Technical Appendix 6.3

Sediment and Contaminant Plume Modelling

Falmouth Docks Redevelopment

Sediment and contaminant plume modelling

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21 March 2025

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1 Introduction

1.1 Background

The Falmouth Docks is located in the Docks Basin in the Inner Harbour at Falmouth, Cornwall (see Figure 1.1).

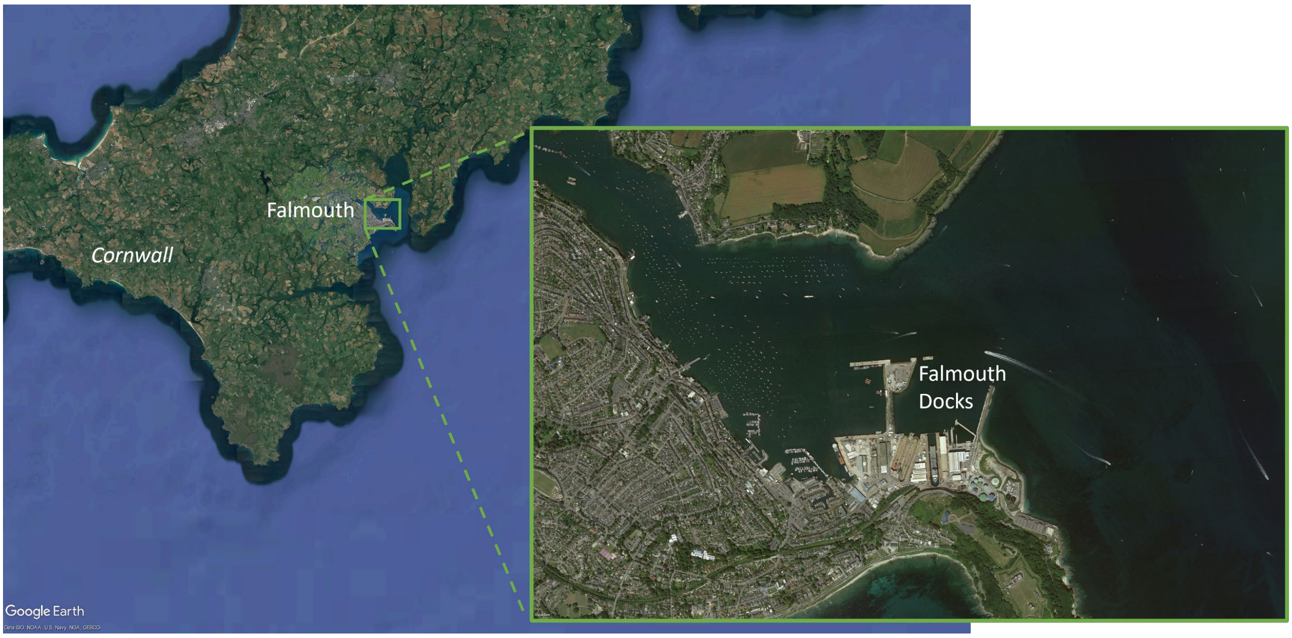

Figure 1.1: Project location

The proposed development aims to restore and upgrade the existing facilities at Falmouth Docks, in order to reinstate and provide new alongside berth capacity, to facilitate the floating offshore wind (FLOW) renewable energy industry and accommodate cruise ships up to Excellence Class at the Docks (see Figure 1.2).

The works will include construction of new suspended deck structures (Western Wharf, Northern Wharf and FLOW Deck) with a rock revetment under the suspended decks, an area of reclamation behind the Western Wharf, an extension of Queen's Wharf and demolition of the eastern and western parts of the existing Northern Arm. Dredging of the berths will also be carried out to accommodate cruise ships up to Excellence Class and FLOW devices, as detailed in the Dredging Plan shown in Figure 1.3.

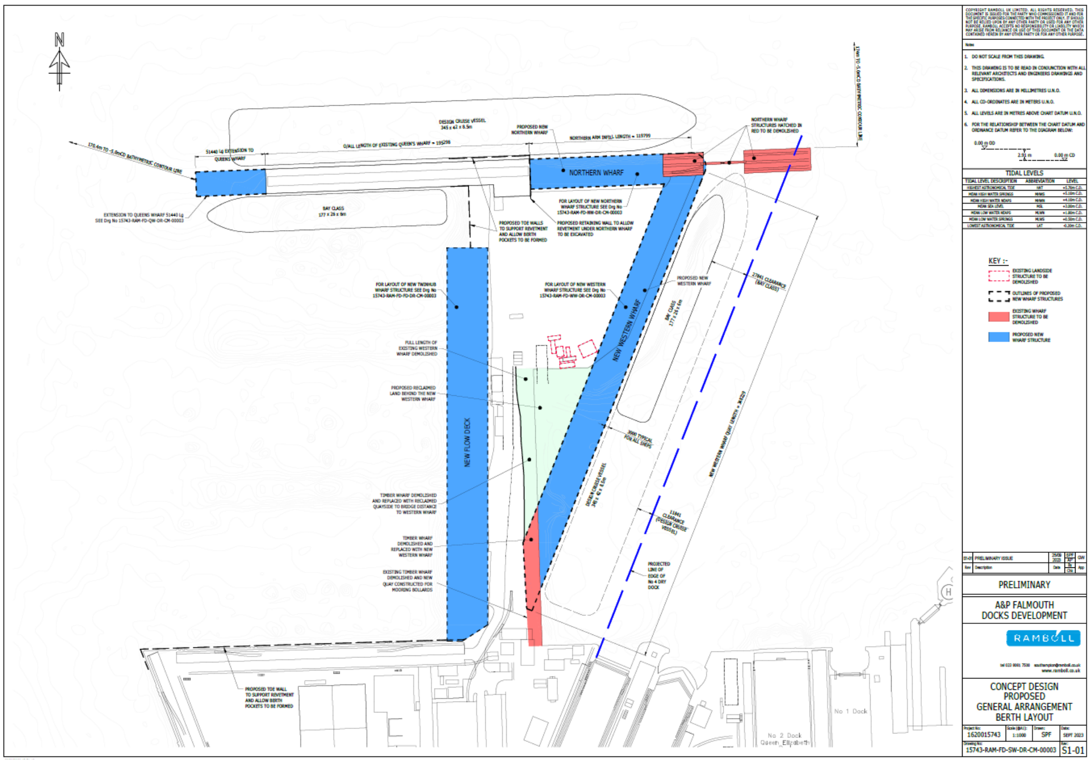

Figure 1.2: Proposed development works of Falmouth Docks

Source: Ramboll

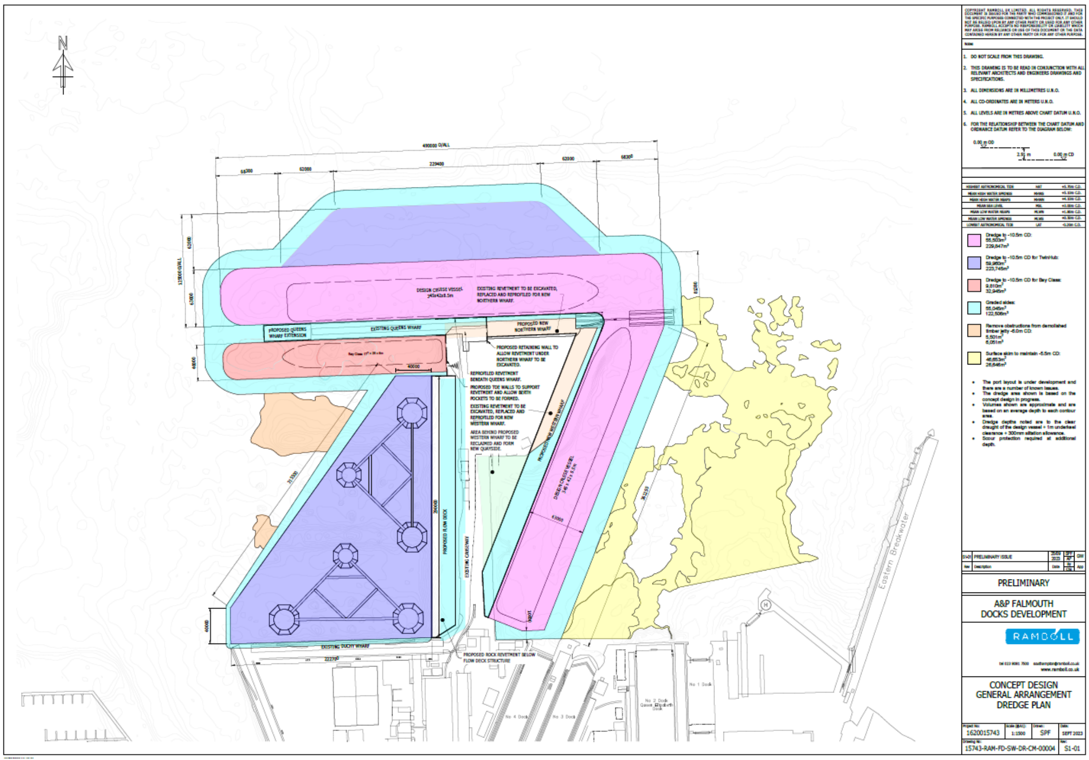

Figure 1.3: Proposed Dredging Plan

Source: Ramboll

1.2 Objectives

This study is part of modelling studies, including hydrodynamics (ES Technical Appendix 6.4), sediment dynamics (ES Technical Appendix 6.2), waves (ES Technical Appendix 6.1), and under-water noise (ES Technical Appendix 7.1), undertaken by HR Wallingford to support the Environmental Impact Assessment (EIA) for the proposed development.

This report presents the sediment and contaminant modelling study, carried out to model the effect of the proposed dredging and disposal operations on levels of suspended sediment and of contaminants in the water column. A separate study of the effect of the proposed development on the naturally occurring levels of suspended sediment and infill rates within the existing operational areas of the port and the across the wider estuary is reported in the sediment transport report (ES Technical Appendix 6.2).

1.3 Report structure

The remainder of this report is arranged as follows:

- Section 2 presents an overview of the proposed dredging works.
- Section 3 describes the baseline hydrodynamic and sedimentation regime.
- Section 4 describes the contaminant analysis of the material to be dredged.
- Section 5 presents the modelling methodology and input data used.
- Sections 6 and 7 present the results of the modelling for the release of sediments and contaminants, respectively.
- Section 8 provides the study conclusions.

2 Proposed dredging works

The proposed dredging works are summarised in Figure 1.3. The total capital dredging volume is around 643,000 m^3. The vast majority of this volume involves dredging berths around the present and extended quays to 10.5 metres below Chart Datum (mCD) with the remainder arising from removal of the western wharf jetty and from a skim of a patch east of the site. However, a proportion of the sediment proposed for removal is contaminated as summarised in Figure 2.1. It is currently thought that around $^1/_3$ of the proposed capital volume (around 221,000 m^3) is contaminated and will require appropriate on-land disposal. The remainder will be disposed offshore at Falmouth Bay Disposal Site (PL075). The nature of this contaminated sediment is summarised in Section 4.

The dredging method has been identified as a backhoe dredger in order to keep the rate of release of fine sediment into the wider estuary (and in particular the maerl habitats found in the vicinity) as low as possible. In particular, the contaminated material needs to be removed using a “environmental bucket” which generally means a lidded bucket which is designed to minimise release of suspended sediment losses and therefore contaminants to the water column.

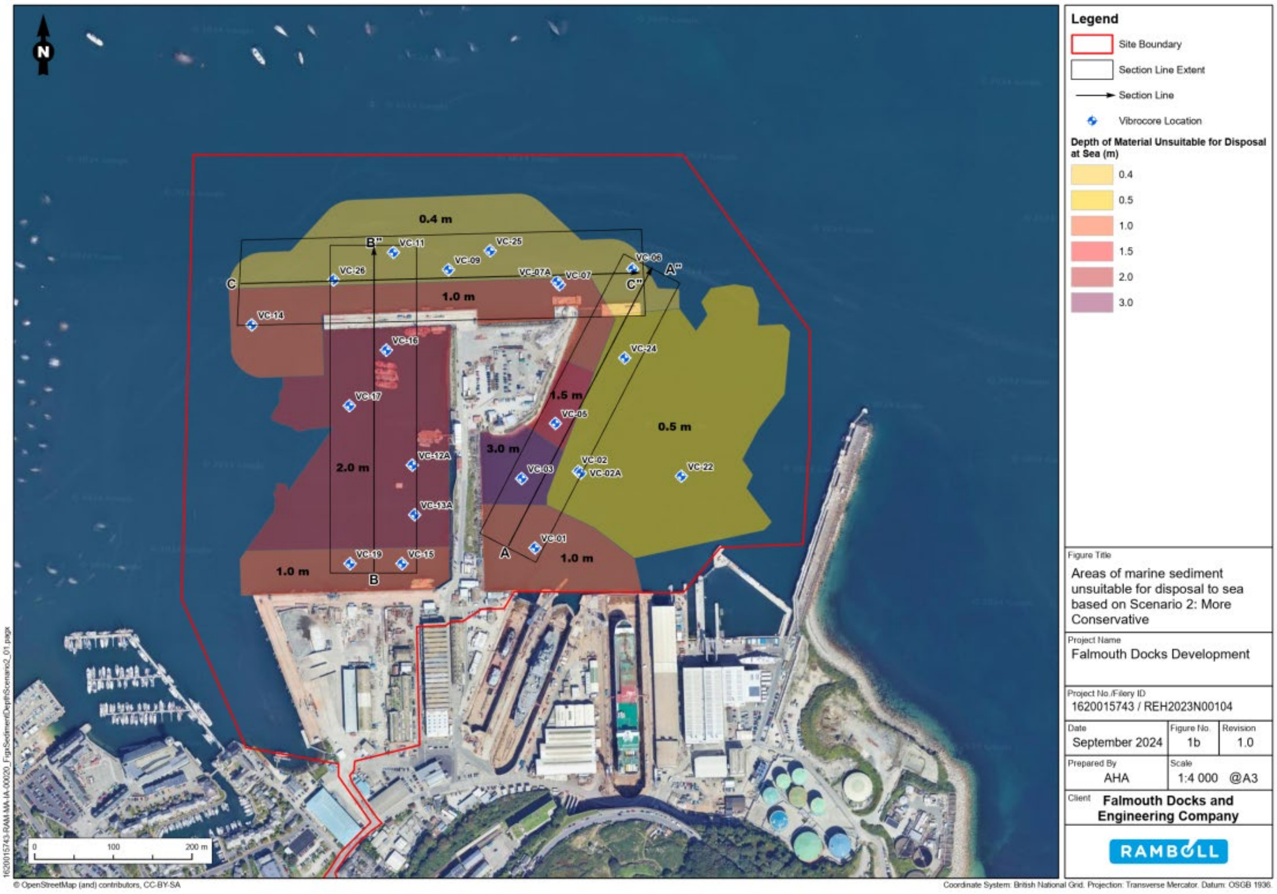

Figure 2.1: Summary of contaminated material arising from the proposed dredge

Source: Ramboll

2.1 Dredging scenarios modelled

Three scenarios were developed to explore the sensitivity of the effects to size and operation of a single, large backhoe dredger operating in each area and for each sediment type sequentially. These types of marine plant can be in considerable in market demand. In addition, the requirement for a relatively large, lidded bucket for removal of the contaminated material may also prove challenging. These challenges may result in the use of two smaller dredgers acting in parallel to achieve a targeted schedule. However, for this study a single large backhoe dredger, with larger productivity, has been used as this will result in a larger footprint of plume impact (than two smaller dredgers) and therefore is conservative.

Additionally it was assumed that the dredging was able to continue without hinderance from the supply of barges to take material to sea or land disposal or by any landside limits of the removal or treatment of contaminated sediment arising from the dredging.

2.1.1 Scenario 1 – maximum production rate, all tide dredging

This scenario is considered the maximum possible rate of dredging using a backhoe dredger and targeted a 17 week programme to complete the dredge. It assumes continuous dredging throughout the tide. Two sizes of dredger bucket are used as follows:

- The sediment with contamination levels above CAL2 will need to be removed more carefully, and this is likely to be using a backhoe with a closed bucket. The size of the lidded bucket required to meet the schedule would be around 10 m^3.

- Once the contaminated sediment has been removed the reminder (around 422,000 m^3) is likely to be removed using a large backhoe – assumed for the purpose of this report to have a bucket size of 13-14 m^3.

The productivities estimated for the purpose of this scenario and the duration of the dredging are presented in Table 2.1.

Table 2.1: Estimated production rates – Scenario 1

Description	Production rate (m^3/wk)	Duration of dredging (weeks)
Medium BHD with lidded bucket	26,900	8
Large BHD	46,600	9

2.1.2 Scenario 2 – medium production rate, flood tide dredging

Another recent project in the Falmouth area has used flood tide only dredging and this scenario employs a similar approach using the 10 m^3 lidded bucket backhoe dredger for all sediment. The backhoe dredger production rate has been amended to reflect flood tide only dredging.

- As above sediment with contamination levels above CAL2 will be removed using a backhoe with a 10 m^3 closed bucket. Flood tide only dredging.
- Once the contaminated sediment has been removed, the reminder is removed using the same 10 m^3 closed bucket backhoe dredger. Flood tide only dredging.

The dredger productivity and total duration of the dredging estimated for the purpose of this scenario are presented in Table 2.2. As shown by the table, flood tide only dredging for the whole project significantly increases the duration of the dredging. As above this scenario is a conservative one for plume impact assessment, the programme may be reduced by using two smaller dredgers, working at the same time.

Table 2.2: Estimated production rates – Scenario 2

Description	Production rate (m^3/wk)	Duration of dredging (weeks)
Medium BHD with lidded bucket	11,000	58

2.1.3 Scenario 3 – medium production rate, late ebb/early flood tide dredging

Inspection of the results for Scenario 2 revealed that the plume from dredging towards the end of the flood tide remained in suspension during the following ebb tide for long enough to deposit on the areas of live mearl to the east of the project site. Therefore a scenario was added to move the period of dredging 1.75 hours earlier to avoid this occurrence. The duration of dredging and hence the production rate, was kept the same as Scenario 2.

- All sediment will be removed using a backhoe with a 10 m^3 closed bucket. Dredging during the late ebb tide and early flood tide only.

The dredger productivity and total duration of the dredging estimated for the purpose of this scenario are presented in Table 2.3.

Table 2.3: Estimated production rates – Scenario 3

Description	Production rate (m^3/wk)	Duration of dredging (weeks)
Medium BHD with lidded bucket	11,000	58

3 Hydrodynamic and sedimentary environment

3.1 Tides and depths

The proposed works are sited in Falmouth Inner Harbour. This is located at the confluence of the lower Fal Estuary with the Penryn River.

The main channel into Falmouth (Carrick Roads) is at 20-30 mCD. This deep channel extends further into the Fal Estuary but bypasses the location of the Inner Harbour. The Inner Harbour and approaches have water depths which are at around 6 mCD. Immediately outside of the Inner Harbour the water depths shallow to a few metres.

Tidal ranges at Falmouth are 4.6 m on spring tides and 2.3 m on neap tides (Admiralty Chart Tables).

3.2 Currents

The current speeds and direction at peak ebb and peak flood on spring tide conditions are shown in Figure 3.1. Current speeds within the Inner Harbour are less than 0.1 m/s except for the north of the Inner Harbour where they exceed 0.1 m/s but are less than 0.2 m/s. Within the entrance to the Fal Estuary current speeds may be as high as 0.7 m/s on the flood tide and 0.5 m/s on the ebb tide.

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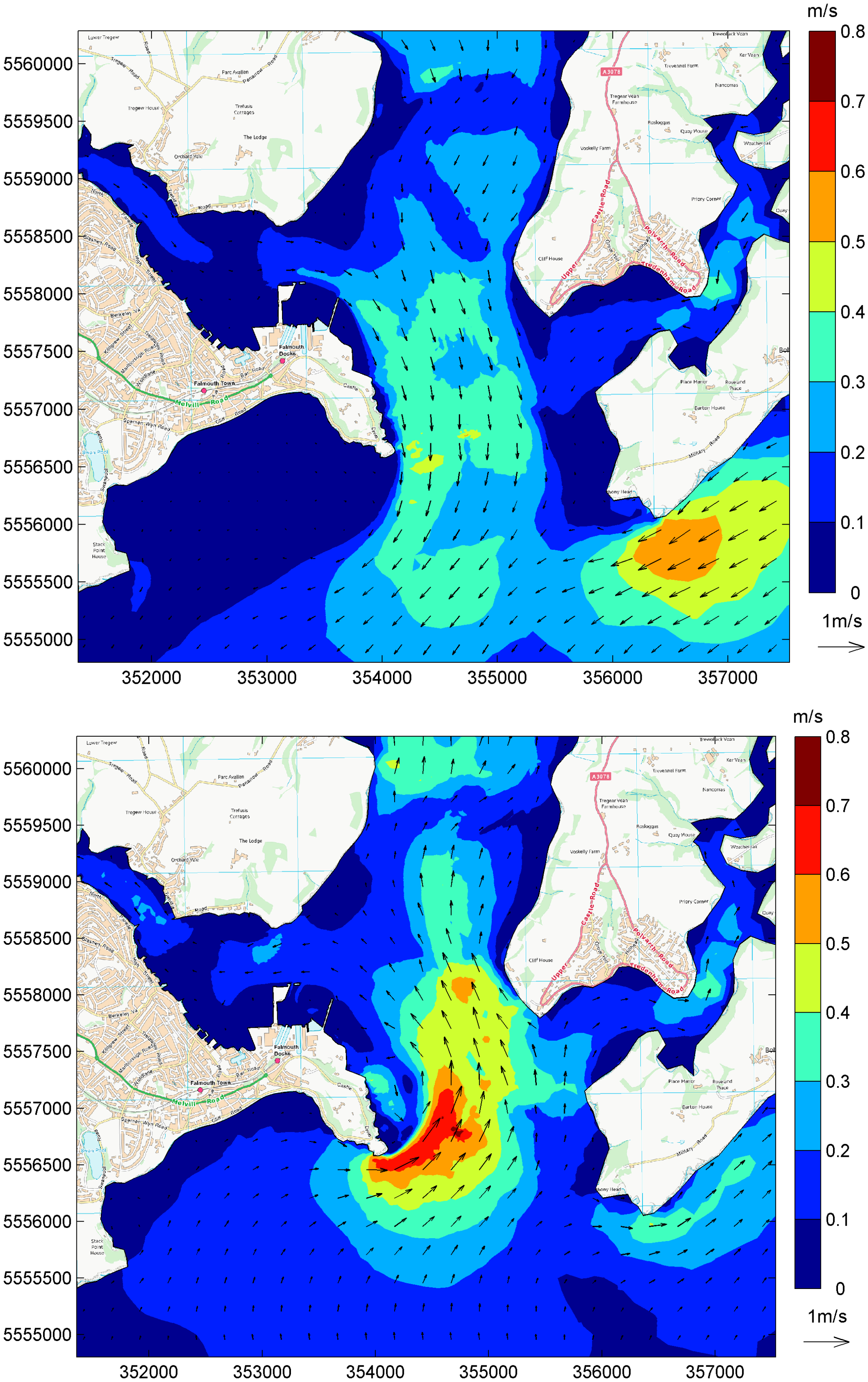

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Figure 3.1: Current magnitude and direction at (*Top*) peak ebb and (*Bottom*) peak flood

3.3 Waves

Wave measurements are available from a Waverider wave buoy at the Fal Estuary entrance, located in 7 m depth. The data was collected between June 1984 and June 1985. The data shows the mean wave height at the entrance is around 0.5 m though on occasion wave heights may exceed 2 m.

Within the Inner Harbour, waves are generally small. Even under storm conditions (e.g. Return Period 0.2 years) wave heights do not exceed 0.3 m. Data confirming this view, for the summer, is provided by measured waves collected at a wave buoy located in the entrance of the docks (location: 50.16N -5.04W), for the time period between 16 June and 21 Aug 2024.

3.4 Sediment

The locations of the vibrocores and grab samples available to this study are shown in Figure 3.2 and Figure 3.3 (data from Ramboll). Both sources of data indicate that the local sediment to be dredged, both at the surface and within the bed, is predominantly gravelly sandy mud. The fine sediment (silt/clay with particle sizes less than 63 µm [µm = 10^{-6} m]) content is 47% at the surface and 67% in total within the bed sediment that will be removed.

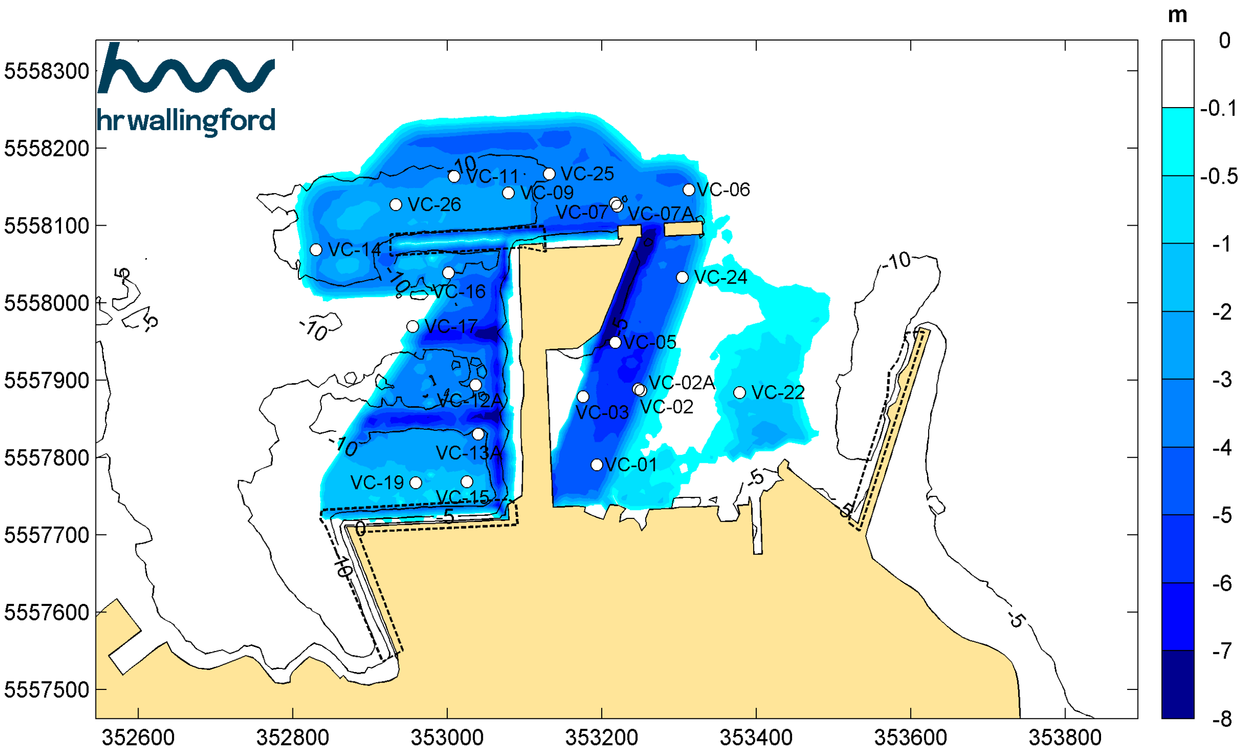

Figure 3.2: Vibrocore locations overlaid on proposed depth of dredging

Source: Ramboll

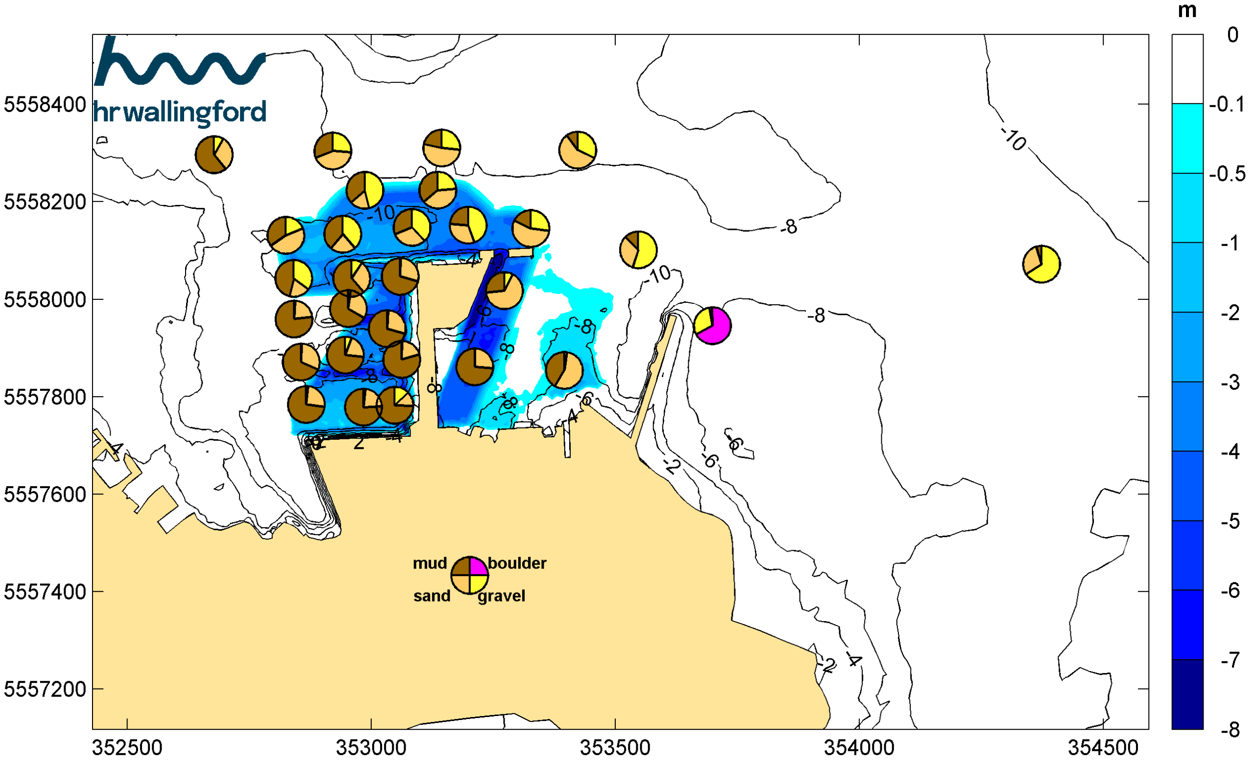

Figure 3.3: Sediment types identified by bed sampling

Source: Ramboll

3.5 Sensitive sites

Fal and Helford Special Area of Conservation (Natural England, 2014b)

The Fal and Helford Special Area of Conservation (SAC) is a ria (drowned river valley) system that supports a wide range of communities representative of marine inlets and shallow bays. There is a diverse algal flora, and a number of warm-water species are present. It supports extensive and rich sediment communities, as well as rocky shores and subtidal rock and boulder communities. The site also contains a large, dispersed population of shore dock *Rumex rupestris*.

Subtidal sandbanks support rich invertebrate communities with eelgrass *Zostera marina* beds near the mouth of both the Fal and Helford and in some channels of the rias. Of particular importance are the maerl (*Phymatolithon calcareum* and *Lithothamnion corallioides*) beds that occur in the lower Fal on St Mawes Bank, and the extensive areas of maerl gravel which extend throughout the Carrick Roads and Falmouth Bay. These are the largest maerl beds in south-west Britain and harbour a rich variety of both epifaunal and infaunal species.

Sheltered intertidal mudflats and sandflats are particularly important for species living in the sediments, including amphipods, polychaete worms, burrowing sea urchins and bivalve molluscs. Most of the shores of the Fal and Helford rias are fringed by sandflats and mudflats. These support particularly rich and nationally important sediment communities in the Fal/Ruan estuary, Percuil River and in Passage Cove, including beds of dwarf eelgrass *Zostera noltii* and diverse invertebrate communities.

Falmouth Bay to St Austell Bay Special Protection Area (SPA) (Natural England, 2014a)

Falmouth Bay to St Austell Bay Special Protection Area (SPA), immediately east of Falmouth Inner Harbour, is on the south coast of Cornwall, covering the marine environment incorporating five shallow, sandy bays; Falmouth Bay, Gerrans Bay, Veryan Bay, Mevagissey Bay and St Austell Bay. It also includes Carrick Roads, an estuarine area which meets the sea between Falmouth and

St Mawes, and part of the tidal Helford River. The river complex areas are part of a ria system, typified by steep sides and slow tidal currents, with subtidal rocky shores and exposed intertidal mud on creeks and river branches. The site qualifies as SPA as it is used regularly by 1% or more of the Great Britain population of the following species listed in Annex I in any season: Black-throated Diver, Great Northern Diver and Slavonian Grebe (Natural England, 2014a).

4 Nature of contaminated sediment proposed for dredging

4.1 Summary of sampling and analysis of contaminants

The analysis of the contaminated sediment (data provided by Ramboll) has been undertaken on the basis of chemical analysis of vibrocores. The data has been summarised in three different areas, to the north, east and west of the site. For further information, refer to ES Technical Appendix 8.3 Ground Investigation Interpretative Report (Ramboll, 2024).

Various contaminants have been encountered in the marine sediment across the site, such as heavy metals, PCBs, organo-tins, pesticides, PAHs, and BDE. These show clear lateral and vertical patterns across the site: there is a general trend of decreasing contamination at greater depths, and with increasing distance away from the wharfs. The vertical and lateral distribution of material with concentrations of contaminants which may pose a risk to the marine environment are summarised in Figure 2.1.

For the purposes of this assessment, Cu, Hg, Pb, Zn, Tributyltin, Dibutyltin and PCBs have been selected as the contaminants of most concern.

4.2 Contaminant concentrations used in this report

On the basis of the data collected , mean contaminant concentrations for those contaminants exceeding CAL2 thresholds within the volume of contaminated sediment to be dredged (221,000 m^3), i.e. Cu, Hg, Pb, Zn, Tributyltin, Dibutyltin and PCBs have been calculated for the North, East and West areas of the proposed dredging. Mean concentrations within the different areas are used here because in practice hotspots of contamination will be mixed with less contaminated material within a bucket and mixed again when released into the water column through the dispersion and movement of water. The resulting mean contaminant concentrations are presented in Table 4.1 below. Those mean values exceeding the CAL2 level are presented in **bold**.

Table 4.1: Estimated mean contaminant concentrations for contaminated sediment within North (Queens Wharf), East (Western Wharf) and West (FLOW Basin) areas (mg/Kg)

Area	Cu	Hg	Pb	Zn	Tributyltin	Dibutyltin	PCBs
North	136	2.4	169	354	0.82	0.21	0.16
East	346	**3.6**	115	374	**5.2**	0.77	**0.20**
West	**466**	**3.5**	**526**	**1982**	0.85	0.23	**0.21**
CAL2	*400*	*3*	*500*	*800*	*1*	*1*	*0.2*

Data Source: Ramboll

Table 4.1 indicates that the mean sediment concentrations of contaminants in the North area do not exceed the CAL2 level. The East area exceeds the CAL2 level for Mercury and Tributyltin and the West area exceeds the CAL2 level for Copper, Mercury, Lead, Zinc and PCBs.

The above sediment concentrations of contaminants represent around $^1/_3$ of the proposed capital volume (around 221,000 m^3). The remainder (around 422,000 m^3) has contaminant levels below CAL2 and therefore can be disposed offshore at the licensed Falmouth Bay Disposal Site (PL075).

For the remainder of this report, the material with contaminant level below CAL2 that can be disposed of to sea will be referred to as ***uncontaminated*** – merely as a shorthand to delineate it from the material that cannot be disposed of to sea which will be referred to as ***contaminated***.

5 Plume dispersion model

5.1 Description of SEDPLUME-RW model

The 3D sediment plume dispersion model SEDPLUME-RW has been employed in this study to consider the fate of fine material released by the proposed dredging activities. This model is able to use either 3D flow model output or 2D flow model output (the latter, with an assumption of a logarithmic velocity profile through the water column) to predict the 3D movement of sediment particles.

Dispersal in the direction of flow is provided by the shear action of differential current speeds while turbulent dispersion is modelled using a random walk technique. The deposition and erosion of particles are modelled by establishing critical bed shear stresses for erosion and deposition. Erosion of deposited material occurs when this erosion threshold is exceeded while deposition occurs when bed shear stress falls below the deposition threshold.

Note that the dispersion modelling does not represent background concentrations but simulates the increase of suspended sediment concentrations caused by the plumes generated by the dredging activities over and above these background concentrations.

Note also that the plume dispersion modelling represents the fate of fine sediment only. Sand (or gravel) particles resuspended by the dredging process are considered to settle out rapidly either in, or in the vicinity of, the dredger and the fate of these particles is not considered in this report.

5.2 Flow model input

5.2.1 TELEMAC hydrodynamic modelling system

Hydrodynamic modelling was undertaken using TELEMAC, an industry-accepted finite element modelling system currently being used by more than 200 professional and research organisations worldwide. TELEMAC uses an unstructured, triangular grid to finely resolve waters with complex coastlines. For this study TELEMAC-2D, was used.

5.2.2 Modelled area

The flow model covers the area as shown in Figure 5.1, extending from The Lizard in the southwest towards Portholland in the northeast and extending between 15 km and 20 km offshore. The bathymetry and mesh resolution used in the model local to the proposed works is shown in Figure 5.2. The resolution is less than 10 m in the vicinity of the works, and around 40 m within the Fal Estuary, but much larger (around 1000 m) near the model boundary.

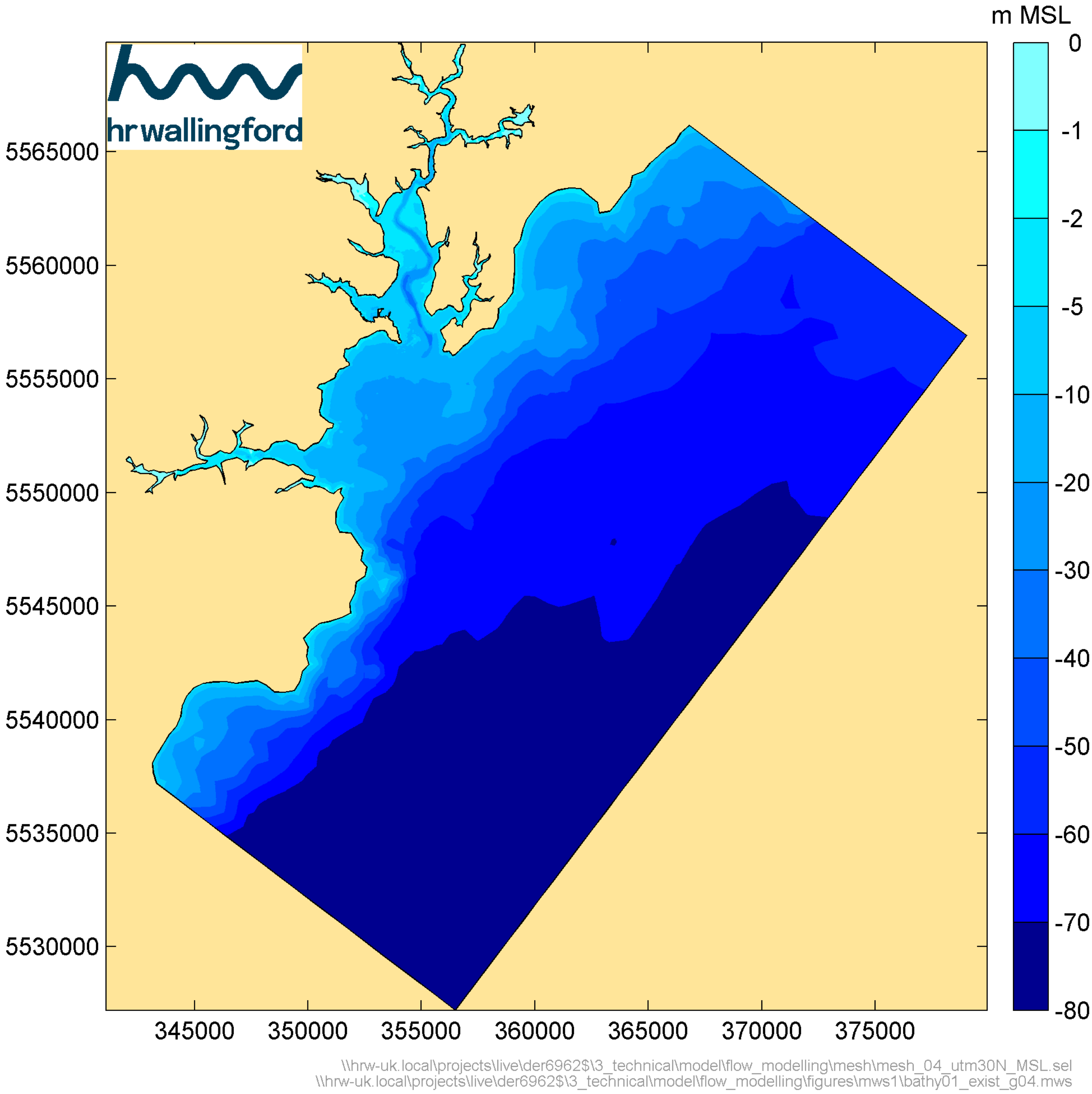

Figure 5.1: Flow model extent

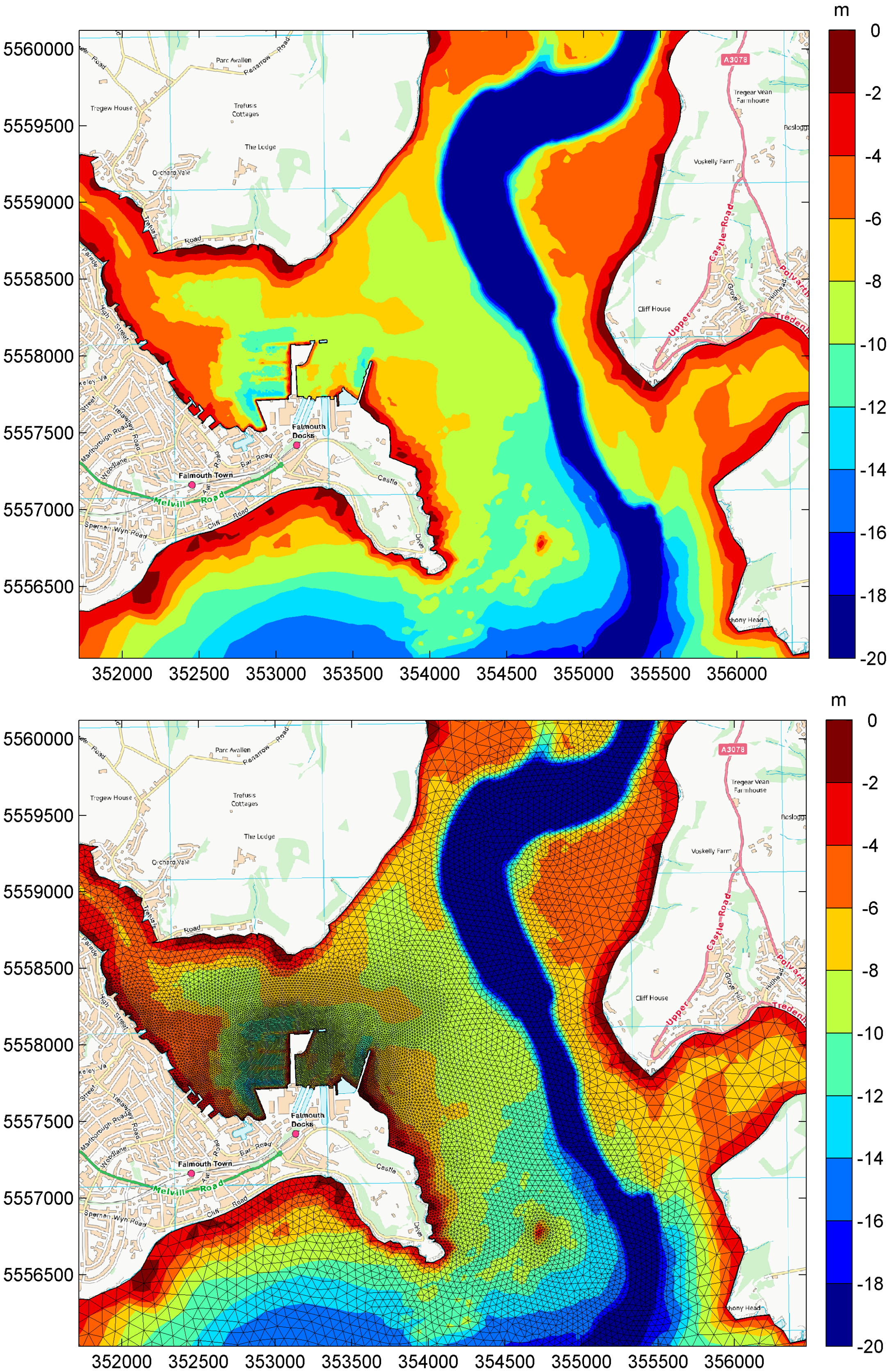

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Figure 5.2: Flow model bathymetry (top) and mesh (bottom) in the vicinity of the proposed works

5.2.3 Boundary conditions

Tidal boundary conditions for the flow model were obtained from version 9.1 of the TPXO global tidal model (Efficient Inverse Modeling of Barotropic Ocean Tides in: Journal of Atmospheric and Oceanic Technology Volume 19 Issue 2 (2002)).

The Fal River, together with the various creeks that flow into the Fal Estuary, provides very little freshwater input to the estuary system (National River Flow Archive, National River Flow Archive). For this reason, the TELEMAC model is run without freshwater input.

For the present study, hydrodynamic conditions were chosen that will be representative of those that occur at the site. A typical spring-neap cycle was simulated in which spring and neap tidal ranges are close to the mean spring and mean neap ranges, therefore ensuring that the simulations are suitably representative of the range of tidal variation. For the purposes of the plumes study the flow model was used to generate a 17-day period of flow starting on 3 March 2021.

5.3 Description of sediment plume dispersion simulations

5.3.1 Location of dredging

Simulations were undertaken to reproduce the effects of the proposed dredging. These simulations all simulated a 15-day spring-neap period but represented dredging moving throughout the eastern, northern and western parts of the site. The dredging paths represented in the simulations are shown in Figure 5.3. The West area is also referred to as the Floating Offshore Wind (FLOW) basin. This approach meant that each simulation included sediment released thought the area of most dredging and showed the variability of effect associated with difference tide ranges.

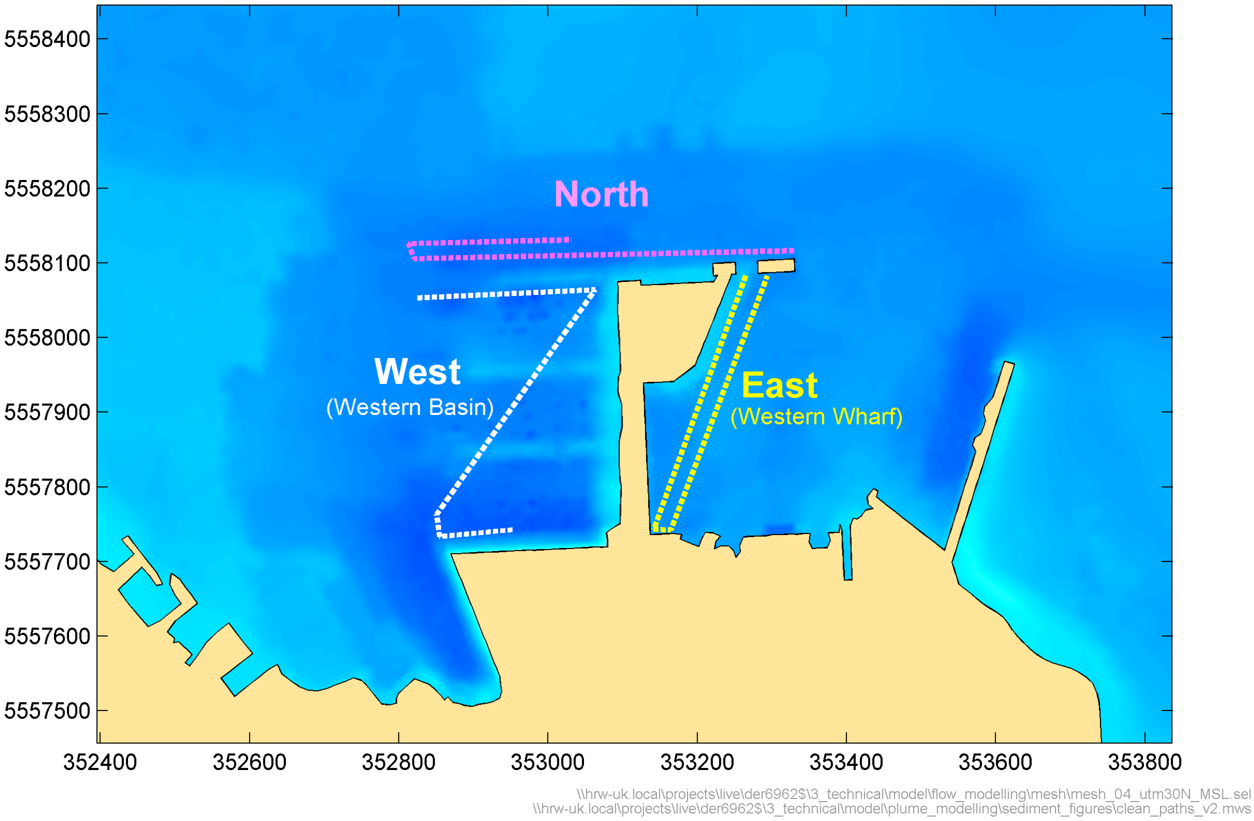

Figure 5.3: Dredging paths used in plume dispersion modelling

5.3.2 Sediment release rates

The sediment to be dredged is predominantly described as sandy mud with an average fine sediment content of 67%. Assuming this data and the dredging approach described in Section 2, representative source terms for the release of fine sediment resulting from the dredging were estimated and are shown in Table 5.1. Source terms are provided for a backhoe with a larger bucket (and productivity) for removing uncontaminated sediment and two cases for a medium/large, lidded bucket (with a lower productivity) for removing contaminated sediment in a controlled fashion. Because of the lower productivity involved with dredging of contaminated sediment, the dredger moves less far along the dredge paths shown in Figure 5.3 within the period simulated compared to the uncontaminated dredging scenario.

The release rates presented in Table 5.1 correspond to the lidded bucket reducing the loss of fine sediment through a smaller bucket (and smaller productivity) and through reducing losses from the absence of surcharging (heaping) of the bucket. These loss rates are the same whether the dredger was operating for the whole tidal cycle (Scenario 1) or for a reduced period around the flood tide (Scenarios 2 and 3).

No further mitigation benefits are ascribed to the lidded bucket through reduction in fine sediment losses. This is a conservative assumption but studies (Wang et al, 2004) of the effects of lidded buckets (backhoes and grab dredgers) indicate that the evidence for additional benefits (loss reductions) is mixed. Using a lid reduces the spillage that occurs from open buckets, but the presence of the lid increases the disturbance occurring at the bed immediately prior to, and during, the progress of the bucket through the bed. Furthermore, these studies indicates that the biggest benefits in reducing sediment release rates come through more controlled, slower and careful dredging (resulting in lower productivity). Changes to the release rate would not reduce the total deposition depth at the end of the whole dredge, just the rate at which the deposition occurred.

Table 5.1: Estimated fine sediment release rates used in plume dispersion modelling

Dredging Plant	Mean release rate of fine sediment (kg/s)	Mean weekly progress of dredger over the ground (m)	Applicable scenario
Medium BHD with lid	1.7	290	2, 3
Medium/large BHD with lid	2.1	290	1
Large BHD	2.9	376	1

5.3.3 Disposal

A simulation of the plumes resulting from sediment disposal at the Licensed Disposal Site PL080 (Falmouth Bay – see Figure 5.4) was undertaken. The simulation represented the regular placement of uncontaminated capital material by barge from the proposed dredging operation using the large 13m^3 backhoe, outlined above and corresponds to Scenario 1 as described in Section 2.1.1. This is the worst case for the rate of sediment disposed at the disposal site.

The simulation was based on two barges of 700 m^3 capacity placing material at the disposal site every 94 minutes and it was assumed that this disposal operation would be representative for capital dredging in the east, north and west of the dredging site. The placed sediment was assumed to be on average 17% gravel, 16% sand and 67% silt/clay on the basis of vibrocore samples provided by Ramboll.

It was further assumed that during a disposal event a small part (2% for dense disposal releases, Land and Bray, 1998) of the release would form a “surface plume” in the water column while the remainder would form a dynamic plume which would descend to the seabed under the action of gravity. During this descent ambient water is entrained into the plume, causing mixing and dilution. When the plume impinges onto the bed it forms a density current and expands radially outwards over the bed driven by the (negative) buoyancy. As the plume expands it become more dilute due to mixing and settling of particles onto the bed. At some point the remaining density current is sufficiently diffuse that it can be entrained by currents in the overlying water, whereupon it forms a passive plume. All of these processes are included in the SEDPLUME-RW model (referred to as SEDTRAIL-3D in Spearman et al, 2003, 2007).

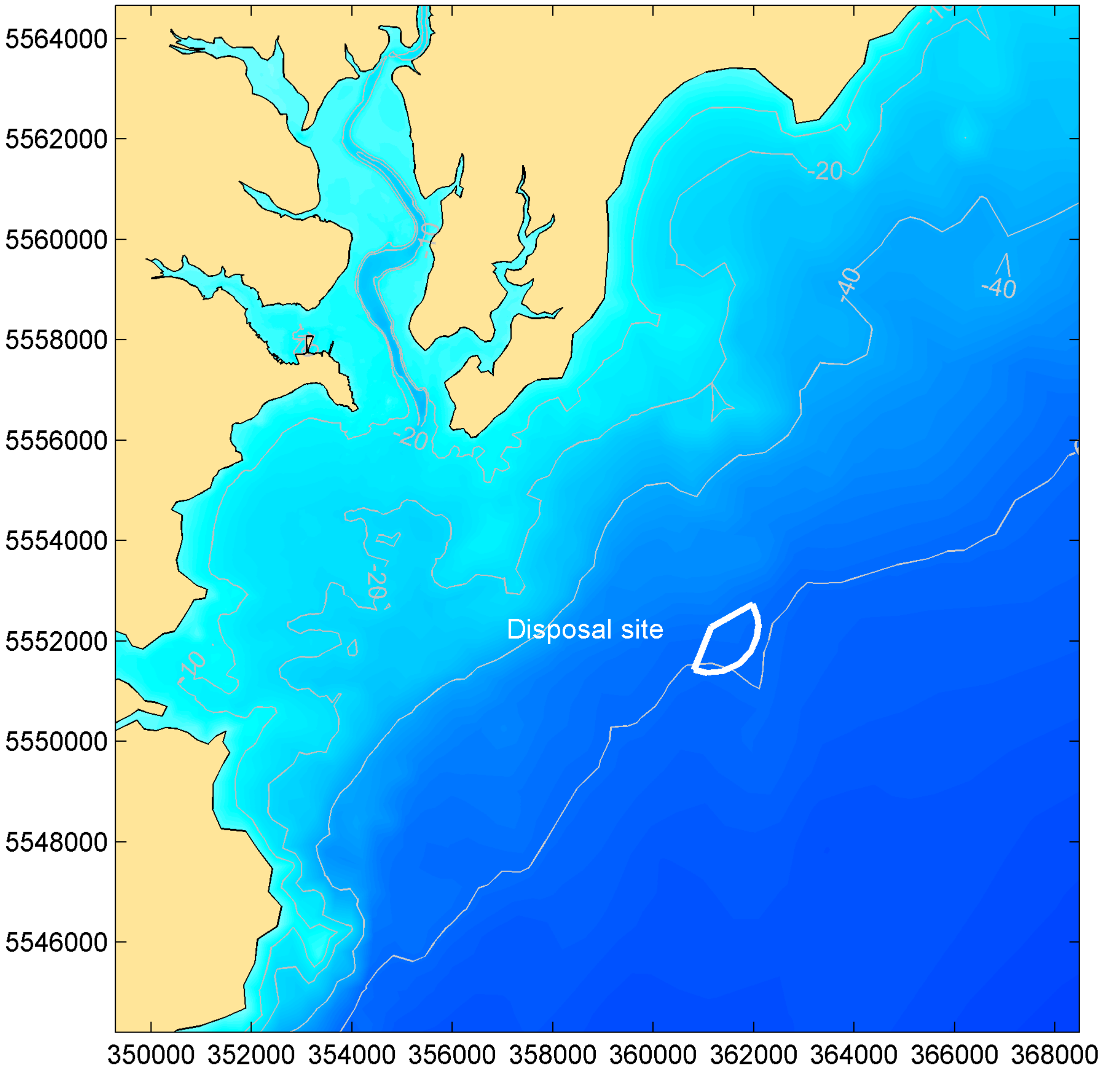

Figure 5.4: Offshore disposal site PL080

5.4 Simulation parameters

The sediment parameters used in all simulations are summarised in Table 5.2.

Table 5.2: Sediment parameter settings

Parameter	Value
Critical shear stress for deposition of sediment	0.1 N/m²
Critical shear stress for erosion of silt/clay	0.2 N/m²
Erosion constant, M_e $[\frac{\partial m}{\partial t} = M_e(\tau - \tau_e)]$	0.002 kg/N/m2/s
Settling velocity of fine sediment fraction	1 mm/s
Dry sediment density of deposited fine sediment	500 kg/m³

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6 Results of sediment plume dispersion modelling

6.1 Introduction

Four types of figures are presented to summarise the predicted changes in suspended sediment concentration and the predicted fine sediment deposition resulting from the proposed works. These are as follows:

- **Plots of peak suspended sediment concentration increases**. These figures show the envelope of the maximum increases that occur over the simulation and so form an amalgam of results from different times over the simulation. These figures clearly indicate the scale and location of where concentration increases will occur but do not show the nature of the plume at any given time, or how representative any increases are. For the purposes of this report only suspended sediment increases of more than 1 mg/l (approximately 20% of the typical baseline concentrations seen) are plotted.
- **Plots of mean suspended sediment concentration increases**. These figures show the mean increases that occur over the simulation. These figures indicate the average conditions experienced at any particular location, but they do not provide information on the scale and location of the plume at any given time and so should be considered along-side the peak concentration figures. For the purposes of this report only suspended sediment increases of more than 1 mg/l (approximately 20% of the typical baseline concentrations seen) are plotted.
- **Time series of increase in suspended sediment concentration**. These figures show the variation in suspended sediment concentration over time at a selected set of locations are presented in Section 6.2.7. From these figures the variation from tide to tide can be seen as well as the duration of any predicted increase in concentration.
- **Plots of total deposition depth**. By using the calculated dredger production rate and knowledge of the total volume to be dredged in each area, a suitable scaling was calculated to combine the results and present the total depth of deposition from the whole project. For these figures, the area of the main dredging is masked as any deposition in these areas would be subject to re-dredging.

6.2 Results for dredging scenario 1

In this scenario the contaminated sediment requiring land disposal is removed by the 10 m^3 lidded bucket backhoe and the remaining sediment is removed by the 13 m^3 bucket backhoe. The dredging occurs throughout the tide.

6.2.1 Dredging of uncontaminated sediment in the east of the site (Western Wharf)

Figure 6.1 and Figure 6.2 summarise the results for dredging **uncontaminated** sediment in the **east** of the site (in the Western Wharf).

The predicted peak increase in suspended sediment concentration resulting from dredging uncontaminated sediment in the east part of the site is shown in Figure 6.1. The figure shows that the footprint of the plume concentration increases extends just outside of the red line to the west of the site and up to 2 km south of the site (around 400 m south of Pendennis Point), at which point the increases in concentration fall below 1 mg/l. In the immediate vicinity of the dredging, concentration increases are of the order of 100’s of mg/l above background.

The mean peak increase in suspended sediment concentration resulting from dredging uncontaminated sediment in the east part of the site is shown in Figure 6.2. The figure shows that the mean concentration increases of 1 mg/l or more are (more or less) confined to the site area defined by the red line.

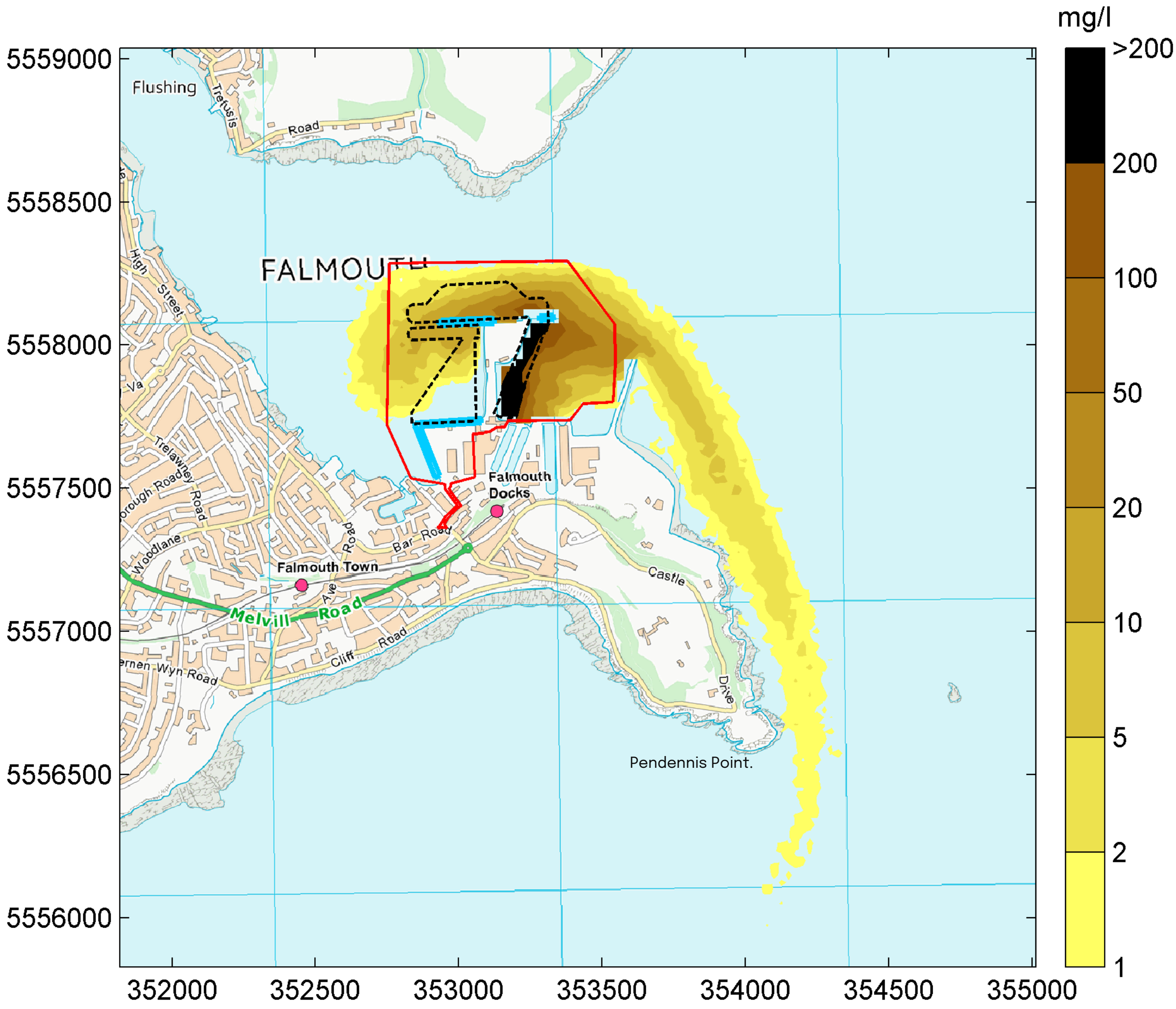

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Figure 6.1: Peak predicted increase in suspended sediment concentration, dredging **uncontaminated** sediment in the **east** part of the site (Western Wharf)

The site area is defined by the red line (information provided by Ramboll)
The specific areas of dredging are shown by the dotted black line

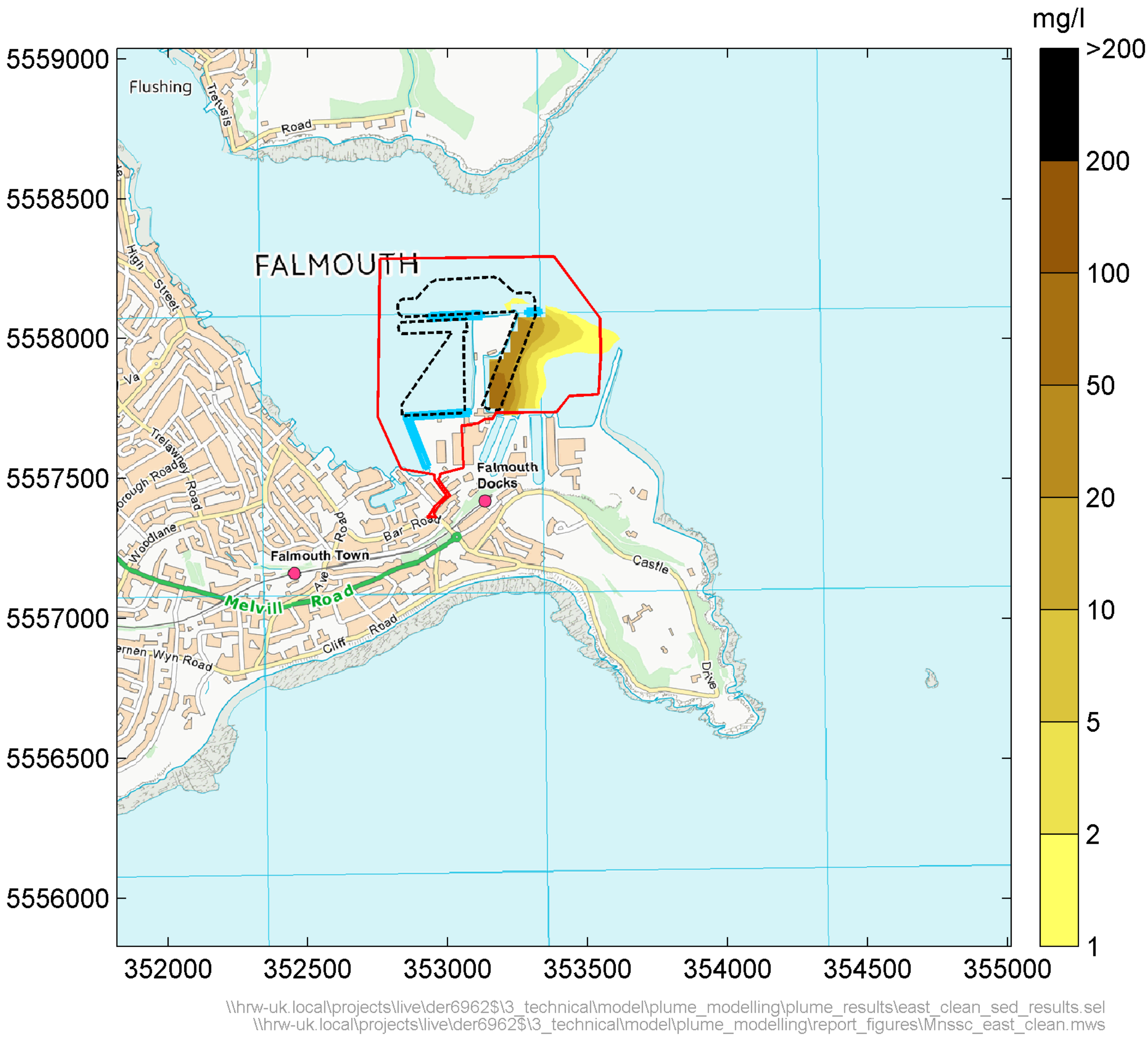

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Figure 6.2: Mean predicted increase in suspended sediment concentration, dredging **uncontaminated** sediment in the **east** part of the site (Western Wharf)

The site area is defined by the red line (information provided by Ramboll)
The specific areas of dredging are shown by the dotted black line

6.2.2 Dredging of contaminated sediment in the east of the site (Western Wharf)

Figure 6.3 and Figure 6.4 summarise the results for dredging **contaminated** sediment in the **east** of the site (in the Western Wharf).

The predicted peak increase in suspended sediment concentration Figure 6.3. The figure shows that the footprint of the plume concentration increases extends just outside of the red line to the west of the site and up to 2 km south of the site (around 500 m south of Pendennis Point), at which point the increases in concentration fall below 1 mg/l. In the immediate vicinity of the dredging, concentration increases are of the order of 100's of mg/l above background.

The mean peak increase in suspended sediment concentration resulting from dredging contaminated sediment in the east part of the site is shown in Figure 6.4. The figure shows that the mean concentration increases of 1 mg/l or more are (more or less) confined to the site area defined by the red line.

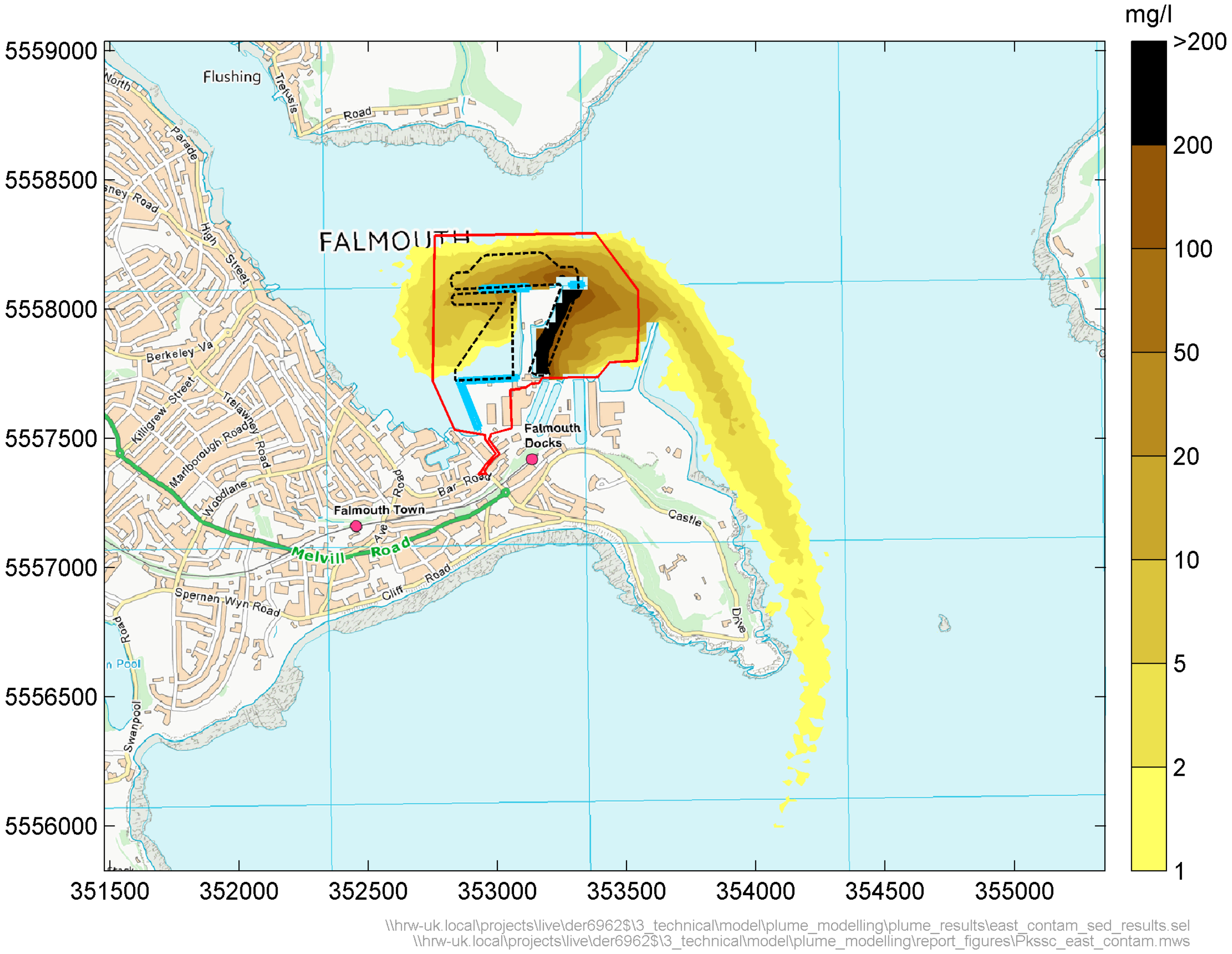

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Figure 6.3: Peak predicted increase in suspended sediment concentration, dredging **contaminated** sediment in the **east** part of the site (Western Wharf)

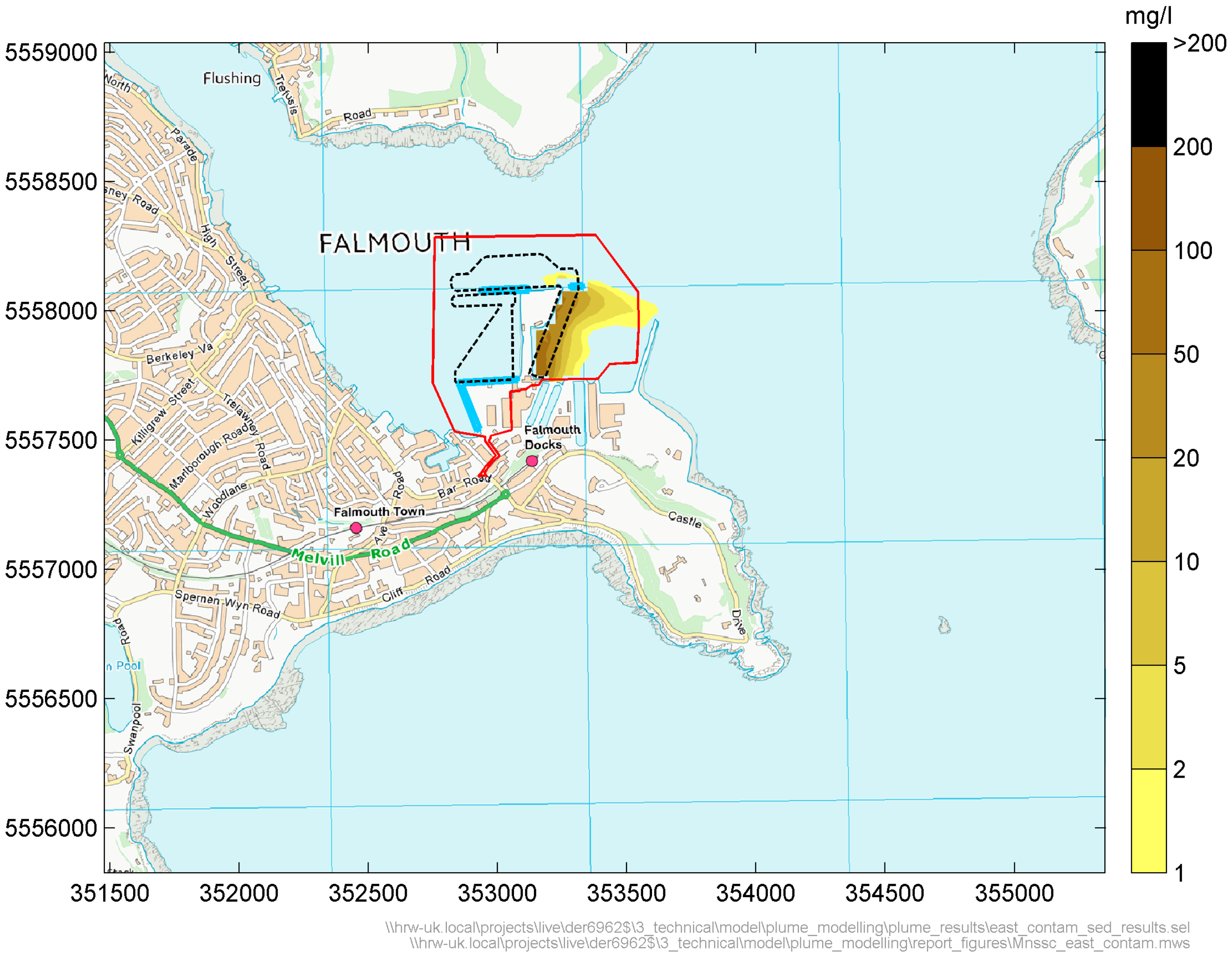

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Figure 6.4: Mean predicted increase in suspended sediment concentration, dredging **contaminated** sediment in the **east** part of the site (Western Wharf)

6.2.3 Dredging uncontaminated sediment in the north of the site

Figure 6.5 and Figure 6.6 summarise the results for dredging **uncontaminated** sediment in the **north** of the site.

The predicted peak increase in suspended sediment concentration resulting from dredging uncontaminated sediment in the east part of the site is shown in Figure 6.5. The figure shows that the footprint of the plume concentration increases extends up to 450 m west of the site area (red line) and up to 2.8 km south of the site (around 1.7 km southwest of Pendennis Point), at which point the increases in concentration fall below 1 mg/l. In the immediate vicinity of the dredging, concentration increases are of the order of 100's of mg/l above background.

The mean peak increase in suspended sediment concentration resulting from dredging uncontaminated sediment in the east part of the site is shown in Figure 6.6. The figure shows that the mean concentration increases of 1 mg/l or extend up to 140 m west of, and up to 220 m east of, the site area (red line).

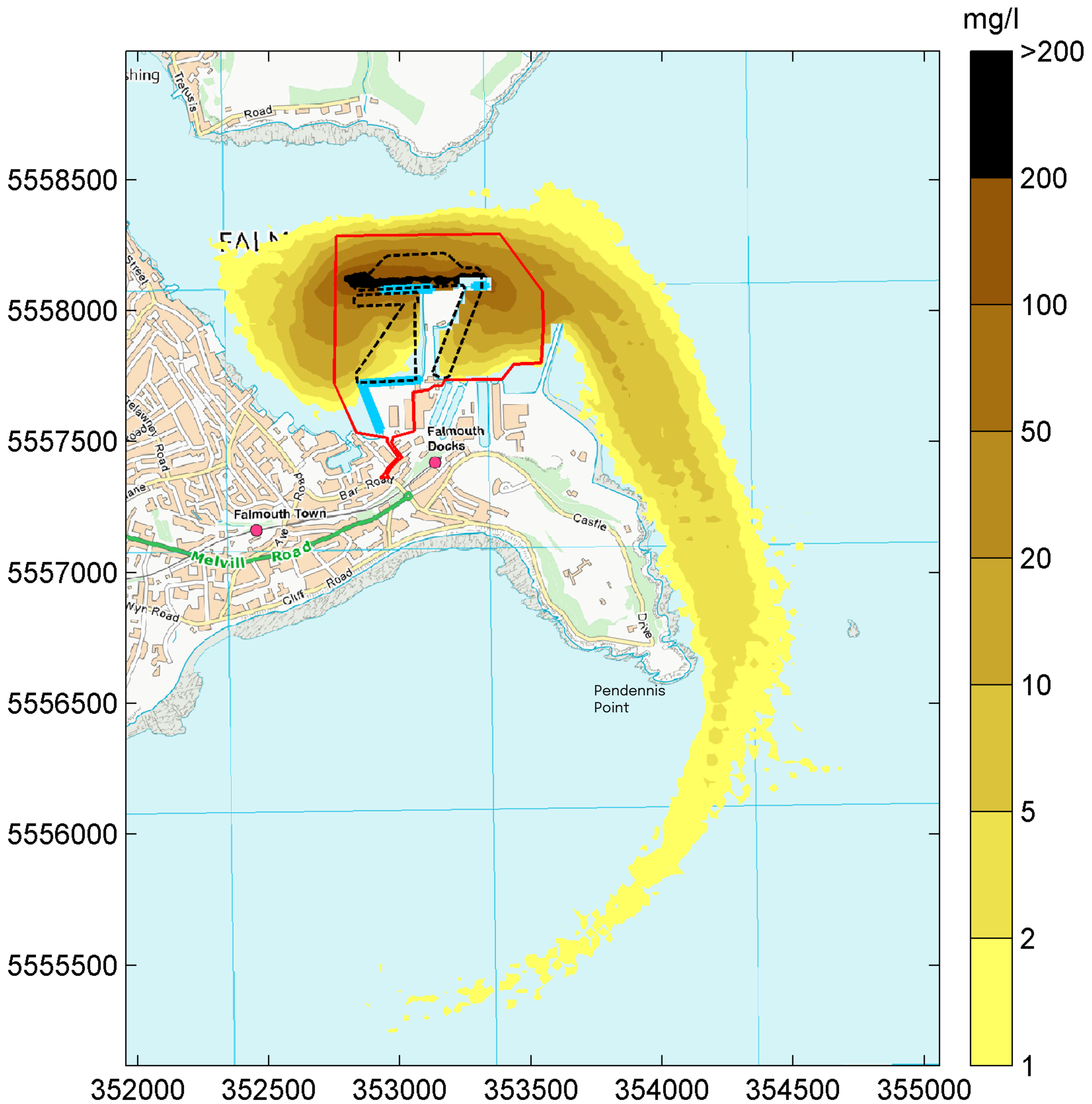

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Figure 6.5: Peak predicted increase in suspended sediment concentration, dredging **uncontaminated** sediment in the **north** part of the site

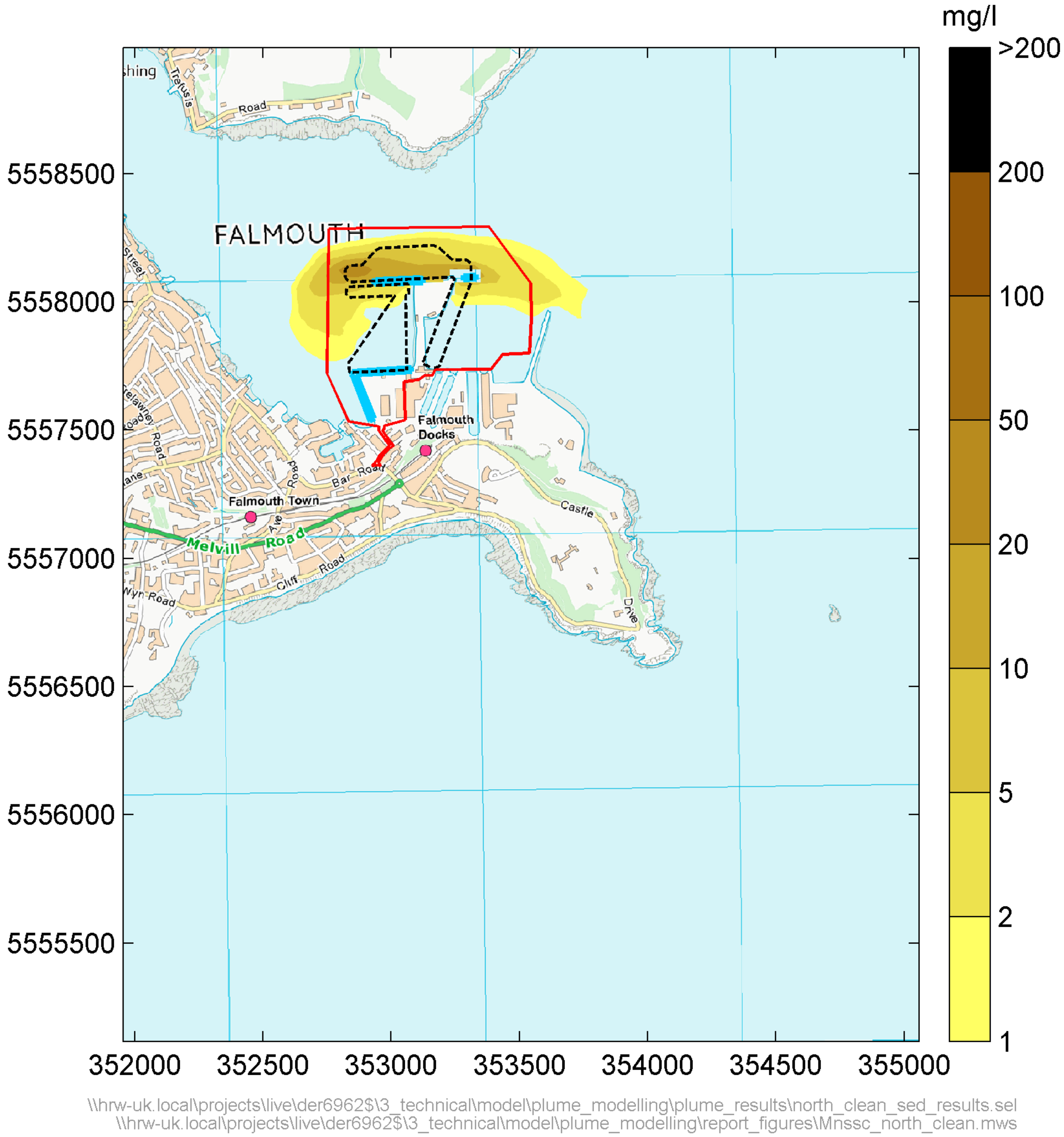

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Figure 6.6: Mean predicted increase in suspended sediment concentration, dredging **uncontaminated** sediment in the **north** part of the site

6.2.4 Dredging contaminated sediment in the north of the site

Figure 6.7 and Figure 6.8 summarise the results for dredging **contaminated** sediment in the **north** of the site.

The predicted peak increase in suspended sediment concentration resulting from dredging contaminated sediment in the east part of the site is shown in Figure 6.11. The figure shows that the footprint of the plume concentration increases extends up to 300 m west of the site area (red line) and up to 2.2 km south of the site (around 700 m south of Pendennis Point), as which

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point the increases in concentration fall below 1 mg/l. In the immediate vicinity of the dredging, concentration increases are of the order of 100’s of mg/l above background.

The mean peak increase in suspended sediment concentration resulting from dredging contaminated sediment in the east part of the site is shown in Figure 6.8. The figure shows that the mean concentration increases of 1 mg/l or extend up to 120 m west of, and up to 160 m east of, the site area (red line).

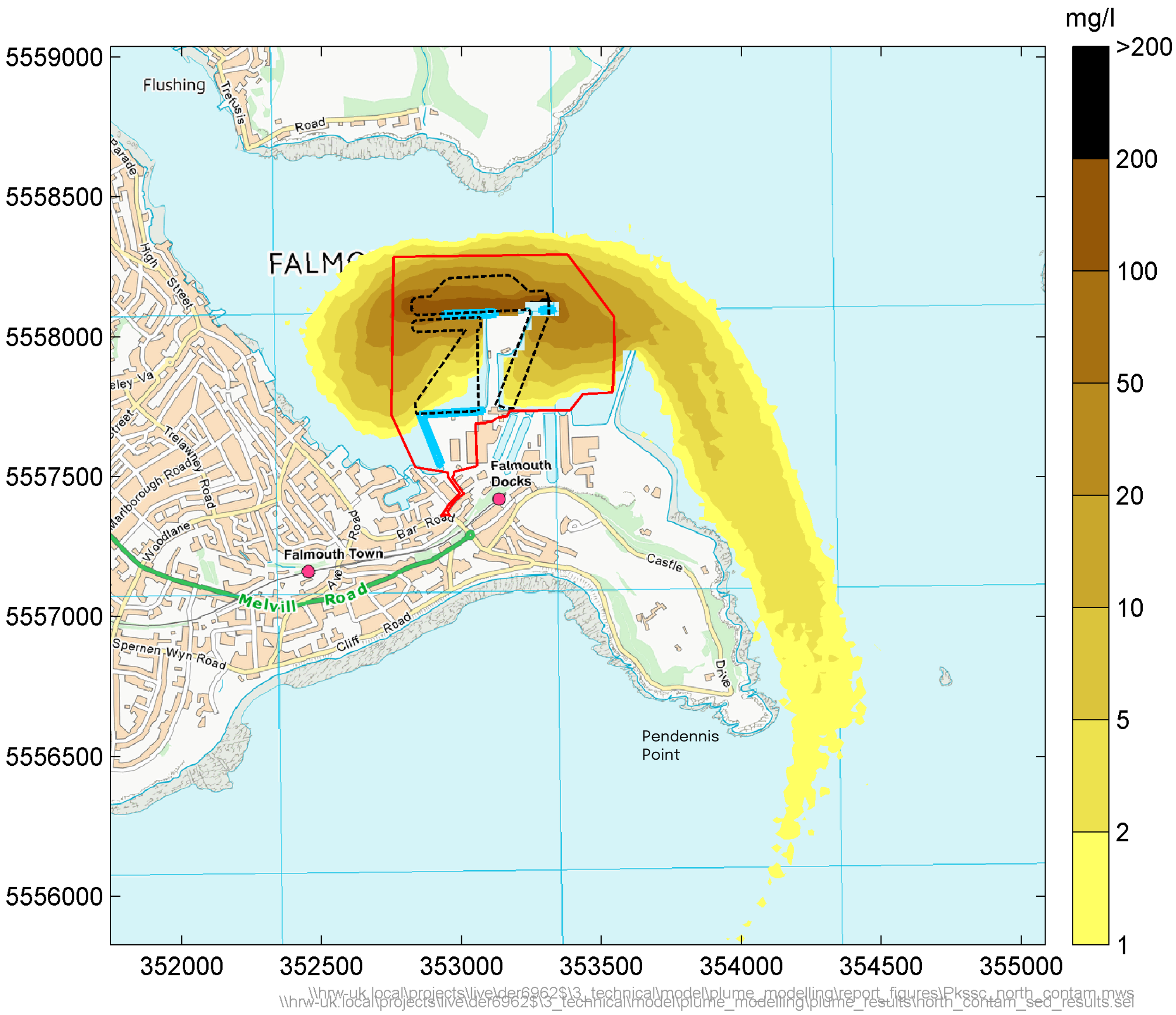

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Figure 6.7: Peak predicted increase in suspended sediment concentration, dredging **contaminated** sediment in the **north** part of the site

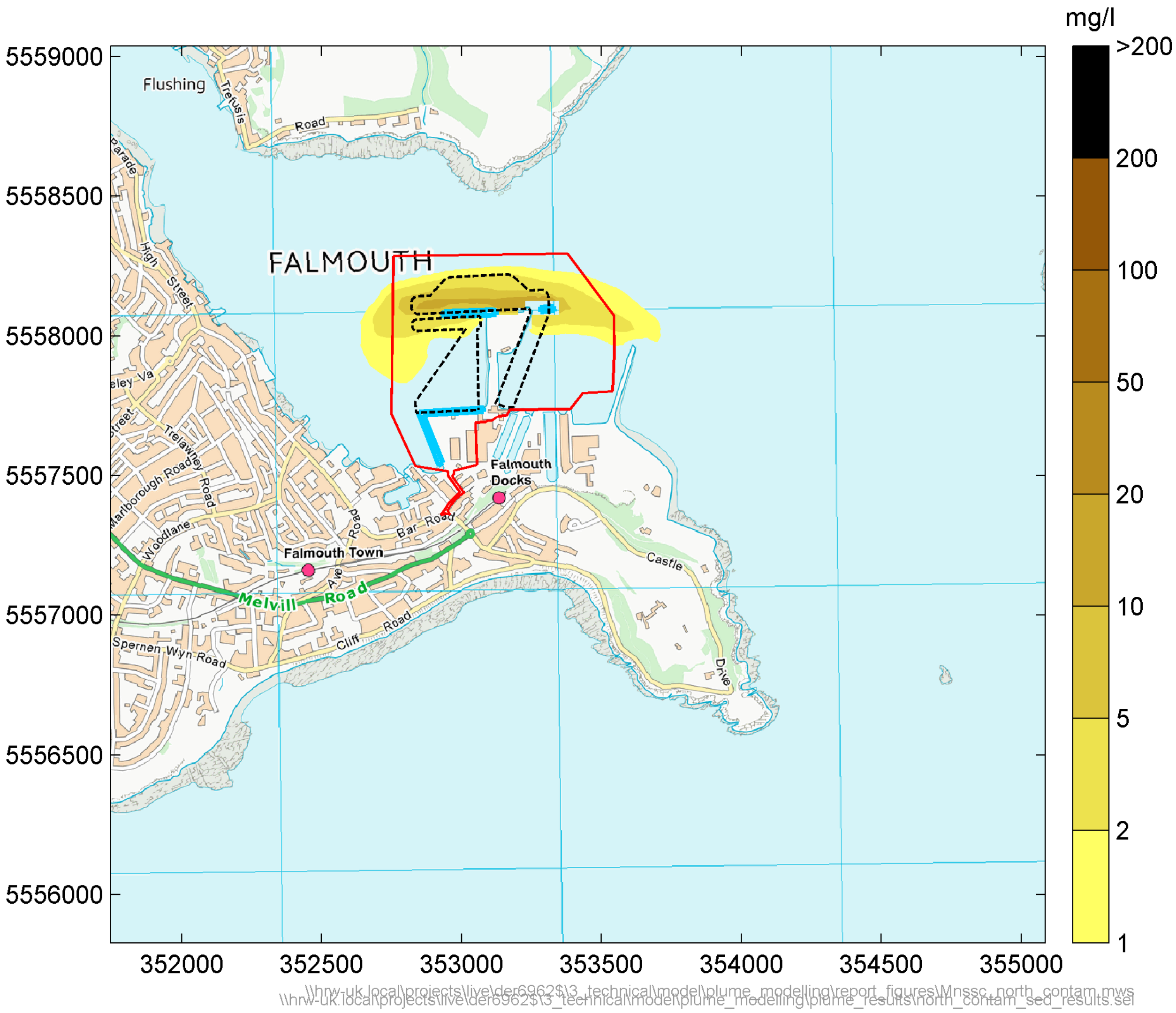

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Figure 6.8: Mean predicted increase in suspended sediment concentration, dredging **contaminated** sediment in the **north** part of the site

6.2.5 Dredging uncontaminated sediment in the west of the site (FLOW Basin)

Figure 6.9 and Figure 6.10 summarise the results for dredging **uncontaminated** sediment in the **west** of the site.

The predicted peak increase in suspended sediment concentration resulting from dredging uncontaminated sediment in the east part of the site is shown in Figure 6.5. The figure shows that the footprint of the plume concentration increases extends up to 450 m west of the site area (red line) and up to 2 km south of the site (around 700 m south of Pendennis Point), at which point the increases in concentration fall below 1 mg/l. In the immediate vicinity of the dredging, concentration increases are of the order of 100's of mg/l above background.

The mean peak increase in suspended sediment concentration resulting from dredging uncontaminated sediment in the east part of the site is shown in Figure 6.10. The figure shows that the mean concentration increases of 1 mg/l or extend up to 110 m west of, and up to 190 m east of, the site area (red line).

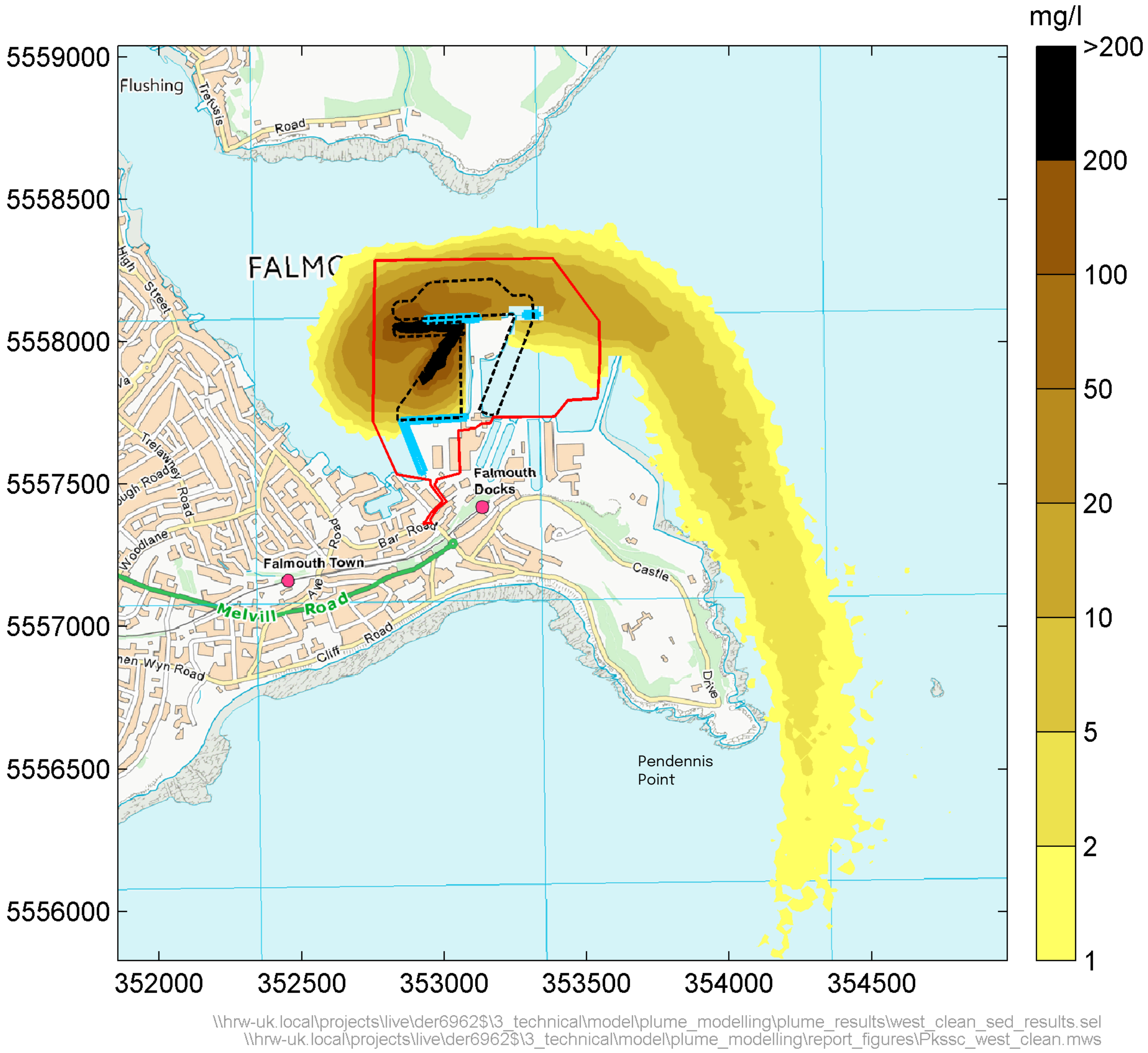

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Figure 6.9: Peak predicted increase in suspended sediment concentration, dredging **uncontaminated** sediment in the **west** part of the site (FLOW Basin)

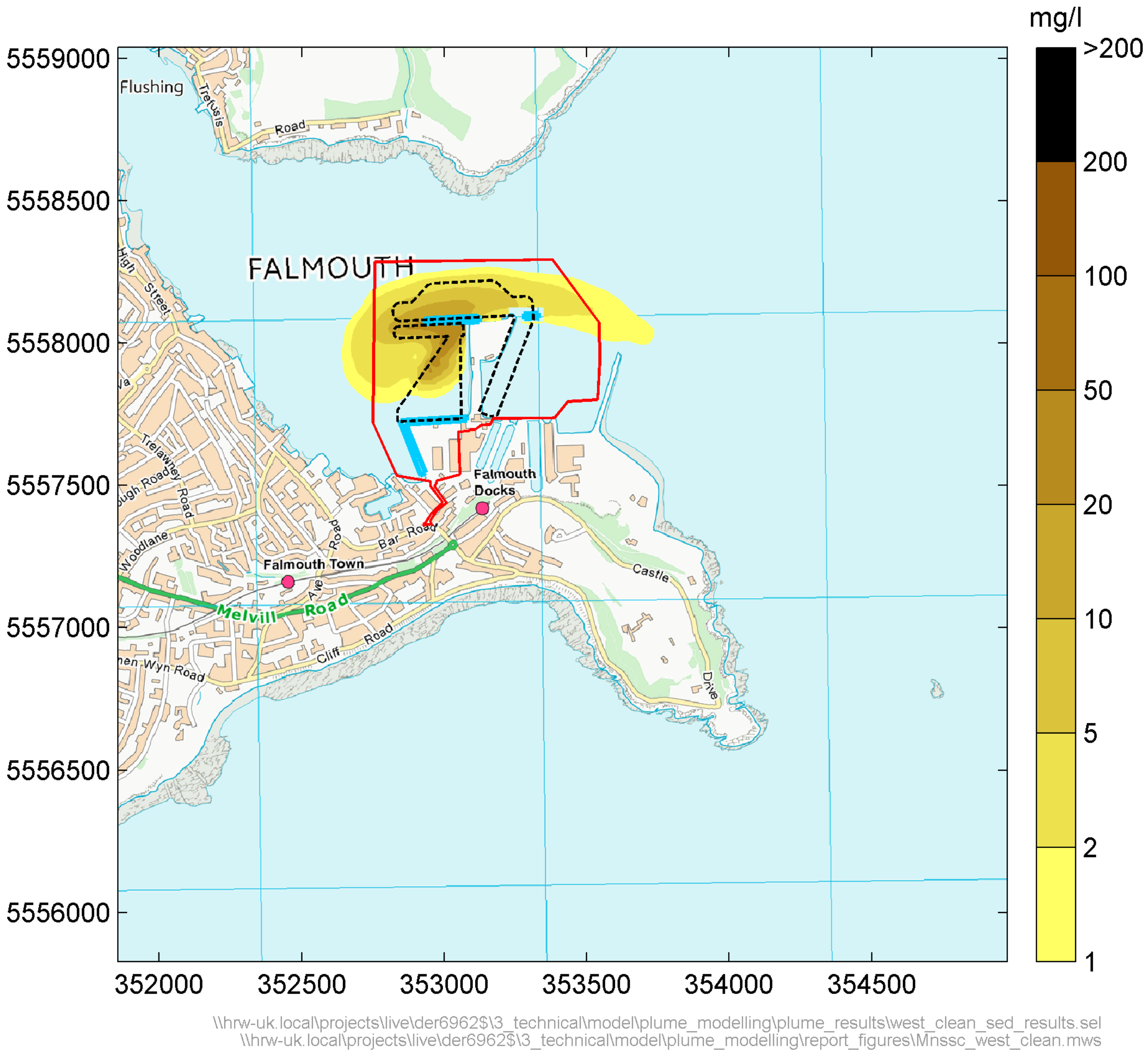

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Figure 6.10: Mean predicted increase in suspended sediment concentration, dredging **uncontaminated** sediment in the **west** part of the site (FLOW Basin)

6.2.6 Dredging contaminated sediment in the west of the site (FLOW Basin)

Figure 6.11 and Figure 6.12 summarise the results for dredging **contaminated** sediment in the **west** of the site.

The predicted peak increase in suspended sediment concentration resulting from dredging contaminated sediment in the east part of the site is shown in Figure 6.11. The figure shows that the footprint of the plume concentration increases extends up to 200 m west of the site area (red line) and up to 2 km south of the site (around 400 m south of Pendennis Point), at which point the increases in concentration fall below 1 mg/l. In the immediate vicinity of the dredging, concentration increases are of the order of 100's of mg/l above background.

The mean peak increase in suspended sediment concentration resulting from dredging contaminated sediment in the east part of the site is shown in Figure 6.12. The figure shows that the mean concentration increases of 1 mg/l or extend up to 90 m west of, and up to 120 m east of, the site area (red line).

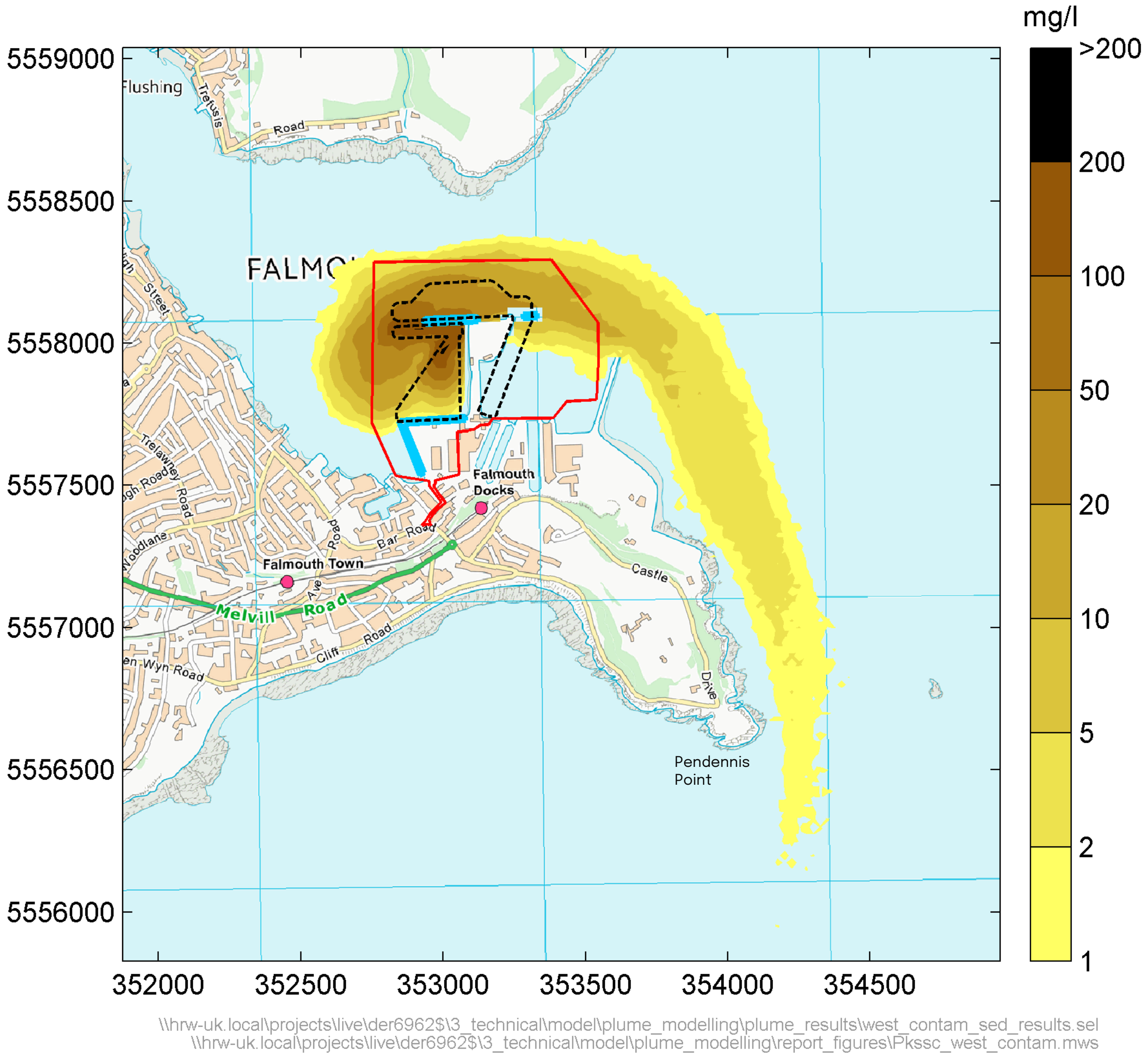

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Figure 6.11: Peak predicted increase in suspended sediment concentration, dredging **contaminated** sediment in the **west** part of the site (FLOW Basin)

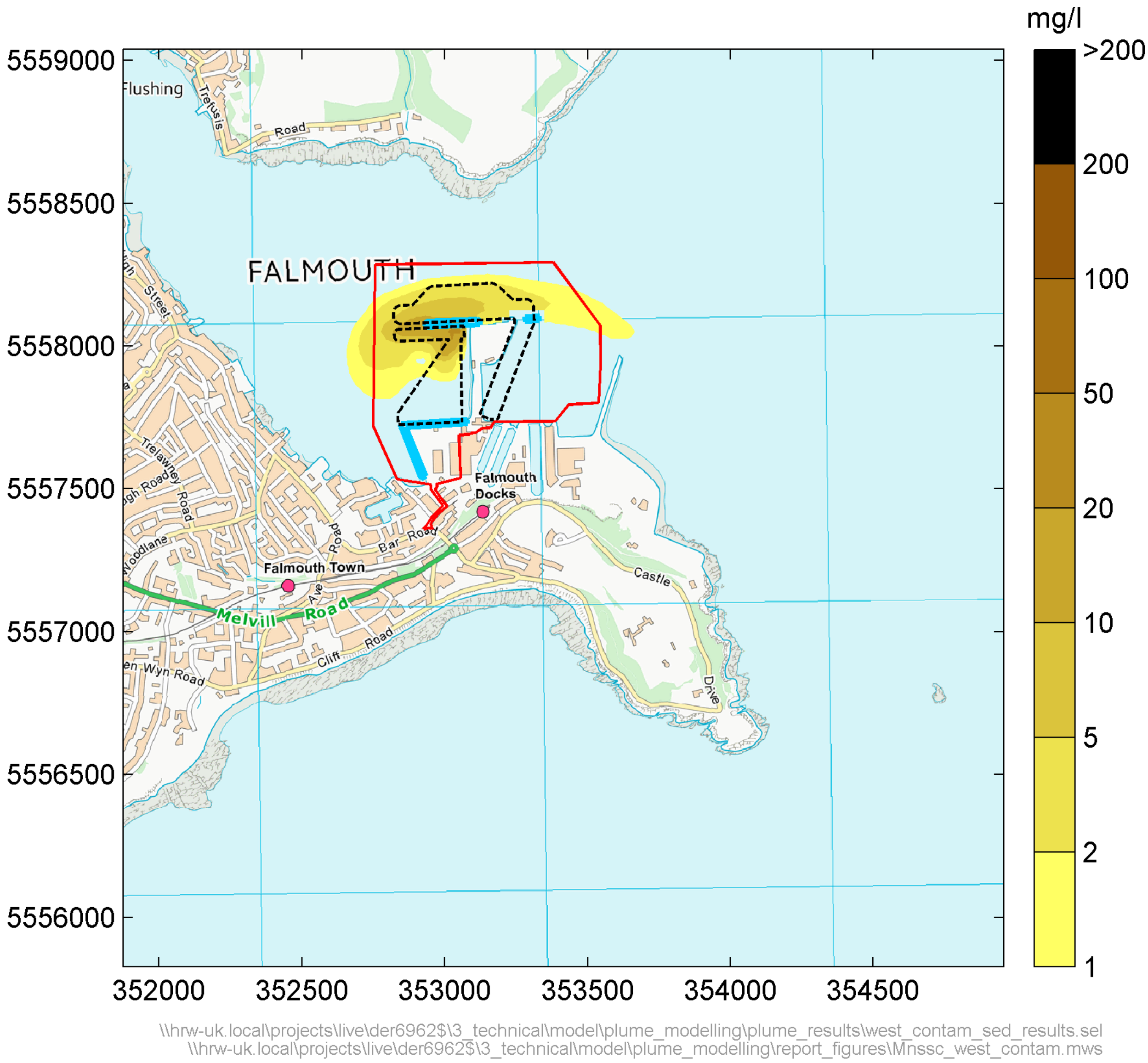

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Figure 6.12: Mean predicted increase in suspended sediment concentration, dredging **contaminated** sediment in the **west** part of the site (FLOW Basin)

6.2.7 Time series of predicted increases in suspended sediment concentration

The following sections present time series plots of increases in suspended sediment concentration at the locations shown in Figure 6.13, arising from dredging in the east, north and west of the site. The locations of the time series were selected by the EIA team in order to inform the marine ecology ES chapter.

Only the suspended sediment concentration increases resulting from the dredging of uncontaminated sediment are shown as more of the sediment to be dredged is uncontaminated and the rates of production, and hence the increases in suspended sediment concentration will be highest in this case.

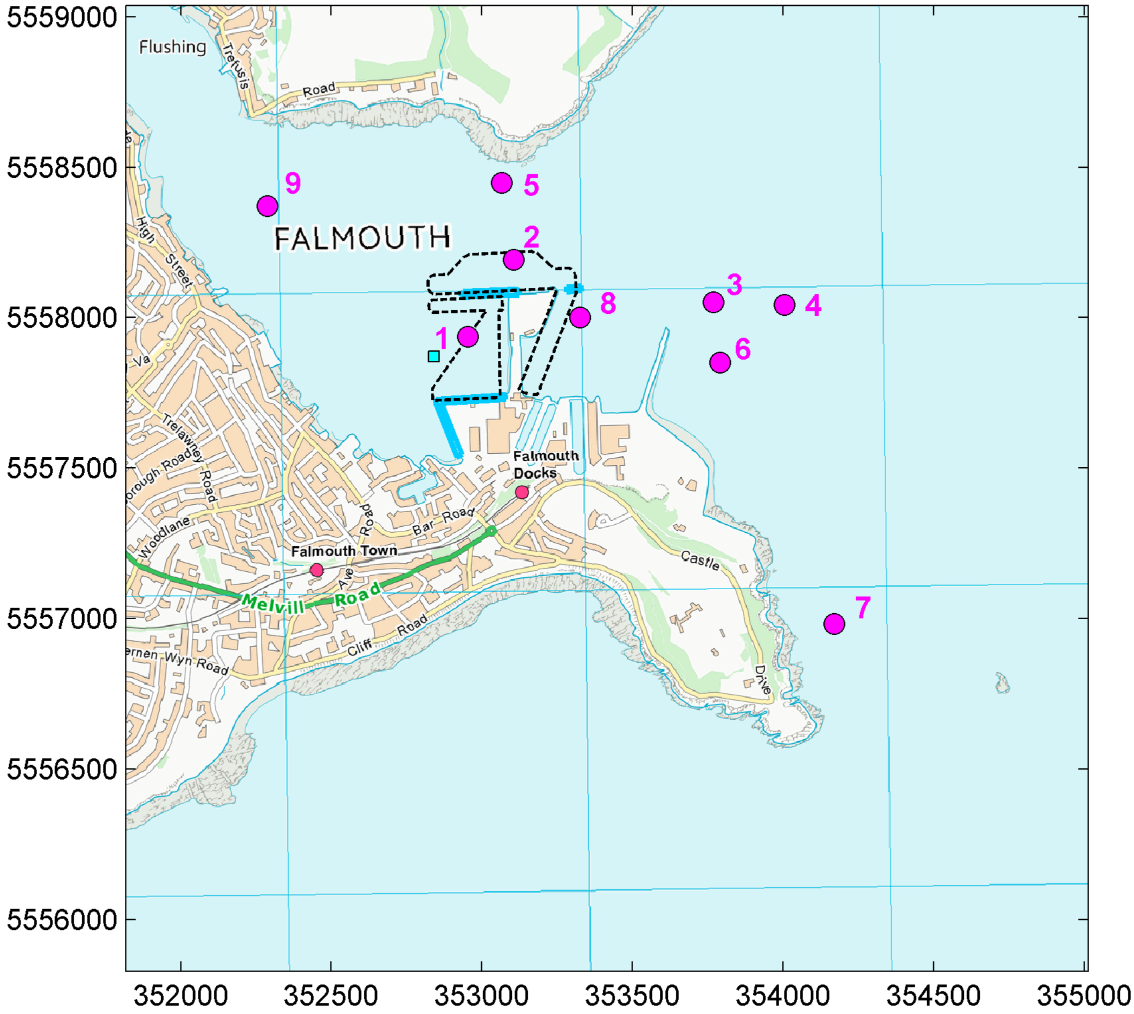

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Figure 6.13: Locations of time series used in the following sections

6.2.8 Time series for dredging in east of the site (Western Wharf)

The predicted increases in suspended sediment concentration above background arising from 15 days of dredging in the east of the site are presented in Figure 6.14. The peak concentration increase (~110 mg/l) occurs at Location 8 which is adjacent to the dredging. Only Locations 2 and 8 exceed increases of 10 mg/l, for 0.05% and 28% of the time, respectively. The results are summarised by Table 6.1 for increases in suspended sediment concentrations.

Table 6.1: Summary of predicted increase in suspended sediment concentration, dredging in the east of the site (Western Wharf)

Point	1	2	3	4	5	6	7	8	9
Maximum increase in SSC (mg/l)	3.2	11.4	1.2	0.1	<0.1	6.3	1.4	108.6	0.3
Average increase in SSC (mg/l)	<0.1	0.1	<0.1	<0.1	<0.1	0.2	<0.1	14.1	<0.1
95% of increase in SSC (mg/l)	0.1	0.1	<0.1	<0.1	<0.1	1.6	0.2	73.0	<0.1

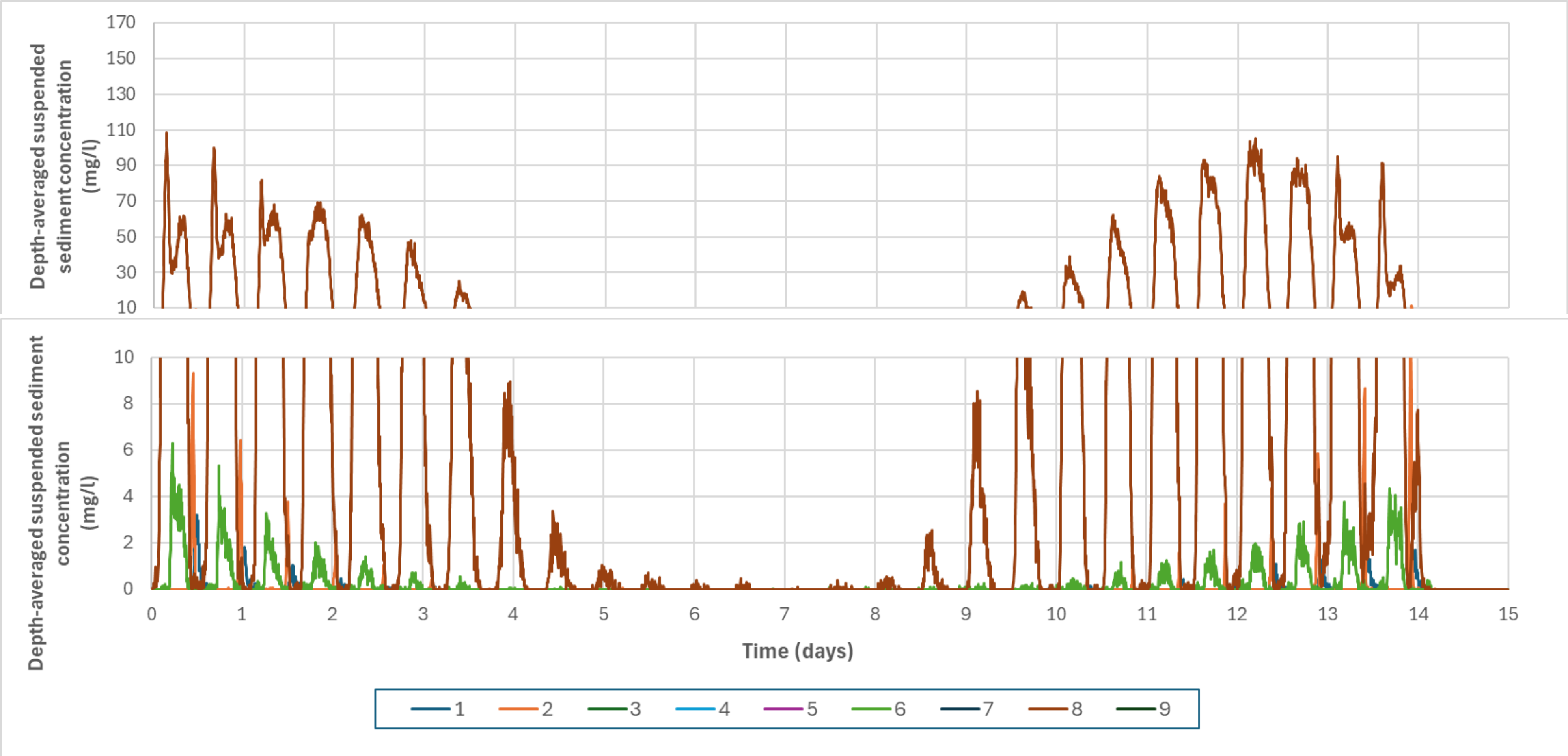

Figure 6.14: Time series of predicted increase in suspended sediment concentration, dredging in the east of the site

6.2.9 Time series for dredging in north of the site

The predicted increases in suspended sediment concentration above background arising from 14 days of dredging in the north of the site are presented in Figure 6.15. The peak concentration increase (~60 mg/l) occurs at Location 2 which is adjacent to the dredging. At the other locations, the predicted peak concentration increase is 14 mg/l or less. Only Locations 2, 3, 6 and 8 exceed increases of 10 mg/l, for 26%, 1.0%, 0.02%, and 1.9% of the time, respectively.

The results are summarised by Table 6.2 for increases in suspended sediment concentrations.

Table 6.2: Summary of predicted increase in suspended sediment concentration, dredging to the north of the site

Point	1	2	3	4	5	6	7	8	9
Maximum increase in SSC (mg/l)	9.7	59.5	14.0	0.7	0.3	10.3	3.0	35.2	0.3
Average increase in SSC (mg/l)	0.7	7	1.1	<0.1	<0.1	0.6	0.1	0.8	<0.1
95% of increase in SSC (mg/l)	2.6	29.7	7.1	0.1	<0.1	3.2	0.7	4.4	<0.1

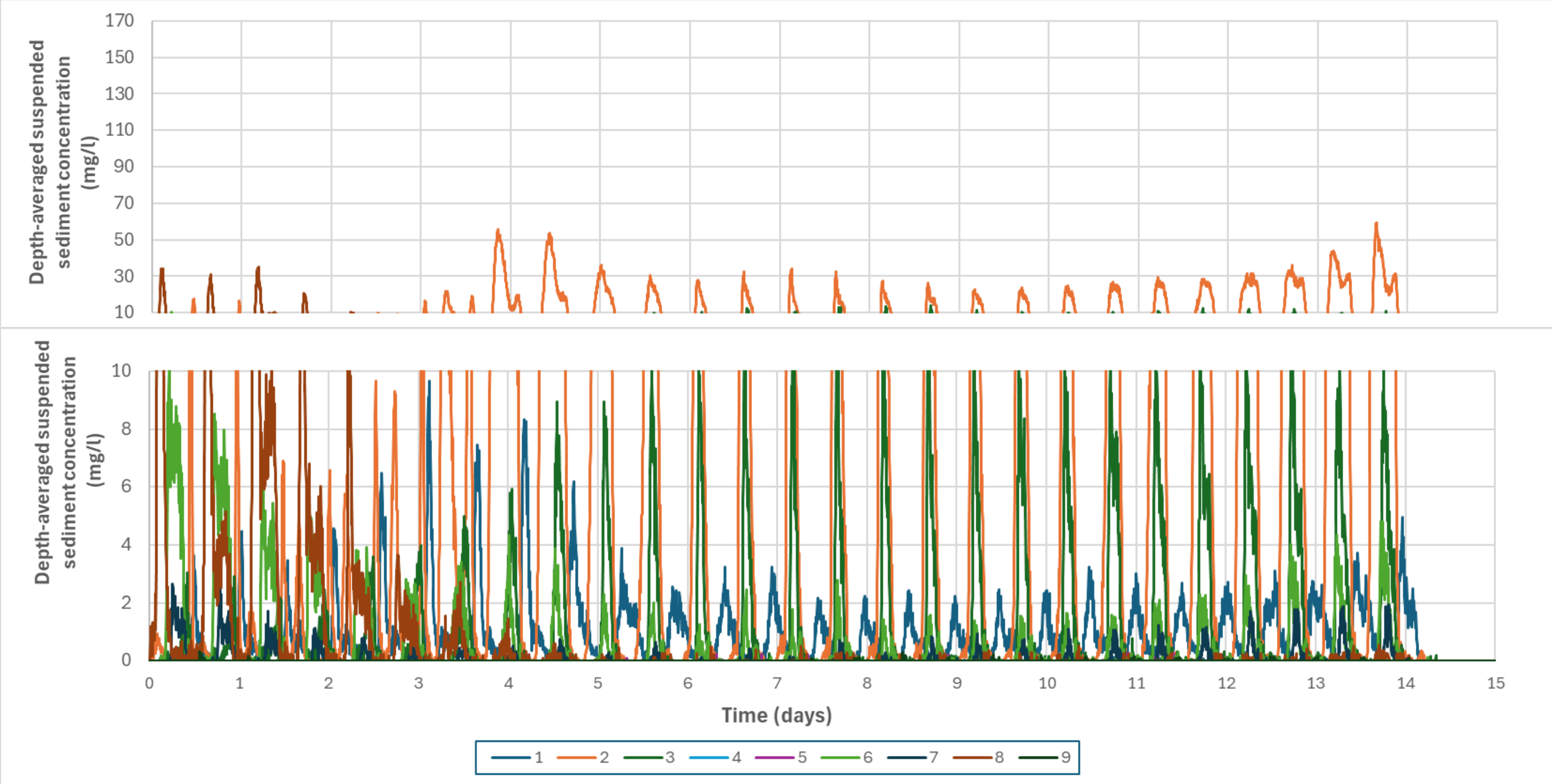

Figure 6.15: Time series of predicted increase in suspended sediment concentration, dredging in the north of the site

6.2.10 Time series for dredging in west of the site (FLOW Basin)

The predicted increases in suspended sediment concentration above background arising from 14 days of dredging in the west of the site are presented in Figure 6.16. The peak concentration increase (~170 mg/l) occurs at Location 1 which is adjacent to the dredging. The next highest peak concentration increase is at Location 2 with 36 mg/l. At the other locations, the predicted peak concentration increase is 10.3 mg/l or less. Only Locations 1 and 2 exceed increases of 10 mg/l, for 30% and 14.4% of the time, respectively.

The results are summarised by Table 6.3 for increases in suspended sediment concentrations.

Table 6.3: Summary of predicted increase in suspended sediment concentration, dredging in the west of the site

Point	1	2	3	4	5	6	7	8	9
Maximum increase in SSC (mg/l)	165.0	35.9	10.3	0.8	0.2	6.4	2.5	2.1	0.1
Average increase in SSC (mg/l)	13.8	3.7	0.5	<0.1	<0.1	0.3	0.1	0.1	<0.1
95% of increase in SSC (mg/l)	66.7	20.8	3.0	0.1	<0.1	2.1	0.5	0.7	<0.1

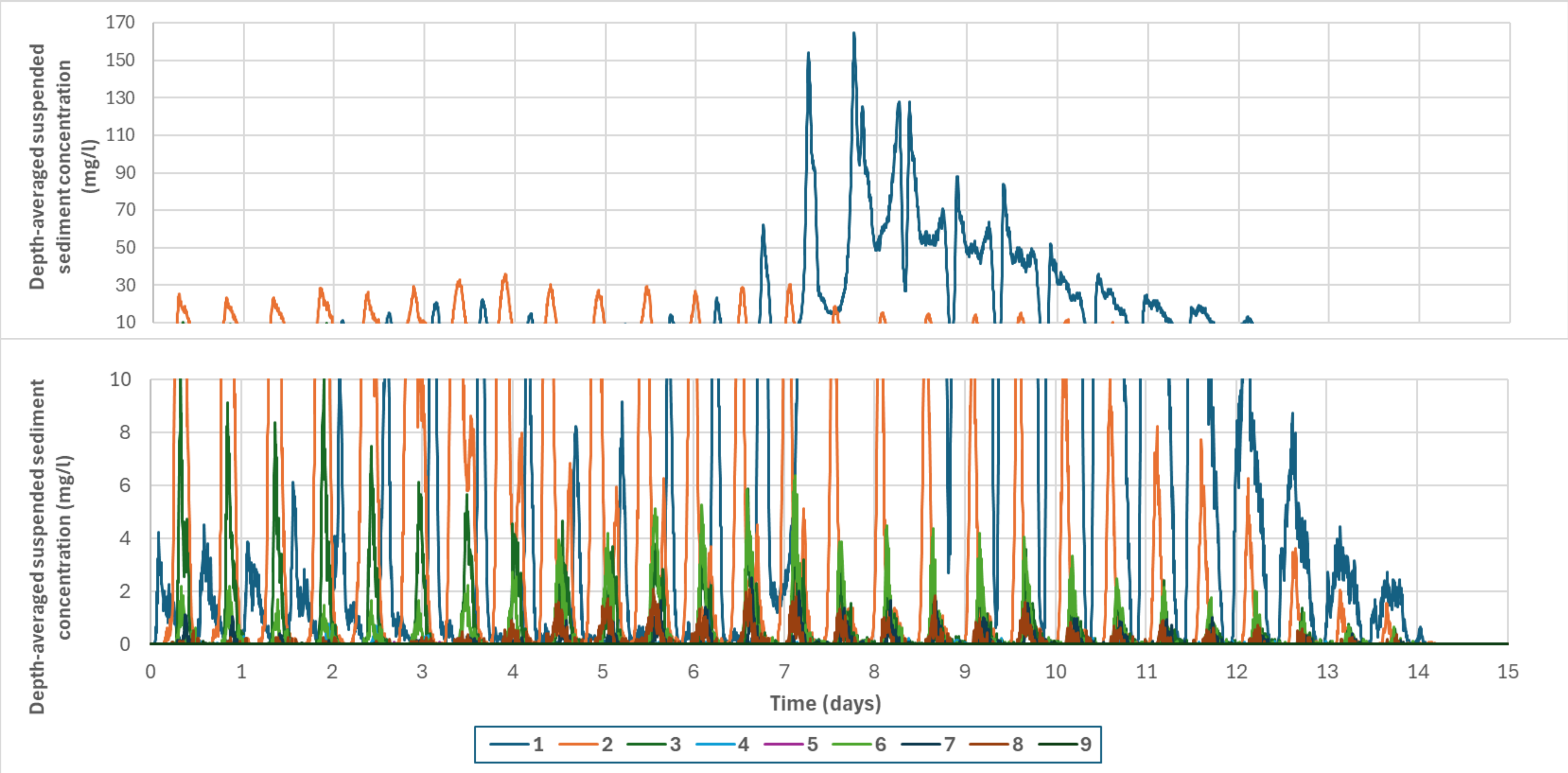

Figure 6.16: Time series of predicted increase in suspended sediment concentration, dredging in the west of the site (FLOW Basin)

6.2.11 Total deposition of fine sediment arising from works

The predicted fine sediment deposition resulting from dredging Scenario 1 as a whole is shown by Figure 6.17. The figure is composed by weighting the contributions of dredging of contaminated and uncontaminated sediment from the different zones in the north, east and west of the site.

Within the dredging areas themselves any deposition will be re-dredged in order to meet the required dredged level. Outside of this area, but still within the site area (red line) deposition of a few tens of centimetres is predicted. Up to a few tens of centimetres of deposition is also predicted up to 150 m west of the site area (red line) and at the end of the eastern breakwater. Outside of these areas the predicted deposition is of up to a few centimetres, declining to less than 1 mm at distances of 370 m (west of the site), and 460 m (east of the site), and as far south as Pendennis Point. There are also some scattered small patches of 1-2 mm of deposition further south of Pendennis Point.

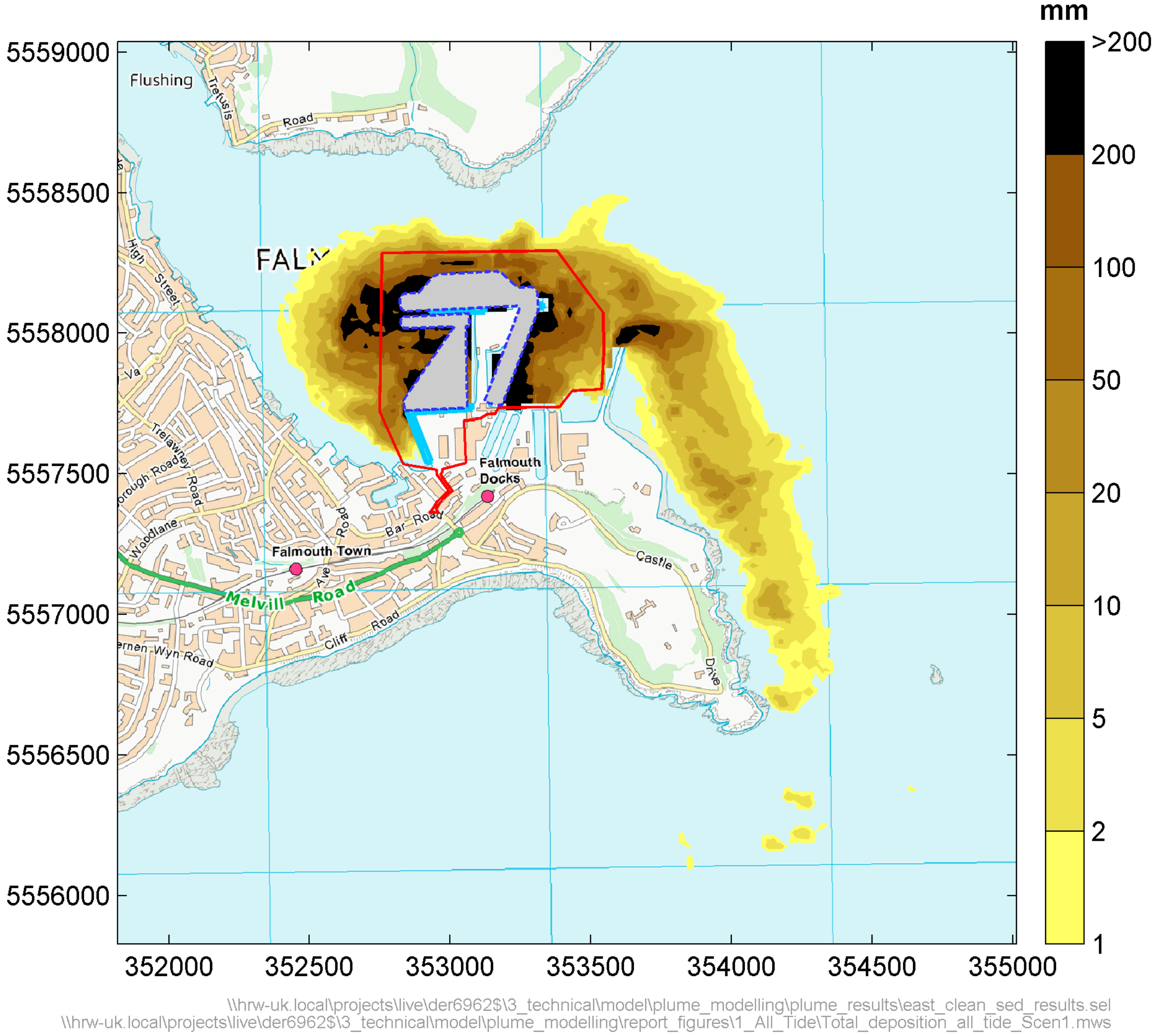

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Figure 6.17: Predicted fine sediment deposition resulting from dredging Scenario 1 as a whole (Dredging areas marked in grey)

The results are summarised by Table 6.3 which shows the total deposition at the timeseries locations. The points with the highest total deposition 1, 2 and 8 are within the site limit shown by the red line and are in or adjacent to the areas to be dredged. Outside of the site area only points 3 and 6 show total deposition depths greater than 10 mm. Comparison of these results with the spatial plot (Figure 6.17) show how spatially variable total deposition is and how a small movement of the locations noticeably increase, or decrease, the values tabulated.

Table 6.4: Summary of predicted total fine sediment deposition resulting from Scenario 1

Point	1	2	3	4	5	6	7	8	9
Depth of fine sediment deposition (mm)	1161.8	319.0	20.5	0.5	0.1	24.0	7.5	171.0	0.1

6.3 Results for dredging scenario 2

In this case all the dredging is undertaken by the 10 m^3, lidded backhoe. The dredging occurs only during the flood tide. It should be noted that as dredging is occurring on the flood tide only the total quantity of sediment released in a given tide is approximately halved compared to all tide dredging, hence increases in suspended sediment concentration will unavoidably be reduced.

6.3.1 Dredging in the east of the site (Western Wharf)

Figure 6.18 and Figure 6.19 summarise the results for dredging in the **east** of the site (in the Western Wharf).

The plot of predicted peak increase in suspended sediment concentration (Figure 6.18) shows that the footprint of the plume concentration increases extends outside of the red line to the west of the site with increases of almost 20 mg/l, and up to 1 km south-east of the site (around 500 m north of Pendennis Point), at which point the increases in concentration fall below 1 mg/l. In the immediate vicinity of the dredging, concentration increases are of the order of 100's of mg/l above background. Compared to the equivalent all tide dredging case the area of the plume to the east of the site is reduced, particularly along the north east side of the site boundary.

The mean peak increase in suspended sediment concentration resulting from dredging in the east part of the site is shown in Figure 6.19. The figure shows that the mean concentration increases of 1 mg/l or more are entirely confined to the site area defined by the red line.

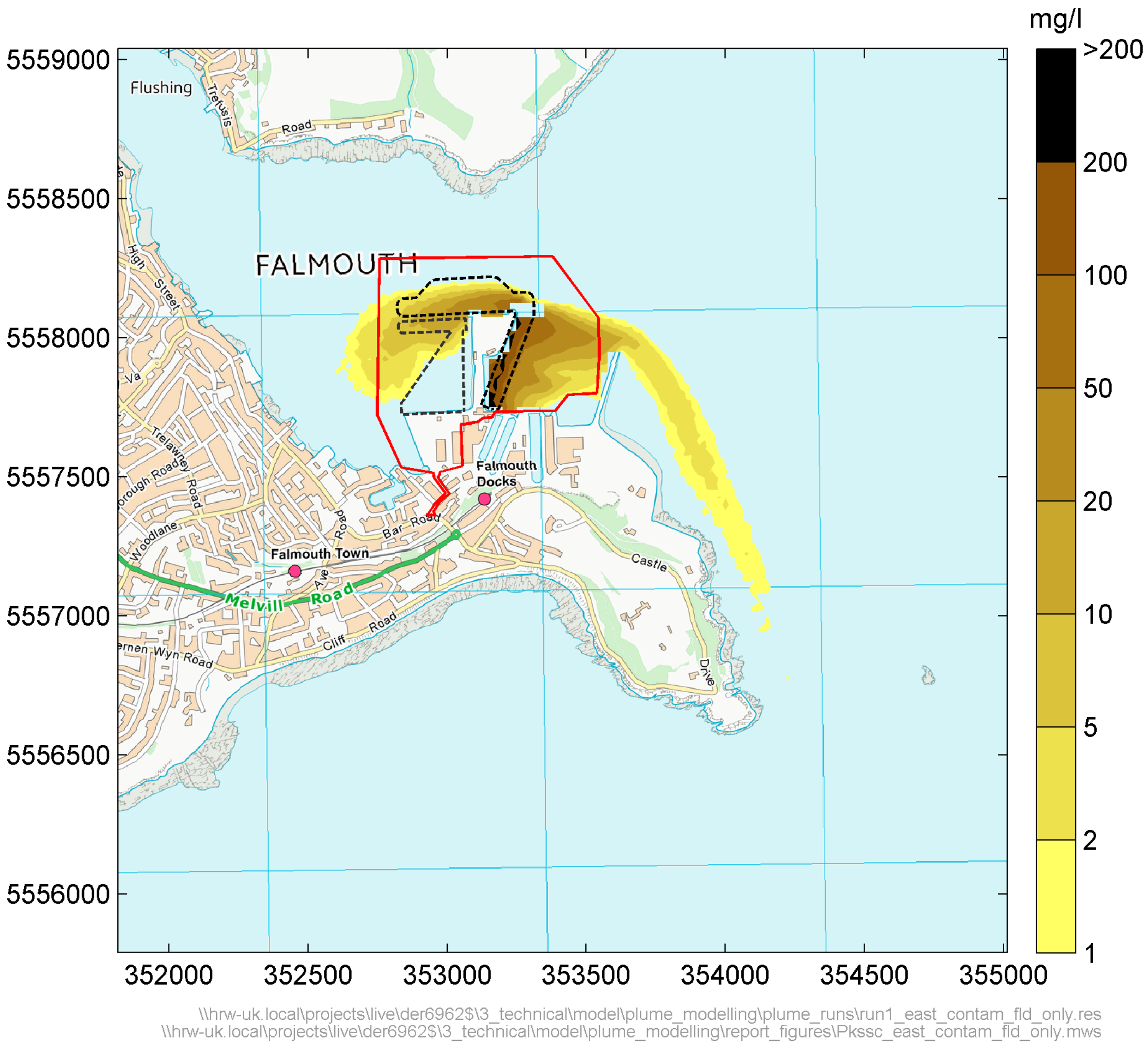

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Figure 6.18: Peak predicted increase in suspended sediment concentration, flood tide dredging in the **east** part of the site (Western Wharf)

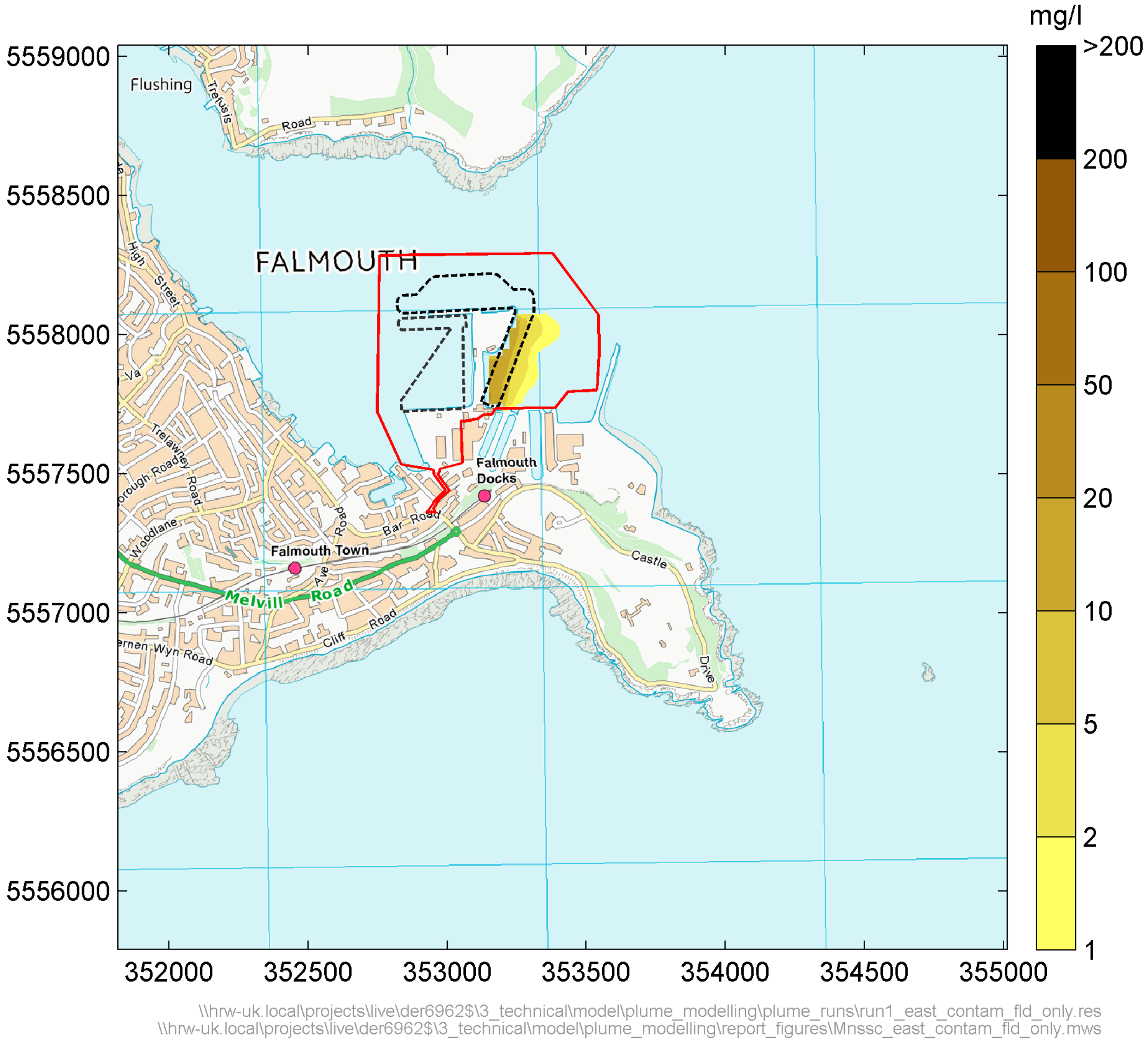

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Figure 6.19: Mean predicted increase in suspended sediment concentration, flood tide dredging in the **east** part of the site (Western Wharf)

6.3.2 Dredging in the north of the site

Figure 6.20 and Figure 6.21 summarise the results for dredging in the **north** of the site.

The predicted peak increase in suspended sediment concentration is shown in Figure 6.20. The figure shows that the footprint of the plume concentration increases extends up to 350 m west of the site area (red line) and up to 2 km south of the site (to around Pendennis Point), as which point the increases in concentration fall below 1 mg/l. In the immediate vicinity of the dredging, concentration increases are of the order of 100's of mg/l above background.

The mean peak increase in suspended sediment concentration resulting from dredging in the north part of the site is shown in Figure 6.21. The figure shows that the mean concentration increases of 1 mg/l or more extend up to 150 m west of the site area (red line) but are otherwise confined to the site area.

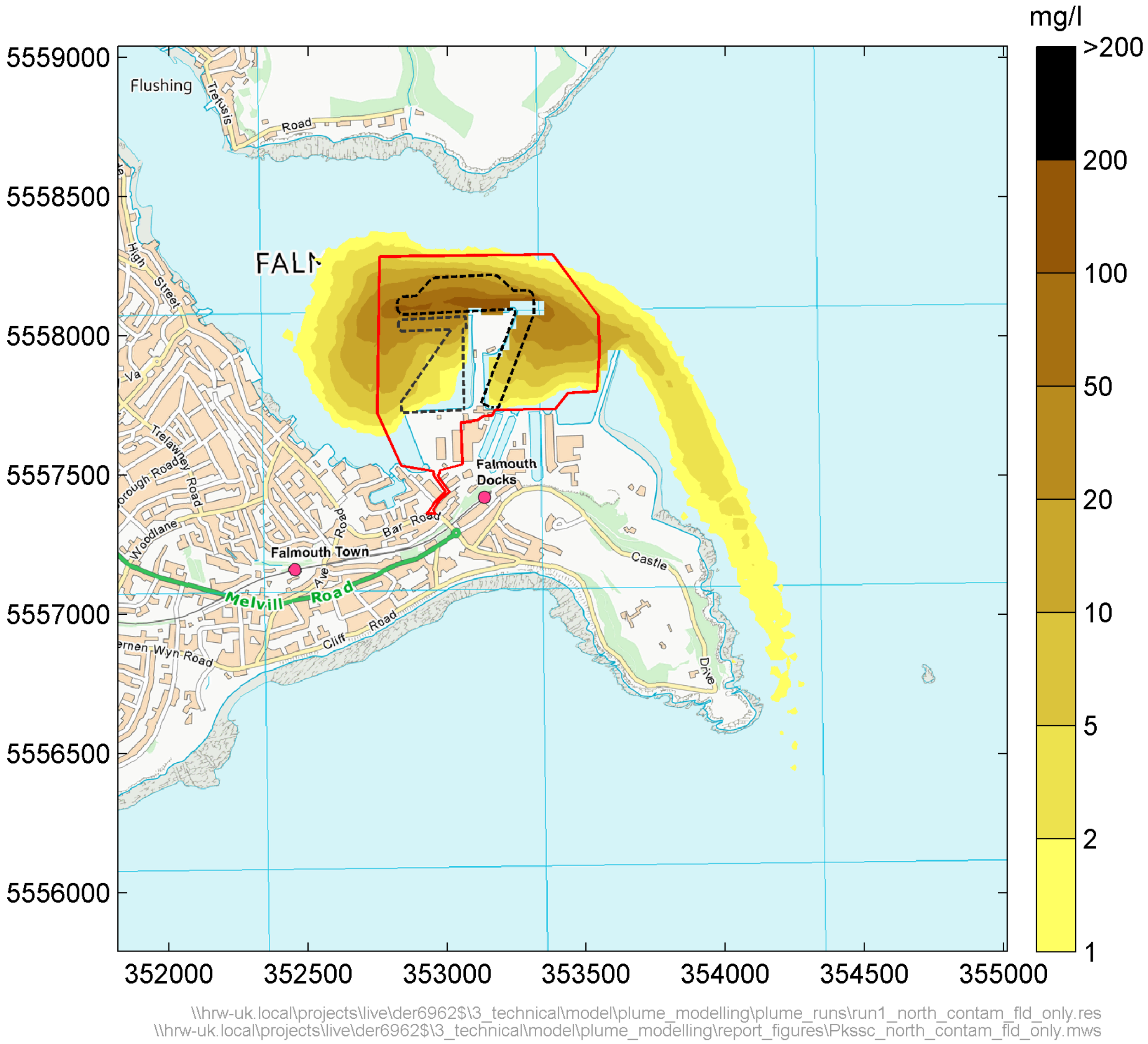

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Figure 6.20: Peak predicted increase in suspended sediment concentration, flood tide dredging in the **north** part of the site

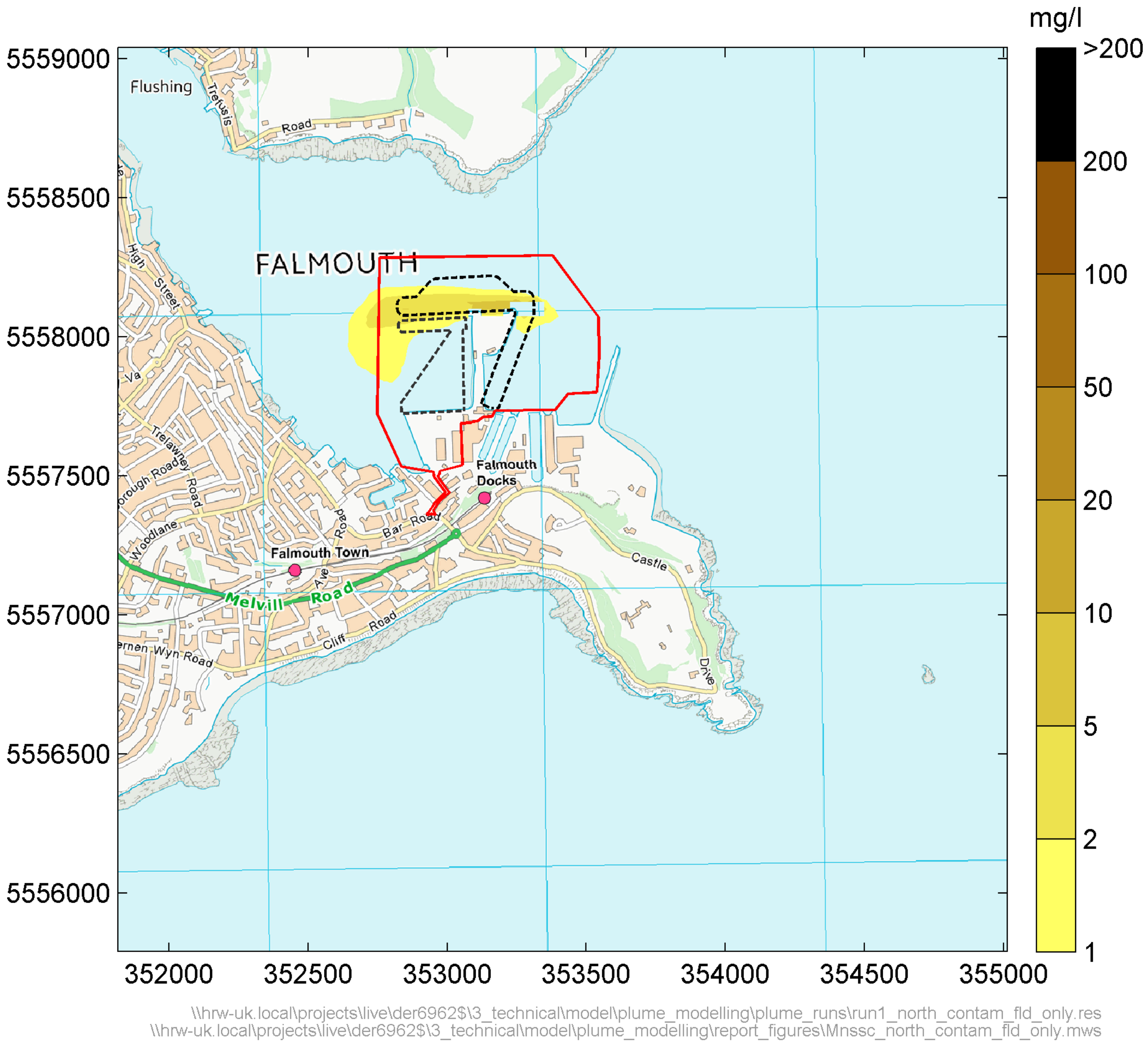

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Figure 6.21: Mean predicted increase in suspended sediment concentration, flood tide dredging in the **north** part of the site

6.3.3 Dredging in the west of the site (FLOW Basin)

Figure 6.22 and Figure 6.23 summarise the results for dredging in the **west** of the site.

The predicted peak increase in suspended sediment concentration is shown in Figure 6.22. The figure shows that the footprint of the plume concentration increases extends up to 250 m west of the site area (red line) and up to 1.6 km south of the site (just south of Pendennis Point), at which point the increases in concentration fall below 1 mg/l. In the immediate vicinity of the dredging, concentration increases are of the order of 100's of mg/l above background.

The mean peak increase in suspended sediment concentration resulting from dredging in the east part of the site is shown in Figure 6.23. The figure shows that the mean concentration increases of 1 mg/l or more extend up to 100 m west of the site area (red line) with values in the range 2-5 mg/l, but are otherwise confined to the site area.

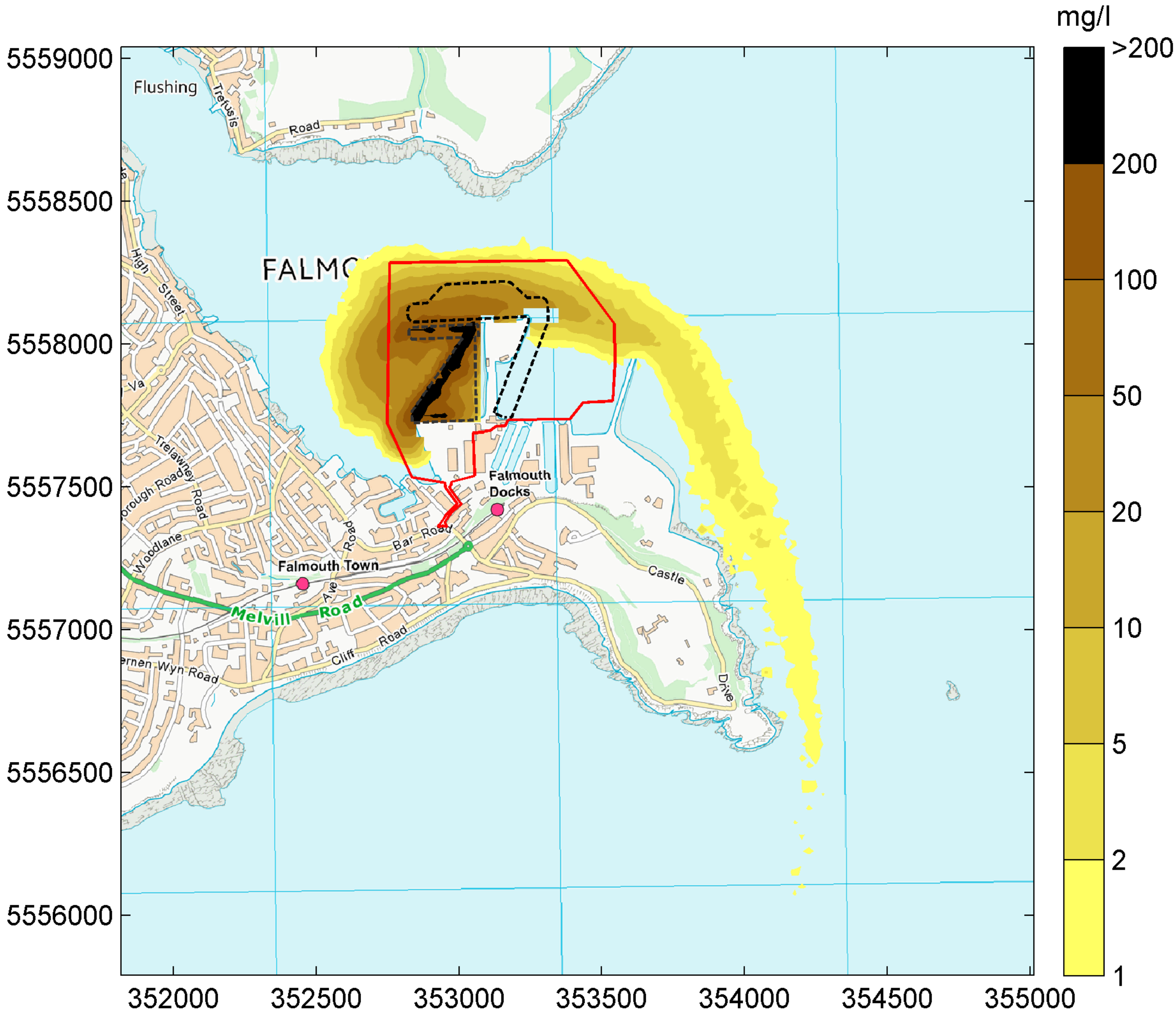

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Figure 6.22: Peak predicted increase in suspended sediment concentration, flood tide dredging in the **west** part of the site (FLOW Basin)

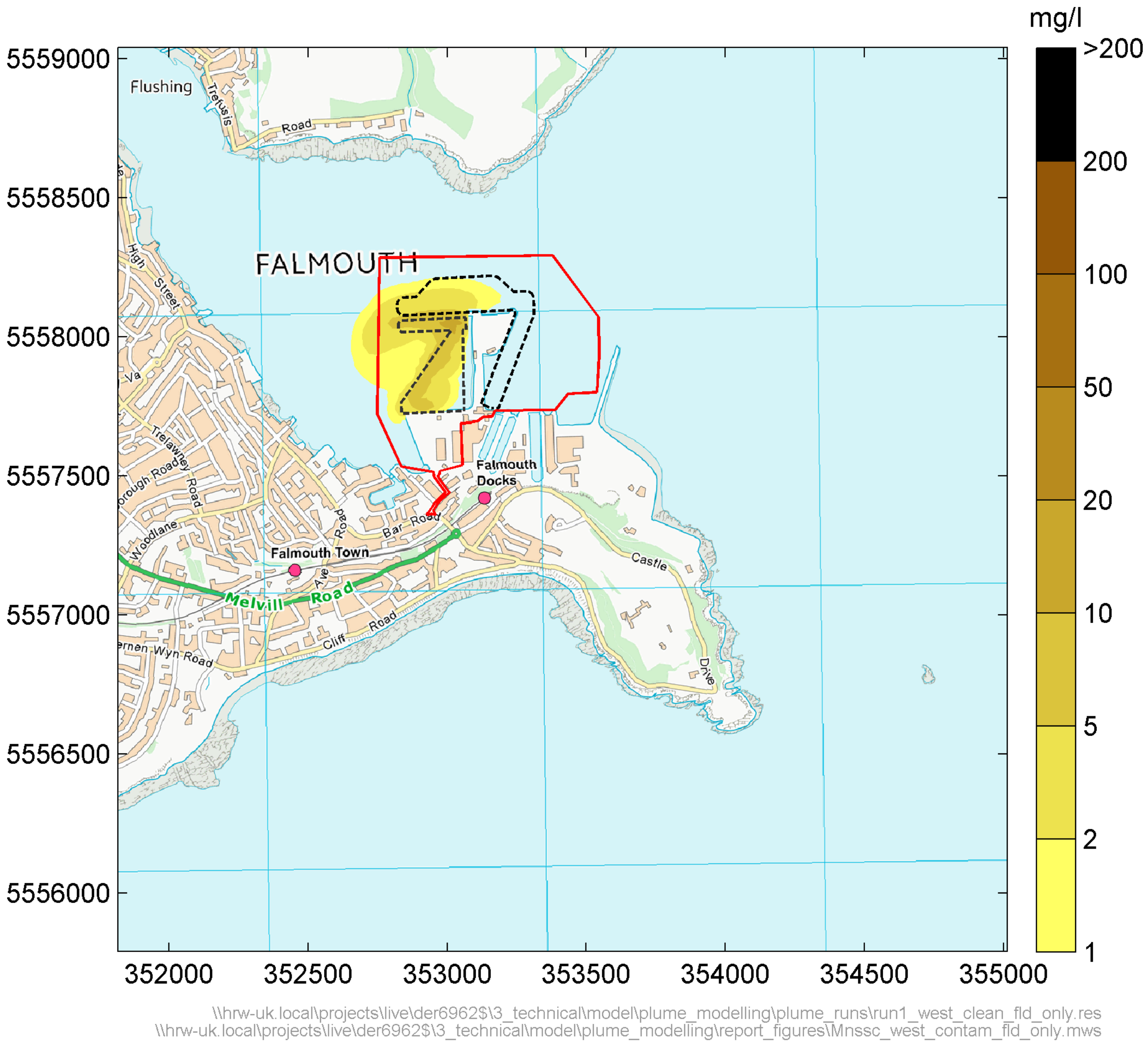

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Figure 6.23: Mean predicted increase in suspended sediment concentration, flood tide dredging in the **west** part of the site (FLOW Basin)

6.3.4 Time series of predicted increases in suspended sediment concentration

The following sections present time series plots of increases in suspended sediment concentration at the locations shown in Figure 6.13, arising from flood tide only dredging in the east, north and west of the site.

6.3.5 Time series for flood tide dredging in east of the site (Western Wharf)

The predicted increases in suspended sediment concentration above background arising from 15 days of dredging in the east of the site are presented in Figure 6.24 and summarised by

Table 6.5. The peak concentration increase (~50 mg/l) occurs at Location 8 which is adjacent to the dredging. Only Locations 1, 2 and 8 exceed increases of 5 mg/l. Other than Location 8 the 95% increase in suspended sediment concentration is 0.1 mg/l or less.

Table 6.5: Summary of predicted increase in suspended sediment concentration, flood tide dredging in the east of the site (Western Wharf)

Point	1	2	3	4	5	6	7	8	9
Maximum increase in SSC (mg/l)	1.0	1.6	0.2	0.1	0.0	2.4	0.5	51.8	<0.1
Average increase in SSC (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.8	<0.1
95% of increase in SSC (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	12.7	<0.1

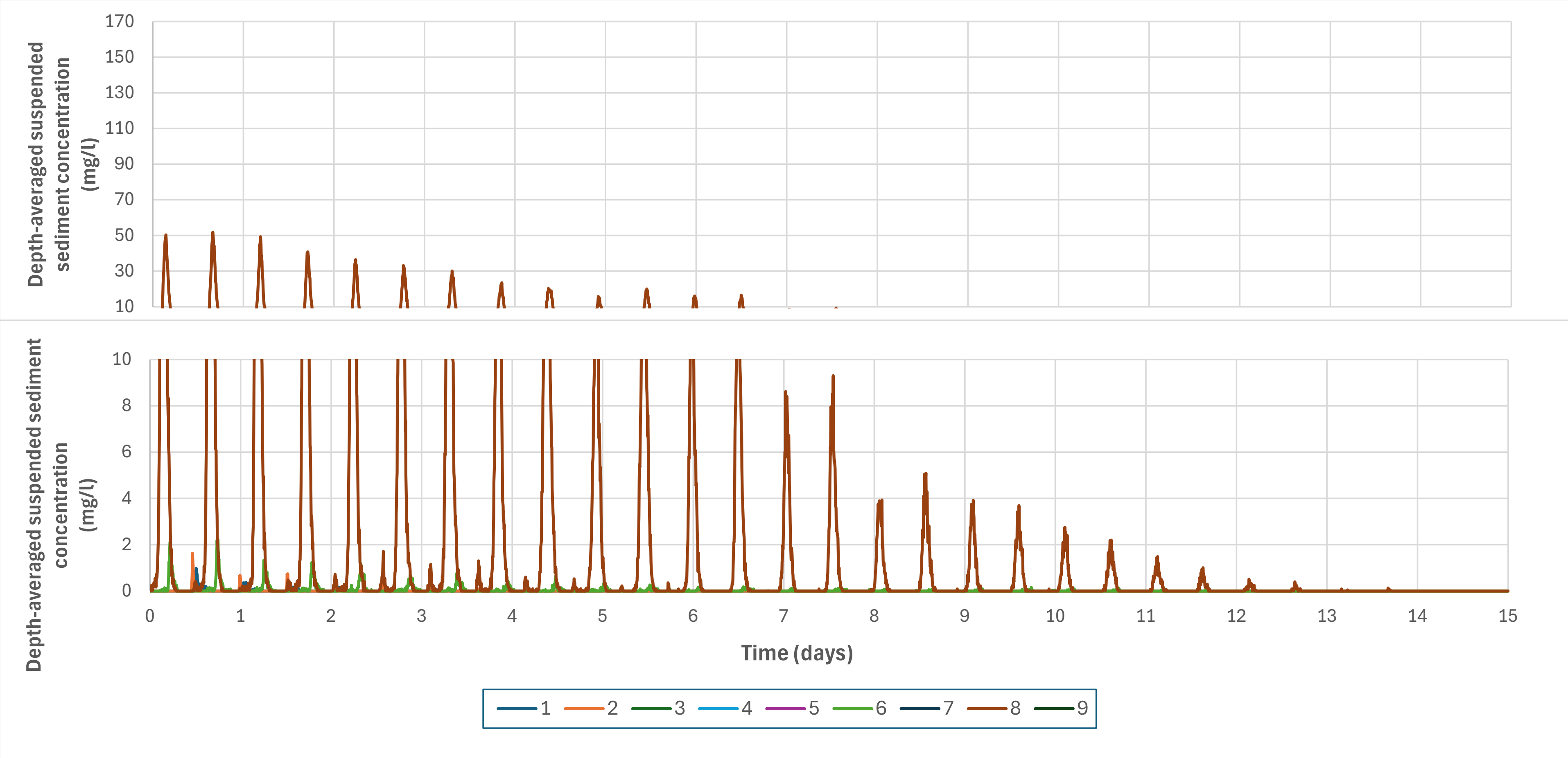

Figure 6.24: Time series of predicted increase in suspended sediment concentration, flood tide dredging in the east of the site

6.3.6 Time series for flood tide dredging in north of the site

The predicted increases in suspended sediment concentration above background arising from 14 days of dredging in the north of the site are presented in Figure 6.25 and summarised by Table 6.6.

The peak concentration increase (~23 mg/l) occurs at Location 2 which is adjacent to the dredging. Second highest value is at Location 8 with 19.7 mg/l. At the other locations, the predicted peak concentration increase is less than 5 mg/l. All the 95% increases in suspended sediment concentrations are less than 5 mg/l indicating how short lived the predicted maximum increases in suspended sediment concentration are.

Table 6.6: Summary of predicted increase in suspended sediment concentration, flood tide dredging to the north of the site

Point	1	2	3	4	5	6	7	8	9
Maximum increase in SSC (mg/l)	3.9	23.5	0.5	0.1	0.1	3.7	0.7	19.7	0.1
Average increase in SSC (mg/l)	0.3	0.5	<0.1	<0.1	<0.1	0.1	<0.1	0.5	<0.1
95% of increase in SSC (mg/l)	1.3	2.4	0.1	<0.1	<0.1	0.5	0.1	3.1	<0.1

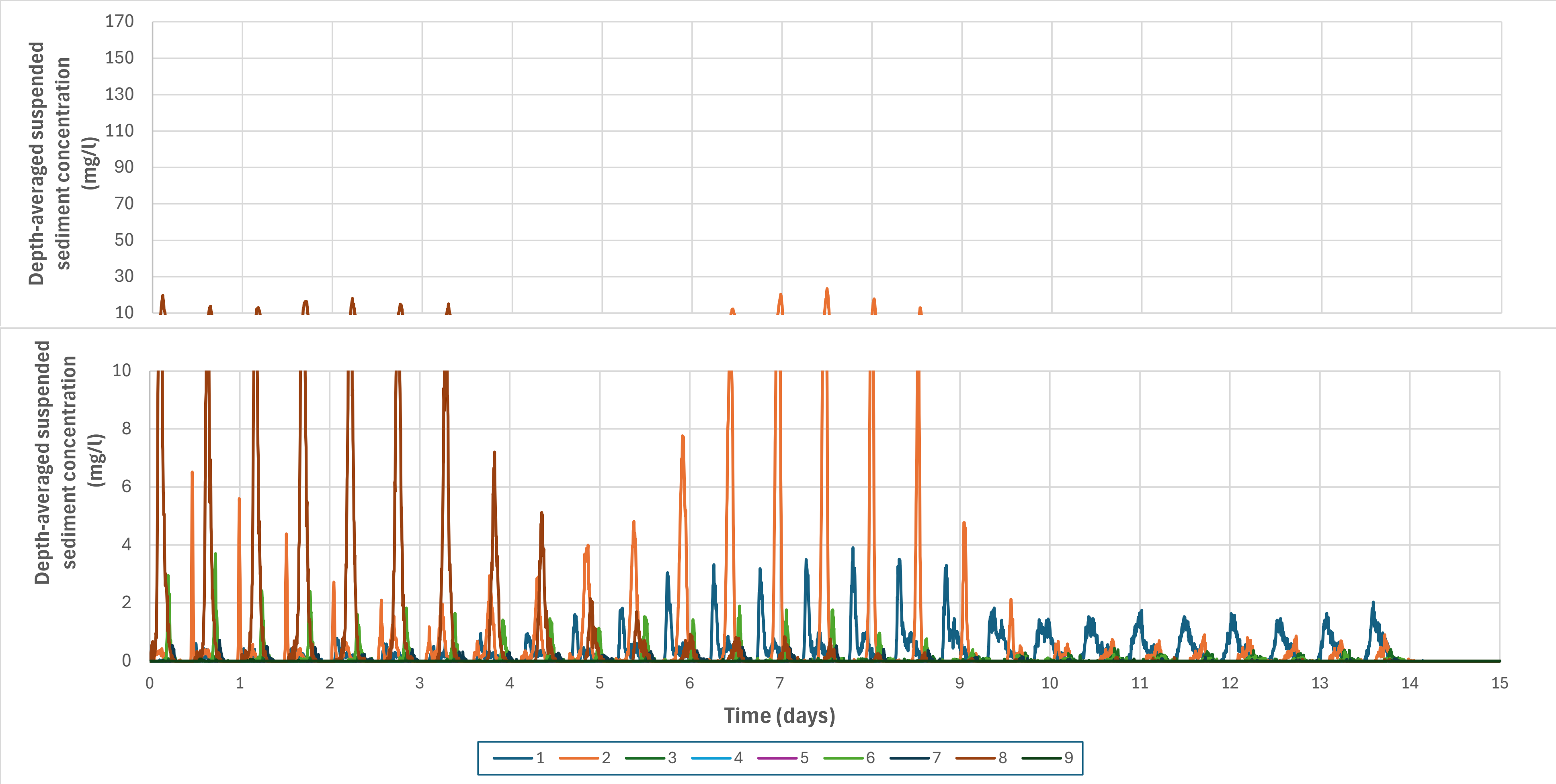

Figure 6.25: Time series of predicted increase in suspended sediment concentration, flood tide dredging in the north of the site

6.3.7 Time series for flood tide dredging in west of the site (FLOW Basin)

The predicted increases in suspended sediment concentration above background arising from 14 days of dredging in the west of the site are presented in Figure 6.26 and summarised by Table 6.7.

The peak concentration increase (~60 mg/l) occurs at Location 1 which is adjacent to the dredging. The peak concentration increase at Location 2 is 14 mg/l. At the other locations, the predicted peak concentration increase is less than 2 mg/l.

Table 6.7: Summary of predicted increase in suspended sediment concentration, flood tide dredging in the west of the site

Point	1	2	3	4	5	6	7	8	9
Maximum increase in SSC (mg/l)	61.6	14.0	0.8	0.1	0.1	1.3	0.4	0.7	0.0
Average increase in SSC (mg/l)	3.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
95% of increase in SSC (mg/l)	25.3	3.8	0.1	0.0	0.0	0.2	0.1	0.1	0.0

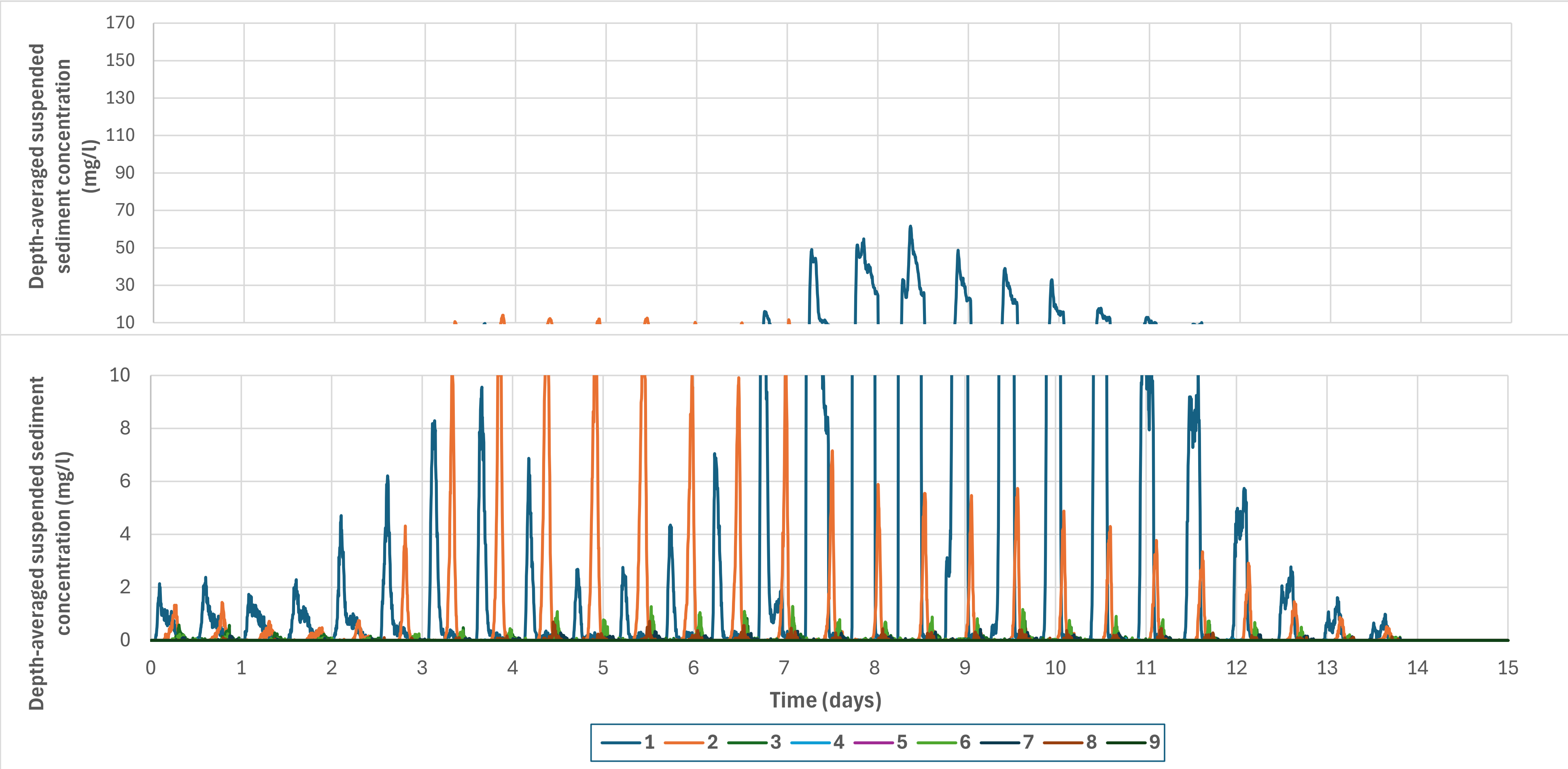

Figure 6.26: Time series of predicted increase in suspended sediment concentration, flood tide dredging in the west of the site (FLOW Basin)

6.3.8 Total deposition of fine sediment arising from works

The predicted fine sediment deposition resulting from dredging Scenario 2 as a whole is shown by Figure 6.27. The figure is composed by weighting the contributions of dredging of sediment from the different zones in the north, east and west of the site. For flood tide only dredging the period of dredging and therefore rate of sediment released per tide is approximately halved. However the overall duration of the dredging will roughly double.

Within the site area (red line) deposition of a few tens of centimetres is predicted. Up to a few tens of centimetres of deposition is also predicted up to 200 m west of the site area (red line) and at the end of the eastern breakwater. Outside of these areas the predicted deposition is of up to a few centimetres, declining to less than 1 mm at distances of 350 m (west of the site), and 300 m (east of the site). There are some scattered small patches of 1-2 mm of deposition around Pendennis Point.

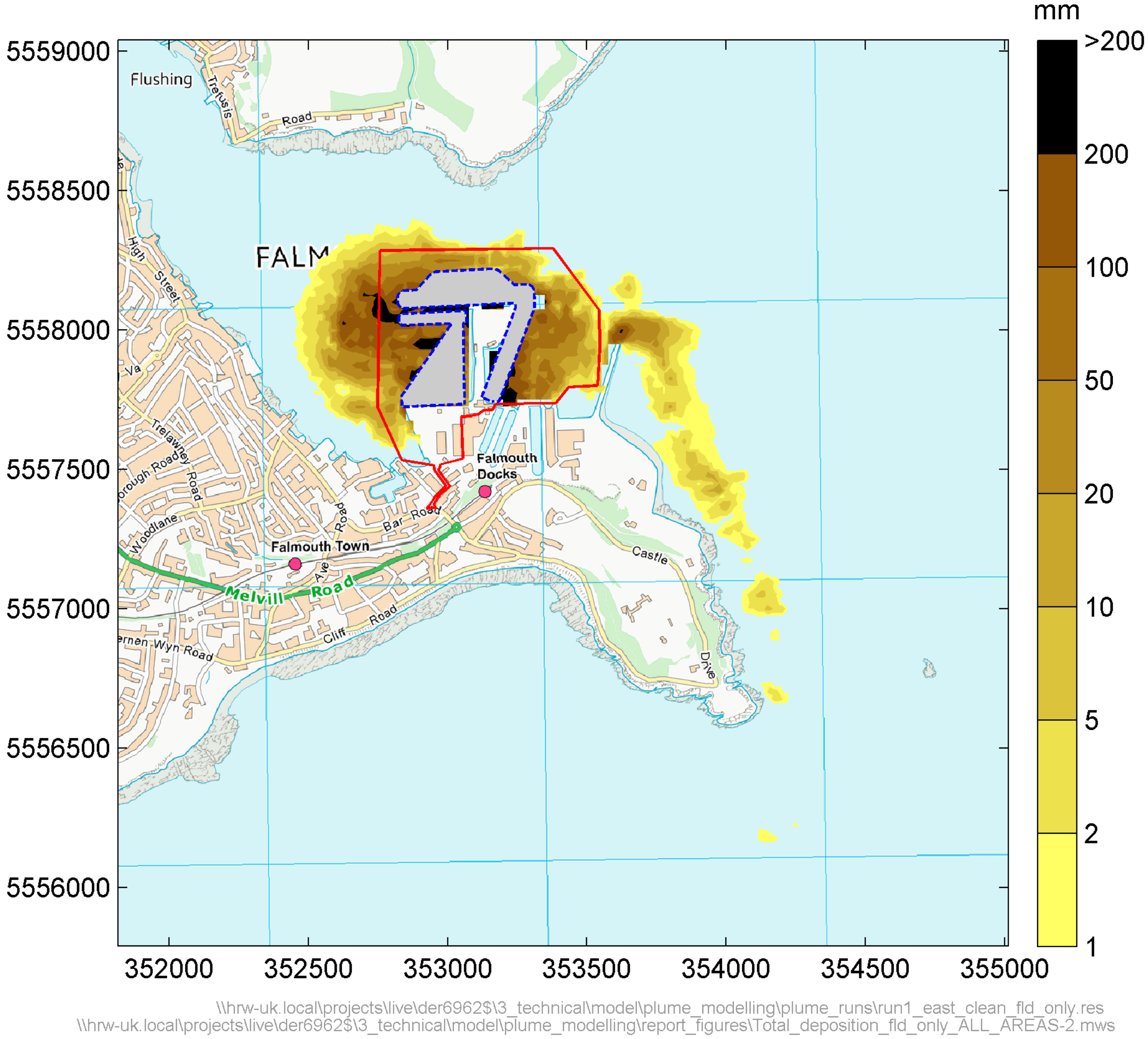

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Figure 6.27: Predicted fine sediment deposition resulting from dredging Scenario 2 as a whole (Dredging areas marked in grey)

The results are summarised by Table 6.8 for total deposition at the timeseries locations. Locations 1, 2 and 8, the Locations with the highest depths of deposition are within the site boundary. Outside of the site boundary, approximately 5 mm of deposition is predicted at Location 6, elsewhere deposition depths do not exceed 2 mm.

Table 6.8: Summary of predicted total fine sediment deposition resulting from Scenario 2

Point	1	2	3	4	5	6	7	8	9
Depth of fine sediment deposition (mm)	496.5	51.1	1.2	<0.1	<0.1	5.2	1.9	51.9	<0.1

6.4 Results for dredging scenario 3

In this case all the dredging is undertaken by the 10 m^3, lidded backhoe. The dredging occurs only during the late ebb and early flood tides. Similarly to flood tide only dredging the rate of sediment release per tide is approximately halved, hence a reduction in the increases in suspended sediment concentration is unavoidable, however in the case the detail of the timing of the dredging was amended to focus on restricting the footprint of the plume towards the sensitive habitats present to the east of the project area (maerl).

6.4.1 Dredging in the east of the site (Western Wharf)

Figure 6.28 and Figure 6.29 summarise the results for dredging in the **east** of the site (in the Western Wharf).

The predicted peak increase in suspended sediment concentration is shown in Figure 6.28. The figure shows that the footprint of the plume concentration increases extends approximately 200 m outside of the red line to the west of the site and up to 100 m east of the site with increases in the range 2-5 mg/l, at which point the increases in concentration fall below 1 mg/l. In the immediate vicinity of the dredging, concentration increases are of the order of 100’s of mg/l above background.

The mean peak increase in suspended sediment concentration resulting from dredging in the east part of the site is shown in Figure 6.29. The figure shows that the mean concentration increases of 1 mg/l or more are entirely confined to the site area defined by the red line.

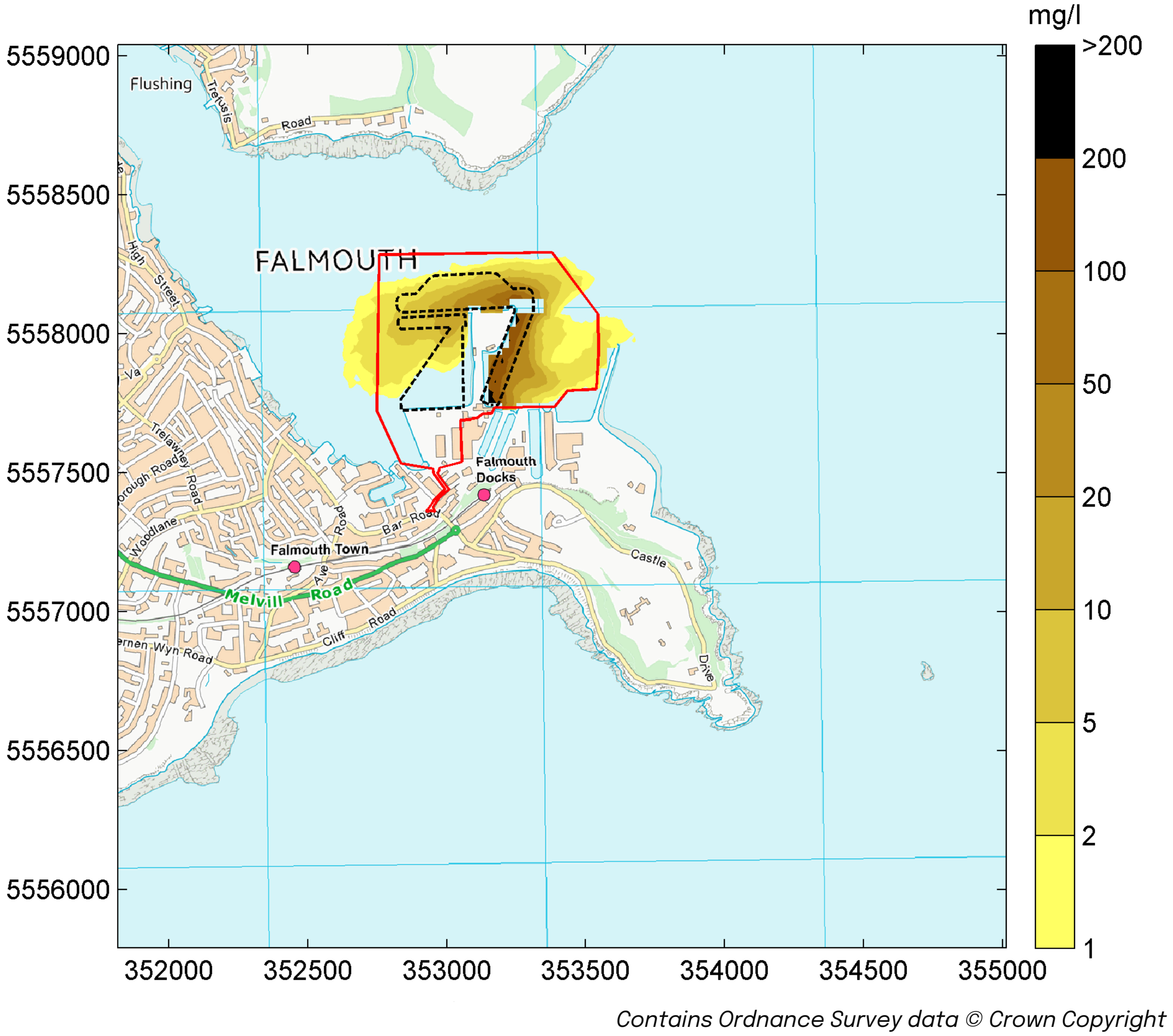

Figure 6.28: Peak predicted increase in suspended sediment concentration, dredging in the **east** part of the site (Western Wharf)

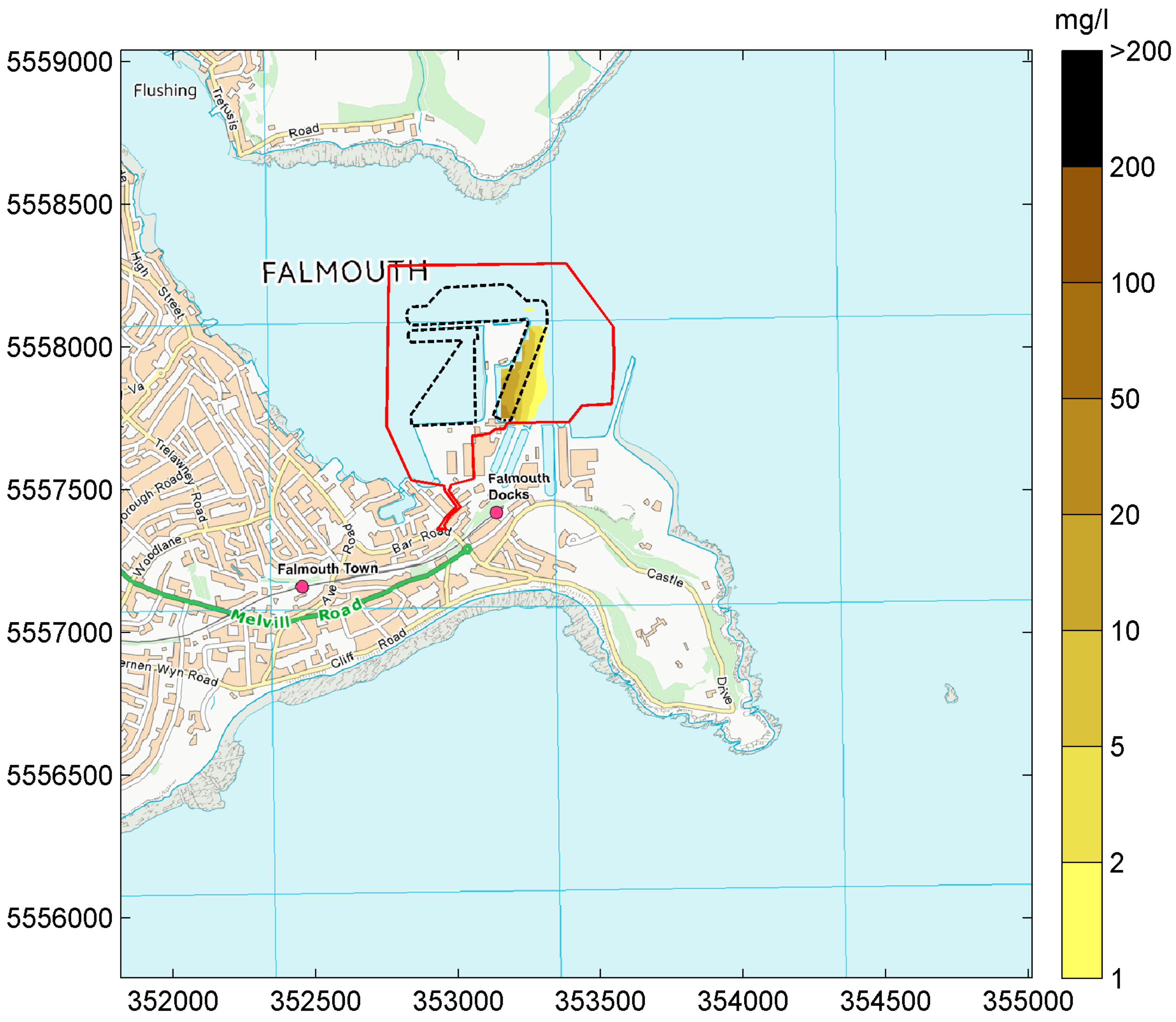

Figure 6.29: Mean predicted increase in suspended sediment concentration, dredging in the **east** part of the site (Western Wharf)

6.4.2 Dredging in the north of the site

Figure 6.30 and Figure 6.31 summarise the results for dredging in the **north** of the site.

The predicted peak increase in suspended sediment concentration is shown in Figure 6.30. The figure shows that the footprint of the plume concentration increases extends up to 300 m west of the site area (red line) and up to 900 m east of the site, at which point the increases in concentration fall below 1 mg/l. In the immediate vicinity of the dredging, concentration increases are of the order of 100's of mg/l above background.

The mean peak increase in suspended sediment concentration resulting from dredging in the east part of the site is shown in Figure 6.31. The figure shows that the mean concentration increases of 1 mg/l or more extend up to 100 m west of the site area (red line) but is otherwise confined to the site area.

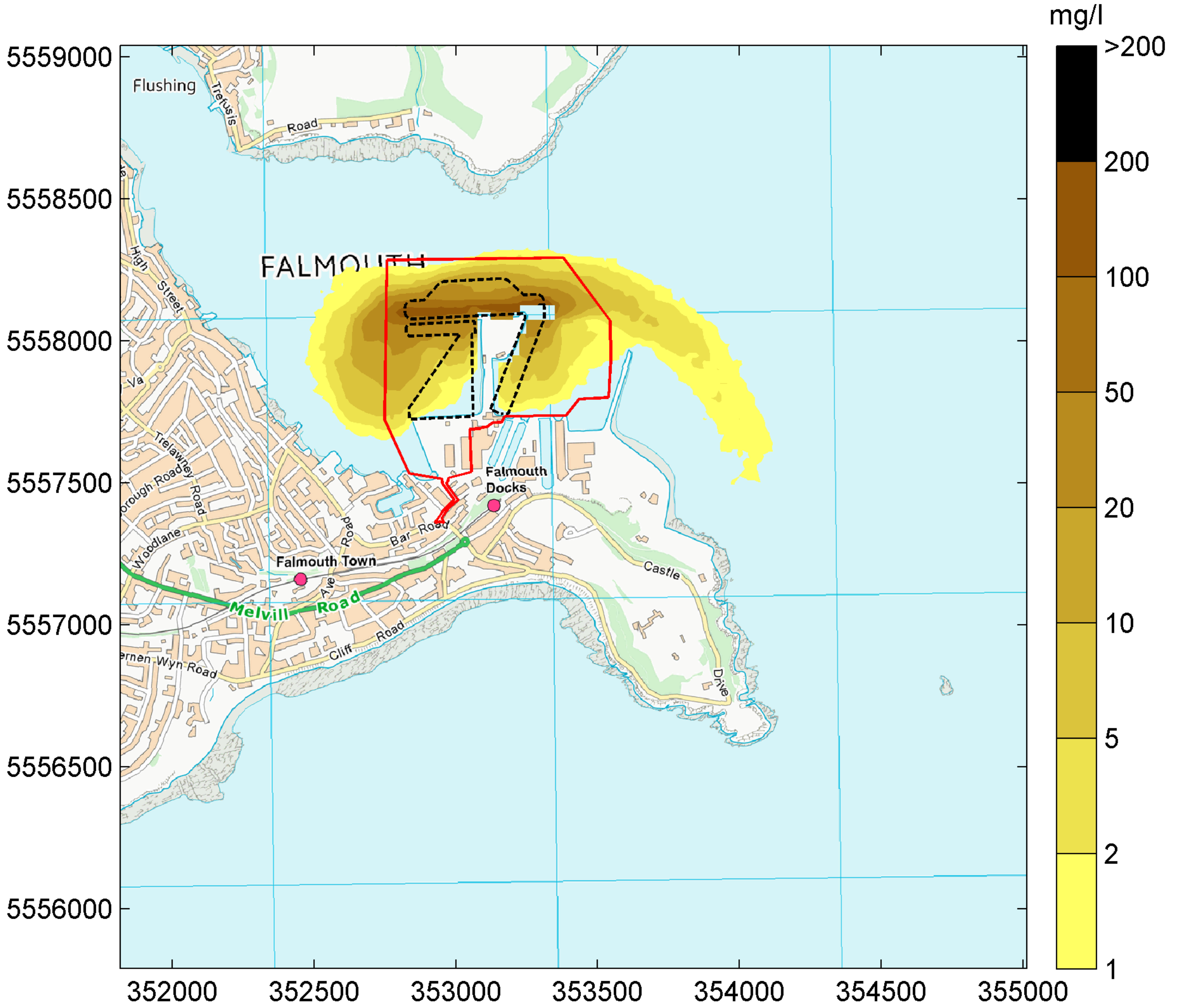

Figure 6.30: Peak predicted increase in suspended sediment concentration, dredging in the **north** part of the site

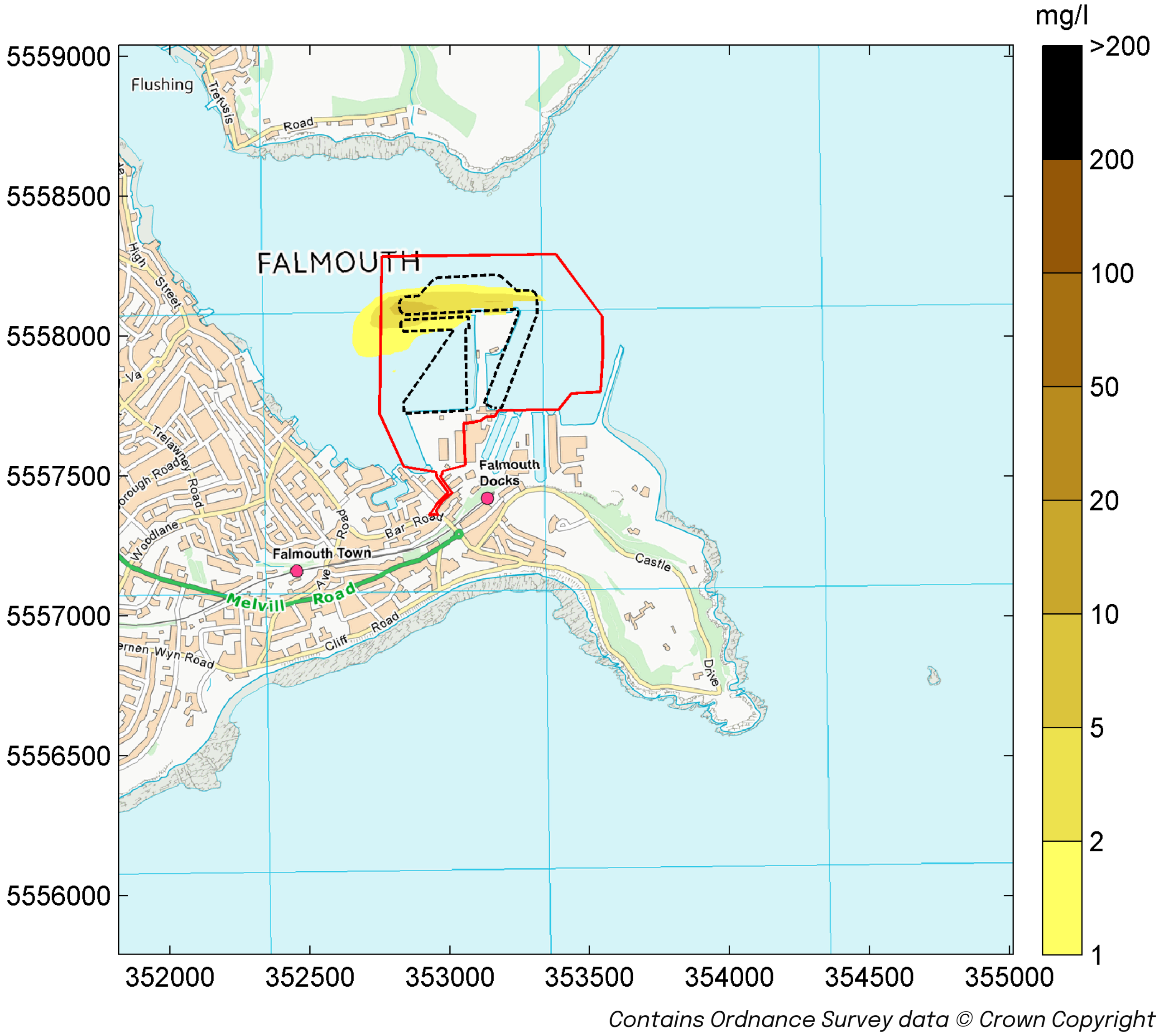

Figure 6.31: Mean predicted increase in suspended sediment concentration, dredging in the **north** part of the site

6.4.3 Dredging in the west of the site (FLOW Basin)

Figure 6.32 and Figure 6.33 summarise the results for dredging in the **west** of the site.

The predicted peak increase in suspended sediment concentration is shown in Figure 6.32. The figure shows that the footprint of the plume concentration increases extends up to 200 m west of the site area (red line) but otherwise does not extend outline the site area. In the immediate vicinity of the dredging, concentration increases are of the order of 100's of mg/l above background.

The mean peak increase in suspended sediment concentration resulting from dredging in the east part of the site is shown in Figure 6.33. The figure shows that the mean concentration increases of 1 mg/l or more extend just outside (less than 100 m) to the west of the site area (red line) but are otherwise within the site area.

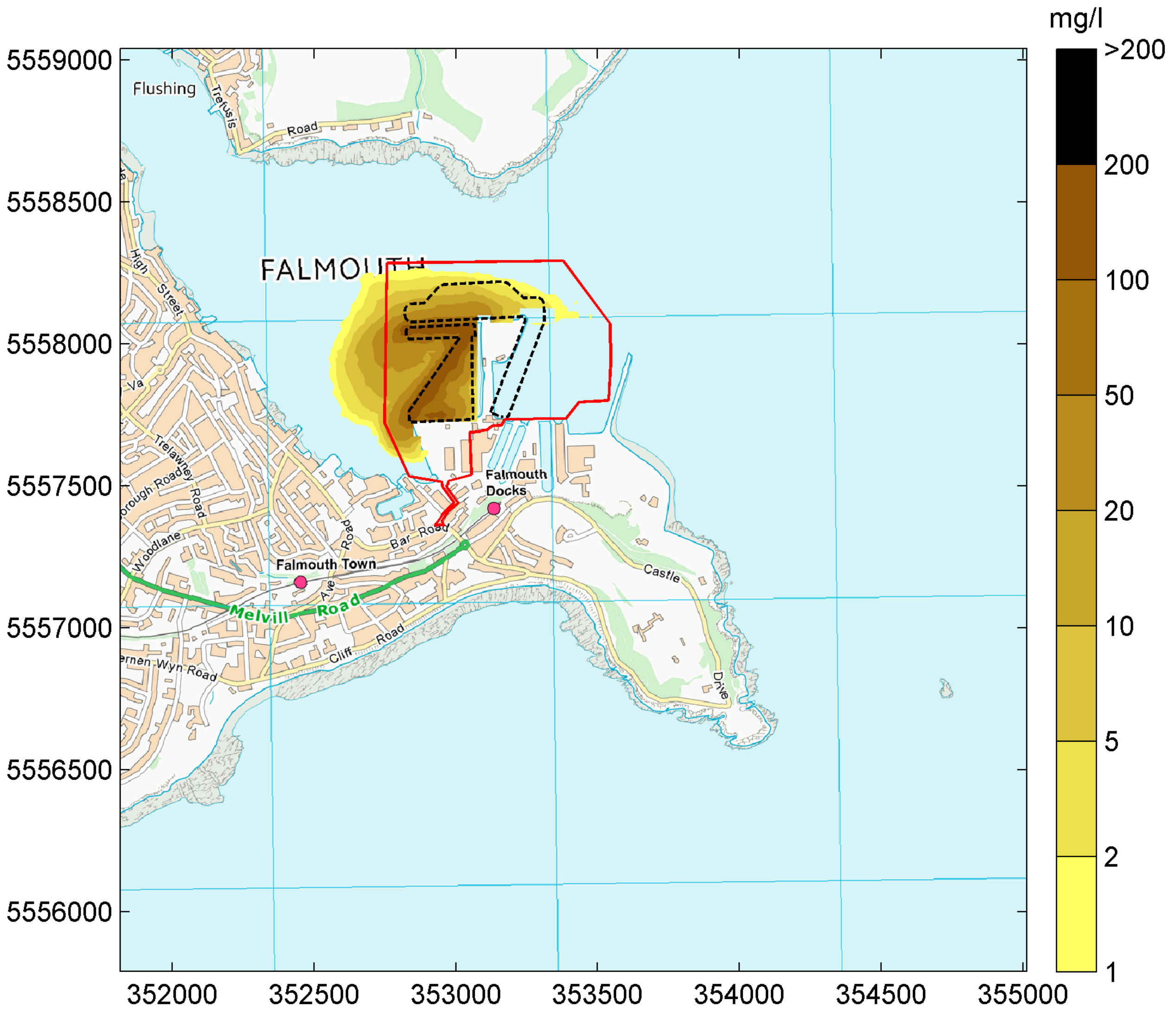

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Figure 6.32: Peak predicted increase in suspended sediment concentration, dredging in the **west** part of the site (FLOW Basin)

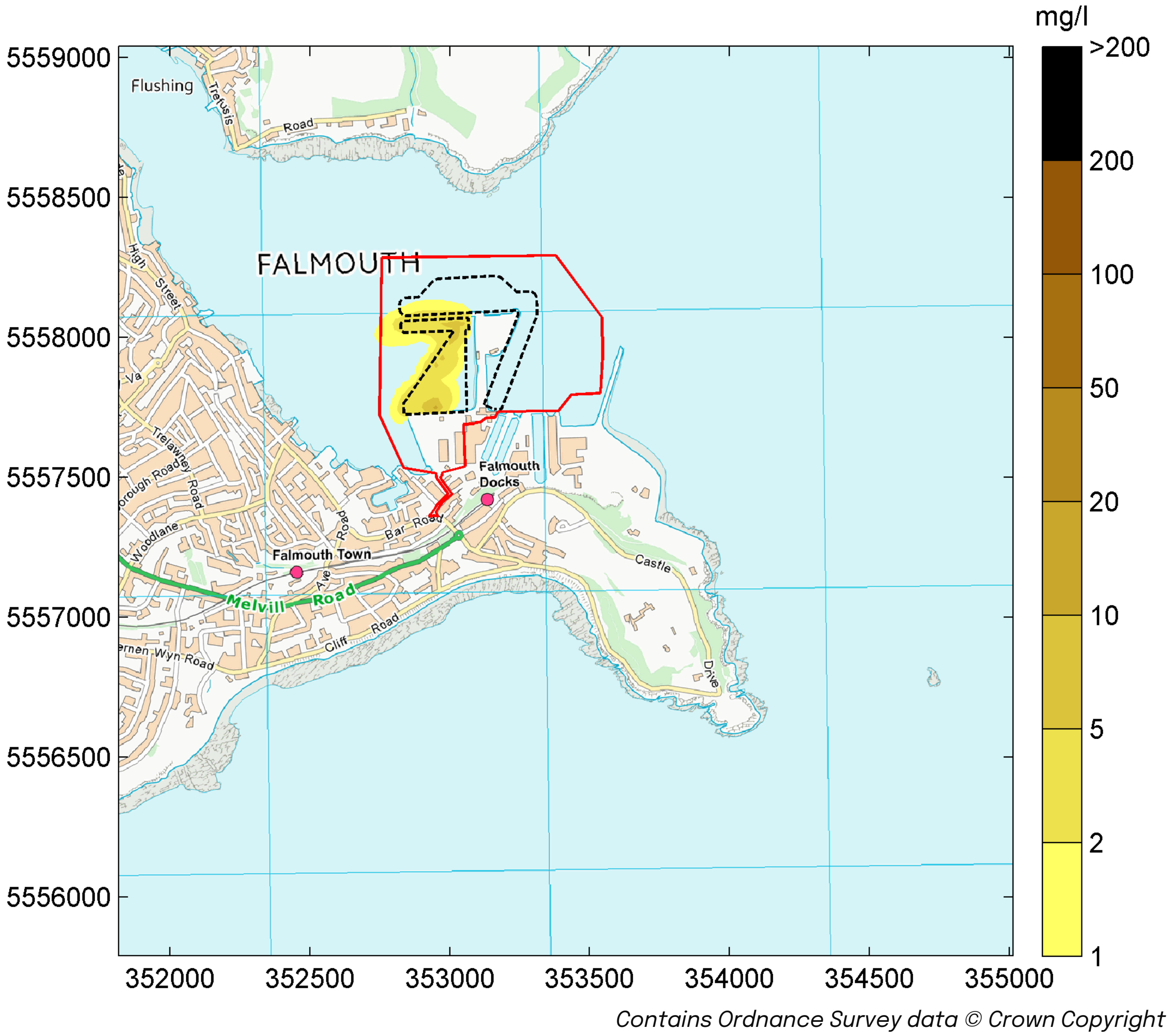

Figure 6.33: Mean predicted increase in suspended sediment concentration, dredging in the **west** part of the site (FLOW Basin)

6.4.4 Time series of predicted increases in suspended sediment concentration

The following sections present time series plots of increases in suspended sediment concentration at the locations shown in Figure 6.13, arising from dredging during the late ebb tide and early flood tide in the east, north and west of the site.

6.4.5 Time series for dredging in east of the site (Western Wharf)

The predicted increases in suspended sediment concentration above background arising from 15 days of dredging in the east of the site are presented in Figure 6.34 and summarised by Table 6.9.

All the peak concentration increases are less than 10 mg/l. Other than Location 6, all the 95% increases in suspended sediment centration are 0.1 mg/l or less. This results demonstrates how the choice of the timing of the dredging can act to significantly reduce the footprint of the plume.

Table 6.9: Summary of predicted increase in suspended sediment concentration, dredging in the east of the site (Western Wharf)

Point	1	2	3	4	5	6	7	8	9
Maximum increase in SSC (mg/l)	3.0	6.3	0.1	<0.1	<0.1	0.2	0.1	6.2	0.1
Average increase in SSC (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	<0.1
95% of increase in SSC (mg/l)	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	2.3	<0.1

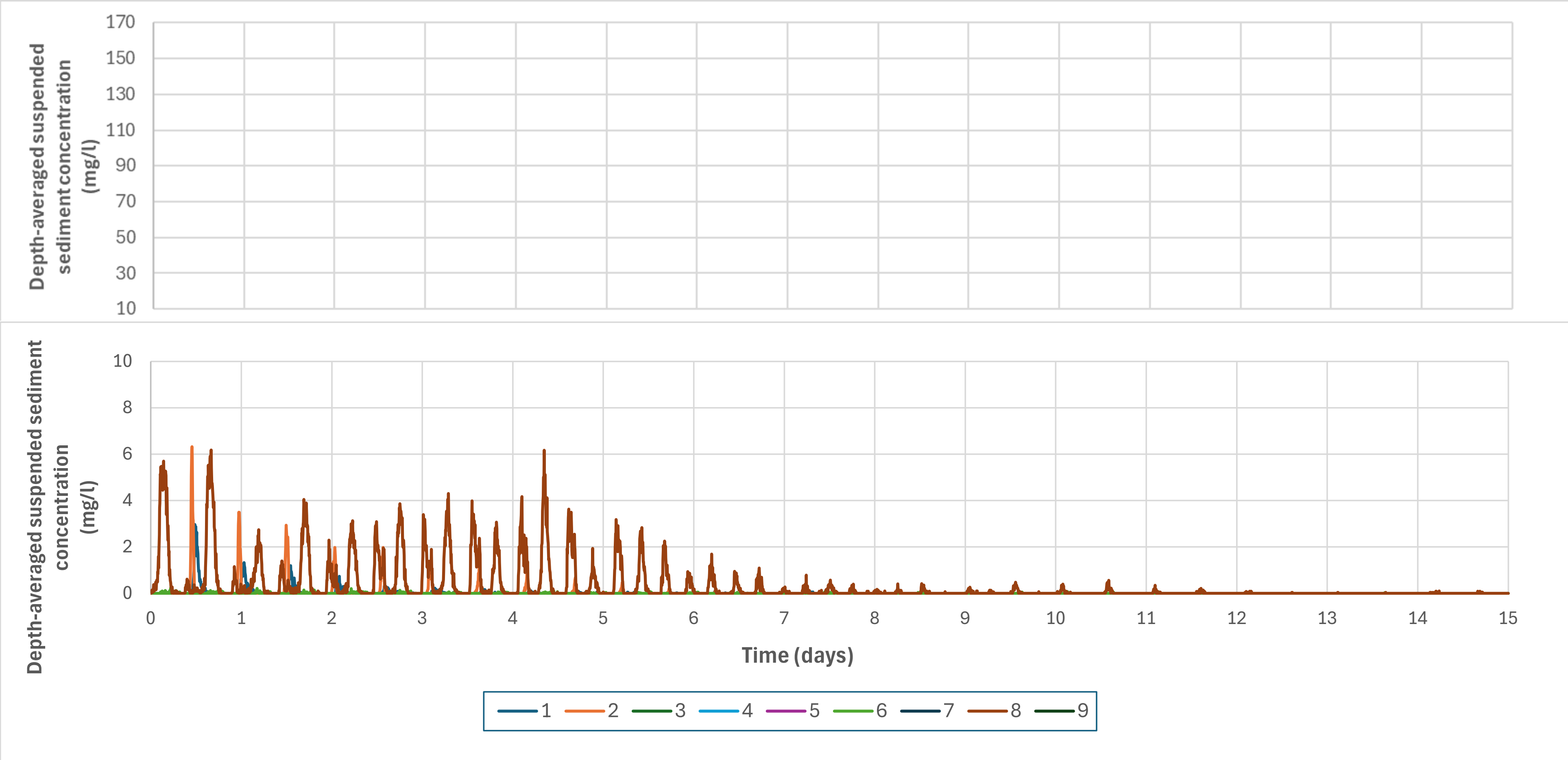

Figure 6.34: Time series of predicted increase in suspended sediment concentration, dredging in the east of the site

6.4.6 Time series for dredging in north of the site

The predicted increases in suspended sediment concentration above background arising from 14 days of dredging in the north of the site are presented in Figure 6.35 and summarise by Table 6.10.

The peak concentration increase (~14 mg/l) occurs at Location 2 which is adjacent to the dredging. The peak concentration increase at Location 8 is 13 mg/l. At the other locations, the predicted peak concentration increase is 5 mg/l or less. Only Location 2 has a 95% increase in suspended sediment concentration greater than 5 mg/l.

Table 6.10: Summary of predicted increase in suspended sediment concentration, dredging to the north of the site

Point	1	2	3	4	5	6	7	8	9
Maximum increase in SSC (mg/l)	4.7	13.7	3.5	0.2	0.1	0.5	0.1	12.6	0.1
Average increase in SSC (mg/l)	0.4	0.8	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1
95% of increase in SSC (mg/l)	1.6	5.3	<0.1	<0.1	<0.1	0.1	<0.1	1.5	<0.1

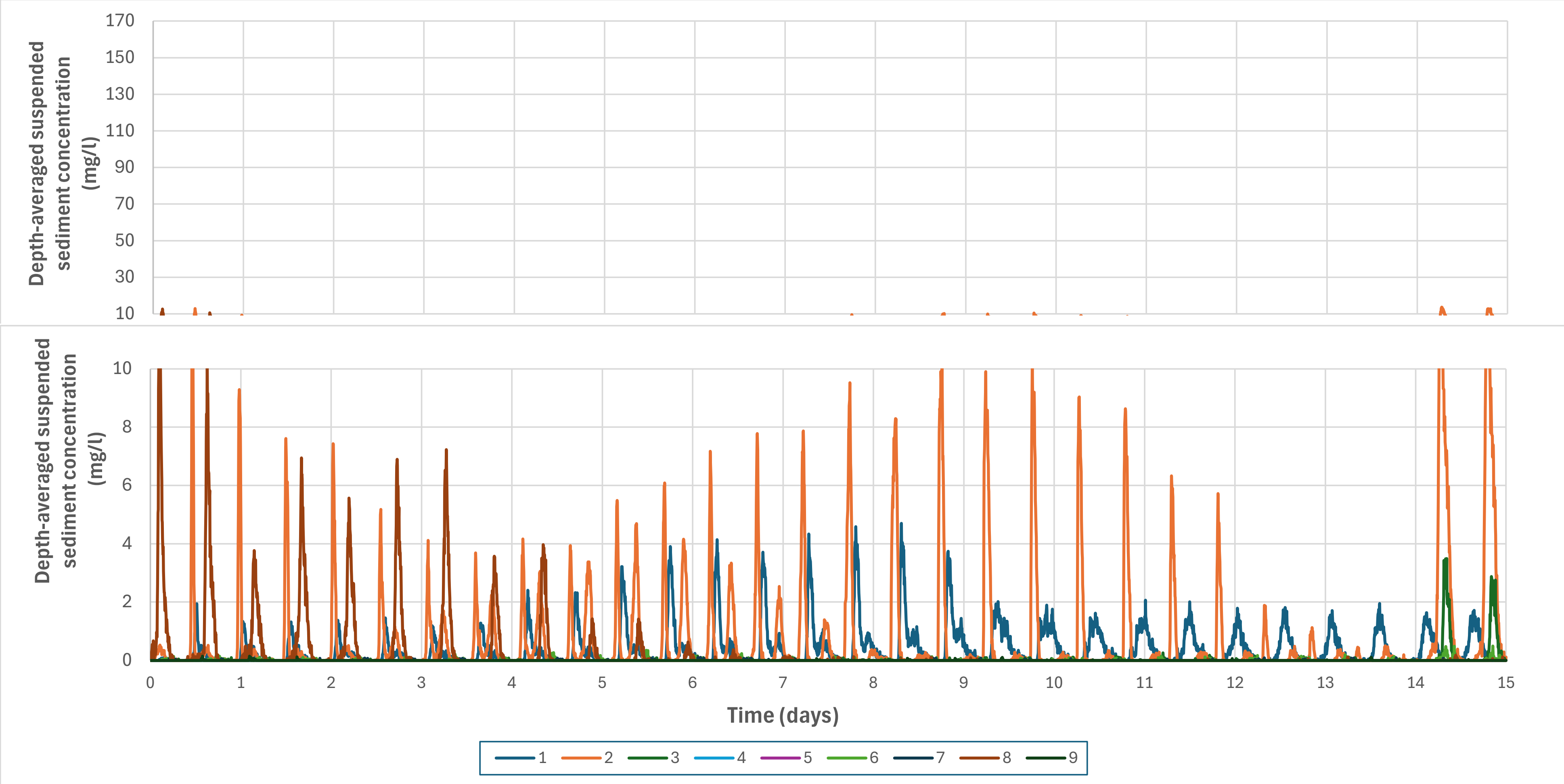

Figure 6.35: Time series of predicted increase in suspended sediment concentration, dredging in the north of the site

6.4.7 Time series for dredging in west of the site (FLOW Basin)

The predicted increases in suspended sediment concentration above background arising from 14 days of dredging in the west of the site are presented in Figure 6.36 and summarised by Table 6.11.

The peak concentration increase (~80 mg/l) occurs at Location 1 which is adjacent to the dredging. None of the other peak concentration increases are greater than 5 mg/l.

Other than Location 1 all the 95% increases in suspended sediment concentration are less than 1 mg/l. As for the other cases this result shows the effectiveness of the amended timing of the dredging in reducing the footprint of the plume, particularly to the east of the site.

Table 6.11: Summary of predicted increase in suspended sediment concentration, dredging in the west of the site

Point	1	2	3	4	5	6	7	8	9
Maximum increase in SSC (mg/l)	78.1	4.4	0.3	<0.1	<0.1	0.3	0.1	0.2	0.1
Average increase in SSC (mg/l)	3.7	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
95% of increase in SSC (mg/l)	27.7	0.8	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

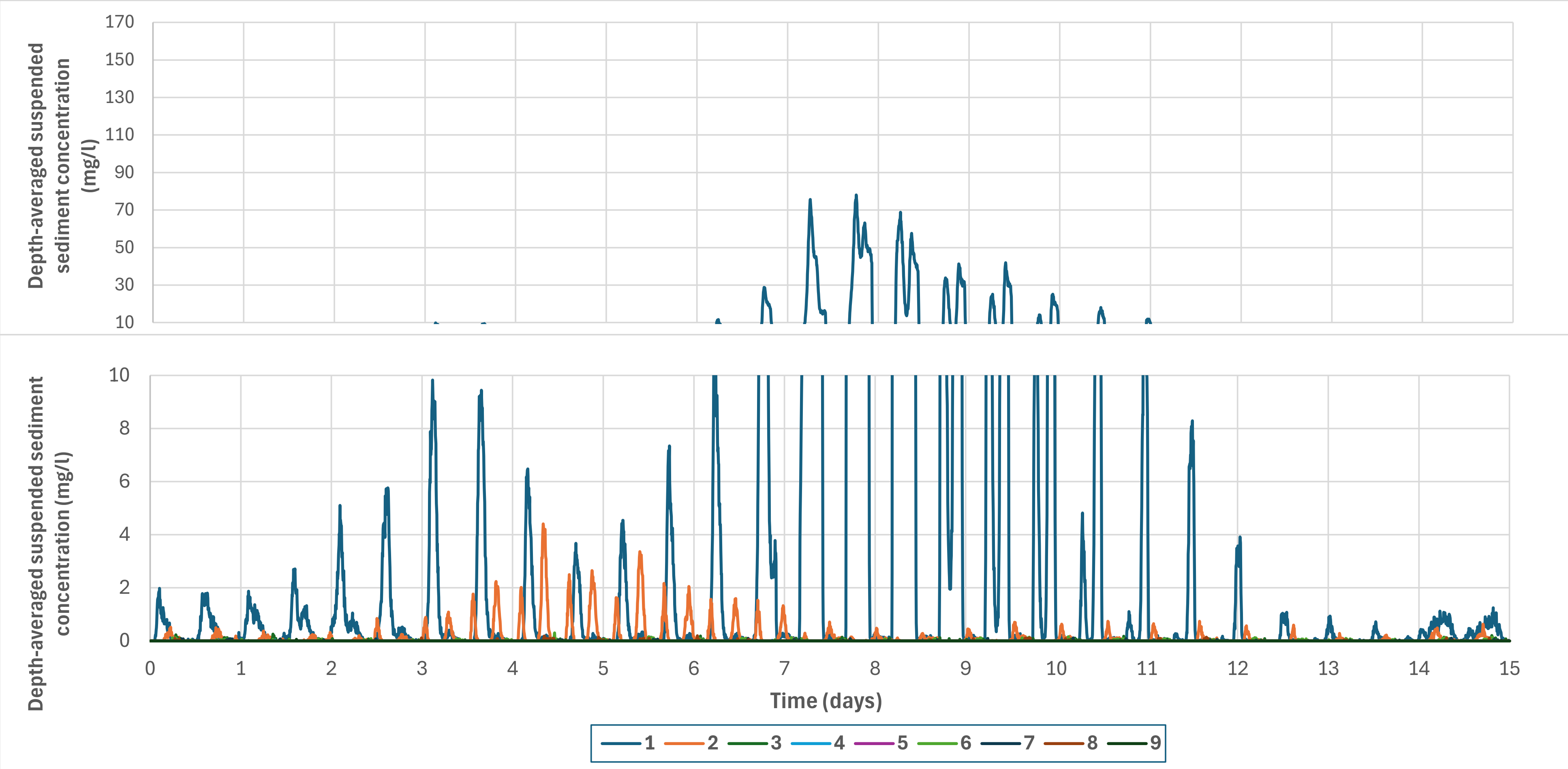

Figure 6.36: Time series of predicted increase in suspended sediment concentration, dredging in the west of the site (FLOW Basin)

6.4.8 Total deposition of fine sediment arising from works

The predicted fine sediment deposition resulting from dredging Scenario 3 as a whole is shown Figure 6.37. The figure is composed by weighting the contributions of dredging in the different zones in the north, east and west of the site.

Within the site area (red line) deposition of a few tens of centimetres is predicted. Up to a few tens of centimetres of deposition is also predicted up to 150 m west of the site area (red line) and at the end of the eastern breakwater. West of the site the predicted deposition is of up to 20 cm, declining to less than 1 mm at a distance 370 m from the boundary. East of the site depths of up to 50 mm are predicted at the end of the Eastern Breakwater. No deposition beyond approximately 300 m east of the site boundary is predicted. The limitation of the sediment plume associated with the tidal state for the dredging is reflected in the noticeable reduction in the area of deposition to the east of the site boundary.

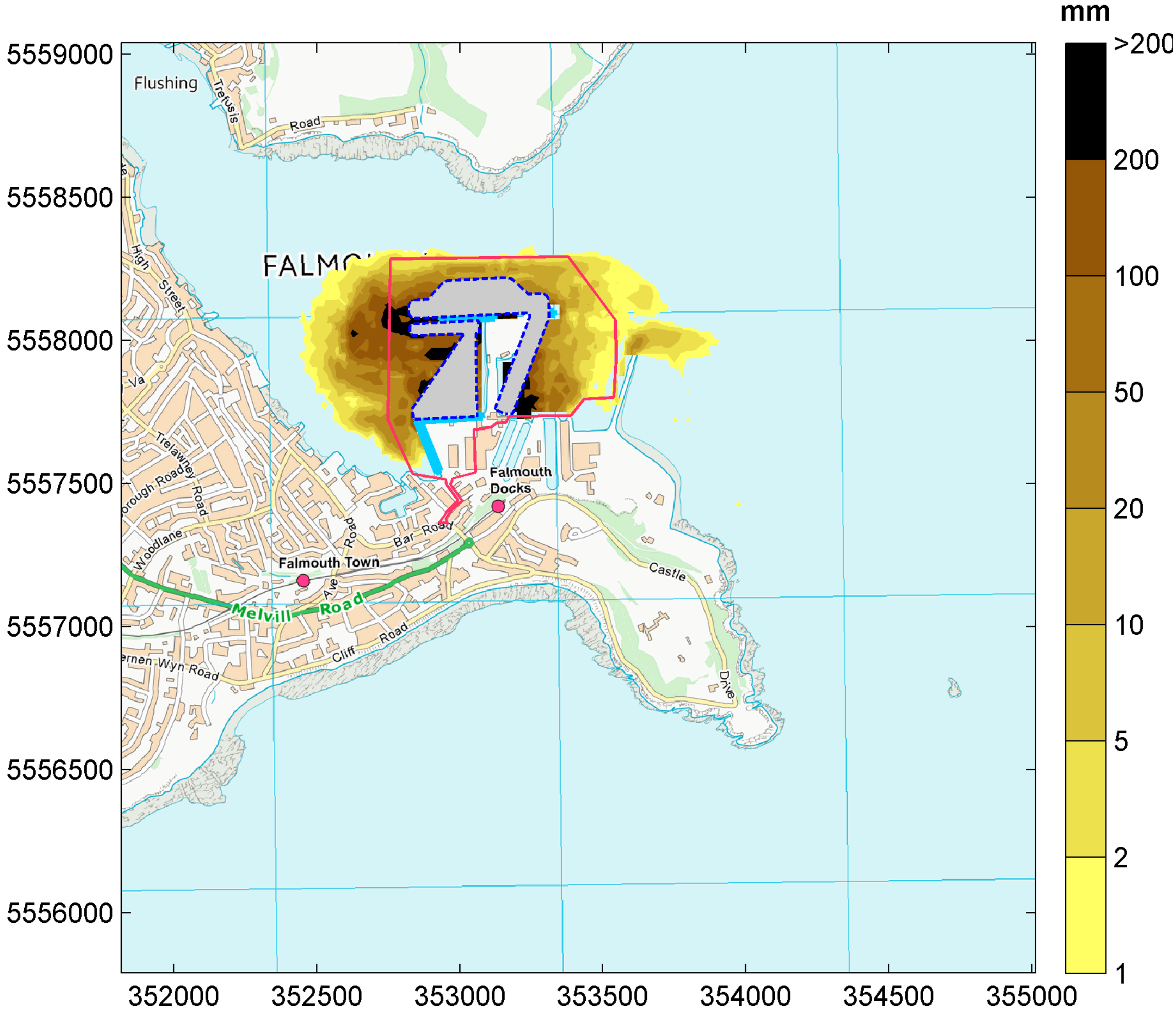

Figure 6.37: Predicted fine sediment deposition resulting from dredging Scenario 3 as a whole (Dredging areas marked in grey)

The results are summarised by Table 6.12 for total deposition at the timeseries locations. Locations 1, 2, and 8 which show the highest depth s of deposition, are within the project area.

None of the points outside the project area show deposition depths above 1 mm. However, as shown by Figure 6.37, deposition above 1 mm does occur elsewhere outside the project area.

Table 6.12: Summary of predicted total fine sediment deposition resulting from Scenario 3

Point	1	2	3	4	5	6	7	8	9
Depth of fine sediment deposition (mm)	465.9	51.8	0.7	<0.1	<0.1	0.6	0.2	14.9	<0.1

6.5 Results for sediment disposal

As for the dredging simulations above, the results of the disposal simulation are summarised as plots of peak and mean concentration increases, snapshots of the plume at specific instants and plots of deposition. The deposition resulting from disposal is shown for approximately 2 weeks of disposal and for an estimate of the total disposal resulting from the entire capital dredging operation.

The dredging scenario associated with the disposal operations as simulated is Scenario 1 as that represents a worst case for rate of sediment disposal.

The predicted peak depth-averaged concentration increases above background resulting from disposal are shown in Figure 6.38. The figure shows that the plume footprint (here defined as increases in concentration above 5 mg/l) extend up to 6.5 km SW and 13 km NE of the disposal site. Within the disposal site, at the location of the disposal, peak increases of hundreds of mg/l are predicted. This magnitude of concentration reduces to below 20 mg/l at a distance of 3.3 km from the site.

The predicted mean depth-averaged concentration increases above background resulting from disposal are shown in Figure 6.39. The figure shows that the plume footprint (here defined as increases in concentration above 5 mg/l) extend up to 2.4 km SW and 0.8 km NW of the disposal site. Within the disposal site, at the location of the disposal, mean increases of hundreds of mg/l are predicted. This magnitude of mean concentration reduces to below 20 mg/l at a distance of 900 m from the site.

Examples of snapshots of the disposal plume from near the end of the simulation are shown in Figure 6.40 and Figure 6.41. The figures show the plume when the plume is westward and eastward, just after a disposal event. It should be noted that the extent of the plume(s) at any time is much smaller than the peak concentration footprint shown in Figure 6.38.

The predicted fine sediment deposition at the end of the (2 week) simulation is shown in Figure 6.42. It can be seen that the main body of sedimentation (as defined by deposition of less than 1 mm) extends up to 2 km NE and 3 km SW of the disposal site. Additional patches of sedimentation of 1-2 mm occur NNE of the disposal site. The total fine sediment deposition resulting from the entire disposal operation is estimated in Figure 6.43. This figure indicates deposition of more than 5 mm within 3.2 km NE of, and within 2.1 km SW in the streamline of the disposal site with patches of around a centimetre of deposition up to 10 km NNE of the site. Deposition of more than 10 cm is predicted within 2.2 km (SW) and 500 m (NE) of the site.

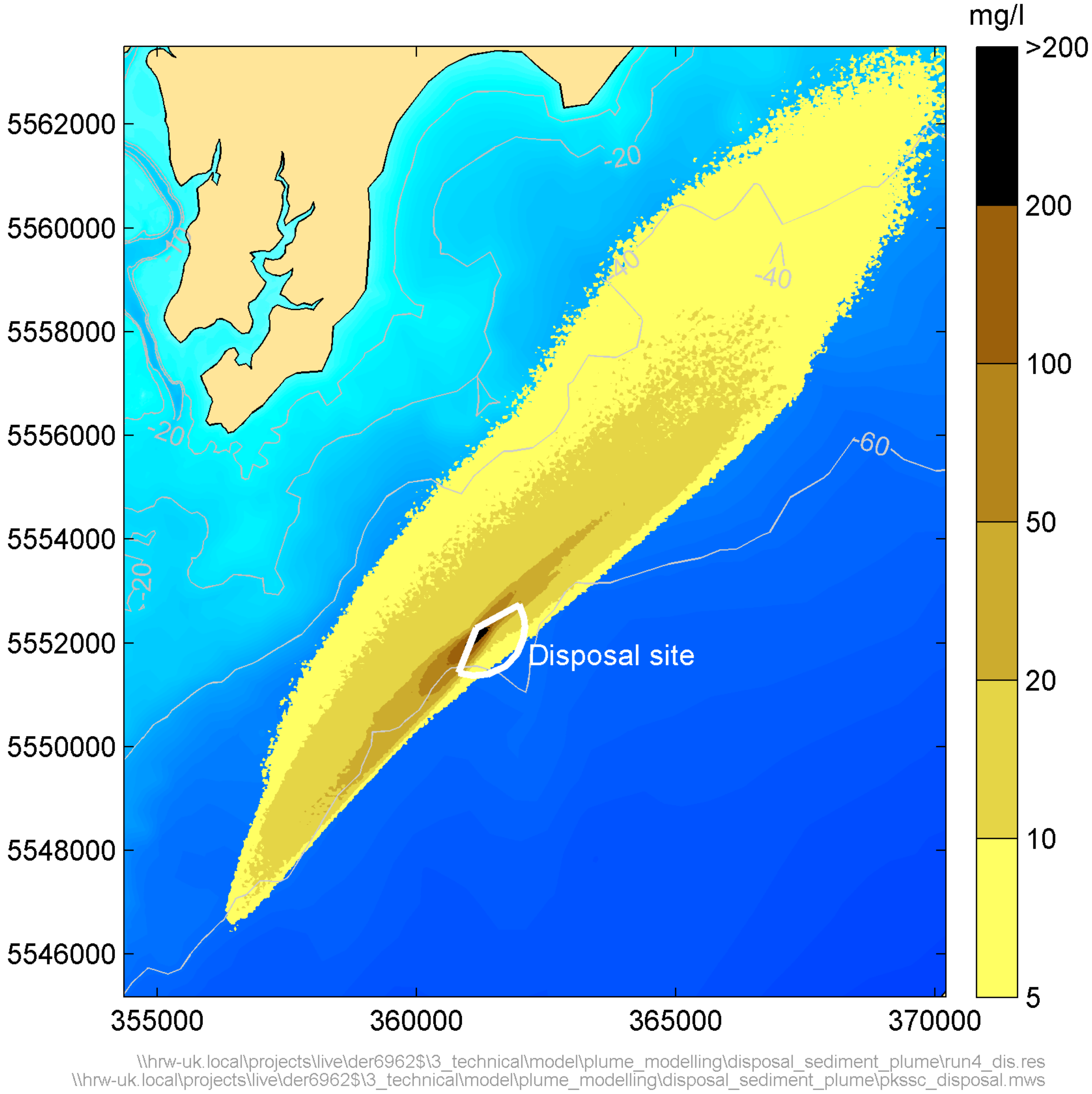

Figure 6.38: Predicted peak increase in depth-averaged suspended sediment concentration resulting from disposal of uncontaminated sediment at the disposal site

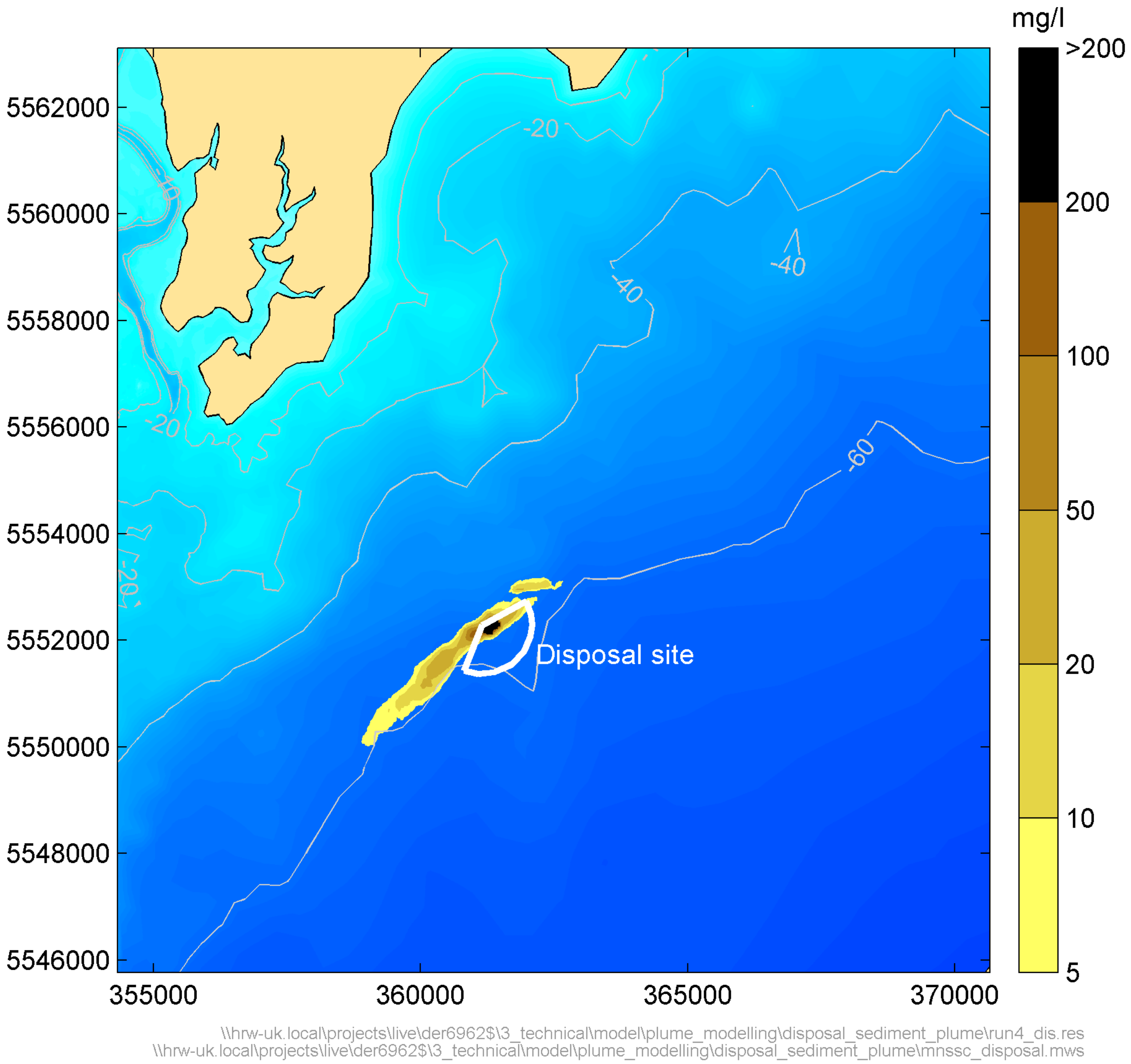

Figure 6.39: Predicted mean increase in depth-averaged suspended sediment concentration resulting from disposal of uncontaminated sediment at the disposal site

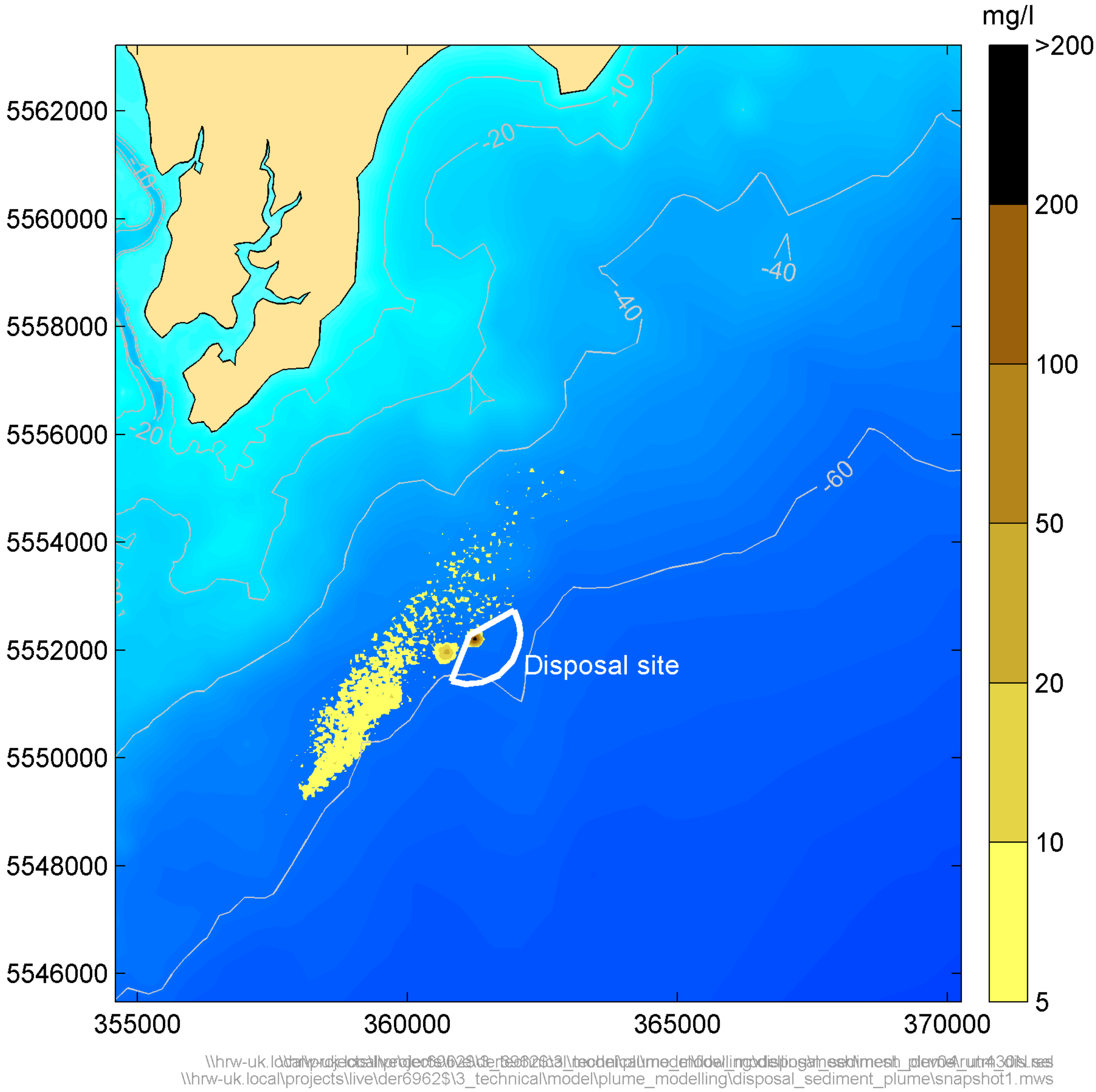

Figure 6.40: Snapshot of the plume (predicted depth-averaged suspended sediment concentration) resulting from disposal of uncontaminated sediment at the disposal site, just after disposal during SW-ward flowing currents

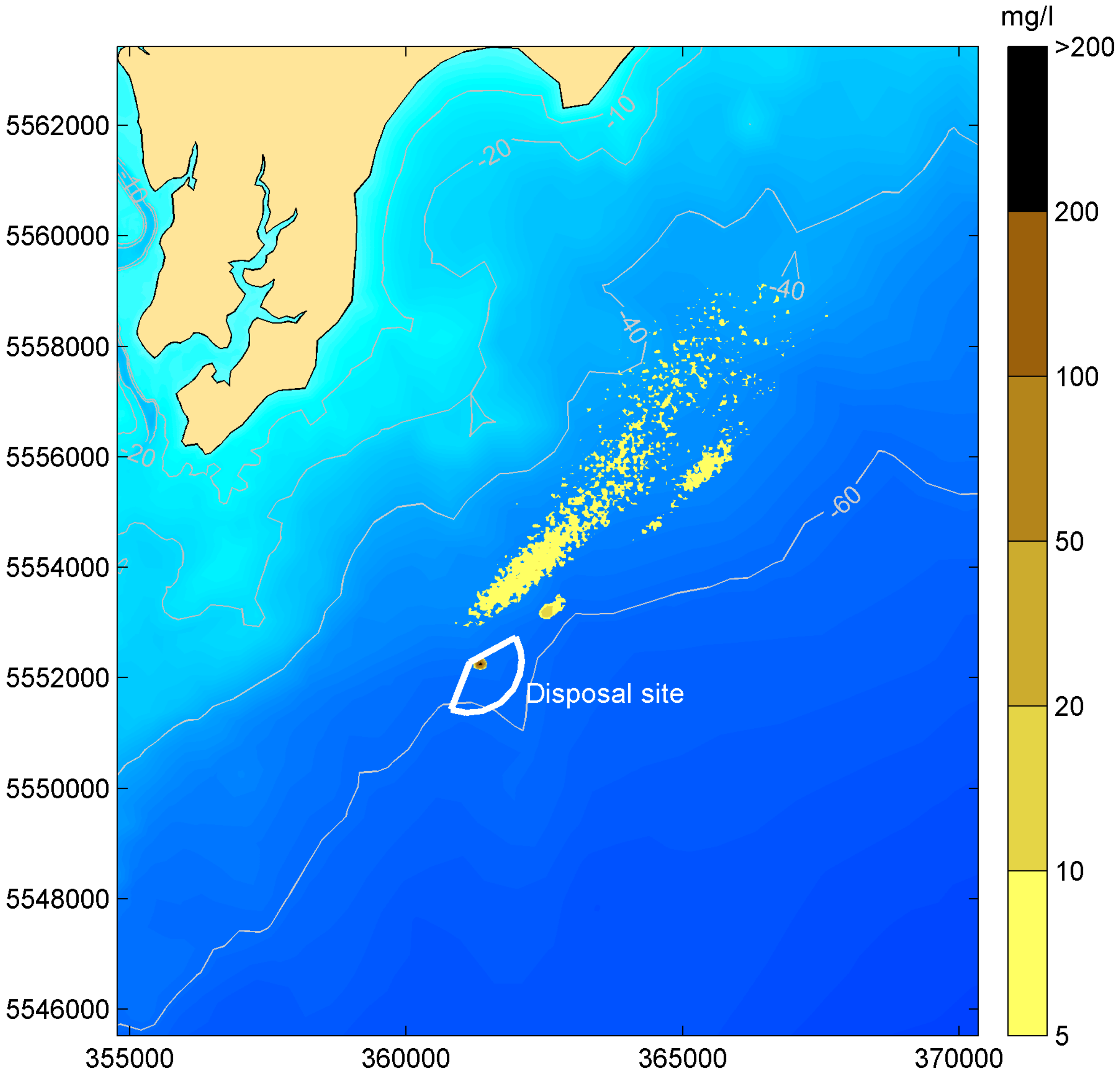

Figure 6.41: Snapshot of the plume (predicted depth-averaged suspended sediment concentration) resulting from disposal of uncontaminated sediment at the disposal site, just after disposal during NE-ward flowing currents

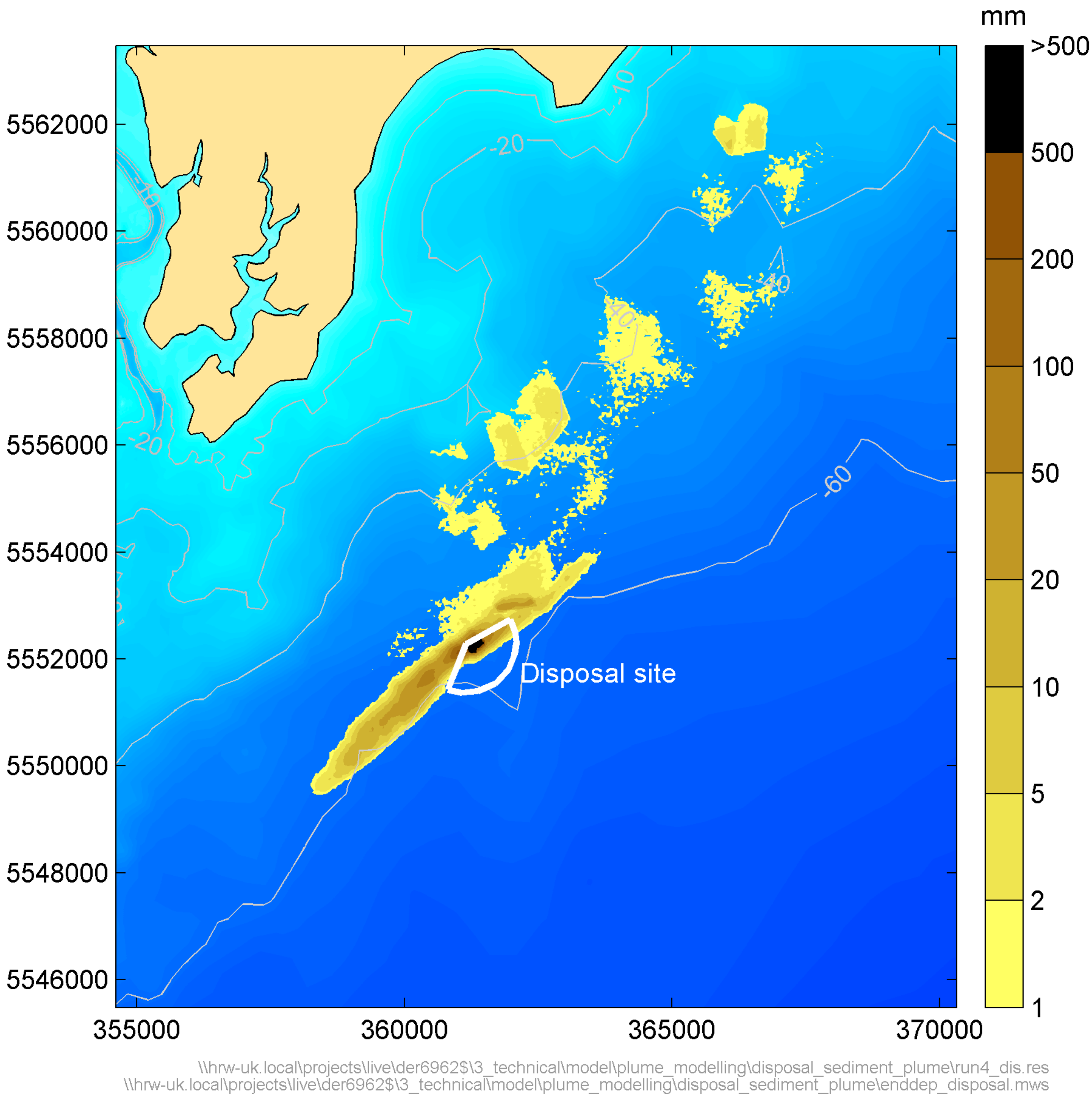

Figure 6.42: Predicted fine sediment deposition resulting from 2 weeks of disposal of uncontaminated sediment at the disposal site

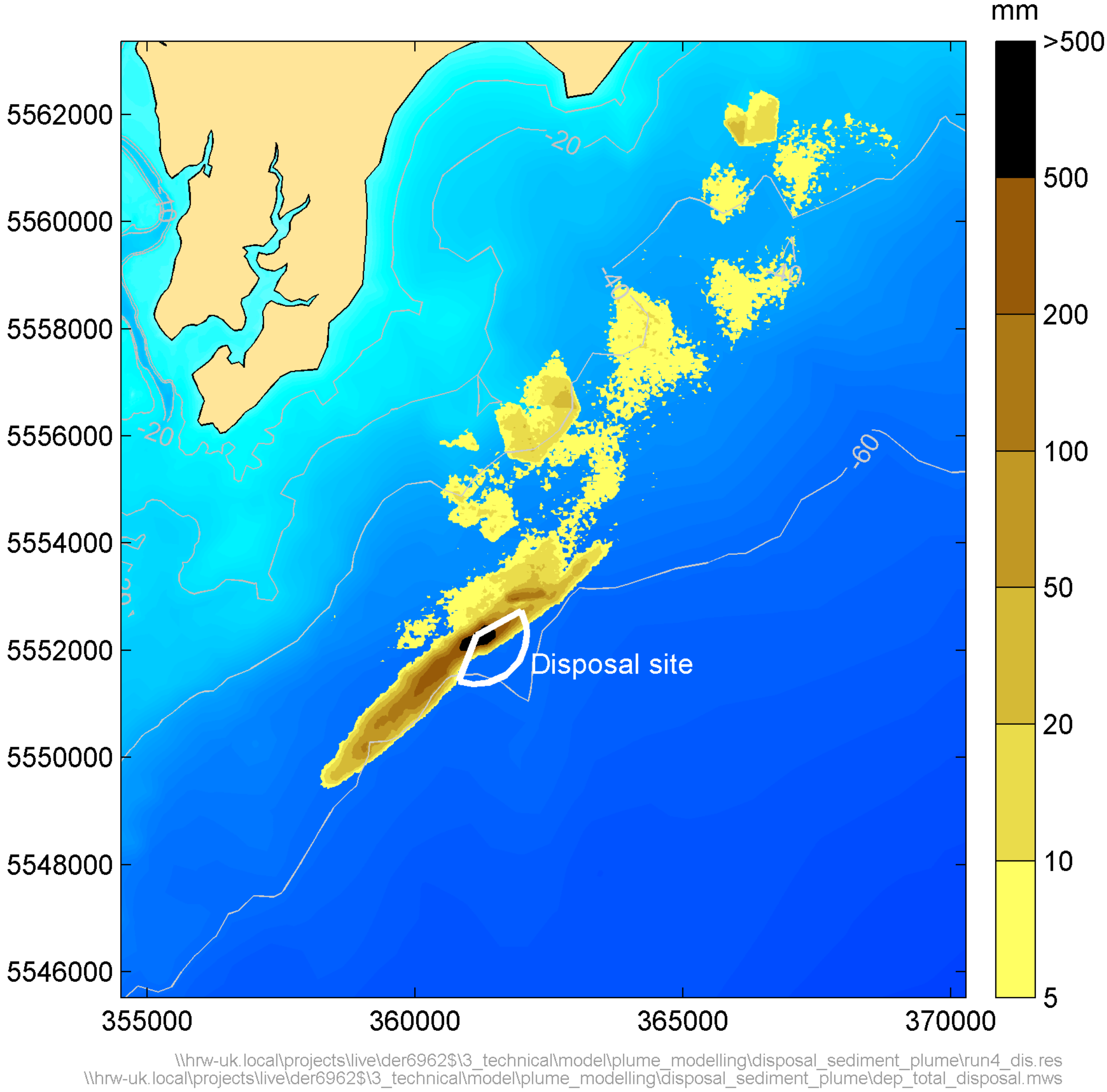

Figure 6.43: Estimated fine sediment deposition resulting from the whole disposal operation

7 Prediction of dispersion of contaminants

7.1 Introduction

A first order assessment of changes in water quality resulting from release of contaminants was undertaken, using a similar steady-state approach to that undertaken for the previous assessment (HR Wallingford, 2008). The amount of contaminant released into the water column is a function both of the concentration of contaminant on the disturbed sediment and the amount of contaminant that passes from the sediment into the dissolved phase. The distribution of the contaminants between the dissolved phase and that adsorbed onto the sediment is controlled by the partition coefficient. These coefficients vary from site to site and for differing levels of background parameters such as ambient suspended solids, salinity, etc. The partition coefficients used for the study were those used in the previous study and are listed in Table 7.1.

Note that estimation of dissolved concentrations of Dibutyltin and of “PCB-25 congeners” were not undertaken in this study because of the absence of either partition coefficients or EQS standards.

Table 7.1: List of contaminants used to estimate dissolved concentrations arising from proposing dredging, together with the partition coefficients used for the assessment

Contaminant	Partition Coefficient (l/kg)
Copper (Cu)	40,000
Mercury (Hg)	200,000
Lead (Pb)	100,000
Zinc (Zn)	15,000
Tributyltin (TBT)	10,000

For the purpose of the analysis the partitioning of the contaminants was assumed to occur at the point of dredging. This assumption would be expected to give the highest dissolved contamination levels. Estimates of dissolved contaminant concentration were therefore derived by:

- Running a dissolved contaminant plume simulation where the source terms for each contaminant are a function of the average sediment contaminant concentration in the dredged sediment.
- The contaminant plume source term was calculated for each of the different zones (east, north, west) using the average sediment contaminant concentration for each contaminant and zone (see Table 4.1) and to derive the dissolved sediment concentration this source term was multiplied by the factor (Chapra, 1997).

  $$\frac{1}{K_p.c+1}$$ where K_p is the partition coefficient (units of l/Kg) and c is the suspended sediment concentration (in units of Kg/l).

- The resulting dissolved contaminant plume dispersion was then time averaged over the 2 weeks of simulated dredging.

When sediment containing contaminants is disturbed by dredging the sediment released will also contain levels of contamination. The disturbance of the contaminated sediment also results in some of the contaminants desorbing from the sediment to which they are attached and becoming dissolved in the ambient water body. The dispersion of the various released contaminants required assessment both to demonstrate the implications for both water and sediment quality and as input for analysis of any ecological impacts undertaken as part of the EIA for the study.

The implications for the modelled results should be considered by comparison against Specific pollutant, priority substance and hazardous priority substance environmental quality standards (EQS) (Environment Agency, 2022a, 2022b).

As a worst case for dispersion of contaminants the simulations represented dredging throughout the tide with the 10 m^3 lidded backhoe as presented by the sediment plume results for dredging contaminated sediments in Scenario 1.

Table 7.2: Environmental Quality Standards (EQS) for the assessed contaminants

	Maximum Allowed Concentration (µg/l)	**Annual Average (µg/l)**
Copper (Cu)	N/A	3.8
Mercury (Hg) – *priority substance*	0.07	N/A
Lead (Pb) - *priority hazardous substance*	14	1.3
Zinc (Zn)	N/A	6.8
Tributyltin (TBT) - *priority hazardous substance*	0.0015	0.0002

Source: Environment Agency (2022a,b)

The ecological implications of the predicted concentrations are presented in the relevant sections of the Environmental Statement for the proposed development.

7.2 Prediction of changes in water and sediment quality from dredging contaminated sediment in east part of site (Western Wharf)

In this and the following sections the predicted time-averaged dissolved concentrations for each contaminant (Cu, Hg, Pb, Zn and TBT) are presented. Where the EQS thresholds are exceeded, this is indicated in the results by presenting the exceeded iso-contour of contaminant concentration - either the Maximum Allowed Concentration (MAC) or Annual Average (AA) threshold.

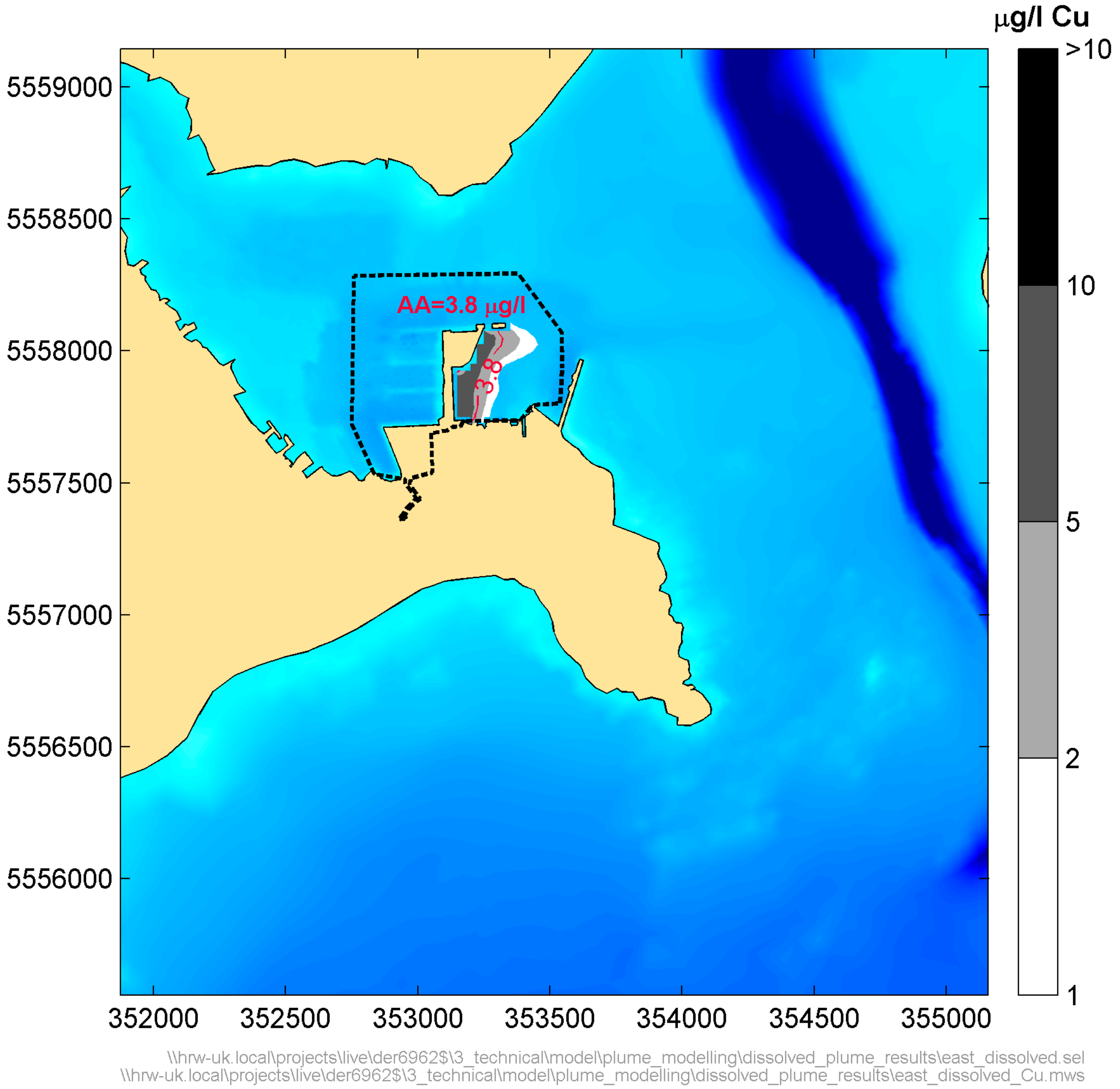

Figure 7.1: Predicted time-averaged concentration of **Copper (Cu)** over 15 days of dredging in the **east** of the site (Western Wharf)

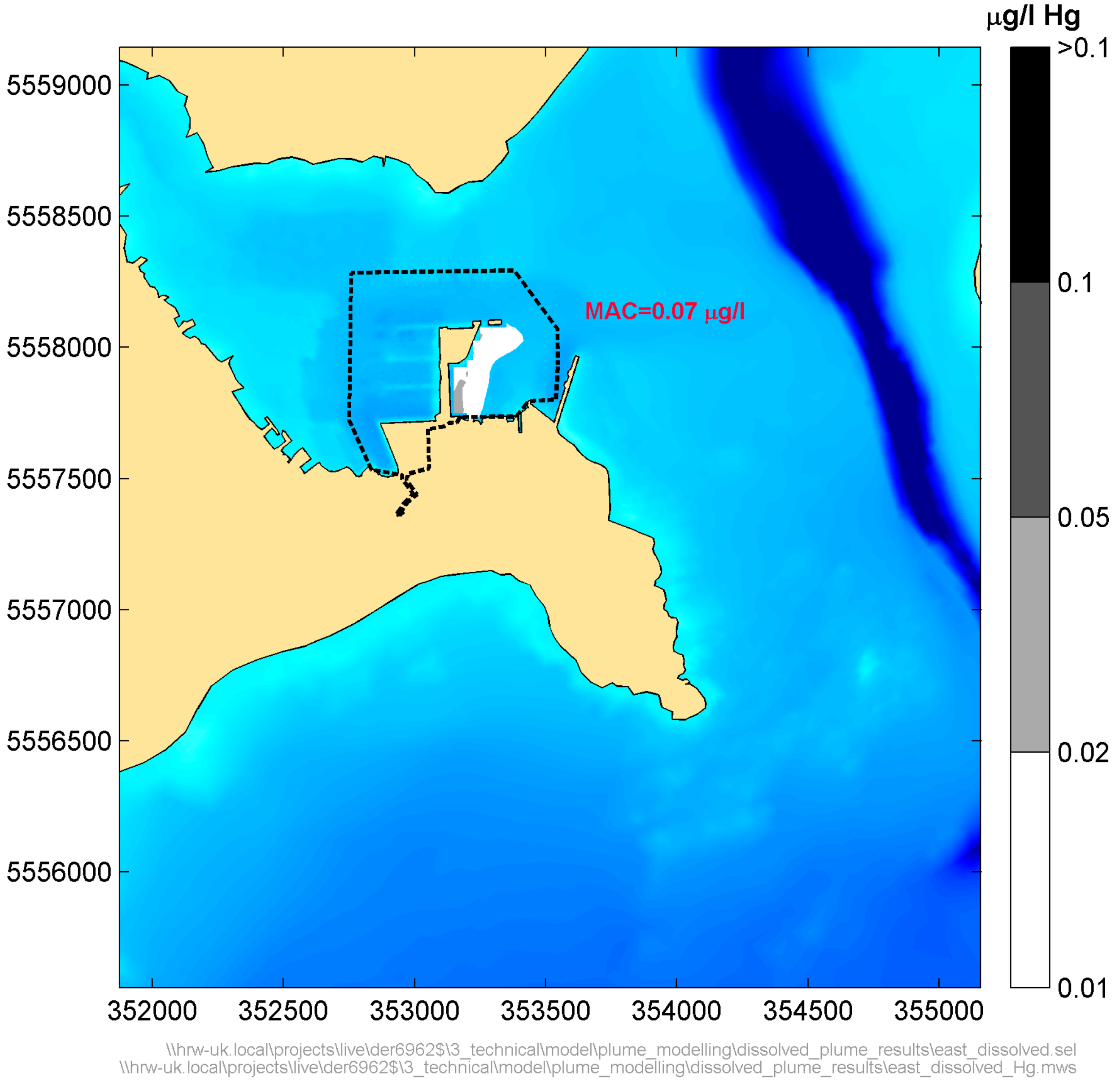

Figure 7.2: Predicted time-averaged concentration of **Mercury (Hg)** over 15 days of dredging in the **east** of the site (Western Wharf)

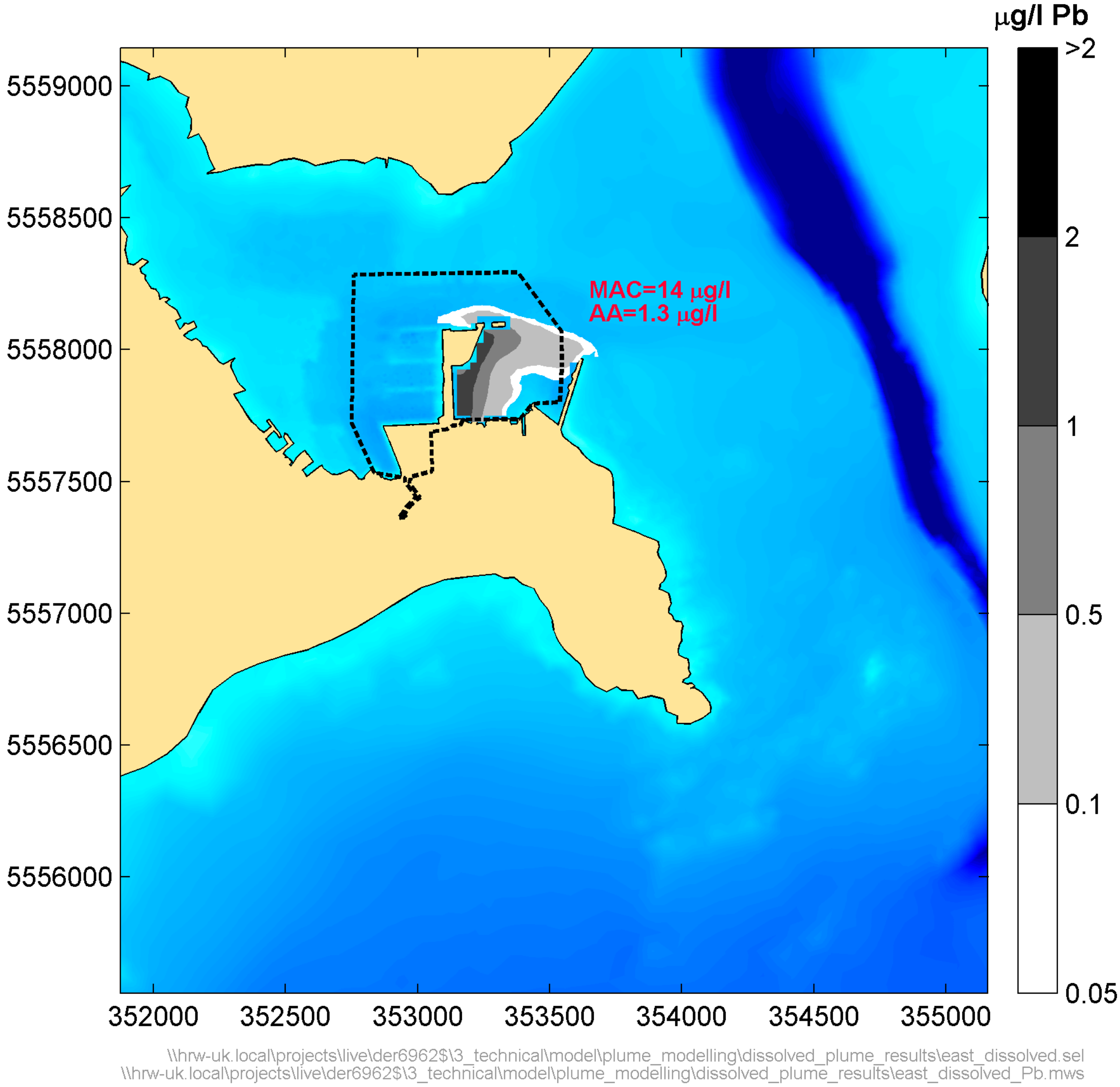

Figure 7.3: Predicted time-averaged concentration of **Lead (Pb)** over 15 days of dredging in the **east** of the site (Western Wharf)

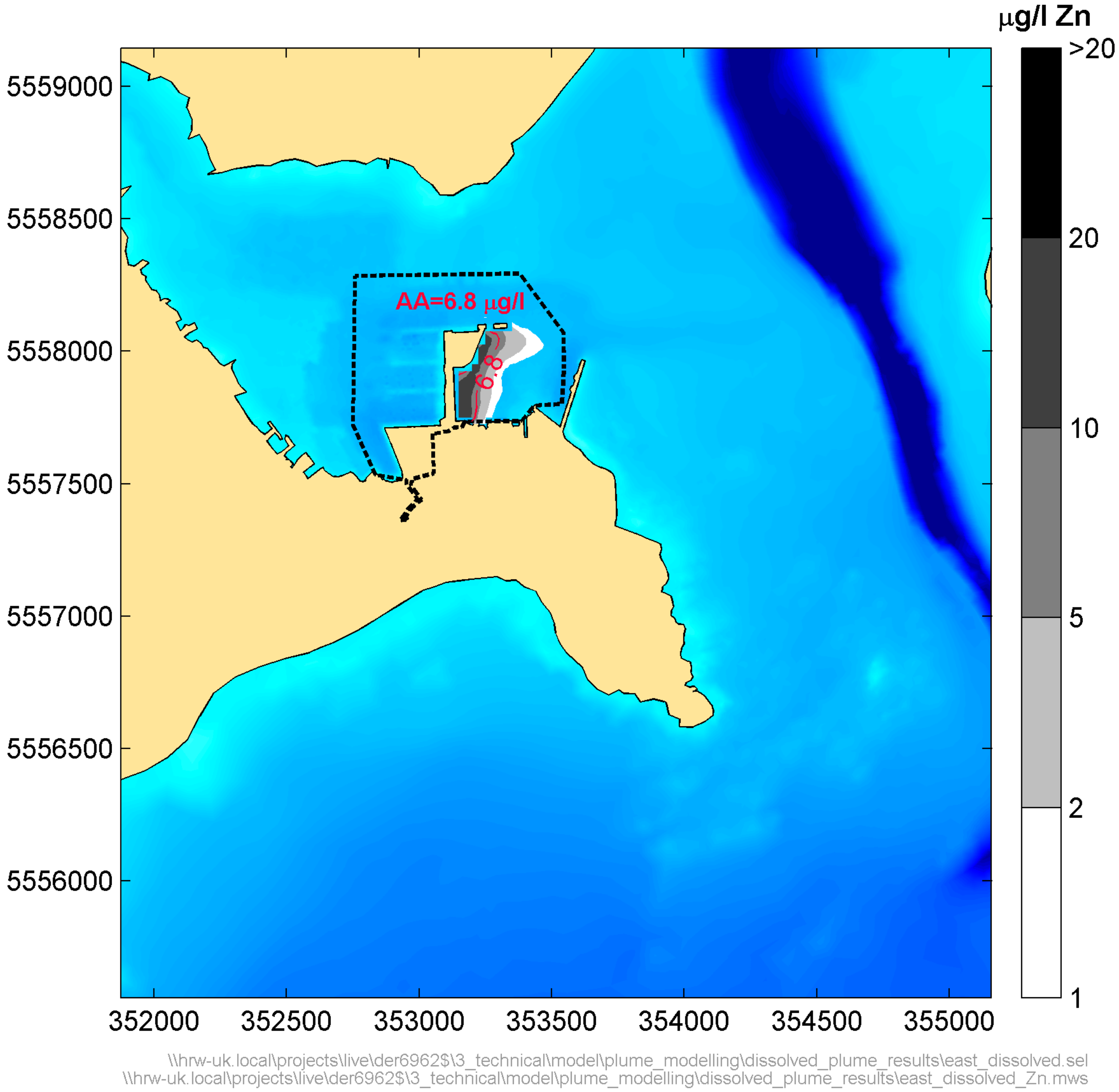

Figure 7.4: Predicted time-averaged concentration of **Zinc (Zn)** over 15 days of dredging in the **east** of the site (Western Wharf)

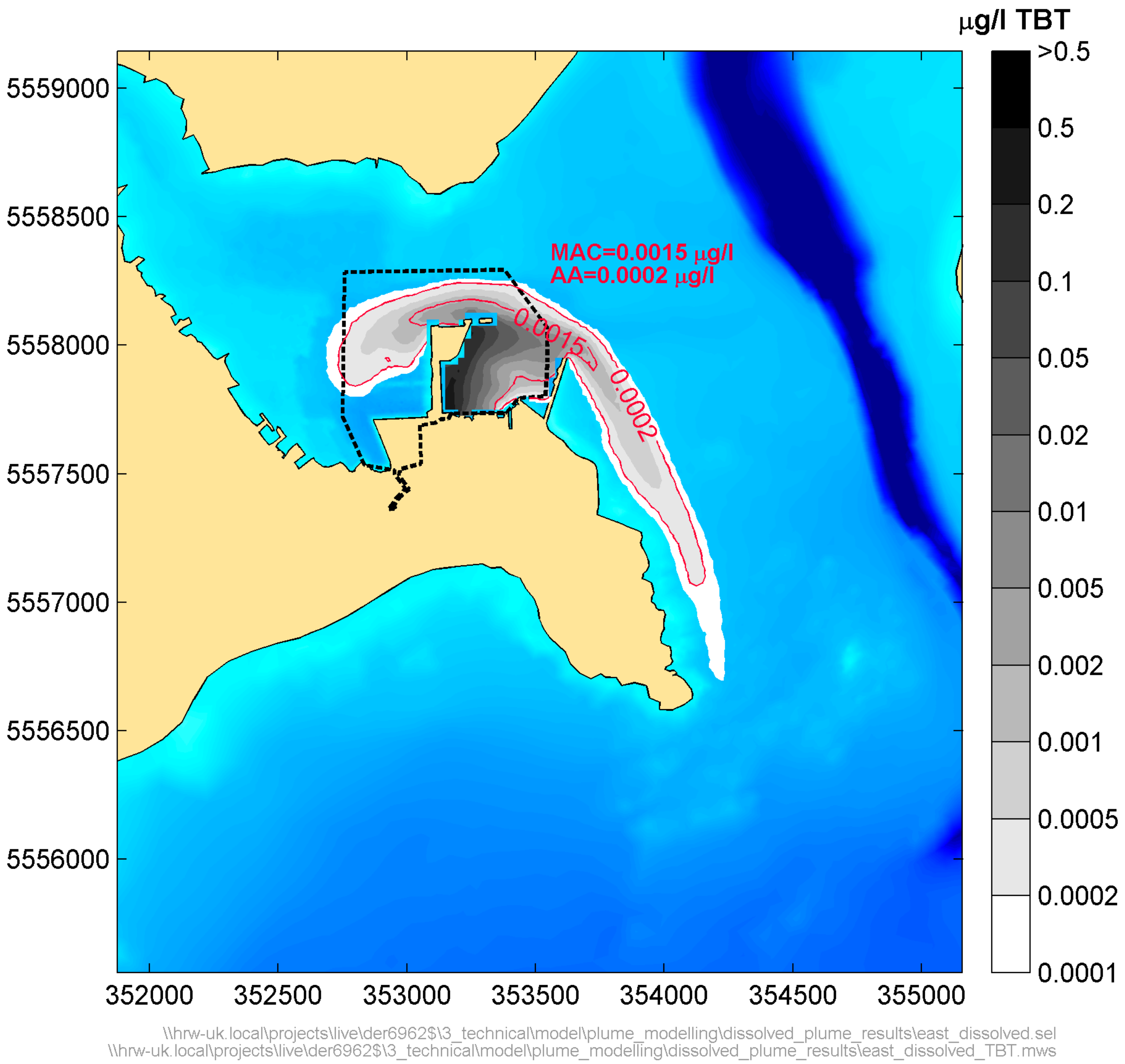

Figure 7.5: Predicted time-averaged concentration of **Tributyltin (TBT)** over 15 days of dredging in the **east** of the site (Western Wharf)

7.3 Prediction of changes in water and sediment quality from dredging in north part of site

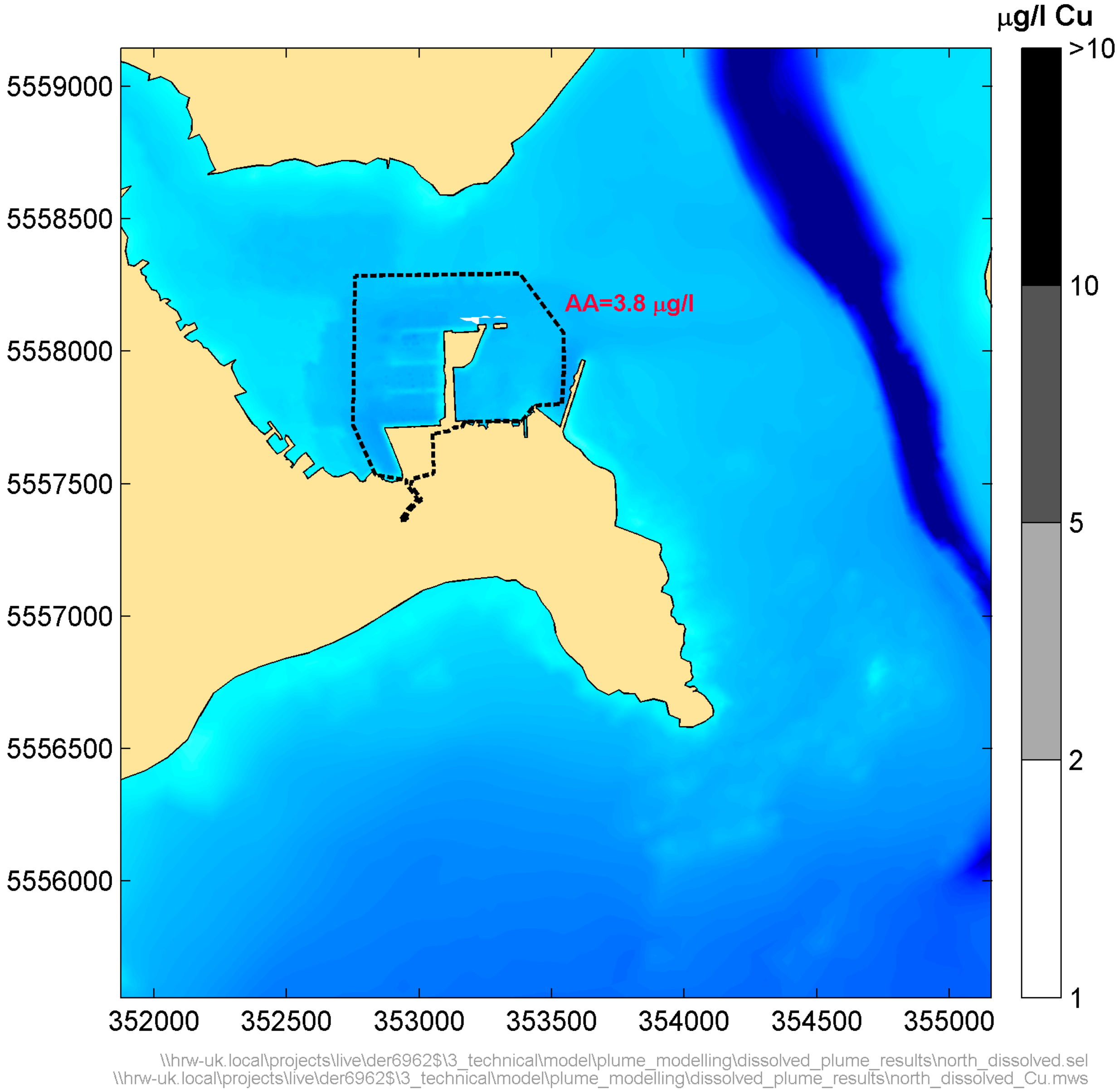

Figure 7.6: Predicted time-averaged concentration of **Copper (Cu)** over 15 days of dredging in the **north** of the site

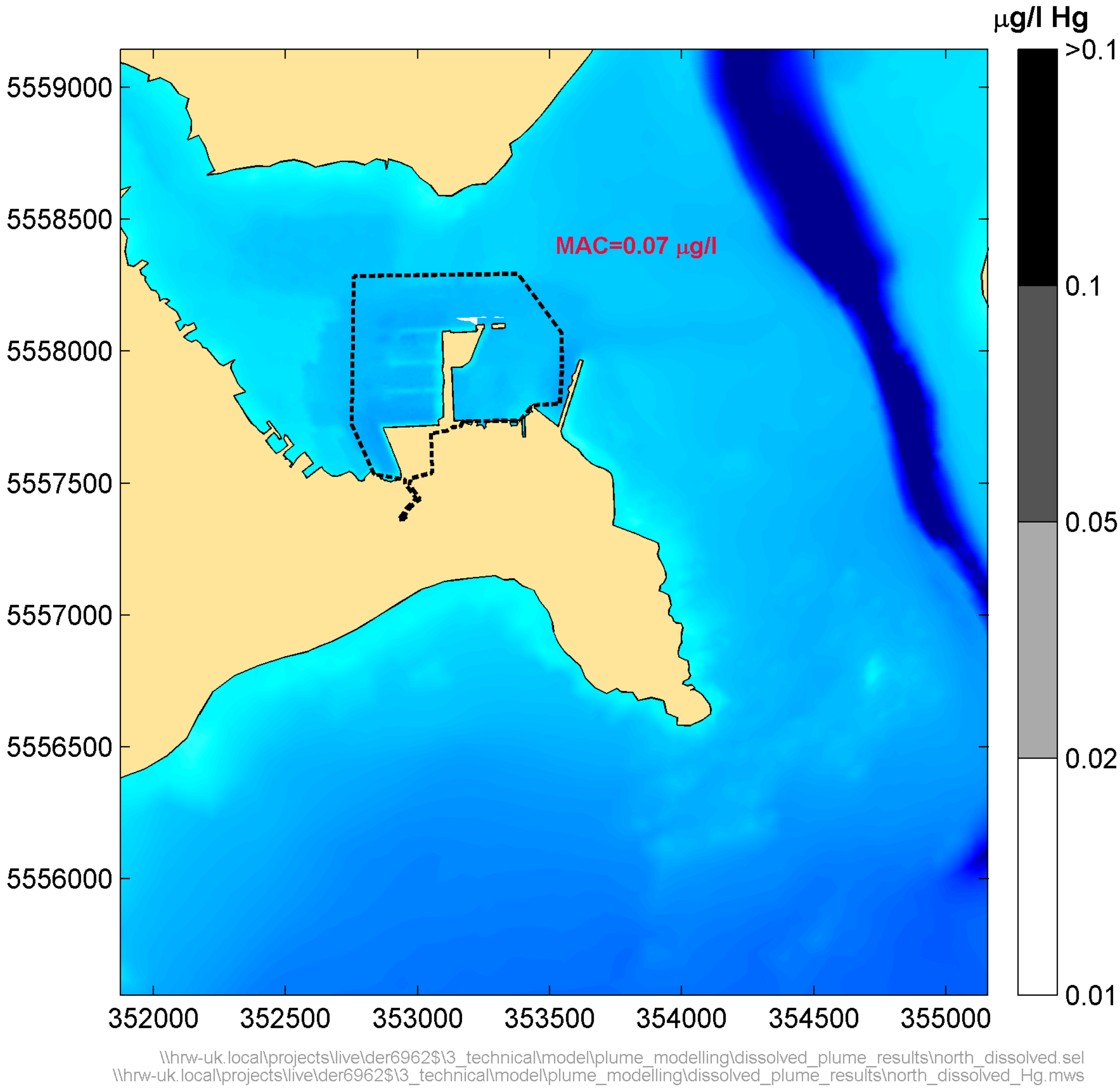

Figure 7.7: Predicted time-averaged concentration of **Mercury (Hg)** over 15 days of dredging in the **north** of the site

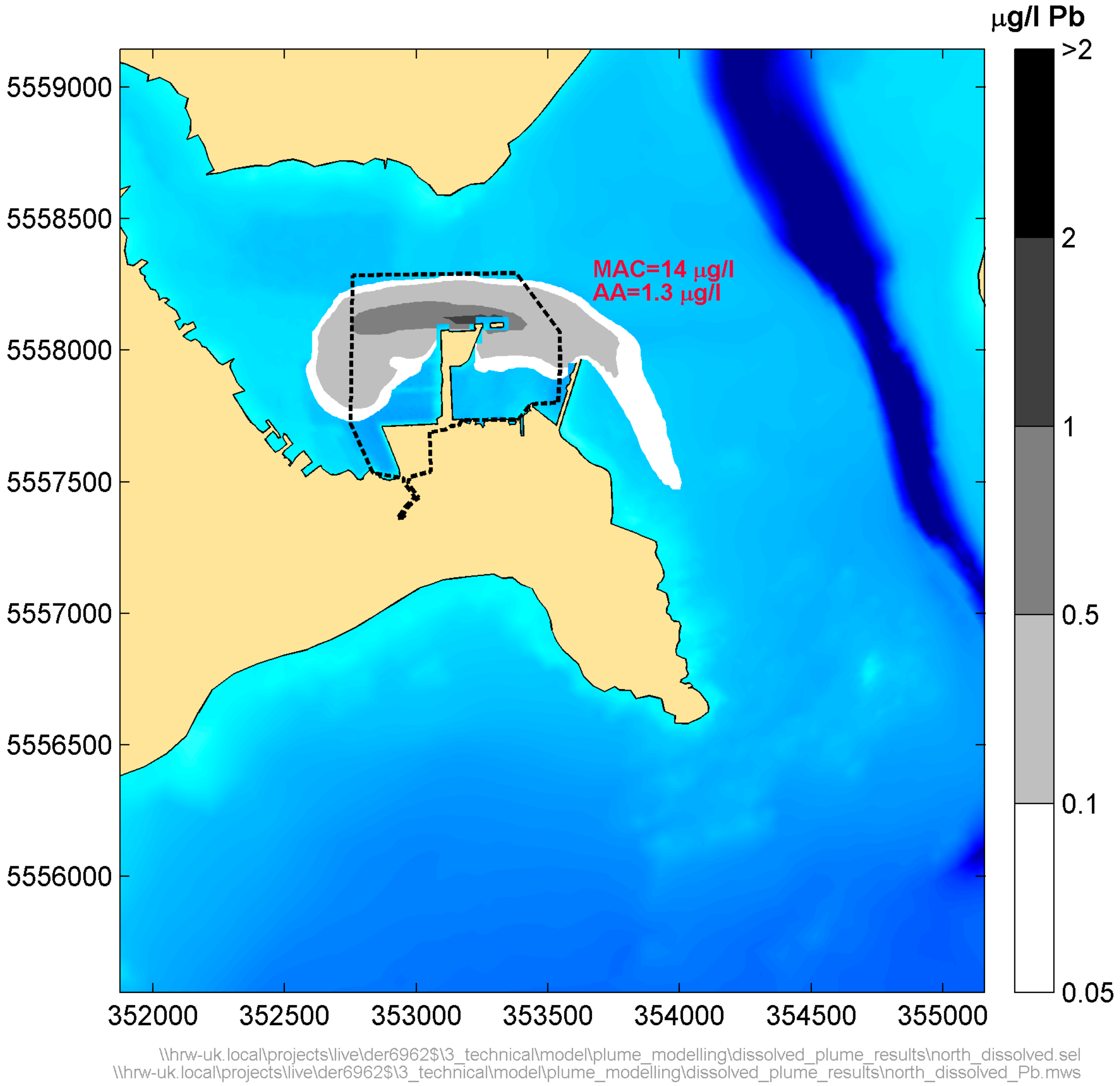

Figure 7.8: Predicted time-averaged concentration of **Lead (Pb)** over 15 days of dredging in the **north** of the site

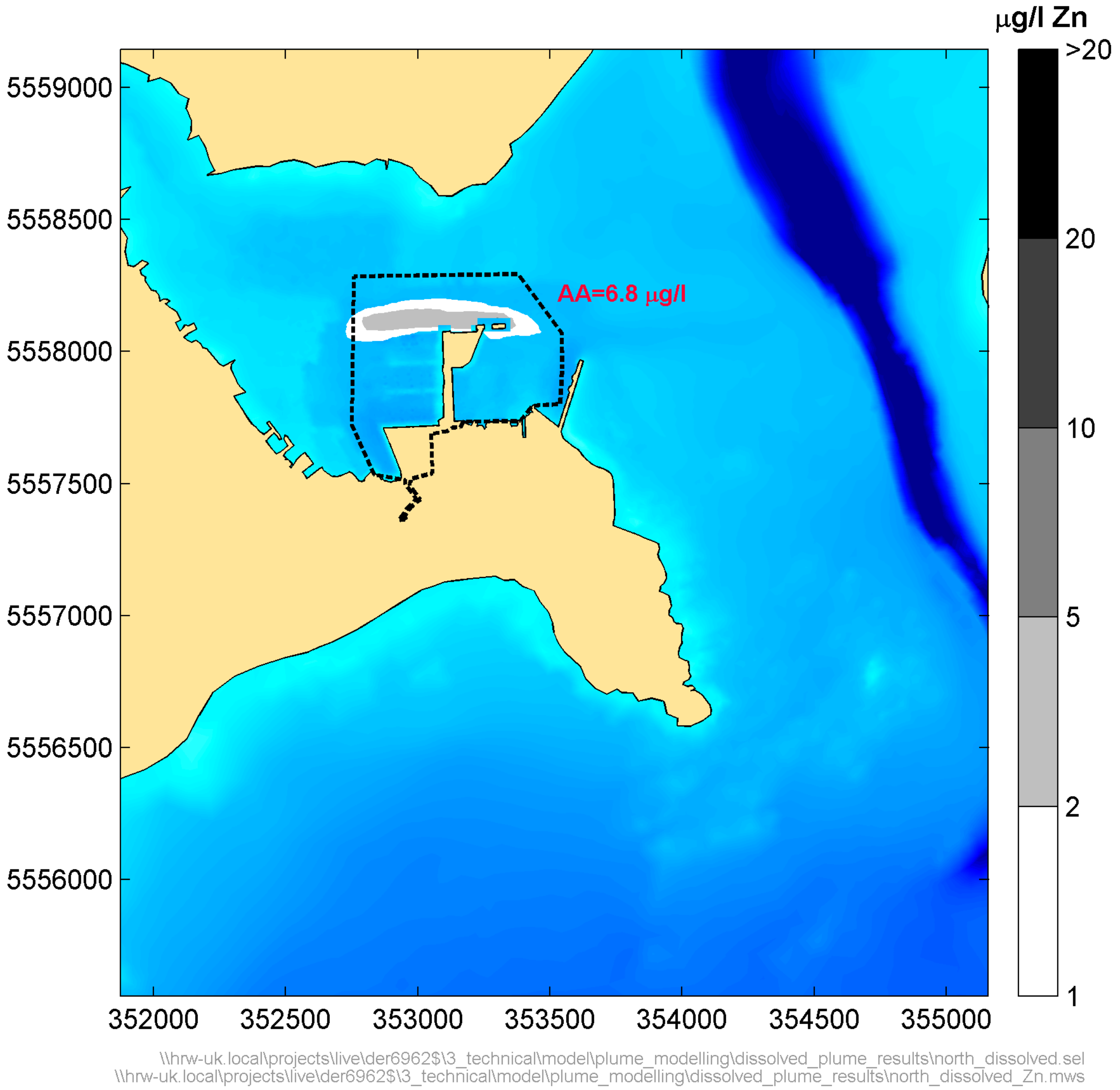

Figure 7.9: Predicted time-averaged concentration of **Zinc (Zn)** over 15 days of dredging in the **north** of the site

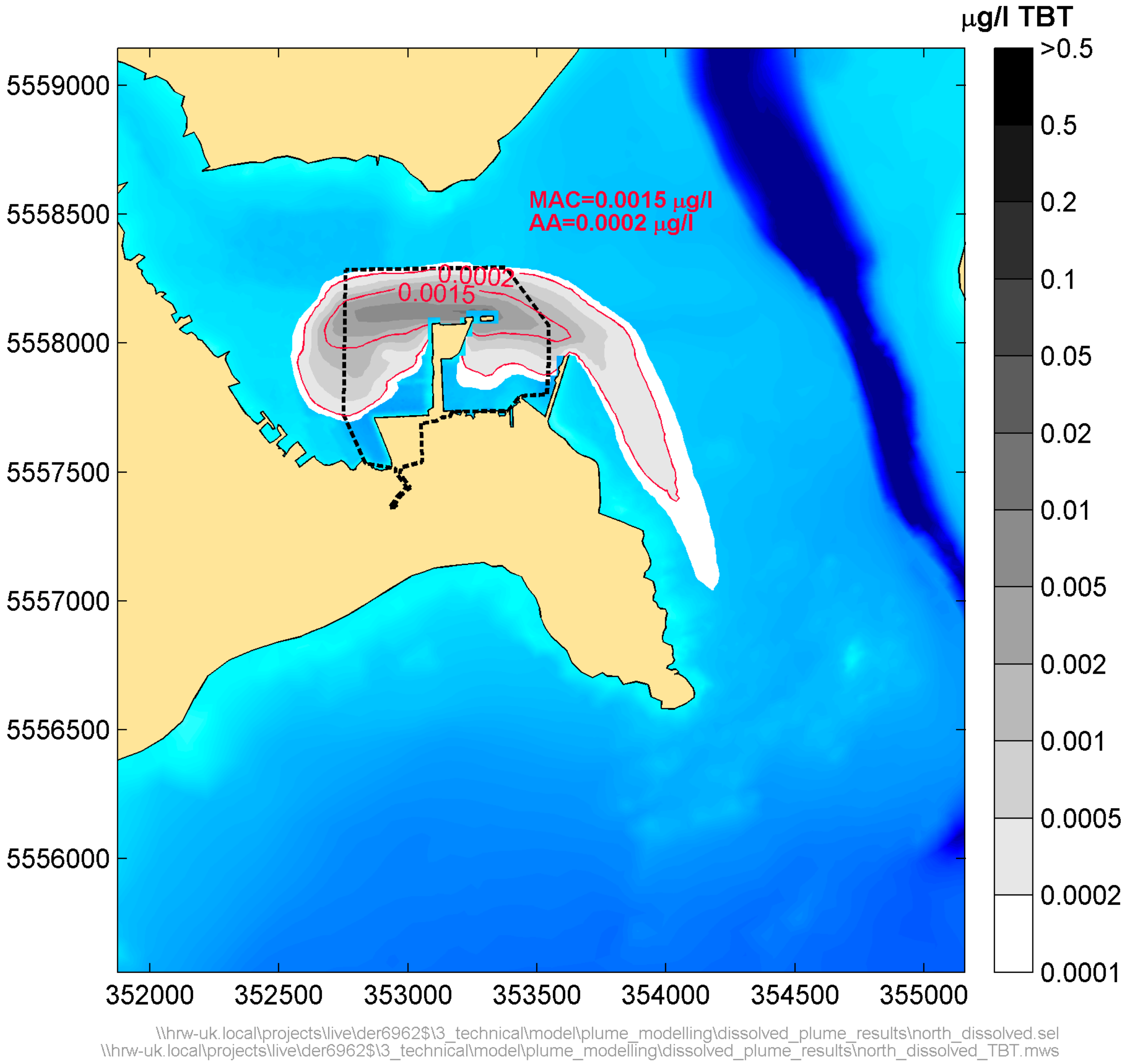

Figure 7.10: Predicted time-averaged concentration of **Tributyltin (TBT)** over 15 days of dredging in the **north** of the site

7.4 Prediction of changes in water and sediment quality from dredging in west part of site

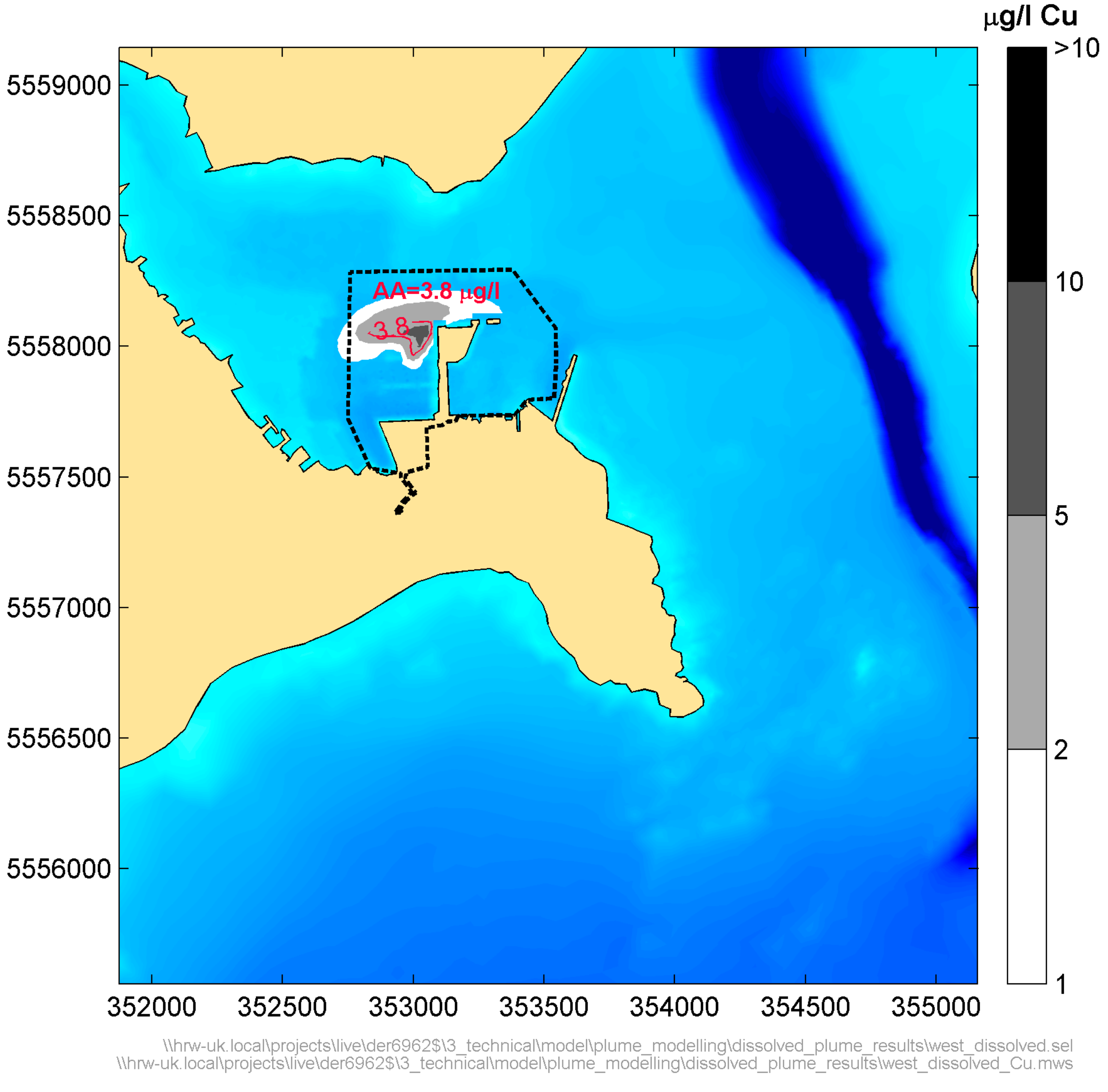

Figure 7.11: Predicted time-averaged concentration of **Copper (Cu)** over 15 days of dredging in the **west** of the site (FLOW Basin)

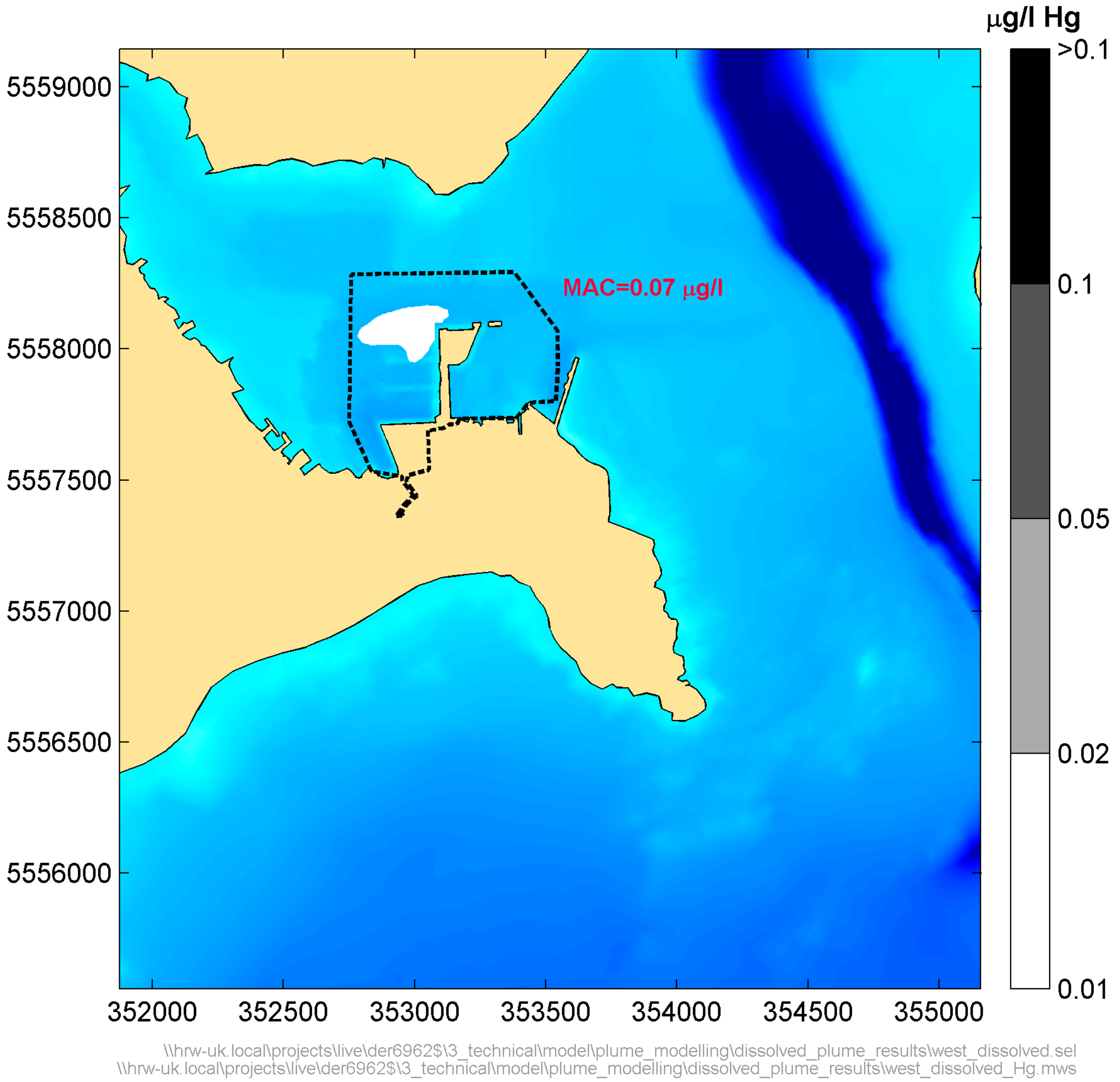

Figure 7.12: Predicted time-averaged concentration of **Mercury (Hg)** over 15 days of dredging in the **west** of the site (FLOW Basin)

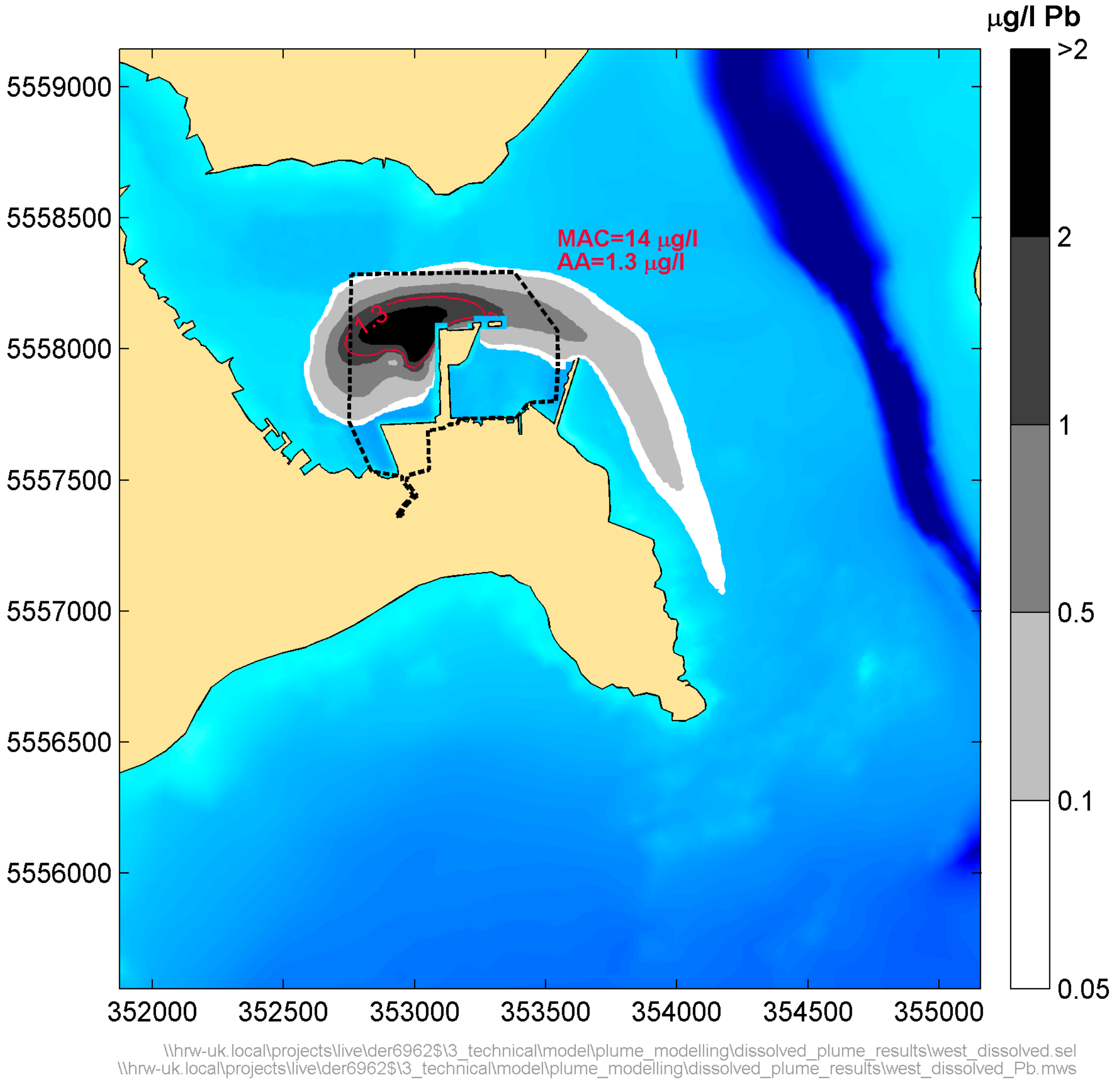

Figure 7.13: Predicted time-averaged concentration of **Lead (Pb)** over 15 days of dredging in the **west** of the site (FLOW Basin)

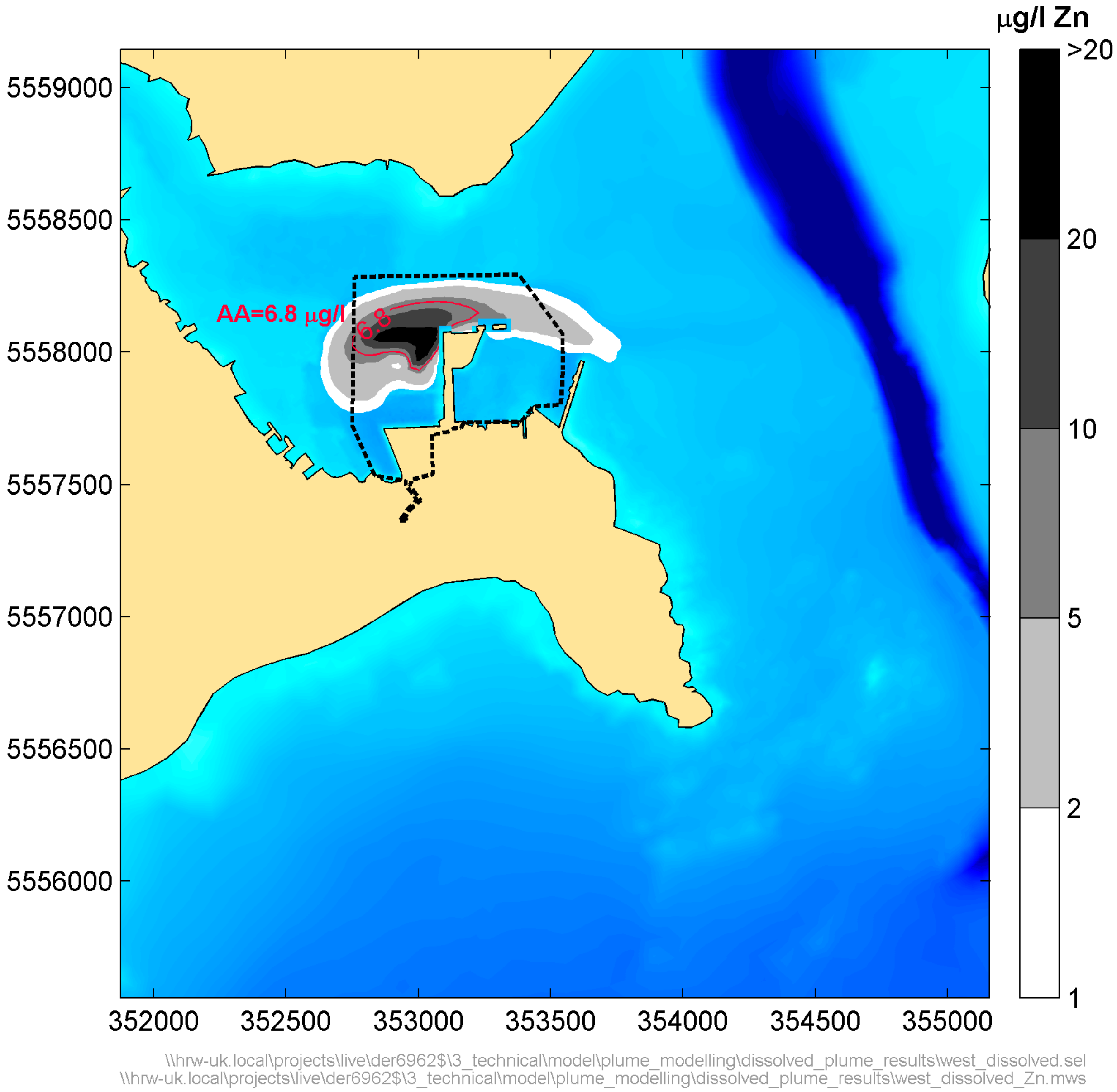

Figure 7.14: Predicted time-averaged concentration of **Zinc (Zn)** over 15 days of dredging in the **west** of the site (FLOW Basin)

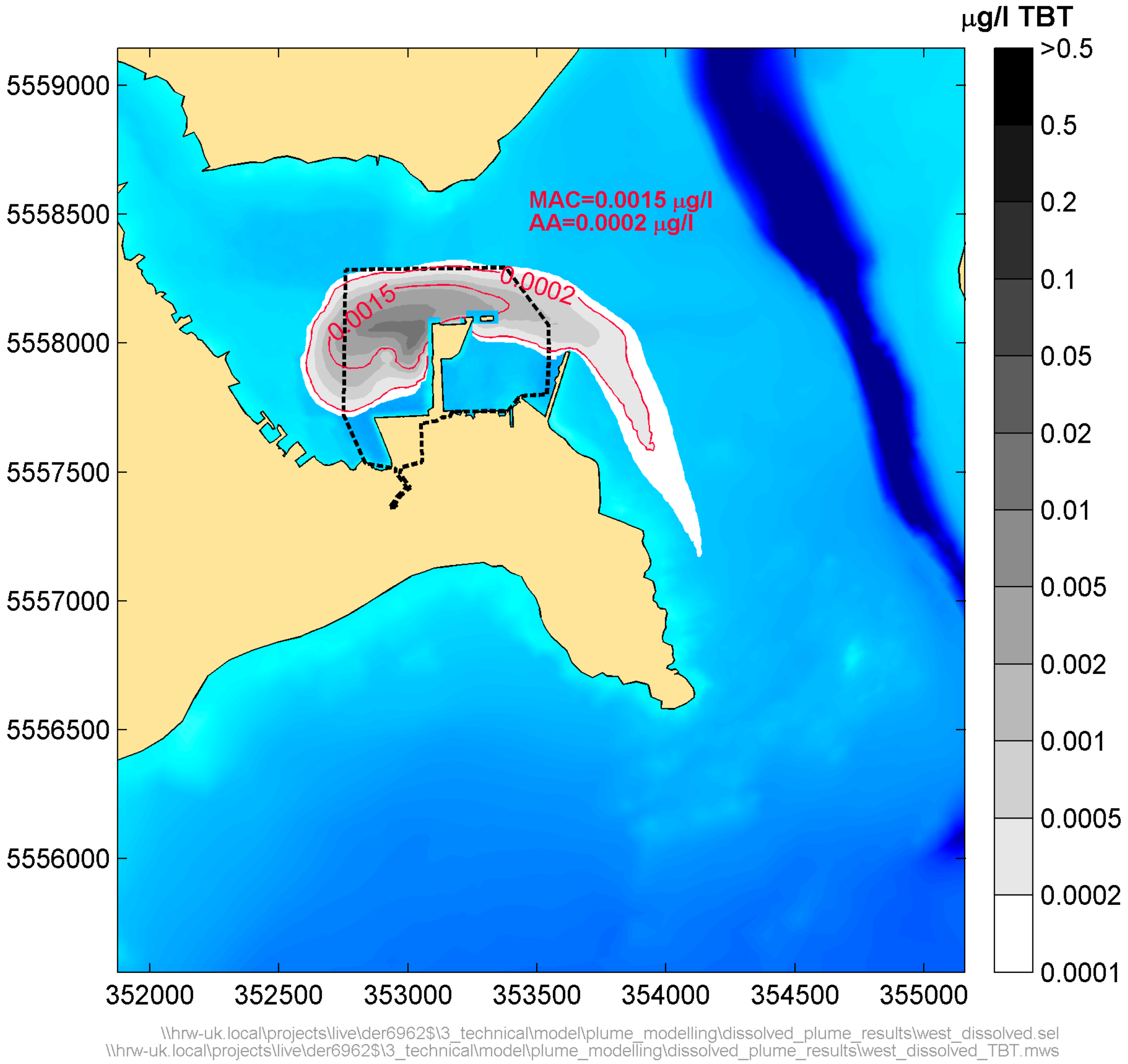

Figure 7.15: Predicted time-averaged concentration of **Tributyltin (TBT)** over 15 days of dredging in the **west** of the site (FLOW Basin)

7.5 Summary of contaminant results

Table 7.3 summarises the results of the contaminant modelling by noting whether the contaminant in a given zone is predicted to exceed the Annual Average (AA) or Maximum Acceptable Concentration (MAC) outside of the site area. It should be noted that the simulations were for continuous dredging as a worst case. The sediment results reported in Section 6 show that careful consideration of the timing of dredging can bring noticeable benefit in reduction of the footprint of dispersion.

It can be seen that the AA and MAC values for TBT are exceeded in the dredging of all 3 zones: east, north and west and that these exceedances extend some distance from the site area. The

AA values for Copper and Zinc are exceeded during dredging in the east and west dredging zones, but only locally within the site area. The AA value for lead is exceeded during dredging in the west dredging zone and the footprint of exceedance is largely contained within the site area, with a small exceedance west of the site area (by 20 m).

Table 7.3: Summary of contaminant results

Dredging zone	Contaminant	EQS exceeded within the site area?	EQS exceeded outside the site area?
East (Western Wharf)	Cu	Yes (AA)	No
	Hg	No	No
	Pb	No	No
	Zn	Yes (AA)	No
	TBT	Yes (AA and MAC)	Yes
North	Cu	No	No
	Hg	No	No
	Pb	No	No
	Zn	No	No
	TBT	Yes (AA and MAC)	Yes
West (FLOW Basin)	Cu	Yes (AA)	No
	Hg	No	No
	Pb	Yes (AA)	Yes, but limited to within 20 m of site area limit
	Zn	Yes (AA)	No
	TBT	Yes (AA and MAC)	Yes

7.6 Implications of dredging Scenario 2 or 3 on contaminant dispersion results

The results presented above are from the dredging of material contaminated above CAL2 throughout the tide and are therefore a worst case for release of contaminants into the water column and the magnitude and footprint of any effect on water quality.

As shown by the sediment plume results for Scenario 2 and 3, changing the period of dredging to be only during the flood tide (Scenario 2), or only during the late ebb tide and early flood tide (Scenario 3), can change the magnitude and footprint of the sediment plume. The implications of these dredging scenarios on the dispersion of contaminants are described below.

For Scenarios 2 and 3 the dredging duration on each tide is approximately halved compared to Scenario 1. Therefore the mass of sediment dredged and the quantity of contaminants released (on each tide) will also halve. As the effects on contaminant dispersion are assessed above as time average concentrations, the effects would be expected to reflect the reduced release rate and so it also would be expected that the average concentrations of contaminants within the water column roughly halve.

As seen for the sediment plume results, the Scenario 2 or Scenario 3 dredging would be expected to move the footprint of excess contaminant concentration towards the west (flood tide direction). For dredging in the East area (Western Wharf) this change in the footprint might mean the EQS exceedances are more confined within the site area. However, noting the very low EQS values for TBT it is considered unlikely that for TBT the exceedances of EQS would be confined to the site area. For dredging in the North and West areas some exceedances of EQS would still be expected outside the site area for TBT, though these EQS exceedances west of the site will fall inside the corresponding footprint of the Scenario 1 results.

8 Conclusions

A modelling study has been completed to investigate the dispersion of sediment and contaminants released as part of the dredging associated with the proposed development.

Three dredging scenarios were considered:

- Scenario 1: A maximum production rate scenario using a backhoe with a 10 m^3 lidded bucket for the material that is considered unsuitable for sea disposal due to the level of contamination and a larger backhoe for the uncontaminated material that is suitable for sea disposal.
- Scenario 2: A medium production rate using a using a backhoe with a 10 m^3 lidded bucket for all sediment. Dredging only during the flood tide.
- Scenario 3: A medium production rate using a using a backhoe with a 10 m^3 lidded bucket for all sediment. Dredging during the late ebb tide and early flood tide only.

Simulations of plume dispersion over a 15-day period were undertaken for each scenario with dredging in the east, west and north of the site. The simulated dredger followed a path throughout the areas to be dredged to simulate sediment release from throughout the dredged areas.

Sediment dredging plume

- The results for the dredging of uncontaminated sediments are set out below. Contaminated sediment represents under half the volume of dredging compared to that of uncontaminated sediment, and at a lower rate of production. The dredging of contaminated sediment results in a lower rate of release of fine sediment, and hence less extensive plumes, over a shorter period of time.
- Moving from Scenario 1 (all tide dredging) to Scenario 2 (flood tide only dredging) reduced the footprint of the plume due to a combination of the reduced production rate (roughly halved) and the timing of the dredging. However notable deposition depths were predicted to the east of the project site, in areas of sensitive habitats (maerl).
- Amending the timing of the dredging by 1.75 hours (dredging on late ebb and early/mid flood) had a significant effect on further reduction of the footprint of increases to suspended sediment concentration and on the resultant deposition depths in the sensitive habitat areas to the east of the project site.

Dissolved contaminant plumes

- Contaminant release was simulated for Scenario 1 (all tide dredging) as a worst case.
- The EQS water quality threshold AA and MAC values for TBT are predicted to be exceeded in the dredging of all 3 zones: east, north and west and these exceedances are predicted to extend some distance from the site area.
- The AA values for Copper and Zinc are predicted to be exceeded during dredging in the east and west dredging zones, but only locally within the site area.
- The AA value for lead is predicted to be exceeded during dredging in the west dredging zone and the footprint of exceedance is predicted to be largely contained within the site area, with a small exceedance west of the site area (by 20 m).
- For all other contaminants/dredging zones the AA and MAC values are not exceeded.
- For Scenario 2 or 3, average contaminant concentrations in the water column can be expected to roughly halve.
- Even with the expected reduction in average TBT concentration in the water column for Scenarios 2 or 3 the EQS water quality threshold AA and MAC values are still likely to be exceeded outside of the site area, although with a reduced footprint of effect.

Disposal sediment plume

- The footprint of the peak concentration increases is predicted to extend up to 6.5 km SW and 13 km NE of the disposal site. Within the disposal site, at the location of the disposal, peak increases of hundreds of mg/l are predicted. This magnitude of concentration reduces to below 20 mg/l at a distance of 3.3 km from the site.
- The predicted mean depth-averaged concentration increases above background resulting from disposal are predicted to extend up to 2.4 km SW and 0.8 km NW of the disposal site. Within the disposal site, at the location of the disposal, mean increases of hundreds of mg/l are predicted. This magnitude of mean concentration reduces to below 20 mg/l at a distance of 0.9 km from the site.
- The total fine sediment deposition resulting from the entire disposal operation is predicted to be more than 5 mm within 3.2 km NE of, and within 2.1 km SW in the streamline of the disposal site with patches of around a centimetre of deposition up to 10 km NNE of the site. Deposition of more than 10 cm is predicted within 2.2 km (SW) and 0.5 km (NE) of the site.

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