GAVIN & DOHERTY GEOSOLUTIONS

Assessment and Report on Dispersion Modelling due to Water Injection Dredging at Wicklow Harbour

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DISCLAIMER

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EXECUTIVE SUMMARY

Gavin and Doherty Geosolutions Ltd has been commissioned by Wicklow County Council to conduct an assessment of sediment dispersion due to Water Injection Dredging, in connection with the proposed Eight-Year Maintenance Dredging Programme for the years 2025 to 2032. This study serves as support for Wicklow County Council's application to the Environmental Protection Agency, seeking a permit under Section 5 of the Dumping at Sea Acts 1996 to 2010, as well as Stage 1 of the Appropriate Assessment process mandated by the Habitats Directive (92/43/EEC).

Under the proposed maintenance dredging program, a total of 415,800 dry tonnes of sediment will be dredged from various areas within Wicklow Harbour, including the navigation channel, basin, and berthing pockets. The primary operations in the first year are expected to yield 113,575 dry tonnes. This value draws upon three dredging methods: Trailing Suction Hopper Dredging (TSHD) and mechanical dredging, Water Injection Dredging (WID), and Ploughing Dredging. It is anticipated that the initial year of the campaign will involve dredging approximately 26,950 dry tonnes using the WID method in a single phase.

A modelling scenario was established to assess the impact of sediment dispersion on the receiving environment, both within the immediate shoreline surrounding Wicklow harbour and in the vicinity of the nearest Special Areas of Conservation (SACs). This scenario involved simulating the Water Injection dredging operations for the primary year's sediment volume to be dredged. A 13-day simulation period, consisting of 23.3 dredging cycles during ebbing tides, was undertaken to assess sediment dispersion both within and outside Wicklow Harbour. Following the numerical dredging events, an extra two days of simulation were carried out to evaluate the dispersion of sediment resulting from the dredging activities.

The simulation results indicate that, during proposed dredging events coinciding with ebbing tide, the sediment plume does not extend upstream of the dredging areas along River Varty. In terms of Suspended Sediment Concentration (SSC), gravel and sand fractions settle within close range of Wicklow Harbour, remaining near the Harbour boundary throughout the simulation period. In contrast, the silt fraction disperses downstream, exiting Wicklow Harbour and spreading in nearshore areas both northwards and southwards, defining the overall extent of total SSC within a 5 km radius. During dredging operations, near the north coast, values can reach 0.037 kg/m^3 (37 mg/L) at 3.5 km from the Harbour, while on the southern coast at the same distance, the SSC value is 0.0034 kg/m^3 (3.4 mg/L). In the Special Areas of Conservation (SAC) zones, at the point closest to Wicklow Harbour, located at Murrough Wetlands SAC, there is a maximum total SSC value of 0.185 kg/m^3 (185 mg/L) and a mean value of 0.023 kg/m^3 (23 mg/L). The total SSC values for other SAC areas (Wicklow Reef SAC, Magherabeg Dunes SAC, and Buckroney-Brittas Dunes and Fen SAC) are relatively low, registering values below 0.001 kg/m^3 (1 mg/L).

Following a 13-day simulation of Water Injection Dredging (WID) operations, the simulation was extended for an additional 2 days to observe the evolution of dredged material dispersion and changes in deposition areas. This extension allowed us to conclude that SSC after two days without dredging reaches negligible levels, measuring less than 0.00177 kg/m^3 (1.77 mg /L) at the entrance of Wicklow Harbour, where the maximum SSC values are observed.

1 INTRODUCTION

1.1 BACKGROUND

Wicklow County Council has established an eight-year maintenance dredging program for Wicklow Harbour, spanning from 2025 to 2032. The objective of this program is to preserve the advertised charted depths of the navigation channel, turning basin, and berthing pockets within the harbour. This initiative is crucial to ensure the safe navigation of vessels traveling to and from the Port. The maintenance dredging program will include a water injection dredging operation within Wicklow Harbour.

Wicklow County Council enlisted the services of Gavin and Doherty Geosolutions Ltd to evaluate the dispersion of dredged material due to the water injection dredging operations within Wicklow Harbour's surrounding areas. This report focuses specifically on the assessment of material dispersion due to solely the dredging operations using the water injection technique.

1.2 WATER INJECTION DREDGING

Water injection dredging is a specialized technique employed for the removal of sediment and debris from water bodies, offering a low-impact and efficient solution for maintaining navigable channels and harbour depths. This method involves the injection of large volumes of water under low pressure water into the sediment, fluidizing it and creating a slurry that can be easily transported and discharged.

Water injection dredging is recognized for its environmentally friendly nature. By utilizing the natural properties of water to displace sediment, it reduces the need for mechanical intervention and minimizes disturbance to the surrounding ecosystem. The method is particularly effective in areas with challenging conditions, such as restricted access or environmentally sensitive zones.

For Wicklow Harbour, water injection dredging emerges as a viable solution for the planned dredging campaign, targeting the removal of 26,950 dry tonnes of sediment. The harbour's distinctive conditions, characterized by diverse sediment types and potential environmental considerations, render water injection dredging well-suited for this project. The analysis presented in this specific report evaluates the dynamics of sediment dispersal during and after the dredging operations, offering valuable insights into the potential impacts of employing such a technique. The dispersion characteristics of other dredging techniques are contained within a separate dispersion modelling report.

1.3 DREDGING OPERATIONS

As part of the Eight-Year Maintenance Dredging Programme spanning from 2025 to 2032, the loading of dredged material will be limited to specific sections of Wicklow Harbour's navigation channel, basin, and berthing pockets that contain sediments suitable for disposal at sea. The estimated total volume of sediment to be dredged at the Wicklow Harbour over the eight-year duration of the program is approximately 415,800 dry tonnes. The highest volume of material to be dredged during a single dredging phase is expected to occur in the first year of the campaign, totalling 113,575 dry tonnes. This represents the worst-case scenario for the dispersion of the dredged material. The figures provided are based on the use of three dredging techniques: Trailing Suction Hopper Dredging (TSHD) and mechanical dredging, Water Injection Dredging (WID), and Ploughing. The water injection dredging process, as well as the ploughing technique, have the particularity that the dispersed material originates from the dredging area. Consequently, the dredging activity within Wicklow Harbour is also dispersing material from Wicklow Harbour towards the offshore area. The highest dredging volume using the WID technique in a single phase is anticipated in the first year of the campaign, amounting to 26,950 dry tonnes.

The proposed dredging areas in Wicklow Harbour are depicted in Figure 1-1. These areas have been designated for numerical modelling to simulate the dredging and dispersal of sediments.

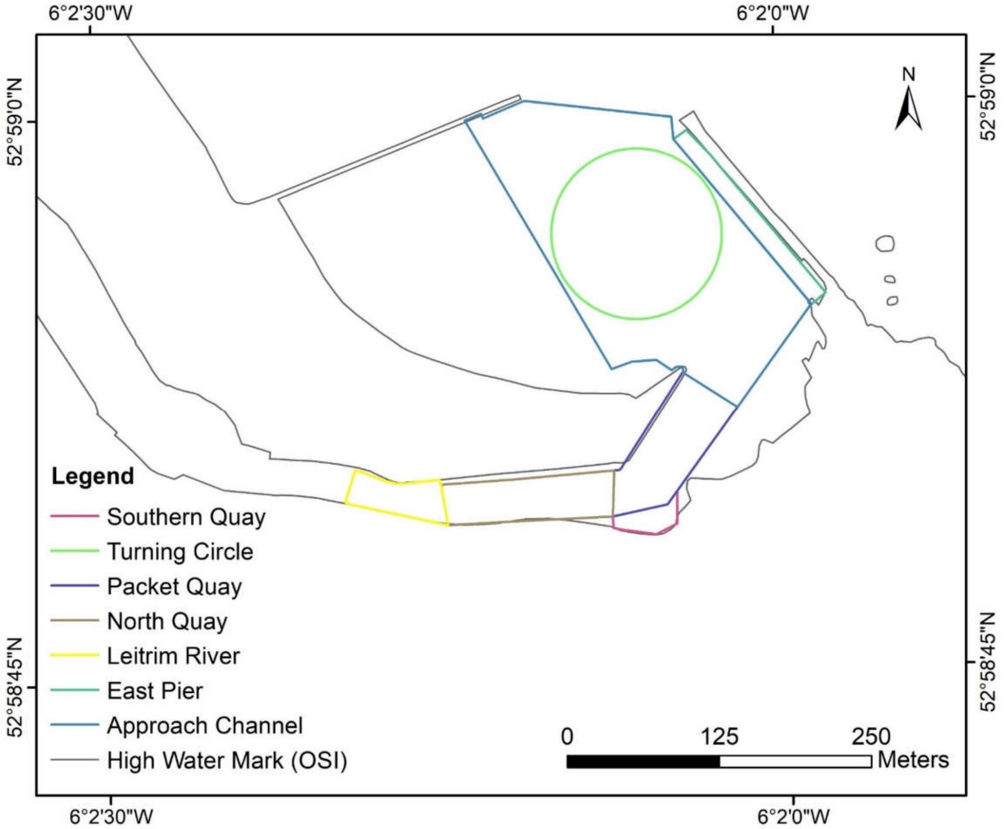

Figure 1-1: Dredging areas in Wicklow Harbour

The location of the Wicklow harbour surrounding offshore area is shown in Figure 1-2 alongside other areas of interest representing nearby Special Areas of Conservation (SACs). These SACs include the Murrough Wetlands SAC, Wicklow Reef SAC, Buckroney-Brittas Dunes and Fen SAC, and Magherabeg Dunes SAC.

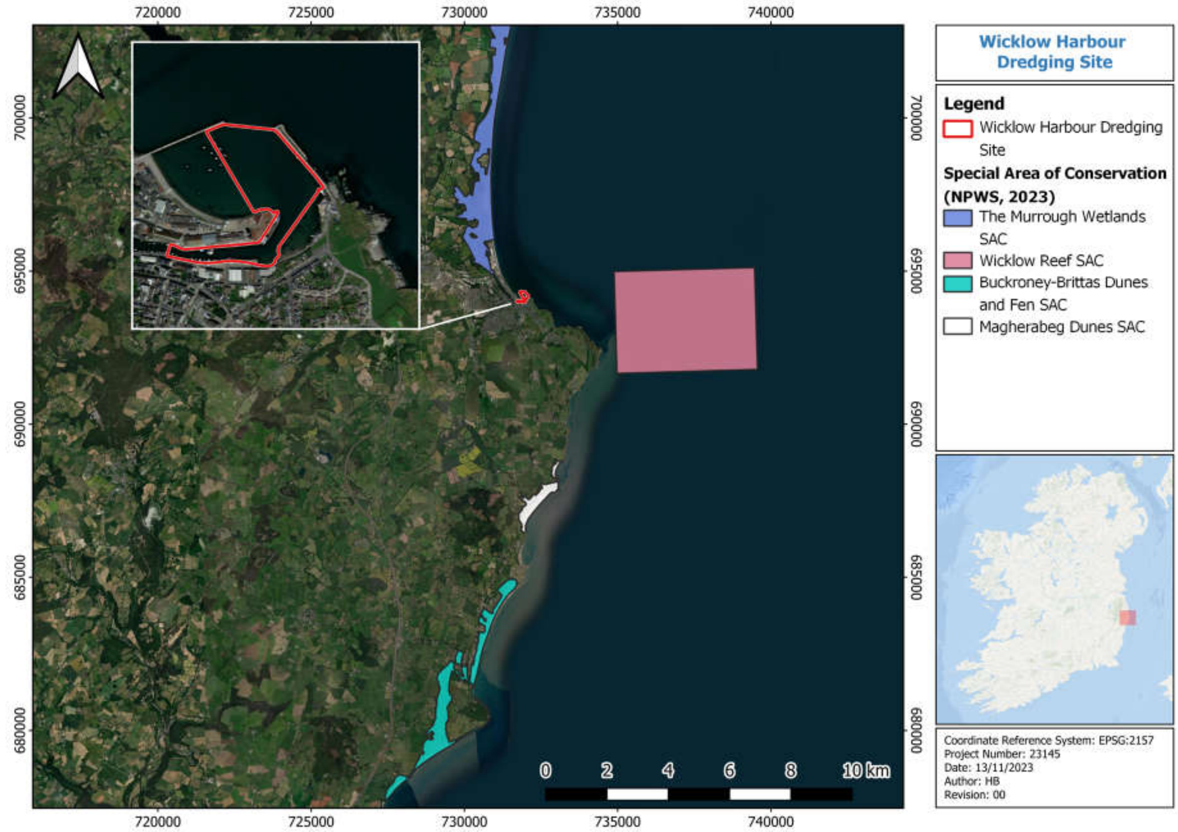

Figure 1-2 Map indicating the locations of the proposed dredge areas, offshore disposal site, and the nearest Special Areas of Conservation (including Murrough Wetlands SAC, Wicklow Reef SAC, Buckroney-Brittas Dunes and Fen SAC, and Magherabeg Dunes SAC).

1.4 SEDIMENT PROPERTIES

In 2021, two sets of sediment samples were collected within Wicklow Harbour. The initial set of samples (samples 1-7) aimed to provide the Marine Institute with insights into the physical and chemical properties of the materials in the designated dredging zones. Subsequently, the second set of samples (samples 8-11) was specifically requested by Wicklow County Council to gather information pertaining to potential future areas of interest. Figure 1-3 illustrates the precise locations of each sample, while Table 1-1 presents the results of the particle size analysis.

Table 1-1 Sediment samples in Wicklow Harbour

Reference	Gravel (> 2 mm)	Sand (63 - 2000 um)	Silt (< 63 um)	Classification
S1	8.7	42.4	48.9	gM: Gravelly Mud
S2	0	56.6	43.4	mS: Muddy Sand
S3	0	36.8	63.2	sM: Sandy Mud
S4	32.5	36.2	31.2	msG: Muddy Sandy Gravel
S5	4.6	21	74.4	(g)sM: Slightly Gravelly Sandy Mud
S6	0	29.3	70.7	sM: Sandy Mud
S7	39.8	57.3	2.9	sG: Sandy Gravel
S8	1.9	91.7	6.4	(g)S: Sandy Gravel
S9	0	94.8	5.2	S: Sand
S10	0	72.9	27.1	mS: Muddy Sand
S11	0	49.7	50.3	sM: Sandy Mud

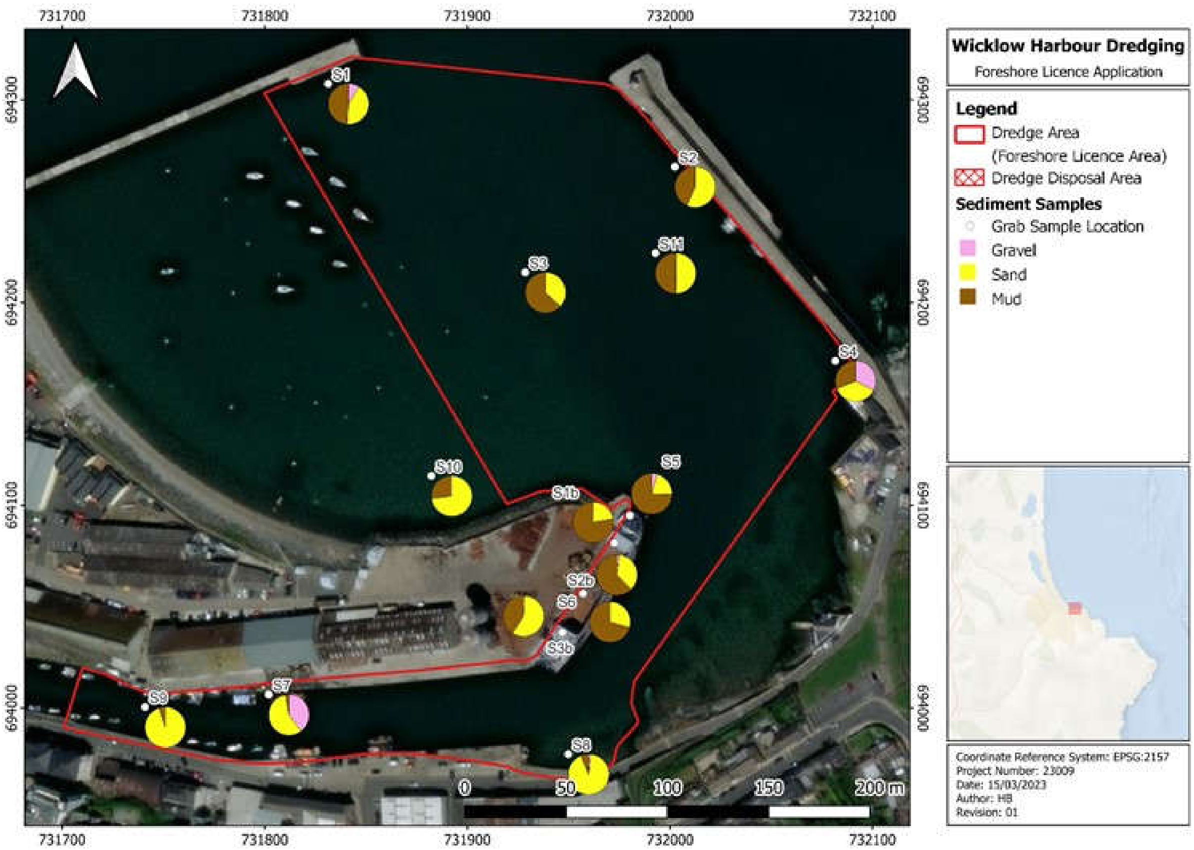

Figure 1-3 Wicklow Harbour Sediment Particle Size Analysis (PSA) from the Dredge Area (Showing Gravel: pink, Sand: yellow and Mud: brown)

1.5 MODELLING SOFTWARE

The tidal flow simulations forming the basis of this study were conducted using the MIKE 21 Flow Model Flexible Mesh (FM) modelling system, developed by DHI. The MIKE system is a state-of-the-art modelling system that employs a flexible mesh approach. These flexible mesh modelling systems allow for the dynamic coupling of relevant modules in both two and three dimensions, enabling the simulation of the mutual interaction between currents and sediment transport.

The Flow Model FM modules consist of the Hydrodynamic Module (HD) and the Mud Transport (MT) Module. The MIKE 21 Flow Model FM Hydrodynamic (HD) Module is a 2-dimensional depth-averaged hydrodynamic module that resolves the shallow water equations, specifically the Navier Stokes Momentum and continuity equations [1] [2]. These equations are resolved using a finite volume scheme, and the Riemann solver [3] determines the fluxes within the domain mesh. Various approximation schemes are applied to resolve second-order variance.

The flow velocity is derived from the depth-integrated resolution of the shallow water equations, and tide-induced bottom stresses are determined by a quadratic friction law that utilizes drag coefficient and flow velocity. The simulated drag coefficient is calculated by resolving the Manning number (M) for bed friction [4].

The main features and effects included in the Hydrodynamic Module are:

- Flooding and drying
- Momentum dispersion
- Bottom shear stress
- Coriolis force
- Wind shear stress
- Barometric pressure gradients
- Ice coverage
- Tidal potential
- Precipitation/evaporation
- Wave radiation stresses
- Sources and sinks

The Mud Transport (MT) module [5] addresses the processes of erosion, transport, and deposition of mud or sand/mud mixtures under the influence of currents and, where applicable, waves. Notably, the module considers non-cohesive materials, making it well-suited for simulating sediment dispersion resulting from dredging activities. The hydrodynamic foundation for the MT Module is computed using the Hydrodynamic Module of the MIKE 21 Flow Model FM modelling system, and the MT Module is implemented as a coupled model, with both running concurrently. The simulation may encompass the following processes:

- Multiple sediment fractions
- Inclusion of non-cohesive sediments
- Multiple bed layers
- Flocculation

- Hindered settling
- Bed shear stress from combined currents and waves
- Forcing by waves
- Consolidation
- Tracking sediment spills
- Morphological update of the bed.

In the MT module, the settling velocity varies based on salinity (if included) and concentration, considering flocculation in the water column. Bed erosion can occur in two modes: non-uniform, involving the erosion of soft and partly consolidated bed, or uniform, involving the erosion of a dense and consolidated bed. The bed is depicted as layered and characterized by density and shear strength [6].

2 HYDRODYNAMIC MODELLING

2.1 HD MODEL SET-UP

The hydrodynamic model domain, covering the entire Irish Sea, was previously defined and validated in the report [7] (Dredging Area Site Dispersion Modelling Assessment and Report: 23009-REP-001-00. Figure 2-1 illustrates the applied numerical computational mesh. Two open boundaries were established: one across the Celtic Sea and another in the North Channel. These boundaries are influenced by water level data obtained from the Global Tide Model [8]. Bathymetric data is referenced to OD Malin for coastal waters and Mean Sea Level for offshore areas. The comprehensive development and validation of this regional model are thoroughly documented in the works of Coughlan et al [9] and Creane et al [10].

This model underwent an update, incorporating a refined coastline and the layout of Wicklow Harbour, including Broad Lough and the River Vartry. The River Vartry flows into Broad Lough, which, in turn, connects to the Irish Sea via Wicklow Harbour. Broad Lough is classified as a 'tidal lough' [11], making it essential to include this geographical feature in the numerical model to accurately represent flows through the harbour. A point source with a discharge rate of 1.06 m^3/s was added to simulate river flow into the Lough [12].

The model resolution was fine-tuned for the area of interest, featuring an unstructured triangular mesh. The element size varies from 2.5 km at the open boundaries to 200 m around Wicklow Head and 15 to 20 m in the harbour. Site-specific bathymetry provided by the client was integrated into the model.

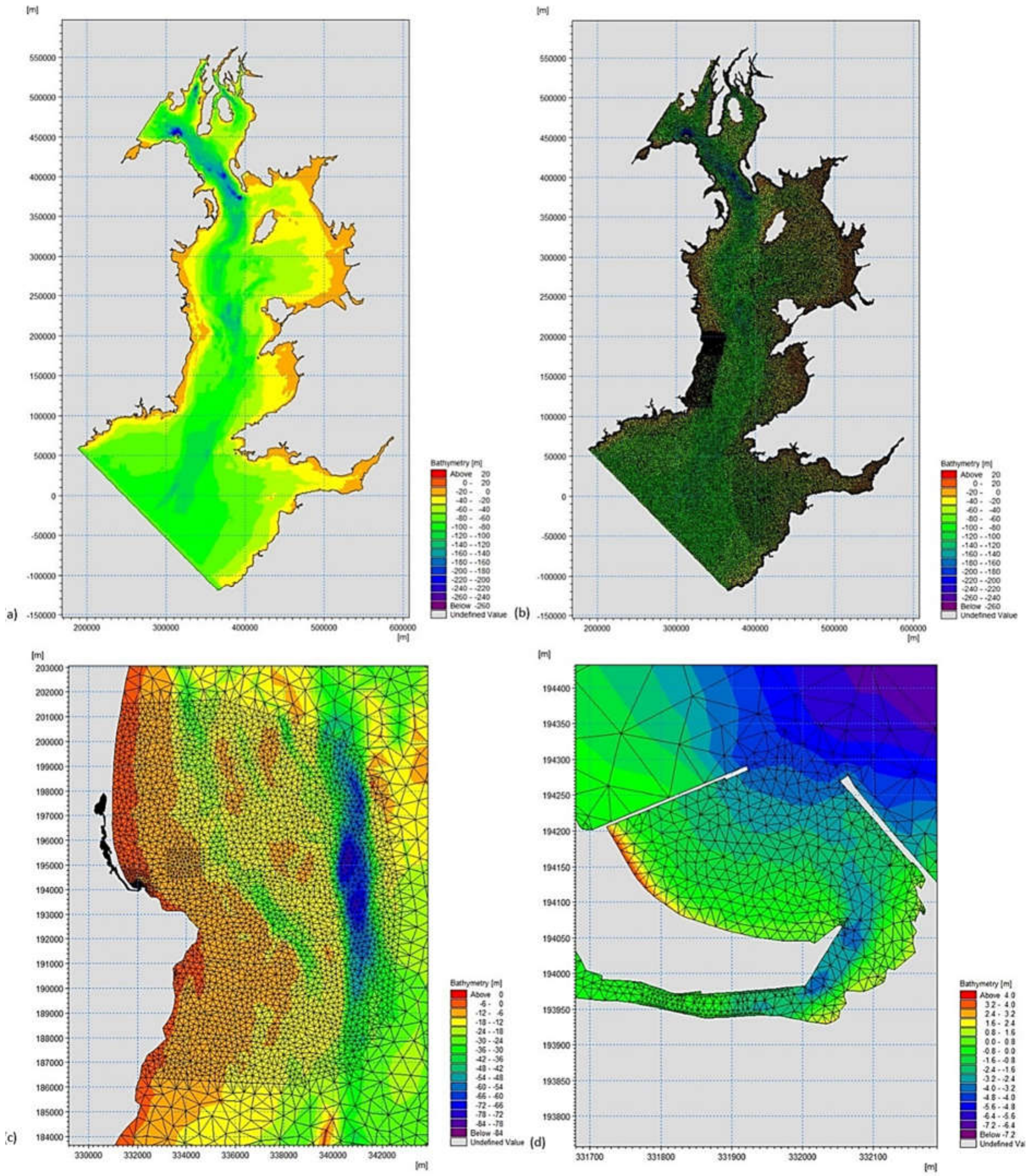

Figure 2-1 Numerical computational domain: a) Outline of the model domain with b) to d) spatial resolution of the unstructured triangular mesh refined for the area of interest.

All site-specific bathymetry datasets provided by the client underwent processing to align with the model's specific requirements. The received bathymetry for the disposal site and harbour are from geophysical surveys, carried out in 2014 and 2022 respectively. Both datasets are referenced to Irish Transverse Mercator (ITM) and Chart Datum at Wicklow Harbour. these datasets were subsequently transformed into the Irish National Grid (ING) and adjusted vertically to OD Malin. This transformation and adjustment procedure, outlined in Figure 2-2, was followed to prepare the data for input into the model. These modified datasets were then utilized as inputs for the model. The 2022 harbour bathymetry was modified during calibration in order to better represent what occurs in reality in terms of drying areas.

Furthermore, additional bathymetric data from INFOMAR and EMODnet were integrated into the numerical model to encompass the entire computational domain.

Figure 2-2 Differences between vertical reference datums

The validation of the site-specific model is comprehensively detailed in [7] (Dredging Area Site Dispersion Modelling Assessment and Report: 23009-REP-001-00). In this report [7], the hydrodynamic model underwent validation against in situ measurements of current speed and direction obtained from two current meters positioned in the former disposal site, located 1.5 km east of the Harbour dredge area. The calibration and validation of the model were conducted, using a Manning number of 43.

2.2 Modelling Simulations

The modelling approach incorporates the use of the MIKE 21 FM Mud Transport Module, which is driven by the Hydrodynamic Module (as discussed in 1.5).

The modelling scenario devised to meet the study objectives entails simulating the dredging cycle through the Water Injection Dredging (WID) method for the complete volume of dredging planned for the primary year. This scenario accounts for the worst-case scenario, wherein the maximum volume planned for dredging for a 3-year programme is continuously dredged over a 13-day period in the Wicklow Harbour dredging area.

The simulations also include an additional two days of sediment dispersal following the completion of the numerical dredging events. These extra simulation days aim to draw conclusions regarding sediment dispersal and accretion after the dredging operations.

Further information regarding the modelling of the dredge cycle can be found in section 2.4.1.

2.2.1 Dredged material dispersion modelling setup

The simulated scenario focuses on modelling the dispersion of material dredged within Wicklow Harbour. The simulations consider that each dredging cycle occurs during an ebbing tide, precisely 1 hour after high tide and 1 hour before low tide. This ensures the presence of tide outflow during the dredging event, facilitating the proper removal of the dredged volume within the Harbour.

Each ebbing tide was modelled for the total dredging volume of 35000 m^3 representing the maximum volume to be dredged by Water Injection Dredging (WID) technique for a 3-year program. The ebbing tides were identified and simulated within the same time window as the calibration and validation of the model, occurring between the 2nd and the 14th of August 2012. Figure 2-3 illustrates the free surface elevation within the Harbour, indicating the identified simulated dredging events.

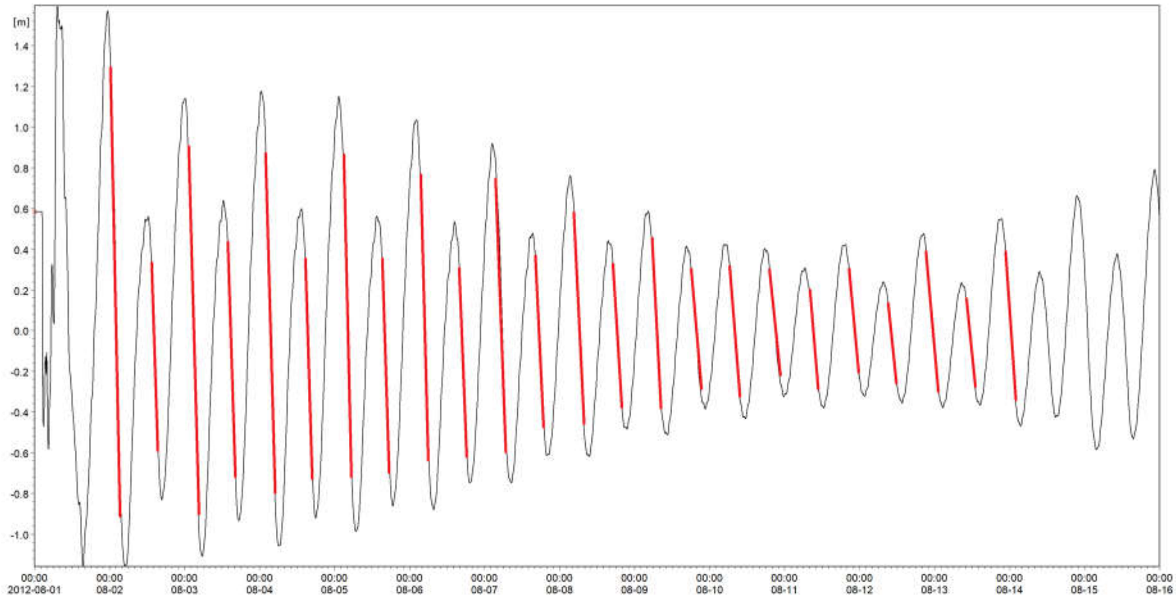

Figure 2-3: Dredging cycles at ebbing tides (red) – Free surface elevation within Wicklow Harbour

The numerical modelling of dredging activities considers that the areas to be dredged over the thirteen days are selected in chronological order from upstream to downstream. Consequently, the dredging modelling activities were segmented into four areas, each representing different sections within the Harbour, as illustrated in Figure 1-1. Six dredging events (each corresponding to 6 ebbing tides) were allocated to each selected dredging area. Figure 2-4 depicts the dredging activities progressing from upstream to downstream, considering each designated area within Wicklow Harbour.

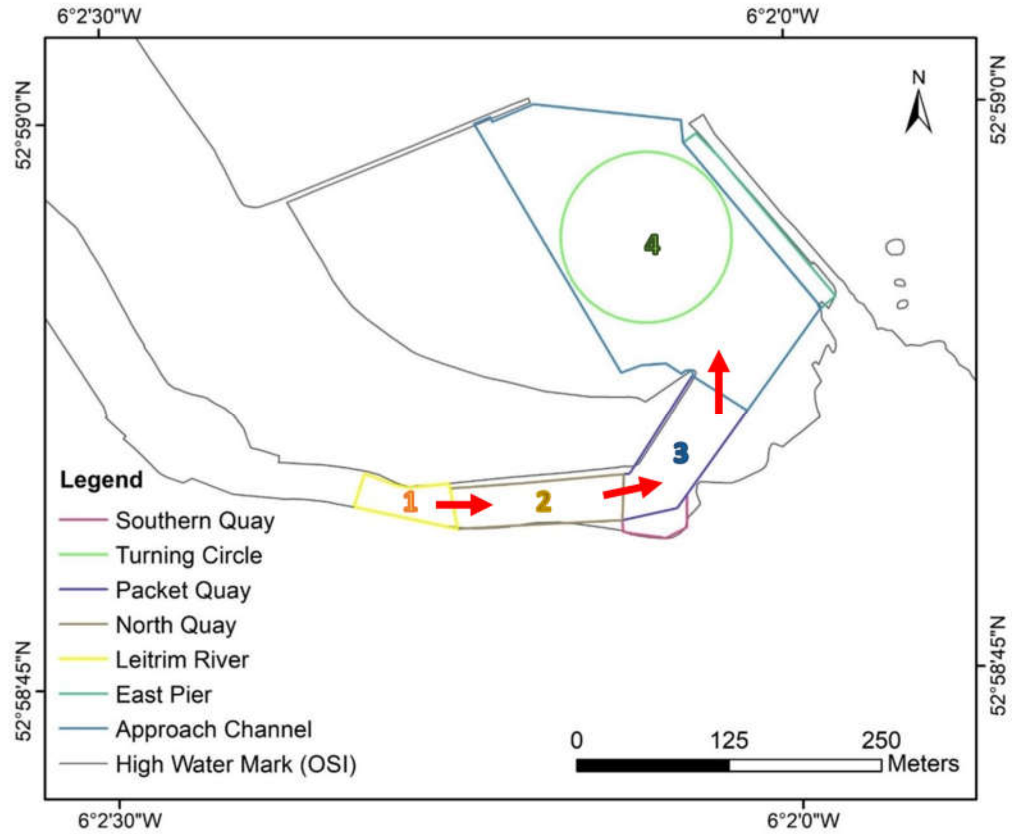

Figure 2-4: Numerical Modelling sequence for Dredging areas in Wicklow Harbour

As per the agreement with the client, the representative material for the disposal modelling scenario was chosen as the average of all provided sediment sample data, as outlined in Table 1-1. The selected representative sediment sample comprises three sediment classes and is detailed in Table 2-2. The critical shear stress for particle motion was determined using the following equation [12].

$$\tau_c = \theta^*(s-1)\rho_m g d_{50} \qquad \text{Eq. (1)}$$

where τ_c is the critical bed shear stress, θ^* is the dimensionless Shields parameter for the given particle size, s is the specific gravity of the particles and is calculated as the ratio of specific weight of sediment to the specific weight of water, ρ_m is the density of water, g is the constant for acceleration due to gravity, and d_{50} is the median particle size.

The drag coefficient, K, for each sample was derived using the following formula:

$$\mathrm{K} = d_{50}\left(\frac{g\rho_m(\rho_p-\rho_m)}{\mu^2}\right)^{1/3} \qquad \text{Eq. (2)}$$

where g is the acceleration due to gravity, d_{50} is median grain size, ρ_p is the density of the particle, ρ_m is the density of water and μ is the dynamic viscosity of a liquid. The settling velocity (U_t) is then calculated according to the following equation:

$$U_t = \left(\frac{4 g d_{50}{}^{(1+n)} (\rho_p - \rho_m)}{3 b \mu^n \rho_m^{(1-n)}} \right)^{1/(2-n)} \qquad \text{Eq. (3)}$$

whereby the b and n coefficients are tabulated to the value of K (Table 2-1) [13] [14].

Table 2-1 Determination settling velocity coefficients b and n determined based on drag coefficient K

Flow Regime	Drag coefficient (K)	b	n
Stokes	K < 3.3	24	1
Intermediate	3.3 <K < 43.6	18.5	0.6
Newton	43.6 < K <2360	0.44	0

Table 2-2 Model input sediment properties for dredging and disposal operations

Representative Material Type	Fraction	Representative grain Size (mm)	Settling Velocity (m/s)	Shield's parameter (dimensionless)	Critical Shear Stress for deposition (N/m²)	Proportion (%)
Very fine gravel	1	2	0.2996	0.039	1.25	8.0
Medium Sand	2	0.375	0.04202	0.041	0.24	53.5
Medium Silt	3	0.0156	0.0001636	0.25	0.06	38.5

A conservative uniform outflow of 1 m^3/s was assumed for the water injection during the dredging process.

3 MODEL RESULTS

The presented results illustrate sediment dispersion patterns, encompassing both SSC and bed thickness change values related to deposition. The selection of result points was driven by the primary objective of this report to evaluate to assess the dynamics of the dredged sediment dispersal in the surrounding environment of Wicklow Harbour. Consequently, 10 points were identified along the north and south shorelines of the Wicklow Harbour coastal area, representing nearshore (a) and offshore points (b). Additionally, results were derived from points situated in the surrounding four Special Areas of Conservation (SACs): Murrough Wetlands SAC (Point 6), Wicklow Reef SAC (Point 7), Magherabeg Dunes SAC (Point 8), and Buckroney-Brittas Dunes and Fen SAC (Point 9).

Table 3-1 provides the list of points where results were extracted with its description and geolocation. The map location of these points can be seen in Figure 3-1.

Table 3-1 Point locations for the extracted numerical results.

Point Number	Name	Easting (m)	Northing (m)
Point 1a	Farthest North Nearshore Point	331190	197868
Point 1b	Farthest North Offshore Point	331590	197868
Point 2a	Nearest North Nearshore Point	331340	195819
Point 2b	Nearest North Offshore Point	331740	195819
Point 3a	Wicklow Harbour Entrance	331980	194307
Point 3b	Wicklow Harbour Offshore	332380	194307
Point 4a	Nearest South Nearshore Point	333110	193600
Point 4b	Nearest South Offshore Point	333510	193600
Point 5a	Farthest South Nearshore Point	334470	192725
Point 5b	Farthest South Offshore Point	334870	192725
Point 6	Murrough Wetlands SAC	331058	195974
Point 7	Wicklow Reef SAC	334914	194307
Point 8	Magherabeg Dunes SAC	333330	188696
Point 9	Buckroney-Brittas Dunes and Fen SAC	331718	184476

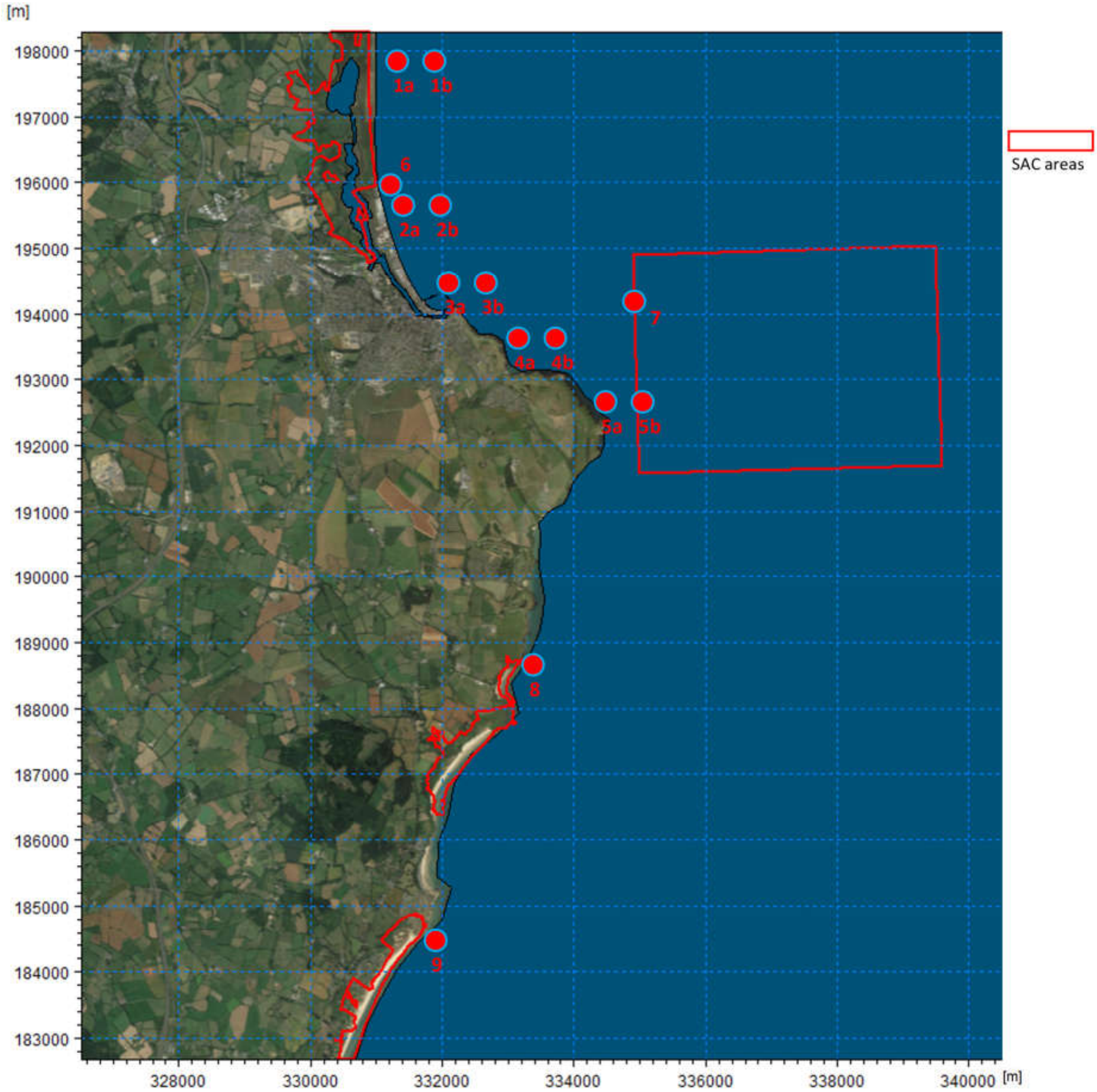

Figure 3-1 Location of the extracted results points.

3.1 MAXIMUM AND MEAN VALUES FOR WATER INJECTION DREDGING OPERATIONS PERIOD

Both Figure 3-2 and Figure 3-3 displays the maximum and mean total SSC over the course of the 13-day simulation, which covers most of both spring and neap tidal cycles. The maximum total SSC plots represent the highest values observed in each cell at any given time during the simulation period. It's important to note that these values may not have occurred simultaneously nor persisted for any significant period of time. Conversely, the mean total SSC plots represent the average values in each cell at any time during the 13-day simulation period.

The results indicate that there is no penetration of the sediment plume upstream through Broad Lough and the River Vartry. This absence of penetration can be attributed to the timing of the dredging cycles, which occur during ebbing tides. Consequently, there is no upstream movement of the dredged material into the river. In conclusion, negligible SSC values, specifically less than 0.00001 kg/m^3 (0.01mg/L), were observed upstream of the dredging area within Wicklow Harbour.

Examining Table 3-2, the highest total Suspended Sediment Concentration (SSC) values were recorded at the Wicklow Harbour entrance (Point 3a), with a value of 17.46 kg/m^3 (17460 mg/L). This outcome is as anticipated, given that all the suspended dredged material flows out through the Wicklow Harbour entrance. Beyond the entrance, the flow disperses the dredged material primarily along the shoreline, exhibiting a prevailing northward direction but also some southward movement. The offshore point situated 600 meters from the Harbour Entrance (Point 3b) displays significantly lower maximum and mean values compared to those observed at the Harbour entrance. It registers maximum values of 0.14 kg/m^3 (140 mg/L) and mean values of 0.0086 kg/m^3 (8.6 mg/L). This discrepancy indicates that limited hydrodynamic flow from nearshore to offshore is hindering the dispersion of sediment material into more offshore areas.

The northern nearshore point closest to Wicklow Harbour (Point 2a), situated 1500 meters from the Harbour, exhibits a maximum total SSC value of 0.15 kg/m^3 (150 mg/L). However, its mean values during the dredging operations hover around 0.02 kg/m^3 (20 mg/L). This value significantly differs from the northern offshore point nearest to Wicklow Harbour (Point 2b), which records a maximum total SSC value of 0.03 kg/m^3 (30 mg/L) and a mean value of 0.0009 kg/m^3 (0.9 mg/L). Further north, Point 1a and Point 1b, approximately 3.5 km north of the Harbour, a noticeable decrease is observed in the total SSC results. The nearshore point (Point 1a) shows a maximum value of 0.037 kg/m^3 (37 mg/L) and a mean value of 0.0037 kg/m^3 (3.7 mg/L), while the offshore point (Point 1b) records a maximum value of 0.008 kg/m^3 (8 mg/L) and a mean value of 0.0004 kg/m^3 (0.4 mg/L).

Along the southern shoreline, a similar trend is observed, albeit with slightly lower total SSC values. The southern nearshore point (Point 4a) records maximum and mean values of 0.126 kg/m^3 (126 mg/L) and 0.0076 kg/m^3 (7.6 mg/L), respectively, while the offshore point (Point 4b) shows a maximum of 0.035 kg/m^3 (35 mg/L) and a mean of 0.0018 kg/m^3 (1.8 mg/L). This consistent pattern of values between nearshore and offshore points continues for the southernmost locations (approximately 3.5 km south of the Harbour). For Point 5a (nearshore), a maximum of 0.0034 kg/m^3 (3.4 mg/L) and a mean value of 0.00012 kg/m^3 (0.12 mg/L) are observed. As for the offshore point, maximum and mean values of 0.0023 kg/m^3 (2.3 mg/L) and 0.00008 kg/m^3 (0.08 mg/L) are showed, respectively.

With regard to the total SSC values in the surrounding four SACs, the Murrough Wetlands SAC (Point 6) shows the higher maximum values due to its proximity to the Wicklow Harbour. This area displays a maximum total SSC value of 0.185 kg/m^3 (185 mg/L) and a mean value of 0.023 kg/m^3 (23 mg/L). In contrast, the total SSC values for the other SAC areas (Wicklow Reef SAC, Magherabeg Dunes SAC, and Buckroney-Brittas Dunes and Fen SAC) are below 0.001 kg/m^3 (1 mg/L), indicating values much lower than those observed closer to Wicklow Harbour.

The total SSC values registered in this report and its order of magnitude are in general accordance with those calculated by GDG in report [7].

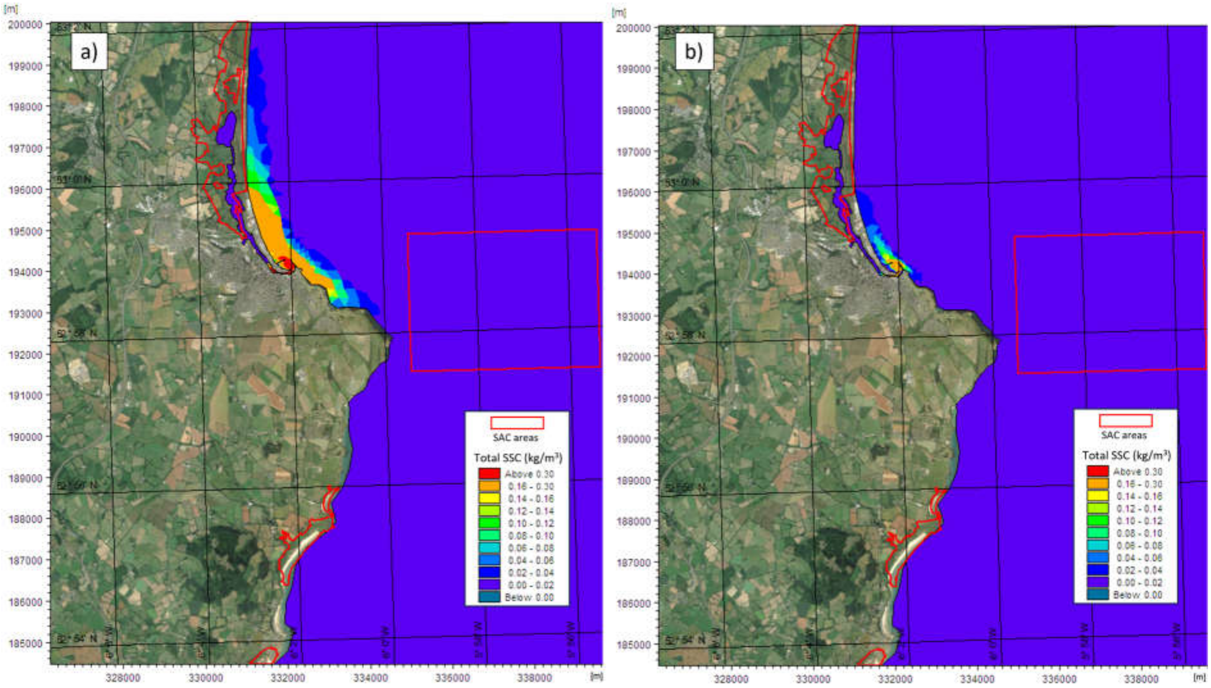

Figure 3-2 Total Suspended Sediment Concentration (SSC) considering the 13-day simulation: (a) maximum values and (b) mean values.

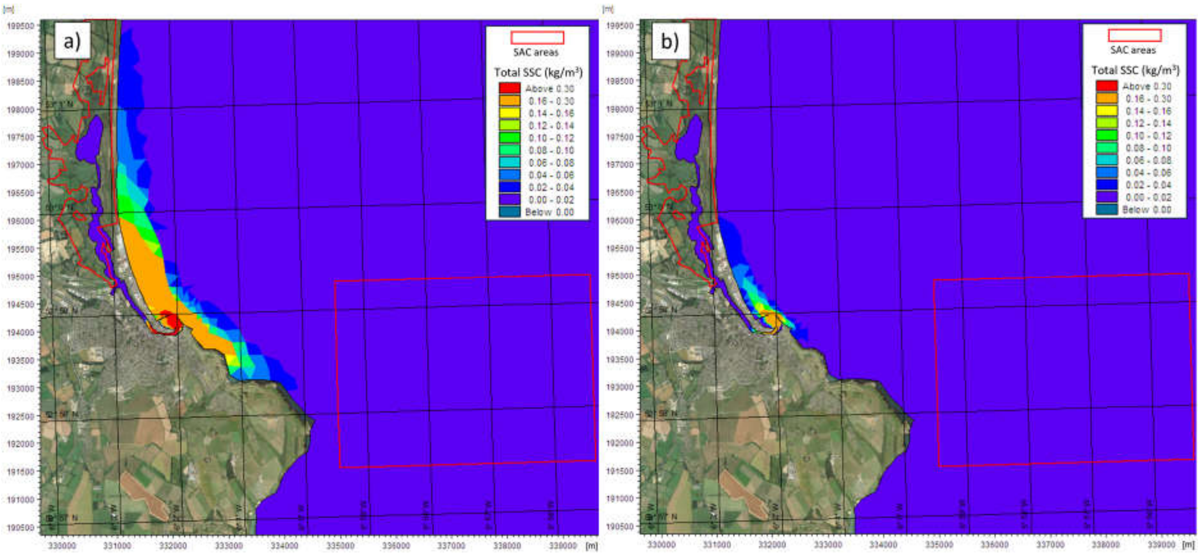

Figure 3-3 Total Suspended Sediment Concentration (SSC) – close-up view - considering the 13-day simulation: (a) maximum values and (b) mean values.

Table 3-2 Maximum and mean values of total Suspended Sediment Concentration (SSC) for the extracted numerical results.

Point Number	Name	Max total SSC (kg/m³)	Mean total SSC (kg/m³)
Point 1a	Farthest North Nearshore Point	0.03686	0.00375
Point 1b	Farthest North Offshore Point	0.00814	0.00040
Point 2a	Nearest North Nearshore Point	0.15293	0.02197
Point 2b	Nearest North Offshore Point	0.03116	0.00094
Point 3a	Wicklow Harbour Entrance	17.46190	0.33256
Point 3b	Wicklow Harbour Offshore	0.14361	0.00862
Point 4a	Nearest South Nearshore Point	0.12562	0.00755
Point 4b	Nearest South Offshore Point	0.03487	0.00182
Point 5a	Farthest South Nearshore Point	0.00340	0.00012
Point 5b	Farthest South Offshore Point	0.00231	0.00008
Point 6	Murrough Wetlands SAC	0.18513	0.02327
Point 7	Wicklow Reef SAC	0.00084	0.00002
Point 8	Magherabeg Dunes SAC	0.00092	0.00001
Point 9	Buckroney-Brittas Dunes and Fen SAC	0.00018	0.00001

The temporal evolution of the total SSC values for each point throughout the simulation, spanning from the 2nd to the 16th of October, covering the 13 days of dredging and the two days following dredging activities, is illustrated in Figure 3-4.

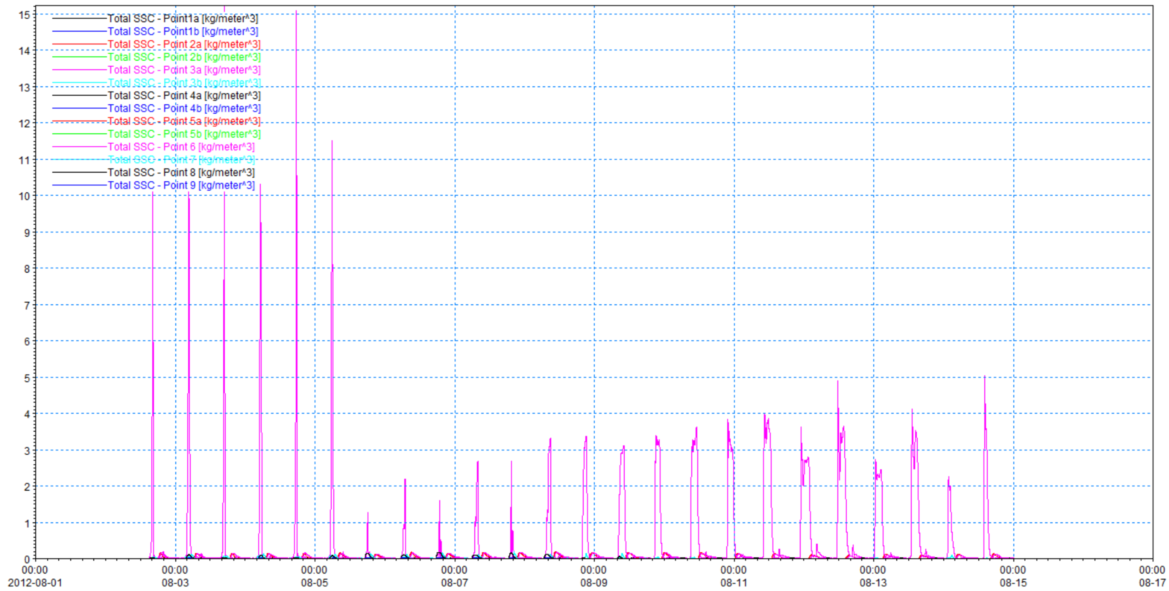

Figure 3-4 Total Suspended Sediment Concentration (SSC) – Results at each point along the simulation.

The maximum and mean SSC for each of the three fractions over the 13-day simulation are illustrated in Figure 3-5 to Figure 3-12. The gravel fraction (Figure 3-5 and Figure 3-6) and the sand fraction (Figure 3-8 and Figure 3-9) remain in close proximity to the Wicklow Harbour throughout the dredging campaign. Maximum SSC values for these fractions consistently stay below 1 x 10^{-8} kg/m^3 (1 mg/L), even at the point located at the entrance of Wicklow Harbour. This is as expected as water injection dredging cannot fluidise the coarser sediments present in the Harbour. In the Special Areas of

Conservation (SACs), the SSC values for fractions 1 and 2 are negligible, with values registering lower than 1 x 10^{-11} kg/m^3 (0.001 mg/L) (Table 3-3 and Table 3-4).

In contrast, the silt fraction (fraction 3) (depicted in Figure 3-11 and Figure 3-12 is transported as suspended sediment out of Wicklow Harbour, forming the majority of the SSC along the northern and southern shorelines. The distribution and concentrations of fraction 3 closely correspond to the overall extent of total SSC within a 5 km range from Wicklow Harbour and in the Special Areas of Conservation (SAC) areas.

Within the Murrough Wetlands SAC (Point 6), the silt fraction exhibits a maximum total SSC value of 0.177 kg/m^3 (177 mg/L) and a mean value of 0.023 kg/m^3 (23 mg/L). In contrast, the total SSC values for other SAC areas (Wicklow Reef SAC, Magherabeg Dunes SAC, and Buckroney-Brittas Dunes and Fen SAC) are negligible, registering below 0.001 kg/m^3 (1 mg/L) (refer to Table 3-5). It is important to note that the figures illustrating SSC for each material fraction have varying scales, reflecting the substantial differences in data magnitudes among these fractions. To accurately observe SSC patterns and derive meaningful insights, distinct scaling approaches were employed to represent the results.

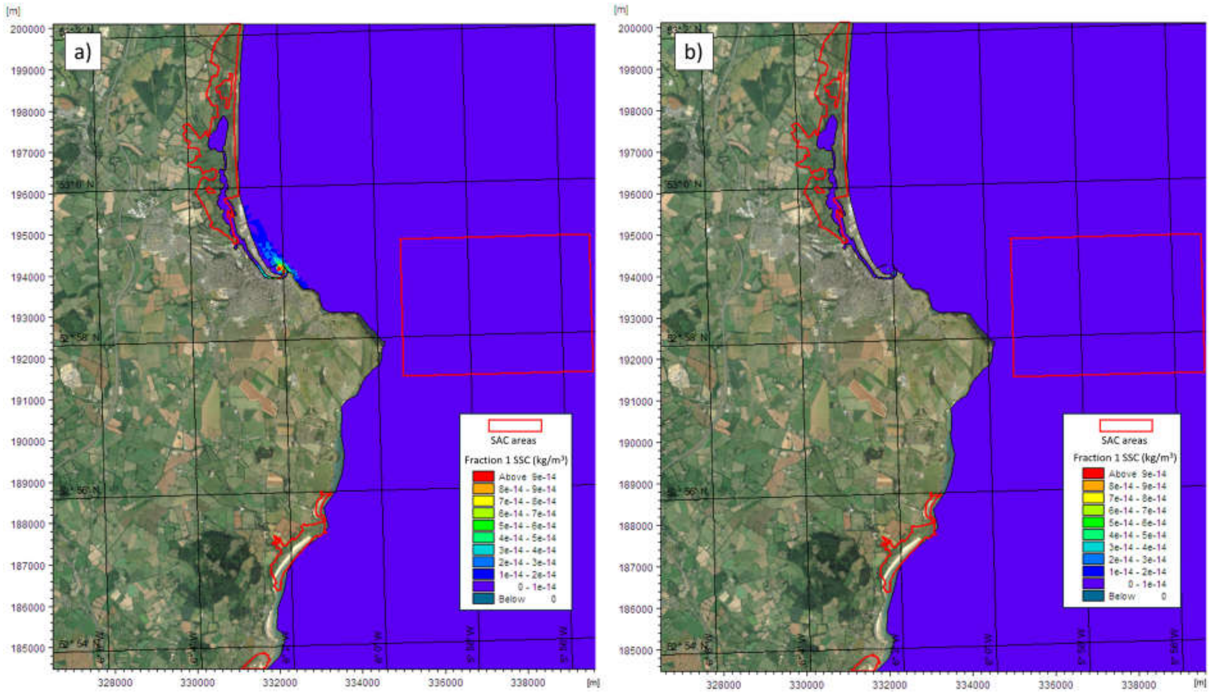

Figure 3-5 Fraction 1 – SSC considering the 13-day simulation: (a) maximum values and (b) mean values.

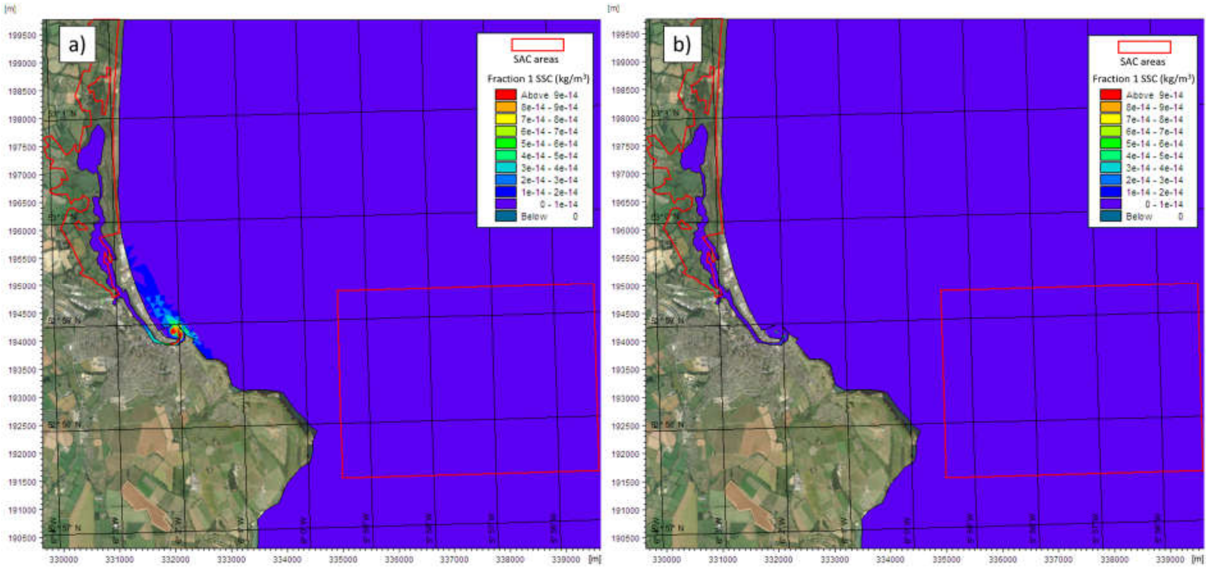

Figure 3-6 Fraction 1 – SSC – close-up view – considering the 13-day simulation: (a) maximum values and (b) mean values.

Table 3-3 Maximum and mean values of Fraction 1 SSC for the extracted numerical results.

Point Number	Name	Max Fraction 1 SSC (kg/m³)	Mean Fraction 1 SSC (kg/m³)
Point 1a	Farthest North Nearshore Point	9.97E-16	3.52E-17
Point 1b	Farthest North Offshore Point	1.47E-16	5.35E-18
Point 2a	Nearest North Nearshore Point	7.20E-15	2.52E-16
Point 2b	Nearest North Offshore Point	3.18E-16	1.05E-17
Point 3a	Wicklow Harbour Entrance	4.75E-14	8.14E-16
Point 3b	Wicklow Harbour Offshore	4.03E-15	1.10E-16
Point 4a	Nearest South Nearshore Point	6.39E-15	1.96E-16
Point 4b	Nearest South Offshore Point	1.19E-15	5.77E-17
Point 5a	Farthest South Nearshore Point	4.61E-16	5.22E-17
Point 5b	Farthest South Offshore Point	4.99E-16	3.45E-17
Point 6	Murrough Wetlands SAC	7.67E-15	2.70E-16
Point 7	Wicklow Reef SAC	2.04E-16	2.18E-17
Point 8	Magherabeg Dunes SAC	3.46E-16	5.18E-17
Point 9	Buckroney-Brittas Dunes and Fen SAC	1.94E-16	2.61E-17

The temporal evolution of the SSC values for fraction 1 for each point throughout the simulation, spanning from the 2nd to the 16th of October, covering the 13 days of dredging and the two days following dredging activities, is illustrated in Figure 3-7.

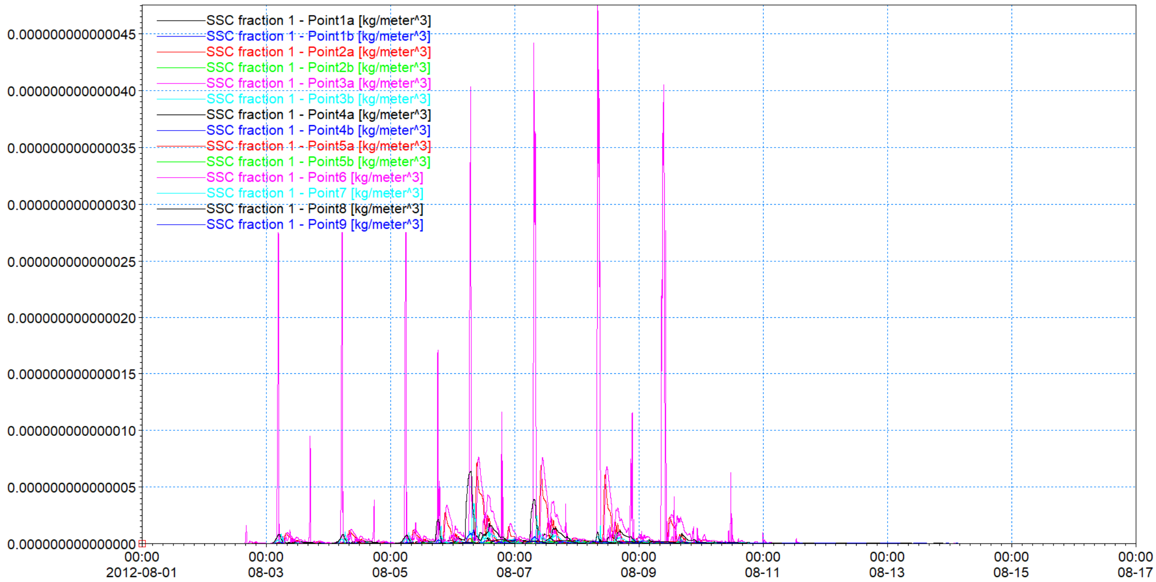

Figure 3-7 Fraction 1 Suspended Sediment Concentration (SSC) – Results at each point along the simulation.

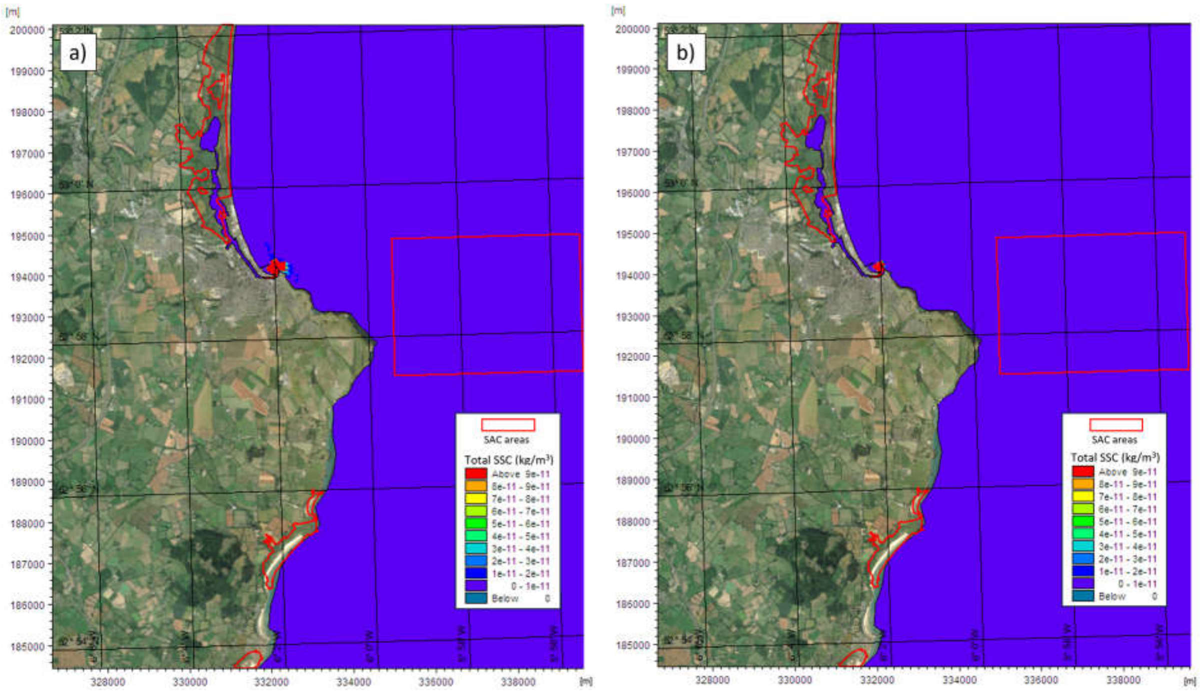

Figure 3-8 Fraction 2 SSC considering the 13-day simulation: (a) maximum values and (b) mean values.

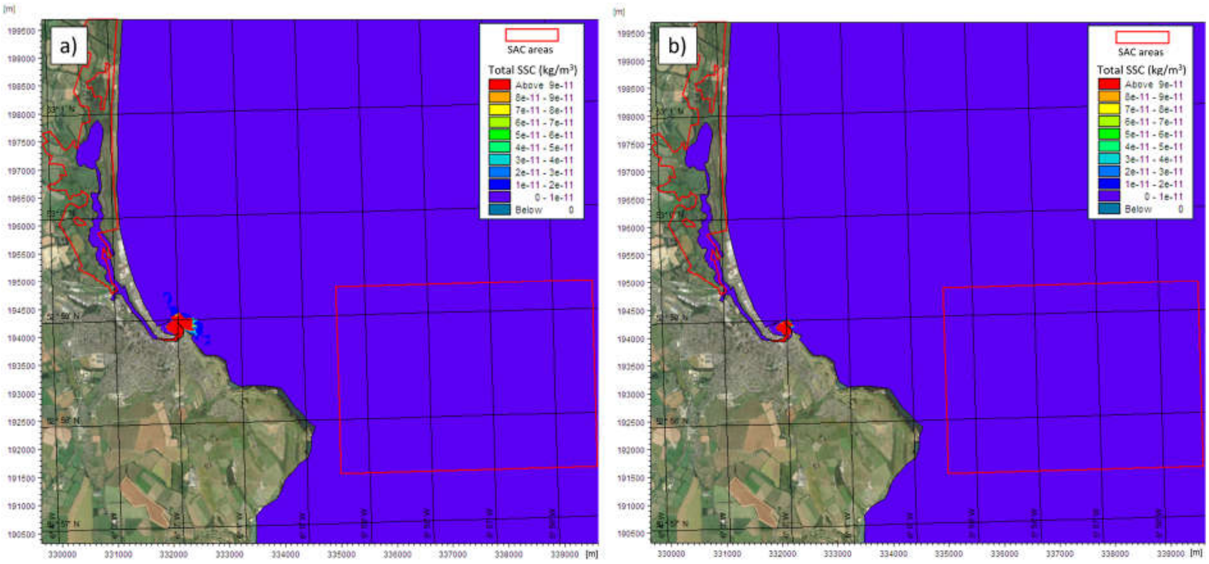

Figure 3-9 Fraction 2 SSC – close-up view – considering the 13-day simulation: (a) maximum values and (b) mean values.

Table 3-4 Maximum and mean values of Fraction 2 SSC for the extracted numerical results.

Point Number	Name	Max Fraction 2 SSC (kg/m³)	Mean Fraction 2 SSC (kg/m³)
Point 1a	Farthest North Nearshore Point	1.46E-12	3.39E-14
Point 1b	Farthest North Offshore Point	6.05E-14	9.09E-16
Point 2a	Nearest North Nearshore Point	5.23E-12	2.15E-13
Point 2b	Nearest North Offshore Point	5.85E-13	2.57E-15
Point 3a	Wicklow Harbour Entrance	1.35E-09	2.00E-12
Point 3b	Wicklow Harbour Offshore	3.02E-11	1.71E-13
Point 4a	Nearest South Nearshore Point	4.73E-12	7.09E-14
Point 4b	Nearest South Offshore Point	7.90E-13	9.07E-15
Point 5a	Farthest South Nearshore Point	1.55E-13	4.26E-16
Point 5b	Farthest South Offshore Point	8.61E-14	1.71E-16
Point 6	Murrough Wetlands SAC	4.37E-12	2.18E-13
Point 7	Wicklow Reef SAC	5.86E-14	8.32E-17
Point 8	Magherabeg Dunes SAC	1.21E-16	1.91E-18
Point 9	Buckroney-Brittas Dunes and Fen SAC	4.77E-17	1.21E-18

The temporal evolution of the SSC values for fraction 2 for each point throughout the simulation, spanning from the 2nd to the 16th of October, covering the 13 days of dredging and the two days following dredging activities, is illustrated in Figure 3-10.

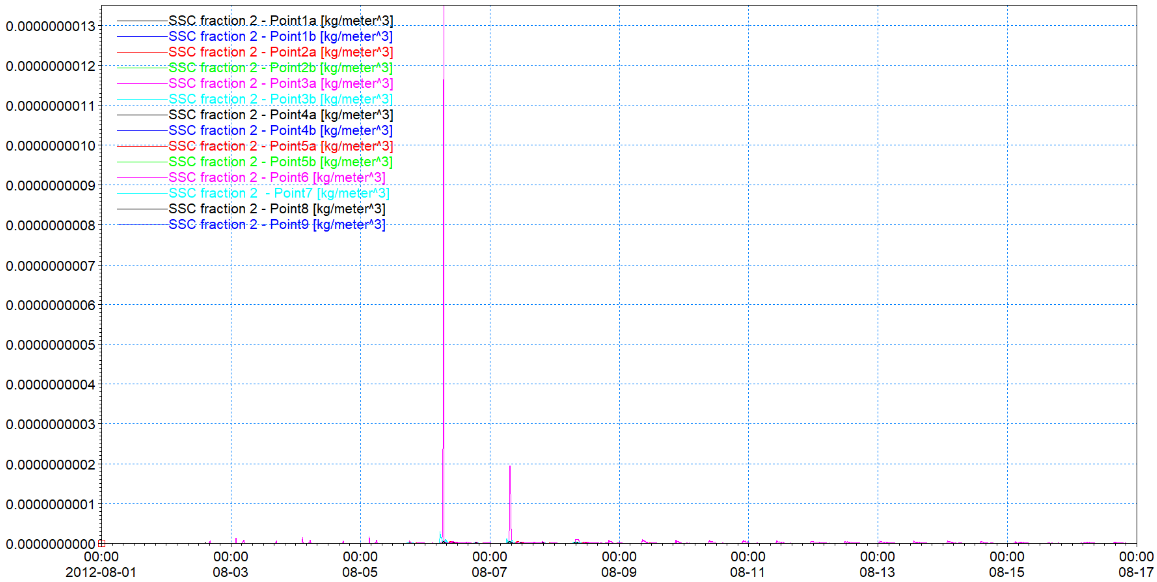

Figure 3-10 Fraction 2 Suspended Sediment Concentration (SSC) – Results at each point along the simulation.

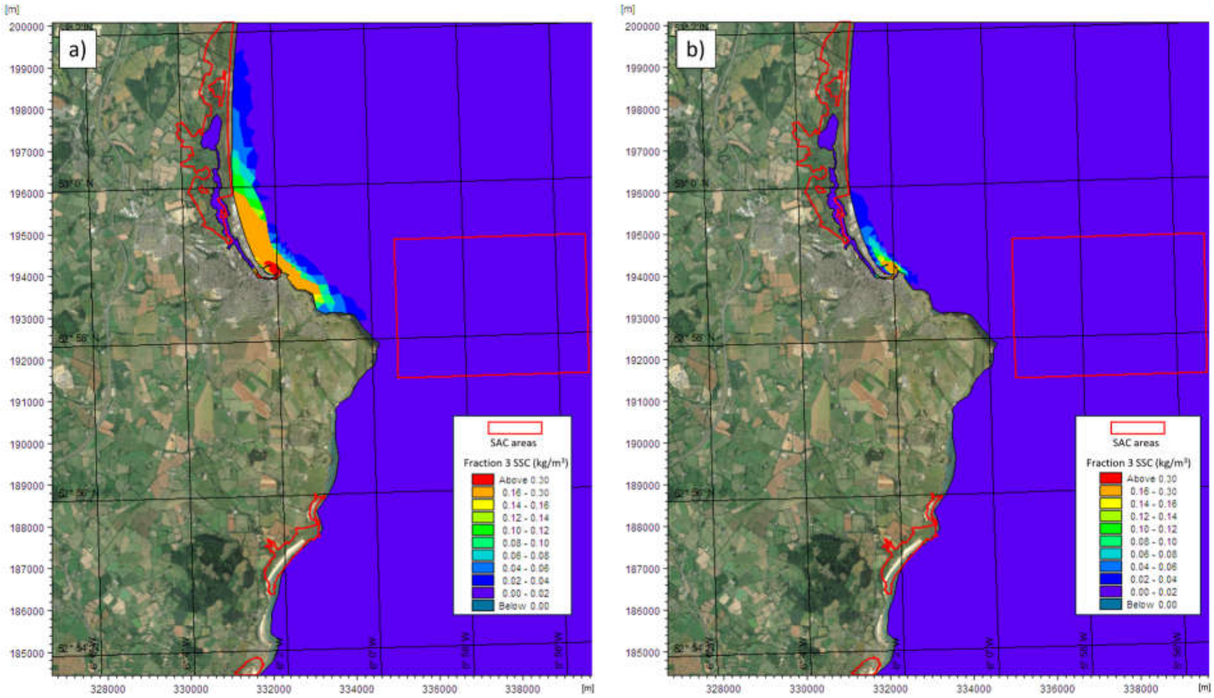

Figure 3-11 Fraction 3 SSC considering the 13-day simulation: (a) maximum values and (b) mean values.

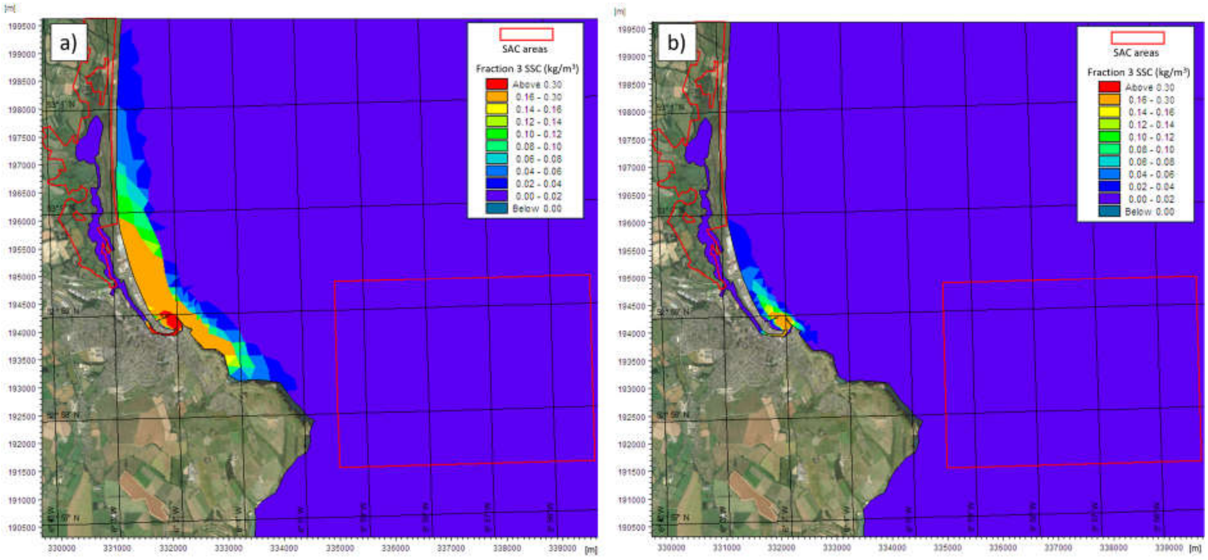

Figure 3-12 Fraction 3 SSC – close-up view – considering the 13-day simulation: (a) maximum values and (b) mean values.

Table 3-5 Maximum and mean values of Faction 3 SSC for the extracted numerical results.

Point Number	Name	Max Fraction 3 SSC (kg/m³)	Mean Fraction 3 SSC (kg/m³)
Point 1a	Farthest North Nearshore Point	0.03507	0.003750
Point 1b	Farthest North Offshore Point	0.00604	0.000396
Point 2a	Nearest North Nearshore Point	0.18765	0.021967
Point 2b	Nearest North Offshore Point	0.01249	0.000940
Point 3a	Wicklow Harbour Entrance	15.23530	0.332556
Point 3b	Wicklow Harbour Offshore	0.17729	0.008618
Point 4a	Nearest South Nearshore Point	0.16833	0.007548
Point 4b	Nearest South Offshore Point	0.03220	0.001820
Point 5a	Farthest South Nearshore Point	0.00333	0.000119
Point 5b	Farthest South Offshore Point	0.00235	0.000083
Point 6	Murrough Wetlands SAC	0.17699	0.023273
Point 7	Wicklow Reef SAC	0.00064	0.000024
Point 8	Magherabeg Dunes SAC	0.00051	0.000009
Point 9	Buckroney-Brittas Dunes and Fen SAC	0.00022	0.000005

The temporal evolution of the SSC values for fraction 3 for each point throughout the simulation, spanning from the 2nd to the 16th of October, covering the 13 days of dredging and the two days following dredging activities, is illustrated in Figure 3-13.

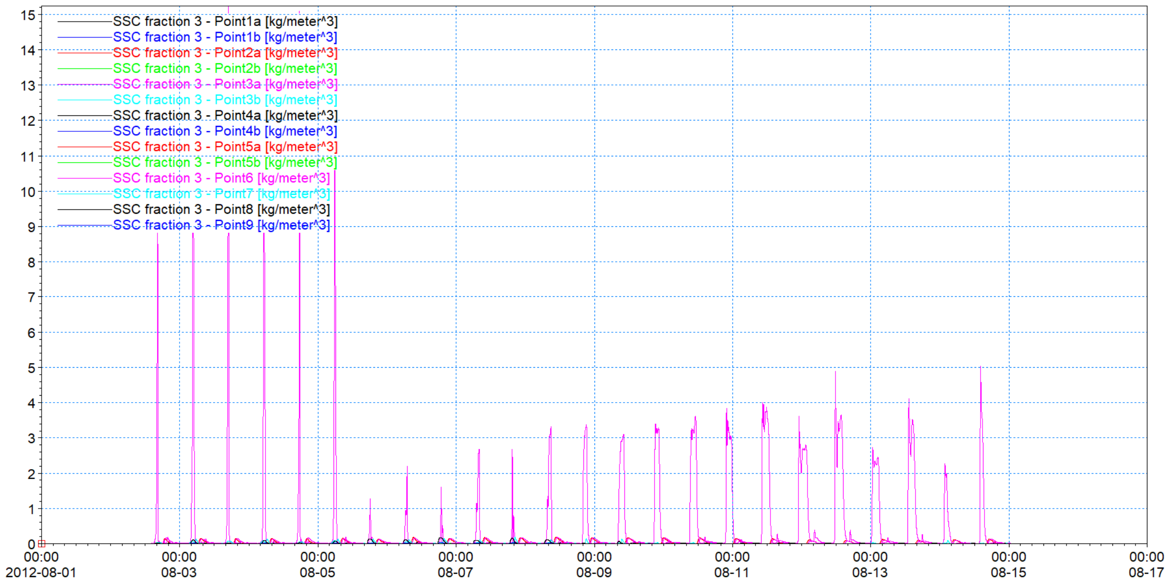

Figure 3-13 Fraction 3 Suspended Sediment Concentration (SSC) – Results at each point along the simulation.

The same analysis is presented here for the bed thickness change during the dredging operations. The maximum total bed thickness change over the 13-day simulation period is depicted in Figure 3-14 and Figure 3-15.

The maximum total change in bed thickness is naturally observed at the entrance of Wicklow Harbour (Point 3a), measuring 0.417 m with a mean value of 0.196 m. This entirely contrasts with the values observed offshore at Point 3b, where the maximum is 0.004 m, and the mean is 0.001 m. The closest northern point to Wicklow Harbour (Point 2a) exhibits the second-highest maximum value at 0.027 m, indicating a more prominent deposition of dredged material on the northern side of Wicklow Harbour. The nearest to Wicklow Harbour northern offshore point (Point 2b) shows a negligible maximum value of 0.00075 m. On the southern side of Wicklow Harbour, there is a relatively low deposition of dredged material, with the maximum bed thickness change recorded at 0.0025 m at the nearest southern nearshore point (Point 4a). All other southern points display bed thickness change values considered negligible (lower than 0.0025 m) (refer to Table 3-6).

The results regarding the total bed thickness over the 13-day sediment disposal simulation for each SAC area are also presented in the Table 3-6. Notably, bed thickness changes are observed only for Murrough Wetlands SAC (Point 6) representing a maximum bed thickness change of 0.029 m. The maximum bed thickness values reflect the immediate change in bed thickness following the 13-day WID dredging activities. Consequently, considering the temporal nature of sediment transport after dredging, these bed thickness values are expected to gradually return to the pre-dredging levels. Contrasting, the bed thickness change values for other SAC areas (Wicklow Reef SAC, Magherabeg Dunes SAC, and Buckroney-Brittas Dunes and Fen SAC) are negligible, registering maximum values below to 0.000024 m.

The results also indicate that the bed thickness remains constant upstream of the dredging area. This is attributed to the timing of the dredging operations, which occur only during the ebbing tide. This timing prevents the sediment plume from traveling upstream through the river Varty.

It is important to note that the bed thickness change inside Wicklow Harbour within the dredging areas is not accurately modelled due to the limitations of the MIKE21 Model. This model does not calculate the dynamic 3D changes of the seabed during dredging operations. While the model effectively calculates the 2D dispersal and accretion of dredged sediment within and outside the harbour, in the dredging areas where the mobile nature of the WID technique is applied, the accumulation of dredged sediment is unrealistic. This is because the WID technique is a highly dynamic process carried out from upstream to downstream, ensuring that the bed undergoes effective changes corresponding to the dredging volumes. As a result, the model produces unreliable bed thickness changes within the dredging areas. However, bed thickness changes are properly modelled in areas not subjected to WID activities, such as the upstream River Varty area and outside Wicklow Harbour.

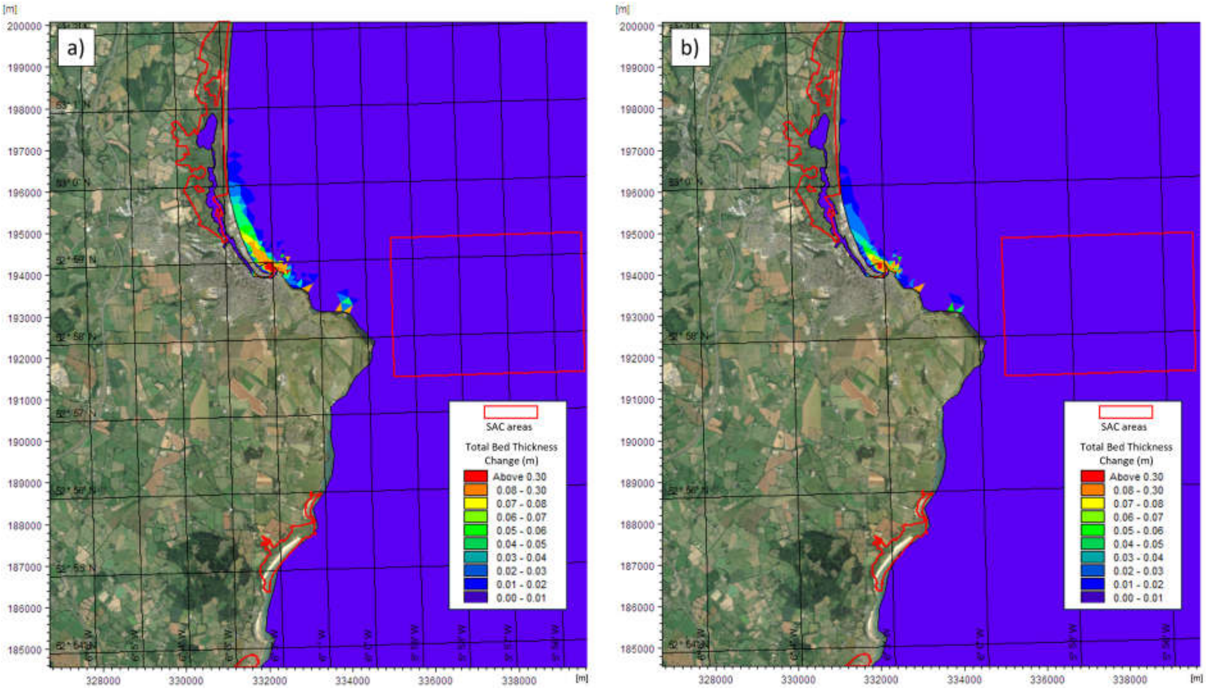

Figure 3-14 Total bed thickness change considering the 13-day simulation: (a) maximum values and (b) mean values.

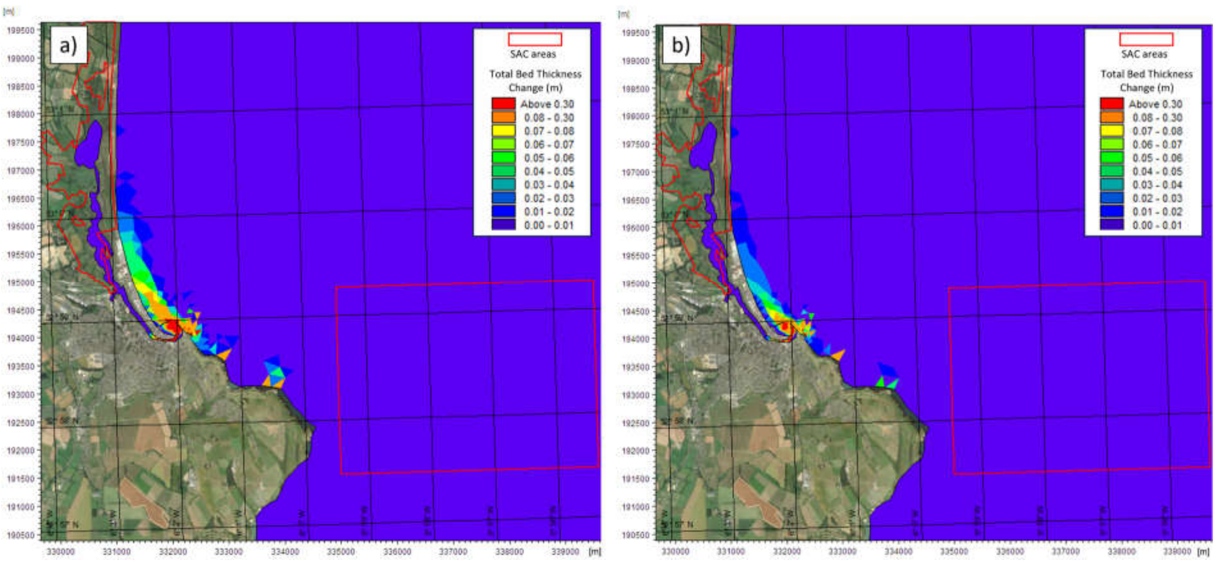

Figure 3-15 Total bed thickness change – close-up view - considering the 13-day simulation: (a) maximum values and (b) mean values.

Table 3-6 Total bed thickness change for the extracted numerical results.

Point Number	Name	Max Total bed thickness change (m)	Mean Total bed thickness change (m)
Point 1a	Farthest North Nearshore Point	0.002566	0.001197
Point 1b	Farthest North Offshore Point	0.000172	0.000042
Point 2a	Nearest North Nearshore Point	0.027600	0.014123
Point 2b	Nearest North Offshore Point	0.000751	0.000349
Point 3a	Wicklow Harbour Entrance	0.417870	0.196973
Point 3b	Wicklow Harbour Offshore	0.004295	0.001759
Point 4a	Nearest South Nearshore Point	0.002511	0.000795
Point 4b	Nearest South Offshore Point	0.000394	0.000067
Point 5a	Farthest South Nearshore Point	0.000263	0.000016
Point 5b	Farthest South Offshore Point	0.000084	0.000004
Point 6	Murrough Wetlands SAC	0.029167	0.015600
Point 7	Wicklow Reef SAC	0.000024	0.000001
Point 8	Magherabeg Dunes SAC	0.000009	0.000002
Point 9	Buckroney-Brittas Dunes and Fen SAC	0.000005	0.000002

The temporal evolution of the bed thickness change values for each point throughout the simulation, spanning from the 2nd to the 16th of October, covering the 13 days of dredging and the two days following dredging activities, is illustrated in Figure 3-16.

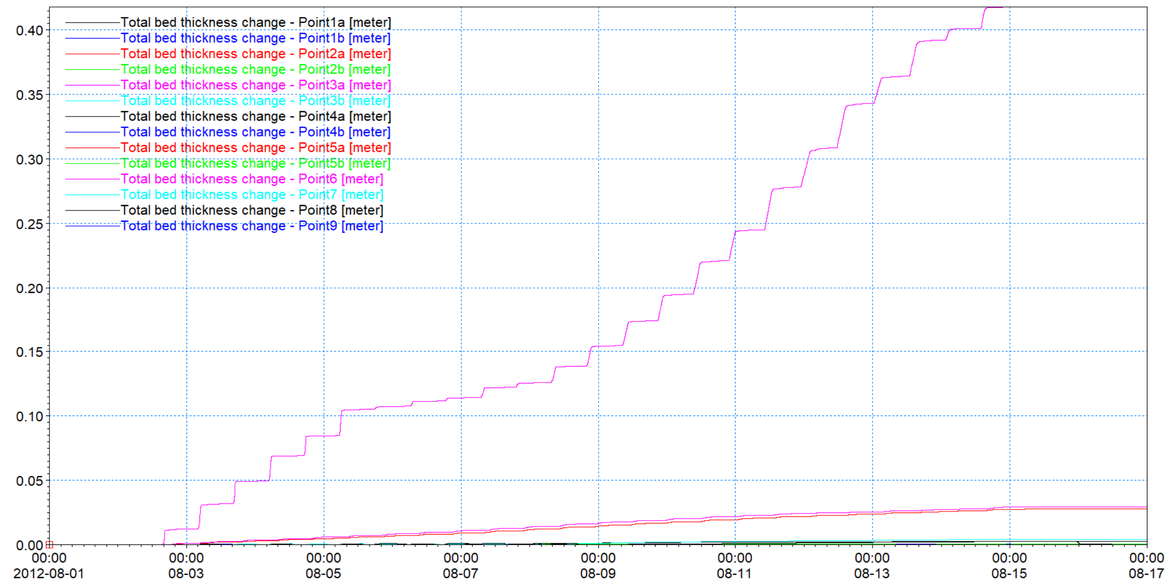

Figure 3-16 Bed thickness change – Results at each point along the simulation.

3.2 Total Suspended Sediment Concentrations and Total Bed Thickness Change Two Days after Water Injection Dredging Operations Period

As mentioned earlier, following the 13-day simulation of the WID operations, the simulation was continued for additional 2-days with the aim of observing the evolution of dredged material dispersion and the changes in deposition areas.

Table 3-7, along with both Figure 3-17 and Figure 3-18, presents the results for two days after the dredging operations. These results encompass both the total SSC and the total bed thickness change due to sediment dispersal, allowing for a comparison with the scenario before dredging. These numerical findings provide insights into the impact and dynamics of sediment dispersal following the completion of dredging operations.

Concerning the Total SSC values, these are less than 0.00177 kg/m^3 (1.77 mg/L) (maximum at the entrance of Wicklow Harbour – Point 3a) and less than 0.00007 kg/m^3 (0.07 mg/L) at all other points. This indicates a significant reduction in SSC values, highlighting that they are nearly negligible two days after the dredging operations. Additionally, it is important to note that assuming SSC equal to zero was considered as the baseline condition in the model domain. This choice stems from the specific focus of this study on the dispersion of dredged material.

In terms of bed thickness change, there is a slight difference between the values at the end of the 13-day simulation and those observed after 2 days without dredging. Notably, a more substantial decrease in bed thickness is evident in the more offshore areas, indicating a faster variation in bed thickness in these regions where the mass transportation of water is greater.

Despite this, the overall decrease in bed thickness is apparent and suggests that over a more extended period, the seabed would stabilize at levels close to those preceding the dredging events.

Please note, as previously explained at the end of Section 3.1, MIKE21 is unable to accurately provide results in the dredging areas due to the dynamic nature of the WID technique. However, the results are precise for areas not subjected to dredging activities, such as the upstream River Varty and outside Wicklow Harbour.

Table 3-7 Total SSC values and Total bed thickness change for the extracted numerical results two days after dredging activities.

Point Number	Name	Total SSC (kg/m3)	Total bed thickness change (m)
Point 1a	Farthest North Nearshore Point	6.20E-03	0.0025627
Point 1b	Farthest North Offshore Point	4.59E-19	0.0000008
Point 2a	Nearest North Nearshore Point	6.78E-05	0.0275996
Point 2b	Nearest North Offshore Point	7.62E-05	0.0007512
Point 3a	Wicklow Harbour Entrance	7.69E-05	0.4178700
Point 3b	Wicklow Harbour Offshore	1.77E-03	0.0040920
Point 4a	Nearest South Nearshore Point	2.82E-08	0.0000010
Point 4b	Nearest South Offshore Point	3.91E-06	0.0000008
Point 5a	Farthest South Nearshore Point	2.31E-09	0.0000008
Point 5b	Farthest South Offshore Point	1.41E-07	0.0000009
Point 6	Murrough Wetlands SAC	7.10E-05	0.0291665
Point 7	Wicklow Reef SAC	1.43E-08	0.0000010
Point 8	Magherabeg Dunes SAC	3.21E-07	0.0000009
Point 9	Buckroney-Brittas Dunes and Fen SAC	2.03E-06	0.0000009

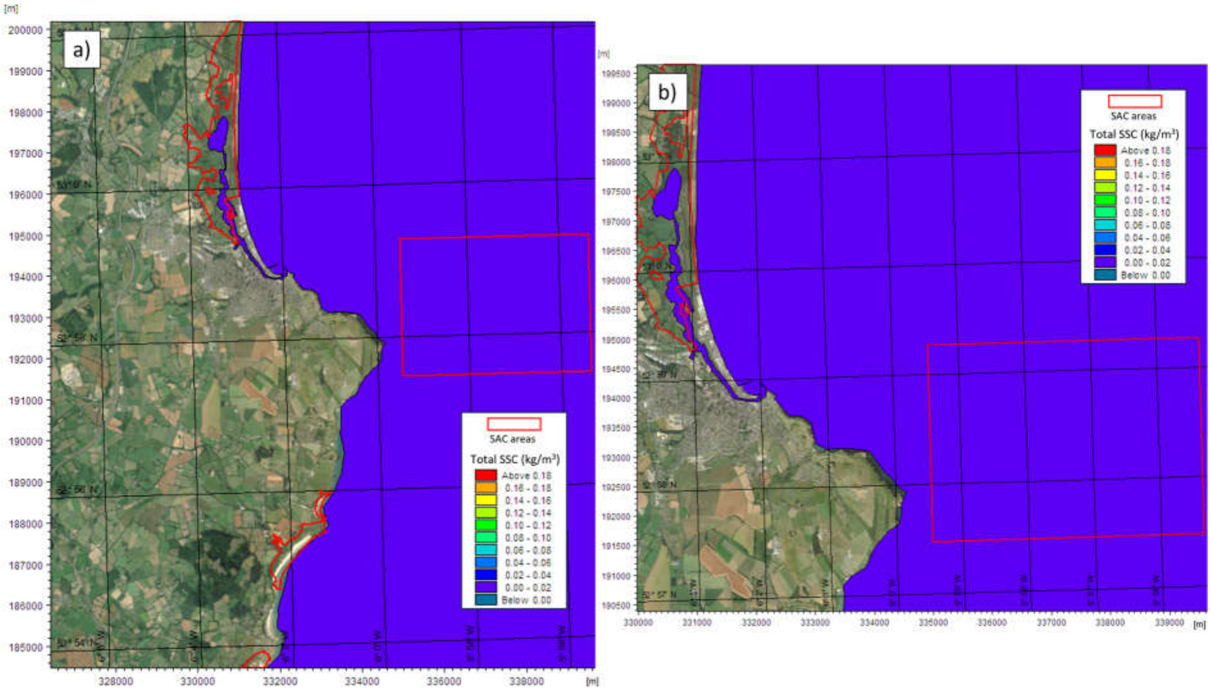

Figure 3-17 Total Suspended Sediment Concentration (SSC) two days after the 13-day WID simulation: (a) large-scale view and (b) close-up view.

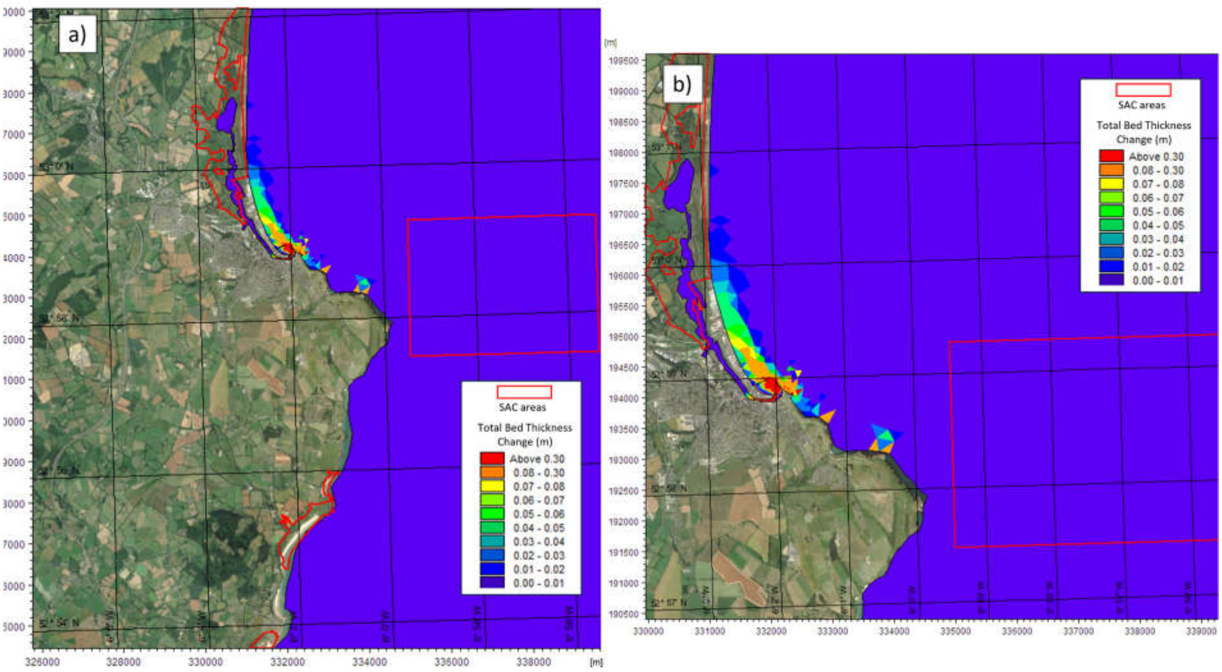

Figure 3-18 Total bed thickness change two days after the 13-day WID simulation: (a) large-scale view and (b) close-up view.

Figure 3-19 depicts the evolution of SSC values following the last water injection activity, illustrating the dynamics of the plume along the coast. The figure clearly demonstrates the attenuation of the plume over time, attributed to the hydrodynamical patterns in the adjacent area to Wicklow Harbour. It is evident from the figure that the SSC values diminish to negligible levels in less than 12 hours, underscoring the effectiveness of coastal hydrodynamics in dispersing the dredged material across the area and significantly reducing SSC values around Wicklow Harbour.

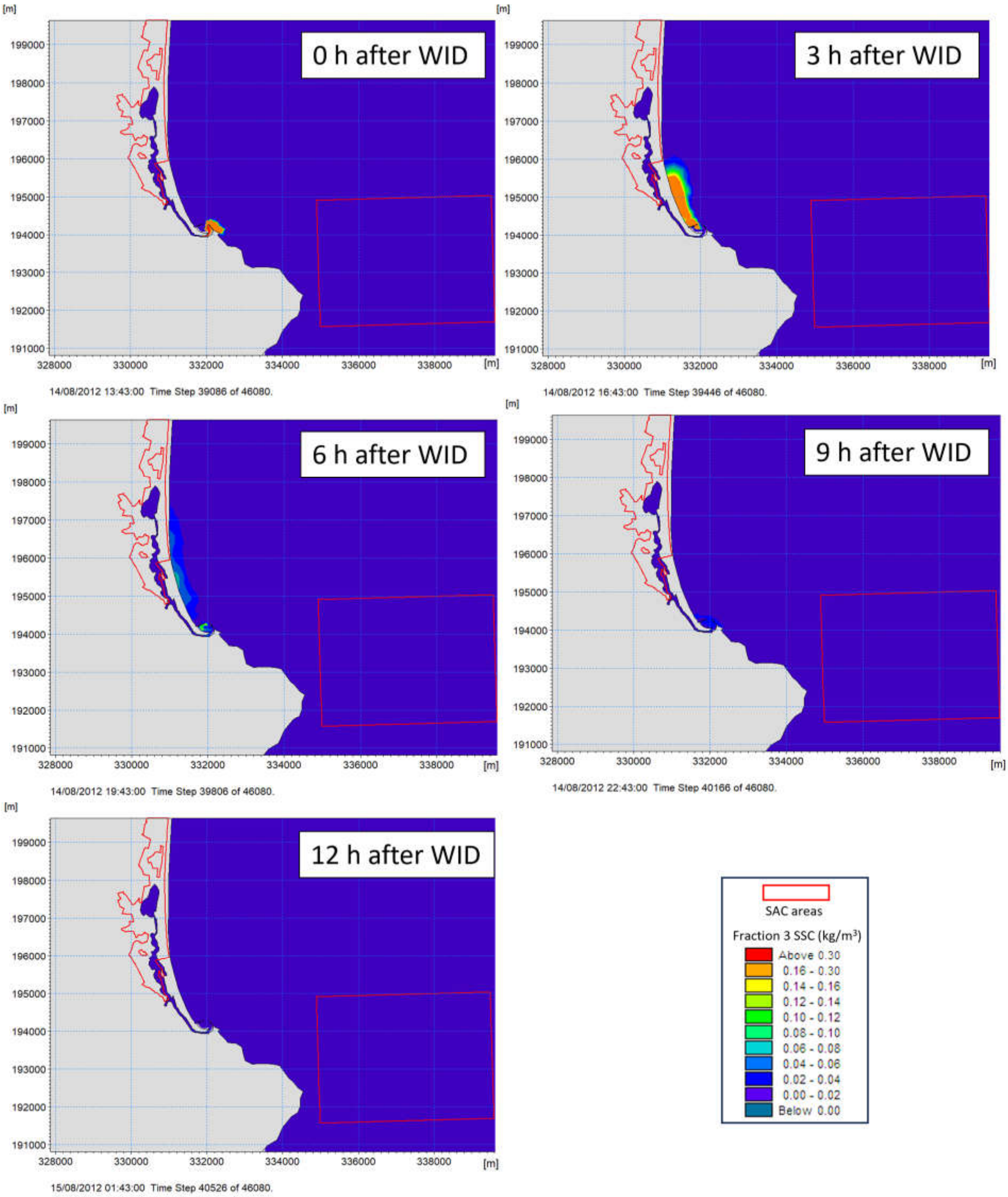

Figure 3-19 Total SSC evolution after last WID activity.

4 SUMMARY AND CONCLUSIONS

The modelling scenario within this report was designed to assess the worst-case dispersion and deposition of sediment arising from the maximum volume intended for dredging using the Water Injection Dredging (WID) technique inside Wicklow Harbour.

The results show that the sediment plume does not extend upstream of the dredging areas along River Varty. This is attributed to the exclusive planning of Water Injection Dredging (WID) activities during the ebbing tide, preventing the sediment plume from traveling upstream and causing changes to the bed thickness in that particular area.

The results indicate that both the gravel and sand fractions settled from suspension, primarily remaining near the boundaries of Wicklow Harbour throughout the simulation period. Although there was some dispersion of these fractions to the north and south of Wicklow Harbour, their concentrations are minimal (refer to Figure 3-5 to Figure 3-9).

In contrast, the silt fraction exhibits a more extensive dispersion, representing the majority of the Total SSC generated by the Water Injection Dredging (WID) activities. The distribution and concentrations of Fraction 3 (Figure 3-11 to Figure 3-12) closely align with the overall extent of total SSC within a 5 km radius from Wicklow Harbour and in the Special Areas of Conservation (SAC) zones. Except for the immediate area at the entrance of Wicklow Harbour, where values can reach 17.46 kg/m^3 (17460 mg/L) during dredging operations, near the north coast, the values can reach 0.037 kg/m^3 (37 mg/L) at 3.5 km from the Harbour. On the southern coast, at 3.5 km, it reaches an SSC value of 0.0034 kg/m^3 (3.5 mg/L).

Specifically, when considering the SAC zones, noteworthy total SSC values are observed at the point closest to Wicklow Harbour, located at Murrough Wetlands SAC (Point 6). In this area, there is a maximum total SSC value of 0.185 kg/m^3 (185 mg/L) and a mean value of 0.023 kg/m^3 (23 mg/L) during the dredging operations. These values signify a temporary peak that rapidly diminishes as a result of the dispersal of sediment plumes. They become negligible after two days of simulation without dredging activities.In contrast, the total SSC values for the other SAC areas (Wicklow Reef SAC, Magherabeg Dunes SAC, and Buckroney-Brittas Dunes and Fen SAC) are relatively low, registering values below 0.001 kg/m^3 (1 mg/L).

The results of bed thickness change during dredging operations (Figure 3-14 and Figure 3-15) indicate that the riverbed maintains a consistent level before and after dredging activities upstream of River Varty. Beyond the Harbour, the dispersed sediments move northwards and southwards along the coastline, with a maximum change of 0.027 m at 1.5 km north near the coast and 0.0025 m south near the coast. In the Special Areas of Conservation (SAC) zones, a similar trend is observed when comparing with the Suspended Sediment Concentration (SSC) values. For instance, at the nearest point to Murrough Wetlands SAC (Point 6), there is a maximum bed thickness change of 0.029 m. In all other SAC zones, the bed thickness changes are negligible, with maximum values below 0.000024 m.

After a 13-day simulation of Water Injection Dredging (WID) operations, the simulation was extended for an additional 2 days to observe the evolution of dredged material dispersion and changes in deposition areas (Table 3-7, Figure 3-17, and Figure 3-18). Results for these two additional days of simulation without dredging activities reveal a significant drop in SSC values to negligible levels throughout the entire computational domain, measuring less than 0.00177 kg/m^3 (1.77 mg/L) at the entrance of Wicklow Harbour where the maximum SSC values were initially observed. Regarding bed thickness values, there is a slight difference between the values at the end of the 13-day simulation and those observed after 2 days without dredging. Notably, a more substantial decrease in bed thickness is evident in the offshore areas, indicating a faster variation in bed thickness in regions where the mass transportation of water is greater. The results suggest a clear tendency for a decrease in bed thickness, indicating that over an extended period, this reduction in bed thickness would become significant.

Regarding the adjacent Special Area of Conservation (SAC) areas, the results indicate a reduction in bed thickness and Suspended Sediment Concentration (SSC) values, implying a natural recovery towards the initial environmental conditions in the SAC areas. The SSC values also show a significant decline, highlighting the effectiveness of the limited time allocated for the dredging operations. The numerical study conducted in this research demonstrates that the application of the WID technique is environmentally suitable when implemented during ebbing conditions, preventing the penetration of sediment plumes upstream at Broad Lough and the River Vartry. The simulations further indicate that both the SSC values and changes in bed thickness remain below allowable limits in both the SAC areas and the zones adjacent to Wicklow Harbour, both offshore and nearshore.

Furthermore, during spring ebbing tides, when tidal currents reach higher velocities, a more pronounced outflow of sediment from the harbour to offshore areas was observed. This results in a greater dispersal of dredged material in the offshore direction.

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