Annex 8.4

Able Marine Energy Park Dredging Plume Dispersion Arisings from Capital Works

(HR Wallingford)

EX 6627

Able Marine Energy Park

Dredging plume dispersion arising from capital works

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Summary

Able Marine Energy Park

Dredging plume dispersion arising from capital works

Report EX6627
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THE COMPUTER MODELLING DESCRIBED IN THIS REPORT WAS UNDERTAKEN FOR A QUAY THAT WAS SET 50M FURTHER INTO THE ESTUARY THAN THE FINAL LAYOUT, (LAYOUT 4 AS SHOWN AT THE TOP OF FIGURE 1). WHERE RELEVANT THE MODELLING RESULTS HAVE SUBSEQUENTLY BEEN ADJUSTED IN THIS REPORT TO REFLECT THE FINAL DREDGE VOLUMES SHOWN IN TABLE 1.

Able UK Ltd proposes to construct a Marine Energy Park (AMEP) near Immingham on the southern bank of the Humber Estuary. The AMEP will be a facility for the construction of offshore wind turbines and other activities associated with sources of renewable marine energy.

The AMEP will consist of a large reclamation approximately 1,300 m in length along the shore and extending 350 - 450 m out into the estuary. Immediately to the northwest of the reclamation there are two existing intake/outfall lines for two gas-fired power stations. One plant is operated by Centrica and the other by E.ON. Further northwest is the Humber Sea Terminal. To the southeast of the proposed reclamation are existing berths at the South Killingholme Oil Jetty and Immingham Gas Terminal, and within a distance of approximately 600 m from the southeastern end of the proposed development an existing reclamation some 900 m in length and extending 300 m out into the estuary (the Humber International Terminal). Further towards the southeast lie the Immingham Bulk Terminal, Immingham Outer Harbour and approaches to the Immingham docks.

This report describes sediment plume dispersion studies undertaken to evaluate the effects of capital dredging to inform the construction impacts section of the Environmental Statement for the proposal.

The capital dredging is characterised as use of a trailer suction hopper dredger (TSHD) to dredge alluvium/clay and sand/gravel and use of a backhoe to dredge glacial till. The TSHD dredging was characterised as not including overflow for the alluvium clay dredge, but including overflow for the sand/gravel dredge, as is standard practice.

Overall it is not considered that the proposed dredging will cause any significant impact to the sediment transport in the Humber Estuary although temporary and significant rises in background concentrations are likely to occur during the dredging of sand/gravel over the course of a week (or less).

The proposed dredging of alluvium by TSHD (without overflow) will cause increases in suspended sediment concentrations at the southern (E-on) intake of up to 180mg/l (near bed) and at the northern (Centrica) intake of up to 60mg/l (near bed) for a period of around a three weeks. Owing to the large range of natural suspended sediment concentrations experienced at these locations, and the limited period of impact, these increases are not considered to be unduly onerous for the operation of the intakes.

Summary continued

Should overflowing be utilised during the dredging of alluvium the predicted increases in suspended sediment concentration above background and the deposition of fine sediment arising from this dredging will be considerably larger. Overflowing for ten minutes on every load would result in increases in suspended sediment concentration of up to 800mg/l (near bed) and at the northern intake of up to 1600mg/l (near bed) for a period of up to three weeks. Whilst this may represent a significant increase in the background levels of suspended sediment concentration it is noted that this increase will occur for a limited period of time.

The proposed dredging of sand/gravel by TSHD will cause increases in suspended sediment concentrations at the E-on intake of up to 200mg/l (near bed) and at the Centrica intake of up to 400mg/l (near bed) for a period of around a week. Whilst this may represent a significant increase in the background levels of suspended sediment concentration it is noted that this increase will occur for a limited period of time.

Predicted infill into other nearby berths arising from the capital dredging works is relatively insignificant when compared to annual maintenance dredge requirements and the natural variation in those quantities. This remains true even if overflowing is utilised during the dredging of alluvium.

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1. Introduction

1.1 BACKGROUND

Able UK Ltd proposes to construct a Marine Energy Park (AMEP) near Immingham on the southern bank of the Humber Estuary. The AMEP will be a facility for the construction of offshore wind turbines and other activities associated with sources of renewable energy.

The AMEP will consist of a large reclamation approximately 1,300 m in length along the shore and extending 300 - 400 m out into the estuary. Immediately to the northwest of the reclamation there are two existing intake/outfall lines for two gas-fired power stations. One plant is operated by Centrica and the other by E.ON. Further northwest is the Humber Sea Terminal. To the southeast of the proposed reclamation are existing berths at the South Killingholme Oil Jetty and Immingham Gas Terminal, and within a distance of approximately 600 m from the south-eastern end of the proposed development an existing reclamation some 900 m in length and extending 300 m out into the estuary (the Humber International Terminal). Further towards the southeast lie the Immingham Bulk Terminal, Immingham Outer Harbour and approaches to the Immingham docks.

Modelling assessments of the effects of the proposed scheme on hydrodynamics, coarse sediments and geomorphology, and fine sediments, have already been completed (JBA, 2011a, 2011b, HR Wallingford, 2011).

Figure 1 (top) shows the proposed AMEP development (Layout 4) and existing intake/outfall lines, highlighting the reclamation, quay-line, dredged pockets and turning areas.

The computer modelling described in this report was undertaken for a quay that was set 50 metres further into the estuary (see Figure 1, bottom) than the final layout (Figure 1, top), and included a length of suspended deck. This does not materially affect the results or conclusions of the report as presented. However, where relevant the modelling results have been adjusted in this report to reflect the final estimate of dredging volumes shown in Table 1.

1.2 OBJECTIVE

The objective of this work was to assess the sediment plume dispersion for a number of capital dredging scenarios, and thereby inform the environmental impact assessment for the project.

1.3 REPORT STRUCTURE

The remainder of this report is structured as follows: Section 2 describes the plume dispersion model; Section 3 describes the flow model inputs; Section 4 describes the estimation of dredging source terms; Section 5 describes the modelling scenarios; Sections 6, 7, and 8 present the model results; Section 9 provides a discussion of the background suspended sediment concentrations, and Section 10 provides the conclusions of the report.

2. Plume dispersion model

2.1 SEDPLUME-RW

The SEDTRAIL-RW model is a 3D lagrangian plume dispersion model which reproduces the dispersion of sediment plumes in space and time. The 3D advection of sediment particles is calculated using input from 3D flow model results (see Chapter 3). Dispersal in the direction of flow in the model is provided by the shear action of differential speeds through the water column while turbulent dispersion is modelled using a random walk technique. The deposition and resuspension of particles are modelled by establishing critical shear stresses for erosion and deposition. Erosion of deposited material occurs when the bed shear stress exceeds the critical shear stress for erosion while deposition of suspended material occurs when the bed shear stress falls below the critical shear stress for deposition.

2.2 SEDTRAIL-RW MODEL

The SEDTRAIL-RW model (Spearman 2003, 2007) is a version of SEDPLUME-RW which includes processes specific to trailer suction hopper dredgers (TSHD).

The process of loading the TSHD entails pumping a mixture of solids and water from the seabed into the hopper of the dredger (which is usually partially full of water at the start of loading). The solids content in the pumped mixture is relatively low (approximately 25% by volume) and so the vessel fills quickly with water while loading. In order to allow the vessel to load a full cargo of sand and/or gravel without becoming overloaded, the excess water in the hopper is returned overboard through overflow spillways (however in the case of dredging of mud overflowing does not increase the cargo load and overflowing is generally not utilised, see Section 4.1). The returned water also contains a proportion of suspended solids (typically fine sands and silt). Once returned to the sea, this sediment will be dispersed horizontally and vertically in the form of a plume by tidal flows and wave action and be advected by the tidal currents. The processes of advection and dispersion will continue until the sediment concentrations are reduced to close to background levels. The increase in suspended sediment concentrations and the enhanced deposition (if any) resulting from these fine sediment plumes could potentially have an impact on local ecology.

The TSHD dredging operation causes the following sources of sediment release (see Figure 2): release into the water column from the draghead (1), a surface plume (2), re-entrainment of sediment from the density current caused by the dynamic plume (3) and from erosion by the propeller jet (4). All of these sources contribute to the passive plume which is observed at some distance from the dredger.

The SEDTRAIL-3D model is composed on three parts (See Figure 3):

- An interface which reads the output from a model of the processes inside the hopper developed by HR Wallingford but run off-line. This predicts the concentration and particle size distribution of sediment in the overflow discharge.
- A *dynamic plume* model which uses the information from the trailer hopper process model to predict the mixing that occurs in the dynamic plume descent and collapse onto the bed and predicts the spatial distribution, particle size distribution and concentration of the benthic plume resulting from the dynamic plume.

- A *passive plume* model (SEDPLUME-RW) which takes the contributions from the bed plume and surface plume, (and any contribution from the draghead or propeller) and simulates the far-field dispersion of plumes.

3. Flow model input

The plume dispersion modelling used the results of the TELEMAC-3D modelling described in the sediment modelling report (HR Wallingford, 2011). This 3D flow model was set up using bathymetry information supplied by JBA (JBA, 2011). The bathymetry data contains both estuary-wide bathymetry supported by a project-specific boat survey and LiDAR data for local intertidal areas.

The model coverage and existing bathymetry is shown in Figure 4. The model domain extends from the Humber Bridge (at the landward limit of the model) to Spurn Head (at the seaward limit). The mesh resolution ranges from 10 m close to the proposed development (5 m in the proposed dock), increasing to 50 m mid-channel, 100-150 m in most other locations in the model domain, and approximately 500-600 m at the boundary near Spurn Head.

Boundary conditions were supplied by JBA (JBA, 2011). These were applied as prescribed water levels at both the upriver and sea boundaries and the model was run to simulate a full spring-neap cycle following a 2 day model “spin-up” time.

The model was validated through comparison against both measured ADCP data (at a location in the proximity of the E.ON intake) and against modelled flow speeds and water levels simulated using the JBA model (JBA, 2011).

4. Estimation of dredging source terms

4.1 OVERVIEW

Able (2011) presents the quantities of the different material types that require dredging for the proposed capital works. The report breaks down the results of the geotechnical surveys into three main material types. On the surface of the seabed, including the footprint of the reclamation, is alluvium and soft clays. Underneath this muddy layer lies glacial till with pockets of sands and gravels present at the interface. The total volumes of each of material type that will be dredged in the capital works are reproduced from the Able report in Table 1. It is important to note that these volumes represent the volumes that will be dredged for the final scheme arrangement.

Table 1 Estimated Quantities of Dredge Material and Proposed Dredging Methods (Able, 2011)

Material Type	Volume (m^3)	Dredge Method
Alluvium and Soft Clays	719,200	TSHD
Sands and Gravels	226,350	TSHD
Glacial Till	945,450	Backhoe

The three types of sediment would be dredged in different ways. The alluvium/clay and sand/gravel layers can both be dredged using a trailer hopper suction dredger (TSHD) but the glacial till is too firm for a TSHD and would instead be dredged using a backhoe. The sand/gravel will be dredged by TSHD and, in order to optimise the amount of sediment loaded into the hopper on each loading cycle, the hopper will be allowed to overflow into the surrounding waters, this overflow discharge contains fine sediment which will then disperse within the Humber Estuary. This contrasts with the alluvium/clay which is principally composed of fine cohesive sediment particles which will settle slowly within the TSHD hopper. As a result overflowing does not increase the amount of sediment loaded in the hopper and in these circumstances significant overflowing is generally not implemented. However, even in the case where overflow does not occur there is a small release of fine sediment caused by propeller wash and by draghead disturbance. This propeller/draghead release is dwarfed by the overflow release from sand/gravel dredging but is larger than the release rate from the backhoe and so is also considered in this section.

These considerations suggest that the there are three main dredging scenarios to model:

- The backhoe operations which represent the majority of the dredging and which correspond to a low release rate.
- The dredging of sand/gravel by TSHD which represent the smallest proportion of the dredging by volume but the largest rate of release of sediment into the surrounding waters because this operation involves overflow.
- The dredging of the alluvium/clay by TSHD, with release of fine sediment resulting from propeller wash and draghead disturbance.

In addition, for completeness, consideration is given to the effects of limited overflowing during the dredging of alluvium (see Section 7.4).

4.2 DREDGING USING BACKHOE

Dredging using backhoe does cause release of fine sediment into the water column but the key feature of dredging using a backhoe is that the productivity (the rate at which sediment is dredged from the bed) is relatively small compared to other types of plant such as TSHD. As the productivity is small, the rate of release of fine material is also small.

The calculation of source terms for the dredging of glacial till by backhoe used the following assumptions:

- The backhoe will be similar to Boskalis' Nordic Giant dredger (*pers.comm.* Will Shields of Boskalis-Westminster) with a bucket size of 18 m^3.
- An open bucket will be used.
- Working will occur for 150 hours per week at 85 per cent efficiency (i.e. down-time will be 15 per cent of working hours).
- The bulk density of the glacial tills is about 2 200 kg/m^3.
- The rate of release from backhoe dredging will be represented as a continuous constant rate.

Using models developed by HR Wallingford for assessing productivity in dredging operations the weekly productivity of the backhoe dredging was estimated to be 82,000 m^3/wk and the rate of release of fine material was estimated to be 2.9 kg/s.
The simulation of a fortnight represents dredging of around 17% of the total volume of glacial till that will be dredged using the backhoe.

4.3 SOURCE TERM FOR TSHD DREDGING OF SAND AND GRAVEL

The calculation of source terms for the dredging of sand/gravel used the following assumption:

- The TSHD will be similar to Barent Zanen dredger (*pers.comm.* Will Shields of Boskalis-Westminster).
- Working will occur for 160 hours per week at 85% efficiency (i.e. down-time will be 15% of working hours).
- Disposal will be at the HU080 site, about 15km from the dredging site.
- The loading time will be 130 mins (not including time taken in turning) of which there will be 100 mins of overflowing (*pers.comm.* Will Shields of Boskalis-Westminster).
- The particle size distribution of the in-situ material is taken as the values in Table 2 (based on data from Able, 2011).

Table 2 In-situ particle size distribution for sand/gravel dredging

Particle size (microns)	Proportion in particle size range by mass (%)	
	fine sand	gravels
Less than 60	5	10
60-80	20	2.5
80-100	15	5
100-150	30	5
150-200	20	2.5
200-300	5	10
300-400	2.5	5
400-600	2	5
600-1000	0.5	2.5
1000-2000	0	7.5
2000-4000	0	15
4000+	0	30

Using models developed by HR Wallingford for assessing productivity in dredging operations the weekly productivity, the overflow release rate and overflow particle size distribution for the TSHD dredging were estimated (see Tables 3 and 4). In the case of dredging sand the rate at which solids are discharged in the overflow is 405 kg/s of which 13.5% is fine material (silt or clay particles). In the case of dredging the gravel the rate at which solids are discharged in the overflow is 832 kg/s of which 58% is fine material.

Table 3 Dredging productivity for sand/gravel dredging

Material type	Productivity (m^3/wk)	Total overflow rate (kg/s)	Release rate of fine sediment (kg/s)
Sand	280,000 – 320,000	405	55
Gravel	225,000 – 250,000	832	483

Table 4 Overflow particle size distribution

Particle size (microns)	Proportion in particle size range by mass (%)	
	Fine sand	gravels
Less than 60	13.5	58
60-80	36.5	10
80-100	20.5	16
100-150	23	10.5
150-200	6	2.5
200-300	0.5	3

Table 4 indicates that the release of fine material from dredging of gravel is significantly larger than that corresponding to the dredging of sand and hence the worst case release rate (for gravel) is used in the modelling as worst case. This is because the in situ gravel material contains a higher proportion of fine material than the sand material but also because the settling of larger gravel particles (more so than sand particles) causes a vertical return current which enhances the upward movement of fine sediment particles in the hopper, reducing the amount of fine material that can settle.

The modelled period of a fortnight is significantly longer than the time required to dredge the sand/gravel within the site (around a week). This is intentionally undertaken so that the effect of dredging on neap tides and spring tides can be taken into consideration.

4.4 SOURCE TERM FOR TSHD DREDGING OF ALLUVIUM/CLAY

As discussed above, it is assumed for the plume dispersion modelling that the alluvium/clay will be dredged by TSHD without overflow. Some of the alluvium (about 250,000 m^3; Able, 2011) will be dredged from the reclamation area by a much smaller TSHD and the remainder, approximately 470,000 m^3, will be dredged from the turning area, approach channel and berths using a TSHD similar to the Barent Zanen (*pers.comm.* Will Shields of Boskalis-Westminster).

The dredging of the alluvium will not include overflow but release of fine sediment will occur through disturbance caused by dragheads and/or propeller wash. For the purposes of this study a value of 20 kg/s was taken to represent these effects.

The simulation of a fortnight roughly represents dredging of 65% of the total volume of alluvium that will be dredged with the Barent Zanen.

5. Scenarios used in dispersion modelling

5.1 BACKHOE DREDGING

As worst case the backhoe dredging was represented as occurring at the northern end of the berths (see Figure 5). Dredging was represented for a spring-neap cycle (14 days) with a constant release rate of 2.9 kg/s (see Section 4.2).

5.2 TSHD DREDGING

The modelled scenario for TSHD dredging involved dredging on both ebb and flood tide in the streamline of the intakes. The dredger was represented as moving at 1 m/s along a 1 200 m dredge path shown in Figure 5. Loading was assumed to occur for 130 minutes (not including turning) and the time to sail to the disposal site, dispose of a load, and return was assumed to be 118 minutes. The release rate caused by dragheads and/or propeller wash for the dredging of alluvium was represented as 20 kg/s. The release rate caused by overflowing for the dredging of sand/gravel was represented as 483 kg/s. The bathymetry used in the simulations was the existing bathymetry as the alluvium/clay and sand/gravel is likely to be encountered at the beginning of the operations. (Note however that the berth area will require some dredging either by a small TSHD or will otherwise be limited to High Water, as a large dredger will not initially be able to dredge throughout the tide in this area).

5.3 PARAMETERS USED IN PLUME DISPERSION MODEL

The following sediment parameters were used in the plume dispersion model:

Critical shear stress for deposition for silt, τ_d	= 0.1N/m^2
Critical shear stress for erosion for silt, τ_e	= 0.2 N/m^2
Erosion constant, M_e	= 0.002 kg/Nm^2
Settling velocity for silt, W_s	= 1 mm/s

6. *Results for backhoe dredging*

6.1 GENERAL

The predicted increases in depth averaged suspended sediment concentration above background caused by the backhoe dredging are presented in Figure 6. Figure 6 presents the peak increases which occur throughout the simulation and is a composite figure representing the plumes at different times at different locations. Thus the figure does not show the plume at a particular moment in time.

Figure 6 indicates that peak increases in (depth-average) concentration will be less than 50mg/l but that increases of more than 10mg/l will occur up to 8km from the point of dredging. Some of the elevations in concentration arise from resuspension of temporarily settled material on the flood tide (e.g. the plume to the south of the site).

Figure 7 shows the predicted accretion of fine sediment resulting from the backhoe dredging at the end of the simulated spring neap cycle. The accretion is calculated assuming a dry density for settled fine sediment of 500 kg/m^3. It can be seen that accretion of only a few millimetres is predicted immediately upstream and downstream of the reclamation and in the berths area.

6.2 IMPACTS AT INTAKE/OUTFALL LOCATIONS

Figure 8 shows the predicted increases in suspended sediment concentration at the intake locations to the north of the proposed works. The predicted increases in suspended sediment concentration are less than 30 mg/l and typically of the order of 10mg/l. Near bed concentrations at the intakes were predicted to be similar to those shown in Figure 8.

6.3 ACCRETION AT NEARBY BERTHS

The accretion at nearby berths over the spring-neap cycle resulting from the backhoe dredging is presented in Table 5, together with the projected infill over the whole of the backhoe dredging operations. It can be seen that the infill at the nearby berths resulting from backhoe operation is relatively insignificant when compared to annual maintenance dredge requirements and the natural variation in those quantities.

Table 5 Predicted infill arising from backhoe operations

Local berth	Predicted infill (m^3)	
	(spr-np cycle)	Total
Humber Sea Terminal	0	0
South Killingholme Oil Jetty	140	760
Immingham Gas Terminal	-	-
Humber International Terminal	18	105
Immingham Bulk Terminal	325	1,750
Immingham Bulk Terminal	-	-

7. *Results for TSHD dredging of alluvium*

7.1 GENERAL

The predicted increases in depth averaged suspended sediment concentration (above background concentration) caused by the TSHD dredging alluvium/clay are presented in Figure 9. As before, Figure 9 presents the peak increases which occur throughout the simulation and is a composite figure representing the plumes at different times at different locations and the figure does not show the plume at a particular moment in time.

Figure 10 indicates that peak increases in (depth-average) concentration exceed 100 mg/l in the vicinity of the dredging and the intakes and are less than 100 mg/l further away. The plume disperses more than 12km to the north on a flood tide and up to 12 km to the south on an ebb tide, though concentration increases at this distance are generally below 20 mg/l.

Figure 11 shows the predicted accretion of fine sediment resulting from the TSHD dredging of alluvium/clay at the end of the simulated spring neap cycle. The accretion is calculated assuming a dry density for settled fine sediment of 500 kg/m^3. It can be seen that there is predicted deposition of up to 10mm in subtidal areas up to 2km upstream and downstream of the site and greater accretion within the berth area.

7.2 IMPACTS AT INTAKE/OUTFALL LOCATIONS

Figure 12 shows the predicted increases in suspended sediment concentration at the intake locations to the north of the proposed works. It can be seen that peak increases in suspended sediment concentration above background are in the region of 40-60 mg/l (depth-averaged) and 100-180mg/l (near bed) at the Eon intake and 30-50 mg/l (depth-averaged) and 40-60mg/l (near bed) at the Centrica intake.

7.3 ACCRETION AT NEARBY BERTHS

The accretion at nearby berths over the spring-neap cycle resulting from the TSHD dredging of alluvium is presented in Table 6, together with the projected infill over the whole of the alluvium dredging operations (not including dredging of the reclamation site). It can be seen that the infill at the nearby berths resulting from this operation is relatively insignificant when compared to annual maintenance dredge requirements and the natural variation in those quantities.

Table 6 Predicted infill arising from TSHD dredging alluvium/

Local berth	Predicted infill (m^3)	
	(spr-np cycle)	Total
Humber Sea Terminal	0	0
South Killingholme Oil Jetty	640	960
Immingham Gas Terminal	210	315
Humber International Terminal	630	945
Immingham Bulk Terminal	0	0
Immingham Bulk Terminal	0	0

7.4 EFFECTS OF LIMITED OVERFLOWING

When dredging muddy material, overflowing of water/sediment from the hopper for more than a few minutes is not generally efficient in terms of increasing the sediment load within the hopper. Continued overflowing will result in most of the sediment pumped from the sea bed being discharged from the dredger into the surrounding waters.

Although the hopper load is not increased by overflowing, overflow can still be an effective dredging methodology (since sediment is still being removed from the sea bed) if the sediment disperses sufficiently that the sediment discharged from the dredger is removed from the dredging area and if the environmental consequences of the discharge can be shown to be sufficiently small. However, as the rates of discharge of fine sediment tend to be very high from overflowing of mud, it is often the case that continued overflowing is not considered to be appropriate.

In the case of the proposed works the presence of intakes so close to the works would tend to reduce the scope for continued overflowing but the Humber is a turbid estuary and relatively high suspended sediment concentrations are already experienced both by the intakes and the wider estuary and the dredging is proposed for a limited period. This section will therefore consider the effect of a modest amount of overflowing during the dredging of alluvium as this may be feasible if the resulting impact on the intake operations can be managed.

The loading time for the alluvium dredging by in the berths by the Barent Zanen and approaches is 33 minutes. We will consider the effects of up to 10 minutes of overflowing during this loading period. The application of trailer process models developed by HR Wallingford indicates that such a scenario would result in the loss of roughly 75% of the material entering the hopper over this 10 minute period with a rate of release of fine material in the region of 1850 kg/s. For the remainder of the 20 minute period the rate of release would reduce to around 20 kg/s as described in Section 5.2.

As the release rate from overflowing alluvium is around four times larger than that for dredging gravel, in terms of the resulting increases in suspended sediment concentration it can be considered that for a period of ten minutes (the overflow time) in every 2½ hours (the dredger cycle time) increases in suspended sediment concentrations will up to four times larger than those presented in Figure 9 and Figure 15.

Taking into consideration the different periods of overflow, the different rates of overflow, the different cycle times and the different volumes of dredging required, it can be concluded that the overall mass discharged from the dredger during dredging of alluvium with 10 minutes of overflow is around 40% higher than, and in addition to, the corresponding distribution for the sand/gravel dredging shown in Figure 14. On this basis the corresponding deposition in the local berths arising from the dredging of alluvium would be around 40% higher than that shown in Table 7.

8. Results for TSHD dredging (sand & gravel)

8.1 GENERAL

The predicted peak increases in depth averaged suspended sediment concentration above background caused by the TSHD dredging for one day are presented in Figure 13 (assuming the dredging occurs on spring tides) and Figure 14 (assuming the dredging occurs on neap tides). As before these figures represents the peak increases which occur throughout the simulation and are composite figures representing the plumes at different times at different locations.

These figures indicate that peak increases in (depth-average) concentration rise up to 1000 mg/l in the vicinity of the dredging with near bed concentrations of several thousand mg/l. The intakes are located on the edge of the dredging plume and experience peak increase of around 200mg/l with near bed concentrations of up to 500mg/l (see Section 7.2 below). The plume disperses as far as the Humber Bridge on the flood tide and as far as Spurn Head on the ebb tide, though concentration increases at this distance are generally below 10mg/l.

Figure 14 shows the predicted accretion of fine sediment resulting from the day of TSHD dredging on a spring tide. Accretion of more than 50mm occurs along the berths and of more than 10mm in subtidal areas up to 2km upstream/downstream of the site.

8.2 IMPACTS AT INTAKE/OUTFALL LOCATIONS

Figures 15 and 16 show the predicted depth-averaged and near bed increases in suspended sediment concentration resulting from dredging, on spring tides and neap tides respectively, at the intake locations to the north of the proposed works.

On spring tides there is deposition of 20mm and 80mm in the vicinity of the northern and southern intakes, respectively and the predicted concentration increase is up to 200mg/l at the northern intake (which is further from the dredging) and up to 400 mg/l at the southern intake.

On neap tides there is deposition of 10mm and 40mm in the vicinity of the northern and southern intakes, respectively and the predicted concentration increase is up to 50mg/l at the northern intake (which is further from the dredging) and up to 100 mg/l at the southern intake.

8.3 ACCRETION AT NEARBY BERTHS

The predicted accretion at nearby berths resulting from the TSHD dredging of sand and gravel is presented in Table 7.

Table 7 Predicted infill arising from TSHD dredging sand/gravel

Local berth	Predicted infill (m^3)
Humber Sea Terminal	80
South Killingholme Oil Jetty	1,960
Immingham Gas Terminal	1,160
Humber International Terminal	3,850
Immingham Bulk Terminal	2,370

9. *Background sediment concentrations near the proposed site*

Suspended sediment concentrations within the Humber Estuary vary from several hundred mg/l near the mouth to several thousand mg/l in the upper estuary (Delft Hydraulics, 2004). Measurements of suspended sediment concentrations in the vicinity of the proposed works include:

- Measurements at the Humber Sea Terminal by IECS (see HR Wallingford, 2011). These recorded peak surface concentrations of 1,600 mg/l (flood) and 900 mg/l (ebb) on a spring tide.
- Measurements at Grimbsy by ABPmer (ABP, 2009). These recorded peak surface concentrations of 200 mg/l (ebb) and 150 mg/l (flood) on a neap tide.
- Measurements at Spurn Head (BTDB, 1969) indicate concentrations though depth of several hundred mg/l throughout the ebb tide.

It can be seen that close to the site at the Humber Sea Terminal there are surface suspended sediment concentrations of up to 1600 mg/l, and hence potentially larger concentrations lower in the water column. Predicted depth-average increases form the modelling undertaken are typically less than 100mg/l which is small compared with the observed range of concentrations that occur on typical tides. Whilst the effects of the proposed dredging as characterised in this study cannot be dismissed as negligible, they do represent a relatively small proportional increase that does not significantly change the range of suspended sediment values commonly experienced in what is a highly turbid estuary.

10. *Conclusions*

- Modelling tools have been applied to investigate the potential effects of capital dredging associated with the AMEP development.
- The dredging has been characterised as use of a TSHD to dredge alluvium/clay and sand/gravel and use of a backhoe to dredge glacial till.
- Overall it is not considered that the proposed dredging will cause any significant impact to the sediment transport in the Humber Estuary although temporary and

significant rises in background concentrations are likely to occur during the dredging of sand/gravel over the course of a week (or less).

- The proposed dredging of alluvium by TSHD (without overflowing) will cause increases in suspended sediment concentrations at the southern intake of up to 180mg/l (near bed) and at the northern intake of up to 60mg/l (near bed) for a period of around a three weeks. Owing to the large range of natural suspended sediment concentrations experienced at these locations, and the limited period of impact, these increases are not considered to be unduly onerous for the operation of the intakes.
- Should overflowing be utilised during the dredging of alluvium the predicted increases in suspended sediment concentration above background and the deposition of fine sediment arising from this dredging will be considerably larger. Overflowing for ten minutes on every load would result in increases in suspended sediment concentration of up to 800mg/l (near bed) and at the northern intake of up to 1600mg/l (near bed) for a period of up to three weeks. Whilst this may represent a significant increase in the background levels of suspended sediment concentration it is noted that this increase will occur for a limited period of time.
- The proposed dredging of sand/gravel by TSHD will cause increases in suspended sediment concentrations at the southern intake of up to 200mg/l (near bed) and at the northern intake of up to 400mg/l (near bed) for a period of up to a week. Whilst this may represent a significant increase in the background levels of suspended sediment concentration it is noted that this increase will occur for a limited period of time.
- Predicted infill into other nearby berths arising from the capital works is predicted to be relatively insignificant when compared to annual maintenance dredge requirements and the natural variation in those quantities. This remains true even if overflowing is utilised during the dredging of alluvium.

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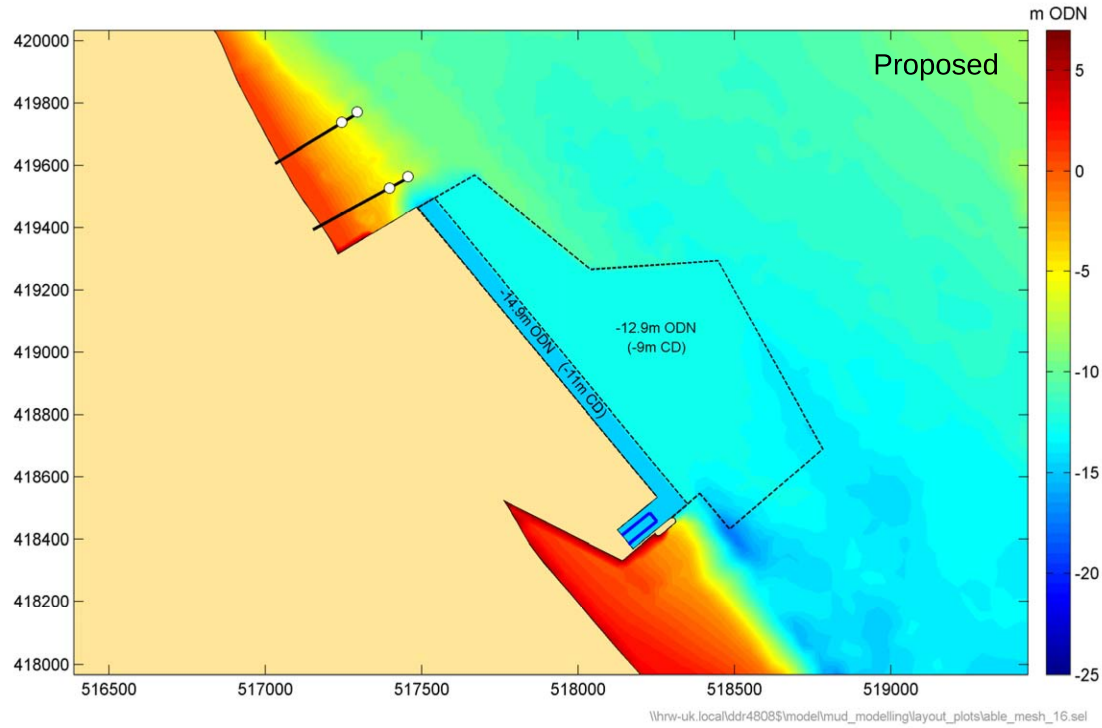
Figures



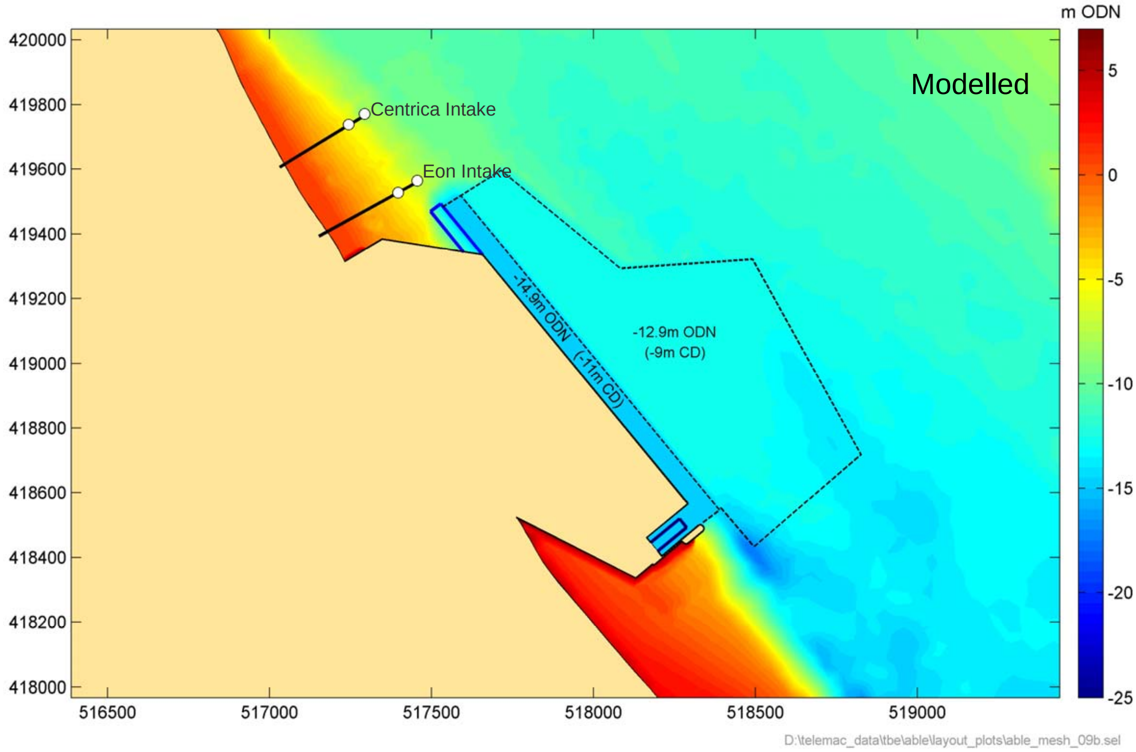


Figure 1 Proposed and modelled AMEP scheme layouts also showing locations of E.ON and Centrica intakes and outfalls. (Top) Proposed (Bottom) Modelled

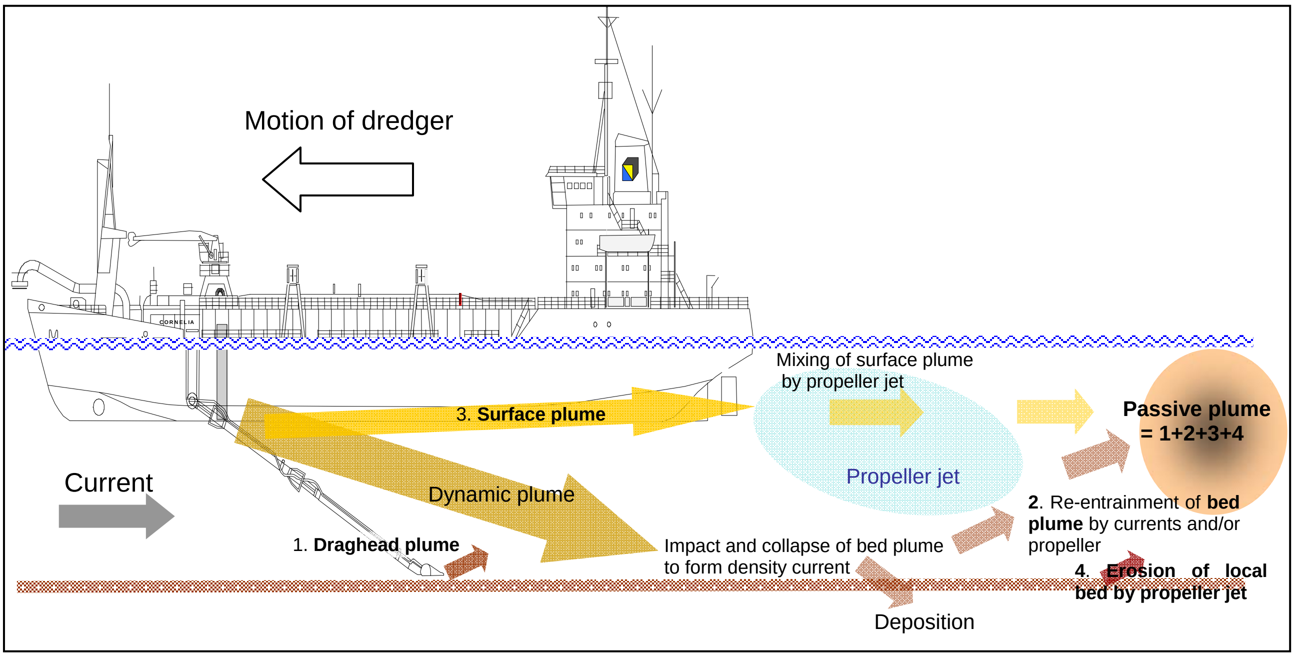


Figure 2 Release of sediment arising from dredging by TSHD

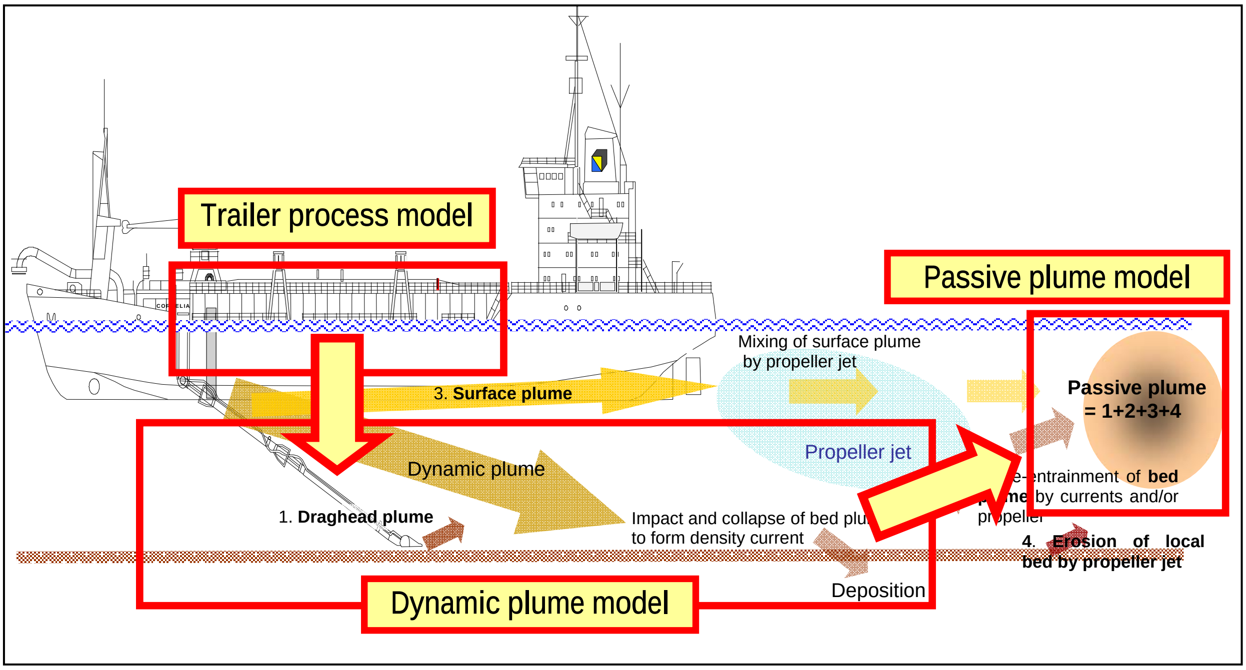


Figure 3 Schematization of TSHD near-field processes by SEDTRAIL-RW

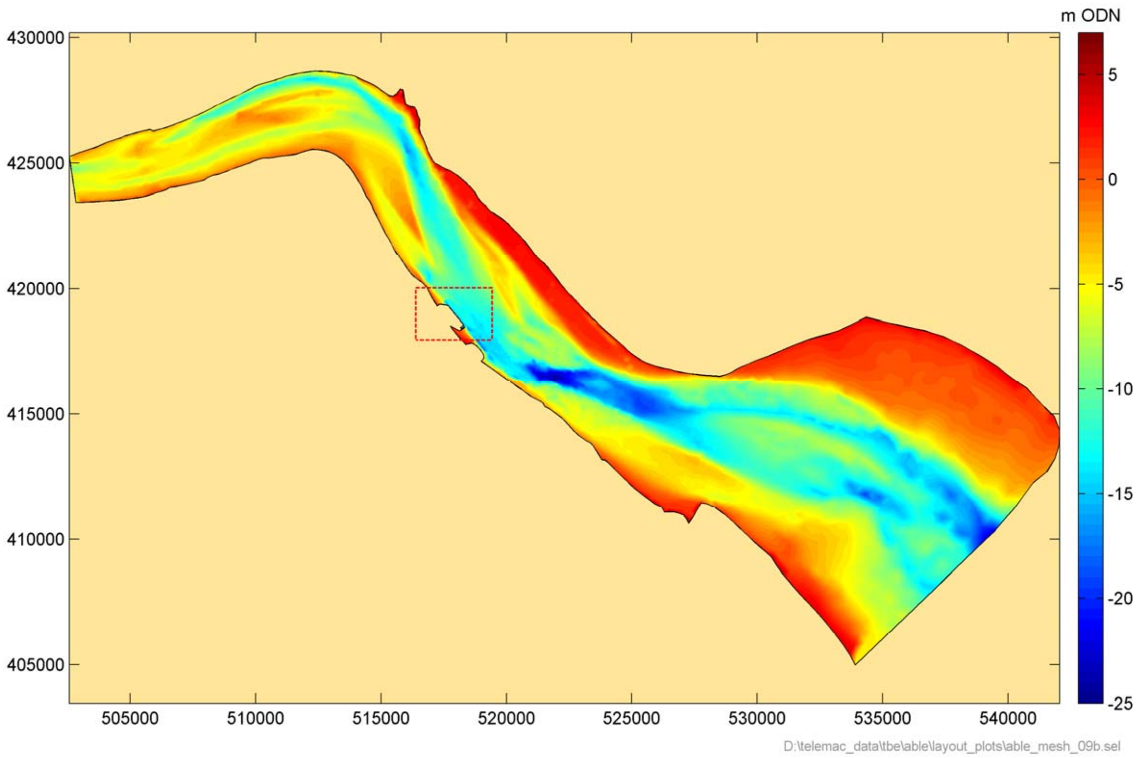


Figure 4 Bathymetry (with AMEP scheme)

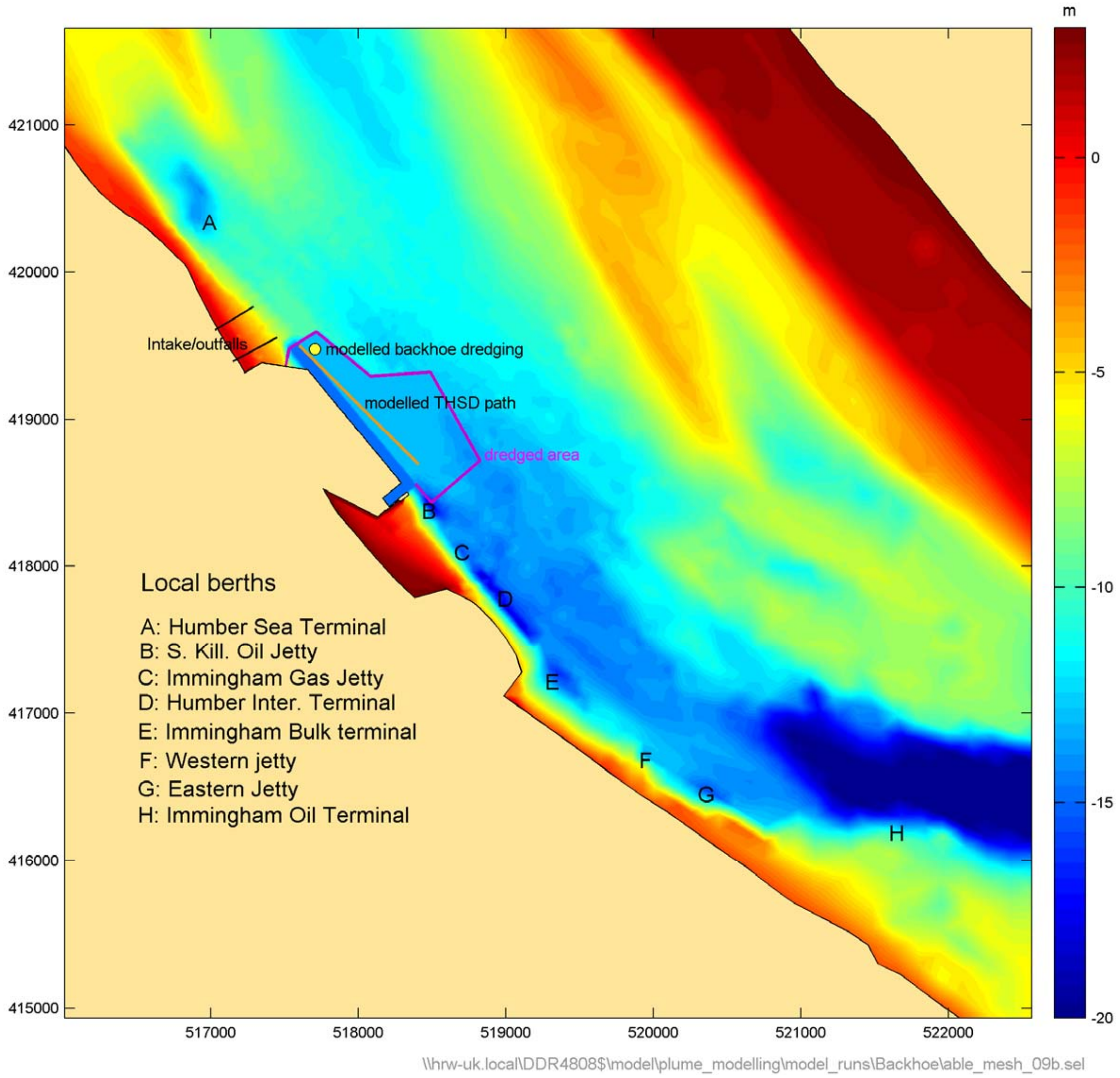


Figure 5 Layout figure (with AMPEP scheme) showing locations of proposed dredging and locations of intakes and local berths

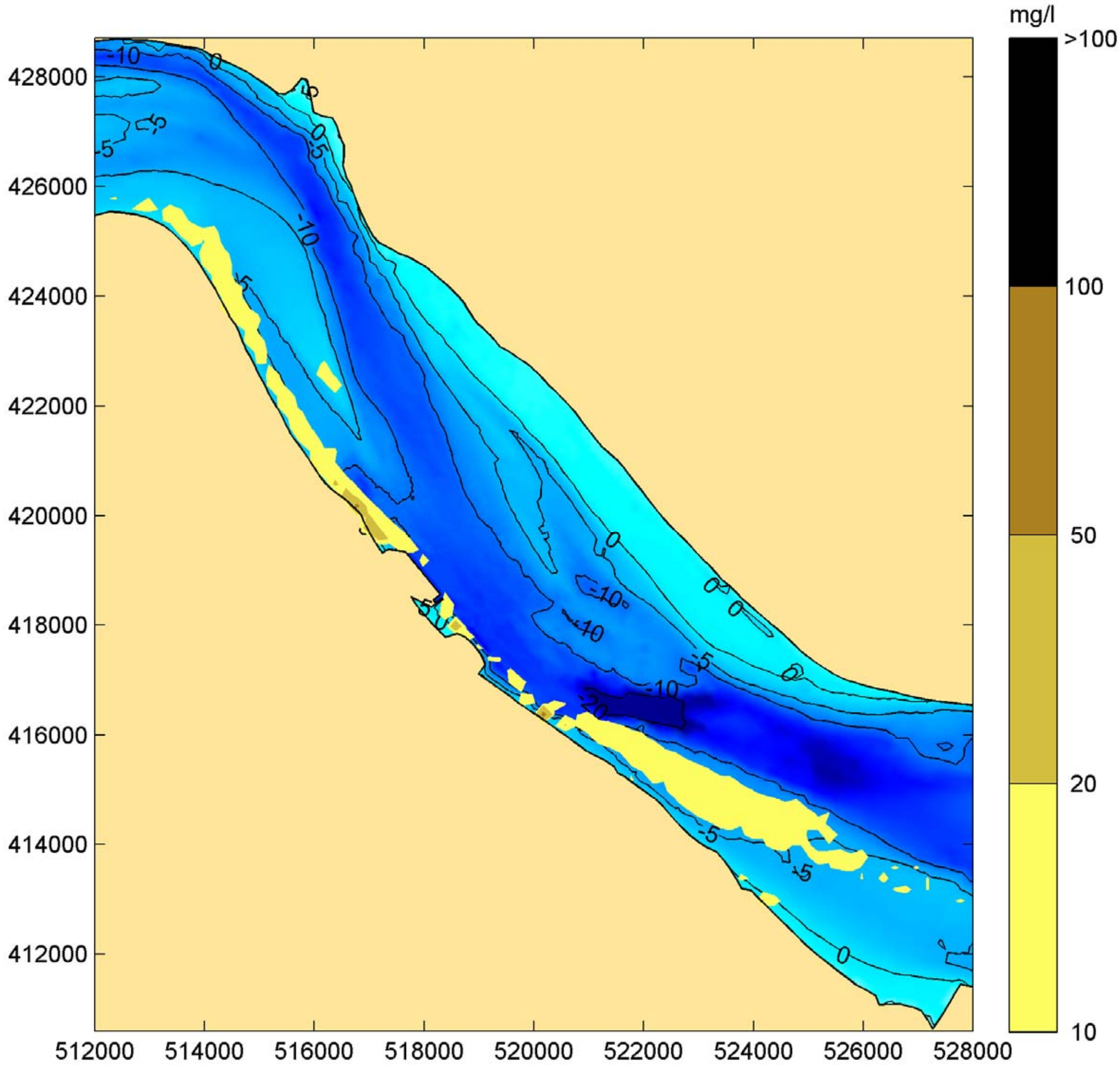


Figure 6 Predicted peak increase in depth-averaged suspended sediment concentration above background over a spring-neap cycle of backhoe dredging at the northern end of the dredging area

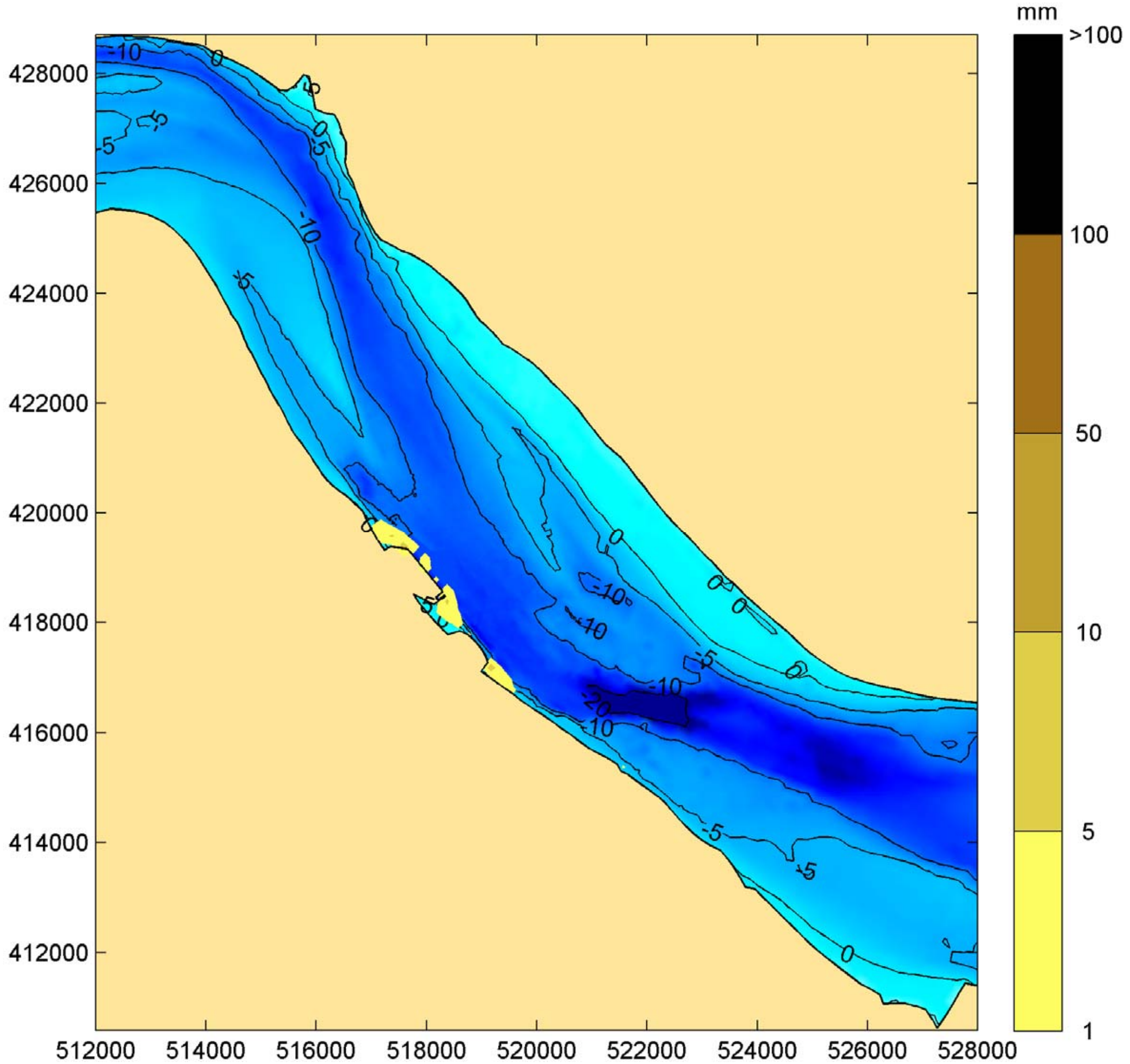


Figure 7 Predicted deposition of fine sediment resulting from a backhoe dredging over a spring-neap cycle at the northern end of the dredging area

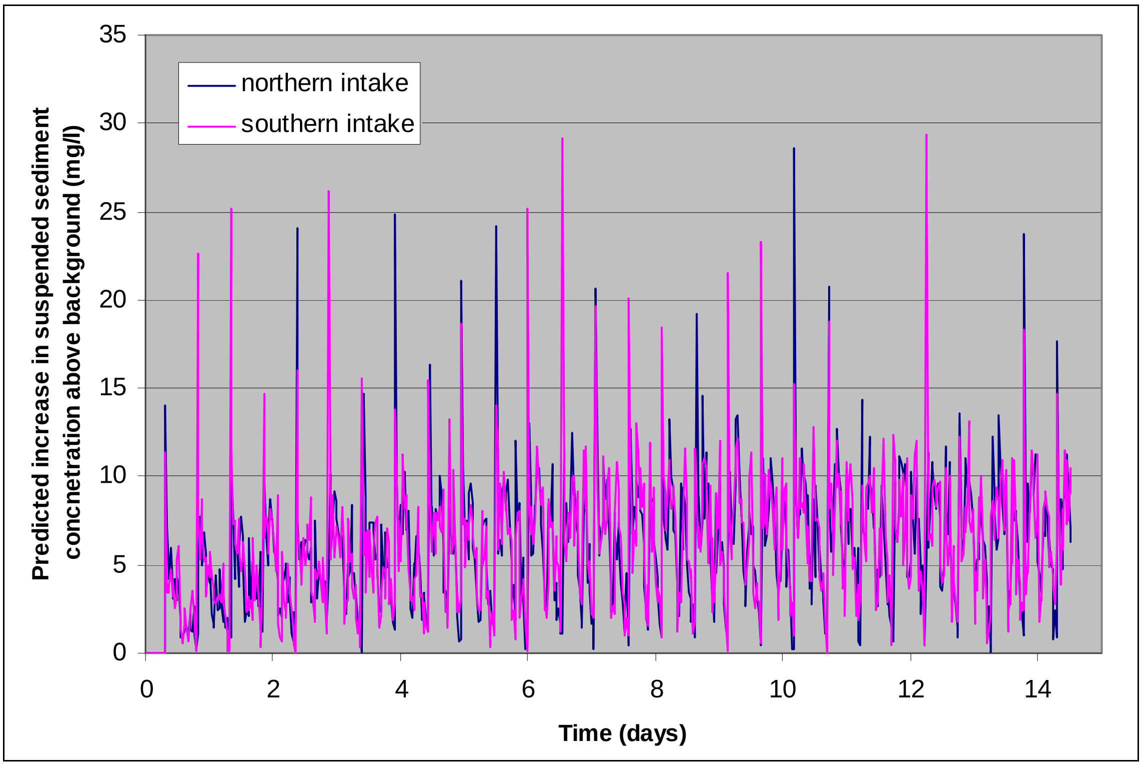


Figure 8 Predicted increase in depth-averaged suspended sediment concentration above background over a spring-neap cycle of backhoe dredging at the northern end of the dredging area

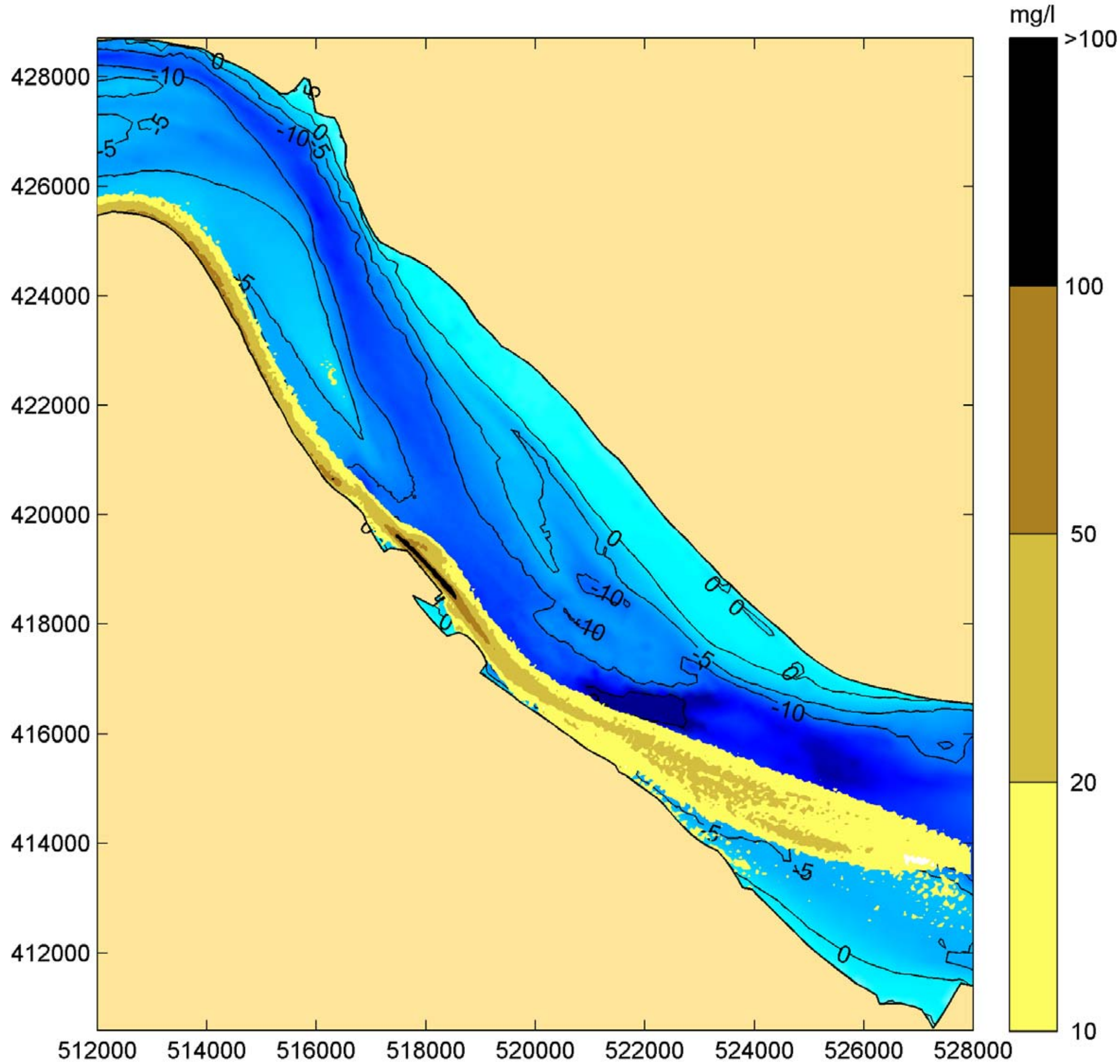


Figure 9 Predicted peak increase in depth-averaged suspended sediment concentration above background resulting from dredging of alluvium/clay by TSHD over a spring-neap cycle

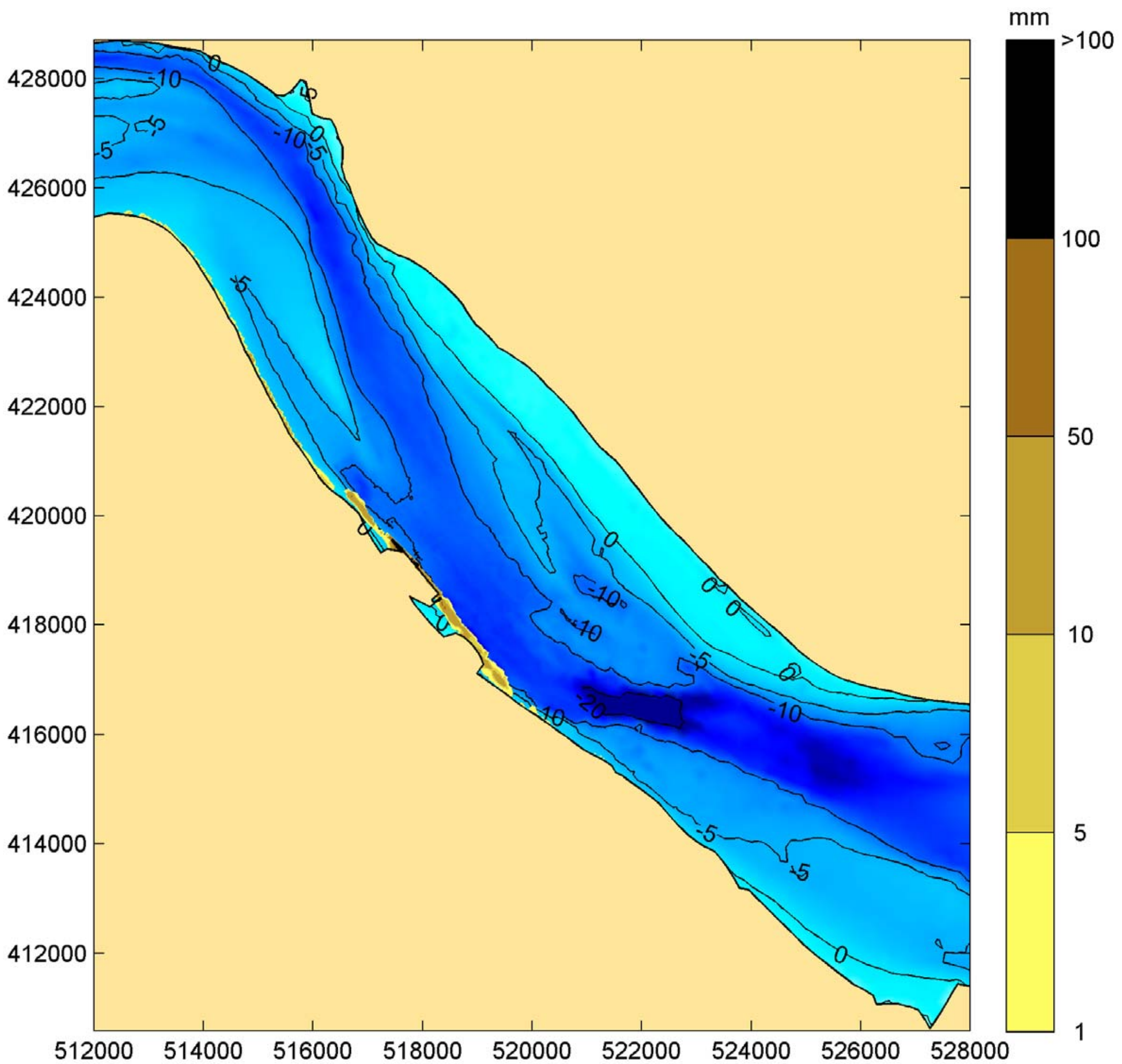


Figure 10 Predicted deposition of fine resulting from dredging of alluvium/clay by TSHD over a spring-neap cycle

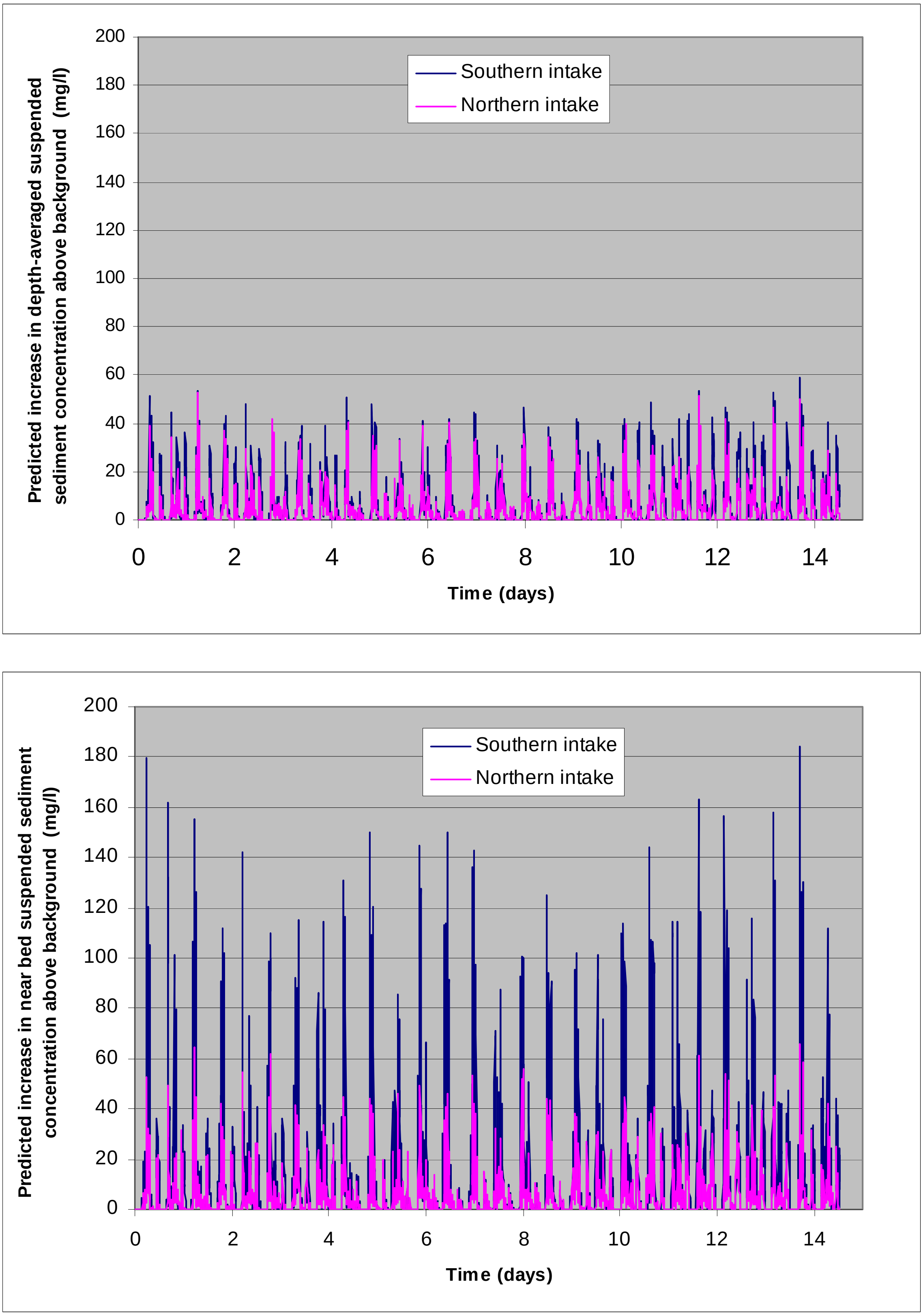


Figure 11 Predicted increase in depth-averaged (top) and near bed suspended sediment concentration (bottom) resulting from dredging of alluvium/clay by TSHD over a spring-neap cycle

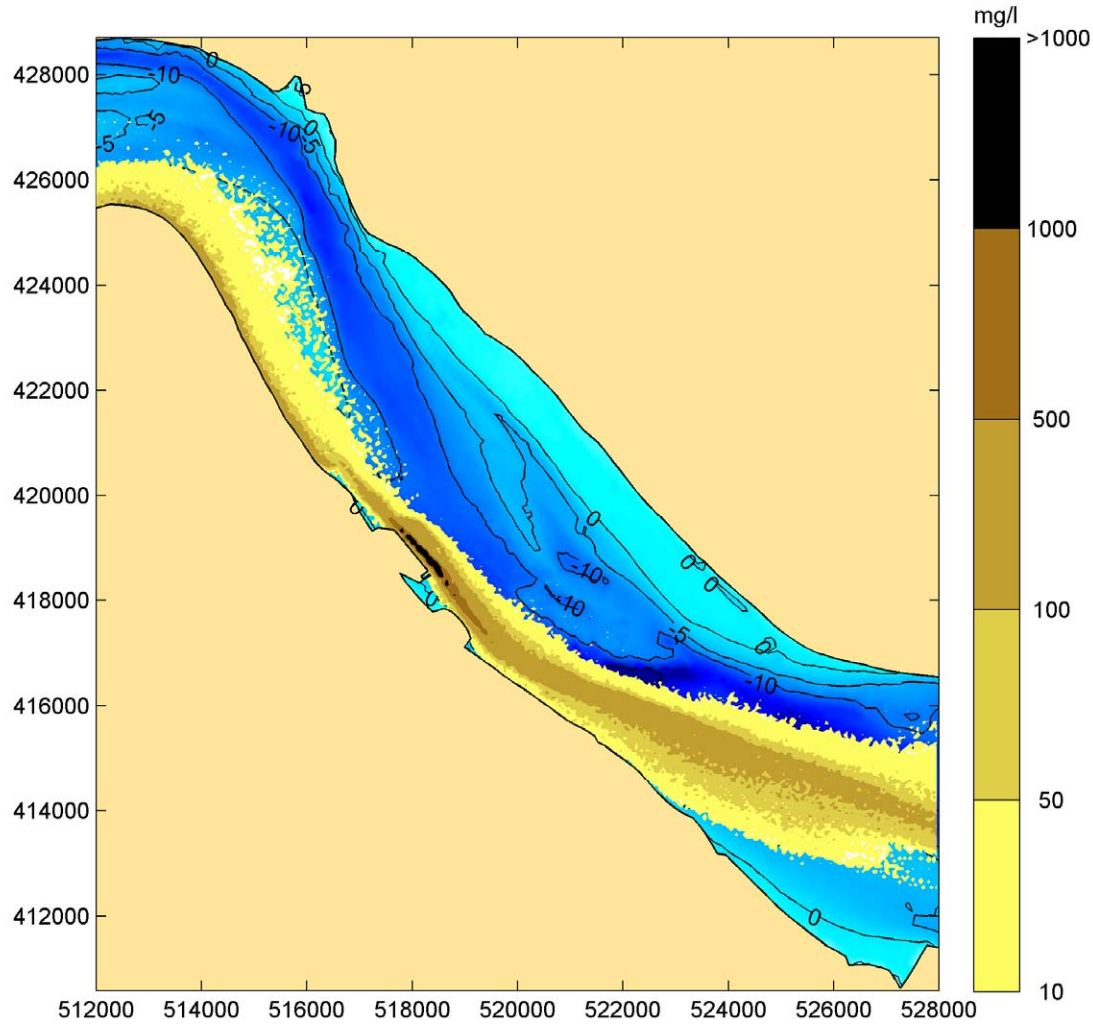


Figure 12 Predicted peak increase in depth-averaged suspended sediment concentration above background from dredging of sand/gravel by TSHD during spring tide conditions

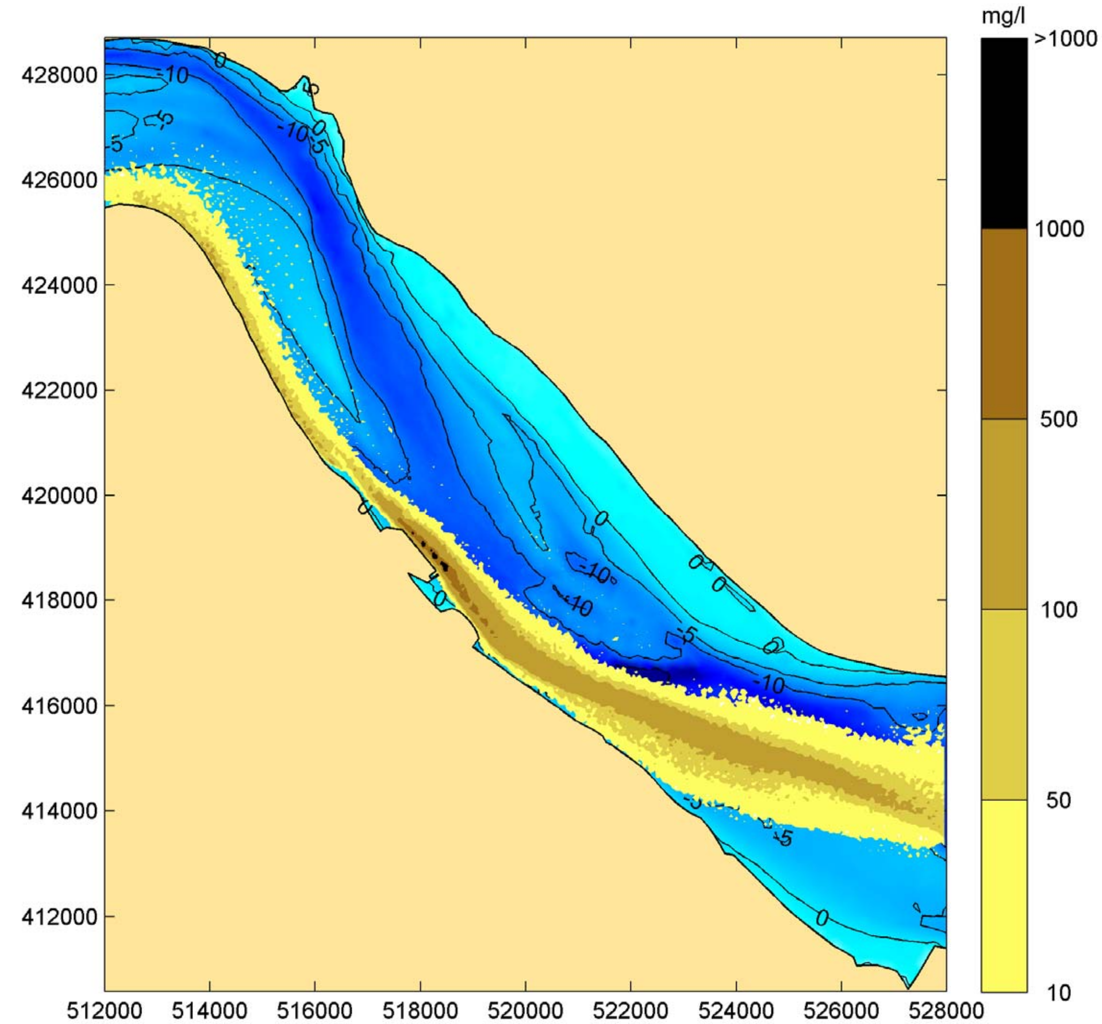


Figure 13 Predicted peak increase in depth-averaged suspended sediment concentration above background from dredging of sand/gravel by TSHD during neap tide conditions

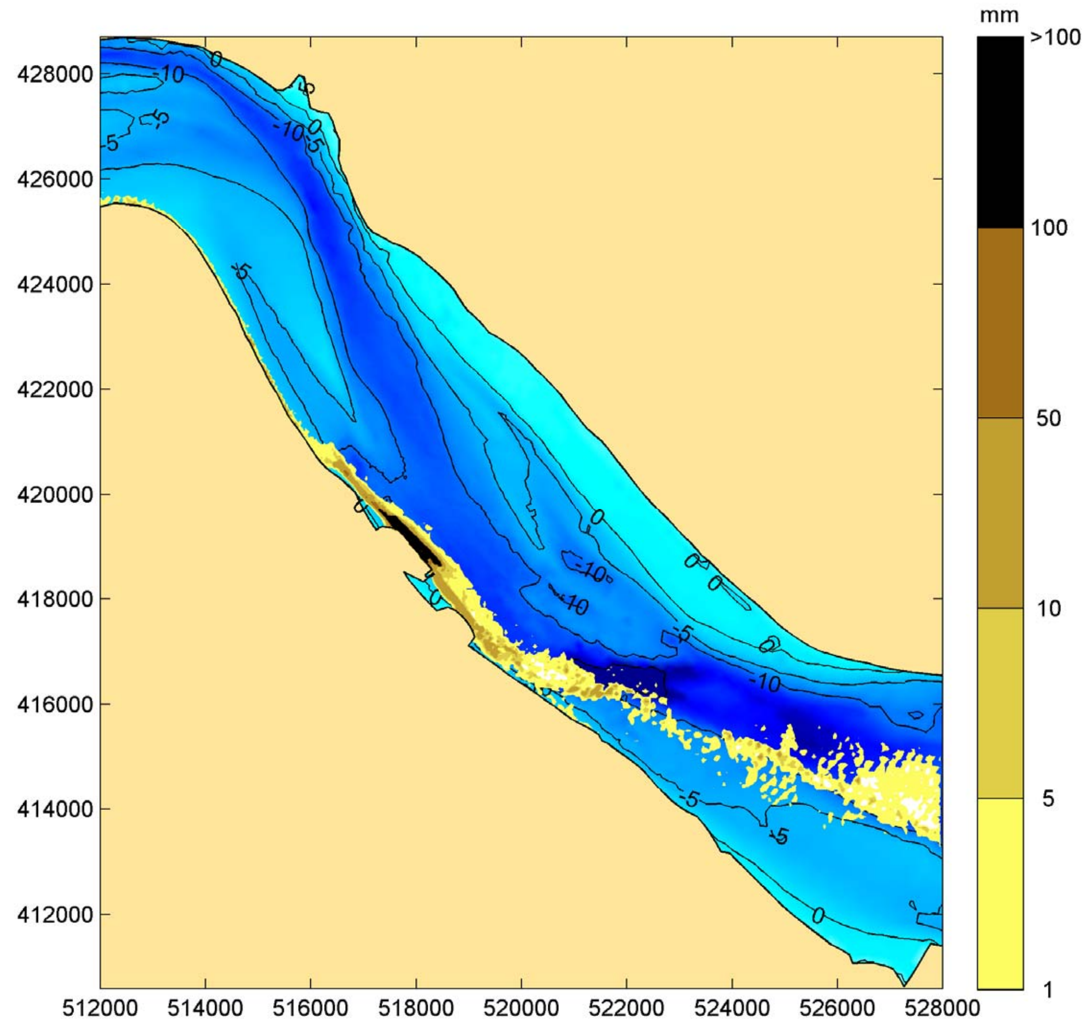
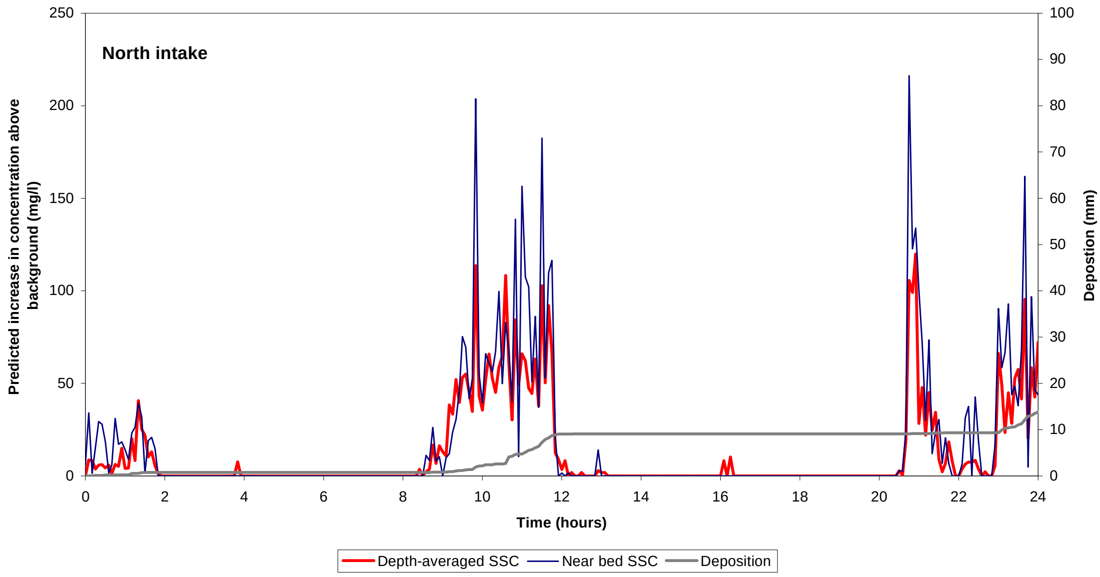


Figure 14 Predicted deposition of fine sediment resulting from TSHD dredging of sand/gravel over a week



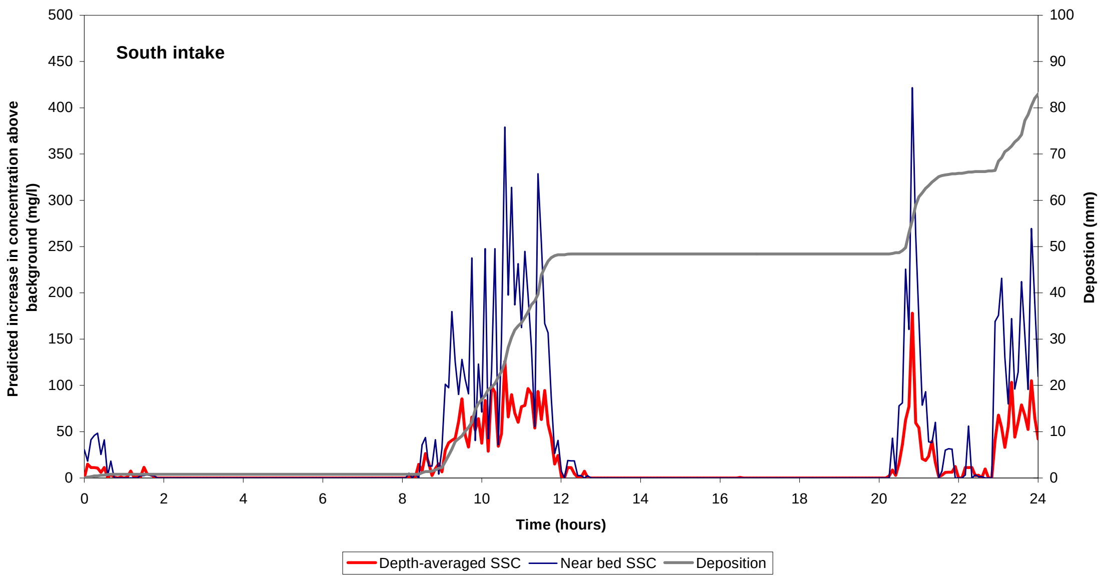
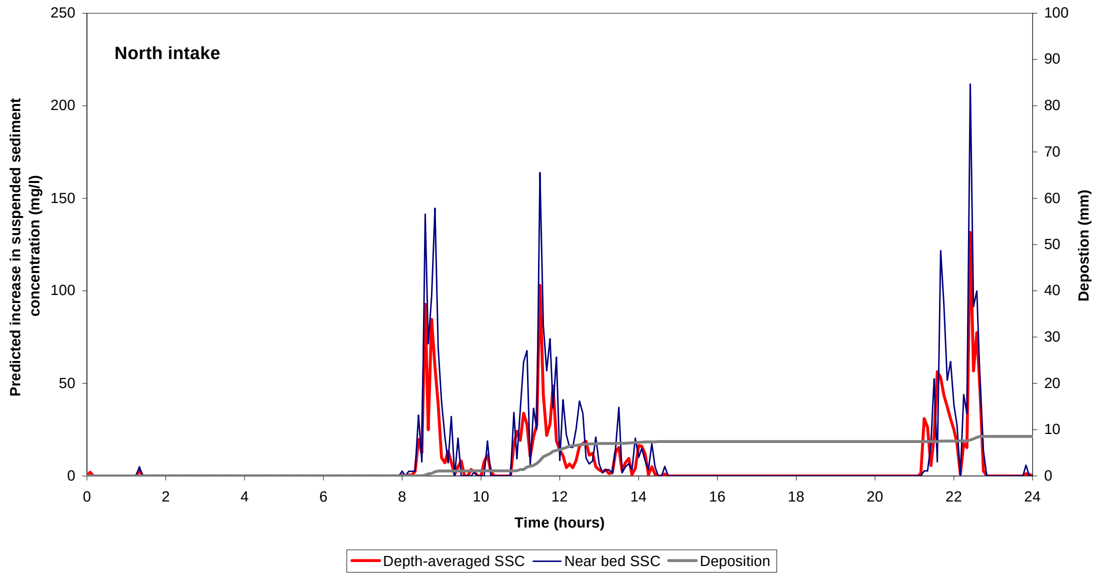


Figure 15 Predicted increase in suspended sediment concentration above background and predicted deposition over a day of dredging of sand/gravel by TSHD on spring tides (Top: North intake (Centrica), Bottom: South Intake (E.On))



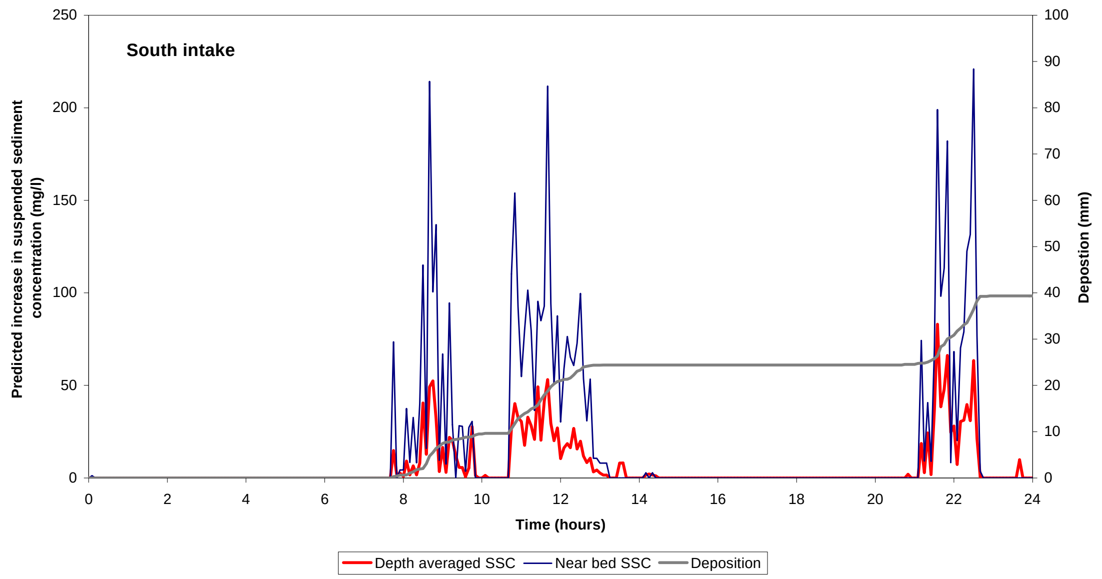


Figure 16 Predicted increase in suspended sediment concentration above background and predicted deposition over a day of dredging of sand/gravel by TSHD on neap tides (Top: North intake (Centrica), Bottom: South Intake (E.On))