the completion of the dredge. As noted in Section 2, peaks in SSC are likely to be overestimated in the model since not all material on the bed will instantaneously be suspended.

In comparison to the other construction activities, following the dredging of the BLF a relatively large proportion of material remains on the seabed (approximately 25% for the run starting on neap tides and 30% for the runs starting on spring tides) at the end of the model run. This material is deposited in shallow inshore areas with deposits of up to about 10 mm thickness where slow tidal flows are not sufficient to re-erode material deposited on the seabed. This material is likely to be detectable on the beach, but is likely to be further redistributed and mixed with beach sediment by wave activity. The effect of waves is considered in Section 5. The maximum instantaneous plume areas above specified levels are tabulated in Table 40 to
Table 42.



Blue shading shows periods of sediment release.

Figure 72. Plume areas in suspension (as depth average and in the surface layer) during and after the capital dredging of the BLF approach channel

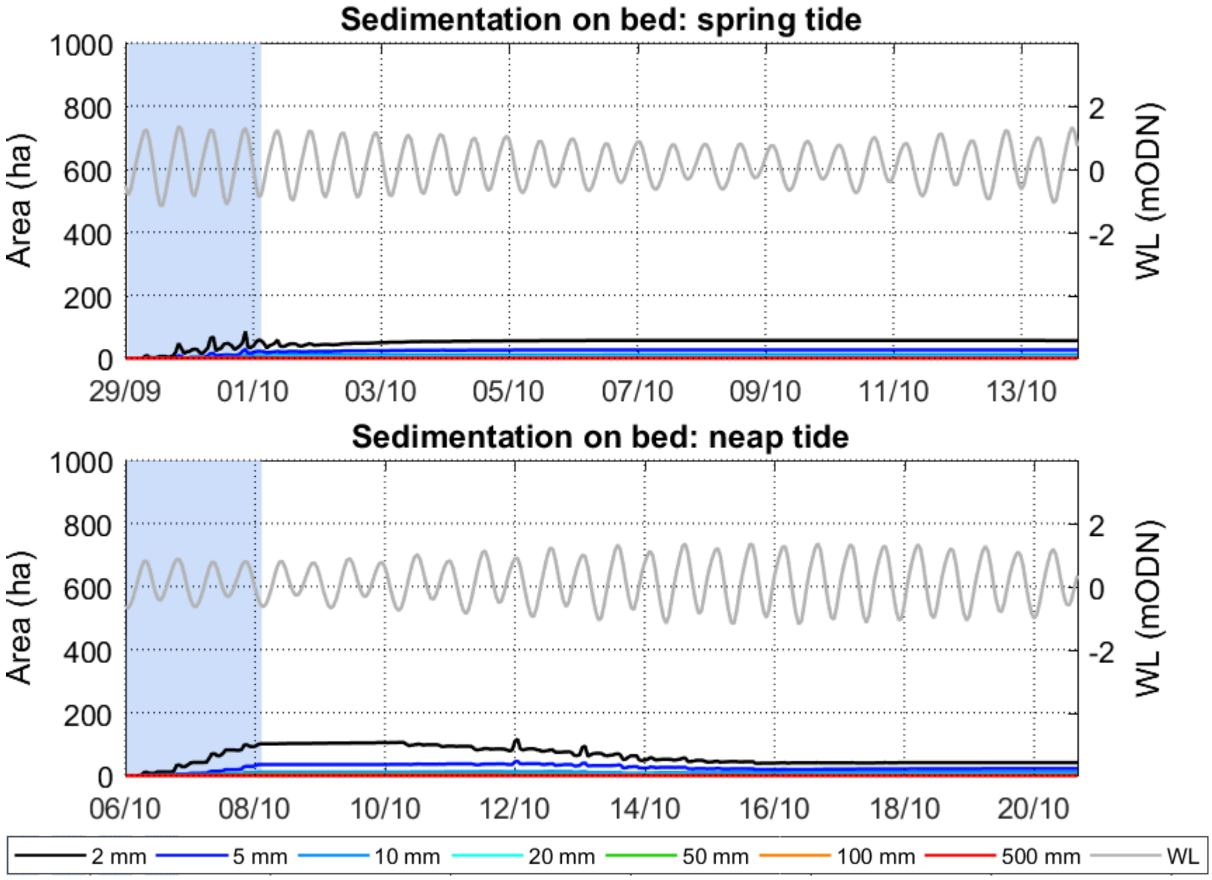


Figure 73. Plume areas on the bed during and after the capital dredging of the BLF approach channel

Table 40. Maximum area of instantaneous depth average SSC resulting from capital dredging of the BLF approach channel

SSC > mg/l	Area (Ha)	
	Spring Tides	Neap Tides
20	592	252
50	188	92
100	83	51
200	28	36
500	7	12
1000	3	6
2000	1	1

Table 41. Maximum area of instantaneous surface SSC resulting from capital dredging of the BLF approach channel

SSC > mg/l	Area (Ha)	
	Spring Tides	Neap Tides
20	686	449
50	248	117
100	108	51
200	44	37
500	12	11
1000	6	7
2000	2	5

Table 42. **Maximum area of instantaneous sedimentation resulting from capital dredging of the BLF approach channel**

Sediment Thickness > mm	Area (Ha)	
	Spring Tides	Neap Tides
2	85	116
5	28	46
10	12	14
20	3	4
50	1	3
100	0	2
500	0	0

3.3.1 Bird Foraging

The maximum areas of plume intersect (defined as surface SSC above 100 mg/l) with bird foraging areas are provided in Table 43. The maintenance dredge of the BLF approach channel results in some increases in SSC above 100 mg/l within the bird foraging areas. The area of increase accounts for a relatively low proportion of the overall foraging areas (typically 3% or less except for the Little Tern Minsmere colony foraging area which has increases of more than 100 mg/l in surface SSC across 6% of its area).

As noted in Section 3.1.1, for the Sandwich Terns and the Lesser Black Backed Gull, all of the plume is contained within the foraging areas identified in Figure 4. The plume extent accounts for less than 1 % of the foraging areas for these bird species.

To provide an indication of how the plume intersect varies throughout the model simulation, a time series of the percentage foraging area with surface SSC of more than 100 mg/l is shown in Figure 74. There is a tidal variation in the area of intersect, with peaks occurring on the flood and ebb tide when flows maintain sediment in suspension, and with little or no area affected at the times of HW and LW slack when sediment settles to the seabed.

Table 43. **Maximum area of plume intersect with habitat/bird foraging areas resulting from capital dredging of the BLF approach channel. Plume defined as surface SSC above 100 mg/l**

Receptor	Spring Tides		Neap Tides	
	Area (Ha)	% of Foraging Area	Area (Ha)	% of Foraging Area
Little Tern Dingle Colony	51	3	13	1
Little Tern Minsmere Colony	98	6	44	3
Little Tern Slaughden Colony	14	1	14	1
Common Tern (Minsmere Colony)	98	<1	48	<1
Common Tern (Orfordness Colony)	97	<1	48	<1

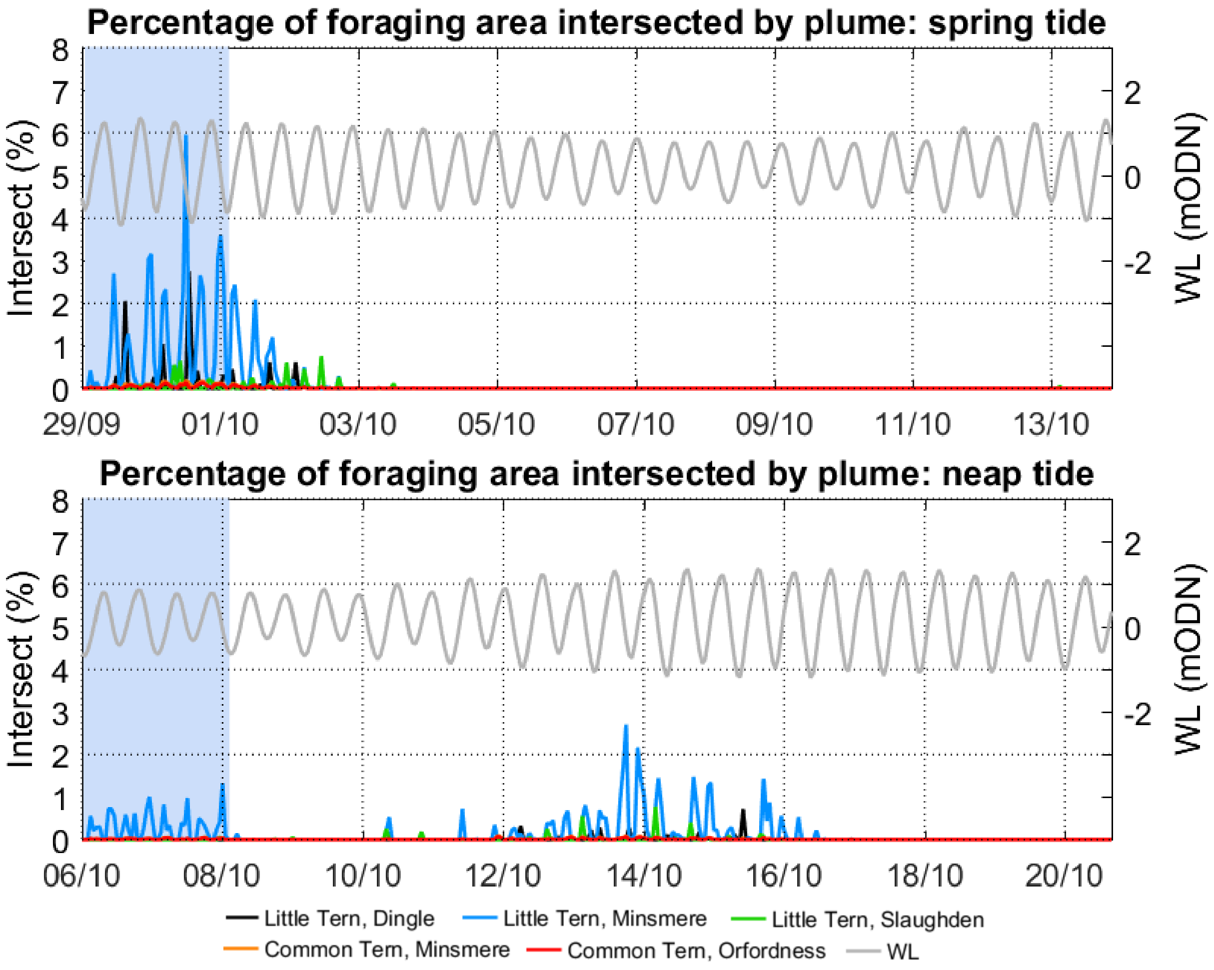


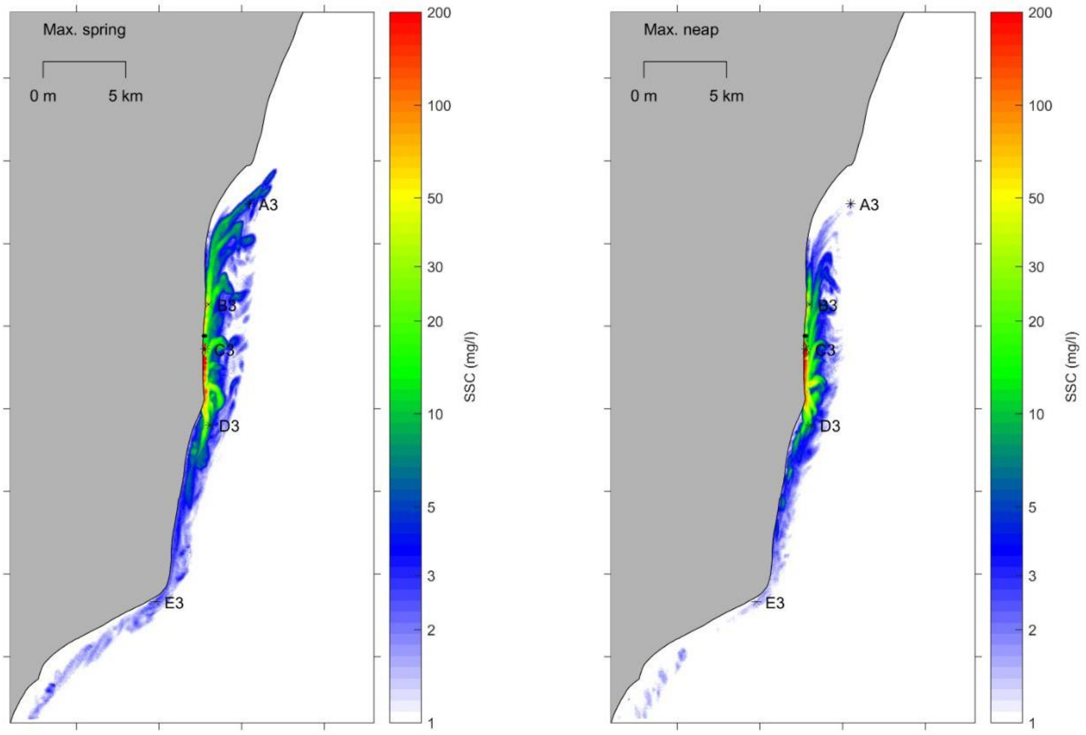
Figure 74. Plume areas in suspension (defined as surface SSC of more than 100 mg/l), intersecting with bird foraging areas during and after the capital dredging of the BLF approach channel

3.4 Scenario 3b. Maintenance dredging of the BLF approach channel

Plan plots of the location maximum SSC associated with the maintenance dredging of the BLF approach channel are shown for the dredge starting on spring and neap tides Figure 75 and Figure 76, for depth average and surface SSC, respectively.

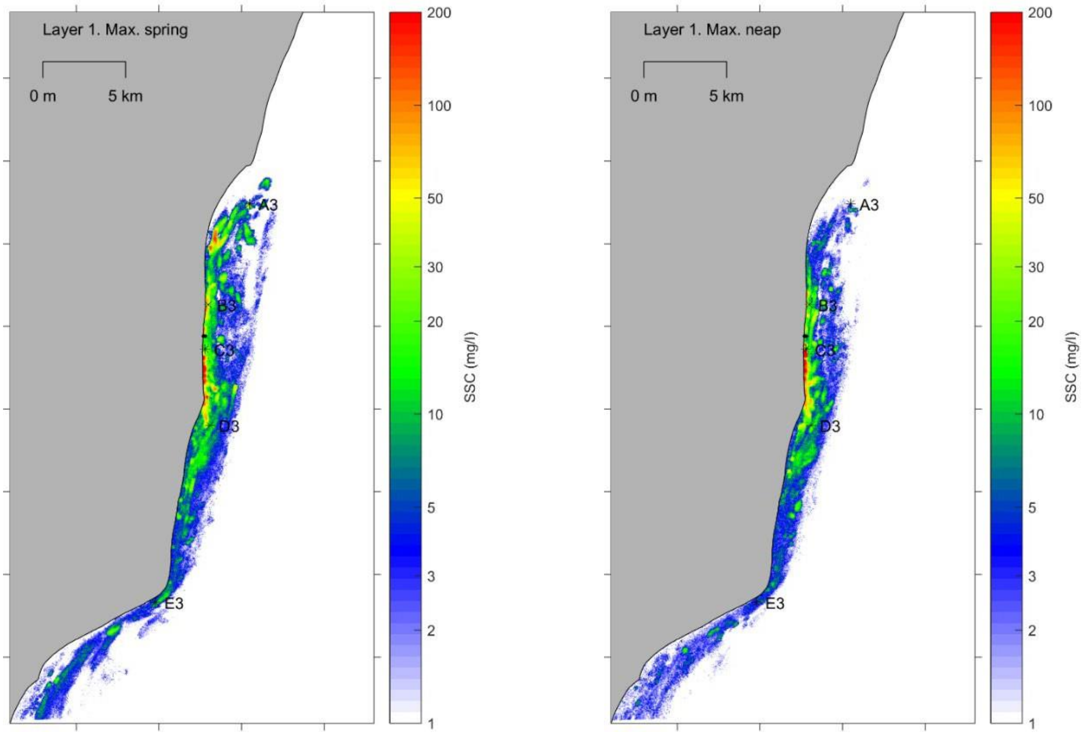
As for the capital dredge of the BLF, these plots show a plume with highest concentrations occurring in a relatively narrow band along the coast. The concentrations for the maintenance dredge are lower than those associated with the capital dredge as a result of the much lower volume of sediment release.

An area of around 40 Ha is affected by increases in depth average SSC of more than 100 mg/l as a result of the maintenance dredge at the BLF approach channel (Table 44 and Table 45). To provide an indication of how long the location maximum may occur, the plume areas have been calculated for different threshold values and durations in Table 46.



Black dots show the sediment release locations, Locations (A3 to E3) show time series extraction points

Figure 75. Location maximum depth average SSC associated with maintenance dredging the BLF approach channel on spring and neap tides



Black dots show the sediment release locations, Locations (A3 to E3) show time series extraction points

Figure 76. Location maximum surface SSC associated with maintenance dredging the BLF approach channel on spring and neap tides

Table 44. Areas of location maximum depth average SSC resulting from capital dredging of the BLF approach channel

SSC > mg/l	Spring Tides		Neap Tides	
	Area (Ha)	% of Plume Area		% of Plume Area
0	15,114	100	14,353	100
20	290	2	262	2
50	116	1	103	1
100	41	<1	41	<1
200	15	<1	15	<1
300	7	<1	8	<1
500	4	<1	2	<1
1000	4	<1	2	<1
2000	1	<1	1	<1

Table 45. Areas of location maximum SSC in the surface layer of the model resulting from maintenance dredging of the BLF approach channel

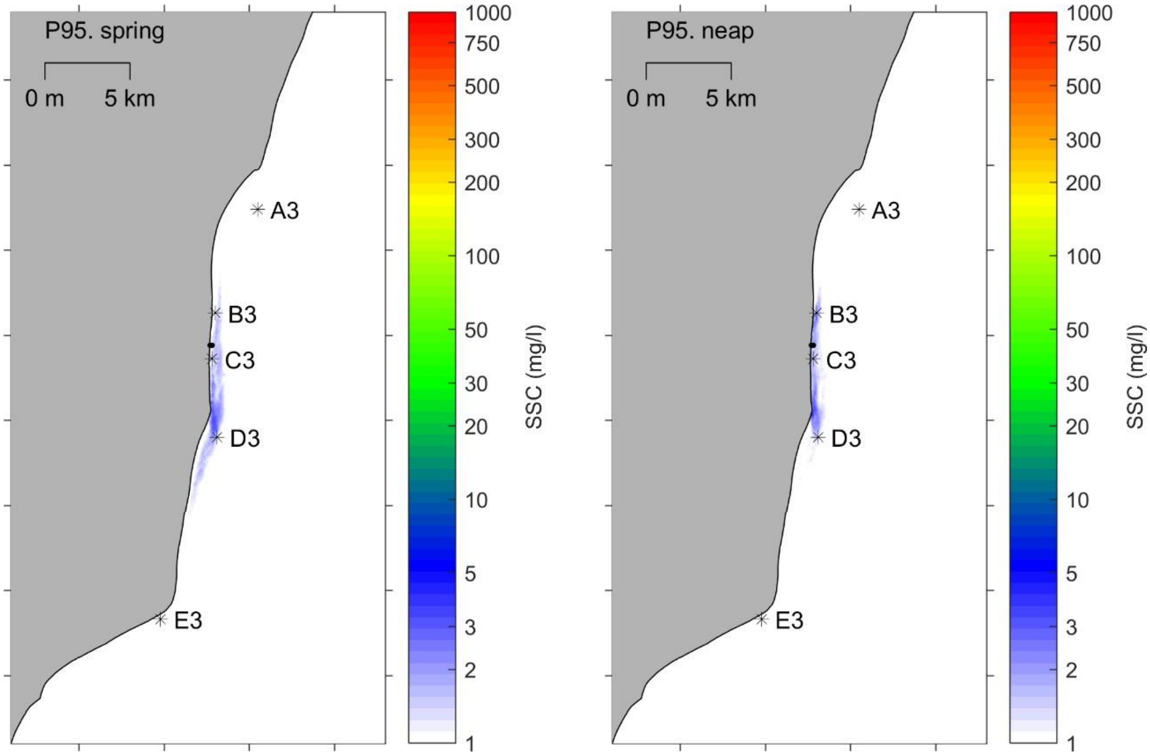
SSC > mg/l	Spring Tides		Neap Tides	
	Area (Ha)	% of Plume Area	Area (Ha)	% of Plume Area
0	9,853	100	9,664	100
20	525	5	352	4
50	170	2	120	1
100	56	1	40	0
200	13	<1	20	0
300	6	<1	11	0
500	1	<1	4	0
1000	0	0	1	0
2000	0	0	1	0

Table 46. Areas of location maximum SSC in the surface layer of the model for different continuous durations resulting from maintenance dredging of the BLF approach channel

SSC > mg/l	Duration (>= hours)	Area (Ha)	
		Spring Tides	Neap Tides
50	1	170	120
50	3	6	13
50	6	0	0
50	12	0	0
100	1	56	40
100	3	1	3
100	6	0	0
100	12	0	0
300	1	6	11
300	3	0	0
300	6	0	0
300	12	0	0

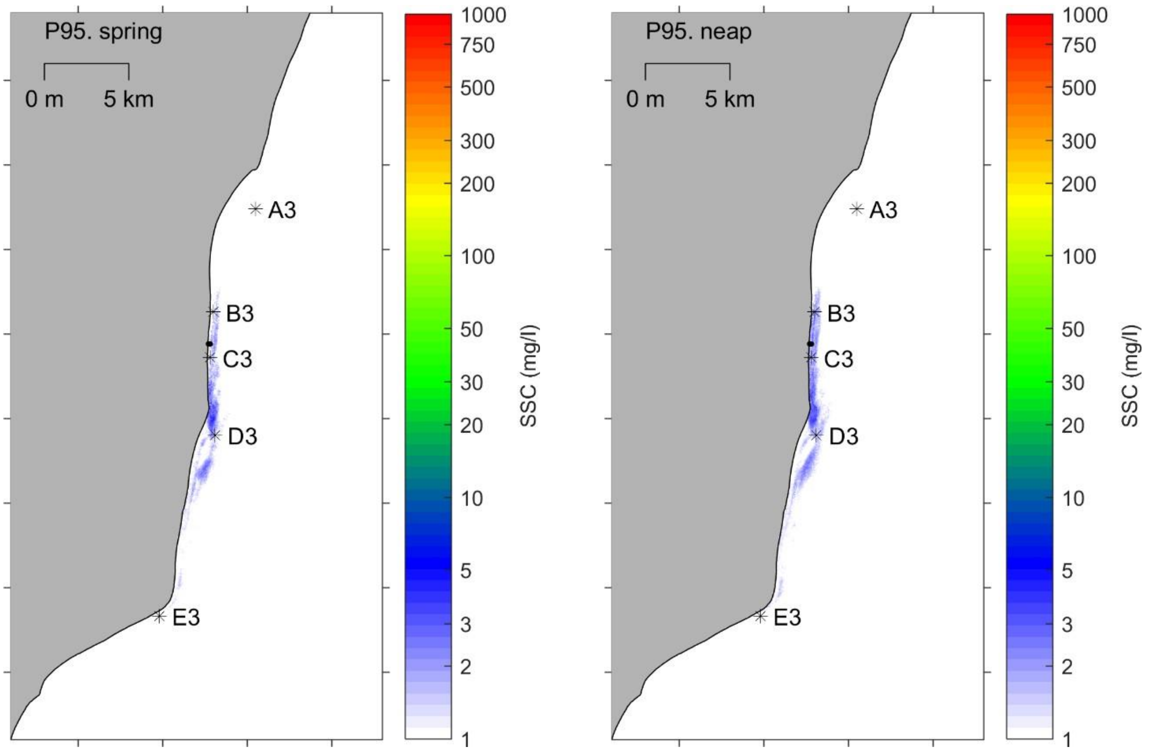
Plan plots of the P95 SSC and location maximum sedimentation associated with the maintenance dredging of the BLF approach channel assuming the removal of 10 % of the sediment dredged during the capital dredge are shown for the dredge starting on spring (upper panels) and neap tides (lower panels) in Figure 77 to Figure 79. As for the other scenarios modelled, the P95 SSC is considerably lower than the location maximum SSC values, demonstrating that the plume is very short lived.

Highest P95 SSC's and location maximum sedimentation are confined to a relatively small area close inshore for the dredge occurring on both the spring and neap range tides.



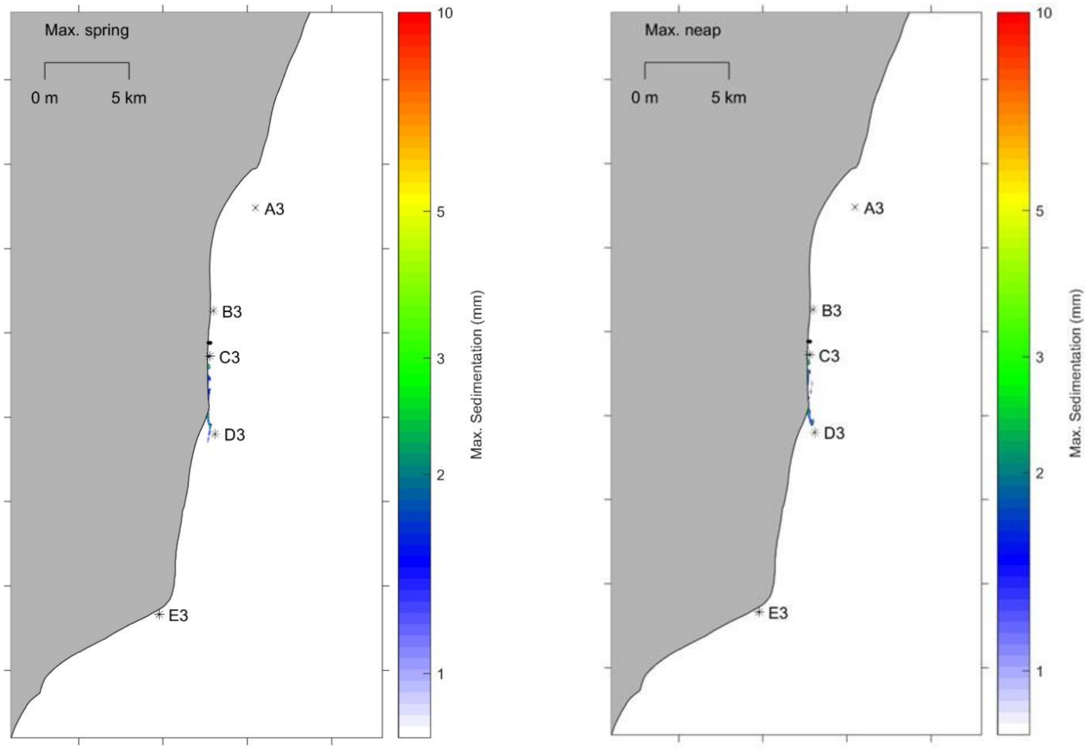
Black dots show the sediment release locations, Locations (A3 to E3) show time series extraction points

Figure 77. 95th Percentile in depth average SSC associated with maintenance dredging of the BLF approach channel on spring and neap tides



Black dots show the sediment release locations, Locations (A3 to E3) show time series extraction points

Figure 78. 95th Percentile in surface SSC associated with maintenance dredging of the BLF approach channel on spring and neap tides



Black dots show the sediment release locations, Locations (A3 to E3) show time series extraction points

Figure 79. Location maximum sedimentation associated with maintenance dredging of the BLF approach channel on spring and neap tides

Areas of location maximum sedimentation are shown in Figure 79 and quantified in Table 47. Deposits on the bed are less than 5 mm thickness when the dredge occurs on spring tides. On neap tides, small areas with deposits of more than 10 mm do occur. This sedimentation is constrained to localised areas of low flow and material is not re-eroded by the flows in these areas (see Table 48).

Table 47. Areas of location maximum sediment thickness resulting from maintenance dredging of the BLF approach channel

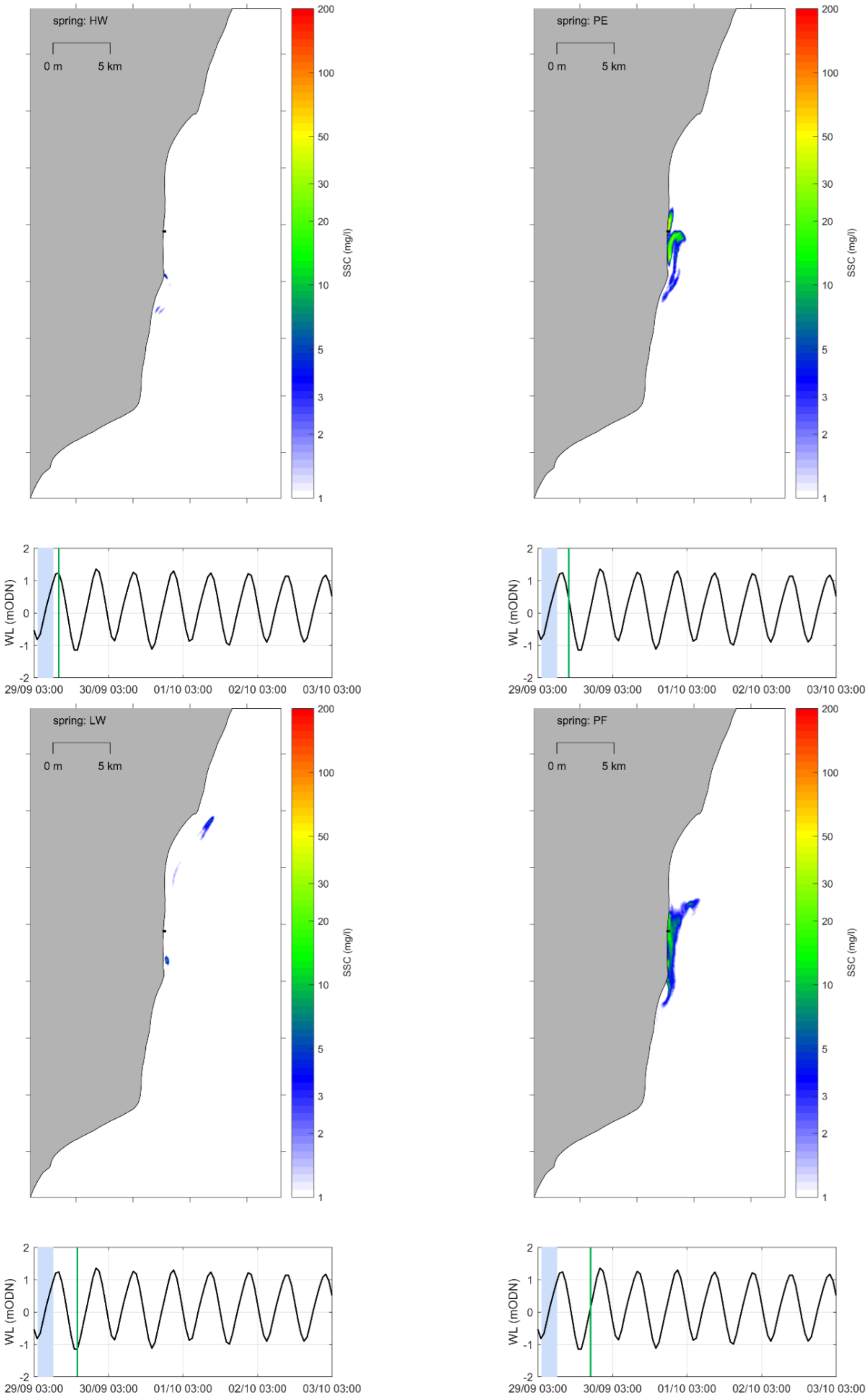
Sediment Thickness > mm	Spring Tides		Neap Tides	
	Area (Ha)	% of Plume Area	Area (Ha)	% of Plume Area
0	12,189	100	12,040	100
2	10	<1	15	<1
5	0	0	2	<1
10	0	0	1	<1
20	0	0	0	0

Table 48. Areas of location maximum sediment thickness for different continuous durations resulting from maintenance dredging of the BLF approach channel

Sediment Thickness > mm	Duration (>= hours)	Area (Ha)	
		Spring Tides	Neap Tides
5	1	0	2
5	3	0	2
5	6	0	2
5	12	0	2
10	1	0	1
10	3	0	1
10	6	0	1
10	12	0	1

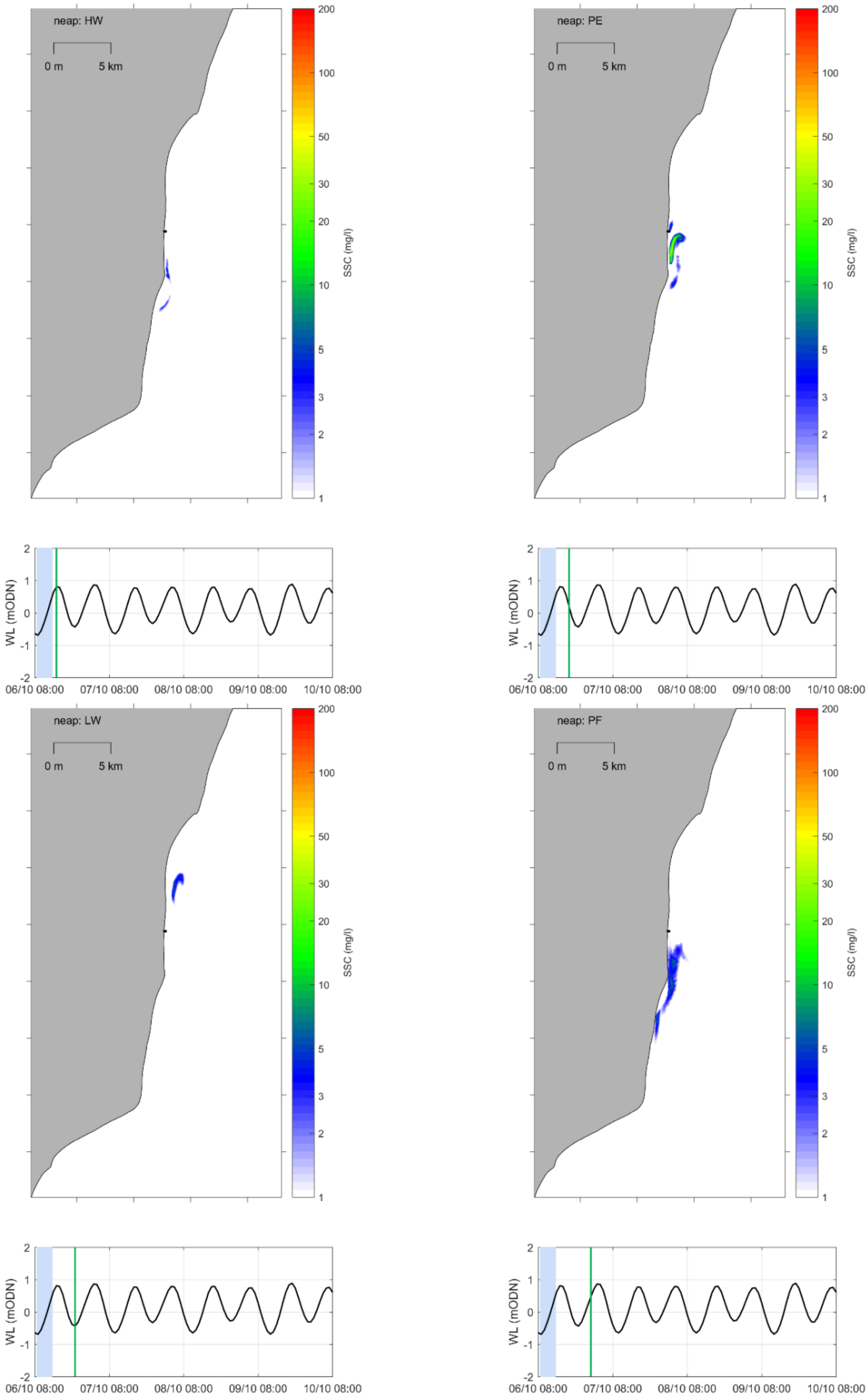
To show how the sediment plume evolves throughout a semi-diurnal tide, plan plots of depth average SSC are shown at HW, PE, LW and PF on a mean spring and a mean neap tide in Figure 80 and Figure 81, respectively. As for the capital dredge, the plume extents are largest at the time of peak flows, and smallest at slack water periods. Disturbed sediment settles on the bed in a thin band along the coast (see plan plots of sedimentation on neap tides in Figure 82).

The evolution of the plume after the dredge is completed is shown by a series of plan plots of depth average SSC at discrete model timesteps in Figure 83 for a neap tide. The plume rapidly disperses with only low concentrations over very small extents apparent. As expected the plume concentrations and extent are significantly reduced compared to the plume associated with the capital dredge of the approach channel (compare Figure 83 with Figure 64).



Black dots show the sediment release locations
The pale blue shading on the time series plots indicate periods of sediment release

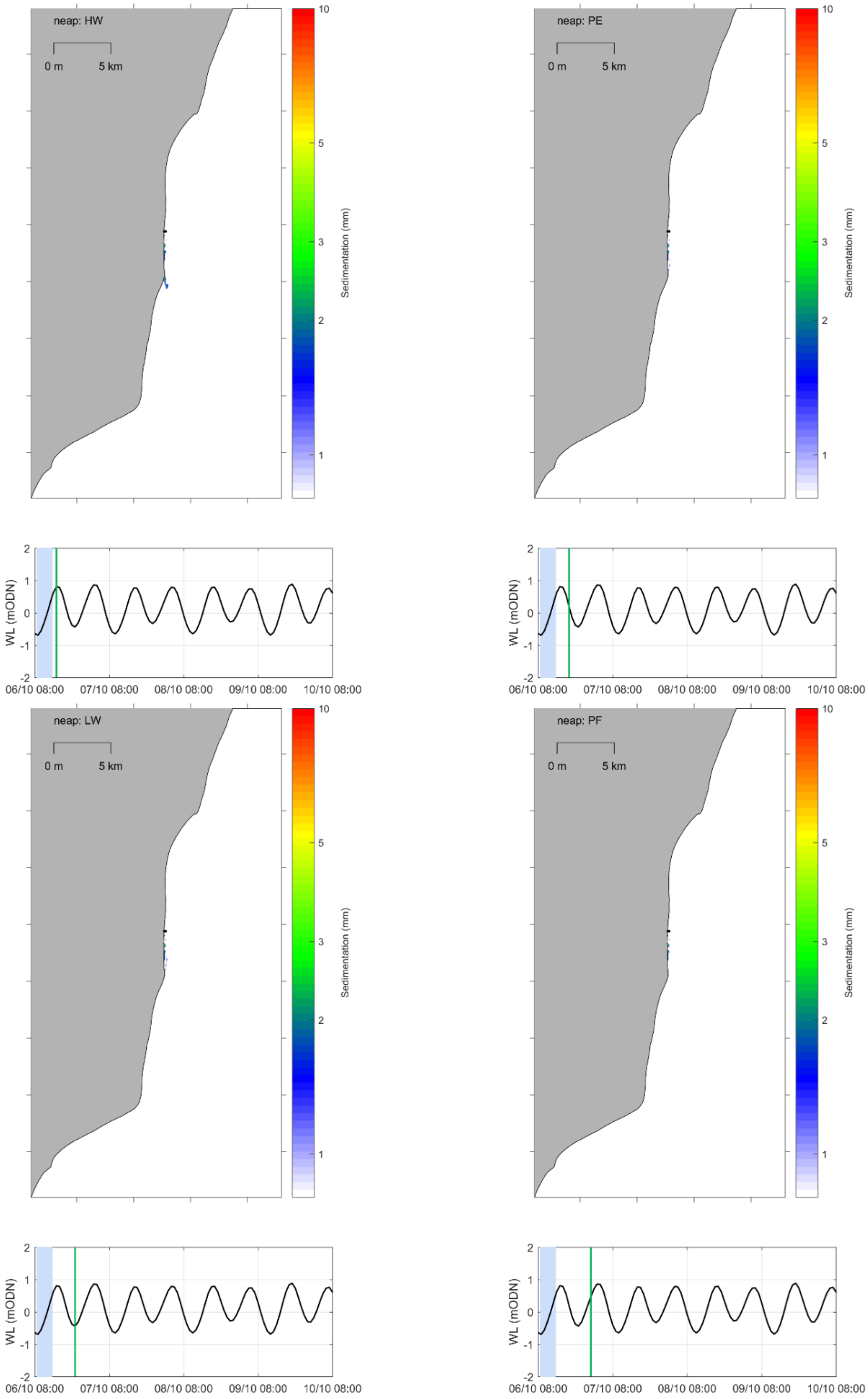
Figure 80. Depth average SSC at HW, PE, LW and PF during maintenance dredging of the BLF approach channel on a spring tide



Black dots show the sediment release locations

The pale blue shading on the time series plots indicate periods of sediment release

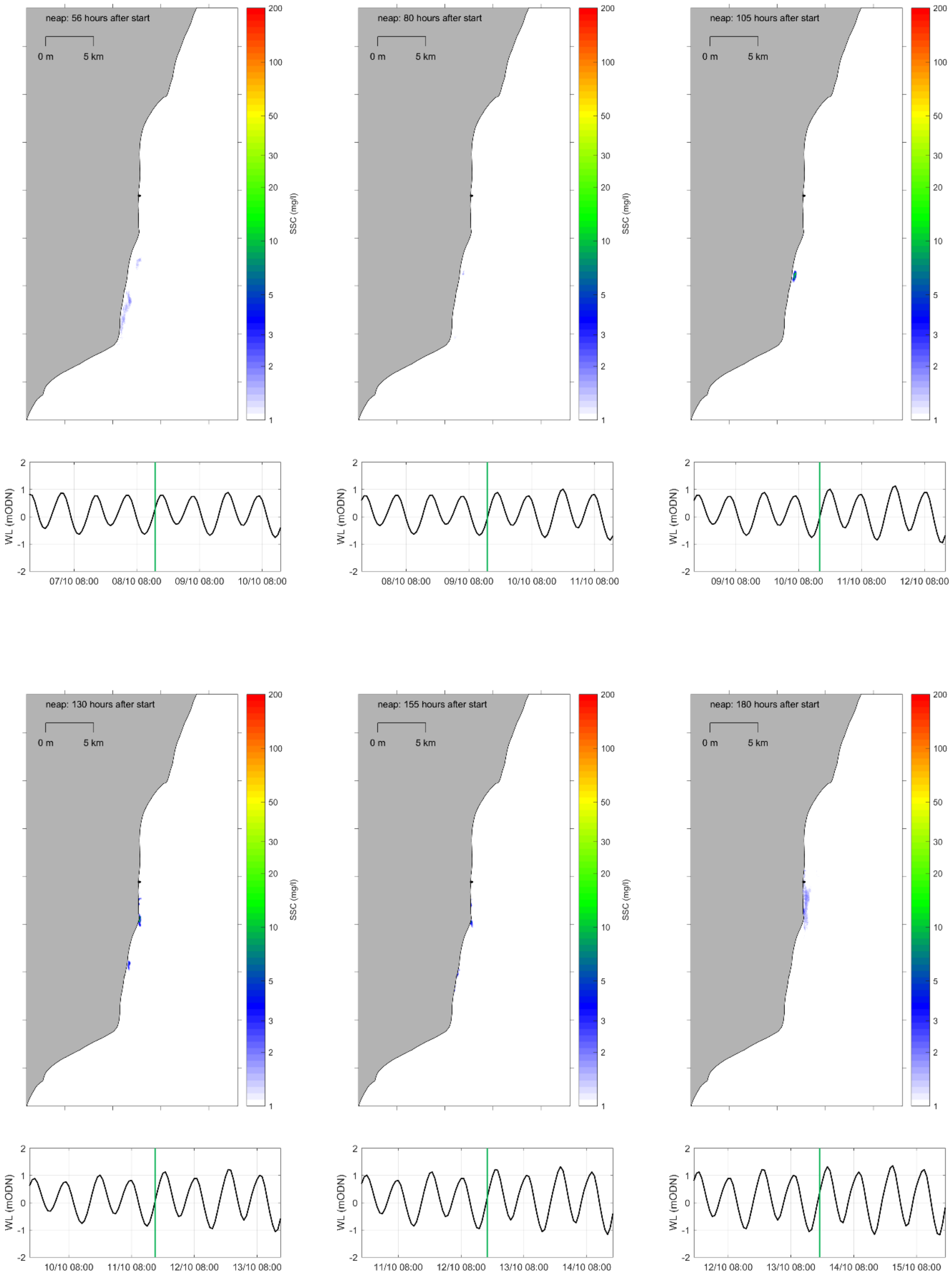
Figure 81. Depth average SSC at HW, PE, LW and PF after maintenance dredging of the BLF



Black dots show the sediment release locations

The pale blue shading on the time series plots indicate periods of sediment release

Figure 82. Sedimentation at HW, PE, LW and PF after maintenance dredging of the BLF approach channel on a neap tide



Black dots show the sediment release locations

The pale blue shading on the time series plots indicate periods of sediment release

Figure 83. Depth average SSC at stages during maintenance dredging of the BLF approach channel

Areas of sediment thickness on the bed at the end of the model simulation are shown in Figure 84 and tabulated in Table 49. The material on the bed at the end of the simulation accounts for approximately 27 % of the total release volume of the maintenance dredge. All deposits remaining on the bed at the end of the simulation are less than 10 mm thickness.

Table 49. **Areas of sediment thickness resulting from the maintenance dredging of the BLF approach channel at the end of the model simulation**

Sediment Thickness > mm	Area (Ha)	
	Spring Tide	Neap Tide
0	515	541
2	3	3
5	<1	1
10	0	0

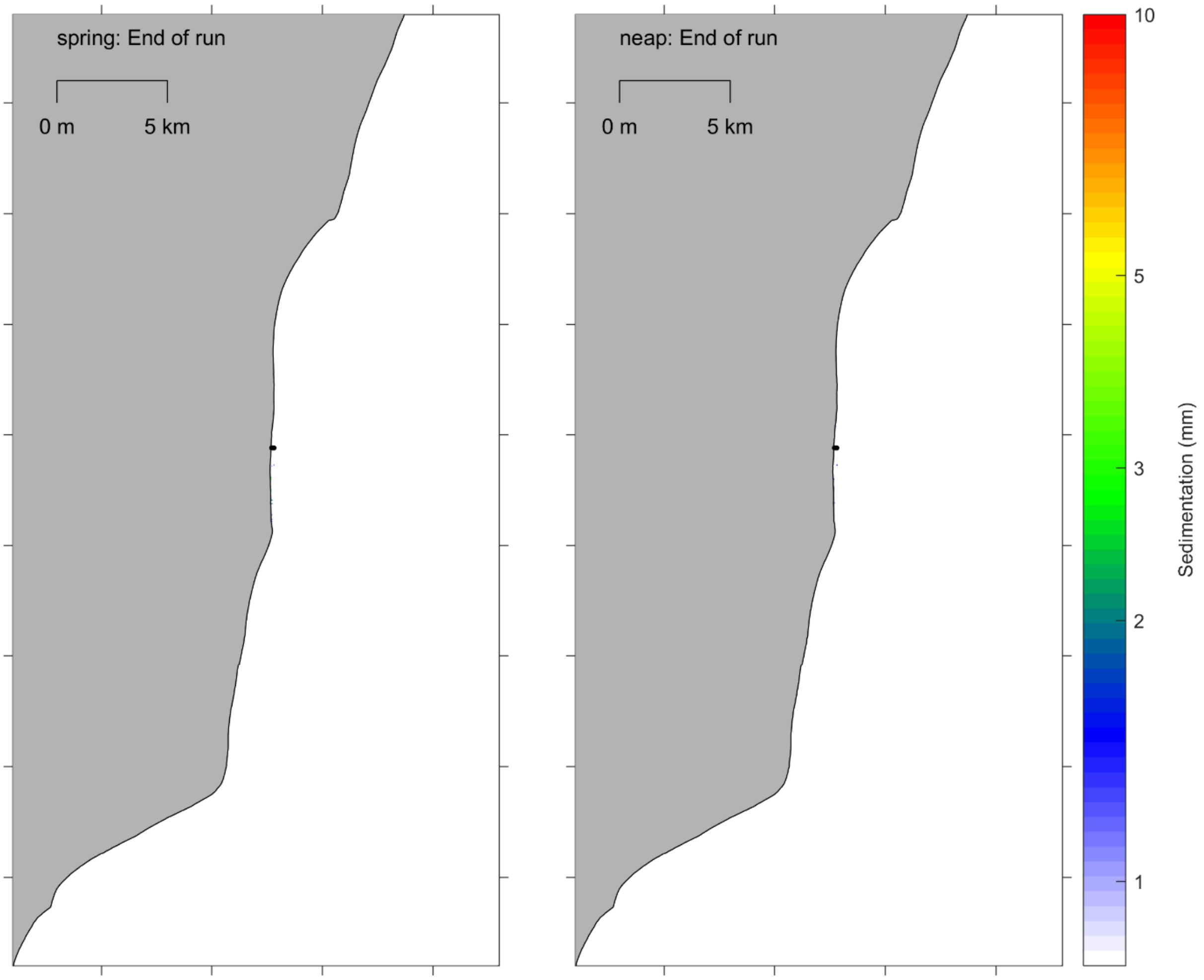


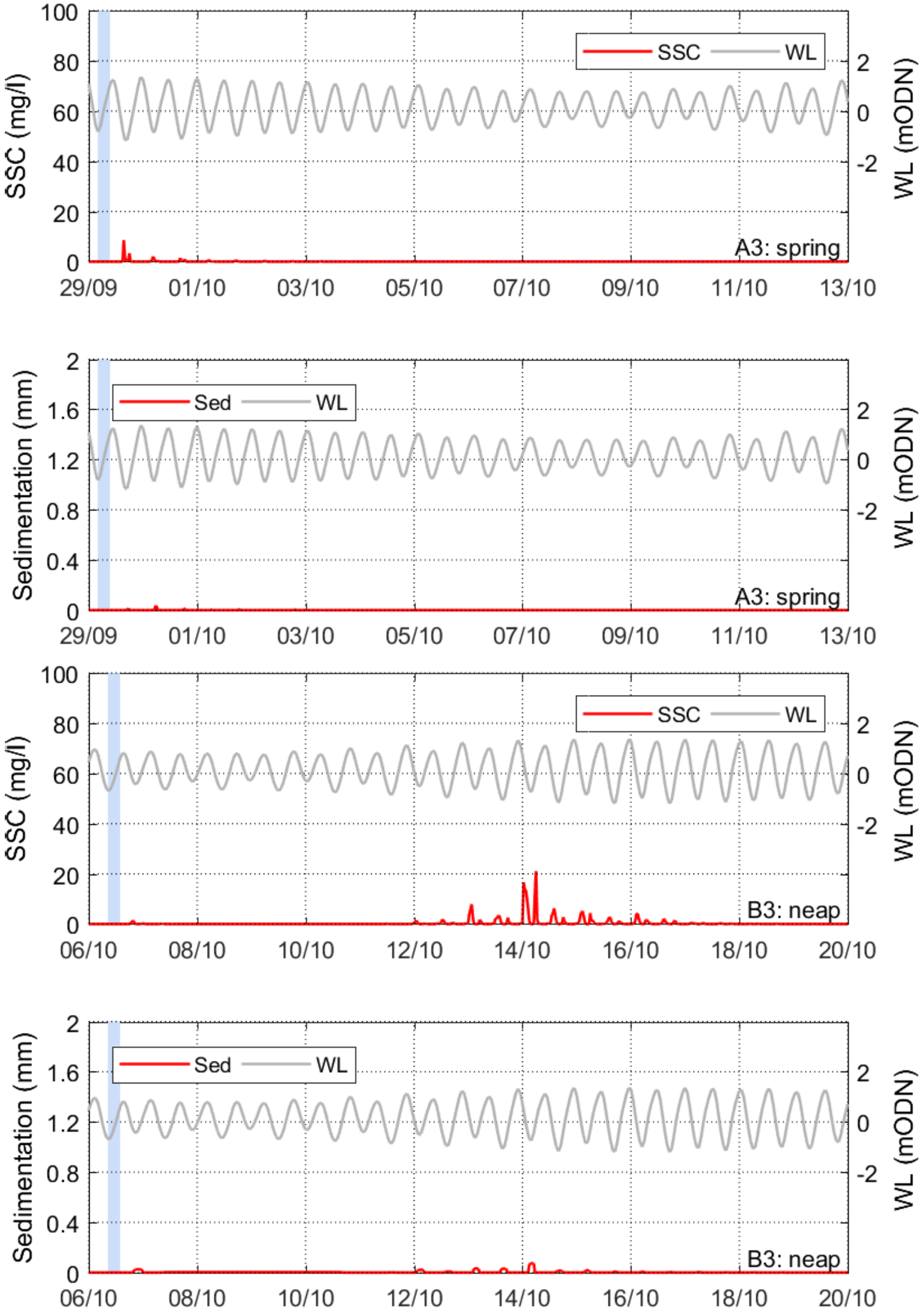
Figure 84. **Sedimentation on the bed at the end of the model run for the maintenance dredging of the BLF access channel (confined to thin band along the coast)**

Time series of SSC and sedimentation at discrete locations are presented in Figure 85 to Figure 89. The trends in SSC and sedimentation are similar to those presented in Figure 66 to Figure 70 and discussed in Section 3.3, albeit with lower sedimentation and a reduced number of peaks in SSC reflecting the reduced volume and duration of sediment release.

A time series of the near bed SSC and sedimentation during and after the dredge are shown at the Sizewell B intake in Figure 90. The instantaneous maximum near bed SSC and sedimentation at the intake are summarised in Table 50.

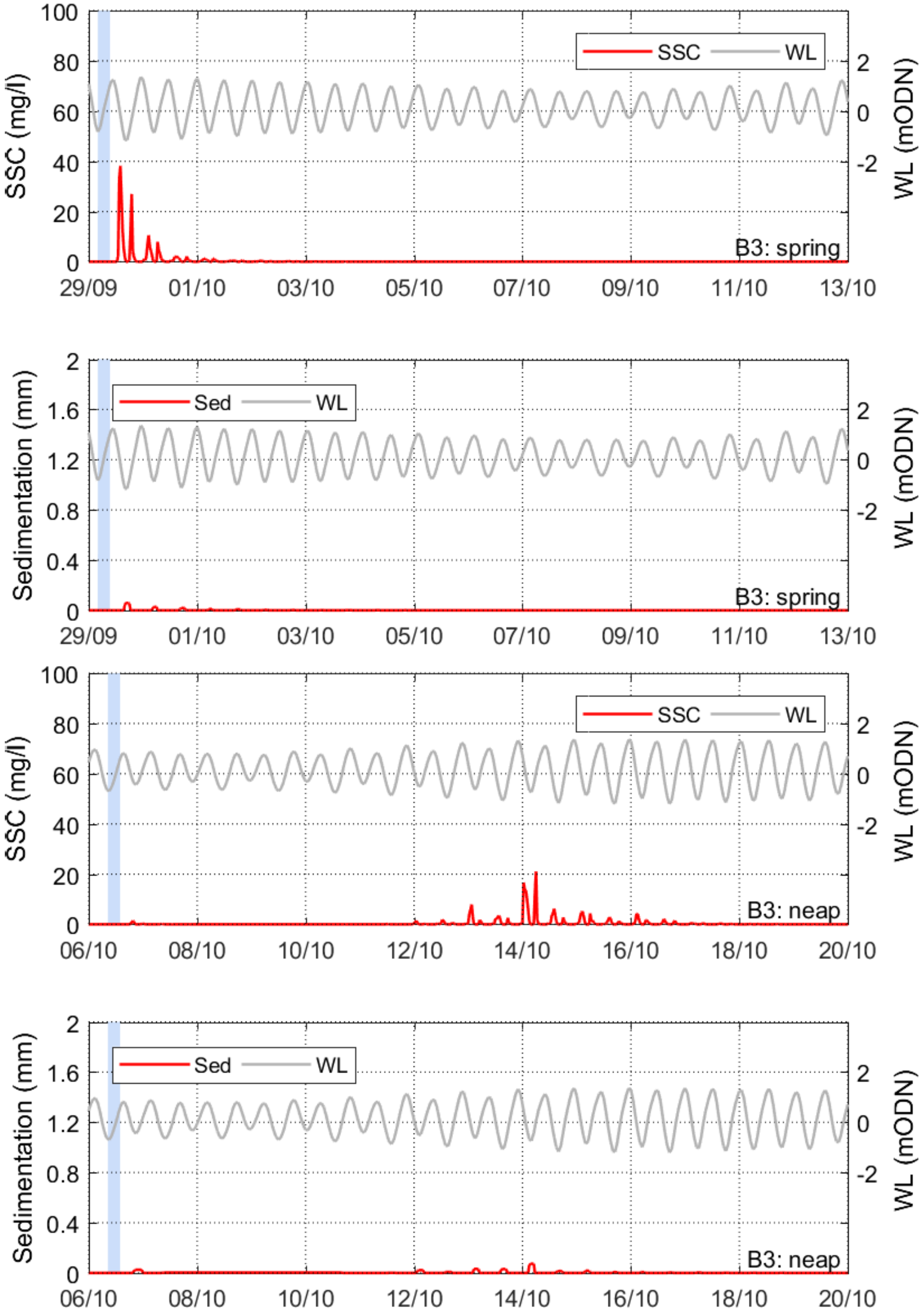
Table 50. Maximum instantaneous near bed SSC and sedimentation at the Sizewell B intake, resulting from maintenance dredging of the BLF approach channel

Tide	Instantaneous Maximum	
	SSC (mg/l)	Sedimentation (mm)
Spring Tide	13	0.2
Neap Tide	40	0.2



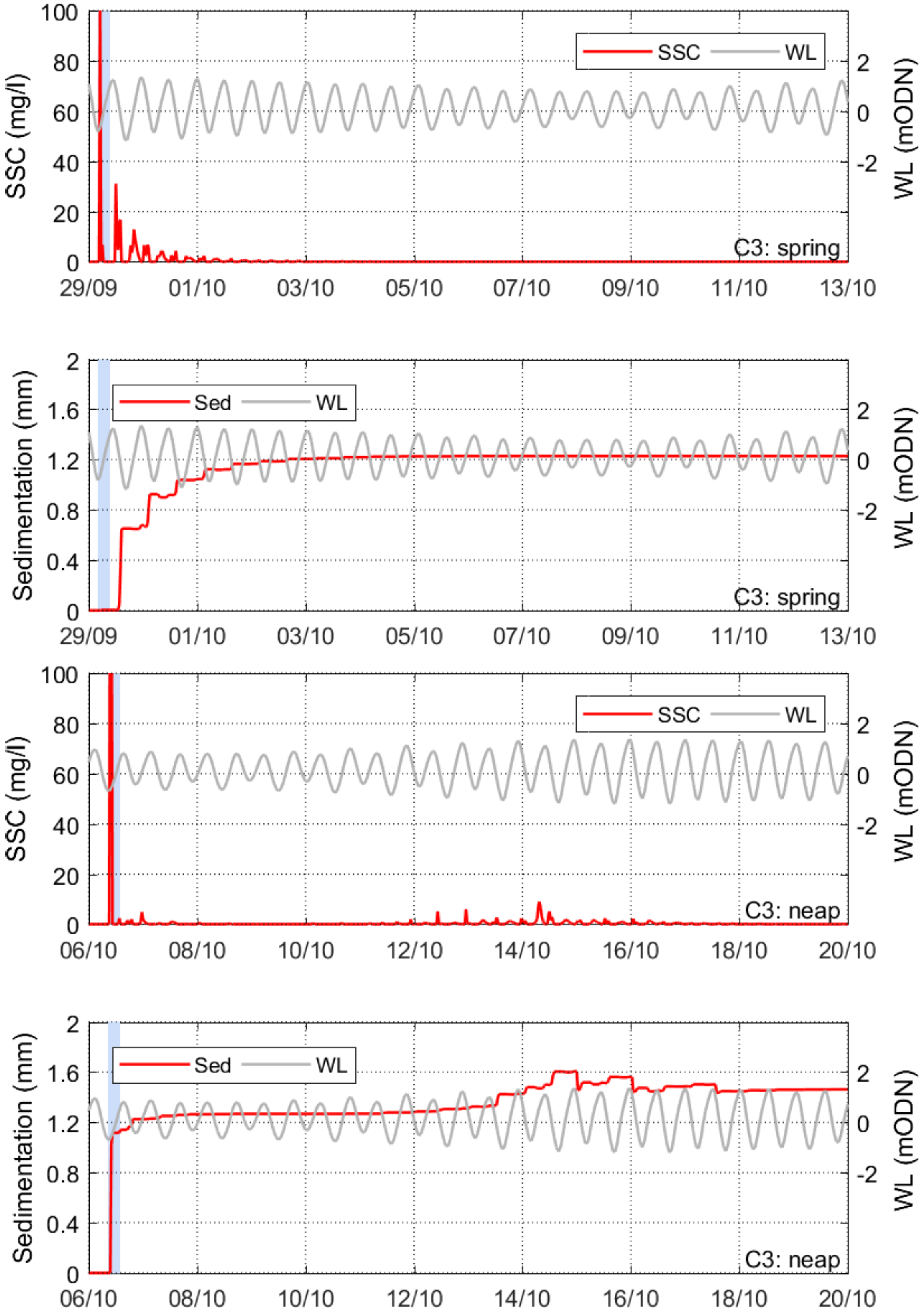
Blue shading shows periods of sediment release

Figure 85. Time series of depth average SSC and Sedimentation at Location A3 on spring (upper two panels) and neap tides (lower two panels) during and after maintenance dredging of the BLF approach channel



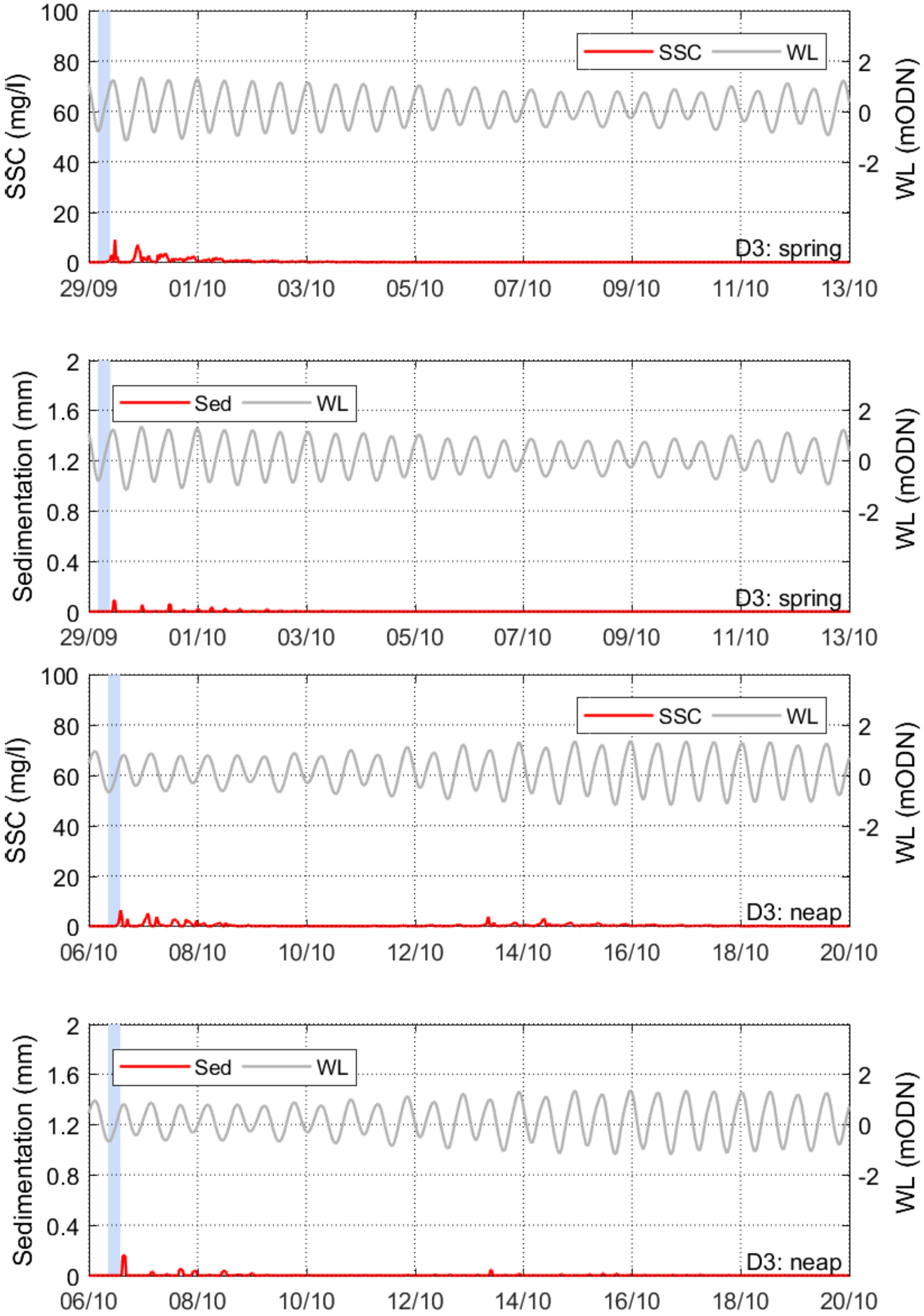
Blue shading shows periods of sediment release

Figure 86. Time series of depth average SSC and Sedimentation at Location B3 on spring (upper two panels) and neap tides (lower two panels) during and after maintenance dredging of the BLF approach channel



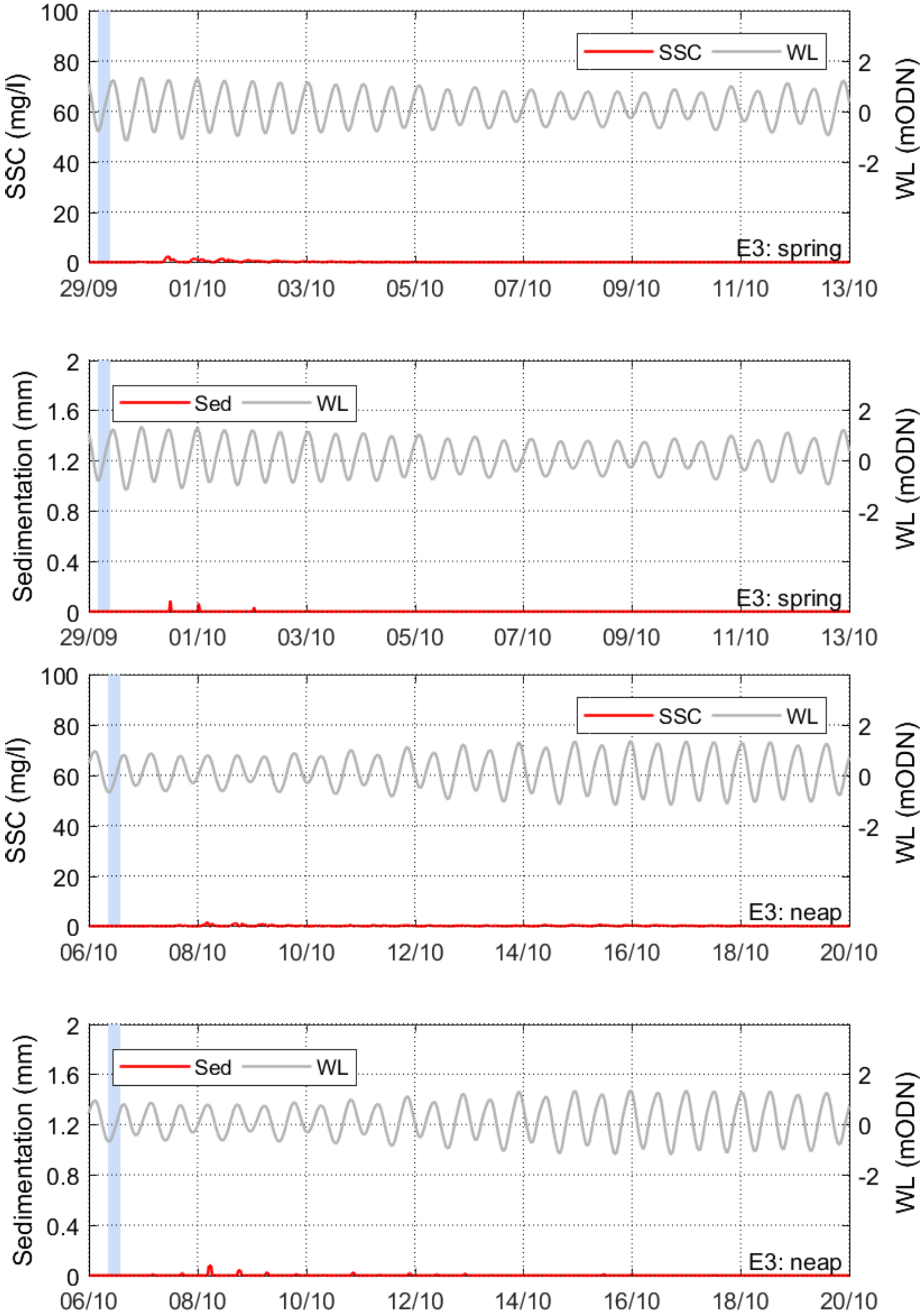
Blue shading shows periods of sediment release

Figure 87. Time series of depth average SSC and Sedimentation at Location C3 on spring (upper two panels) and neap tides (lower two panels) during and after maintenance dredging of the BLF approach channel



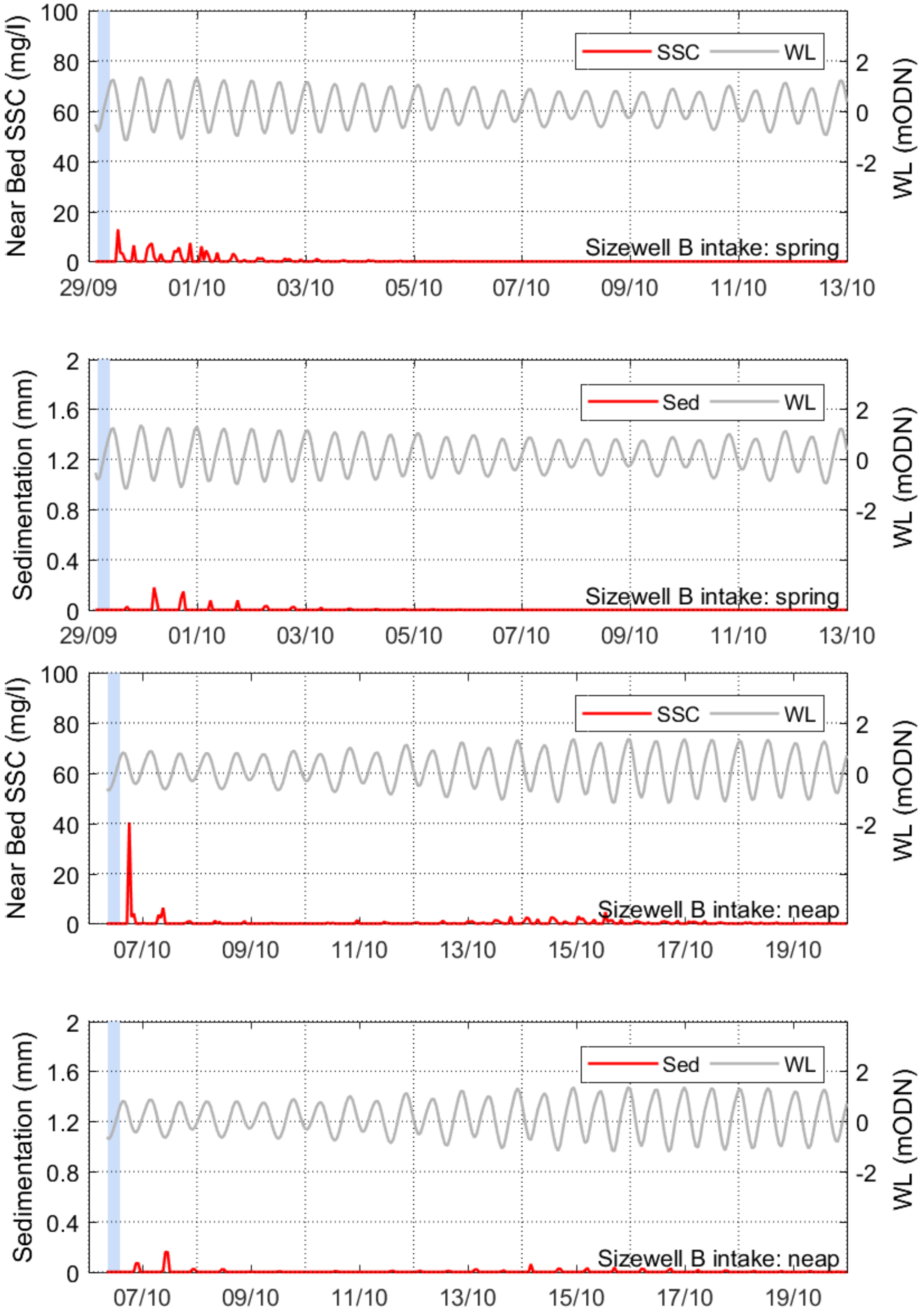
Blue shading shows periods of sediment release

Figure 88. Time series of depth average SSC and Sedimentation at Location D3 on spring (upper two panels) and neap tides (lower two panels) during and after maintenance dredging of the BLF approach channel



Blue shading shows periods of sediment release

Figure 89. Time series of depth average SSC and Sedimentation at Location E3 on spring (upper two panels) and neap tides (lower two panels) during and after maintenance dredging of the BLF approach channel



Blue shading shows periods of sediment release

Figure 90. Time series of the near bed SSC and Sedimentation at the Sizewell B intake on spring (upper two panels) and neap tides (lower two panels) during and after maintenance dredging of the BLF approach channel

To examine the plume dispersion in more detail, time series of plume areas in suspension (as depth average and in the surface layer) are shown in Figure 91. Areas of sedimentation on the bed are shown in Figure 92. Instantaneous maximum plume areas are provided in Table 51 to Table 53. On both the spring and neap tides, the area affected by increases in SSC is relatively small (*circa* 20 Ha above 100 mg/l) and further, periods of increase are short lived. No plume concentrations above 10 mg/l were evident at the end of the model simulation and deposits on the bed thicker than 2 mm were constrained to a small area.

Table 51. Maximum area of instantaneous depth average SSC resulting from maintenance dredging of the BLF approach channel

SSC > mg/l	Area (Ha)	
	Spring Tides	Neap Tides
20	93	107
50	46	62
100	14	22
200	5	6
500	1	1
1000	1	1
2000	1	1

Table 52. Maximum area of instantaneous surface SSC resulting from maintenance dredging of the BLF approach channel

SSC > mg/l	Area (Ha)	
	Spring Tides	Neap Tides
20	108	101
50	46	59
100	17	17
200	5	10
500	1	2
1000	0	1
2000	0	1

Table 53. Maximum area of instantaneous sedimentation resulting from maintenance dredging of the BLF approach channel

Sediment Thickness > mm	Area (Ha)	
	Spring Tides	Neap Tides
2	9	12
5	0	1
10	0	1
20	0	0

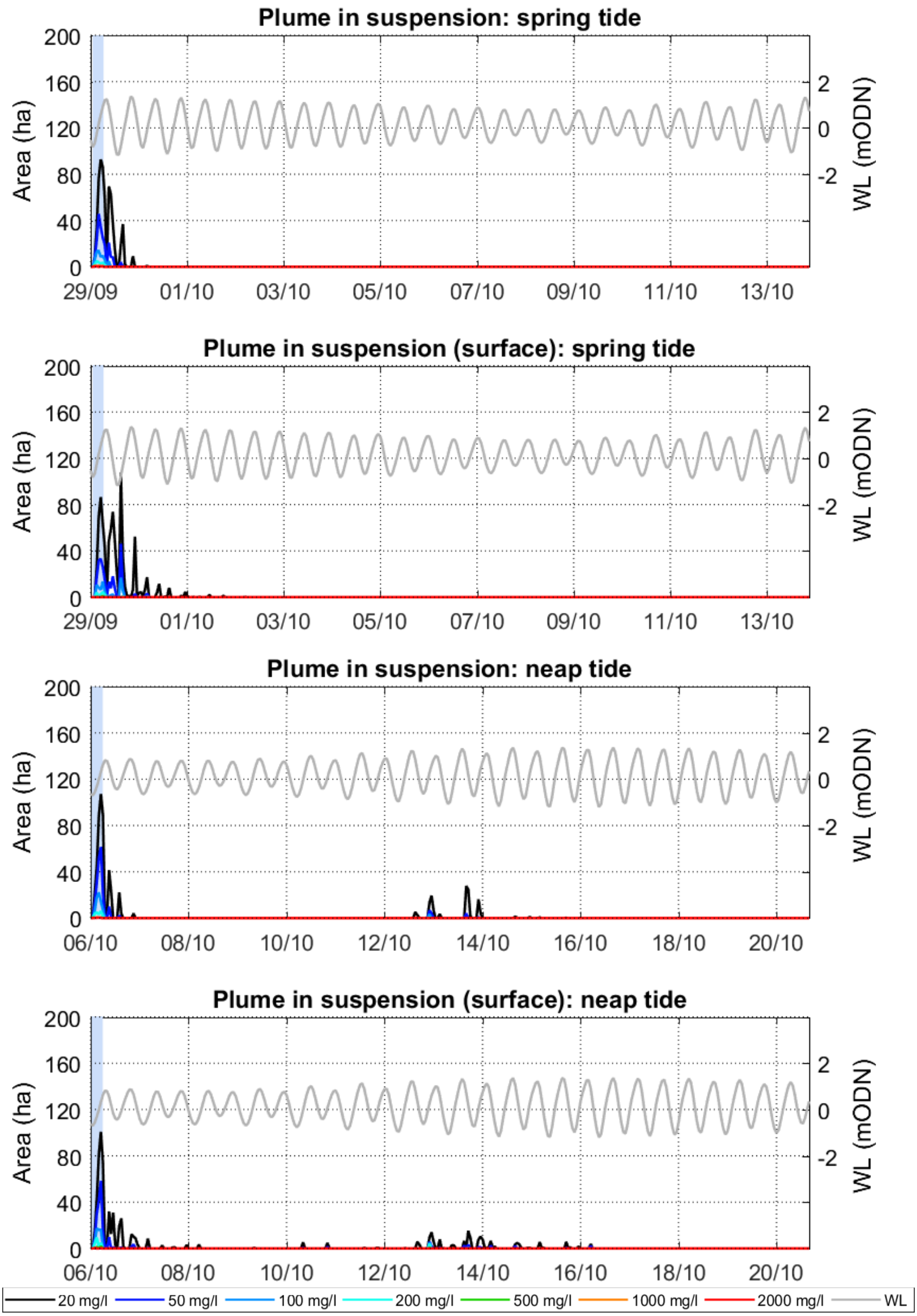


Figure 91. Plume areas in suspension (as depth average and in the surface layer) during and after the maintenance dredging of the BLF approach channel

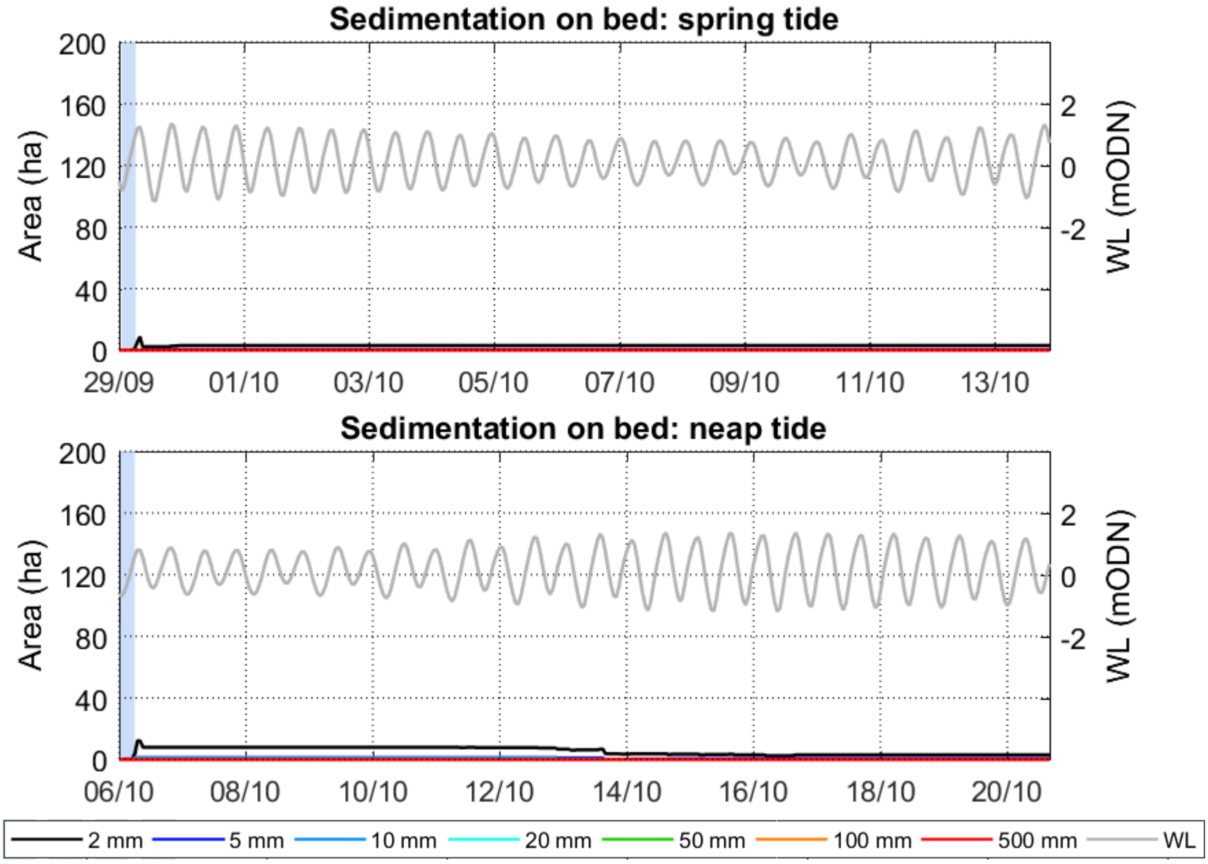


Figure 92. **Plume areas in on the bed during and after the maintenance dredging of the BLF approach channel**

3.4.1 Bird foraging

Areas of plume intersect with bird foraging areas are provided in Table 54. The areas are significantly lower than for the capital dredge of the BLF approach channel indicating that the duration of sediment release contributes to the area of impact (since the rate of release for the two scenarios is unchanged). For completeness, time series of percentage area of plume intersect with foraging areas is also provided (Figure 93).

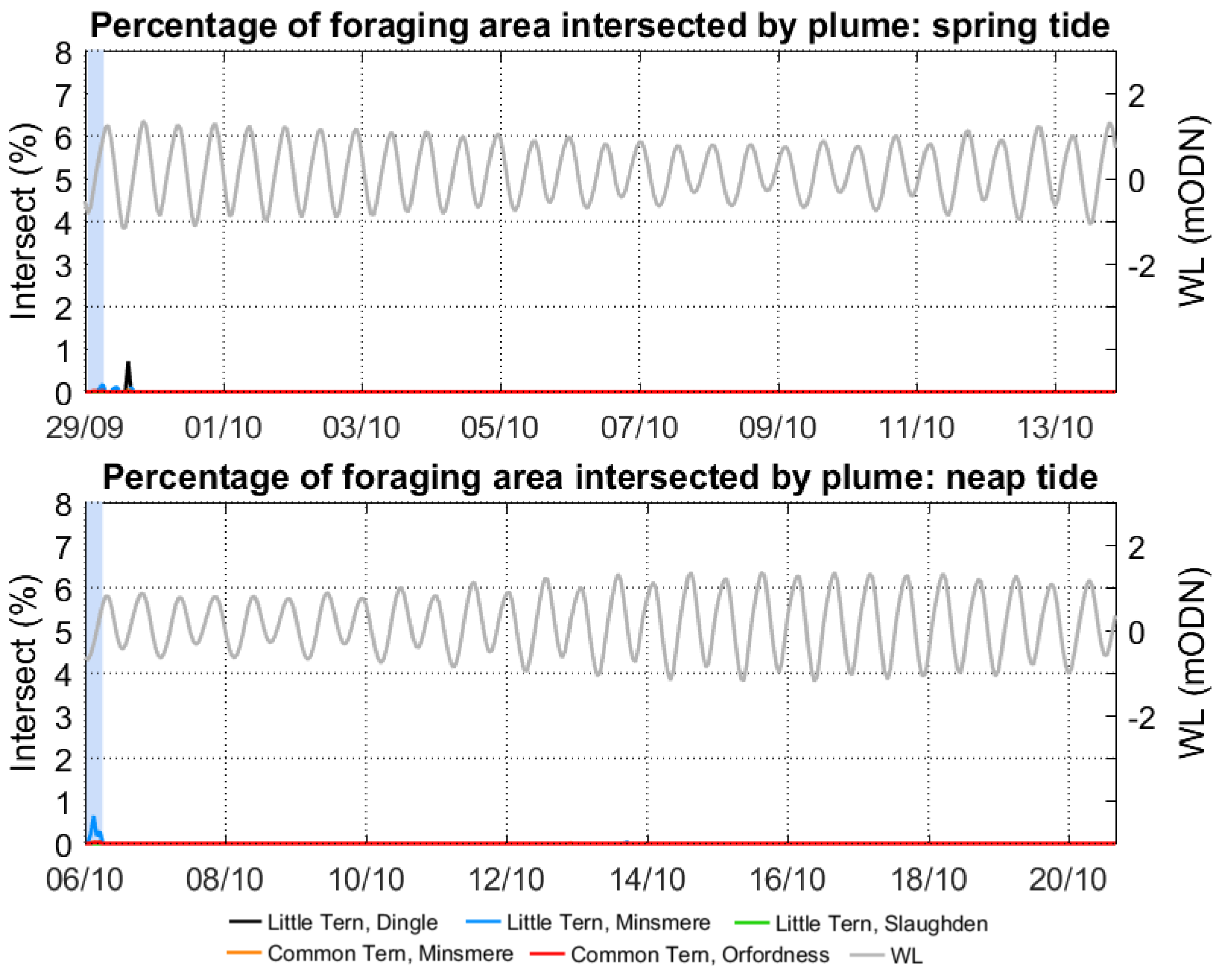


Figure 93. Plume areas in suspension (defined as surface SSC of more than 100 mg/l), intersecting with bird foraging areas during and after the maintenance dredging of the BLF approach channel

Table 54. Maximum area of plume intersect with habitat/bird foraging areas resulting from maintenance dredging of the BLF approach channel. Plume defined as surface SSC above 100 mg/l.

Receptor	Spring Tides		Neap Tides	
	Area (Ha)	% of Foraging Area	Area (Ha)	% of Foraging Area
Little Tern Dingle Colony	13	1	0	0
Little Tern Minsmere Colony	3	<1	11	1
Little Tern Slaughden Colony	0	0	0	0
Common Tern (Minsmere Colony)	17	<1	16	<1
Common Tern (Orfordness Colony)	11	<1	16	<1

4 In-combination Assessment

Depending on the exact timing of the construction related activities, there is the potential for some in-combination effects. In particular, the maintenance dredge of the BLF approach channel could coincide with the dredging of sediments for the installation of either the CWS structures or the installation of the additional outfall structures. To provide an assessment of any in-combination effect arising from these activities, results from the different modelling scenarios have been combined. For the in-combination assessment it is assumed that both activities will start simultaneously. Given the short duration of each activity (between five hours and eight and a half hours) and the similar location of release, this assumption is reasonable.

The results for the in-combination effect of the BLF approach channel maintenance dredge and the dredge at intake I4a are presented in Section 4.1 and results for the in-combination effect of the BLF approach channel maintenance dredge and the dredge at outfall FRR1 are presented in Section 4.2.

4.1 Maintenance dredging of the BLF approach channel and dredging of surficial sediments at the CWS structures

The location maximum depth average and surface SSC associated with the simultaneous maintenance dredging of the BLF approach channel and dredging at the CWS structures are shown in Figure 94 and Figure 95, respectively. These plots indicate that the plumes from these two activities do not interact with two discrete plumes evident in the plots. Similarly, the location maximum sedimentation plot also indicates no area of overlapping effect. As noted previously, the location maximum plots do not indicate how long the conditions prevail and the map plots of instantaneous plume concentration and sedimentation (Figure 97 and Figure 98) are included to demonstrate the transient and short-lived nature of the plumes.

While the plume associated with the dredging at the CWS structures does not interact with the plume from the maintenance dredge of the BLF approach channel, there is potential for in-combination effects arising from an increase in area affected by elevated SSC and sedimentation. To consider this, the combined plume areas in suspension and on the bed have been quantified. The combined results are shown in Figure 99 and Figure 100. For ease of quantification maximum values are also provided in Table 55 to Table 57. Comparison of these in-combination results against those for the dredge at intake I4a alone (Table 18 to Table 20) indicate that the in-combination effect on SSC is minimal with areas with a surface SSC above 20 mg/l increased by 1 Ha. Changes to sedimentation are slightly larger (up to an 8 Ha increase for sedimentation area above 2 mm when the dredging occurs on neap tides) due to the slightly less transient nature of sediment on the bed than in suspension.

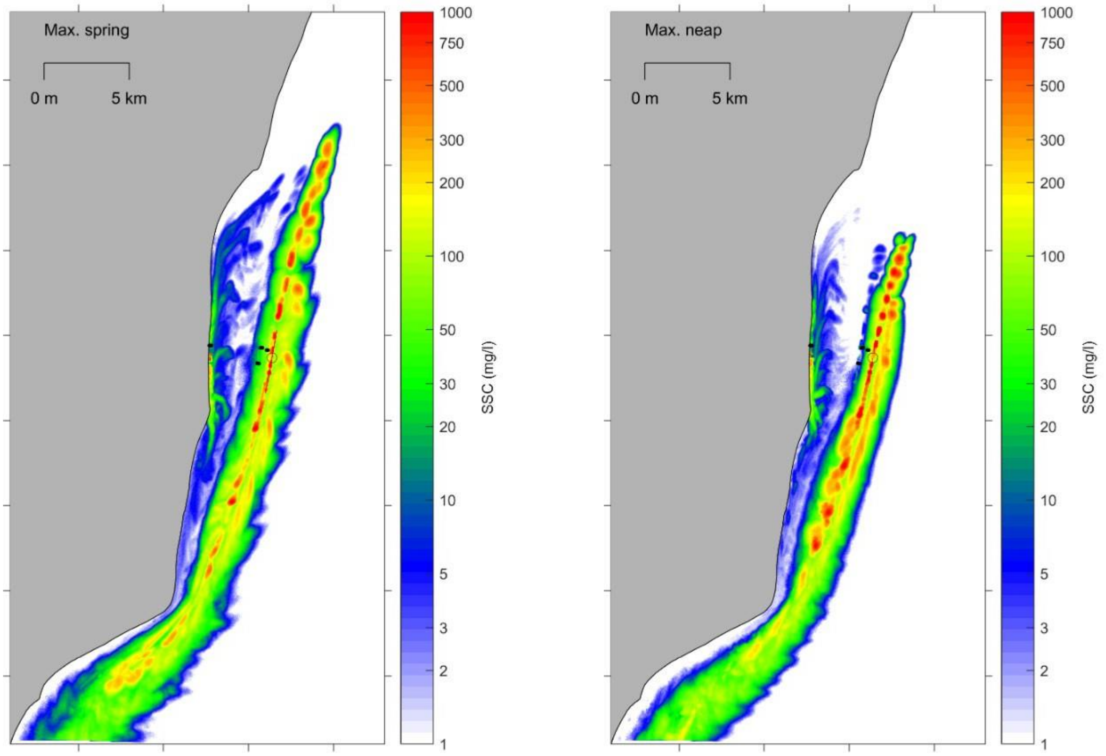


Figure 94. Location maximum depth average SSC associated with the maintenance dredging of the BLF approach channel, in combination with the dredging at Intake I4a on spring and neap tides

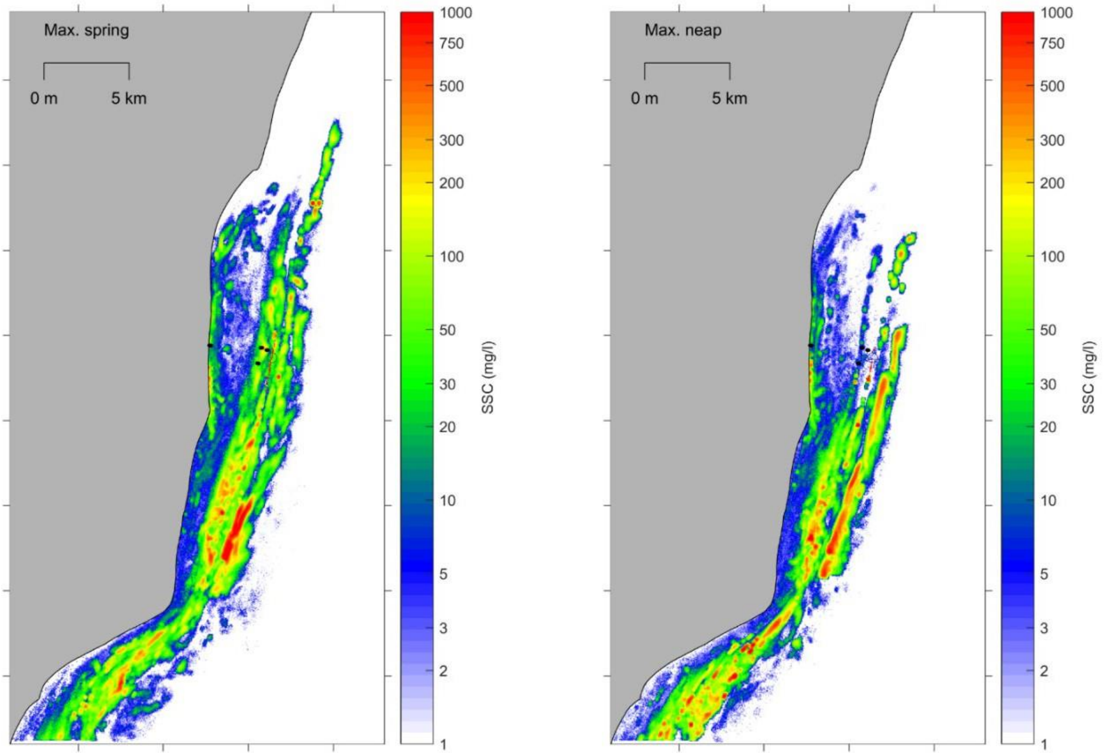


Figure 95. Location maximum surface SSC associated with the maintenance dredging of the BLF approach channel, in combination with the dredging at Intake I4a on spring and neap tides

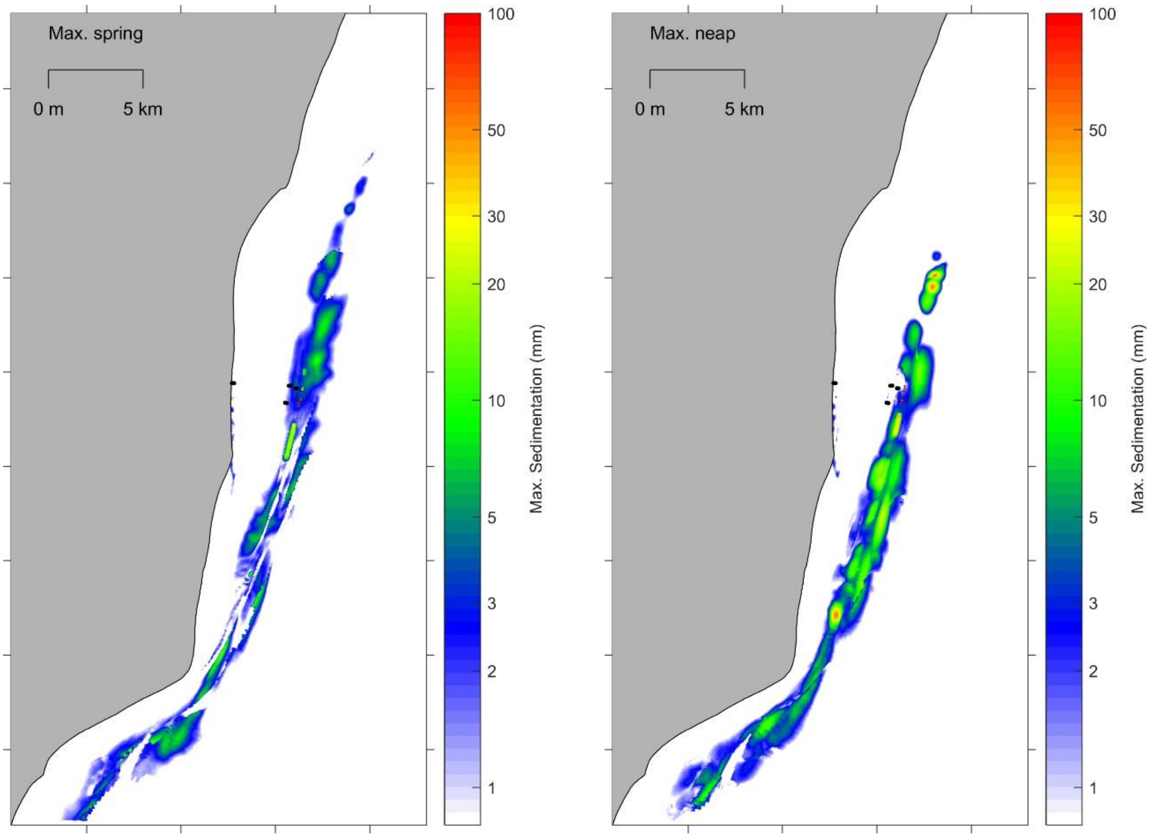


Figure 96. Location maximum sedimentation associated with the maintenance dredging of the BLF approach channel, in combination with the dredging at Intake I4a on spring and neap tides

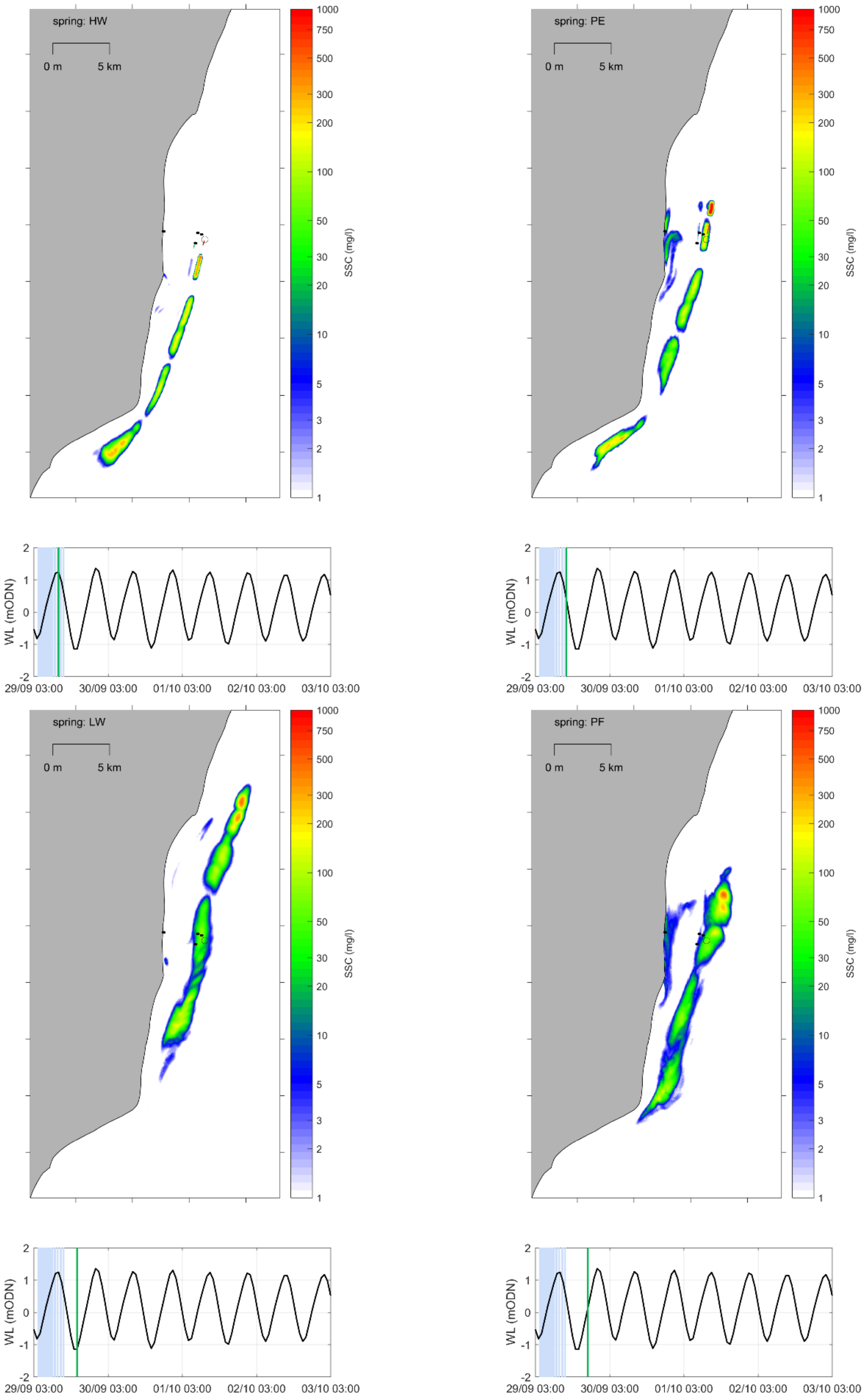


Figure 97. Depth average SSC at HW, PE, LW and PF on a spring tide, during and after maintenance dredging of the BLF approach channel, in combination with the dredging at Intake I4a

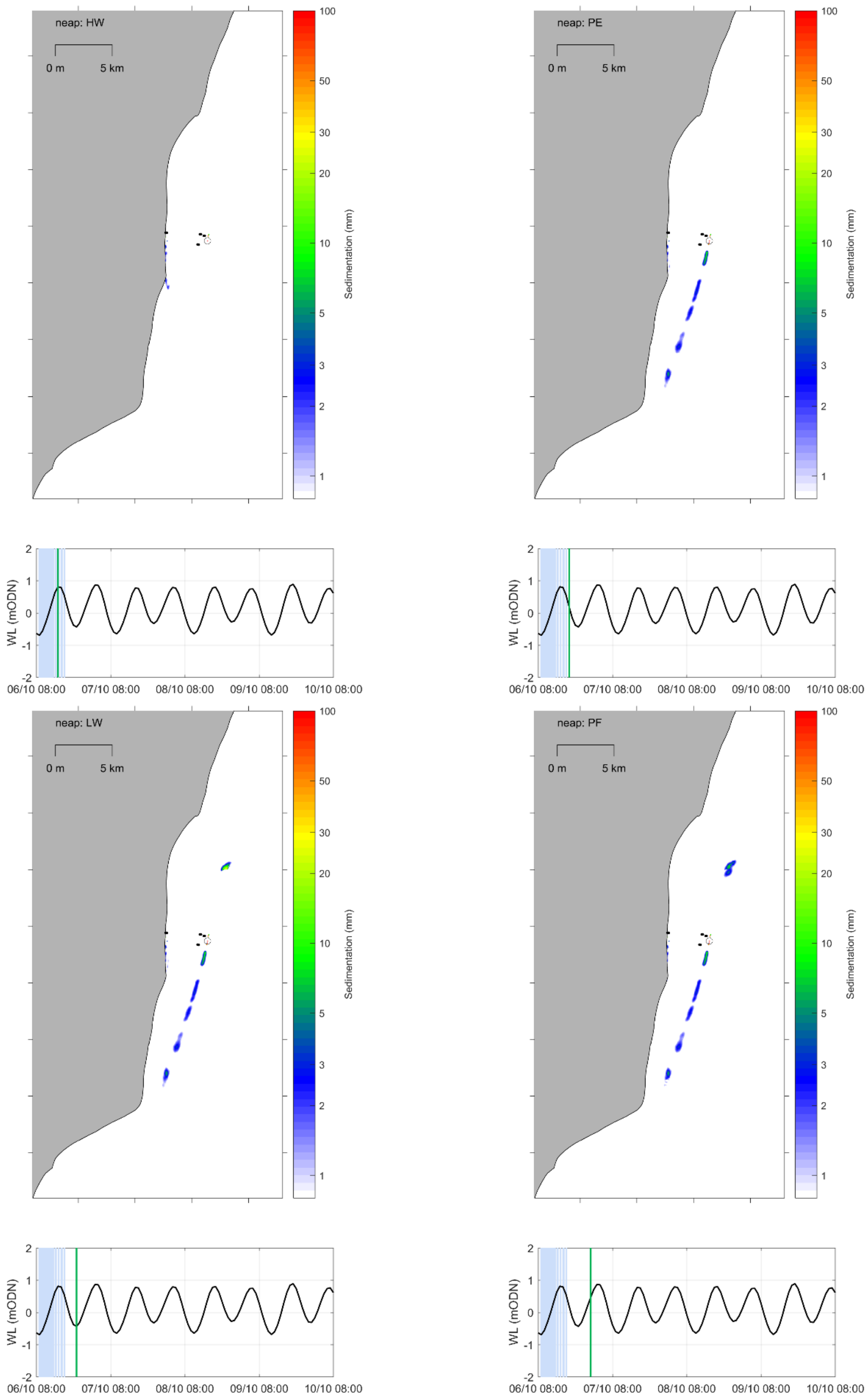


Figure 98. Sedimentation at HW, PE, LW and PF on a neap tide during capital dredging of the BLF approach channel on a neap tide, during and after maintenance dredging of the BLF approach channel, in combination with the dredging at Intake I4a

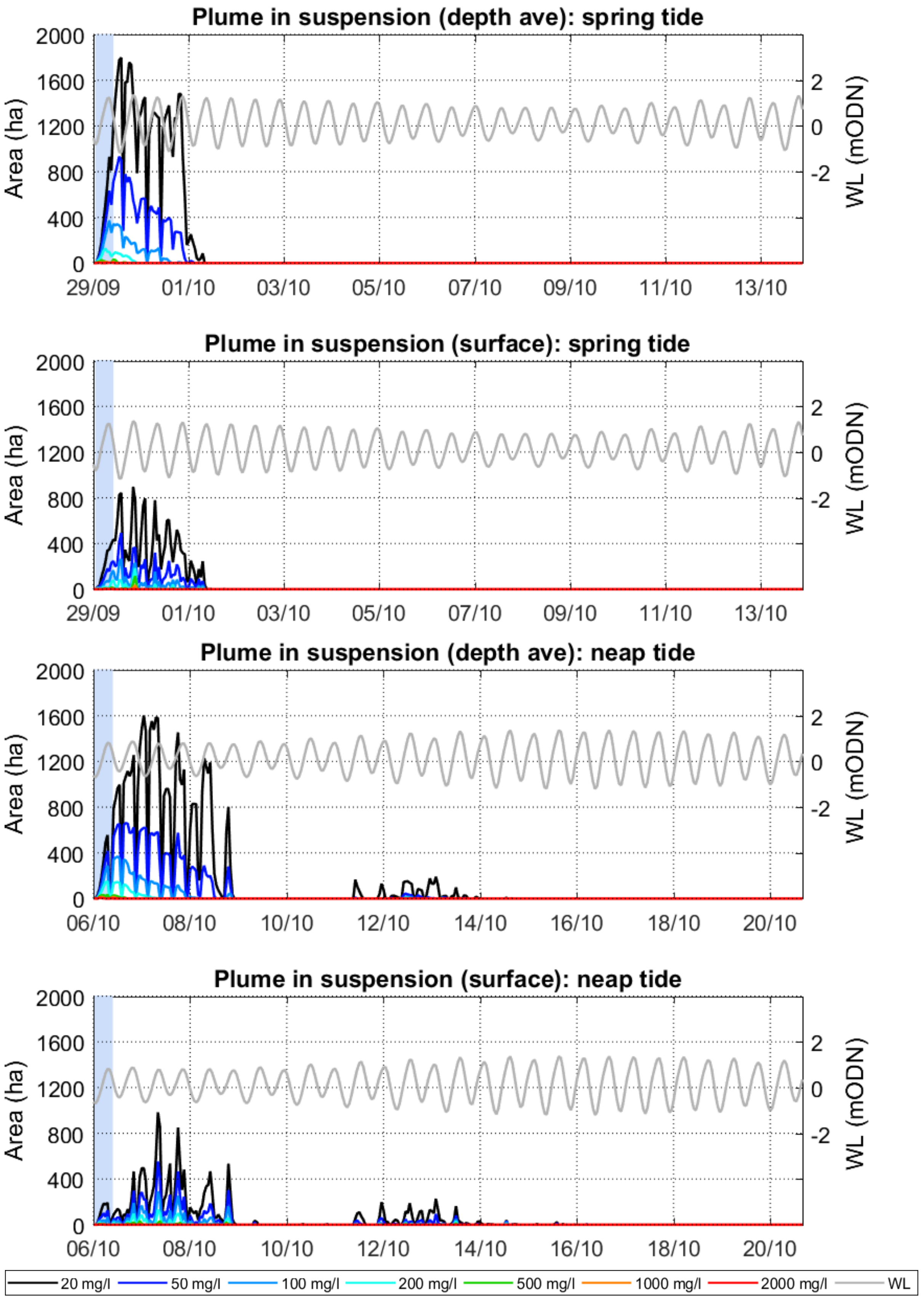


Figure 99. Plume areas in suspension (as depth average and in the surface layer) during and after the maintenance dredging of the BLF approach channel, in combination with the dredging at Intake I4a

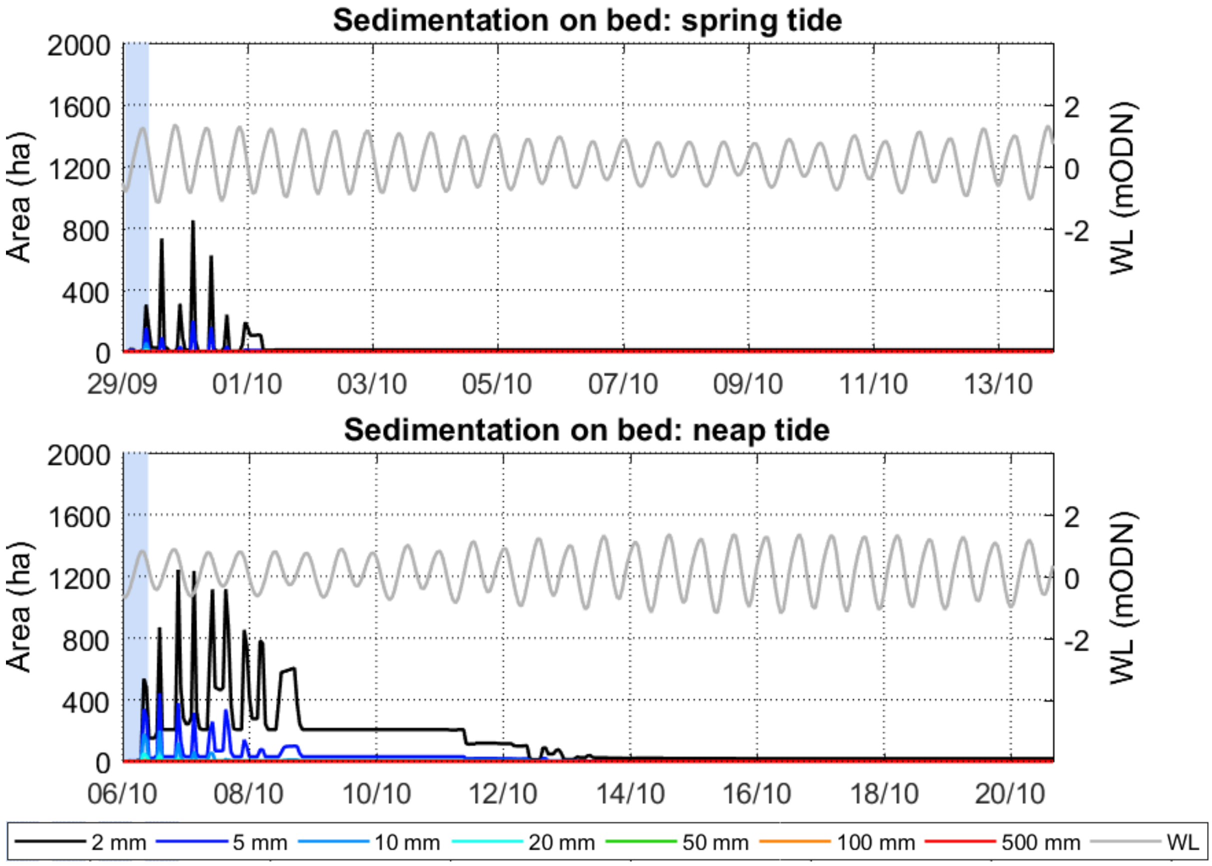


Figure 100. Plume areas on the bed during and after maintenance dredging of the BLF approach channel, in combination with the dredging at Intake I4a

Table 55. Maximum area of instantaneous depth average SSC resulting from maintenance dredging of the BLF approach channel, in combination with the dredging at Intake I4a

SSC > mg/l	Area (Ha)	
	Spring Tides	Neap Tides
20	1,798	1,603
50	932	660
100	373	368
200	128	150
500	30	33
1000	11	14
2000	3	6

Table 56. **Maximum area of instantaneous surface SSC resulting from maintenance dredging of the BLF approach channel, in combination with the dredging at Intake I4a**

SSC > mg/l	Area (Ha)	
	Spring Tides	Neap Tides
20	897	983
50	492	553
100	265	291
200	185	130
500	115	32
1000	34	5
2000	2	2

Table 57. **Maximum area of instantaneous sedimentation resulting from maintenance dredging of the BLF approach channel, in combination with the dredging at Intake I4a**

Sediment Thickness > mm	Area (Ha)	
	Spring Tides	Neap Tides
2	852	1,243
5	201	442
10	58	200
20	14	53
50	3	5
100	3	2
500	0	1

4.1.1 Bird foraging

Areas of the in-combination plumes intersecting with the bird foraging areas (defined as SSC greater than 100 mg/l in the surface layer of the model) are provided in Table 58. In comparison to the results for the individual scenarios, the in-combination assessment results indicate that the foraging areas are not subjected to a greater impact when both activities occur simultaneously. If the start timing of the activities differed, the potential for in-combination effects could be altered. However, any plume interaction occurring would be short lived.

Time series of the area of intersect for the different foraging areas are shown for dredging occurring on spring and neap tides in Figure 101. This plot also shows that the in-combination effect of the two activities occurring simultaneously is not increased above either activity occurring in isolation.

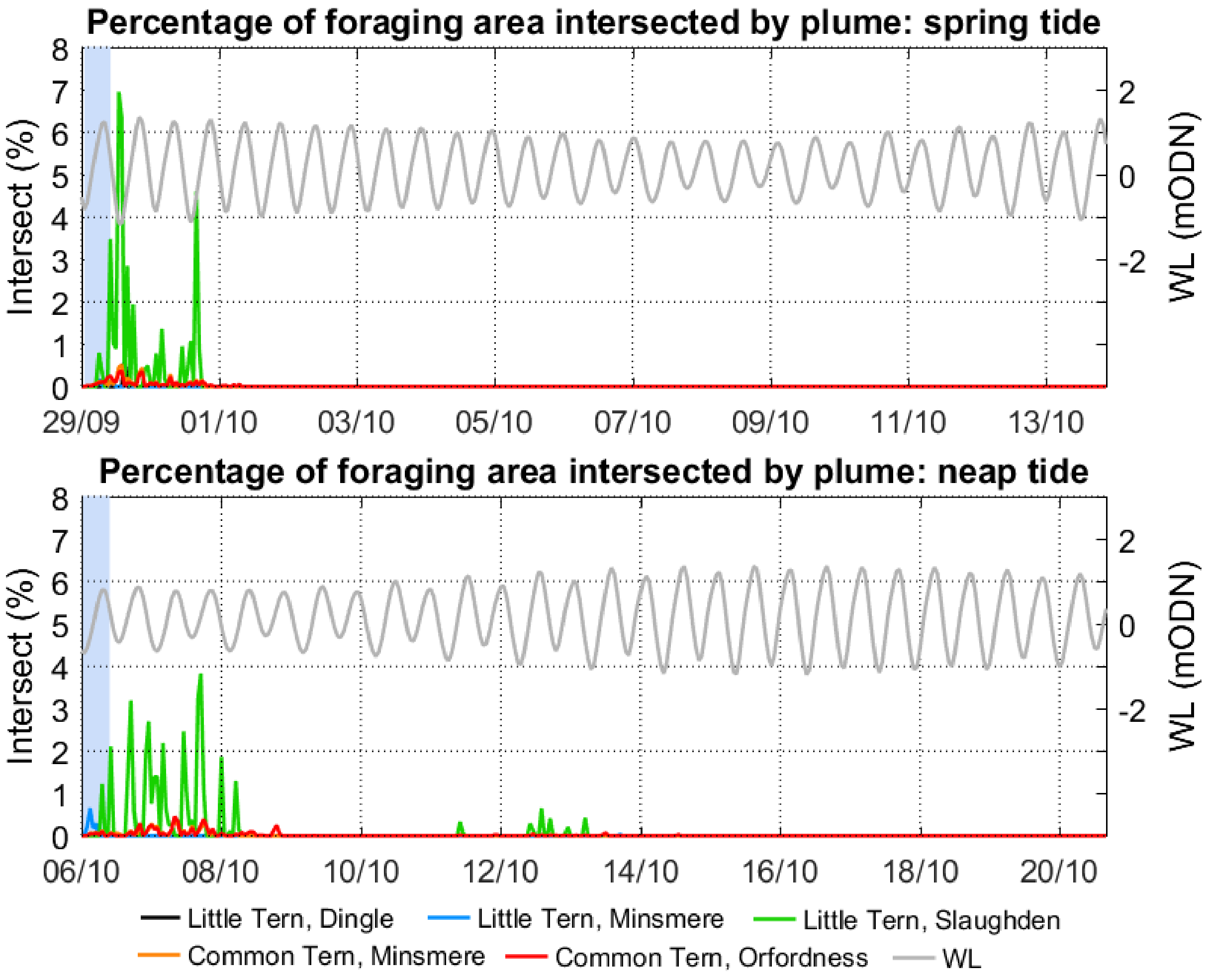


Figure 101. Plume areas in suspension (defined as surface SSC of more than 100 mg/l), intersecting with bird foraging areas resulting from maintenance dredging of the BLF approach channel, in combination with the dredging at Intake I4a

Table 58. Maximum area of plume intersect with habitat/bird foraging areas resulting from maintenance dredging of the BLF approach channel, in combination with the dredging at Intake I4a. Plume defined as surface SSC above 100 mg/l.

Receptor	Spring Tides		Neap Tides	
	Area (Ha)	% of Foraging Area	Area (Ha)	% of Foraging Area
Little Tern Dingle Colony	13	1	0	0
Little Tern Minsmere Colony	3	<1	11	1
Little Tern Slaughden Colony	124	7	69	4
Common Tern (Minsmere Colony)	265	1	206	<1
Common Tern (Orfordness Colony)	238	<1	291	<1

4.2 Maintenance dredging of the BLF approach channel and dredging of surficial sediments at the additional outfalls

The location maximum depth average and surface SSC associated with the simultaneous maintenance dredging of the BLF approach channel and the dredging at FRR1 are shown in Figure 102 and Figure 103. The individual plumes from these two activities are only discernible at concentrations above 100 mg/l indicating that there is potential for some interaction between the plumes. For location maximum sedimentation (Figure 104), the areas affected are more discrete and the potential for interaction is minimal.

Separate sediment plumes are also difficult to identify in map plots of instantaneous SSC (Figure 105).

The interaction of the plumes associated with the maintenance dredging of the BLF approach channel and the dredging at FRR1 could increase the concentrations of material in suspension and could also increase the instantaneous area affected by elevated SSC and sedimentation. The in-combination plume area in suspension and areas of sedimentation on the bed are shown in Figure 107 and Figure 108. Areas of maximum instantaneous plume and sedimentation areas are provided in Table 59 to Table 61.

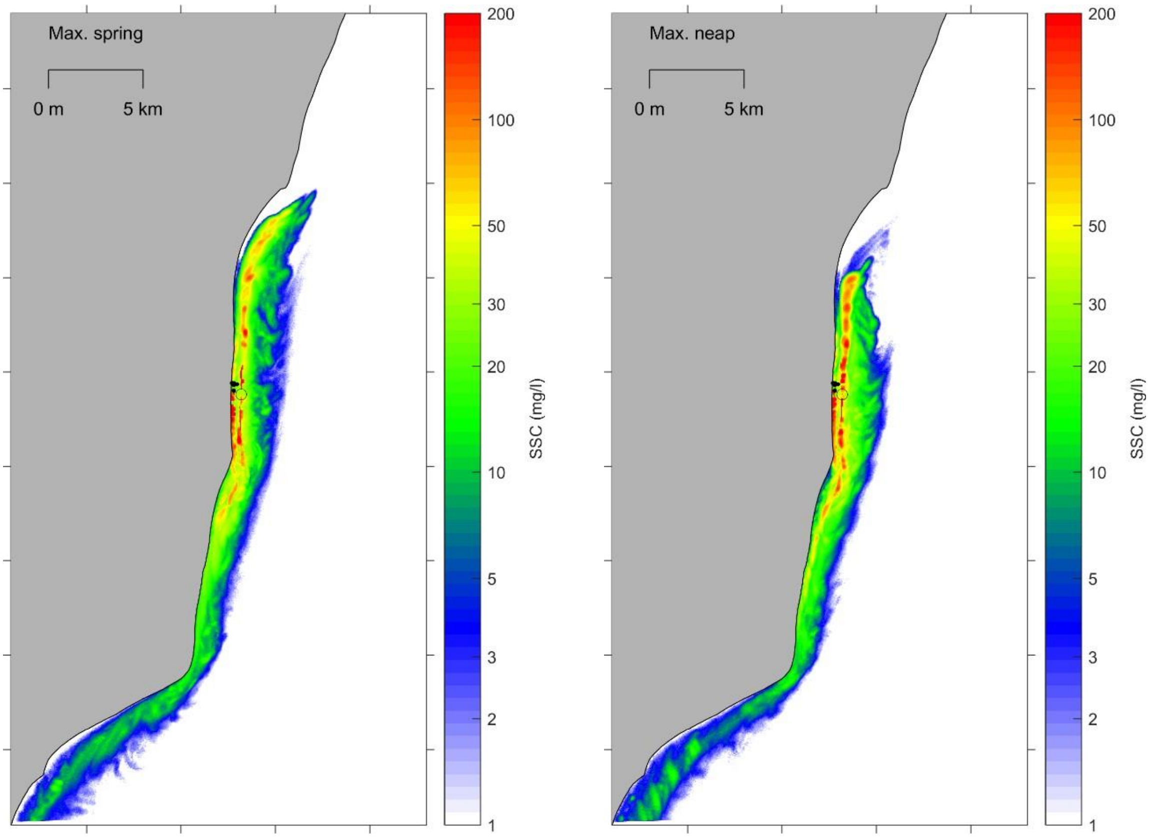


Figure 102. Location maximum depth average SSC associated with the maintenance dredging of the BLF approach channel, in combination with the dredging at FRR1 on spring and neap tides

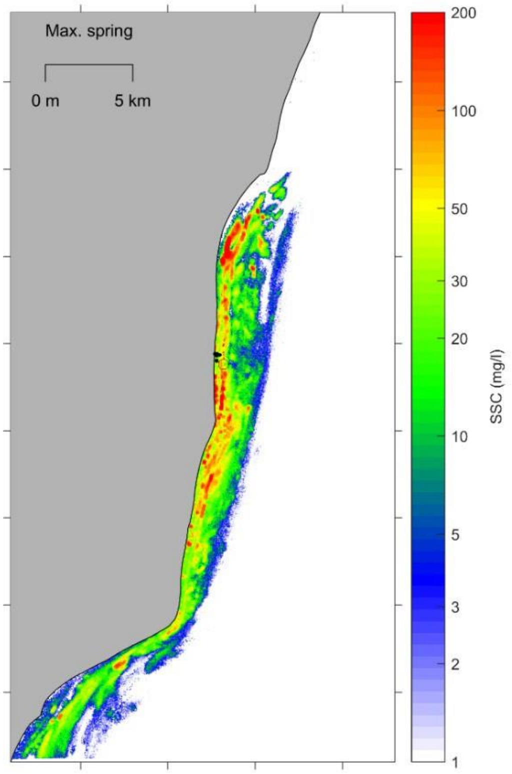


Figure 103. Location maximum surface SSC associated with the maintenance dredging of the BLF approach channel, in combination with the dredging at FRR1 on spring and neap tides

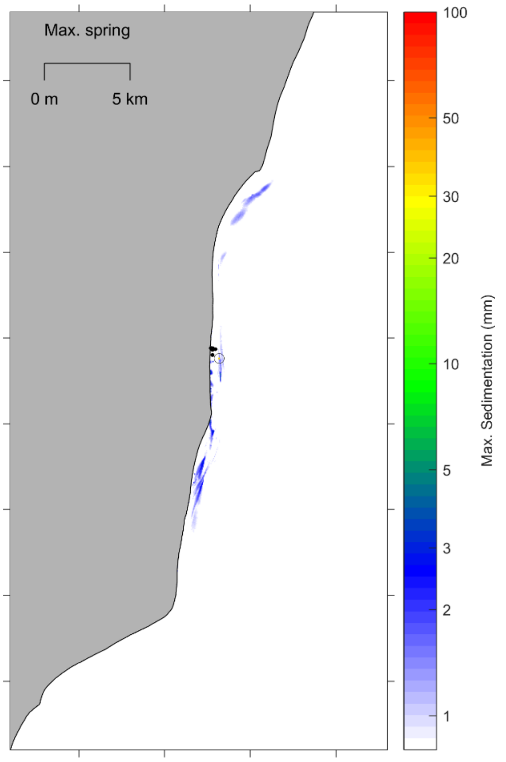


Figure 104. Location maximum sedimentation associated with the maintenance dredging of the BLF approach channel, in combination with the dredging at Intake I4a on spring and neap tides

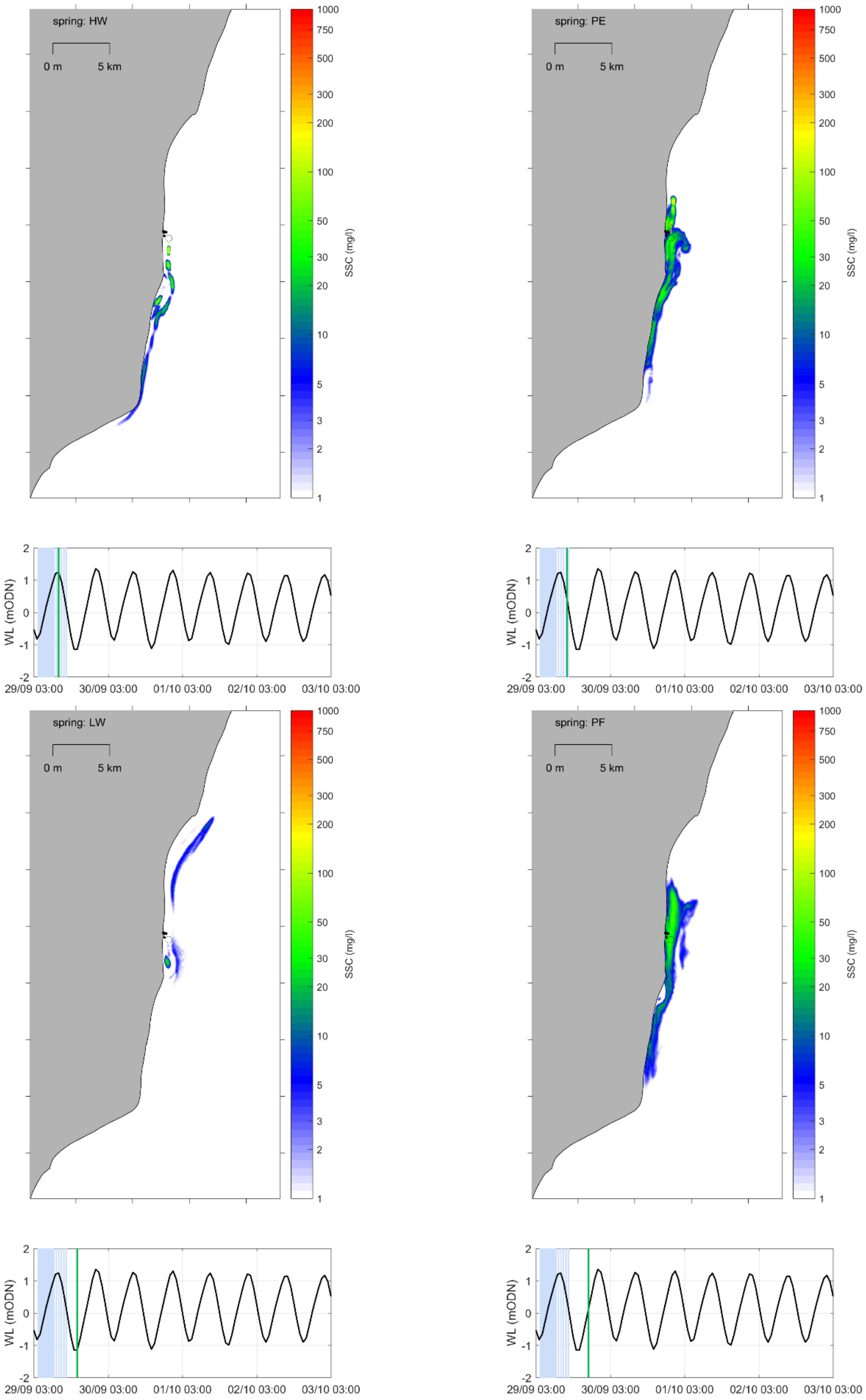


Figure 105. Depth average SSC at HW, PE, LW and PF on a spring tide, during and after maintenance dredging of the BLF approach channel, in combination with the dredging at Intake I4a

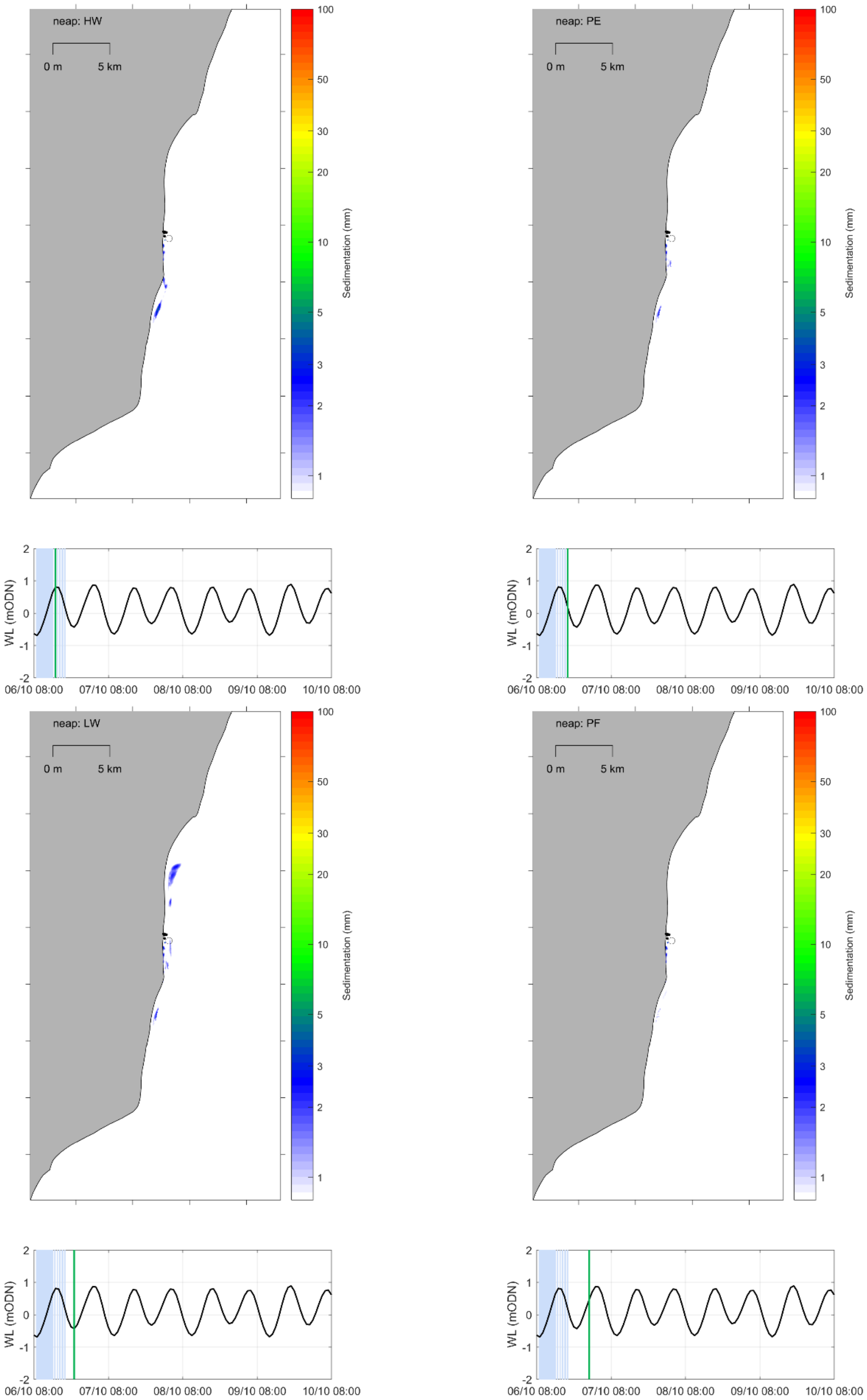


Figure 106. Sedimentation at HW, PE, LW and PF on a neap tide during capital dredging of the BLF approach channel on a neap tide, during and after maintenance dredging of the BLF approach channel, in combination with the dredging at Intake I4a

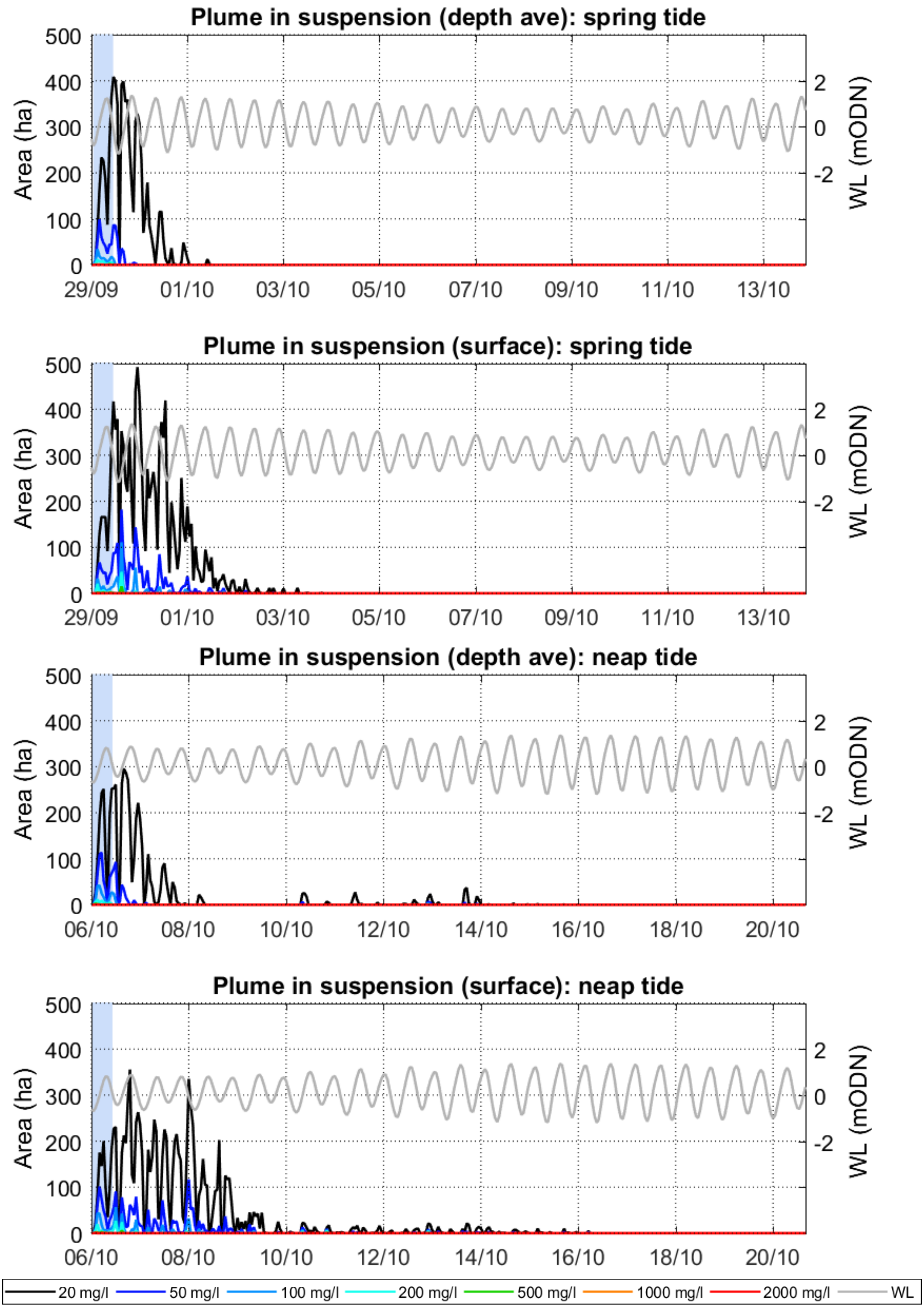


Figure 107. Plume areas in suspension (as depth average and in the surface layer) during and after the maintenance dredging of the BLF approach channel, in combination with the dredging at the FRR1 structure

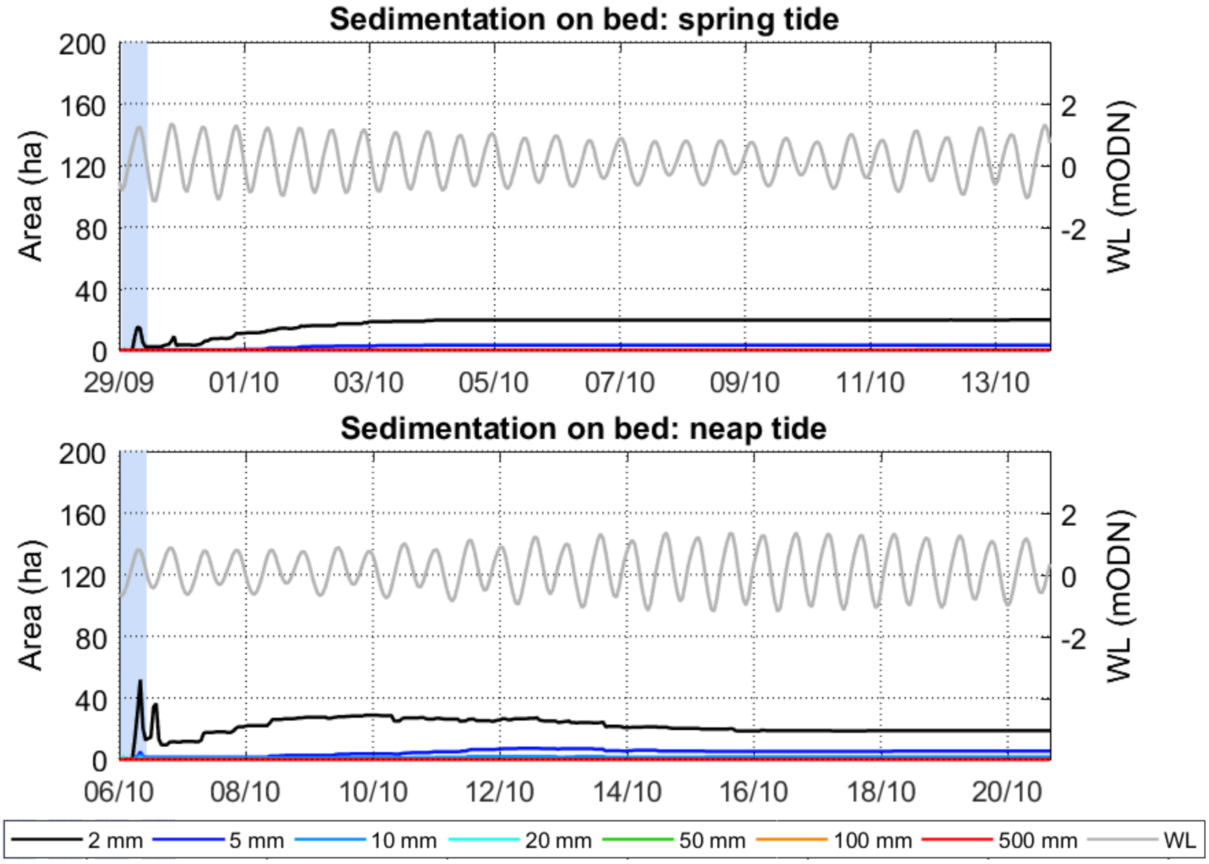


Figure 108. Plume areas on the bed during and after maintenance dredging of the BLF approach channel, in combination with the dredging at the FRR1 structure

Table 59. Maximum area of instantaneous depth average SSC resulting from maintenance dredging of the BLF approach channel, in combination with the dredging at the FRR1 structure

SSC > mg/l	Area (Ha)	
	Spring Tides	Neap Tides
20	409	296
50	99	114
100	35	42
200	12	11
500	2	3
1000	1	1
2000	1	1

Table 60. **Maximum area of instantaneous surface SSC resulting from maintenance dredging of the BLF approach channel, in combination with the dredging at the FRR1 structure**

SSC > mg/l	Area (Ha)	
	Spring Tides	Neap Tides
20	491	356
50	182	117
100	111	57
200	47	27
500	15	6
1000	1	1
2000	0	1

Table 61. **Maximum area of instantaneous sedimentation resulting from maintenance dredging of the BLF approach channel, in combination with the dredging at the FRR1 structure**

Sediment Thickness > mm	Area (Ha)	
	Spring Tides	Neap Tides
2	20	52
5	3	7
10	1	3
20	1	1
50	0	0

4.2.1 Bird foraging

Time series of the percentage area of plume intersect with the different bird foraging areas resulting from maintenance dredging of the BLF approach channel, in combination with the dredging at FRR1 is shown in Figure 109.

Areas of maximum plume intersect with the bird foraging areas (defined as SSC greater than 100 mg/l in the surface layer of the model) are provided in Table 62. In comparison to the results for the individual scenarios (Table 32 and Table 54), the in-combination assessment results in an increase in plume areas and areas of intersect with foraging areas, albeit still remaining less than 5 % of the various receptor areas. For some foraging areas, the in-combination effect is more than the additive plume areas indicating that plume interactions occur. For example, the plume area above 100 mg/l associated with the maintenance dredge of the BLF on spring tides does not intersect with the foraging area of the Slaughden Little Tern colony, while the plume area above 100 mg/l associated with the dredging of the FRR1 outfall intersects with 32 Ha of the foraging area of the Slaughden Little Tern colony and the combined effect of the two activities results in a plume area above 100 mg/l of 45 Ha. Despite the potential for increased intersection of sediment plumes with foraging areas for this in-combination assessment, the percentage of the foraging areas effected remains small.

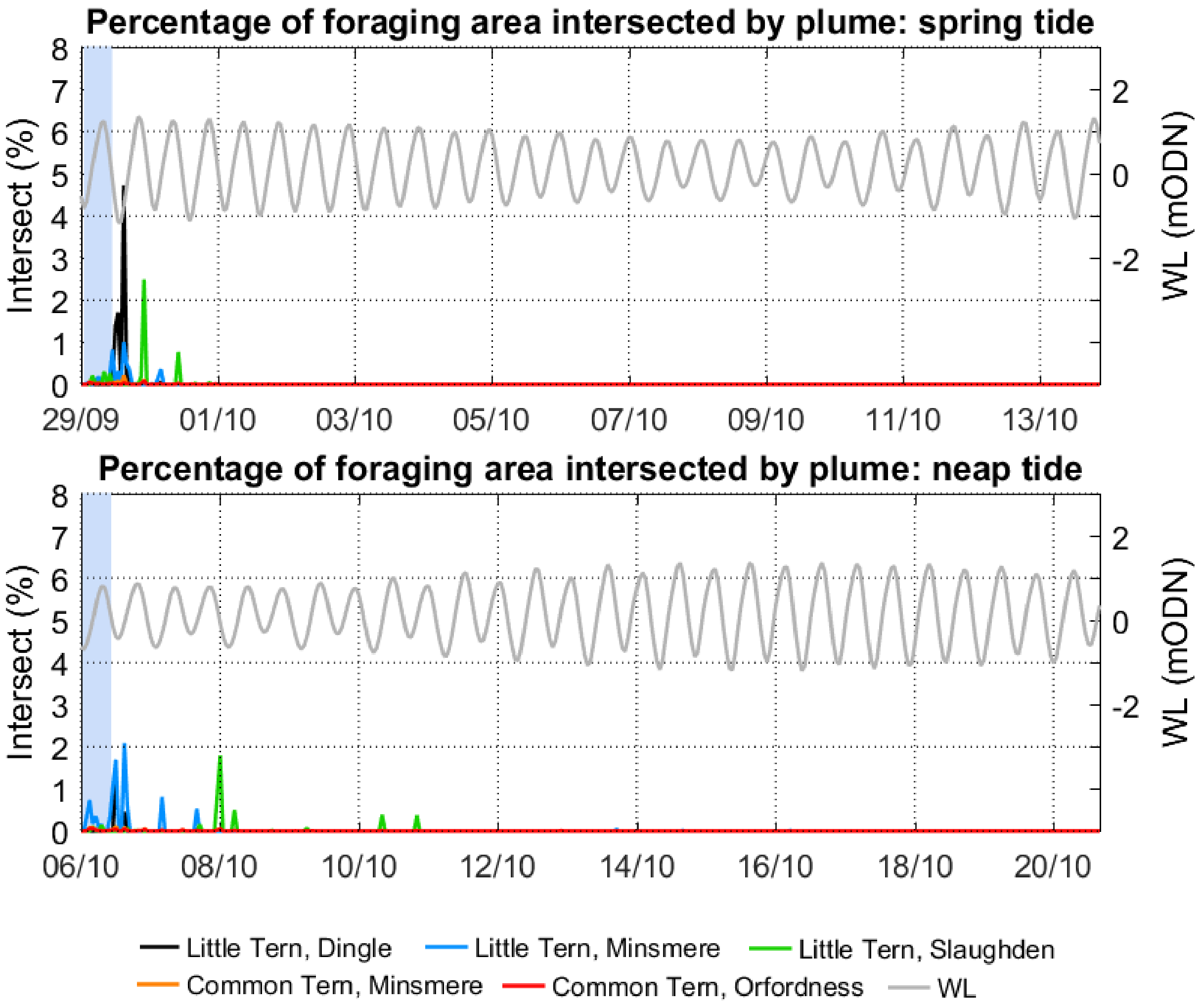


Figure 109. Plume areas in suspension (defined as surface SSC of more than 100 mg/l), intersecting with bird foraging areas resulting from maintenance dredging of the BLF approach channel, in combination with the dredging at FRR1

Table 62. Maximum area of plume intersect with habitat/bird foraging areas resulting from maintenance dredging of the BLF approach channel, in combination with the dredging at the FRR1 structure. Plume defined as surface SSC above 100 mg/l.

Receptor	Spring Tides		Neap Tides	
	Area (Ha)	% of Foraging Area	Area (Ha)	% Of Foraging Area
Little Tern Dingle Colony	88	5	29	2
Little Tern Minsmere Colony	17	1	34	2
Little Tern Slaughden Colony	45	3	32	2
Common Tern (Minsmere Colony)	111	<1	57	<1
Common Tern (Orfordness Colony)	56	<1	42	<1

5 Wave Sensitivity

In addition to the effect of tidal flows on sediment dispersion, Cefas have requested that the effect of waves on sediment dispersion is assessed for sensitivity to ensure that the likely area affected by the plume is fully identified. Sensitivity tests on the patterns of dispersion as a result of the inclusion of the wave driven flows have been undertaken. It should be noted that dredging, and particularly ploughing are unlikely to be undertaken during periods of significant wave activity.

Two wave conditions (identified by Cefas) have been assessed; these are the mean wave conditions at Sizewell for waves from the northeast (from 55°N) and from the southeast (from 165°N). For both wave directions, a significant wave height (H_s) of 0.77 m, a peak period (T_p) of 5.4 seconds and a mean absolute zero crossing period (T_z) of 3.8 seconds were simulated in the Delft3D SWAN wave model. These mean conditions are likely to be tolerable working conditions which could occur during the dredge and drilling operations.

For this sensitivity analysis, the Delft3D SWAN wave model was setup and run on the existing FLOW model grid and bathymetry. The boundary and forcing conditions applied to simulate the above two wave conditions in close proximity to the cooling water intakes and outfalls were derived from ABPmer's existing SEASTATES[1] model (ABPmer, 2013b). These wave boundary conditions were applied as temporally constant throughout the run duration. A summary of the wave conditions applied at the offshore boundaries and the resultant climate at Sizewell is provided in Table 63. These results are based on wave only conditions (i.e. with a mean water level and zero tidal flow).

The magnitude of the wave induced flow for each wave condition is shown in Figure 110. The magnitude of spring and neap peak tidal flows are also shown for comparison. Wave induced flows for mean wave conditions are typically less than 0.3 m/s except in the shallow coastal regions and on some of the shallower offshore banks. This tends to indicate that the additional wave forcing is likely to move the finer sand fractions further inshore and allow re-erosion of finder sediments that would potentially be deposited by tidal flows alone. This suggests waves have greater potential to increase SSC arising from the dredge related works, but reduce the amount of sediment that ultimately deposits close inshore. By comparison, peak tidal flows are typically more than 1 m/s on spring tides (and more than 0.7 m/s on neap tides) in the offshore areas. Tidal flows reduce in an onshore direction, being less than 0.3 m/s along some coastal stretches. Based on the sediment types being modelled, critical flows for erosion are between 0.35 m/s for fine sands, up to 0.95 m/s for medium sands.

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[1] ABPmer SEASTATES http://www.seastates.net/

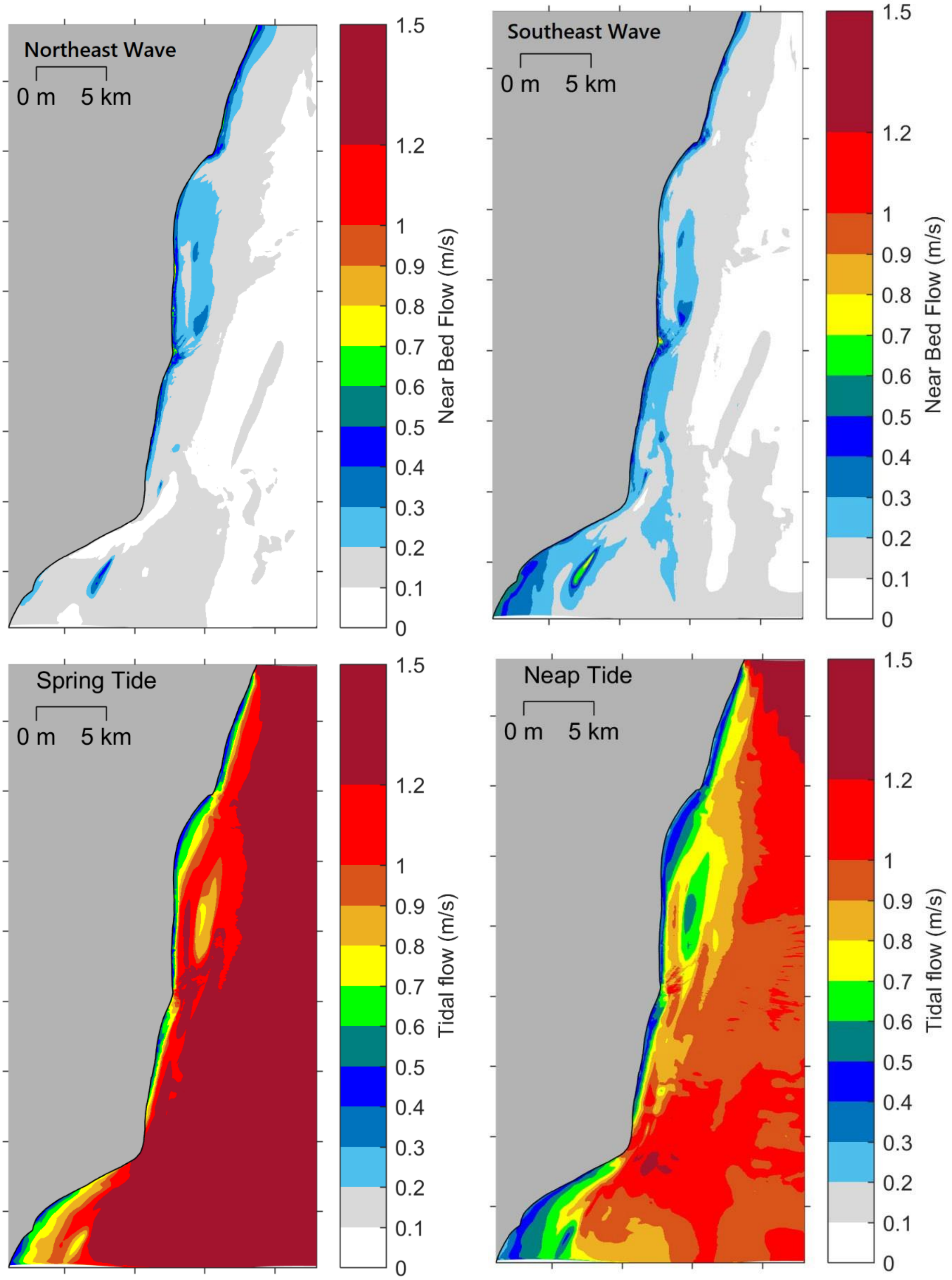


Figure 110. Wave driven flow field and peak tidal flows

Table 63. Wave conditions applied for sensitivity tests

Parameter	Wave from North East		Wave from South East	
	Boundary	Site	Boundary	Site
H_s (m)	0.8	0.77	0.95	0.77
T_p (sec)	7	5.5	7	5.3
Wave direction (° from N)	50	57	175	163
Wind speed (m/s)	3.2	3.2	3.5	3.5
Wind direction (° from N)	50	50	175	175

To assess the sensitivity of the plume dispersion to the effect of wave driven flow, the PART model has been rerun using combined tide and wave driven flows for a selection of the sediment release scenarios. The selected scenarios were;

- Scenario 1 (dredge at CWS intake I4a), wave from the northeast;
- Scenario 1 (dredge at CWS intake I4a), wave from the southeast;
- Scenario 2 (dredge at structure FRR1), wave from the northeast; and
- Scenario 2 (dredge at structure FRR1), wave from the southeast

For each model scenario the sediment release was started at the time of low water on a mean neap tide and the dispersion of the sediment was simulated during a 15 day period, capturing the effects of both spring and neap tidal flows.

The model results for flow-only for Scenario 2 (dredge at FRR1) and Scenario 3 (BLF approach channel dredge) both indicated similar areas of impact from the SSC and from settling on the bed. It is therefore anticipated that the effect of waves on the dispersion of the plume from dredging at the FRR and CDO outfalls would be similar to the effect of waves on the dispersion of the plume from dredging an access channel at the BLF and therefore the effect of waves on the plume dispersion for the BLF dredge are not modelled.

The sensitivity of the plume to wave driven flows during the dredging of the CWS intake structures I4a is shown by a contour plot in Figure 111. The contours show the extent of the location maximum SSC above 50 mg/l for the model run without waves, with a southeast wave and a northeast wave. Location maximum sedimentation above 5 mm is also shown. The plume dispersion is shown to be insensitive to the effects of the wave driven flows associated with the mean wave conditions, with only small differences between plume extents evident for the dredging and disposal works at the offshore locations. The results presented in Section 3.1.1 considering the plume dispersion under the action of tidal flow only are therefore expected to provide a reliable indication of the likely plume extents.

To consider the effect of waves in more detail, time series plots of the SSC and sedimentation throughout the model run are shown at Location D1 (which is at the disposal site) in Figure 112 and at Location J1 (which lies at the sheltered area inshore of Whiting Bank – see Figure 1 for location) in Figure 113. The inclusion of waves does not significantly alter the SSC or sedimentation at either of these locations. The wave driven flows for the mean wave conditions are not sufficient to resuspend material deposited at J1. However, this does not preclude the possibility that larger waves occurring after the completion of the dredge could resuspend material deposited on the bed at this location. The effect of the waves is minor as is expected on the basis that the sediment plume is confined to areas where the wave driven flows are small (typically less than 0.2 m/s, see Figure 110).

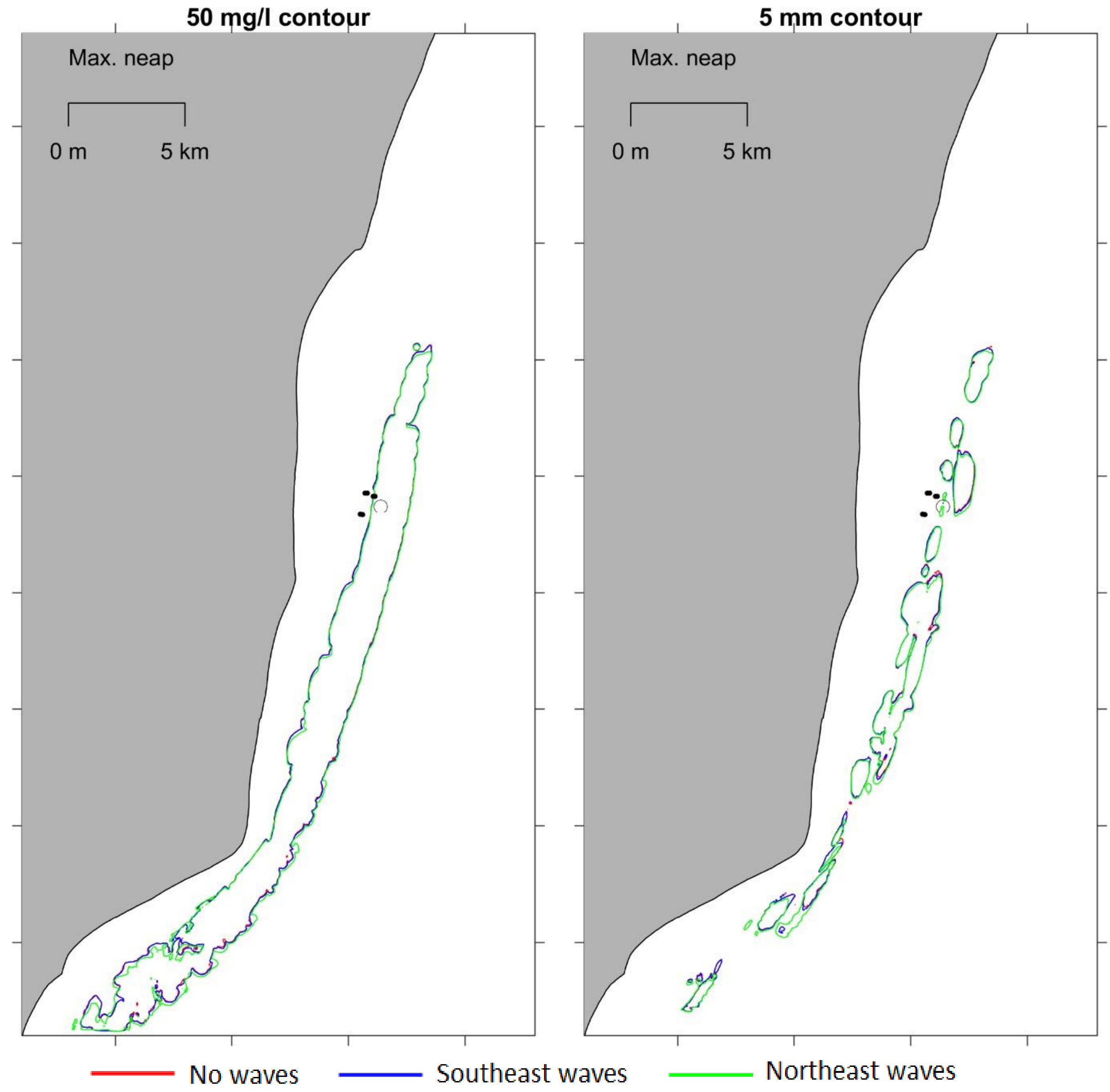
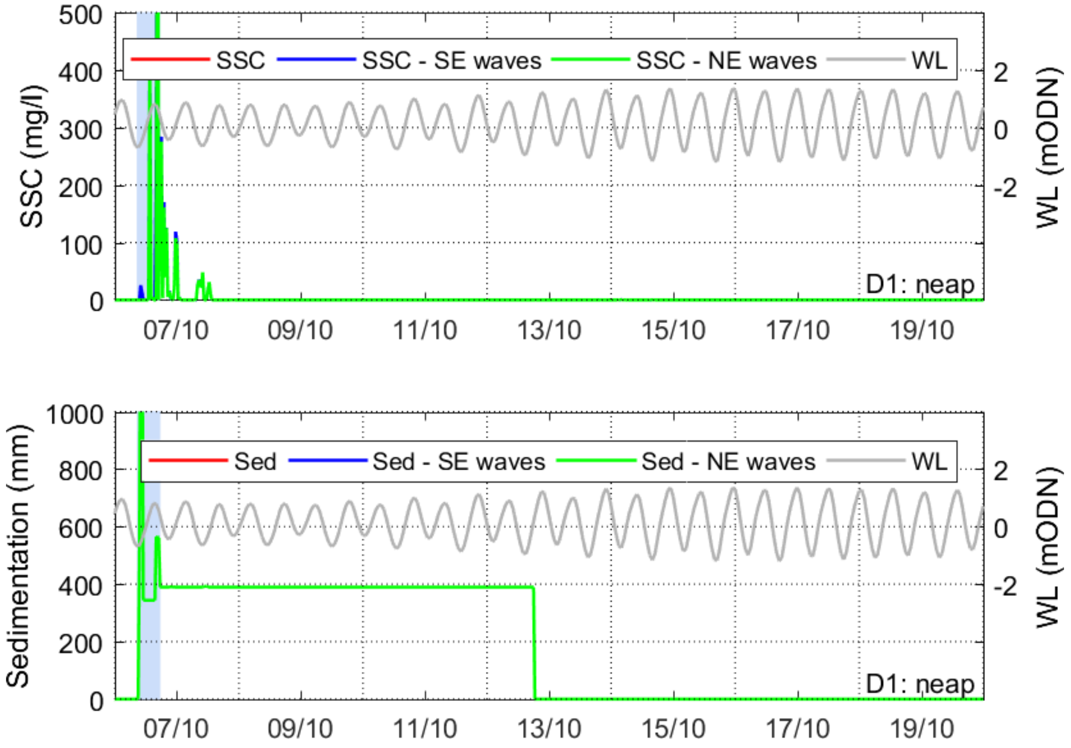
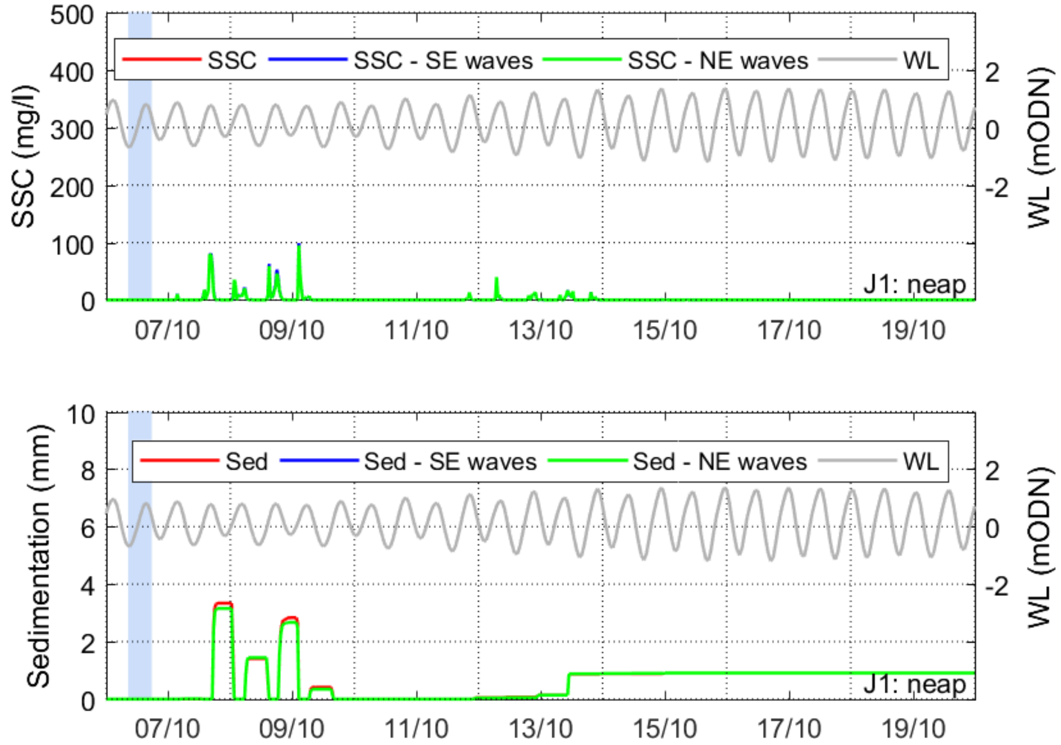


Figure 111. Effect of wave driven flows on the maximum depth average SSC and sedimentation associated with dredging the CWS intake I4a on neap tides



Blue shading shows periods of sediment release.

Figure 112. Time series of SSC and sedimentation at Location D1 during and after dredging the CWS intakes and outfalls with different wave conditions



Blue shading shows periods of sediment release.

Figure 113. Time series of depth average SSC and sedimentation at Location J1 during and after dredging the CWS intake I4a with different wave conditions

The sensitivity of the plume to wave driven flows during the dredging of the FRR1 outfall is shown by a contour plot in Figure 114. The contours show the extent of the location maximum SSC above 50 mg/l for the model run without waves, with a southeast wave and a northeast wave. Location maximum sedimentation above 2 mm is also shown. Note these plots show a smaller spatial extent than the results for Scenario 1 shown in Figure 111 to enable any differences to be identified (since the plume is confined relatively close inshore).

As for the dredging at the CWS intake I4a, the plume dispersion from dredging at structure FRR1 was found to be largely insensitive to the effects of the wave driven flows associated with these mean wave conditions, with only small differences between plume extents evident.

To consider the effect of waves in more detail, time series plots of the SSC and sedimentation throughout the model run are shown at Location E2 (close to the disposal site) in Figure 115 and at Location J2 (located close inshore to the south of Thorpeness - see Figure 36 for location) in Figure 116. The northeast waves act to slightly increase sedimentation on the bed at J2 with the wave driving the plume slightly further inshore. However, this increase is small and sedimentation is transient in nature occurring only around the time of slack water. On this basis, the effect of waves occurring during the dredge operations are not expected to modify the results presented in Section 3 for the plume dispersion under the action of tide only.

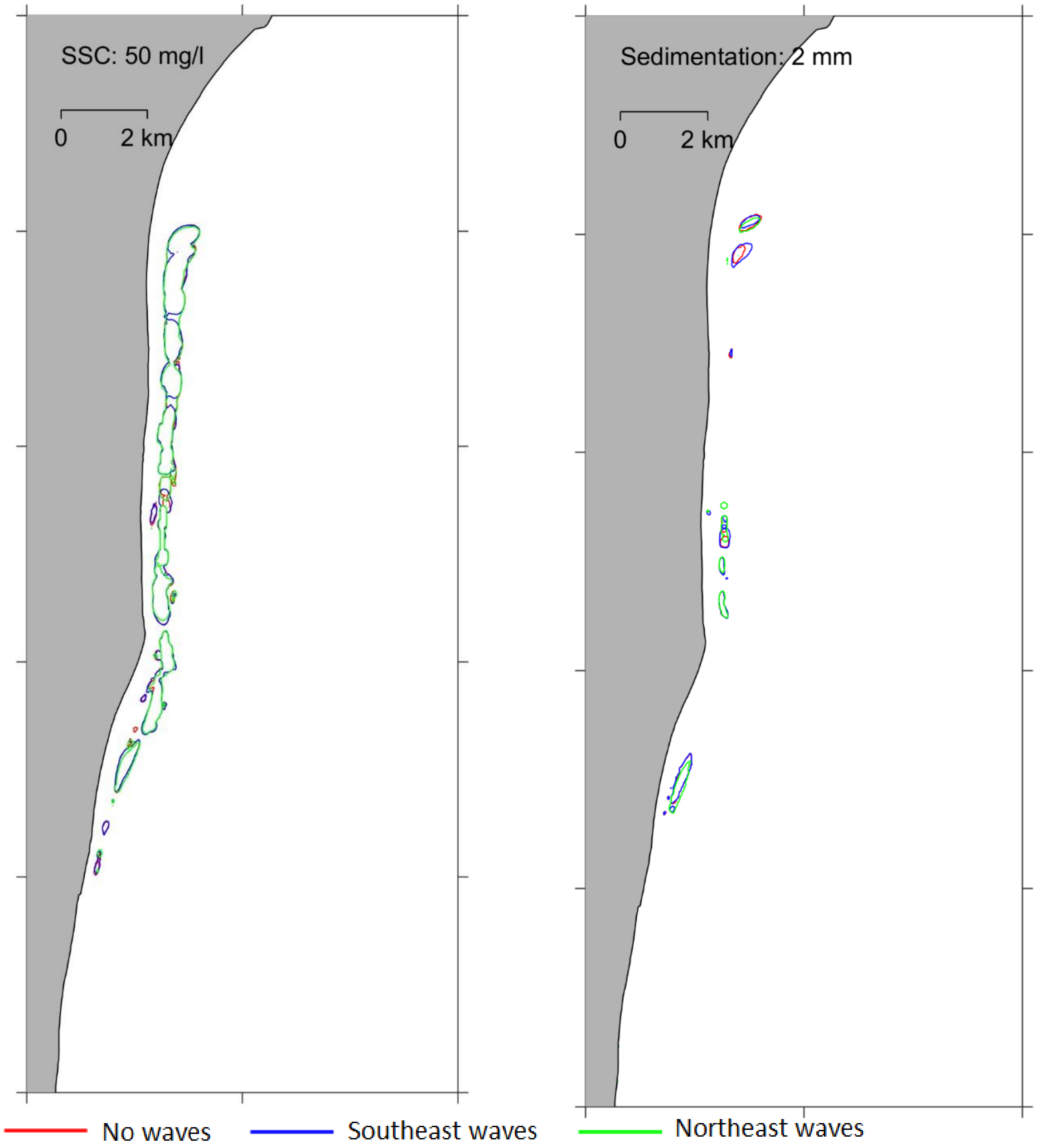
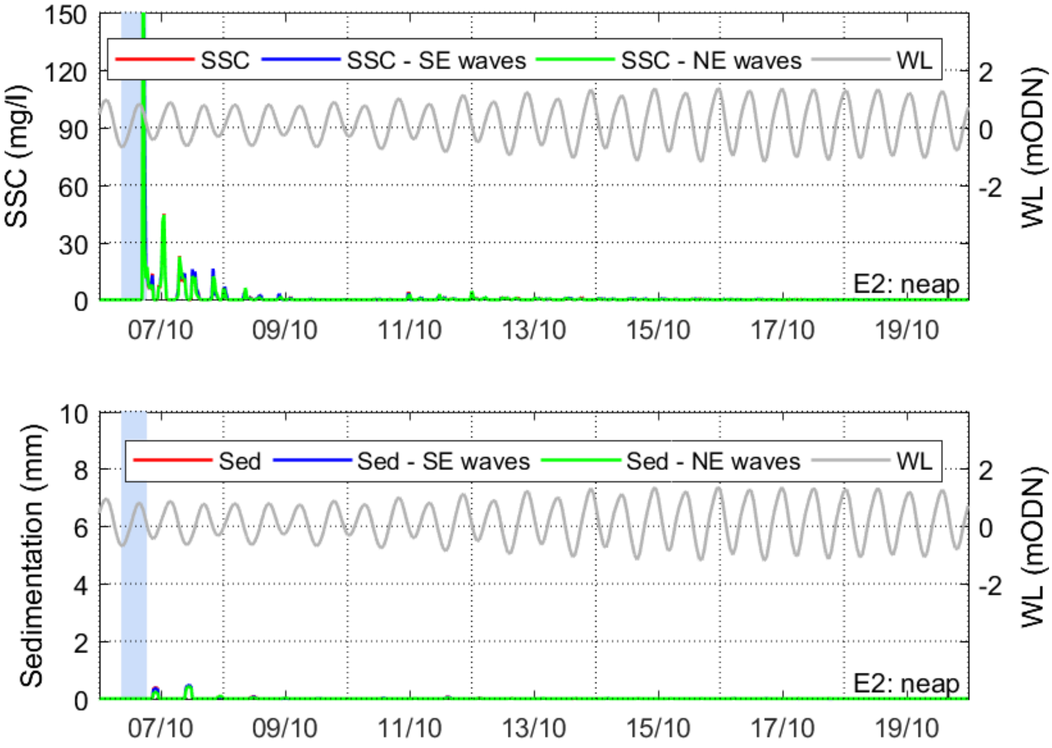
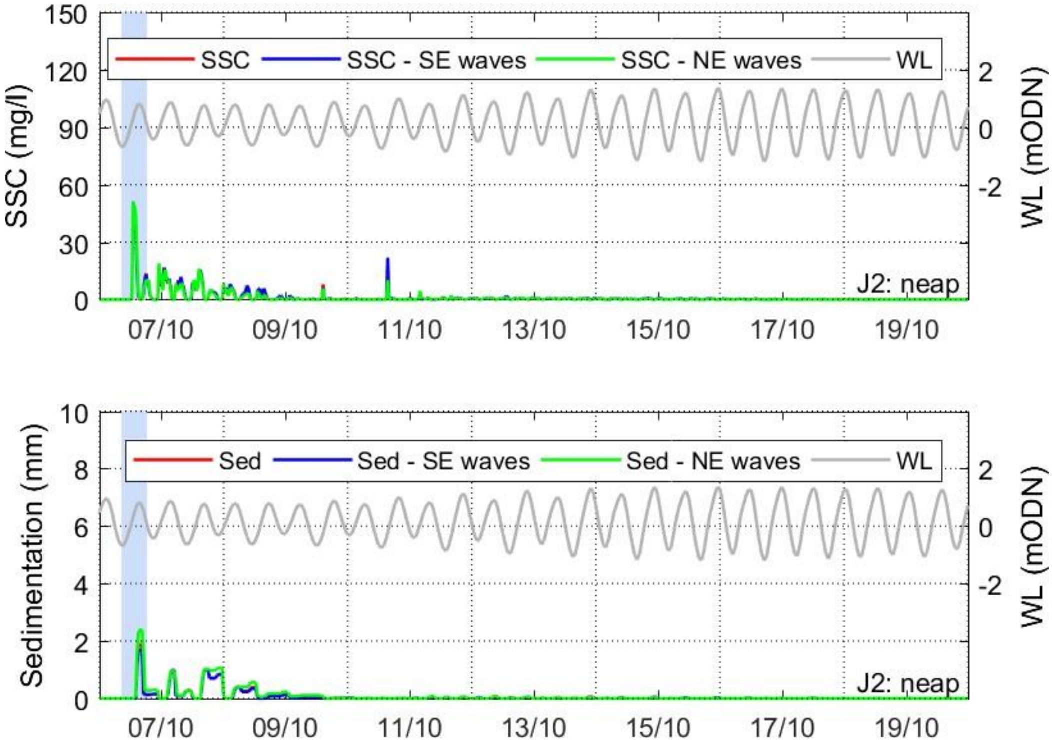


Figure 114. Effect of wave driven flows on the maximum depth average SSC and sedimentation associated with dredging the FRR1 structure



Blue shading shows periods of sediment release.

Figure 115. Time series of SSC and sedimentation at Location E2 during and after dredging the FRR1 structure with different wave conditions



Blue shading shows periods of sediment release.

Figure 116. Time series of depth average SSC and sedimentation at Location J2 during and after dredging the FRR1 structure with different wave conditions

6 Conclusions

This study has provided insight into the likely impact of drilling and dredging activities associated with the latest proposed construction and maintenance methods for the proposed NNB at Sizewell C. A detailed environmental assessment of the results is beyond the scope of this study. This report presents modelling results to facilitate such an assessment in the future. While a detailed assessment is not carried out, it is useful to have some context for the quoted SSC and sedimentation values (which are given above background values). Background variations in SSC vary during the tide from 35 to 246 mg/l in water depths of between 2 and 7 metres (EMU, 2009). As a result, changes within or below this range are unlikely to be discernible from background concentrations. To further aid the assessment of plume impact, areas of plume intersect with bird foraging areas have been quantified. For this purpose, the plume areas are defined as SSC above 100 mg/l, as requested by Cefas.

The modelling shows that dredging of the surficial sediments at the locations of the CWS structures (and associated disposal of material locally) yielded the highest plume SSC and temporary sedimentation on the bed. The plume associated with the disposal of this dredged material is likely to be discernible from background concentrations, although the plume is typically located offshore and is not expected to expose coastal areas to notable increases in SSC.

The areas of instantaneous plume intersect with the bird foraging areas are typically small, accounting for 7% or less of the overall foraging area for all construction related activities modelled.

The potential for in-combination effects arising from activities occurring coincidentally has been assessed by combining results from individual model scenarios. Based on the expected construction sequence, Cefas has indicated that the activities which could occur in-combination would be the maintenance dredge for the BLF approach channel which could occur coincident with dredging of either the CWS structures or the additional outfall structures.

In the following subsections, key results from each model scenario are identified.

6.1 The construction of the CWS intake and outfalls

6.1.1 Dredging of surficial sediments

- During the dredging and associated local disposal of surficial sediments from the location of the CWS intake and outfall structures, location maximum depth average SSC of more than 100 mg/l extend approximately 13 km to the north and 22 km to the south of the disposal location when the dredge is simulated to occur on spring tides.
- Depth average SSCs within the plume, peak at more than 2,000 mg/l above background. These elevated concentrations are highly localised and short lived, with more typical SSC values of 100 mg/l along the plume axis;
- The maximum instantaneous plume area with increases in depth average SSC of more than 100 mg/l is around 370 Ha;
- The observed plume is mainly associated with the disposal of the dredge material; the plumes from the local seabed disturbance at the cutterhead are localised (extending approximately 1 km) and at low concentrations of around 40 mg/l above background (which would be difficult to detect);

- Sedimentation close to the disposal site is high, peaking at more than 1,000 mm (1 m). The sedimentation rapidly reduces with distance from the disposal site with maximum values of 50 mm at distances of more than 1 km;
- The plume is located offshore with no evidence of elevated SSC or sedimentation onshore;
- Following completion of the dredge, the plume quickly dissipates. The elevated concentrations are shown to decay to background levels within *circa* two days on both spring and neap tides after the completion of the disposal operations. When the dredge occurs on neap tides, material deposited on the bed is resuspended once the faster spring tides occur. Elevated SSC are not expected to occur for more than about eight days for the dredge scenarios modelled;
- There is some material remaining on the bed within the model area at the end of the dredge, this accounts for approximately 7 % of the material released and comprises mainly of the medium sand fraction. The area affected by sedimentation is localised being mostly confined to a sheltered area located inshore of Whiting Bank, close to the southern boundary of the model. Furthermore the thickness of deposits is less than 2-3 mm. Wave induced flows occurring during the dredge are not expected to be sufficient to remove this material. However, erosion could occur under the action of larger storm waves, or in the absence of such storm activity there is the potential for material to compact over time, thus reducing the thickness of deposits; and
- The area of the plume (defined as surface SSC above 100 mg/l) intersecting with up to 7 % of the bird foraging areas, being highest for the Little Tern Colony at Slaughden when the dredge occurs on spring tides. For all other colonies and species identified the plume intersects with 1 % or less of the bird foraging areas.

6.1.2 Drilling of bedrock

- During the drilling of the bedrock at the intake and outfall structures, a very diffuse plume with concentrations of around 5 mg/l relative to background develops. Concentrations at this level will not be discernible above background values;
- The results from the model scenario for the drilling operations are consistent with a monitoring study carried out during drilling through chalk at the Lynn and Inner Dowsing wind farm, which despite detailed survey effort did not capture an SSC plume;
- An area of sedimentation is expected to develop close to the drill site. The footprint area of this sedimentation area will depend on the release height for the drill arisings. A release at the surface will result in an area of sedimentation extending up to 60 m from the drill location for the coarsest fractions (>10,000 µm), while the less coarse fractions (around 1,000 µm) will settle within 200 m. The thickness of these deposits immediately adjacent to the drill site are likely to be of the order of 0.05 m to 0.5 m ; and
- Beyond the extent of the initial sedimentation area, the thickness of deposits on the seabed from drilling through the bedrock layer is less than 0.2 mm.

6.2 Dredging for the construction of the FRR and CDO structures

- The area effected by sediment disturbed during the dredging and local disposal of sediment from the FRR and CDO structures extends north-south along the coast, with limited offshore extent. Location maximum depth average SSC of more than 100 mg/l are constrained to within 6.5 km to the north and 5.5 km to the south of the release location.

- During the dredging and associated local disposal of surficial sediments from the additional outfall structures, an elongate plume with a maximum instantaneous area of less than 30 Ha is affected by increases in depth average SSC of more than 100 mg/l;
- The observed plume mainly results from the disposal of the dredged material, the plumes associated with sediment release at the cutterhead are difficult to identify and are unlikely to be detectable in the marine environment;
- The maximum sedimentation is highest close to the disposal site, where values of more than 20 mm are evident. Over the wider area, maximum sedimentation is more typically of the order of a couple of millimetres;
- Following the completion of the dredge the plume quickly disperses. On spring tides material in suspension is at concentrations of less than 100 mg/l above background values within hours of the completion of the dredge and less than 20 mg/l within three days of the completion of the dredge;
- On neap tides, the plume concentrations in suspension also quickly return to values which are close to background, however some resuspension of material is expected once the larger range spring tides occur. The model predicts that the resuspension could result in SSC of more than 100 mg/l in some localised areas; however these peaks in SSC are likely to be an over-prediction, are expected to be short lived (of the order of hours) and are unlikely to be discernible from the background SSC;
- There is some material remaining on the bed within the model area at the end of the dredge, this accounts for approximately 15 % of the material released. These deposits are confined to shallow coastal areas and may interact with beach sediment at certain locations;
- The plume area (defined as surface SSC of more than 100 mg/l) intersects with small parts of the bird foraging areas. The area of increased surface SSC above 100 mg/l accounts for 4 % of the total foraging area for Little Terns in the Dingle colony when the dredge occurs on spring tides and less than this for all other species and colonies; and
- The plume extent is expected to be largely insensitive to the effects of waves that could occur during the dredging operations.

6.3 Dredging BLF access channel

- The area affected by sediment disturbed during the dredging of sediment from the BLF access channel is confined close inshore and extends north-south along the coast. Depth average location maximum SSC of more than 100 mg/l above background extend approximately 5 km north and south of the dredge area for the capital dredge.
- The plume (defined with surface SSC above 100 mg/l) is more extensive when the capital dredge occurs on spring tides;
- The plume associated with the capital dredging of the BLF approach channel covers a maximum instantaneous area of 83 hectares with increases in depth SSC of more than 100 mg/l. This area is reduced to around 20 hectares for the plume associated with the maintenance dredge of the BLF approach channel;
- On both spring and neap tides the sediment only settles on the bed over a relatively small area close inshore. These limited deposits may be discernible on the beach at certain locations;
- Following the completion of the dredge the plume quickly disperses. On spring tides material in suspension is at concentrations of less than 20 mg/l above background within three days;

- On neap tides, the plume concentrations in suspension also quickly return to values which are close to background, however some resuspension of material is expected once the larger range spring tides occur. The model predicts that the resuspension could result in SSC of more than 100 mg/l in some localised areas; however these peaks in SSC are likely to be an over-prediction, are expected to be short lived (of the order of hours) and are unlikely to be discernible from the background SSC;
- Due to the slower tidal flows in the inshore area, the percentage of disturbed material settling on the seabed at the end of the model run is higher than for other activities, with approximately 25 to 30% remaining on the bed and potentially interacting with the beach sediments;
- The plume area (defined as surface SSC of more than 100 mg/l) intersects with small parts of the bird foraging areas. The area of increase accounts for a relatively low proportion of the overall foraging areas (typically 3% or less except for the Little Tern Minsmere colony foraging area which has increases of more than 100 mg/l in surface SSC across 6% of its area); and
- Although not assessed directly, the dispersion of the plume is not expected to be affected significantly by the effect of wave driven flows which could occur during the dredge.

6.4 In-combination assessment

- The in-combination assessment indicates that should the dredging for the CWS structure occur simultaneously with the maintenance dredging of the BLF approach channel, the potential for any additional in-combination effects are limited with no interaction of the two plumes expected to occur and with any potential effects within bird foraging areas to be minimal.
- Should the dredging for the additional outfall structures occur simultaneously with the maintenance dredging of the BLF approach channel, there is the potential for some in-combination effects, with the plume areas intersecting. However, the resultant in- combination plume area above 100 mg/l in surface SSC within the bird foraging areas remains small as a percentage of the total foraging area.

7 References

ABPmer (2015a) Sizewell C Thermal Modelling. ABP Marine Environmental Research Ltd, Report No. R.2390.

ABPmer (2015b) Sediment Dispersion Modelling for Sizewell C. ABP Marine Environmental Research Ltd, Report No. R.2480.

ABPmer (2014a) Sizewell Thermal Plume Modelling: Stage 1 - Model Calibration and Validation. ABP Marine Environmental Research Ltd, Report No. R.1659.

ABPmer, (2014b). Dredge Disturbance Modelling Portsmouth. ABP Marine Environmental Research Ltd, Technical Note, Report No. R.2330TN.

ABPmer, (2014c). Modelling of Dredger Overflow, Southampton Water. ABP Marine Environmental Research Ltd, Report No. R.2257TN.

ABPmer, (2013a). Navitus Bay Wind Park Physical Processes Assessment. ABP Marine Environmental Research Ltd, Report No. R.2075.

ABPmer (2013b). SEASTATES Wave Hindcast Model: Calibration and Validation Report. ABP Marine Environmental Research Ltd, Report No. R.2145. August 2013.

ABPmer, (2012). Moray Offshore Windfarm – Hydrodynamics, Sedimentary and Coastal Processes Baseline Assessment. ABP Marine Environmental Research Ltd, Report No. R.1869.

ABPmer (2011). Sizewell Thermal Plume Modelling: Stage 2 – Modelling Results. ABP Marine Environmental Research Ltd, Report No. R.1770.

ABPmer SEASTATES http://www.seastates.net/

BEEMS Technical Report TR098. Sizewell MiniLander Calibrated Data Report. Cefas, Lowestoft.

BEEMS Technical Report TR189. Sizewell Marine Water Quality Monitoring. Final Summary Report. Cefas, Lowestoft.

BGS, (1993). British Geological Survey – Industrial Minerals Laboratory Manual: Limestone. British Geological Survey, Report No: WG92029. https://www.bgs.ac.uk/research/international/dfid-kar/WG92029_col.pdf [Accessed 12 May 2015].

Blokland, T (1988). Environment conscious dredging and disposal, turbidity measurements Delfzijl (in Dutch). Co.110.18-R8631, Dredging research association.

CREL, (2007). Environmental Report for Monitoring of the Disposal of Drill Arisings [Lynn and Inner Dowsing]. Centrica Renewable Energy Ltd (Document No. LD-E-CE-013-0117-30010-004-R.

CIRIA, (2000). Scoping the assessment of sediment plumes from dredging. Construction Industry Research and Information Association, C547, London 2000 (188pp).

EDF, (2015). Sizewell Shallow Geotechnical Survey. EDF / Fugro Alluvial Offshore Ltd . Project No. 150500.

EMU (2009). British Energy Estuarine and Marine Studies, Oceanographic surveys; Sizewell, Part 2. October, 2009. EMU Ltd, Report No 09/J/1/01/1260/0910.

Environment Agency, (2011) Coastal Trends Report, Suffolk (Lowestoft to Languard Point, Felixstowe) Environment Agency, RP022/S/2011.

Kenneth Pye Associates, (2011). Sea bed sediment characteristics, bedforms and sediment transport pathways in the Sizewell area. Kenneth Pye Associates Ltd, External Investigation Report No. EX1212.

Kirby, R and Land, J. (1991). The Impacts of Dredging - A Comparison of Natural and Man Made Disturbances to Cohesive Sedimentary Regimes. In: Proceedings of CEDA Dredging Days. Amsterdam, November 1991. (Session B, Paper B3).

Osiris, (2010). Galloper Wind Farm, Areas A, B, C, D, R1 & R2 Geophysical & Benthic Ecology Survey. Osiris Projects Ltd. Report No. C9028. Technical Appendix 1 (Part 2) p.222.

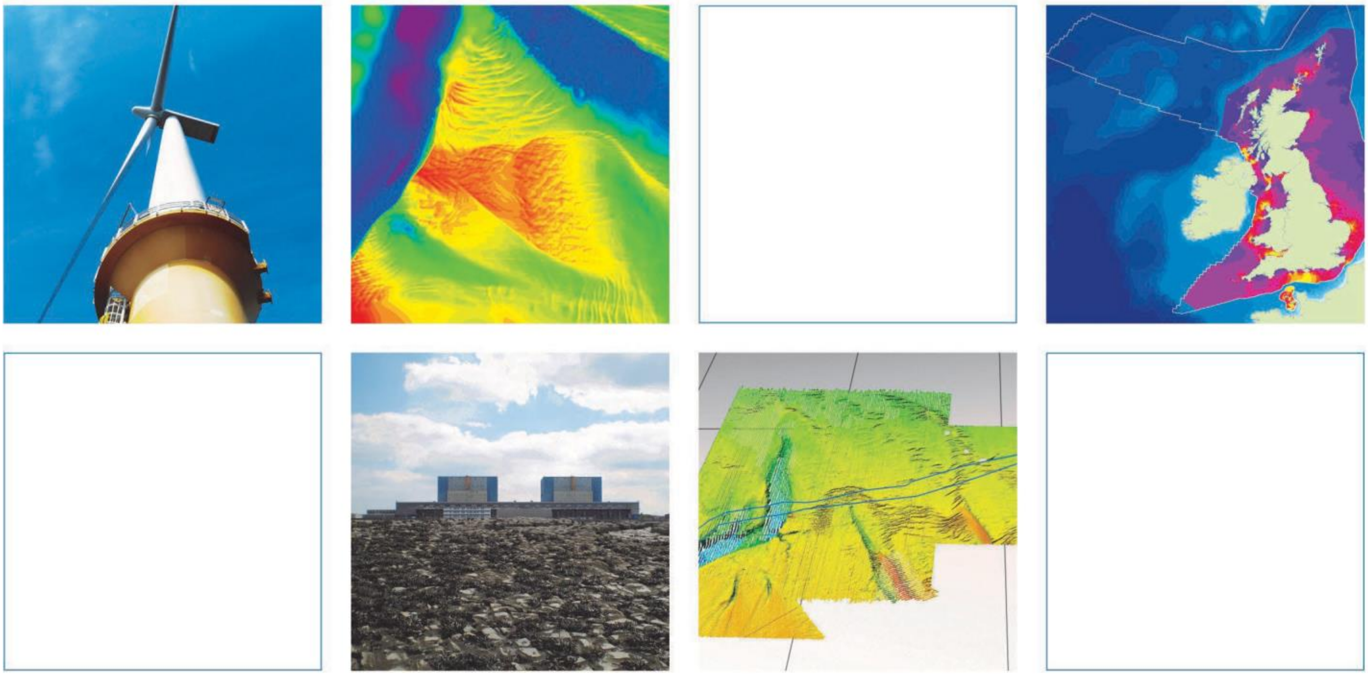
8 Abbreviations/Acronyms

3D	Three Dimension(al)
BEEMS	British Energy Estuarine and Marine Studies
BGS	British Geological Survey
BLF	Beach Landing Facility
CDO	Combined Drainage Outfall
CEDA	Central Dredging Association
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CIRIA	Construction Industry Research and Information Association
CREL	Centrica Renewable Energy Ltd
CWS	Cooling Water System
EDF	EDF Energy
EMU	EMU Ltd
FLOW	Simulation program for tidal and wind driven flow (Delft3D)
FRR	Fish Return and Recovery
Hs	Wave Height
HW	High Water
LW	Low Water
Max	Maximum
Min	Minimum
NNB	Nuclear New Build
ODN	Ordnance Datum Newlyn
PART	Particle Tracking Model
PE	Peak Ebb
PF	Peak Flood
SSC	Suspended Sediment Concentration
SWAN	Wave modelling program (Delft3D)
Tp	Peak Period
Tz	Zero Crossing Period
UK	United Kingdom
UKD	UK Dredging
WL	Water Level

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

Appendix



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