

## Appendix 7.1: Coastal Processes

7.1 This document is comprised of the following elements:

- [Proposed Methodology for Stranraer Marina Modelling Study](#)
  - This document was circulated to NatureScot, SEPA and MSS November 2024 seeking Stakeholder opinion on the proposed methodology.
- [Development of Tidal Ellipses relating to Proposed Dredging Extents](#)
  - This Technical Note was produced during the preliminary modelling stage and used to inform the development of potential zone of influence.
- [Model Calibration Data](#)
  - This section of the document provides additional information on model development, calibration and validation.
- [Additional Information for Stranraer Marina Modelling Study](#)
  - This table was circulated to NatureScot March 2025 following a request for further information.
- [Stranraer Marina Expansion Dredging Plume Modelling](#)
  - This document details the dredging plume modelling undertaken for the application and was circulated to provide information to support the environmental assessments for related disciplines.

## Proposed Methodology for Stranraer Marina Modelling Study

### *Introduction*

- 7.2 The coastal processes Environmental Impact Assessment (EIA) for the proposed development will be supported by a numerical modelling study. Preliminary modelling investigations have been undertaken to determine that suitable datasets are available to support the study; this was informed by the Scoping responses (MS-LOT February 2023). This document details the modelling methodology proposed and data application in light of the findings of these investigations. Noting that the scope of this document relates to the EIA for coastal processes and that harbour disturbance modelling used to determine the project design has been undertaken separately for the purposes of informing the design of the development.
- 7.3 The EIA modelling study is comprised of the following elements:
- Baseline coastal processes
  - Potential impacts on coastal processes as a result of the proposed development
  - Sediment plume modelling in relation to construction of the proposed development
- 7.4 Modelling will be undertaken using the MIKE modelling suite developed by DHI. The MIKE system is an industry-standard, modelling system, utilising a flexible mesh approach. This software was specifically developed for applications within oceanographic, coastal and estuarine environments and is approved by numerous statutory bodies including SEPA (Scottish Environment Protection Agency). The MIKE suite includes modules relating to tidal flow, wave climate, sediment transport and plume dispersion modelling. The coastal processes model extent will cover Loch Ryan and the Stranraer shoreline as illustrated in **Figure 7-1**.
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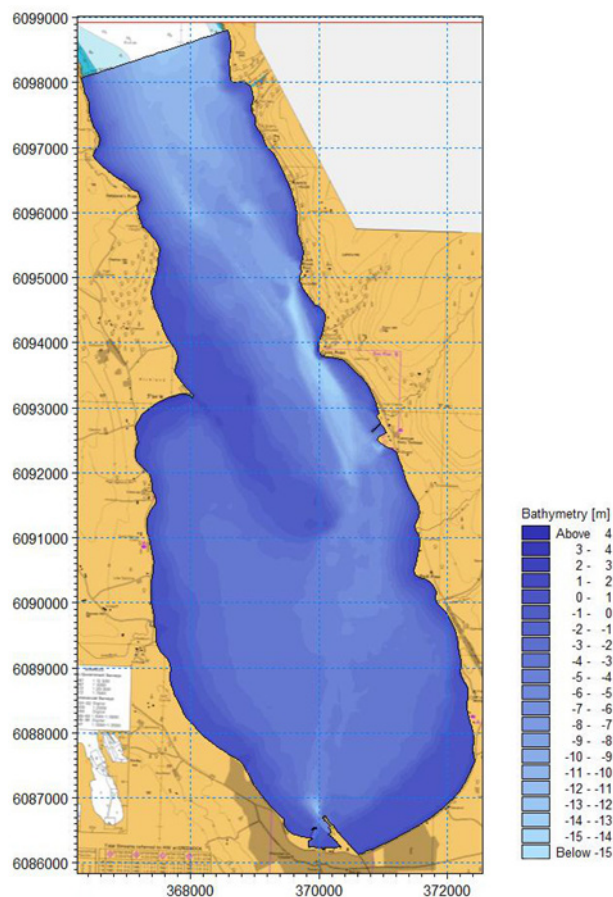


Figure 7-1: Extent of the Stranraer Model

### Data Sources

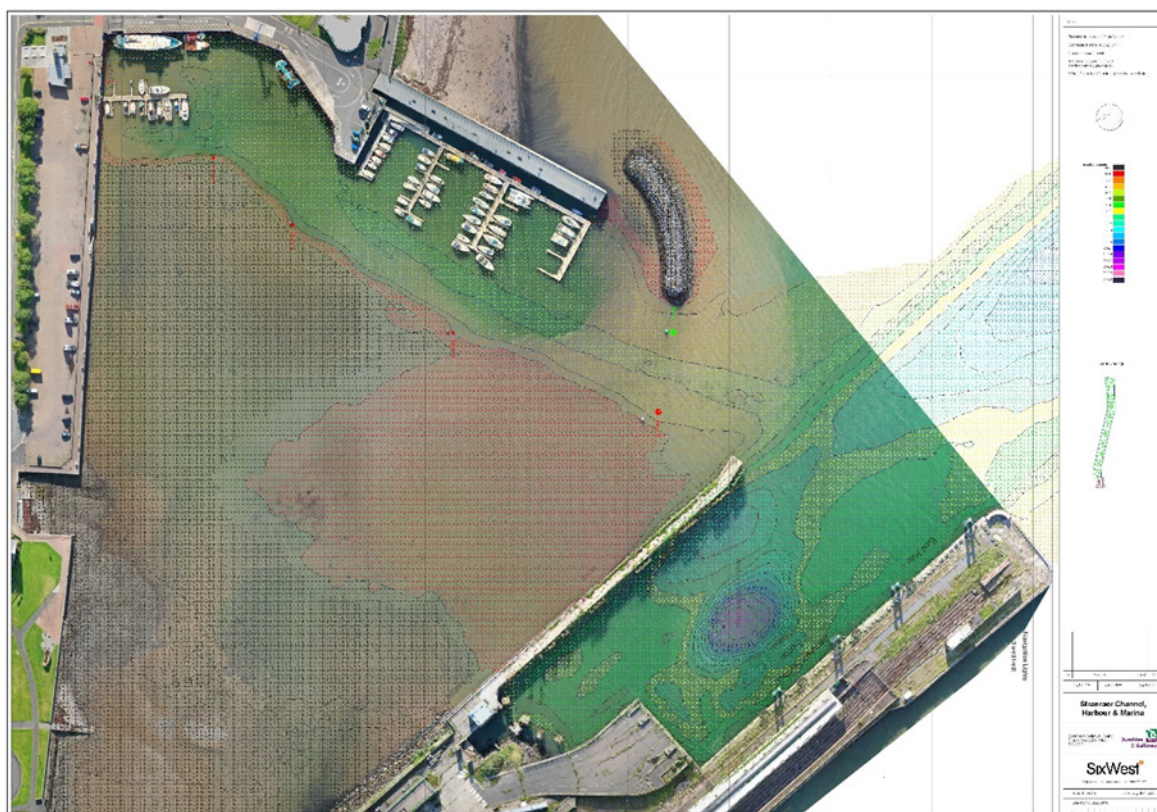
7.5 The numerical model will be developed, driven and validated using a range of datasets which are outlined in the following section.

### Bathymetric data

7.6 The model bathymetry used for all elements of the study be developed using a range of data sources which provide full coverage over the model domain. They include, but are not limited to the following:

- Project specific surveys undertaken by Six West of Stranraer harbour and approaches (2023)
- Surveys relating to other projects undertaken in the vicinity e.g. to the east of the harbour (2013)
- Detailed Lidar along the Stranraer coastline sourced from Scottish Remote Sensing Portal (2011-2012)
- UK Hydrographic Office (UKHO) Bathymetric survey data – Medin (1998, 1999)
- Admiralty chart data (various)

- An example of the project specific survey data from the Six West survey is shown in **Figure 7-2**



**Figure 7-2: Example bathymetric data from Six West survey (2023)**

#### Model Forcing

- 7.7 The hydrodynamic model will include implementation of a 'flather' boundary at the northern extent; whereby both surface elevation and current flows are prescribed. These boundary conditions will be provided from RPS's inhouse model covering the northern section of the Irish Sea and southern Inner Hebrides, as shown in **Figure 7-3**. The performance of these boundaries will be compared against equivalent data from Marine Scotland's Scottish Shelf Model (SSM) with the most suitable being chosen based on comparison of modelled data versus measured gauge data.

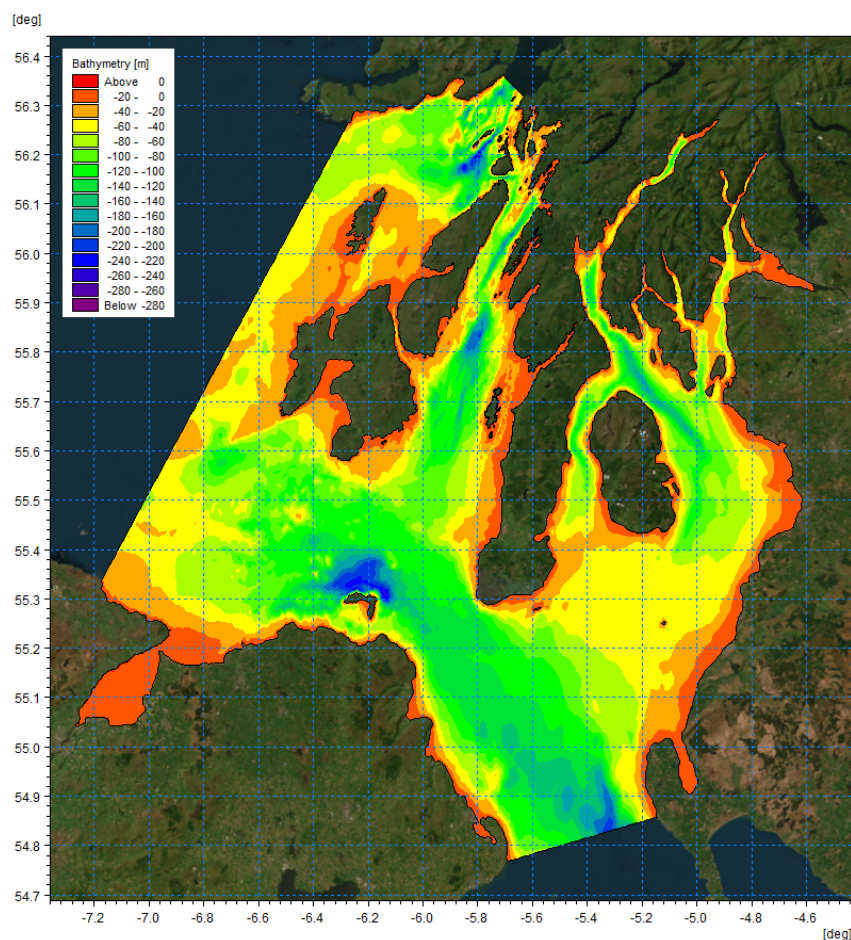


Figure 7-3: RPS Boundary Model

7.8 Where the model is used to simulate a combination of both tidal and meteorological conditions the pressure and wind field will be applied using data from the European Centre for Medium-Range Weather Forecasts (ECMWF) operation model. This is an industry standard dataset which is used by many organisations to force regional models, including the “Atlantic- European North West Shelf - Ocean Physics Analysis and Forecast” model as developed by the UK Met Office.

7.9 It is also recognised that due to the geography and enclosed nature of Loch Ryan and the Stranraer model extent, the application of water levels generated from harmonic analysis also provide effective boundary conditions for simulating tidal flow throughout the Loch under calm conditions (i.e. tide only).

#### Tidal model calibration

7.10 As part of the preliminary investigation a thorough review of available hydrographic datasets was undertaken. The availability of data was explored from the following resources:

- Admiralty

- British Oceanographic Data Centre (BODC)
- European Marine Observation and Data Network (EMODnet)
- License Applications – dredging & dumping
- Loch Ryan Oyster Company
- Marine Data Exchange
- Marine Scotland Data Portal
- Scottish Coastal Observatory Data
- SEPA
- Scottish Marine & Fisheries

7.11 Of these resources two suitable sources of data were identified, namely

- SEPA tide gauge data and
- Admiralty tidal harmonics and tidal streams (shown in **Figure 7-4**).



**Figure 7-4: Location of Admiralty datasets**

7.12 It is noted that several developments have been undertaken in Loch Ryan including the development of the Port of Cairnryan, installation of the marine outfall at Stranraer and works

relating to the development and use of the Stranraer harbour including maintenance dredging of the approaches. RPS has undertaken modelling for many of these projects including the modelling to support the Stranraer Gasworks Remediation work on behalf of Dumfries and Galloway Council in consultation with SEPA. In this case, modelling was undertaken to investigate the potential dilution of pollutants egressing from the seawall into the harbour. The modelling undertaken by RPS to support these studies was verified using these same data sources and accepted by the Statutory Authorities in each case.

- 7.13 It is therefore proposed to use these data sources to verify the tidal model for the proposed development. It is also of note that due to the opening out of the main channel south of Cairnryan into a relatively shallow basin the tidal current speeds are significantly reduced in this area. Within the vicinity of Stranraer harbour they peak around 0.05m/s but are more typically 0.01 to 0.02m/s. This can mean field measurement can be problematic due to both restricted water depth and these current speeds being circa the minimum capable of being recorded with standard Acoustic Doppler Current Profiler (ADCP) equipment.

#### Wave modelling data

- 7.14 As part of the feasibility stage of the proposed development a wave modelling study was undertaken using the MIKE21 Spectral Wave model (SW). The wave transformation was undertaken as a two stage process. First the waves were generated and transformed over the Firth of Clyde and the North Channel and then the wave generation and transformation was modelled in Loch Ryan itself. It is proposed that a similar process is applied to the EIA modelling study for the proposed development.
- 7.15 The extent and mesh of the outer RPS SW model of the North Channel, the Firth of Clyde and the approaches to Loch Ryan is shown in **Figure 7-5**. The wind data for wave generation will be based on the analysis of long term wind data (>30 years) from the ECMWF Atmospheric model and data from extreme winds developed by the UK Met Office for BS EN 1991:2005. Extreme value analysis (EVA) will be undertaken for each 30° directional sector for the wind data from the ECMWF establish the return period wind speeds for wave generation.
- 7.16 The results of the EVA analysis will be compared with data from BS EN1991:2005 and the wind speed for wave generation over the offshore fetches and the fetches within Loch Ryan will be adjusted to take account of over water wind speeds and the length of time required to fully develop the waves over the appropriate fetch. The wave climate will then be simulated for the outer model for a range of typical and extreme events (e.g. 1 in 1 year return period and 1 in 50 year return period).
- 7.17 The second stage of the wave transformation modelling will be undertaken using the model of Loch Ryan as shown in **Figure 7-1**. The wave climate at the boundary of the Loch Ryan model will be taken from the results of the offshore wave model simulations with the wind for wind-wave generation within the Loch.

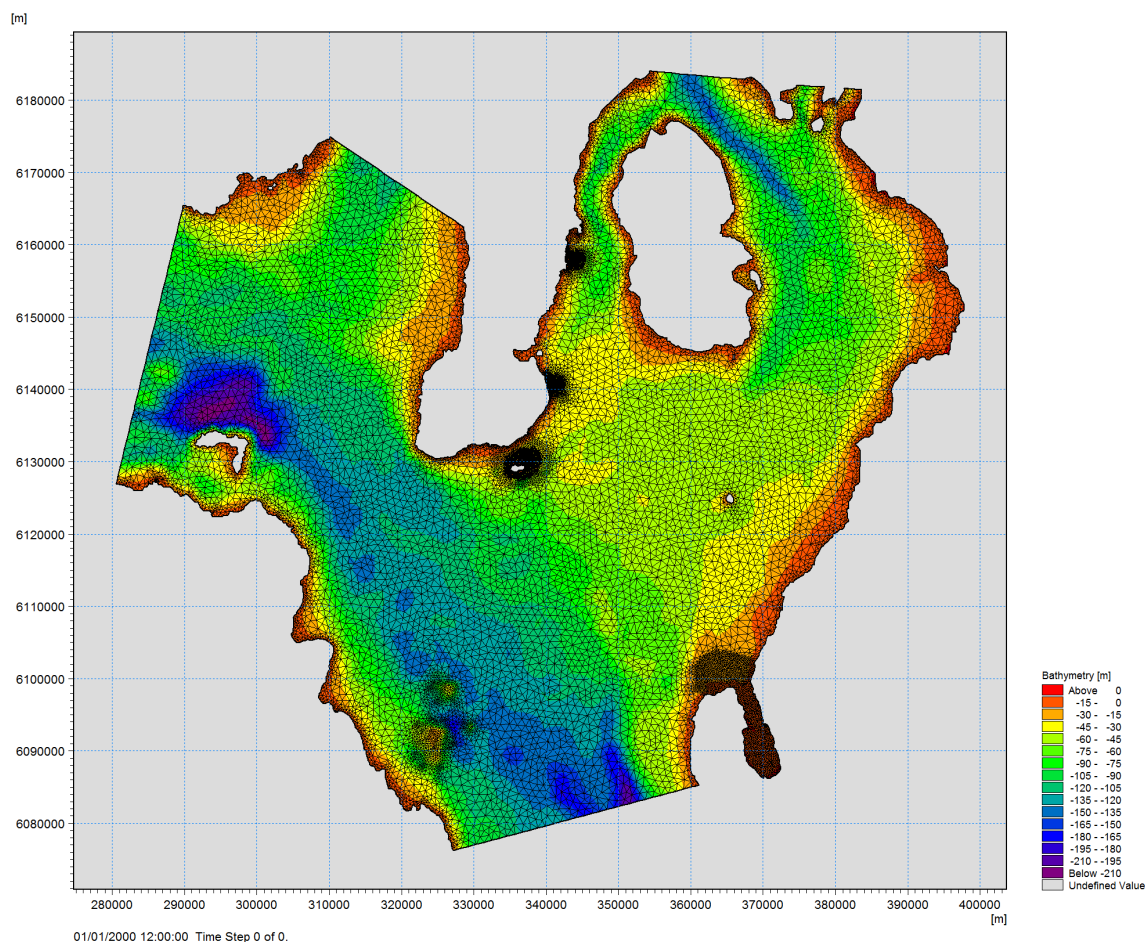


Figure 7-5: Extent and mesh of SW model of the North Channel and the Firth of Clyde

#### Seabed substrate and sediment data

- 7.18 Two elements of the modelling study require data relating to seabed substrate and sediment data, namely the sediment plume modelling relating to the construction phase and also establishing the baseline sediment transport and potential impacts due to the proposed development.
- 7.19 The sediment plumes relating to the proposed sediment dredging and reclamation will be informed by site specific ground investigation surveys which have been undertaken as part of the proposed development. This includes boreholes and particle sieve analysis (PSA) to provide sediment grading to be implemented within the modelling, as illustrated in **Figure 7-6**.

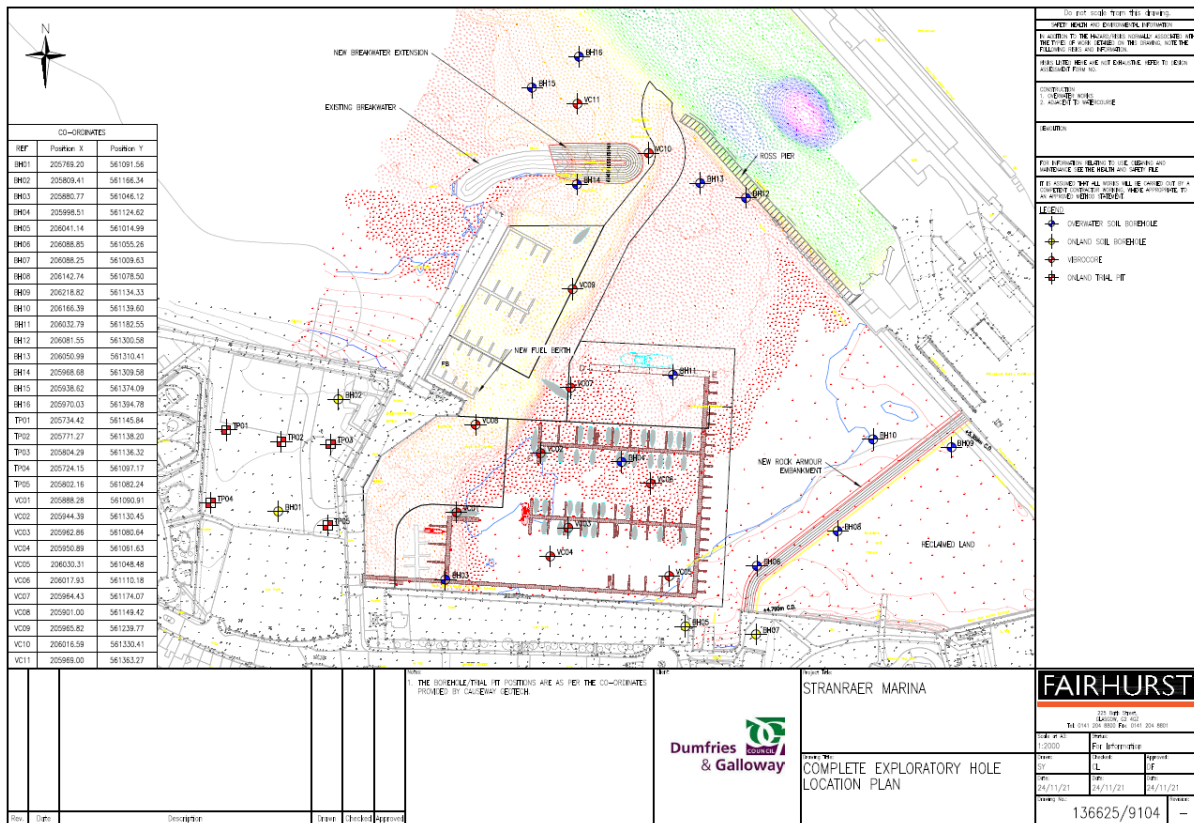


Figure 7-6: Location of exploratory holes (PSA locations blue target symbol)

- 7.20 In order to undertake sediment transport modelling, information is required on the seabed substrate in the wider extent of Loch Ryan. This data will be sourced from British Geological Survey (BGS) which provides generalised seabed sediment types and this will be supplemented with information with information from BGS which holds the borehole information on which the classification is based. It is recognised that there is somewhat less data available in the shallow and intertidal areas therefore data relating to the nature of the seabed published on Admiralty charts and visual assessment from historic satellite data may be used to generalise sediment types where data is sparse.
- 7.21 It is anticipated that due to the nature of the proposed development largely within the harbour that changes in coastal processes are anticipated to occur in the immediate vicinity of the development. It is therefore proposed to undertake a comparative assessment on tidal flow and wave climate which are the underlying drivers of sediment transport and, only if these are found to be significant will changes in sediment transport be investigated further.

**Summary**

- 7.22 To avoid potentially lengthy delays to the project programme and ensuring efficiencies, RPS propose using existing industry standard hydraulic models for the purpose of this EIA study.

These models have previously been developed for projects within Loch Ryan with model performance having been calibrated to the satisfaction of various statutory authorities.

- 7.23 It is the professional opinion of RPS based on extensive experience of hydraulic modelling in this area that no additional hydrographic survey data is required to update these models owing to available tide gauge and UKHO Admiralty tidal diamond data within the Loch.
- 7.24 To this end, RPS are seeking an opinion from MS-LOT on the method described above and the proposal to not procure what is considered unnecessary additional hydrographic survey data for an area which is already extensively characterised in context of coastal processes.

## Development of Tidal Ellipses relating to Proposed Dredging Extents

### Introduction

- 7.25 RPS were commissioned to identify the potential Zone of Influence (Zol) relating to the dredging activities associated with the proposed Stranraer Marina Development. The study was undertaken to support the marine licence application to undertake surveys.
- 7.26 The licence application relates to baseline surveys and consequently the dispersion plume modelling study in support of the Environmental Impact Assessment which has not yet been undertaken. A conservative approach using existing model data was adopted to determine the tidal ellipse, i.e. how far sediment may be carried on the tide from the dredged area prior to either sedimentation or being carried back on the returning tide. The tidal ellipse therefore provides a conservative Zol as, in reality, the mobilisation of sediment (particularly near the bed) would settle and be assimilated by bed sediments.
- 7.27 For further conservatism two tidal ellipses were produced. The first relates to the distance sediment may be advected on a single tide. It was however observed that some material mobilised in the inner harbour settles in the harbour mouth at slack water and, given the increased current speed at this location, may be resuspended on the subsequent tide. Therefore a second tide was considered to provide a more conservative Zol.
- 7.28 This Technical Note is associated with two shapefiles which provide the data relating to the ellipse extents illustrated in **Figure 7-7**.
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Figure 7-7: Tidal Ellipses relating to proposed dredging extents

### Development of Tidal Ellipse

- 7.29 The tidal ellipse was developed by releasing a series of particles within the model domain and tracking their movement over successive tides. The particles were released from a series of locations across the proposed dredging area as shown in **Figure 7-8**. A set of particles was released at high water, to model the path during flood tide, and a second set of particles was released on the following low water, to ascertain the path on ebb tide. The particles were defined as neutrally buoyant, i.e. they would not settle on slack tides and were therefore advected to the full extent of the tidal current. The period used in the modelling related to a spring tide with the largest tidal range typically exhibited in the area. This therefore demonstrated the largest tidal excursion likely to be experienced by any released material.
- 7.30 The ellipses generated relate to the dispersion of particles under the influence of tides alone. It is recognised that further dispersion may occur due to meteorological conditions (i.e., surface wind etc) however the proposed development includes reclamation of the dredged material therefore only a small percentage of the dredged material will be spilled into the water column. Additional dispersion by meteorological conditions is likely to result in a further reduction in suspended sediment concentrations within the plume and associated sedimentation akin to levels associated with existing natural background variation.



**Figure 7-8: Location of particle releases with the proposed dredging extents**

### ***Underlying Model***

- 7.31 As the licence application relates to baseline surveys, the dispersion plume modelling study in support of the Environmental Impact Assessment has not yet been undertaken therefore a pre-existing model of Stranraer Harbour was used to support the development of the tidal ellipse information.
- 7.32 The underlying model was developed to support the Stranraer Gasworks Remediation work on behalf of Dumfries and Galloway Council in consultation with SEPA. Modelling was undertaken to investigate the potential dilution of pollutants egressing from the seawall into the harbour. In order to quantify the dilution potential and water exchange available within the harbour and Loch Ryan RPS carried out an assessment of the dilution and dispersion characteristics using computational modelling techniques. As part of the study a detailed two dimensional flexible mesh model was built using the MIKE modelling software developed by DHI. The model extent is shown in **Figure 7-9**.

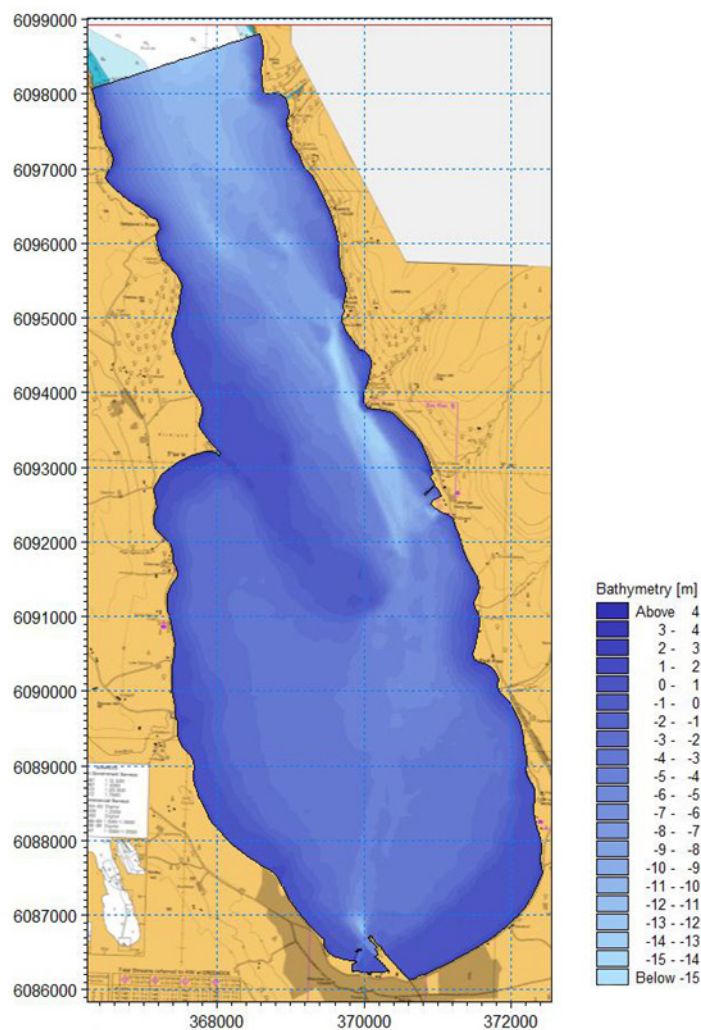
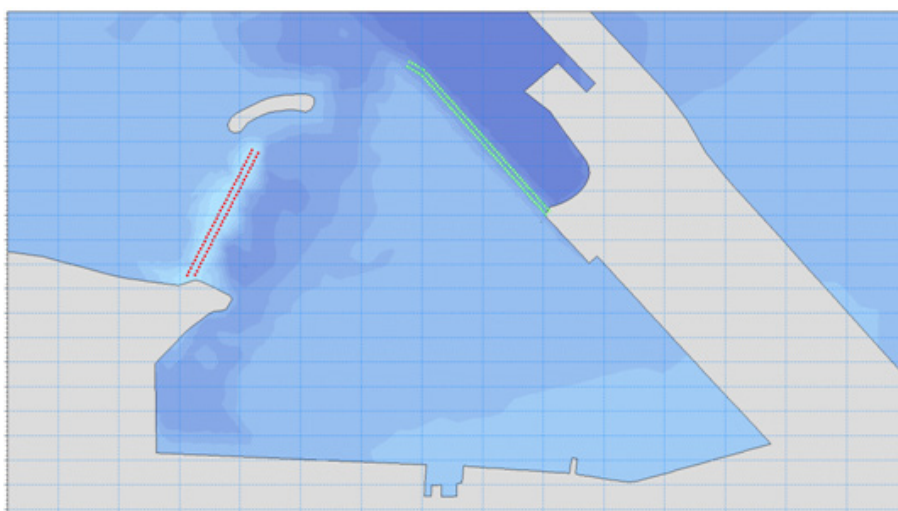


Figure 7-9: Flexible mesh model bathymetry

- 7.33 The bathymetric data was derived from various sources largely available through Admiralty and has been used extensively in the hydrodynamic models of Loch Ryan which have previously been developed in house by RPS. This included an unrelated project for which a bathymetric survey was undertaken in the vicinity of Stranraer Harbour during June 2013.
- 7.34 In addition to the bathymetric data, the model also represented the pier structures, in particular the West Pier. **Figure 7-10** shows a historic photograph showing the West Pier construction (left) whilst the right hand figure shows the Pier in October 2013 following refurbishment. These photographs, along with Google maps and Bing aerial photography were used to determine the detail of the structures. The flexible mesh model includes the capability of incorporating sub-grid sized structures such as bridge piers and piles. The hydrodynamic modelling takes account of the location, shape and orientation of each structure and updates the tidal flux to account for the obstruction to the flow. **Figure 7-11** shows the arrangement which was included within the flexible mesh model.



*Figure 7-10: Photograph under and looking along the West Pier*



*Figure 7-11: Pier structures included within flexible mesh model*

7.35 The flexible mesh was generated across Loch Ryan and extended from Stranraer, north towards the mouth of the Loch as shown in **Figure 7-9**. Although the surveys were incorporated into the bathymetric data in the vicinity of the Harbour, the only data available within the harbour itself at the time was that provided by Admiralty mapping. The limited coverage of the data in this area gave rise to difficulties in establishing a stable numerical model within this flooding and drying zone. For this reason a detailed bathymetry of the area was developed manually using GIS techniques and satellite imagery; this was then interpolated onto a fine mesh. **Figure 7-12** shows the detailed bathymetry whilst **Figure 7-13** shows the mesh resolution within the Harbour.

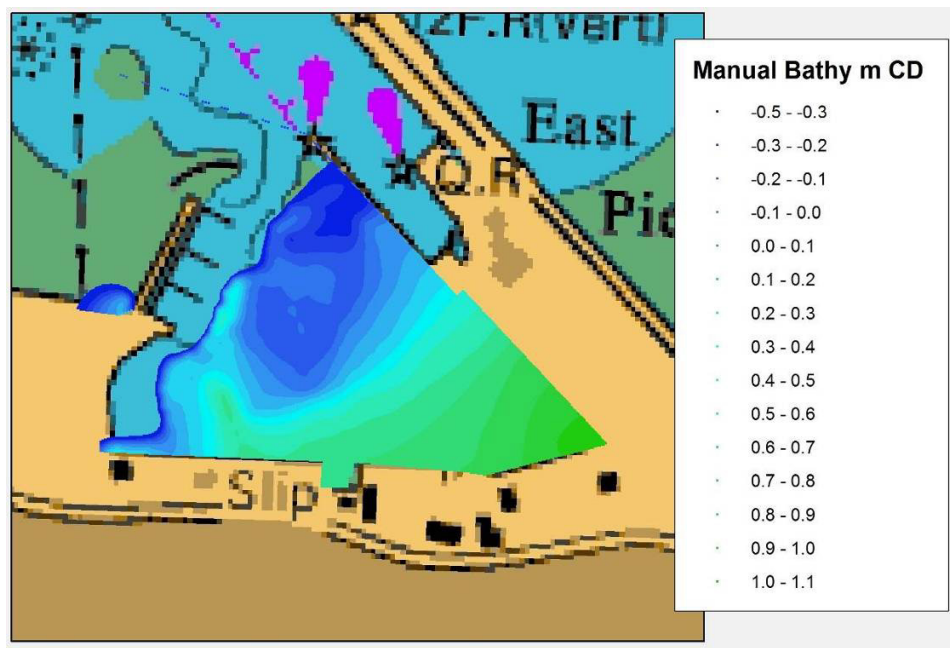


Figure 7-12: : Smoothed bathymetry within Stranraer Harbour

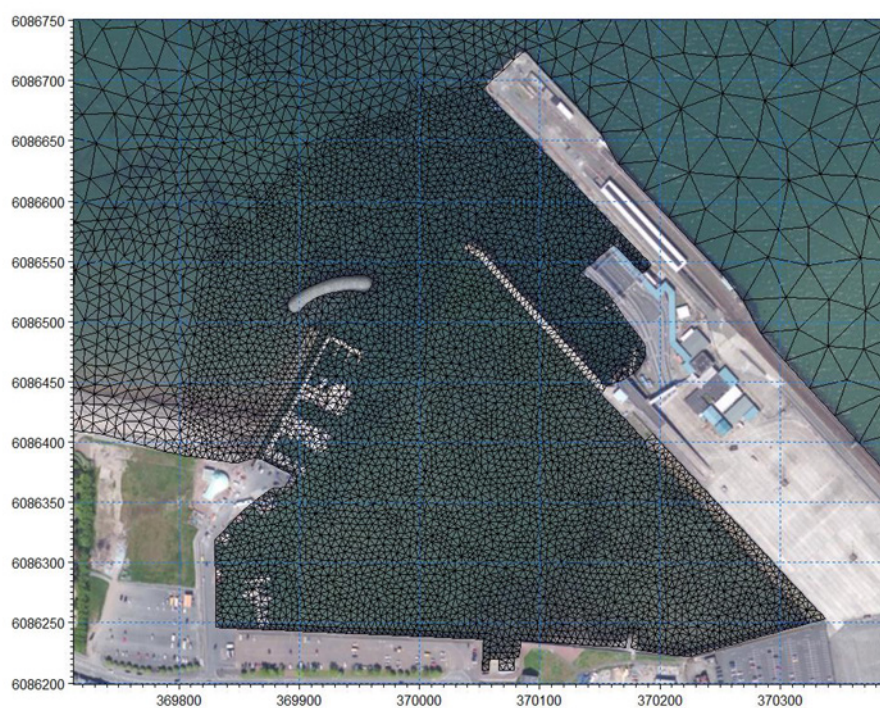


Figure 7-13: Fine harbour mesh to allow complex flow & transport modelling

7.36 The flexible mesh has the advantage of being able to resolve detail in areas where it is required whilst allowing larger cells in other areas to provide computational efficiency. In addition to the refined bathymetry within the Harbour, the flexible mesh was used to ensure that the flow mechanisms within the Loch as a whole were correctly represented. This involved providing

greater refinement within the mesh to incorporate the details of the bathymetry and flow channels. The model was verified using the available water level and tidal current data. A combination of published tidal harmonics and tidal streams from Admiralty Chart 2724 were used in the calibration process. The locations employed are shown on **Figure 7-14**.



*Figure 7-14: Location of model calibration data*

7.37 The model setup and approach were agreed with SEPA prior to undertaking the Stranraer Gasworks Remediation dispersion study. Therefore it was deemed suitable for use in the development of the tidal ellipse for the Stranraer Marina Extension.

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## Model Development and Calibration

- 7.38 RPS used the MIKE 21 hydrodynamic numerical modelling software package developed by the Danish Hydraulic Institute (DHI), to address potential coastal processes impacts / issues. This was undertaking a numerical modelling study to quantify the baseline conditions and then the conditions post-development.
- 7.39 These models were used in conjunction with site specific hydrographic survey and sediment data to assess the potential construction and operational impacts of the proposed development in the context of the following coastal processes:
- The tidal regime.
  - The inshore wave climate.
  - Sediment dynamics under both calm (pure tides) and meteorological conditions.
  - The dispersion of and settlement dredged material.

## Coastal Process Modelling Software

- 7.40 A suite of coastal process models, based on the MIKE software developed by DHI, was used to establish the coastal processes within Stranraer Harbour, along the adjacent shoreline and in the south of Loch Ryan. The MIKE software is an industry-standard modelling system, utilising a flexible mesh approach and is approved by numerous statutory bodies including SEPA. This software was specifically developed for applications within oceanographic, coastal and estuarine environments.
- 7.41 A brief synopsis of the MIKE system, and specific modules used for this assessment, is outlined below:
- **MIKE 21 FM system** - Using these flexible mesh modelling systems, it is possible to simulate the mutual interaction between currents, waves and sediment transport by dynamically coupling the relevant modules.
  - **The Hydrodynamic module** - This module simulates water level variations and flows in response to various forcing functions in lakes, estuaries and coastal regions. The Hydrodynamic (HD) Module is a fundamental computational component of the systems, providing the hydrodynamic basis for the Sediment Transport module. The Hydrodynamic module solves the two dimensional incompressible Reynolds averaged Navier-Stokes equations, subject to the assumptions of Boussinesq and hydrostatic pressure.
  - **The Spectral Wave module** - This module simulates the growth, decay and transformation of wind-generated waves and swell in offshore and coastal areas and accounts for key physical phenomena including wave growth by wave action, dissipation, refraction, shoaling and wave-current interaction where appropriate.
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- **The Sediment Transport module** - The Sediment Transport Module simulates the erosion, transport, settling and deposition of non-cohesive sediment in marine and estuarine environments and includes key physical processes such as forcing by waves. The module can be used to assess the impact of marine developments on erosion and sedimentation patterns by including common structures such as jetties, piles or dikes. Related transport modules enable point sources to be introduced to represent localised increases in current flows with associated sediment loading as a result of various coastal activities such as re-nourishment or dredging operations.

### *Modelling Methodology*

- 7.42 The modelling study undertaken utilised the full scope of the MIKE integrated modelling system, whereby a single base model was used to determine both baseline and post-construction coastal processes, i.e. tidal flow, wave climate and sediment transport regimes.
- 7.43 The coastal processes model domain extended to cover Loch Ryan and the Stranraer shoreline as illustrated in **Figure 7.15**. The triangular element mesh varied in resolution throughout the domain in order to represent the bathymetry with the detail required to simulate variation in tidal flow and wave climate across the domain. The mesh was also tailored to enable the same arrangement of cells to be implemented for the post-construction scenario and for use in dispersion modelling.

### *Model Calibration*

- 7.44 The hydrodynamic model was calibrated for a range of tidal conditions using SEPA tide gauge data, tidal harmonics published in the Admiralty Tide Tables<sup>1</sup> and tidal streams published on Admiralty chart 1404, as illustrated in **Figure 7.15**. The range of conditions included spring and neap tides in addition to a range of meteorological conditions to ensure the model simulated the full range of tidal flow experienced within Loch Ryan. Although it is noted that for the purposes of a comparative study the required tolerance between modelled and measured data is less arduous than that which may be required for the purposes of design.

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<sup>1</sup> The United Kingdom Hydrographic Office (UKHO) Volume 1 of the 2025 Admiralty Tide Tables for United Kingdom and Ireland.

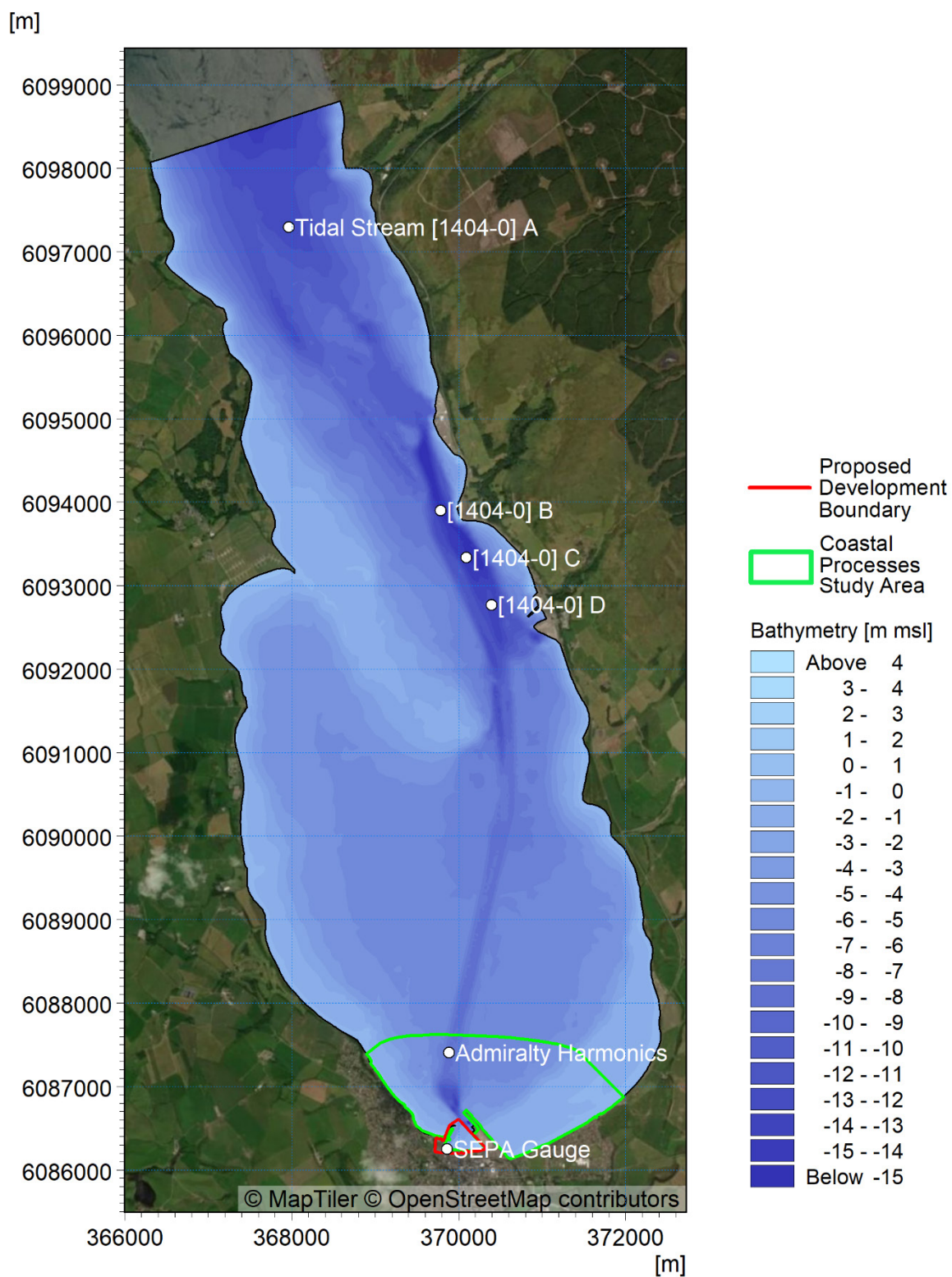
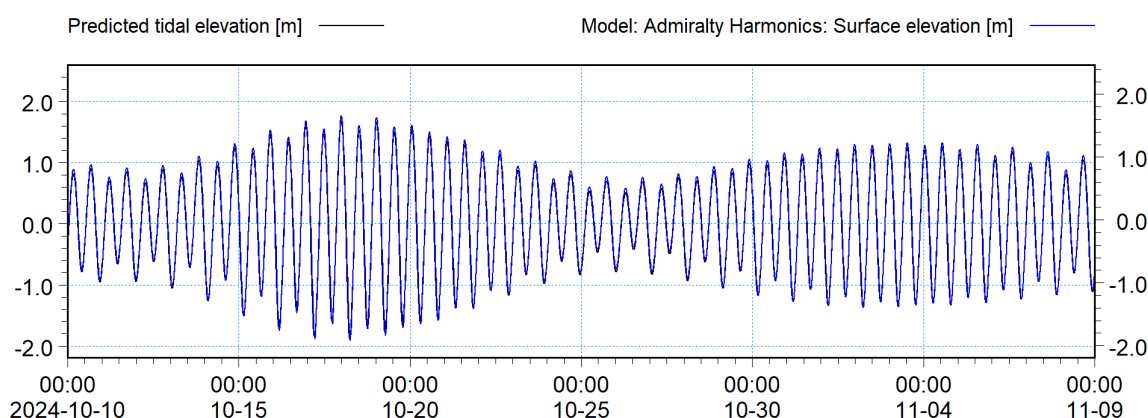


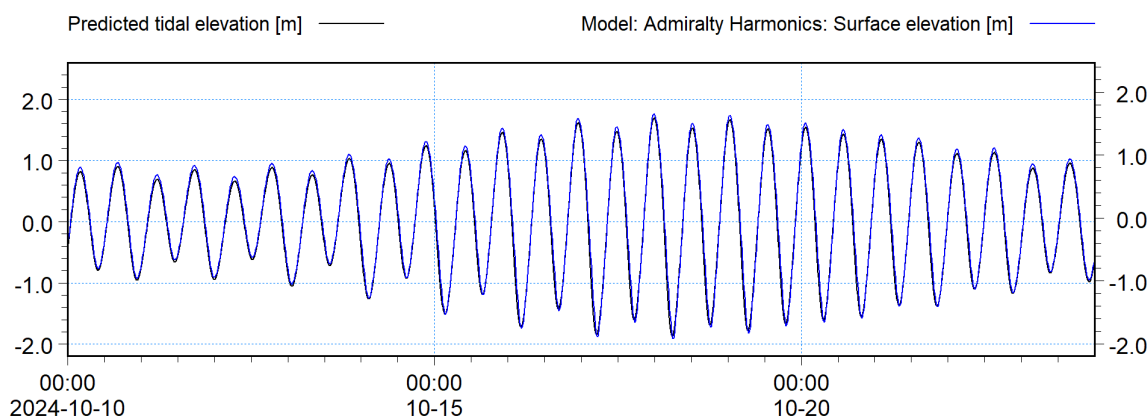
Figure 7.15: Model Domain and Location of Tidal Data used in Model Calibration

### Pure Tides - Tidal Elevation and Admiralty Harmonic Data

7.45 **Figure 7.16** shows the comparison between the surface elevation derived from the Admiralty tidal harmonic constituents for Stranraer (black trace) over a period of one month and the modelled surface elevation (blue trace) at the equivalent location. This presents the range of tidal elevations experienced at this location within the Loch. For further clarity, the single spring-neap cycle is shown in **Figure 7.17**. This indicates that the model simulates the periodic nature of the tides, and the tidal range is well represented within the model, particularly in the vicinity of Stranraer Harbour.



**Figure 7.16: Modelled and Admiralty Predicted Tidal Levels – one month**



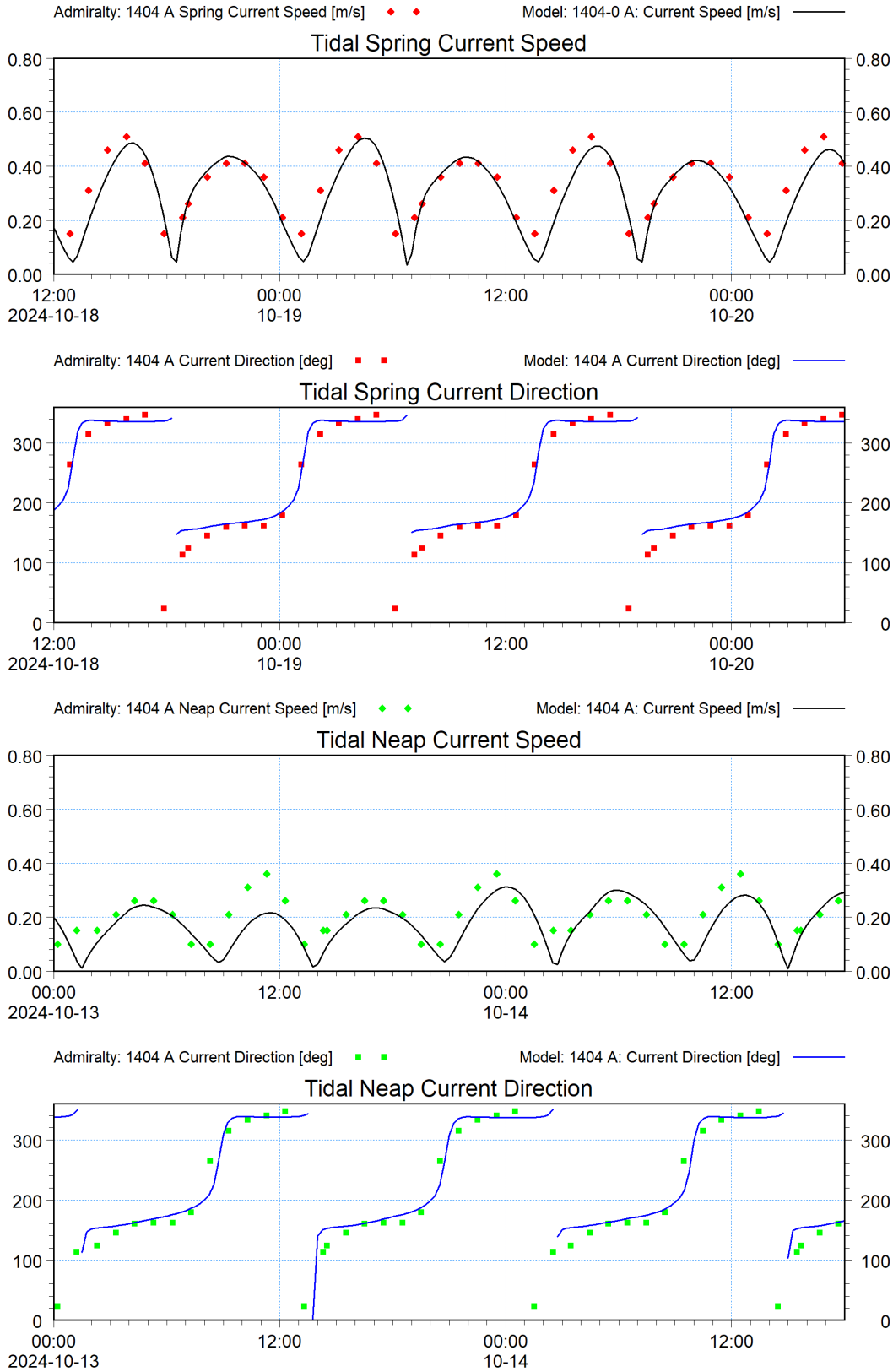
**Figure 7.17: Modelled and Admiralty predicted tidal levels for neap – spring cycle**

### Pure Tides - Tidal Currents and Tidal Stream Data

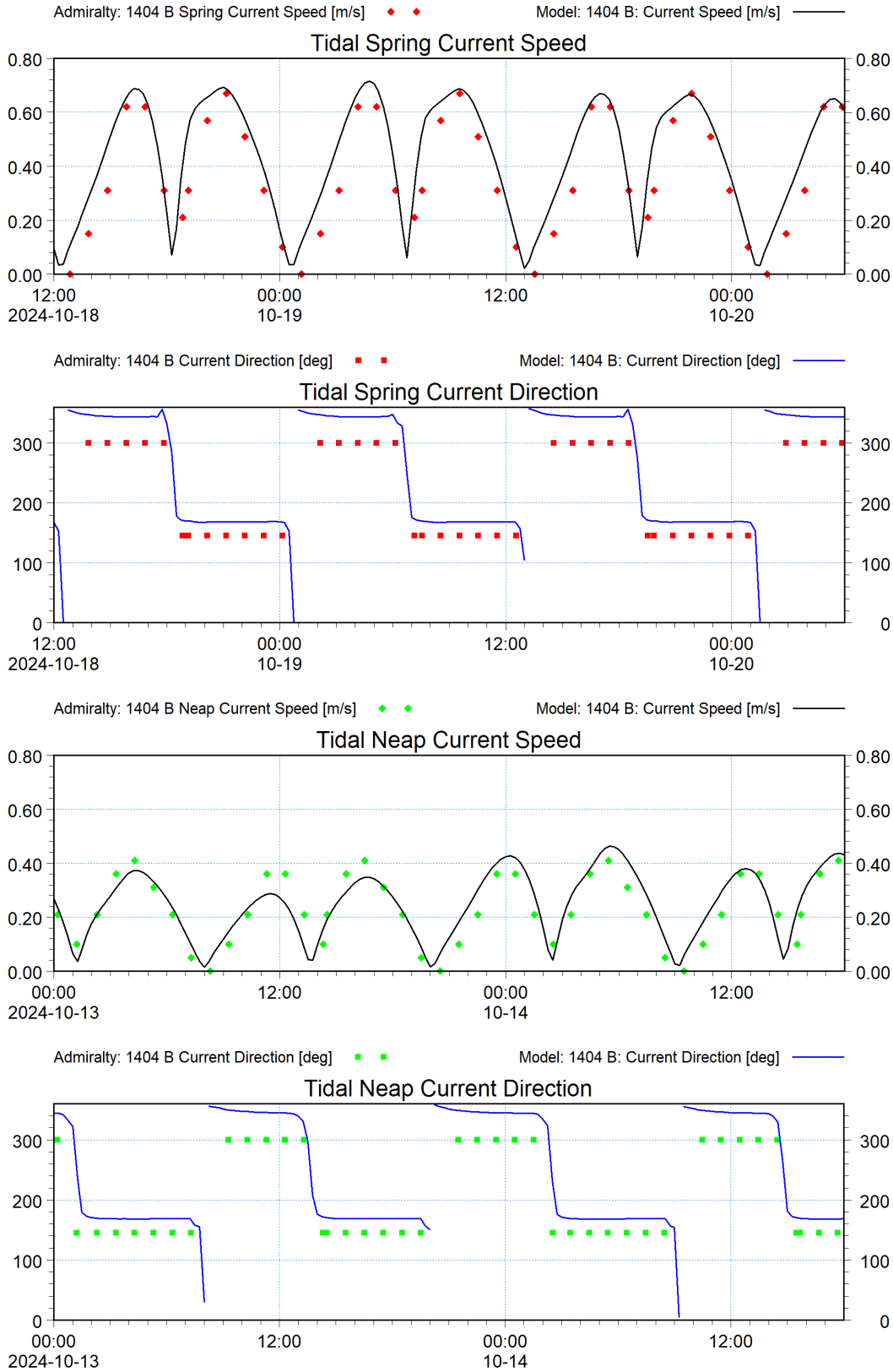
7.46 Tidal stream data is presented on Admiralty charts for the purpose of navigation. It is provided to give mariners an indication of the tidal regime to aid safe passage. The streams provide representative values for each of the locations, derived from historical data which may have been collected over a range of periods (single tides to months or years of data), utilising a range

of monitoring devices. It should be noted that current speed for a single tidal cycle is published for each tidal state (spring and neap) within the tidal stream data, whereas the surface elevation exhibits a range of tidal amplitudes. Therefore, in reality, there will be a range of tidal currents experienced between these values and the tidal stream data can be viewed as indicative. The tidal stream data also provides a single tidal cycle for current direction, which is deemed to be representative for all tidal states; both spring and neap.

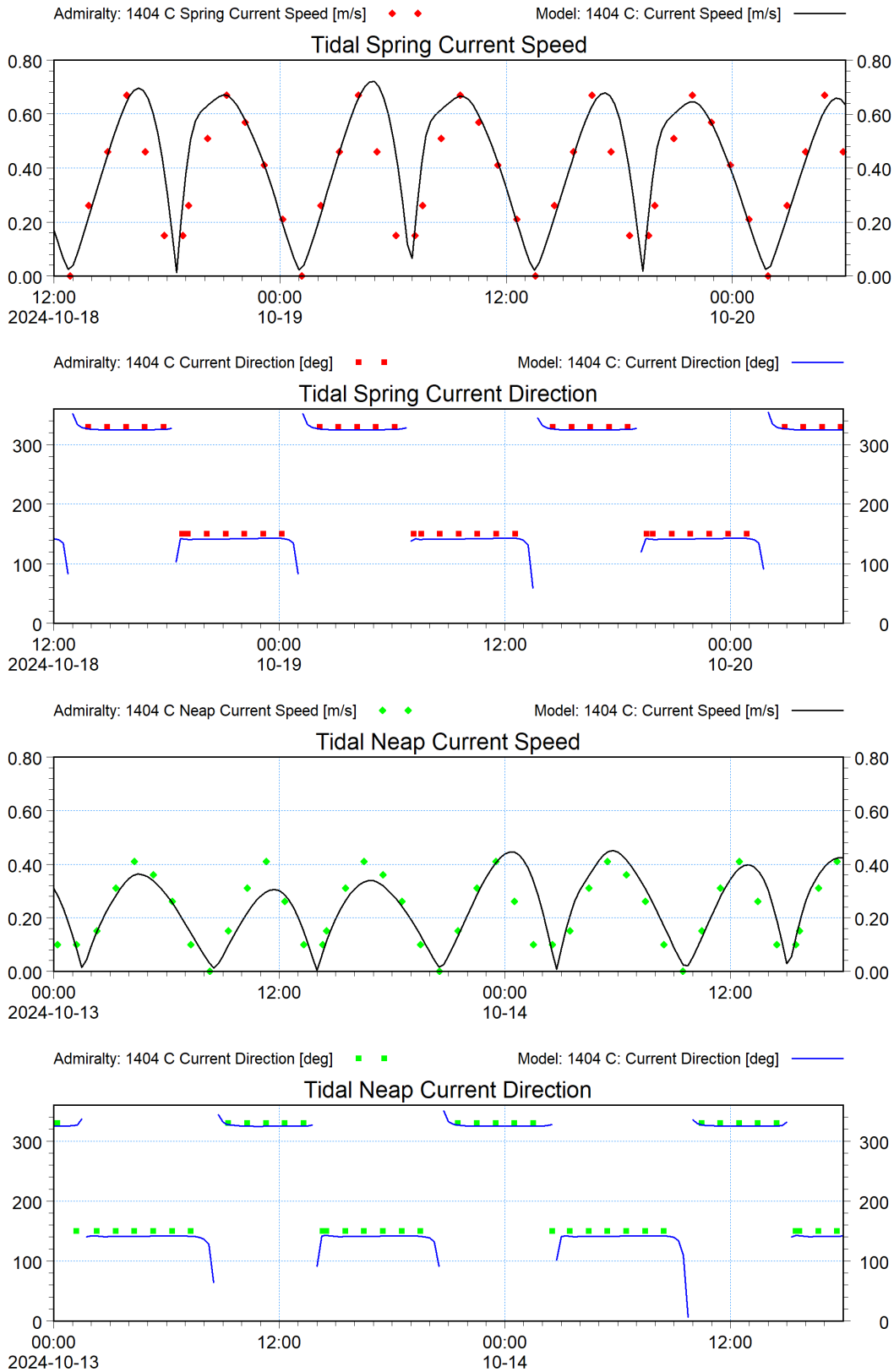
- 7.47 It is also recognised that tidal stream data presented on a single chart was not necessarily derived from field data collected for the same period and may have been influenced by different meteorological conditions or bathymetric changes (such as dredging activity). Notwithstanding this, Admiralty tidal streams do provide a reliable indication of the tidal regime and have previously been used to verify numerical models. They are particularly useful for validation of boundary conditions and for verifying that flow patterns are established accurately in the wider domain.
- 7.48 **Figure 7.18 to Figure 7.21** show the comparison between the tidal stream data (shown as hourly point data) and the model data at the equivalent location (continuous trace). In each figure, four plots are presented. The top pair relate to spring tides and the lower pair to neap tides. Within each pair the upper plot presents current speed, whilst the lower plot shows current direction. In each case the tidal stream data, which is published for a period of 12 hours relative to high water at Greenock, is repeated within the figure and compared with model data from the same location for periods associated with spring and neap tides. As previously noted, the tidal stream current directions have the same values for both spring and neap tides.
- 7.49 **Figure 7.18** shows the data for the location closest to the model boundary and indicates that the model boundary provides a good representation of flow conditions across the range of tidal conditions. The series of locations adjacent to one another in the vicinity of Cairnryan, B, C and D, are shown in **Figure 7.19**, **Figure 7.20** and **Figure 7.21** respectively. At location B there is good correlation between current speeds for both spring and neap tides, but it is noted that the current directions are aligned more to a north-south orientation in the model at this location. However it is seen that when sites C and D, which are also aligned along the deeper channel at the approaches to the Port, are also considered, the current directions are in agreement. Additionally, current speeds show good correlation at all these locations for both spring and neap tidal conditions.
- 7.50 In conclusion, the plots indicate that over a range of tidal conditions and locations, the model shows a good correlation to the tidal stream data.
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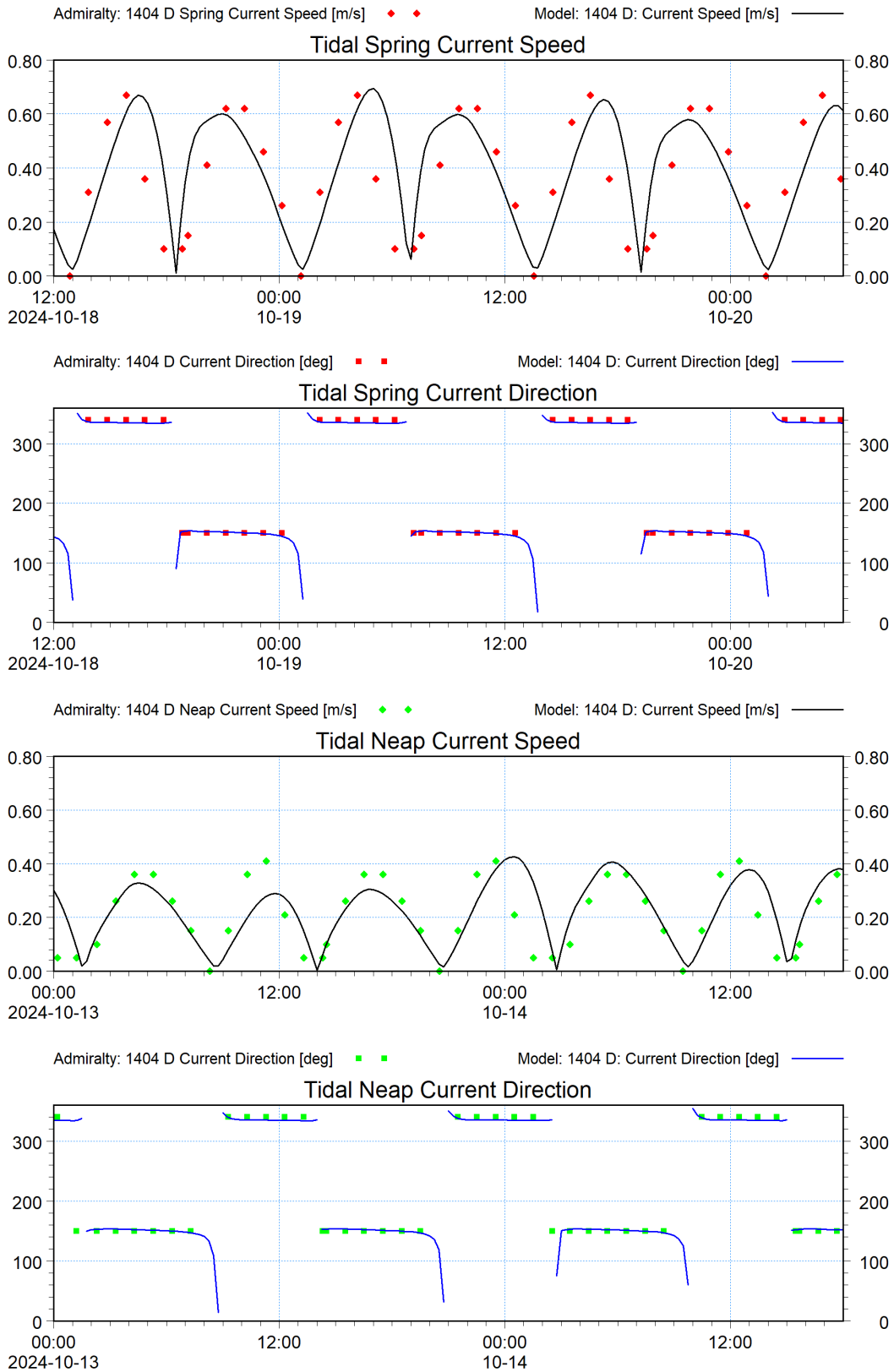
**Figure 7.18: Admiralty and simulated current speeds and directions for springs and neaps at Tidal Stream A (Chart 1404)**



**Figure 7.19: Admiralty and simulated current speeds and directions for springs and neaps at Tidal Stream B (Chart 1404)**



**Figure 7.20: Admiralty and simulated current speeds and directions for springs and neaps at Tidal Stream C (Chart 1404)**



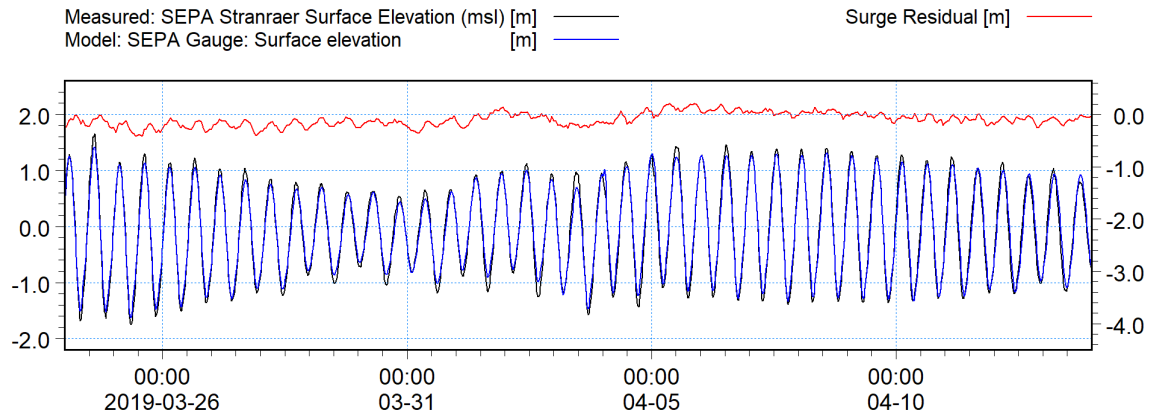
**Figure 7.21: Admiralty and simulated current speeds and directions for springs and neaps at Tidal Stream D (Chart 1404)**

## Meteorological Conditions - Tidal Elevation and SEPA Gauge Data

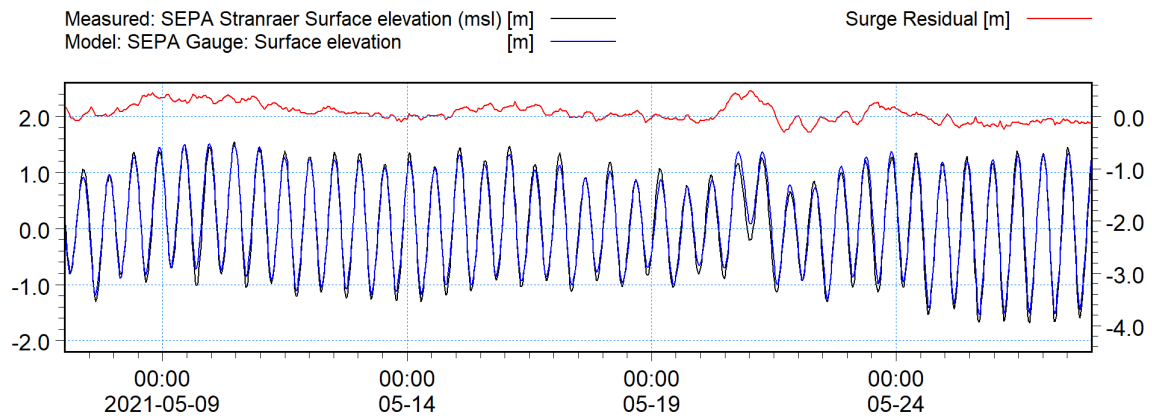
- 7.51 In order to provide further confidence in the model, particularly in the vicinity of Stranraer, further calibration was undertaken using SEPA tide gauge<sup>2</sup> data. Two periods were selected; one for a relatively calm period which was designed to evaluate the application of boundary conditions for the Loch Ryan model from a larger regional model. A second period was selected when surges were present in the Loch and recorded on the gauge.
- 7.52 For these scenarios the model was used to simulate a combination of both tidal and meteorological conditions (even for the calm period) and the pressure and wind field was applied using data from the European Centre for Medium-Range Weather Forecasts (ECMWF) operational model. This is an industry standard dataset which is used by many organisations to force regional models, including the “Atlantic- European North West Shelf - Ocean Physics Analysis and Forecast” model as developed by the UK Met Office. Although the ECMWF data may not be of fine enough resolution to recreate the nuances of wind funnelling within the Loch it was adequate to demonstrate the correct model response.
- 7.53 **Figure 7.22** and **Figure 7.23** show the measured and modelled output for the calm and unsettled periods respectively. In each plot the measured level is shown by the black trace and the modelled values by the blue trace. Also shown on the right axis, in red, is the surge residual. This is the arithmetic difference between the recorded levels and the underlying tidal harmonics, i.e. the pure tide level. It is noted that even under relatively stable pressure conditions the tidal levels can be influenced, and minor fluctuations are seen. In both figures the water level trends are recreated in the model data. This is particularly evident in **Figure 7.23** around both the 19<sup>th</sup> and 21<sup>st</sup> May 2019. As anticipated the wind forcing may be slightly too coarse for precise recreation of specific events, but in the context of use in a comparative study the model responds correctly to meteorological forcing and would be regarded as ‘fit for purpose’.

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<sup>2</sup> <https://marine.gov.scot>



**Figure 7.22: Modelled and measured data during a relatively calm period**



**Figure 7.23: Modelled and measured data during an unsettled / storm period**

## Principal Modelling Studies Used to Inform Methodology

Model Study	Old House Point Stena Line	Cairnryan Linkspan (and Cairnryan Port Study – which did not proceed) Port of Cairnryan Ltd	Stranraer Marina Feasibility Dumfries & Galloway Council	Stranraer Gasworks Remediation Dumfries & Galloway Council	Current Study Stranraer Marina Expansion Dumfries & Galloway Council
<b>Location / Extent</b>	Site: Cairnryan Model: Extent of Loch Ryan	Site: Cairnryan Model: Extent of Loch Ryan	Site: Stranraer Model: Extent of Loch Ryan <i>Wave model (outer/boundary): Firth of Clyde and the North Channel</i>	Site: Stranraer Model: Extent of Loch Ryan	Site: Stranraer Model: Extent of Loch Ryan <i>Wave model (outer/boundary): Firth of Clyde and the North Channel</i>
<b>Modelling Scope</b>	Tides, waves, sediment transport, sediment dispersion	Tides, waves, sediment dispersion	Waves	Tides, WQ dispersion	Tides, waves, sediment transport, sediment dispersion

Table 7-1: Modelling Studies (3 part table)

Model Study	Old House Point Stena Line	Cairnryan Linkspan (and Cairnryan Port Study – which did not proceed) Port of Cairnryan Ltd	Stranraer Marina Feasibility Dumfries & Galloway Council	Stranraer Gasworks Remediation Dumfries & Galloway Council	<u>Current Study</u> Stranraer Marina Expansion Dumfries & Galloway Council
<p><b>Datasets</b></p>	<p><i>Bathymetry:</i> Admiralty C-Map  <i>Boundary data:</i> RPS' tidal model of the Irish Sea, North Channel and Clyde area  <i>Atmospheric data:</i> UK Met Office's UK / Western European waters wave model  <i>Sediment:</i> Acoustic Benthic Survey of Loch Ryan QUB / DARD</p>	<p><i>Bathymetry:</i> Admiralty C-Map  <i>Boundary data:</i> RPS' tidal model of the Irish Sea, North Channel and Clyde area.  <i>Atmospheric data:</i> UK Met Office's UK / Western European waters wave model  <i>Sediment:</i> Acoustic Benthic Survey of Loch Ryan QUB / DARD</p>	<p><i>Bathymetry:</i> Detailed hydrographic surveys North Channel and Firth of Clyde UKHO/INSPIRE, various detailed hydrographic surveys around Loch Ryan and surveys at Stranraer undertaken on behalf of Dumfries and Galloway Council, Admiralty C-Map  <i>Boundary data:</i> Outer Wave model  <i>Atmospheric data:</i> ECMWF from extreme winds developed by the UK Met Office for BS EN 1991:2005</p>	<p><i>Bathymetry:</i> Detailed hydrographic surveys North Channel and Firth of Clyde UKHO/INSPIRE, various detailed hydrographic surveys around Loch Ryan and surveys at Stranraer, Bing &amp; Google maps observed harbour drying  <i>Boundary data:</i> RPS' tidal model of the Irish Sea, North Channel and Clyde area, Groundwater Risk Assessment for Former Stranraer Gasworks</p>	<p><i>Bathymetry:</i> Project specific surveys undertaken by Six West of Stranraer harbour and approaches (2023), Surveys relating to other projects undertaken in the vicinity e.g. to the east of the harbour (2013), Detailed Lidar along the Stranraer coastline sourced from Scottish Remote Sensing Portal (2011-2012), UK Hydrographic Office (UKHO) Bathymetric survey data – Medin (1998, 1999), Admiralty chart data (various via C-Map)  <i>Boundary data:</i> RPS's northern section of the Irish Sea and southern Inner Hebrides, harmonic analysis data (also compared with Marine Scotland's Scottish Shelf Model), Outer Wave model  <i>Atmospheric data:</i> ECMWF operational model, data derived during feasibility stage wave modelling ECMWF/UK Met Office  <i>Sediment data:</i> Project specific GI, British Geological survey, EMODnet, QUB/DARD survey</p>

Model Study	Old House Point Stena Line	Cairnryan Linkspan (and Cairnryan Port Study – which did not proceed)	Stranraer Marina Feasibility Dumfries & Galloway Council	Stranraer Gasworks Remediation Dumfries & Galloway Council	Current Study Stranraer Marina Expansion Dumfries & Galloway Council
<b>Field Measurements</b>	Admiralty harmonics Stranraer – 5 years 54°55'N 5°02'W  Turbidity monitoring at 3 locations during works used for verification	Tidal Harmonics from Cairnryan Port Guage – 5 years  Admiralty harmonics Stranraer – 5 years 54°55'N 5°02'W	N/A	Admiralty harmonics Stranraer – 5 years 54°55'N 5°02'W	SEPA tide gauge Stranraer 54°54.3'N 5°01.8'W  Admiralty harmonics Stranraer – 5 years 54°55'N 5°02'W
<b>Tidal Diamonds</b>	Chart 1404 (2724) A 55°00.30'N 5°03.87'W B 54°58.50'N 5°02.07'W C 54°58.20'N 5°01.77'W D 54°57.90'N 5°01.47'W	Chart 1404/2724 Diamond A, B, C & D	N/A	Chart 1404/2724 Diamond A, B, C & D	Chart 1404/2724 Diamond A, B, C & D
<b>Regulator / Consultee</b>	Consented, built and operational MS-LOT NatureScot SEPA	MS-LOT NatureScot SEPA	MS-LOT NatureScot SEPA	SEPA	MD/MS-LOT NatureScot SEPA
<b>Note</b>	Model also used for oil spill contingency planning. Turbidity monitoring was offered by developer & methodology agreed with regulators.		Local sailing knowledge & observation were used for model substantiation	Methodology agreed with SEPA prior to modelling	

## Stranraer Marina Expansion Dredging Plume Modelling

### Overview

- 7.54 This document presents the dredging plume modelling undertaken for the Stranraer Marina Expansion application and has been prepared to provide information to support the environmental assessments. This information is being circulated in the form of a technical note in advance of the production of the coastal processes technical appendix and chapter to allow these assessments to advance.
- 7.55 The modelling examines the Maximum Design Scenario (MDS) for sediment plume modelling for dredging operations. A realistic worst case is required to ensure any method which is proposed by the contractor at a later stage would be well within the envelope of effects and would have been assessed in terms of suspended sediment concentration (SSC).
- 7.56 The worst case for elevated SSC and deposition will be when dredging rates, and hence spill rates, are highest and/or where sediment can exit the harbour. A simplified approach was required to cover probable scenarios and determine likely plume excursion to identify zone of influence.
- 7.57 The important dredging parameters in terms of SSC relate to the rate of dredging, e.g. the cutter suction equipment capacity, and the hopper size which determines the operational cycle for offshore deposits at the disposal site. The specification was initially based on plant typically used for this size of project (Sospan Dau TSHD) it was subsequently noted that limited water depth, particularly at the commencement of dredging activities, would necessitate the use of a small cutter dredger. In this case the dredging plant is mounted on a barge and pipes are used to transport the dredged material to the hopper barges or to the reclamation area. There is no indication that this smaller plant would dredge any faster or use a hopper any bigger than specified. If anything, potentially the spill rate may be less, i.e. a reduction from worst case spill rate.
- 7.58 In terms of providing a realistic and flexible MDS, the modelling was based on the data initially specified, as this small cutter dredging method would fall within the envelope of effects. It also means that the assessments remain valid if an alternate contractor/supplier has a suitable plant of a size which is somewhere in between the two options or, having undertaken some of the dredging, it is determined that enough draft is available, and it may be beneficial (for operational or economic reasons), to switch to larger plant.
- 7.59 This technical note is comprised of the following sections:
- [Project Parameters](#)
  - [Modelling Methodology](#)
  - [Modelling Results](#)
-

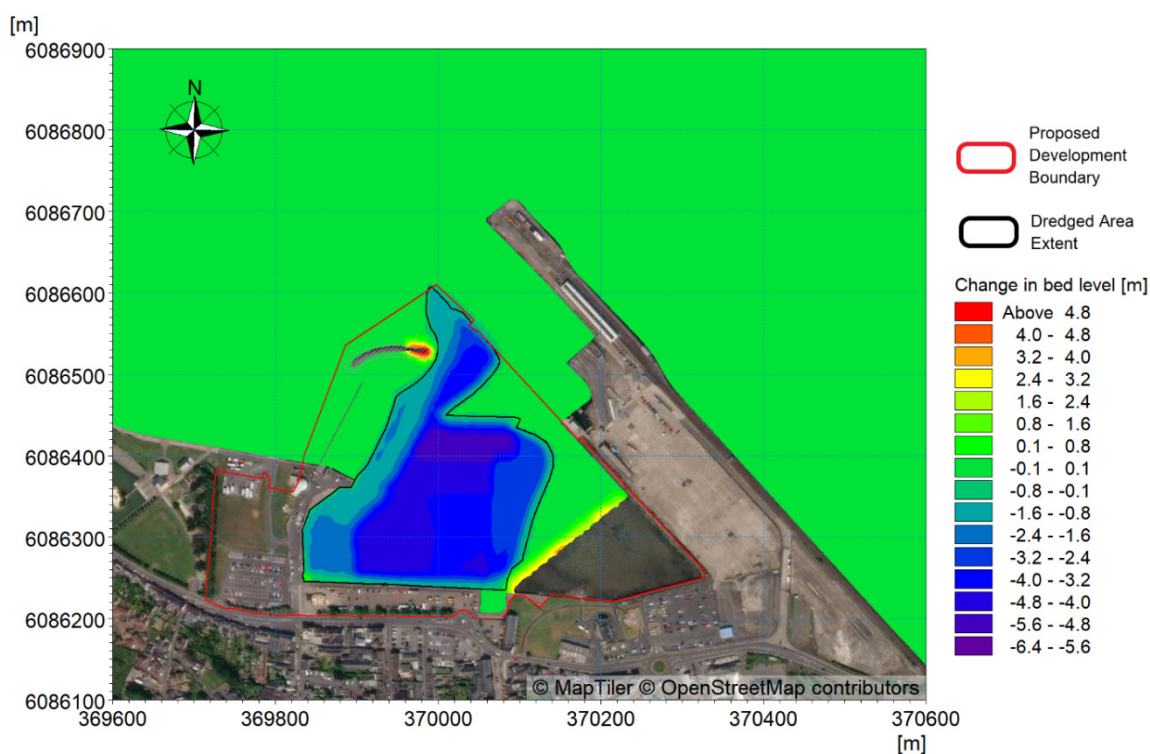
## Project Parameters

### Dredging Volumes

7.60 The project description details the following dredging parameters:

- Total dredging volume 132,891 m<sup>3</sup>
- Use in reclamation 52,203 m<sup>3</sup>
- Disposal at Beaufort's Dyke 80,688 m<sup>3</sup>

7.61 The change in seabed level due to the proposed development and dredging activities is shown in **Figure 7-24** and indicates the proportion of the dredging programme and areas in which dredging activities will take place.



**Figure 7-24: Change in bed level due to the proposed development**

### Construction Information

7.62 The project description provides the following information on construction activity:

- Seawall and revetment will be in place prior to dredging
- Breakwater extension will be built part way through dredging programme
- Site working 12h / day (Mon – Fri, half day Sat)
- Programme - Dredging, Breakwater and East Car Park Revetment and Reclamation indicative duration 190 days

### *General Assumptions*

- 7.63 The following general assumptions were made for the dredging plume modelling based on the project description, site conditions and proposed operations:
- Most dredging methods result in spill rate less than 5% - therefore this spill rate was applied for conservativeness and flexibility
  - Dredging for sea disposal undertaken with marine plant of limited draft due to initial restricted depth
  - Primarily capital dredging - therefore use of the greatest dredging rates associated with large plant, soft sediments and maintenance dredging would be unrealistic
  - Sea disposal anticipated to be undertaken in earlier phases due to
    - better access (before breakwater extension)
    - removal surface layers/silt to potentially expose material better suited to reclamation
    - avoiding the 'less clean' material being used in reclamation (no issues with contaminants)

### *Modelling Methodology*

- 7.64 As previously noted, the modelling methodology was designed to implement a simplified approach to cover probable scenarios and determine likely the plume excursion to identify the zone of influence. It was also designed to apply a MDS which allowed for potential variations in plant and programme in order not to constrain the project in the later detailed planning stage.

### *Modelling Approach*

#### *Overview*

- 7.65 The modelling examined two scenarios designed to encompass the proposed dredging activities, i.e. dredging for disposal offshore and reclamation. The worst case for elevated SSC occurs when dredging rates, and hence spill rates, are highest and when dredging programmes are most condensed; whereby material has more limited opportunity for settlement and amalgamation into the underlying sediment transport regimes. For this reason, the modelling assumed 7 day working, with a 12 hour day. Although it is unlikely that Sunday working would be undertaken, as it requires special permitting, should there be an operational reason, such as a weather window or to enable completion of a phase in time for a specific event, then this is not precluded due to the EIA parameters.
- 7.66 The modelled spill included release of sediment across the dredging areas proportional to the depth of dredging undertaken, as illustrated in **Figure 7-24**. It is recognised that the source of sediment release traverses across this area more quickly in the model than may occur in field operations, particularly if a barge with spud legs is used. However, the model simulation has

been designed to ensure that material is released over the entire coverage of the area, at all stages of the tide, to ensure the full extent of the likely elevated SSC and plume excursion is captured.

- 7.67 The dredging operations are anticipated to be undertaken over a period of 190 days, i.e. *circa* 6 months, which takes account of a 5.5 day working week and contingency. The application of the MDS and condensed 7 day working reduces this considerably, *circa* 54 days for sea disposal and *circa* 52 days for reclamation (based on modelling parameters outlined in the following section). For computational efficiency the modelling was undertaken for half of each of these operations. The spill release over 26 days ensured that discharge occurred at all tidal states; ebb, flood and slack water and during spring, mean and neap tides. The suspended sediment plumes encompassed all phases; including neap tide where SSC may be increased but dispersion is more limited i.e. the plume extent is reduced in comparison to spring tides. The modelling simulated calm conditions, i.e. under pure tides without wind action, therefore in reality the plumes may extend further but would be more widely dispersed giving much smaller increases in SSC and lower levels of sedimentation.
- 7.68 The models also incorporate any material resuspended on subsequent tides and were extended for five days beyond the dredging period to examine the potential for re-suspension and assimilation of spilled material into the underlying sediment transport regime. The total sedimentation was therefore calculated by doubling the settled material at the end of each simulation and summation of the two scenarios. This provides a conservative value as, in reality, some of this material is incorporated into the baseline sediment transport regimes and, where material settles in the dredging area, it will be removed on subsequent dredger passes.

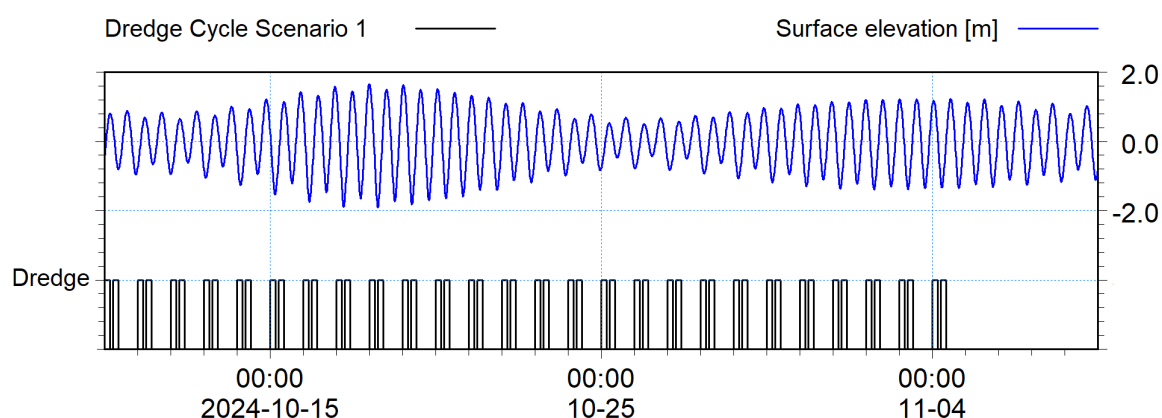
### **Modelling Scenarios**

- 7.69 Two scenarios were modelled; the first related to the offshore disposal of material associated with conditions at the start of the dredging programme and a second relating to reclamation of material associated with conditions at the latter part of the dredging programme. In each case the dredging parameters are specific to the operations and site conditions in each scenario. These are outlined in the following sections.

#### **Scenario 1 – Offshore Disposal**

- 7.70 Plumes representative of conditions at the start of the programme are associated with the following:
- Seawall and revetment in place
  - Existing (pre-dredge) bathymetry
  - Existing outer breakwater
  - Utilising deposition offshore
-

- 7.71 A typical hopper capacity is 1,500m<sup>3</sup> and takes circa 4 hours to fill and to allow for pumping of slurry it is assumed to have a water content of 50%. This gives rise to a dredging rate of 187.5m<sup>3</sup>/h with a 5% conservative spill being applied.
- 7.72 It is dependent on availability, but it is assumed for MDS that two hoppers are operational. A round trip to Beaufort's Dyke is approximately 6 hours (vessel speed circa 7.5 knots) therefore two cycles per day. The dredging cycle and tidal excursion during the Scenario 1 simulation period is presented in **Figure 7-25**.



**Figure 7-25: Dredging Cycle and Tidal Excursion during Scenario 1 Simulation Period**

- 7.73 The sediment characteristics were derived from Ground Investigations (GI) utilising analysis of borehole logs and vibro-core samples at a depth of 1 – 2m along with seabed samples sited within the dredging area. The typical characteristics were described by first defining intervals for which representative sediment grading was determined, this is outlined in **Table 7.2**.

**Table 7-2: Typical Sediment Grading Dredging Area (0 – 2 m)**

Sediment Type	Average Grain Diameter (D <sub>50</sub> ) mm	Proportion %
Coarse material / gravel	>2mm	4
Med / coarse sand	0.9	13
Coarse silt / fine sand	0.11	32
Fine/med silt	0.028	23
Very fine/fine silt	0.006	18
Clay	<0.004	10

7.74 It was noted that the very coarse material, such as gravel, will settle at the cutter head and be removed subsequently by further dredging. It was also seen from the core samples that the clay fraction is highly cohesive and during dredging any spilled material would be deposited as 'clumps' and behave much in the manner of the very coarse material. The material spilled within the model simulation was therefore comprised of the four remaining classifications. The 5% spill was defined as being comprised of very fine silt to coarse sand fractions, rather than excluding 14% of the volume to account for clay and gravel, therefore incorporating a further degree of conservatism, as outlined in **Table 7-3**.

**Table 7-3: Sediment Grading Utilised in Scenario 1 Modelling**

Sediment Type	Average Grain Diameter (D <sub>50</sub> ) mm	Proportion %
Med / coarse sand	0.9	15
Coarse silt / fine sand	0.11	37
Fine/med silt	0.028	27
Very fine/fine silt	0.006	21

7.75 The GI also indicated that cohesive marine and glacial sediments were present, therefore some of the finer silt fractions may behave similarly to clay and be deposited in clumps or flocculate and settle more quickly than non-cohesive silt particles when released. To provide a worst case scenario it was specified in the modelling that all sediment spilled was non-cohesive. The model simulations also accounted for resuspension of settled material should the critical shear stress be exceeded with increasing current speeds due to tidal flow. However, to simulate realistic behaviour, it was taken that the medium silt and sand (which constitute the greatest proportion of the sediment composition) provides some degree of armouring, trapping the fine silt when disposition occurs.

### Scenario 2 - Reclamation

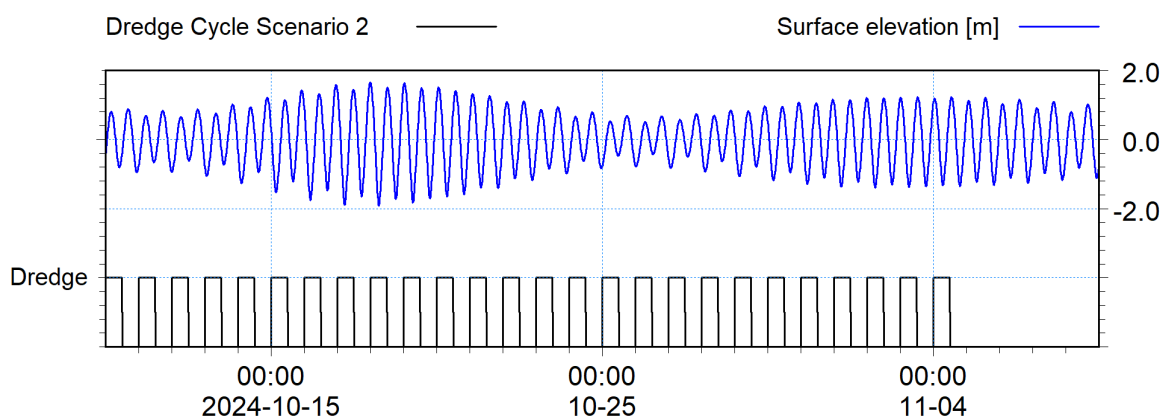
7.76 Plumes representative of conditions near end of the programme are associated with the following:

- Seawall and revetment in place
- Revised (dredged) bathymetry
- Extended outer breakwater
- Utilising onshore reclamation

7.77 In this scenario pumping is directly to the reclamation area. The onshore stabilisation / dewatering is undertaken by a specialist contractor and is limited to an upper bound of *circa* 1000m<sup>3</sup>/d to produce a firm Class 7 or Class 9 material for general fill purposes. In reality,

reclamation dredging may be more intermittent/slower depending on method to prepare sand for re-use as infill material therefore this daily rate provides the MDS.

7.78 It is assumed that dredging operation is continuous for the 12 hour working day and equates to a rate of 83.3m<sup>3</sup>/h, with a conservative spill of 5% applied. The dredging cycle and tidal excursion during the Scenario 2 simulation period is presented in **Figure 7-26**.



**Figure 7-26: Dredging Cycle and Tidal Excursion during Scenario 2 Simulation Period**

7.79 The sediment characteristics were derived from GI utilising analysis of borehole logs and vibrocore samples at 2 – 5m depth in line with the dredging requirements. The typical characteristics were described by first defining intervals for which representative sediment grading was determined, this is outlined in **Table 7.4**. As anticipated sediment comprised slightly coarser sediment than the shallower layers used for Scenario 1.

**Table 7.4: Typical Sediment Grading Dredging Area (2 – 5 m)**

Sediment Type	Average Grain Diameter (D <sub>50</sub> ) mm	Proportion %
Coarse material / gravel	>2mm	4
Med / coarse sand	0.9	18
Coarse silt / fine sand	0.11	48
Fine/med silt	0.028	14
Very fine/fine silt	0.006	9
Clay	<0.004	7

7.80 As noted previously the very coarse material, such as gravel, will settle at the cutter head and be removed subsequently by further dredging. It was also seen from the core samples that the

clay fraction is highly cohesive and during dredging any spilled material would be deposited as 'clumps' and behave much in the manner of the very coarse material. The material spilled within the model simulation was therefore comprised of the four remaining classifications. The 5% spill was defined as being comprised of very fine silt to coarse sand fractions, rather than excluding 11% of the volume to account for clay and gravel, therefore incorporating a further degree of conservatism, as outlined in **Table 7.5**.

**Table 7.5: Sediment Grading Utilised in Scenario 2 Modelling**

Sediment Type	Average Grain Diameter (D <sub>50</sub> ) mm	Proportion %
Med / coarse sand	0.9	20
Coarse silt / fine sand	0.11	54
Fine/med silt	0.028	16
Very fine/fine silt	0.006	10

7.81 The GI also indicated that cohesive marine and glacial sediments were present therefore some of the finer silt fractions may behave similarly to clay and be deposited in clumps or flocculate and settle more quickly than non-cohesive silt particles when released. As in Scenario 1, to provide a worst case scenario it was specified in the modelling that all sediment spilled was non-cohesive. The model simulations also accounted for resuspension of settled material should the critical shear stress be exceeded with increasing current speeds due to tidal flow. However, to simulate realistic behaviour, it was taken that the medium silt and sand (which constitute the greatest proportion of the sediment composition) provides some degree of armouring, trapping the fine silt when disposition occurs.

## Modelling Results

### Model Output

7.82 The modelling results presented in this document relate to SSC and sedimentation with modelling output presented in a number of forms, namely;

- Statistical plume/sedimentation envelopes
- 'Snapshots' indicating magnitude at moment in time during simulation
- Timeseries graphs

7.83 The purpose of the statistical plume/sedimentation envelopes is to convey the dispersion and fate of material which varies over a period of time on a single figure. The maximum plume and sedimentation envelopes show the maximum value that each parameter reaches at each cell

location in any time step during the entire course of each simulation. It is most important for the observer to appreciate that, whilst the resulting diagram is of use in showing the maximum values that can be reached at any point throughout the area covered and throughout the simulation, it does not represent a real situation in space or time because there is little likelihood, particularly in the case of SSC, of the maximum values recorded occurring simultaneously. Additionally, whilst the time for which the maximum value persists in any given mesh cell will vary and, overall, the percentage frequency of occurrence will be reduced due to tidal oscillation.

- 7.84 Similarly, the average concentration is generated by averaging all the values recorded in all time steps in each cell over the course of the period in question. Once again, the resulting diagram is not related to a given point in time, but it is useful when used in conjunction with the maximum plume envelope for gauging the 'typical' values in any area and to indicate how often the maximum values occur. For example, a high concentration may be recorded at one location and presented on the maximum envelope, but when the average plot is interrogated, the value is much lower at this location. This indicates that the maximum value obtained was only experienced for a short period of time. The average values were also calculated for the period of the dredging operations, rather than the entire simulation, to provide a conservative value rather than including the period after the cessation of dredging activities when no further sediment is being released.
- 7.85 A consistent colour palette and associated scale has been applied across all the figures illustrating SSC, and similarly for sedimentation a single pallet has been applied, to enable results to be visually compared. It should be noted that all plotted figures utilise a log scale to cover the range of values whilst also providing clarity for smaller magnitudes. The range of values which are presented also extend much lower than would be discernible from natural variation in background levels and are designed to relate to the coastal processes study area.
- 7.86 Timeseries graphs are provided for ten locations across the plume extent and sedimentation footprint, as illustrated in **Figure 4-9**. For consistency the same locations have been reported for both scenarios, i.e. **Figure 4-27** shows the same information. Each of the timeseries figures indicate the SSC in the upper graph and sedimentation in the lower graph. The graphs show the full duration of the simulation, i.e. including the post dredging period, therefore also indicating any prolonged suspension of fine silt or resuspension of settled material following cessation of dredging activities. The right axes show the variation in tidal level during the course of the simulations. It should be noted that the plotting scales on the left axes were adjusted to suit the magnitude of the parameter presented. The smallest plotting range for SSC was 0 – 30mg/l and for sedimentation 0 – 0.3mm, as values typically less than 1mg/l and 0.01mm respectively (being the lowest marker on the axis) would be indiscernible from the natural background variation.

7.87 To aid in navigation **Table 7.6** provides an overview of the results presented in this document with the associated links.

**Table 7.6: Model Results Presented**

Parameter	Plot/Graph	Scenario 1 – Offshore Disposal		Scenario 2 - Reclamation		
<b>Overall Sedimentation</b>		<b>Figure 7-27</b>				
<b>Suspended Sediment Concentration</b>	Maximum Plume Envelope	Figure 7-28		Figure 7-46		
	Average Plume Envelope	Figure 7-29		Figure 7-47		
	Mid-Ebb Timestep	Figure 7-30		Figure 7-48		
	Mid-Flood Timestep	Figure 7-31		Figure 7-49		
<b>Sedimentation</b>	Maximum Envelope	Figure 7-32		Figure 7-50		
	Cessation of Dredging	Figure 7-33		Figure 7-51		
	One day following Cessation	Figure 7-34		Figure 7-52		
<b>SSC / Sedimentation Timeseries</b>	Time Series Location	Figure 7-35		<b>Figure 7-53</b>		
	Location A	Location B	Figure 7-36	Figure 7-37	Figure 7-54	Figure 7-55
	Location C	Location D	Figure 7-38	Figure 7-39	Figure 7-56	Figure 7-57
	Location E	Location F	Figure 7-40	Figure 7-41	Figure 7-58	Figure 7-59
	Location G	Location H	Figure 7-42	Figure 7-43	Figure 7-60	Figure 7-61
	Location I	Location J	Figure 7-44	Figure 7-45	Figure 7-62	Figure 7-63

**Observations**

7.88 The first model output presented in **Figure 7-27** relates to the total sediment depth due to the dredging operations. It was determined by summation of twice the sedimentation at the end of dredging period for the Scenario 1 and Scenario 2 simulations; each of which comprised half the dredging volume over a condensed work cycle. It is evident that the greatest sedimentation levels occur within the dredging area extent. Beyond the confines of the harbour levels are significantly lower. Within 200m of the harbour mouth sediment depths are below 5mm, and below 0.5mm at a distance of 400m. The sedimentation is characterised by lozenge shapes associated with tidal excursions. These are aligned slightly differently between the two scenarios due to the influence of the breakwater extension in Scenario 2. The modelling was undertaken during pure tide / calm conditions where spreading is limited; it is noted that wind induced dispersion would give rise to lower levels of sedimentation.

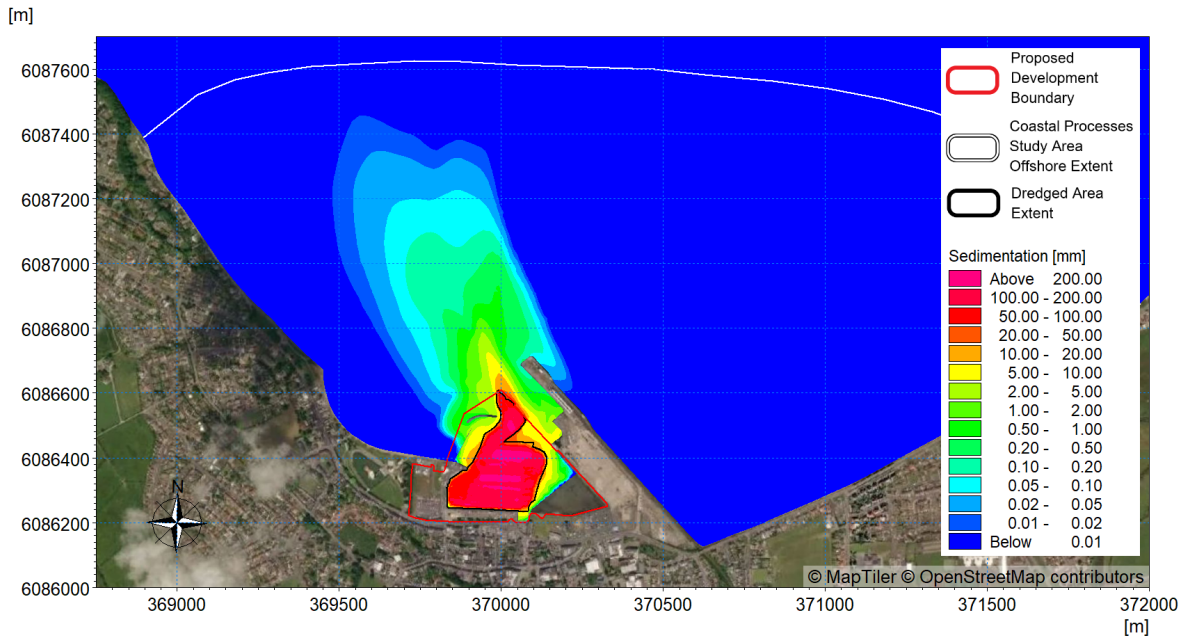
7.89 The wave climate is mainly governed by wind wave generation within the Loch and the winds in Loch Ryan will be influenced by topography; whereby the winds are funnelled from directions that are approximately aligned to the axis of the Loch. The application of meteorological

conditions in the model simulations may increase the extent of the sediment plume, but would also significantly reduce SSC and deposition levels. It is also observed that wind approaching from the northern sectors, with the potential to bring sedimentation onto the intertidal areas in the south of the Loch, would also simultaneously reduce the spill from within the harbour confines by opposing tidal flow. Winds from the southern sectors would act to enhance the tidal mixing and significantly reduce SSC with the Loch. Given the limited levels of sedimentation beyond the proposed area of development it was concluded that the use of the calm condition was appropriate for determination of SSC and sedimentation depths for application in the environmental assessment.

- 7.90 The maximum and average SSC plumes for Scenario 1 and Scenario 2 are presented in **Figure 7-28 & Figure 7-29** and **Figure 7-46 & Figure 7-47** respectively. As anticipated, the SSC levels within the dredging area are elevated – this is associated with the sediment source being located in very shallow water and this is shallower in Scenario 1 where the bathymetry is that prior to dredging. High concentrations are observed as the sediment settles through the water column. The finer fractions are subsequently dispersed into Loch Ryan on the ebb tide. The maximum values within the vicinity of the development are circa 500mg/l whilst average levels are typically one tenth of this value for Scenario 1. For Scenario 2, these values are somewhat lower, this is associated with the reduced rate of spill coupled with the increased depth due to the dredged bathymetry providing greater dilution at the sediment source.
- 7.91 The ‘snap-shots’ for ebb and flood tides are provided in **Figure 7-30 & Figure 7-31** and **Figure 7-48 & Figure 7-49** for the two scenarios respectively. The output from Scenario 1 was extracted from near the start of the dredging operation, whilst the Scenario 2 plots are taken from near the end of the dredging operation. In both cases they are associated with periods of sediment spill. These figures demonstrate instantaneous plumes are smaller than the plume envelope and SSC is generally associated with values below 200mg/l in close proximity to the dredging area and reduces swiftly to background levels with increased distance from the harbour mouth.
- 7.92 For each scenario, three outputs are provided relating the sedimentation levels. These are maximum sedimentation, sedimentation on cessation of dredging operations and one day following this. Scenario 1 is presented in **Figure 7-32, Figure 7-33** and **Figure 7-34** whilst Scenario 2 is presented in **Figure 7-50, Figure 7-51** and **Figure 7-52**. It is apparent in both sets of figures that there is a limited amount of variation between the three plots. Due to the low tidal currents which are present in the south of Loch Ryan much of the sediment remains in situ once settled. The finer sand fractions do undergo some redistribution and it is anticipated that subsequent spring tides and wind induced currents would further disperse sediment. It is noted that deposition levels are in the order of fraction of a millimetre offshore from the immediate vicinity of the dredging extent.

- 7.93 These observations are further supported when timeseries graphs are examined for locations within the sediment plume envelope and deposition footprint. Location B (Sc 1 - **Figure 7-37** and Sc 2 - **Figure 7-55**) and Location E (Sc 1 - **Figure 7-40** and Sc 2 - **Figure 7-58**) are positioned at the mouth of the harbour in alignment with the sediment plume axis. These locations experience SSC of the greatest magnitude circa 120mg/l for Scenario 1 and 250mg/l for Scenario 2. These values do not arise continuously and depend on both the tidal state and the location of the dredging spill source. They exhibit a stepped sediment accumulation in the order of 0.5mm to 1mm. Other locations, such as Location A, **Figure 7-36**, exhibit more gradual sediment accumulation albeit at lower levels, circa 0.1mm, associated with lower SSC circa 20mg/l for Scenario 1. Interestingly for Scenario 2, **Figure 7-54**, at this same position SSC is somewhat higher, with deposition 0.3mm at this location. This is related to local changes in tidal flow due to the presence of the breakwater extension.
- 7.94 Extraction locations located further north from the dredging extent illustrate how quickly SSC and deposition levels reduce with distance. At Location G, circa 400m north of the harbour mouth, both Scenario 1 (**Figure 7-42**) and Scenario 2 (**Figure 7-60**) show SSC significantly less 10mg/l with sedimentation of 0.05mm. At this location SSC does not return to zero on slack water during periods following spring tides indicating that some very fine silt fractions may remain suspended albeit at levels < 1mg/l. At these more distant locations from the dredging activity it can be seen that after the completion of dredging operations SSC are seen to increase with tidal phase, this is also visible in Location H and Location I for both scenarios, **Figure 7-43 & Figure 7-44** and **Figure 7-61 & Figure 7-62** respectively. This is due to a combination of spill material taking a number of tides to reach this site and also some limited resuspension associated with a slight increase in tidal current speed at this position. At Location J, SSC and deposition levels are very low and the plume SSC would not be discernible from background variations for Scenario 1, **Figure 7-45**, or Scenario 2, **Figure 7-63**.
-

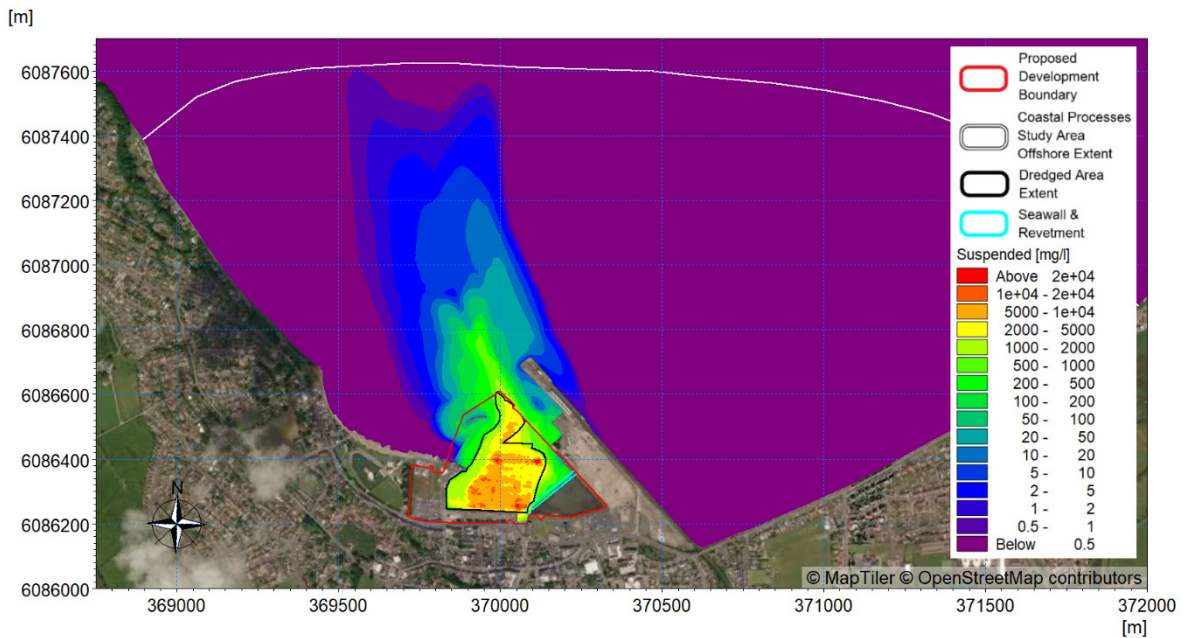
**Overall Sedimentation**



**Figure 7-27: Sedimentation Depth due to Dredging Operations**

**Scenario 1**

**Scenario 1 – Suspended Sediment Concentration**



**Figure 7-28: Scenario 1 - Maximum Plume Envelope of SSC during Dredging Simulation**

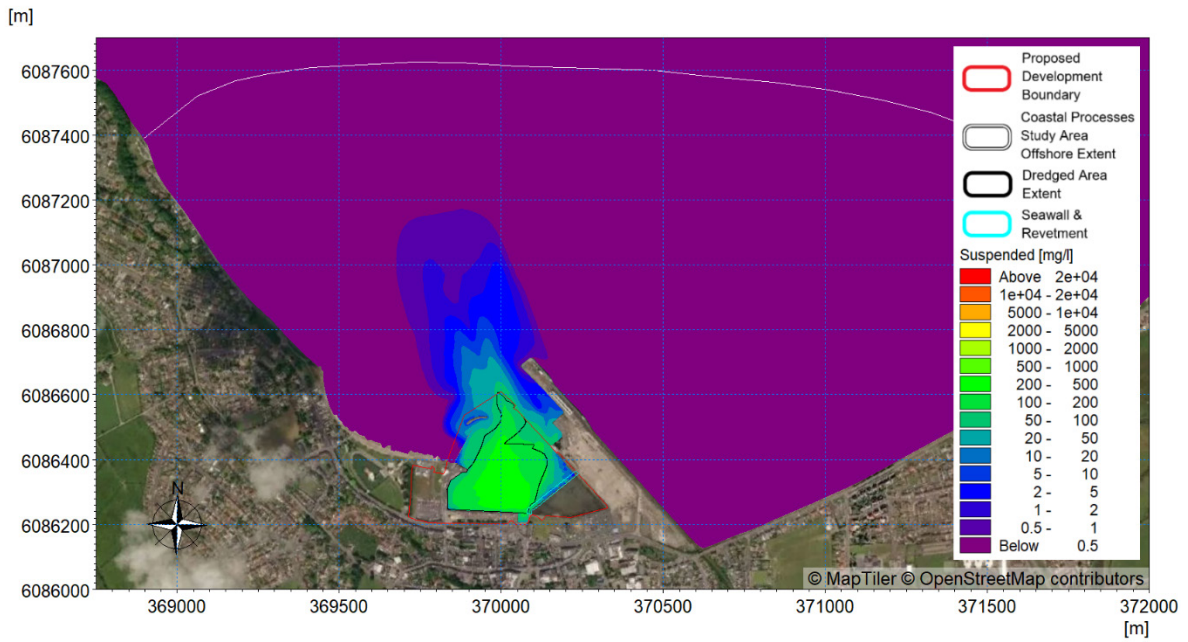


Figure 7-29: Scenario 1 - Average Plume Envelope of SSC during Dredging Operations

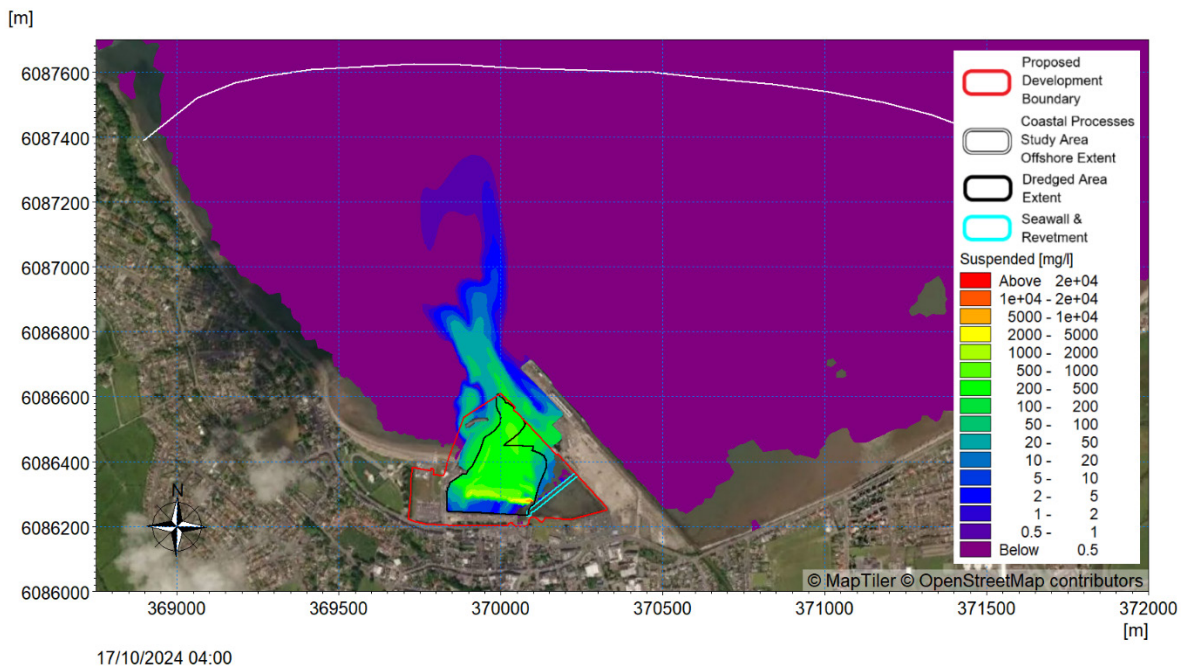
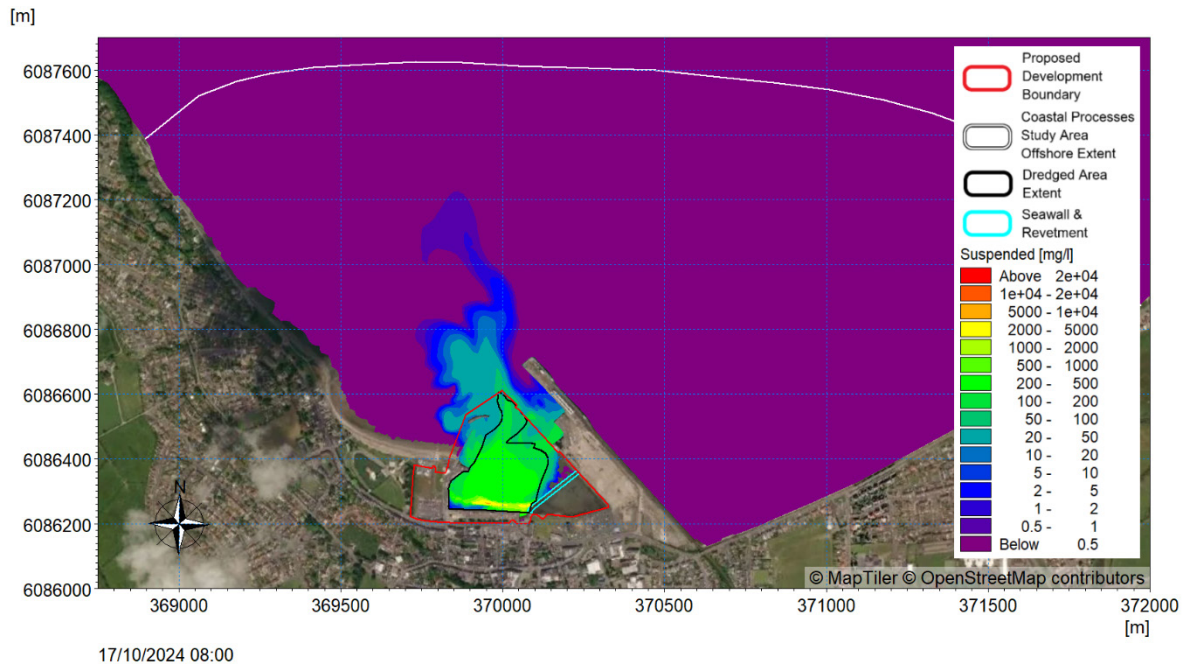
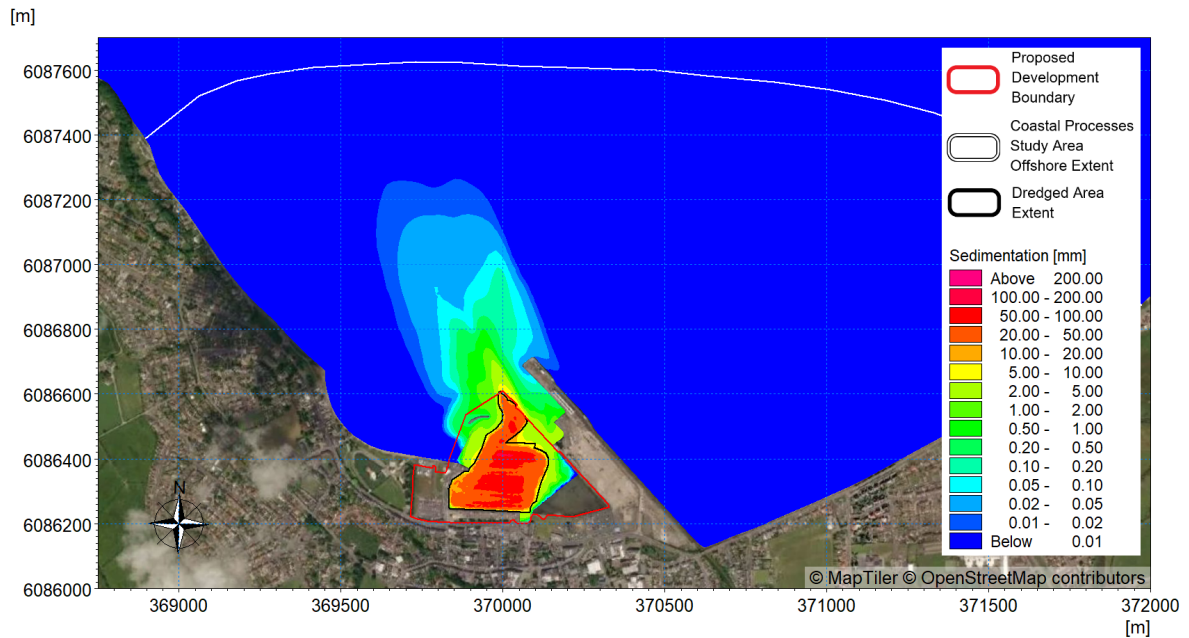


Figure 7-30 : Scenario 1 - Snapshot of SSC Mid-Ebb Tide One Week into Dredging Operations



**Figure 7-31: Scenario 1 - Snapshot of SSC Mid-Flood Tide One Week into Dredging Operations**

Scenario 1 – Sedimentation Characteristics



**Figure 7-32: Scenario 1 - Maximum Plume Envelope of Sedimentation during Dredging Simulation**

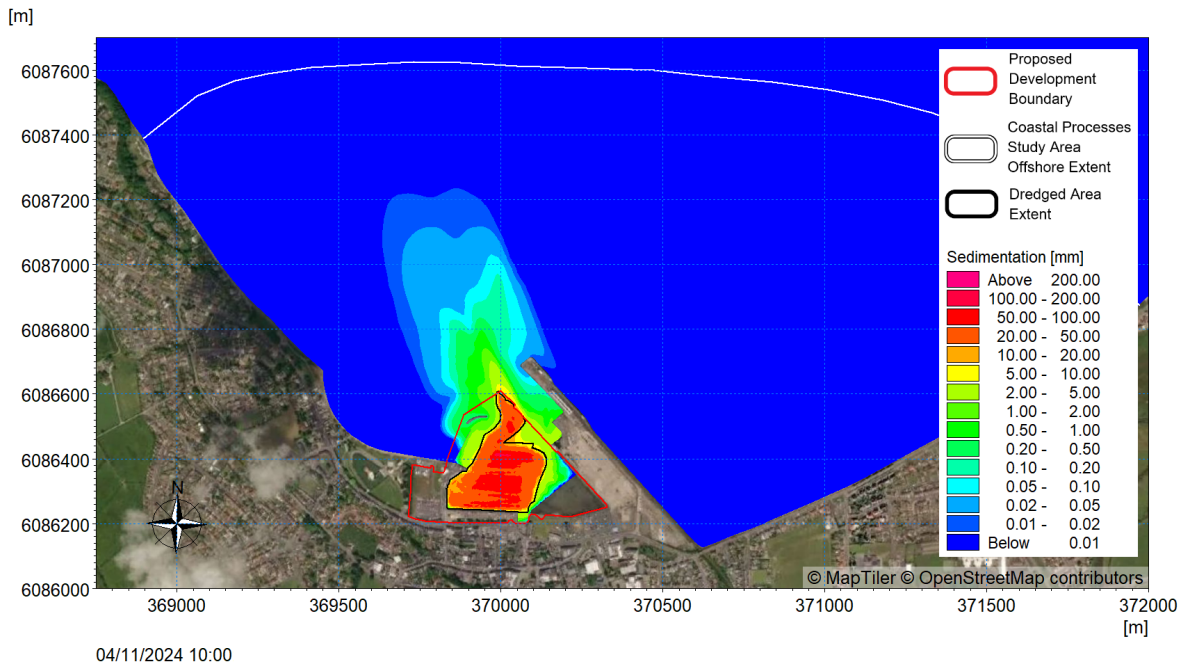


Figure 7-33: Scenario 1 - Sedimentation on Cessation of Dredging Operations

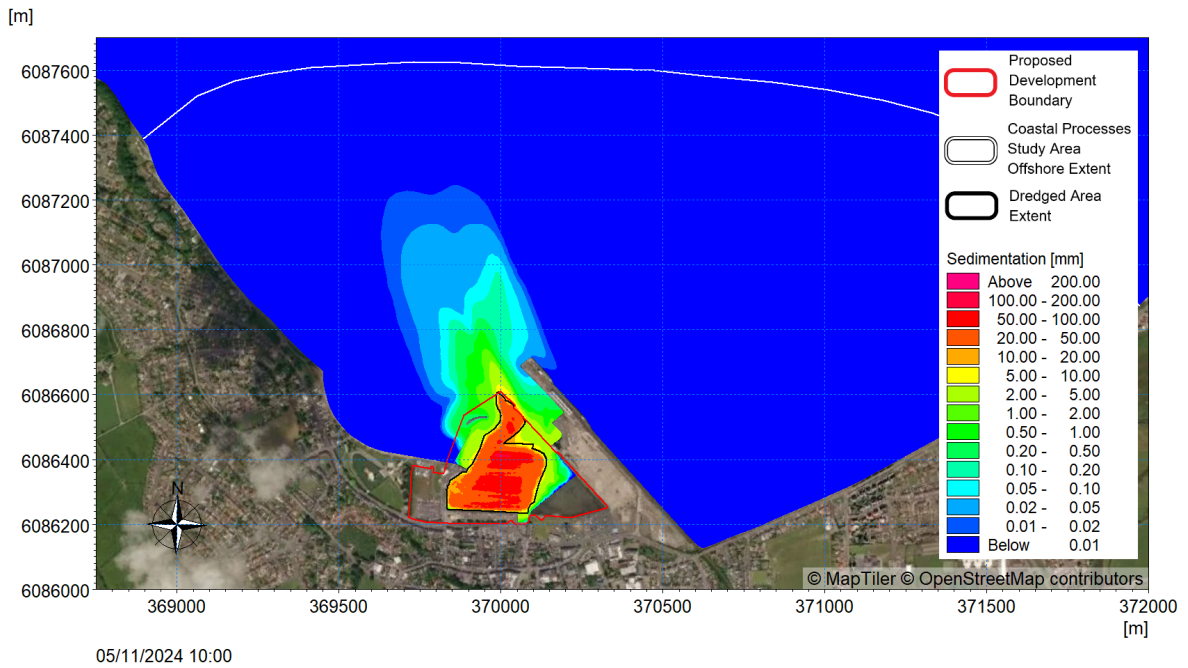


Figure 7-34: Scenario 1 - Sedimentation after One Day following Cessation of Dredging Operations

Scenario 1 – Timeseries SSC and deposition

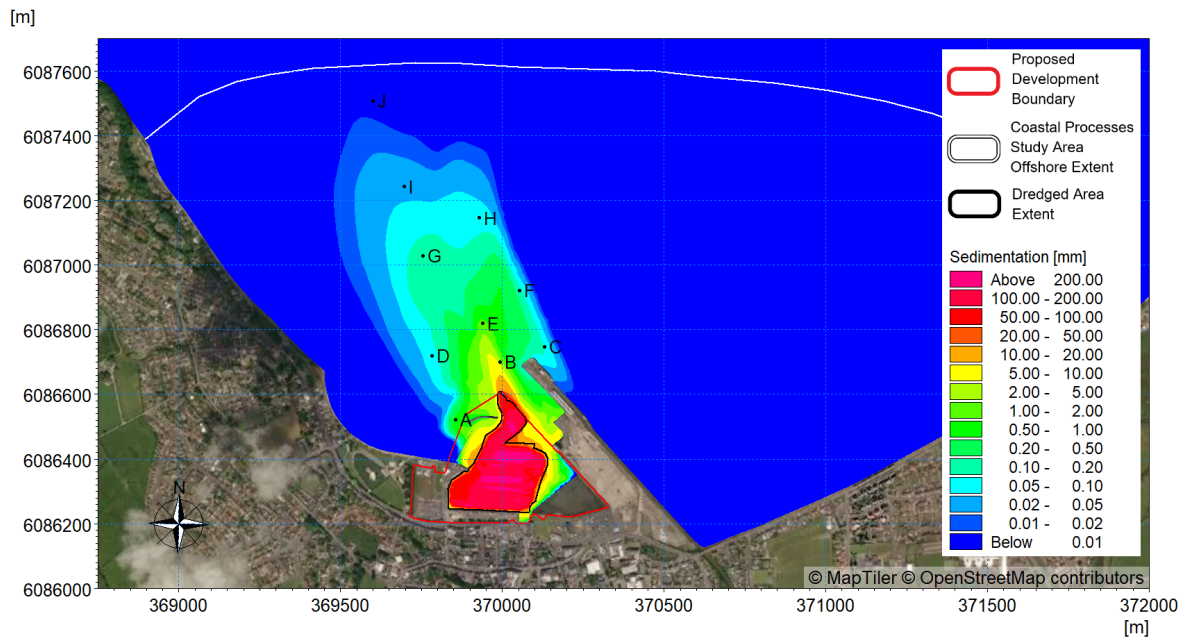
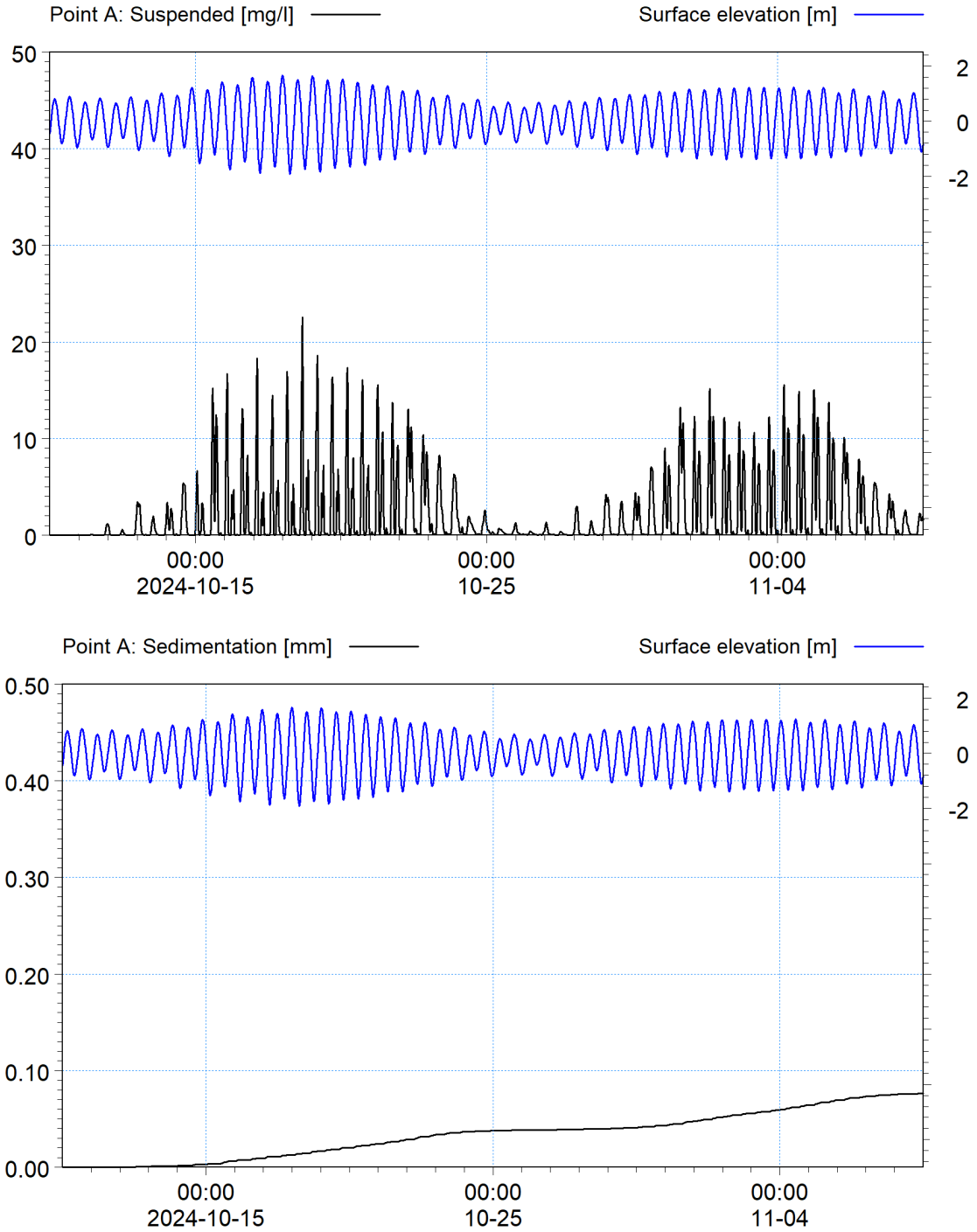
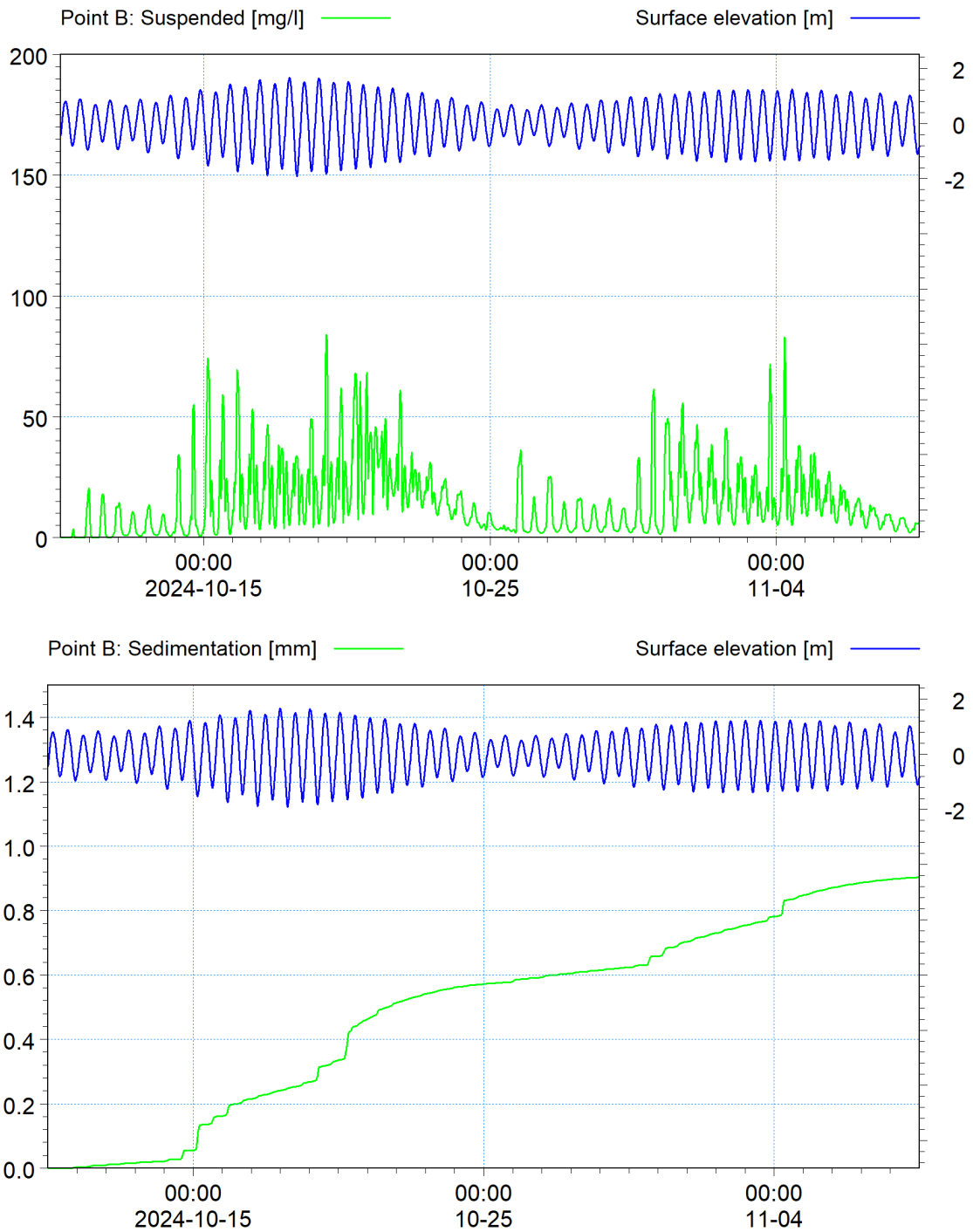


Figure 7-35: Location of Timeseries with respect to Overall Sedimentation



**Figure 7-36: Scenario 1 - SSC (upper) & Sedimentation (lower) at Location A for the Simulation Period**



**Figure 7-37: Scenario 1 - SSC (upper) & Sedimentation (lower) at Location B for the Simulation Period**

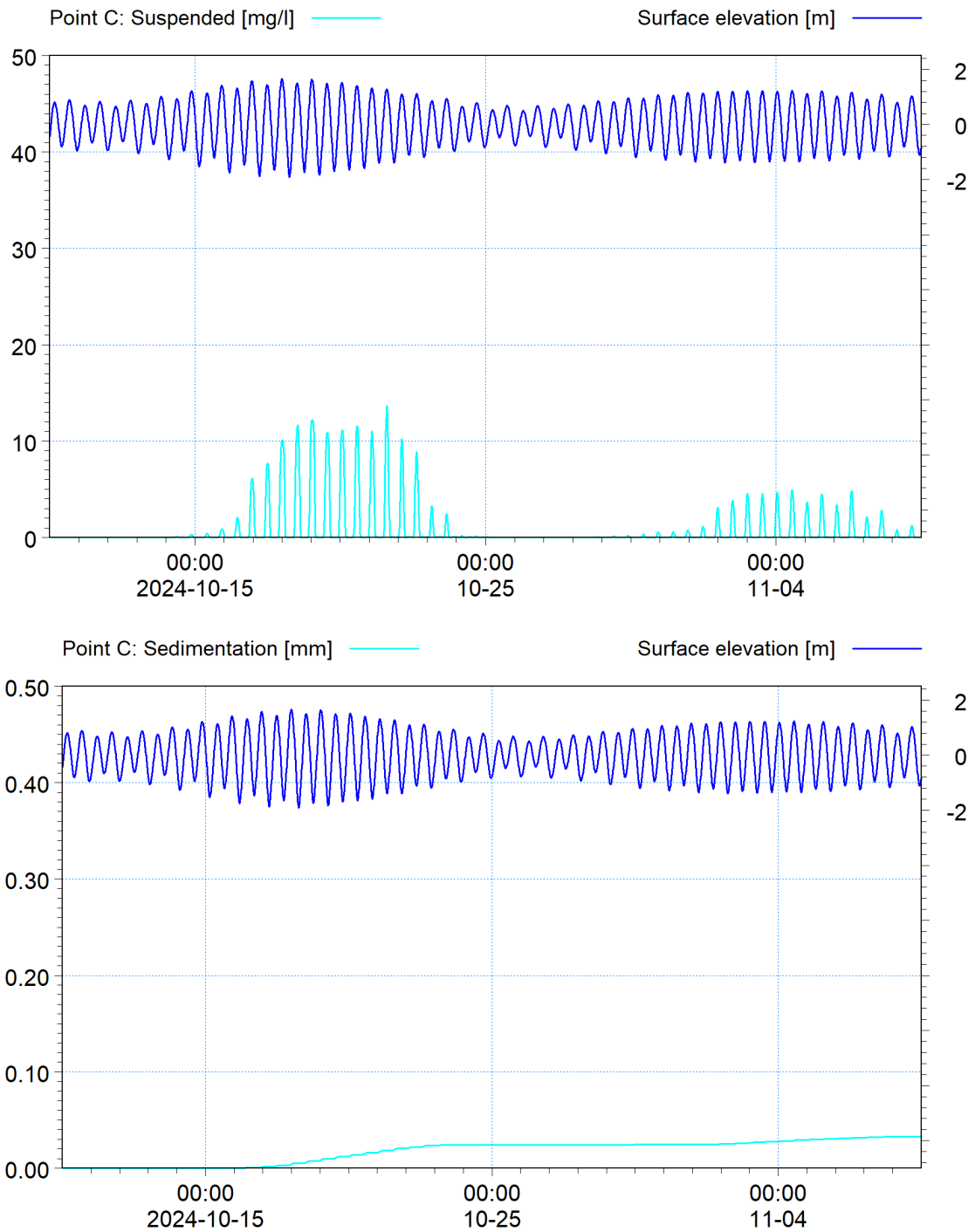
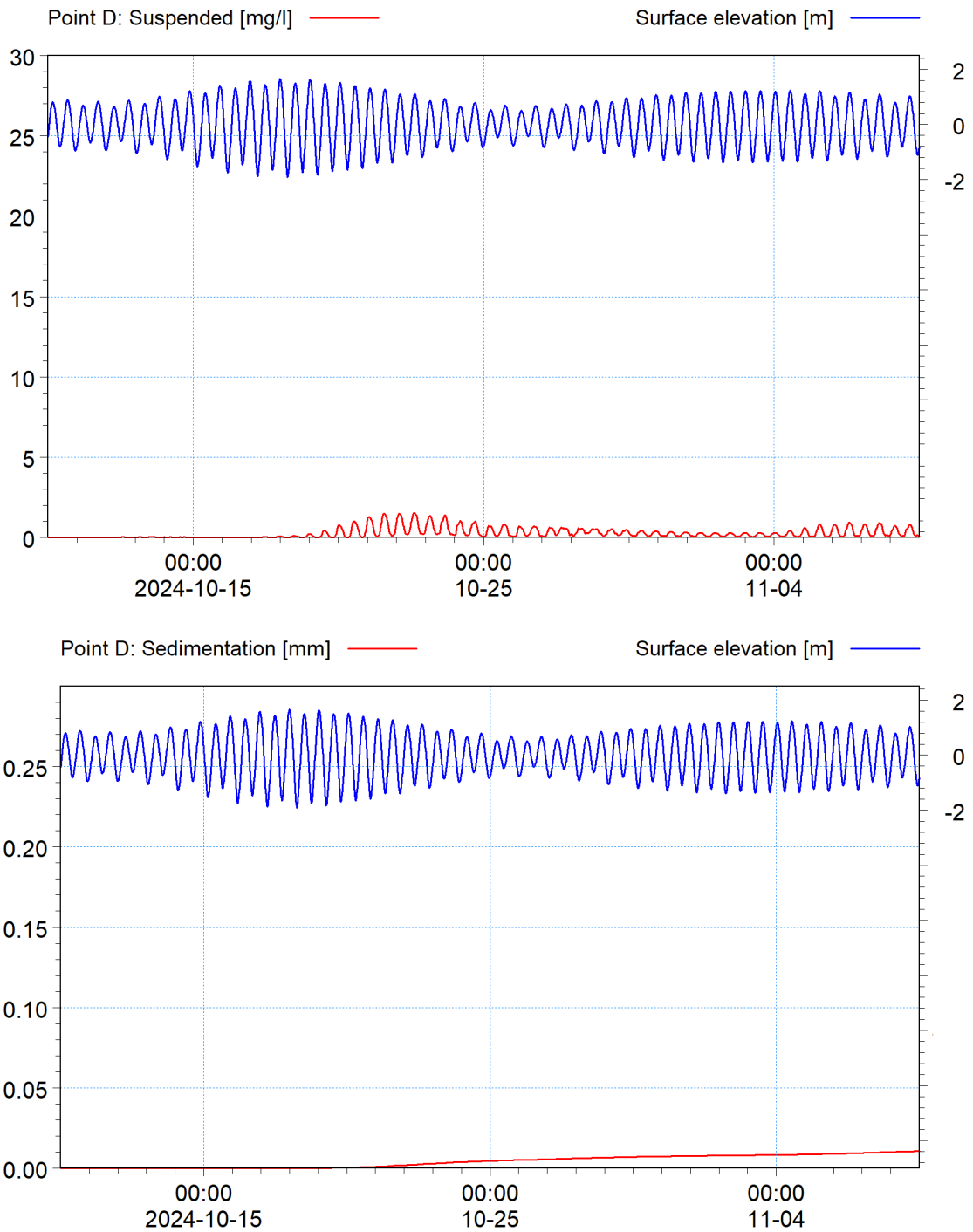
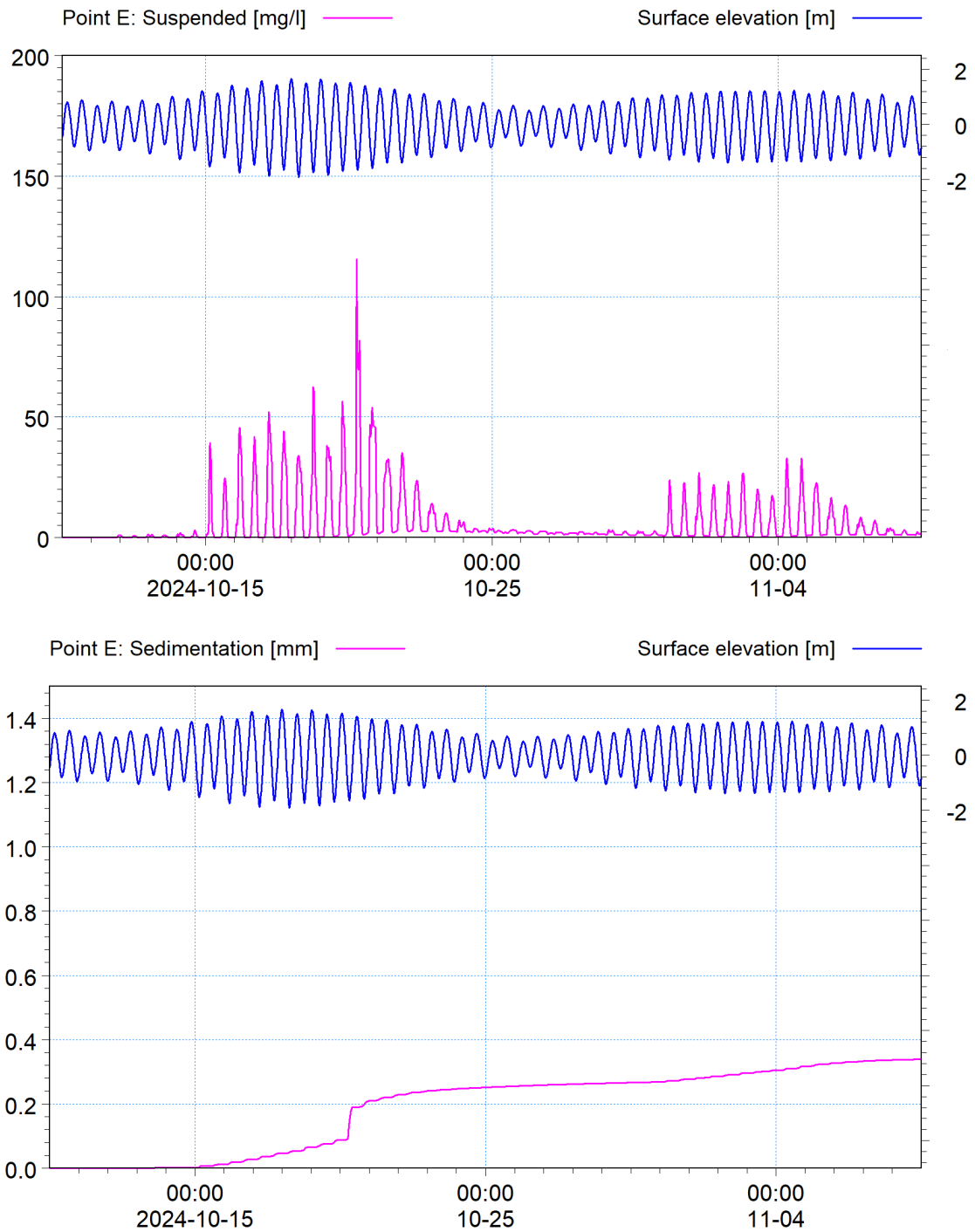


Figure 7-38: Scenario 1 - SSC (upper) & Sedimentation (lower) at Location C for the Simulation Period



**Figure 7-39: Scenario 1 - SSC (upper) & Sedimentation (lower) at Location D for the Simulation Period**



**Figure 7-40: Scenario 1 - SSC (upper) & Sedimentation (lower) at Location E for the Simulation Period**

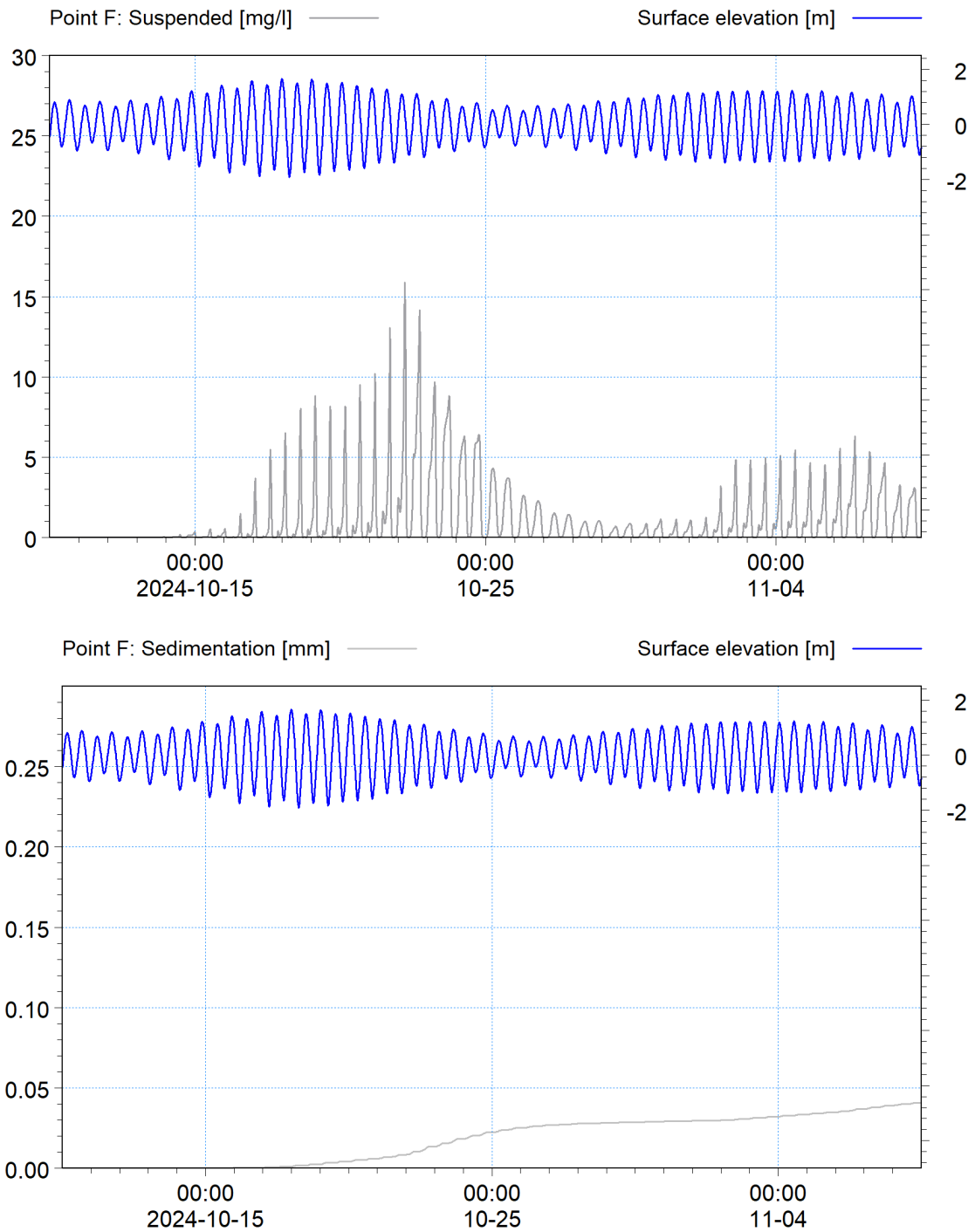
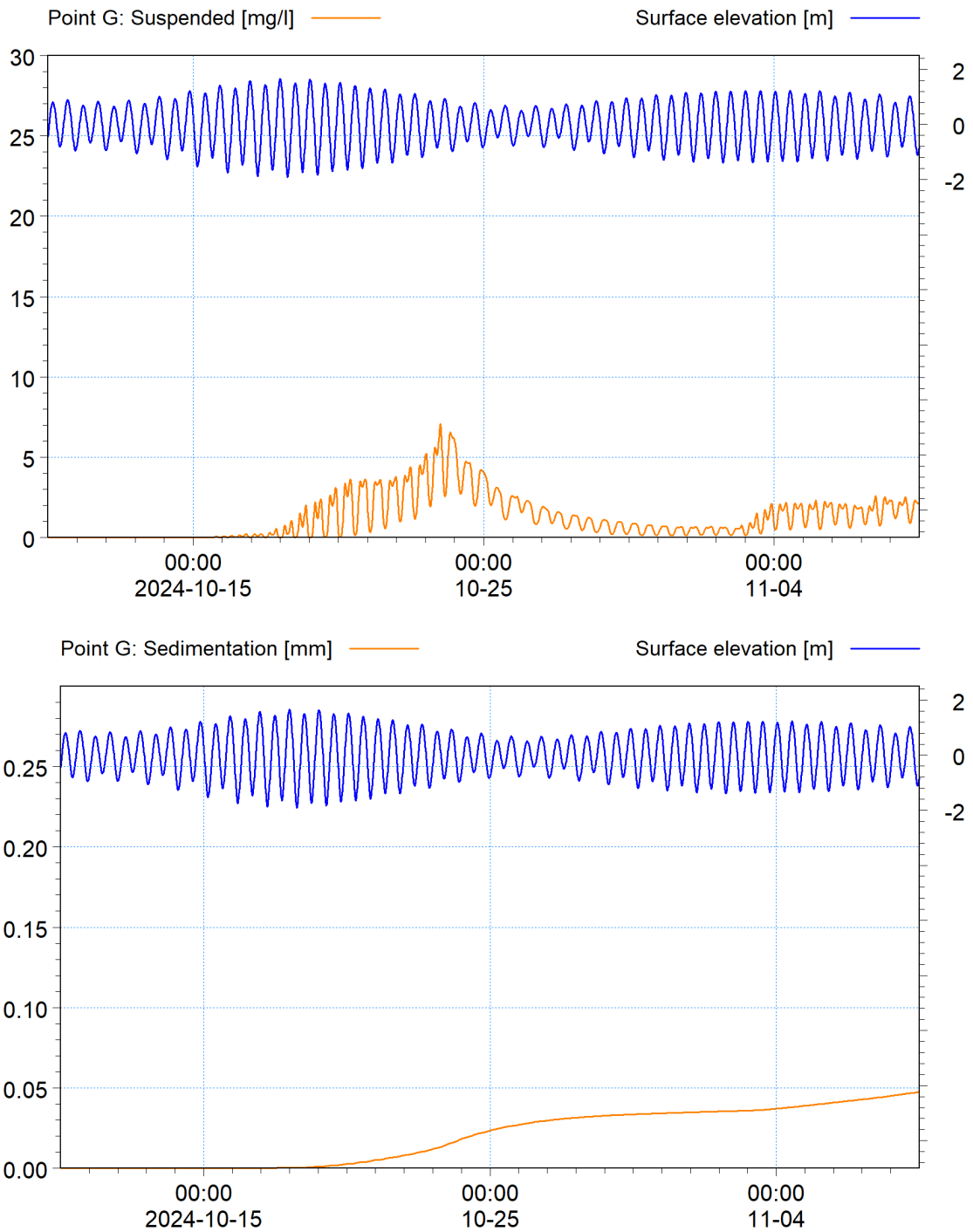


Figure 7-41: Scenario 1 - SSC (upper) & Sedimentation (lower) at Location F for the Simulation Period



**Figure 7-42: Scenario 1 - SSC (upper) & Sedimentation (lower) Location G for the Simulation Period**

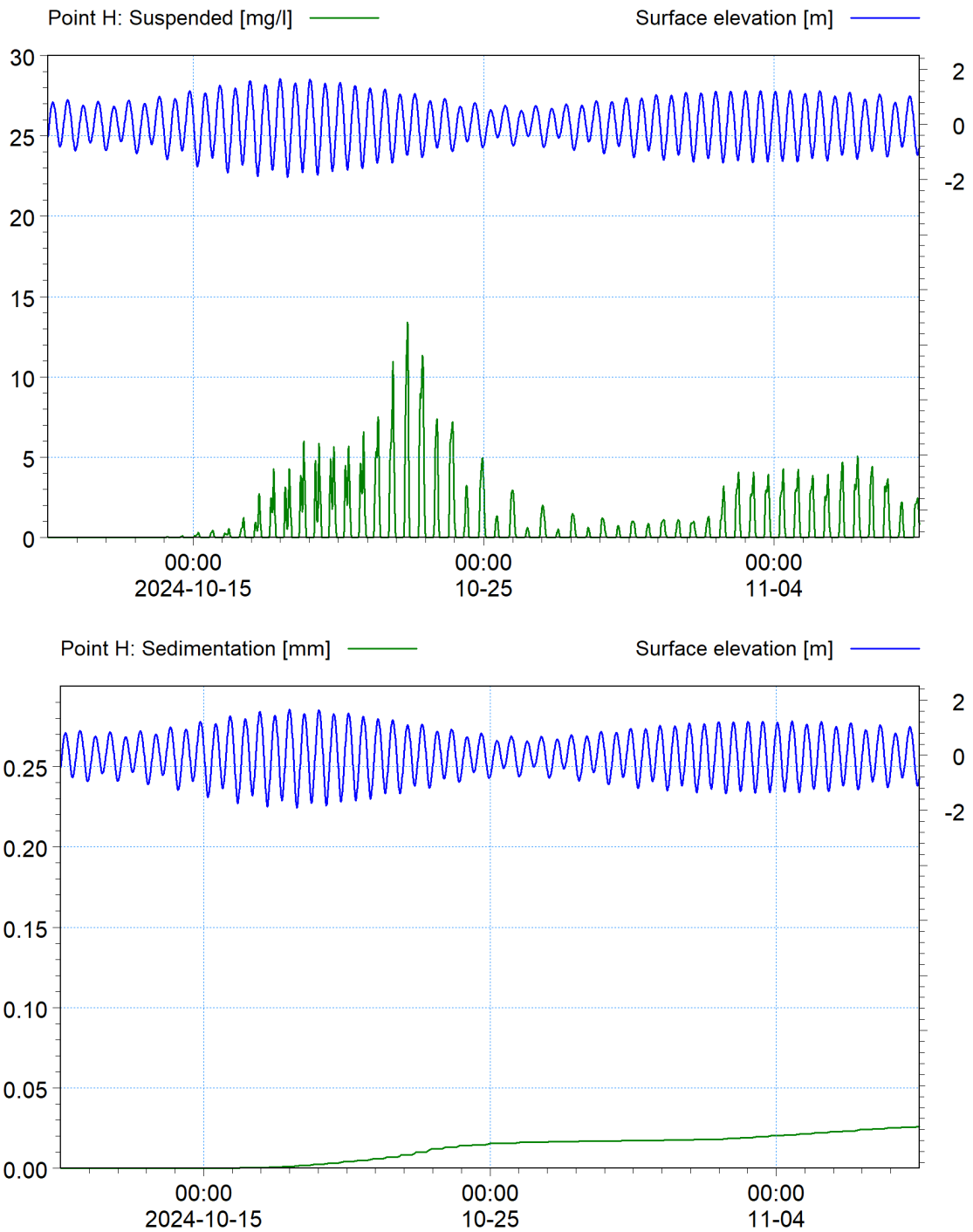


Figure 7-43: Scenario 1 - SSC (upper) & Sedimentation (lower) at Location H for the Simulation Period

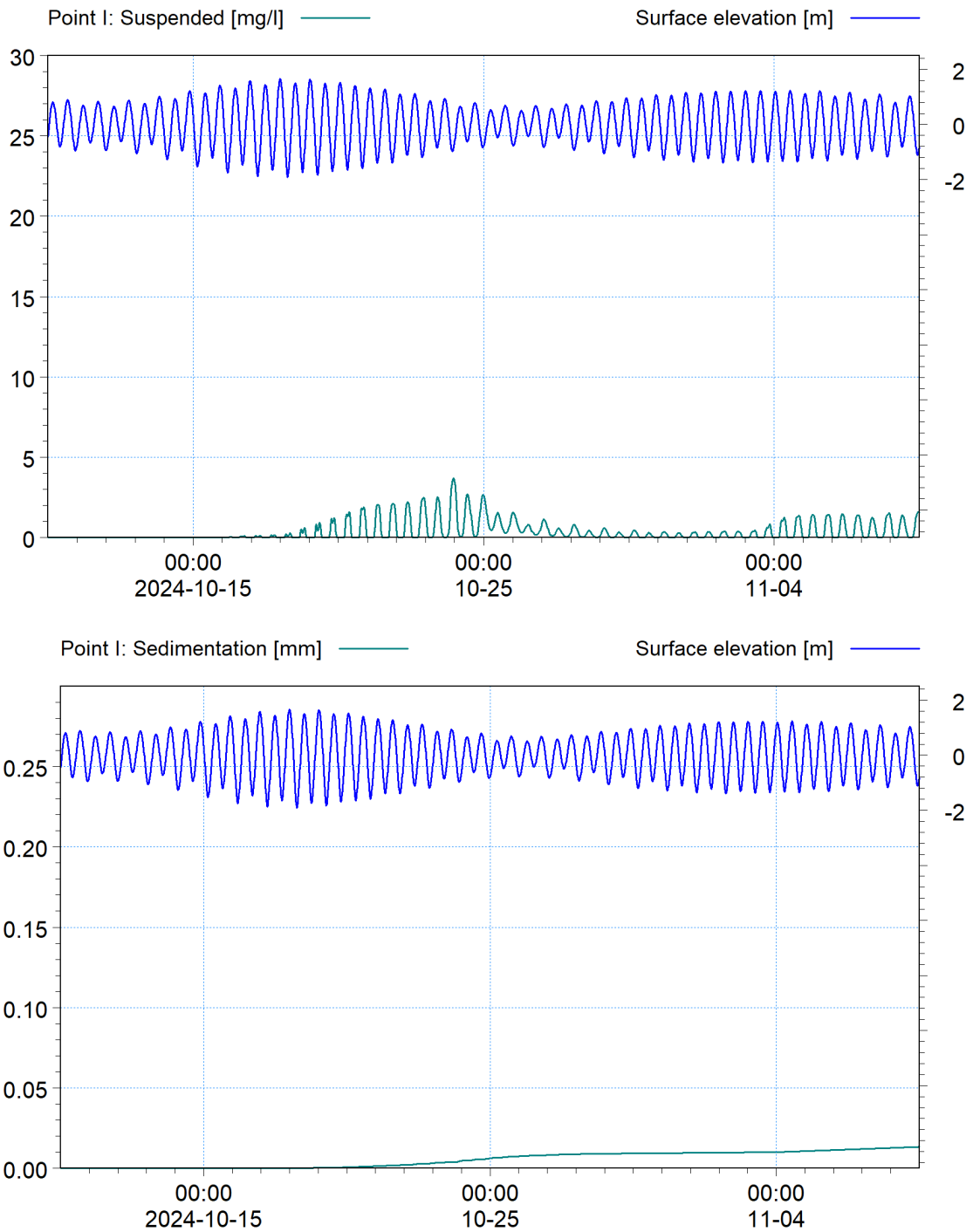
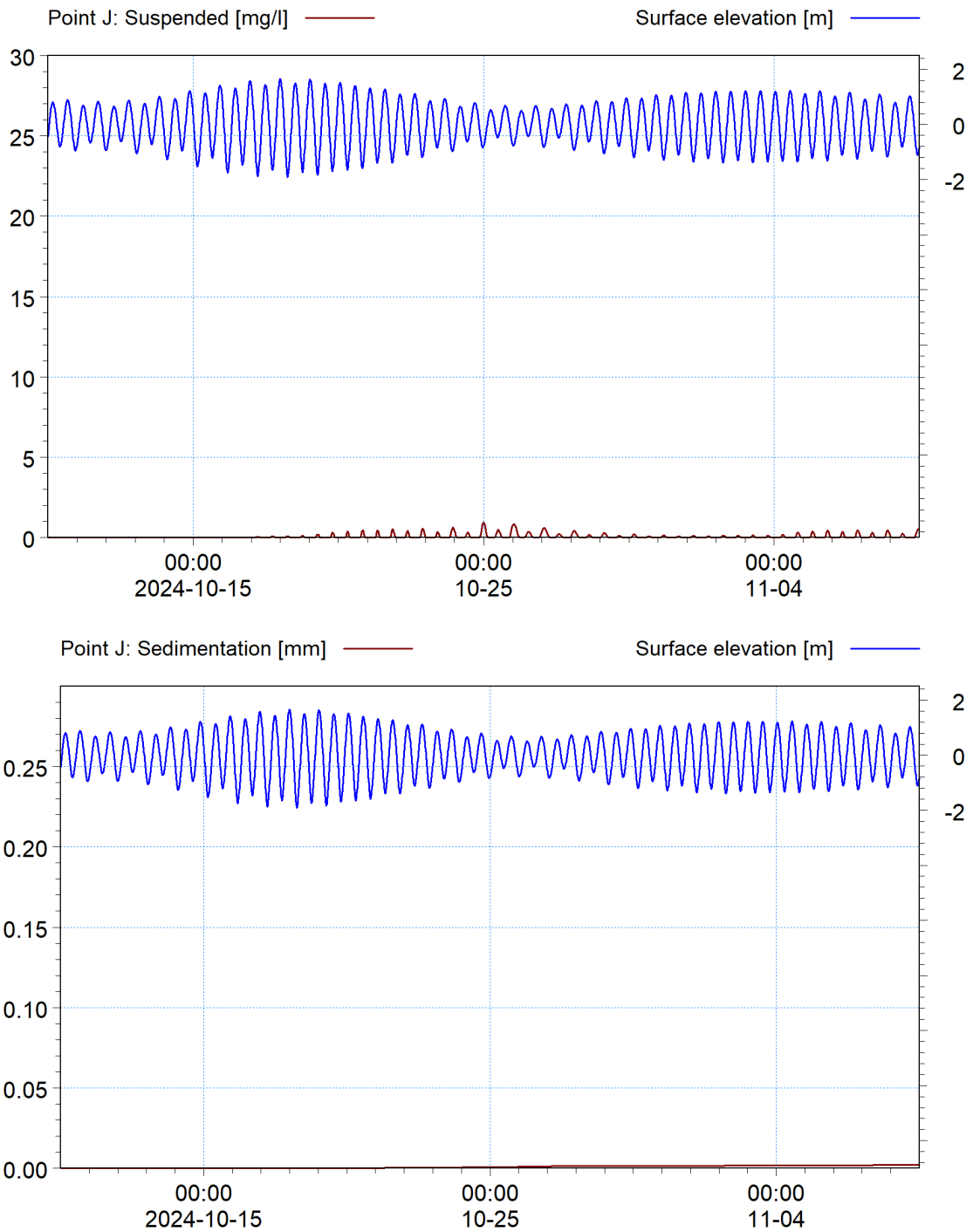


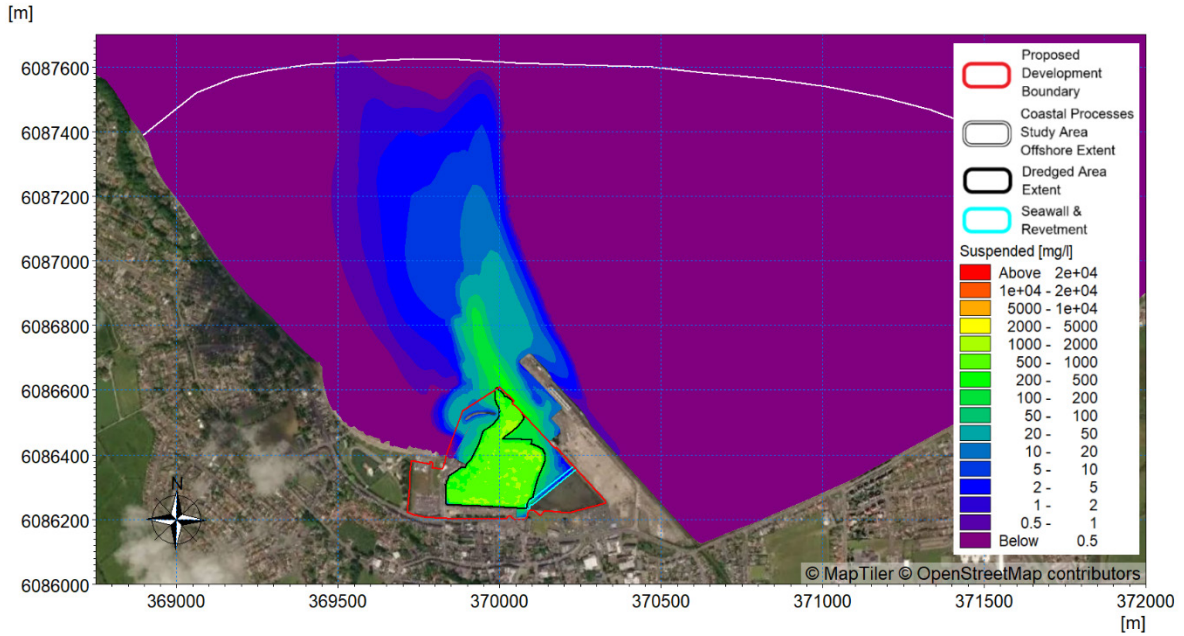
Figure 7-44: Scenario 1 - SSC (upper) & Sedimentation (lower) at Location I for the Simulation Period



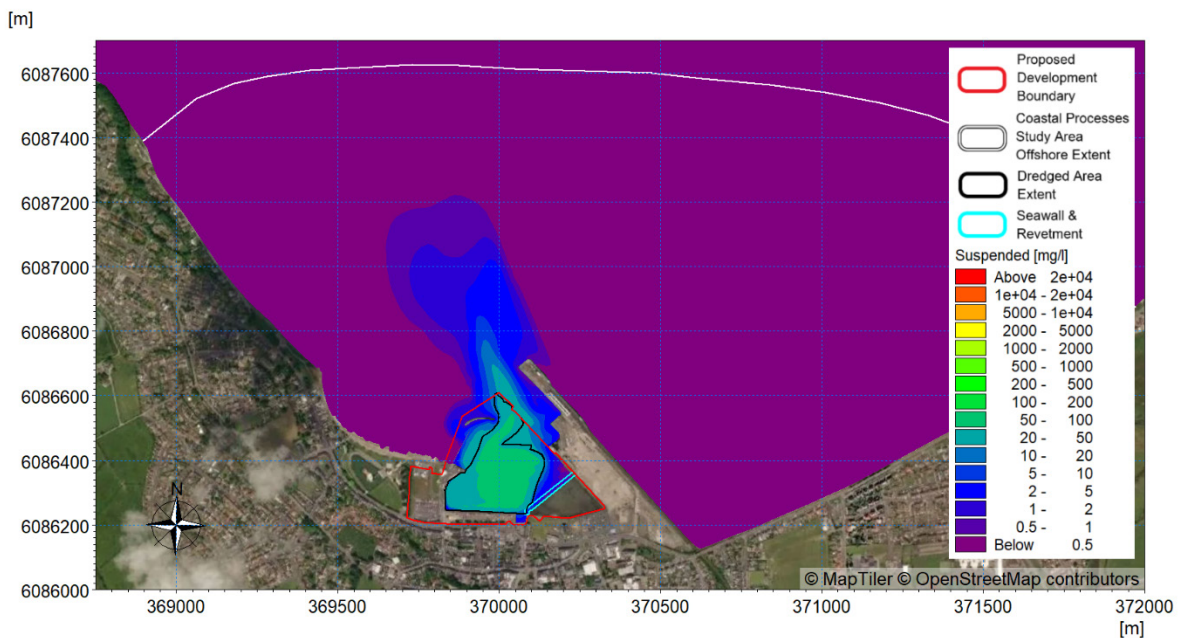
**Figure 7-45: Scenario 1 - SSC (upper) & Sedimentation (lower) at Location J for the Simulation Period**

**Scenario 2**

**Scenario 2 – Suspended Sediment Concentration**



**Figure 7-46: Scenario 2 - Maximum Plume Envelope of SSC during Dredging Simulation**



**Figure 7-47: Scenario 2 - Average Plume Envelope of SSC during Dredging Operations**

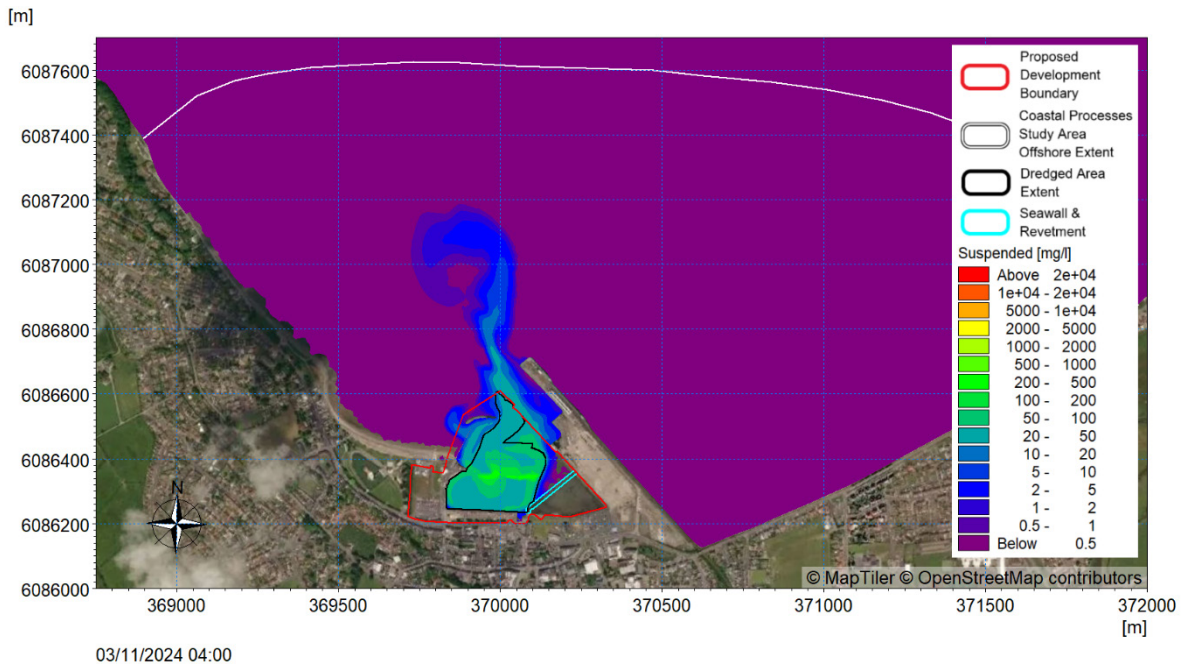


Figure 7-48: Scenario 2 - Snapshot of SSC Mid-Ebb Tide Near Completion of Dredging Operations

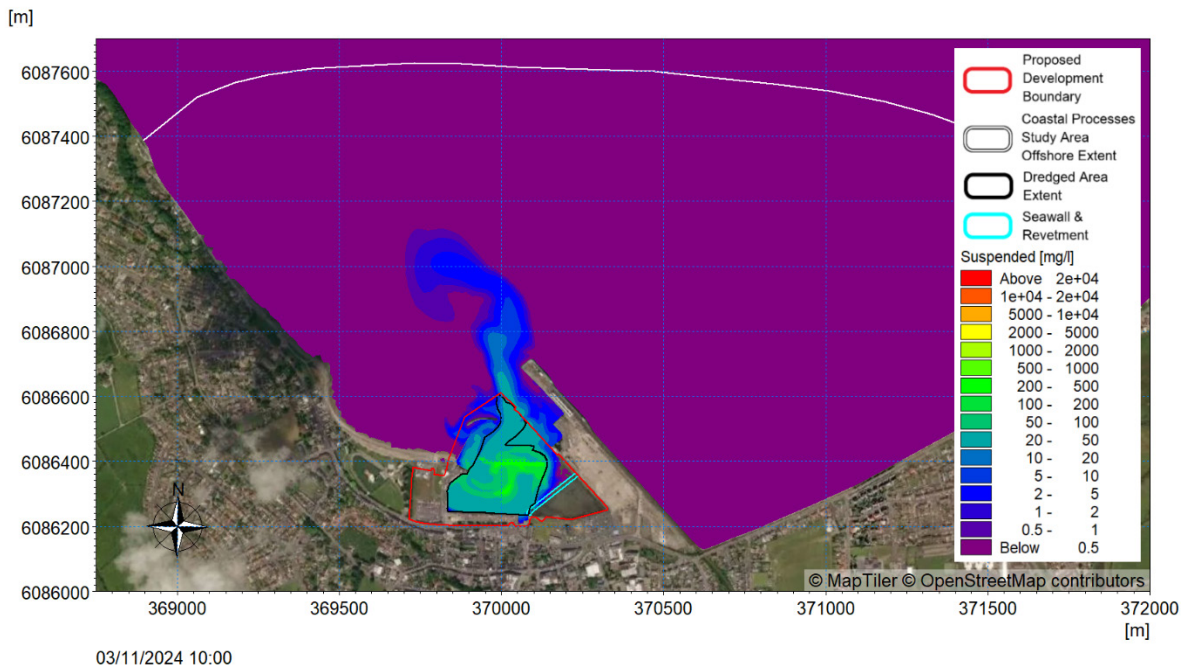


Figure 7-49: Scenario 2 - Snapshot of SSC Mid-Flood Tide Near Completion of Dredging Operations

Scenario 2 – Sedimentation Characteristics

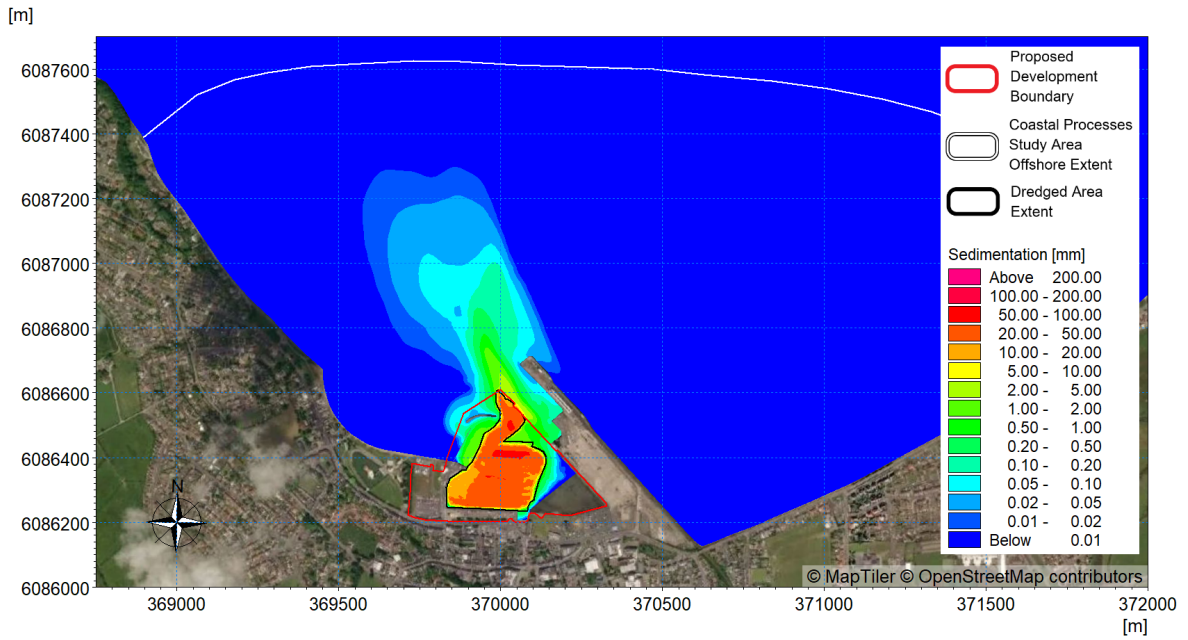


Figure 7-50: Scenario 2 - Maximum Plume Envelope of Sedimentation during Dredging Simulation

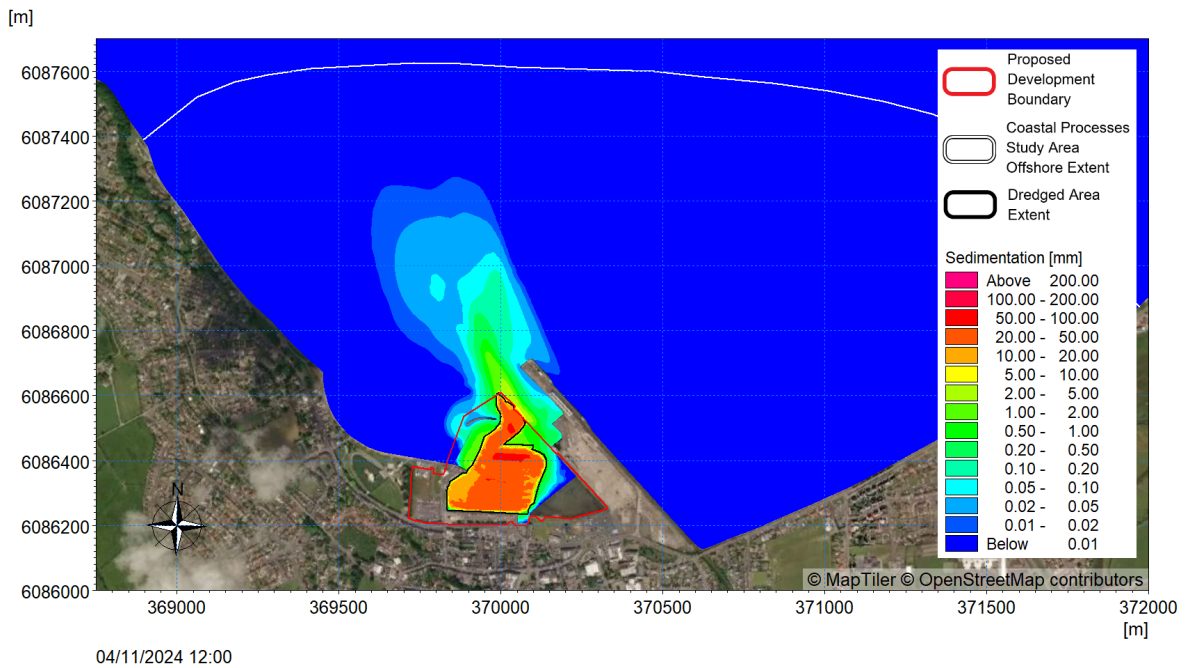
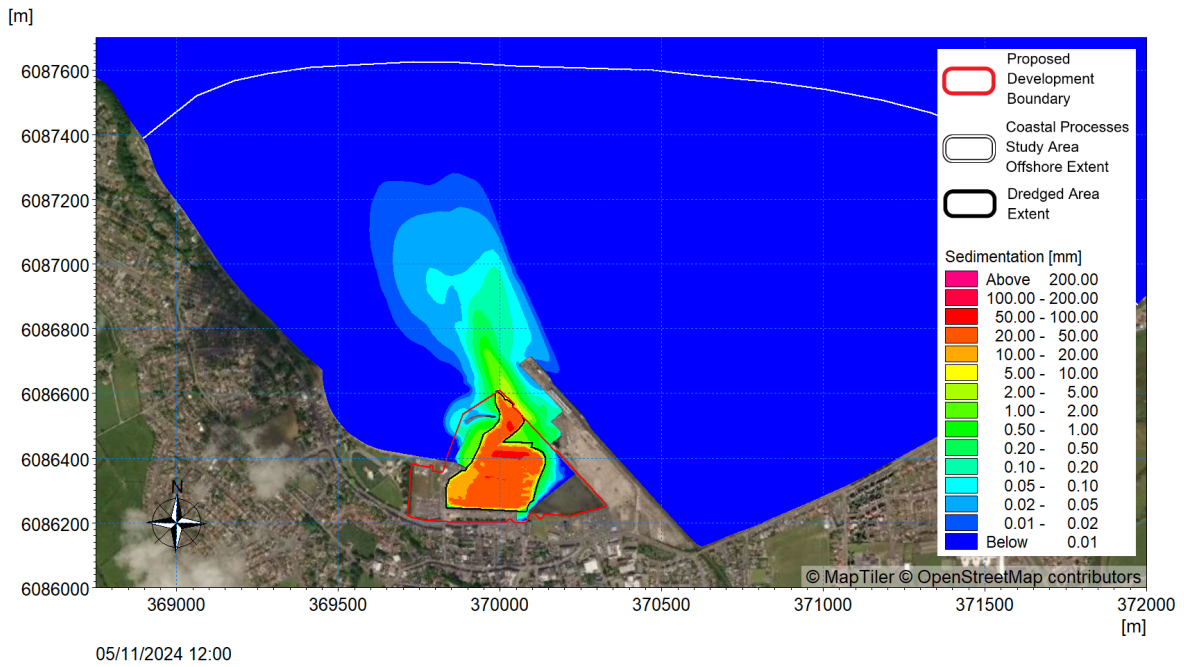
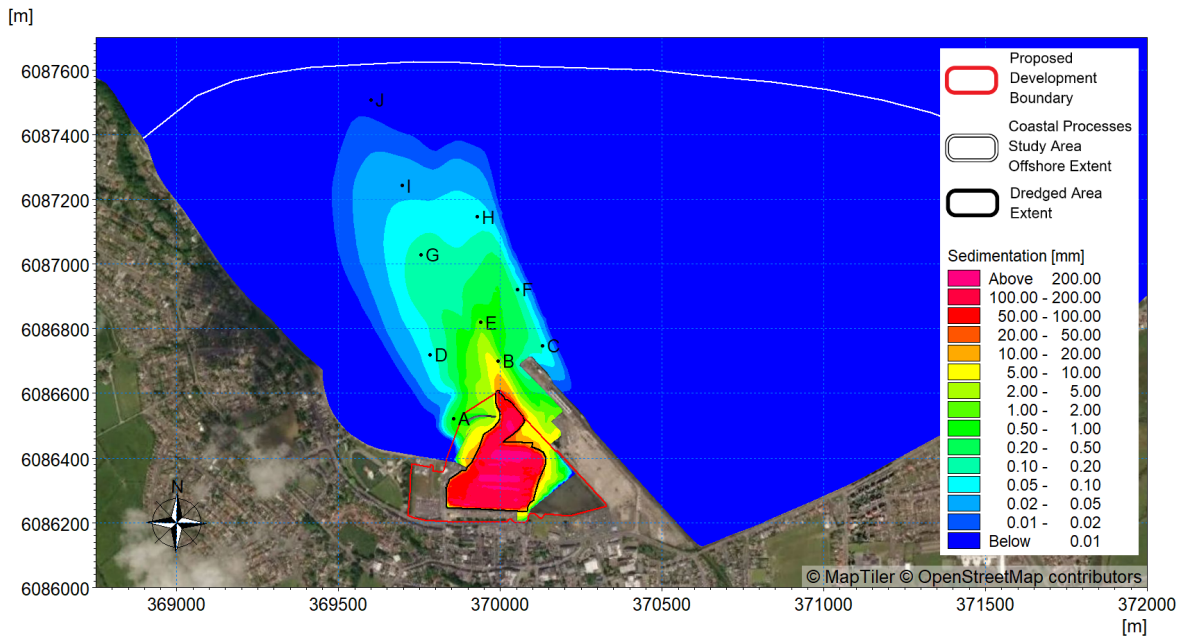


Figure 7-51: Scenario 2 - Sedimentation on Cessation of Dredging Operations

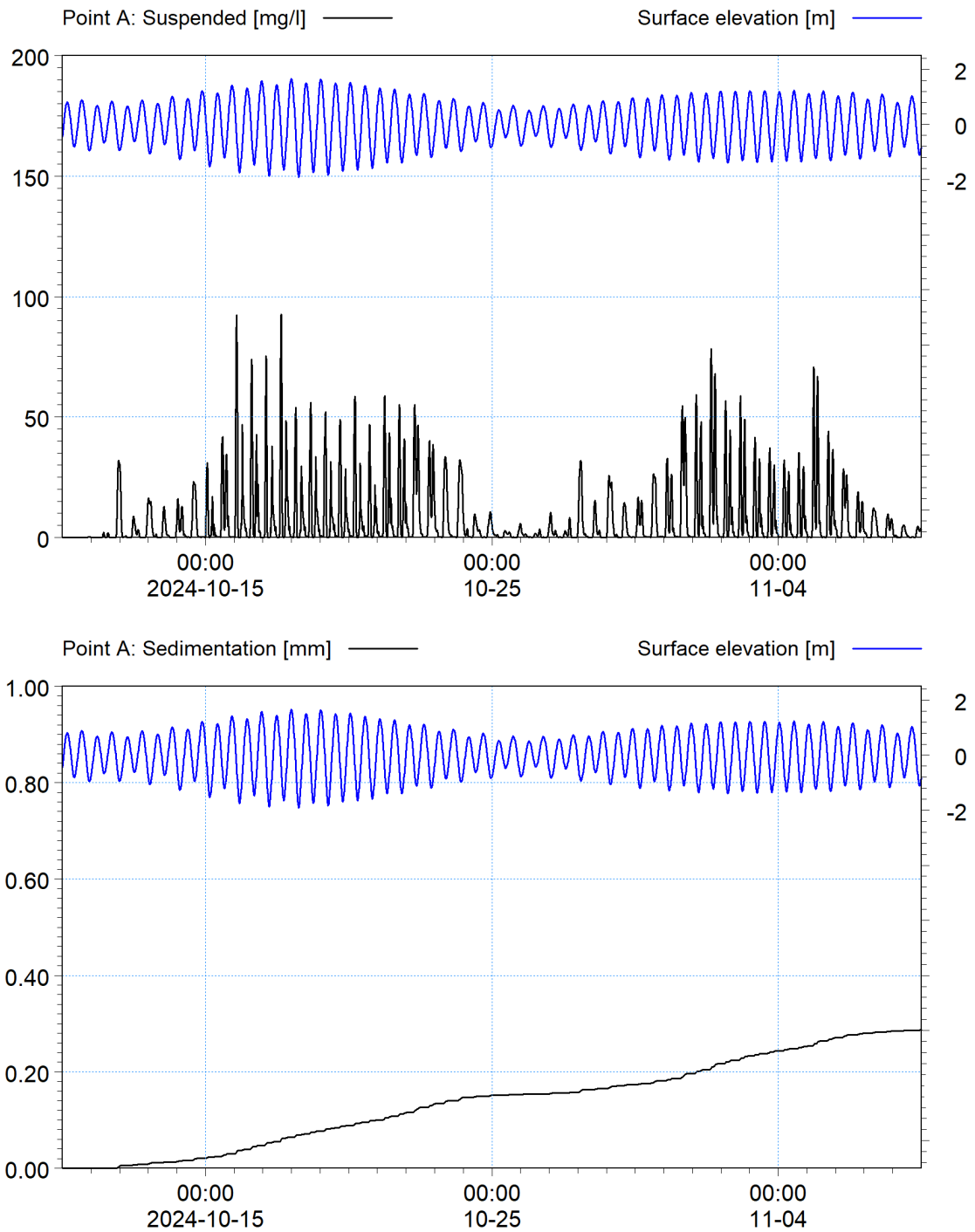


**Figure 7-52: Scenario 2 - Sedimentation after One Day following Cessation of Dredging Operations**

Scenario 2 – Timeseries SSC and deposition



**Figure 7-53: Scenario 2 - Location of Timeseries with respect to Overall Sedimentation**



**Figure 7-54: Scenario 2 - SSC (upper) & Sedimentation (lower) at Location A for the Simulation Period**

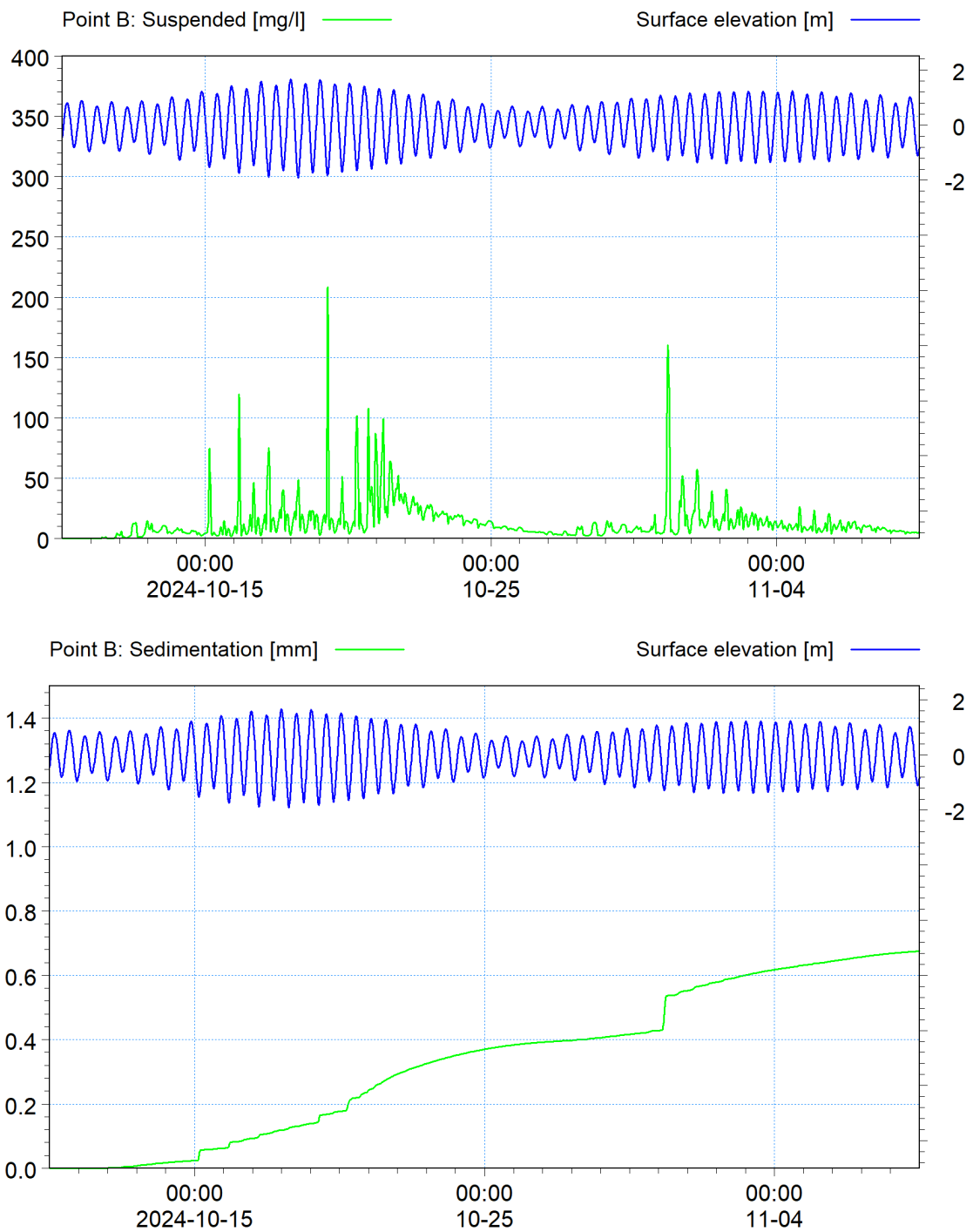
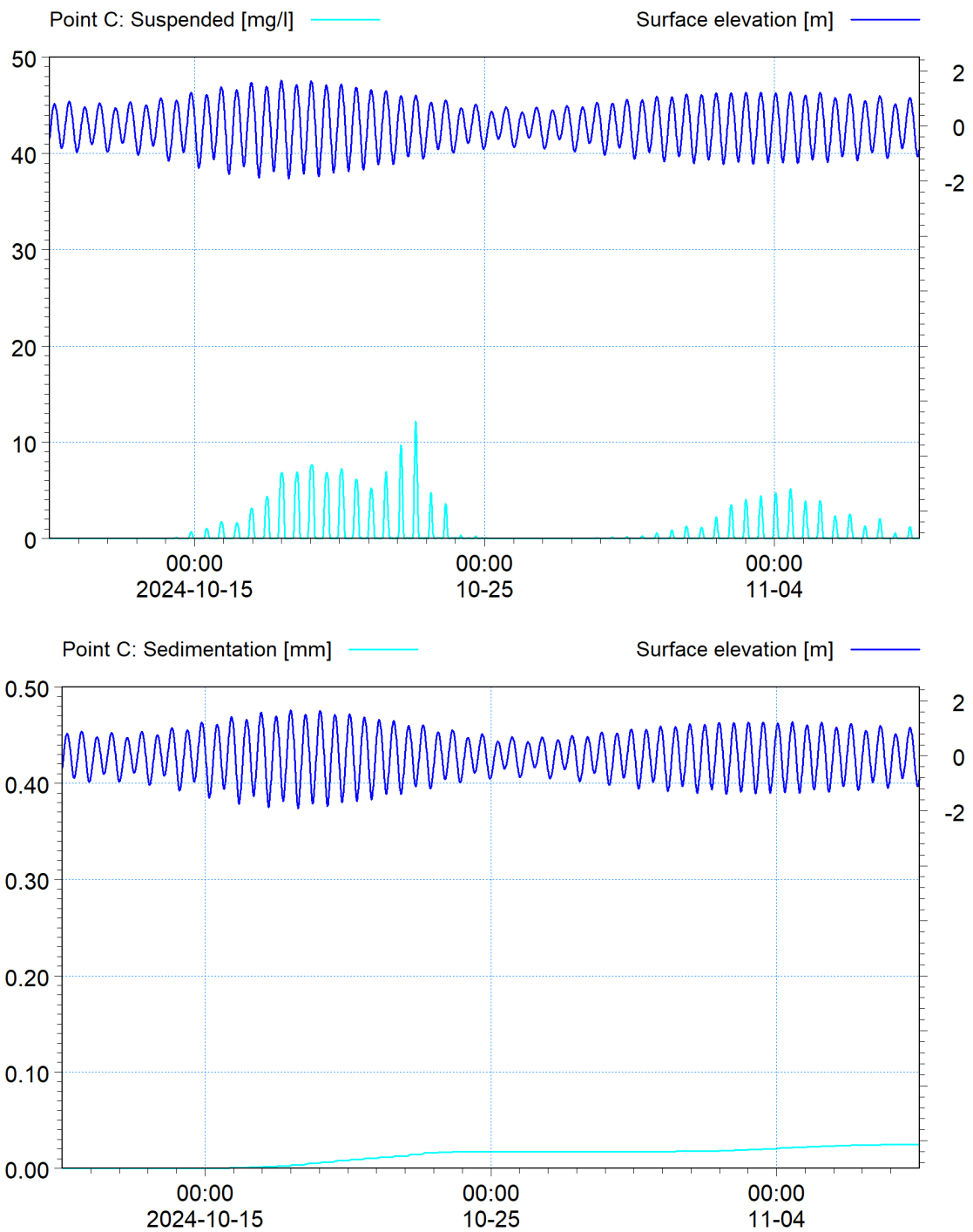
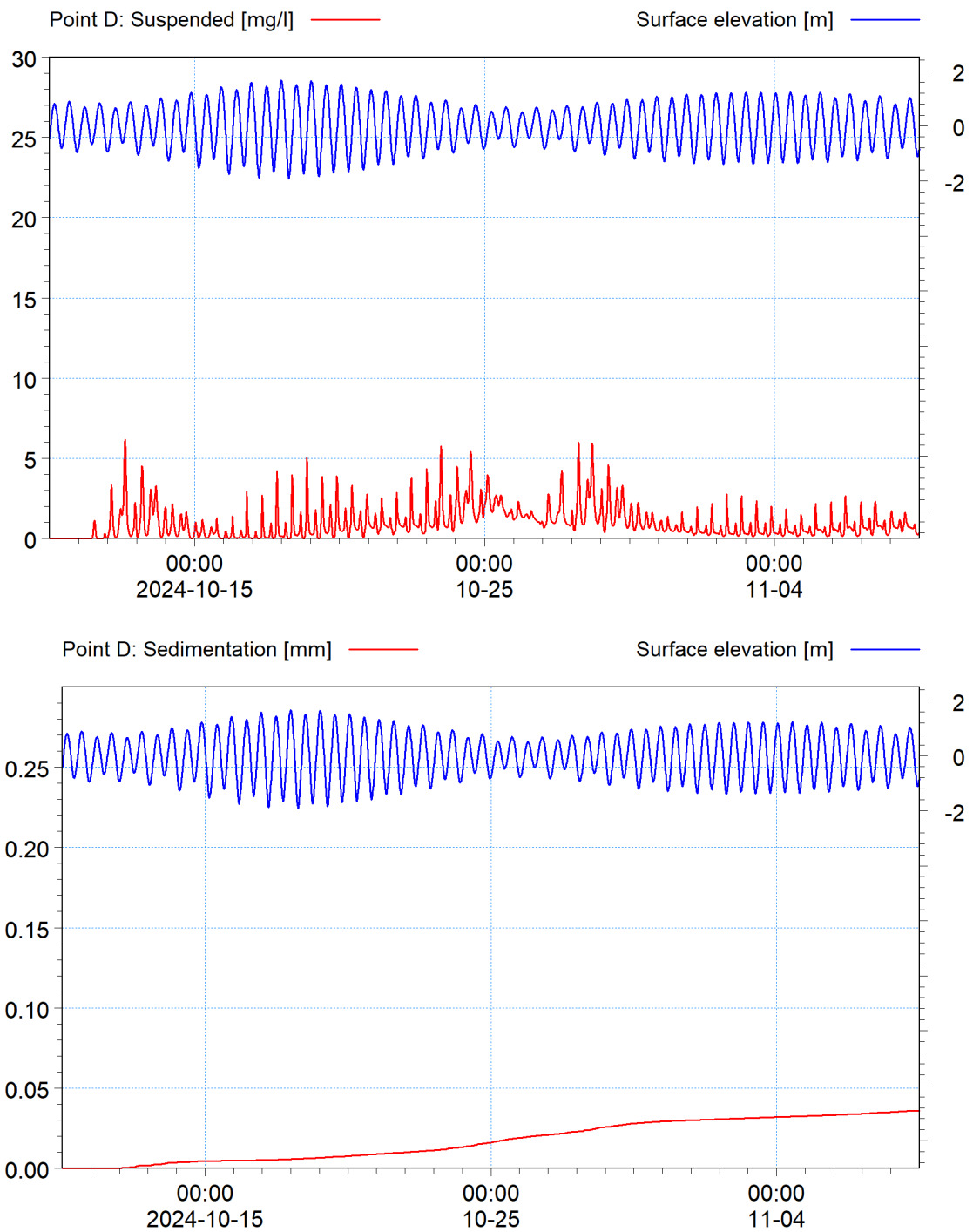


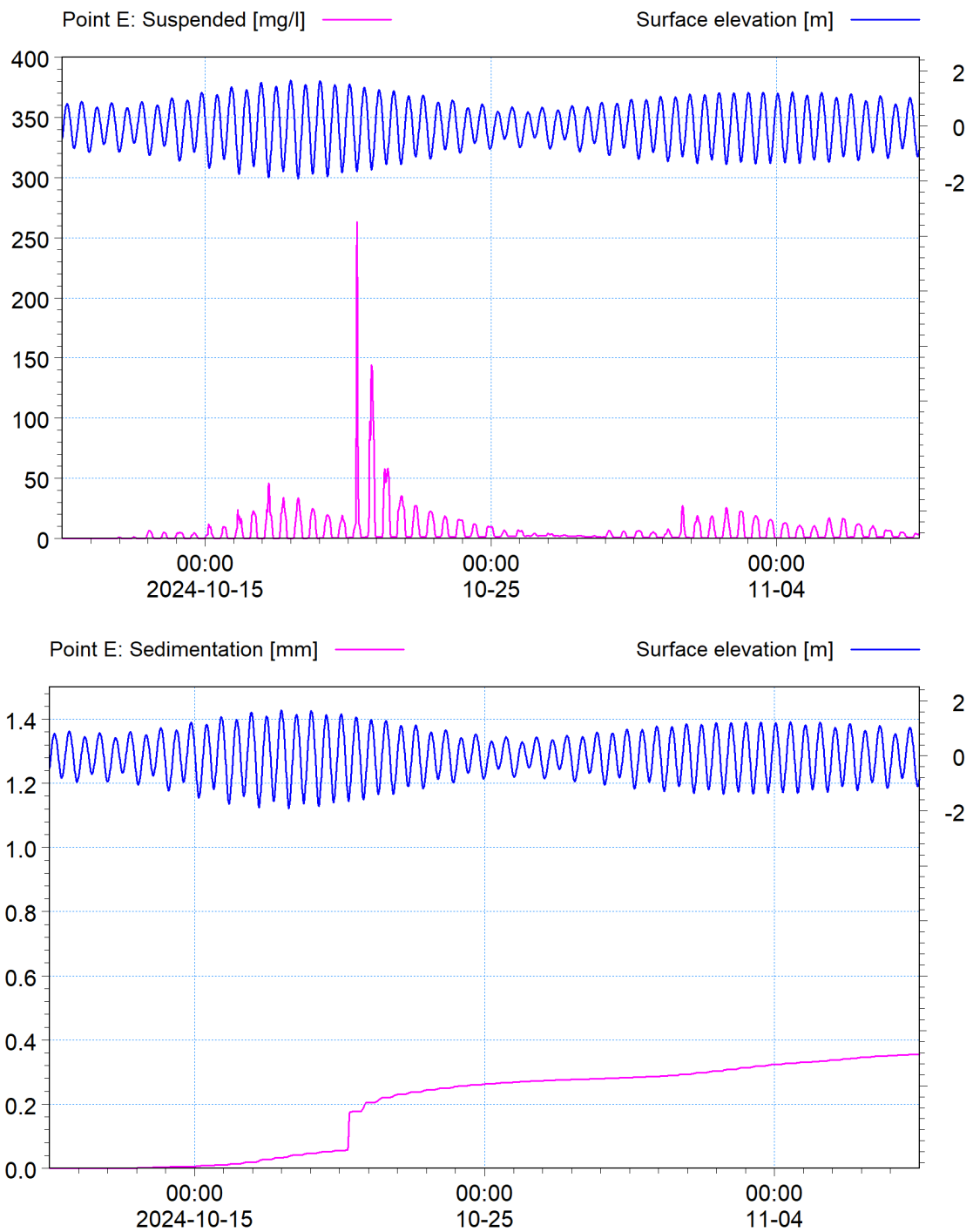
Figure 7-55: Scenario 2 - SSC (upper) & Sedimentation (lower) at Location B for the Simulation Period



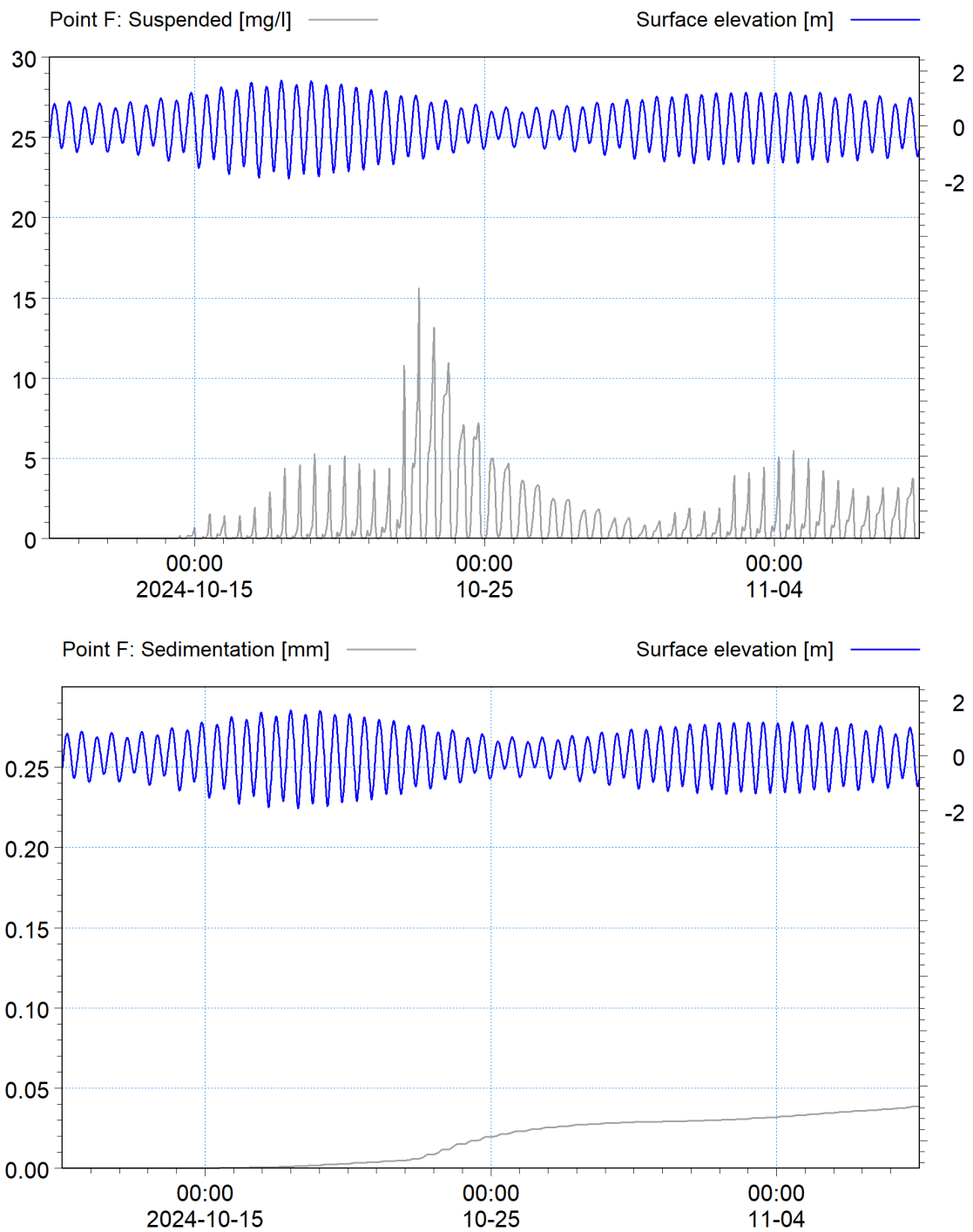
**Figure 7-56: Scenario 2 - SSC (upper) & Sedimentation (lower) at Location C for the Simulation Period**



**Figure 7-57: Scenario 2 - SSC (upper) & Sedimentation (lower) at Location D for the Simulation Period**



**Figure 7-58: Scenario 2 - SSC (upper) & Sedimentation (lower) at Location E for the Simulation Period**



**Figure 7-59: Scenario 2 - SSC (upper) & Sedimentation (lower) at Location F for the Simulation Period**

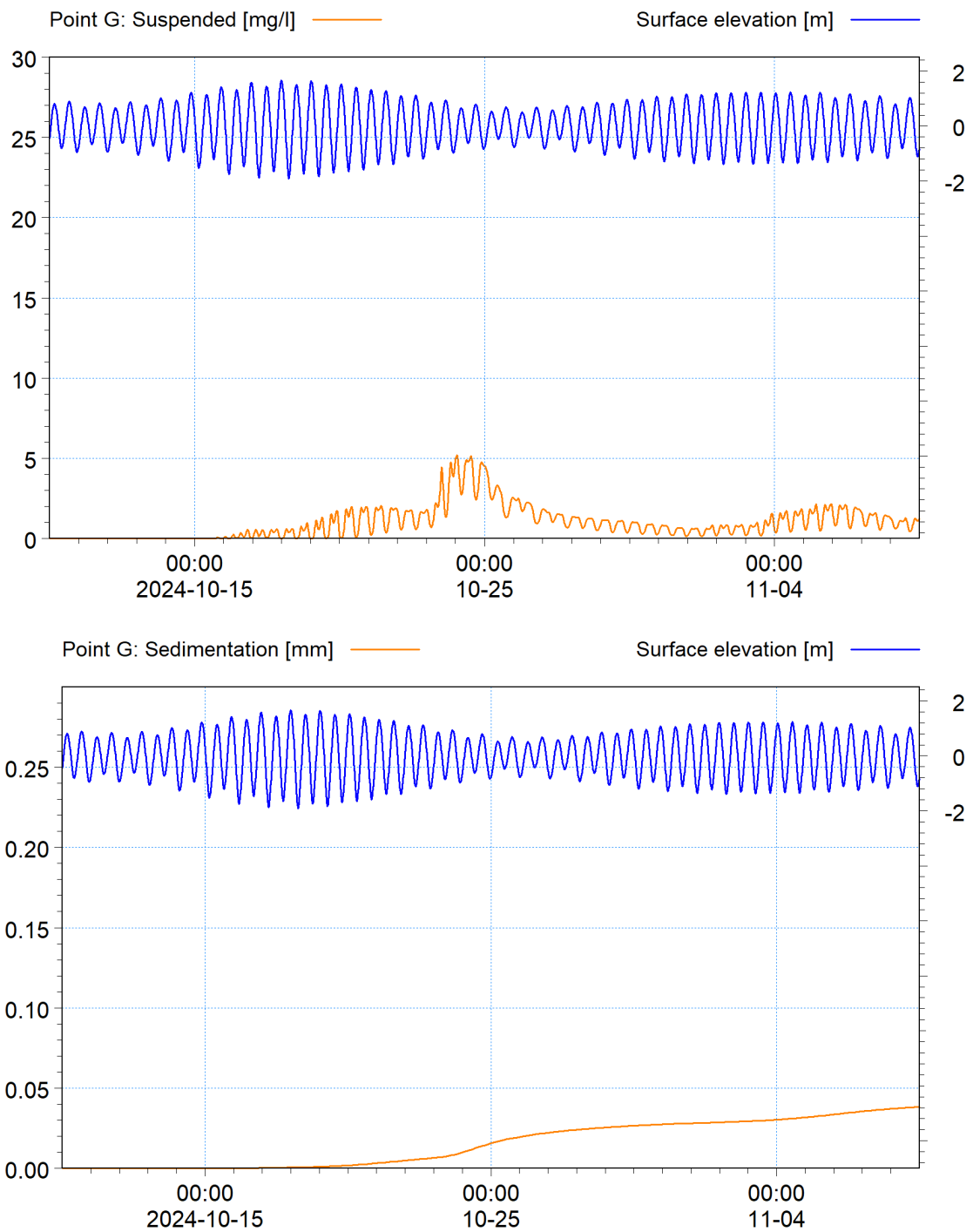
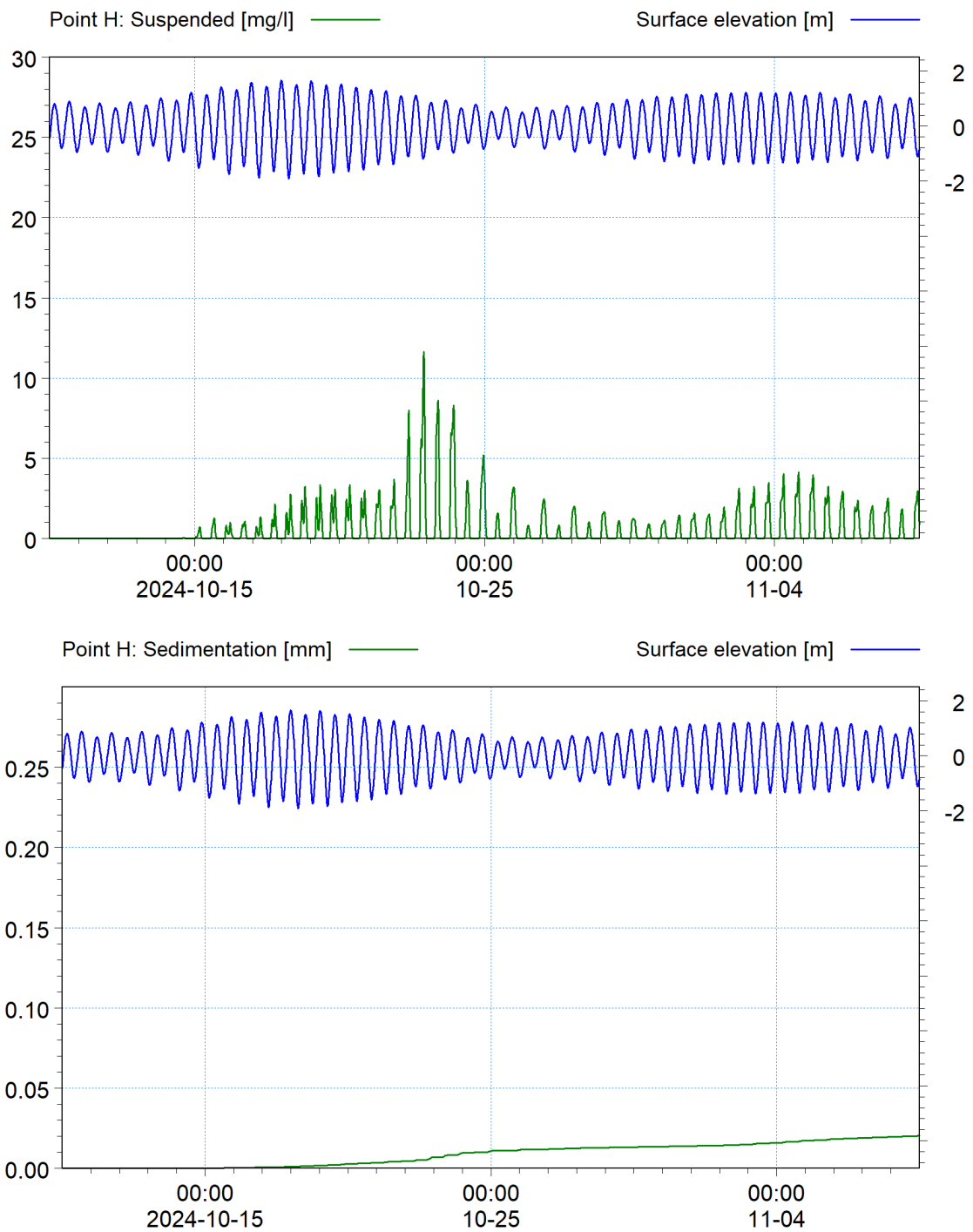
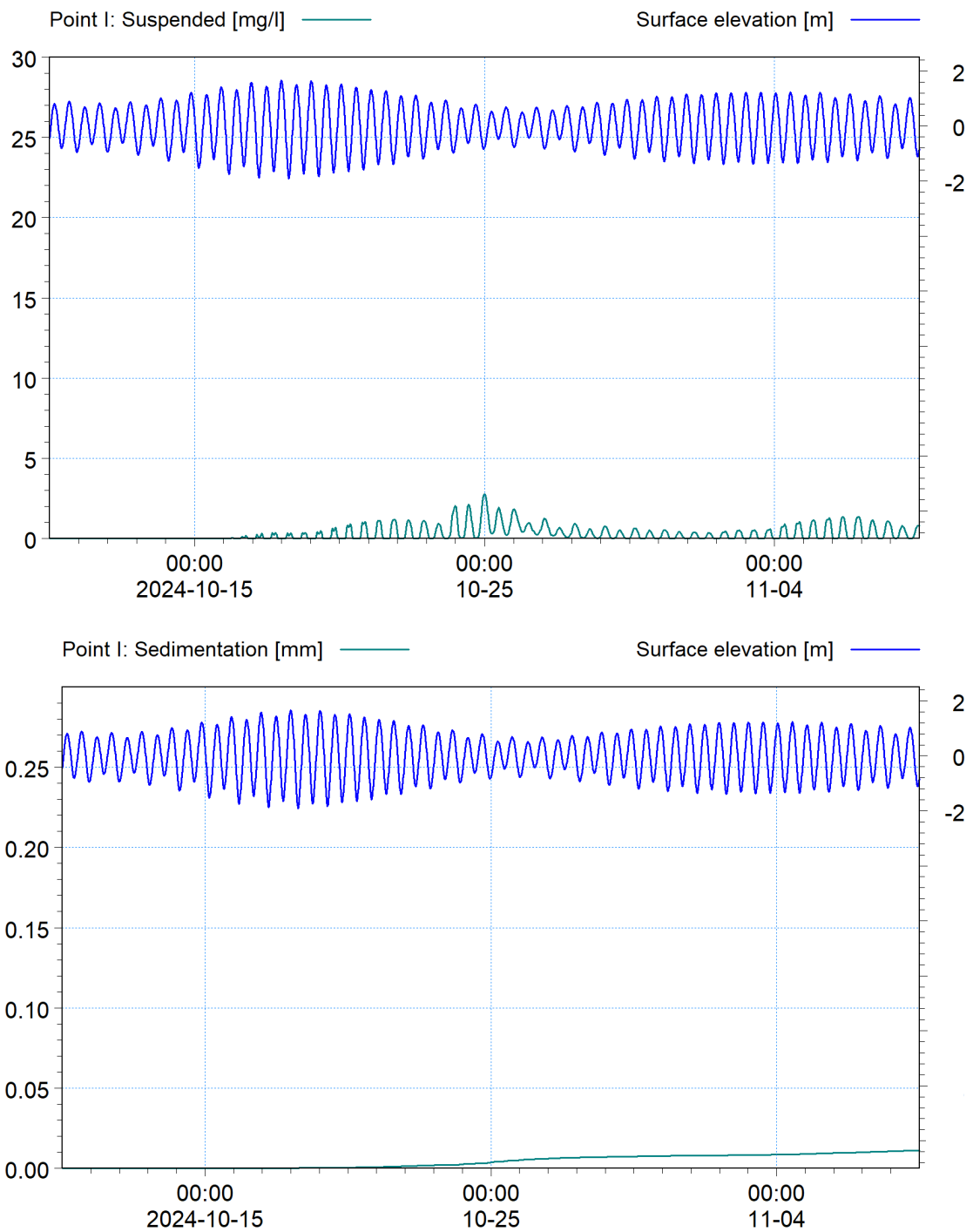


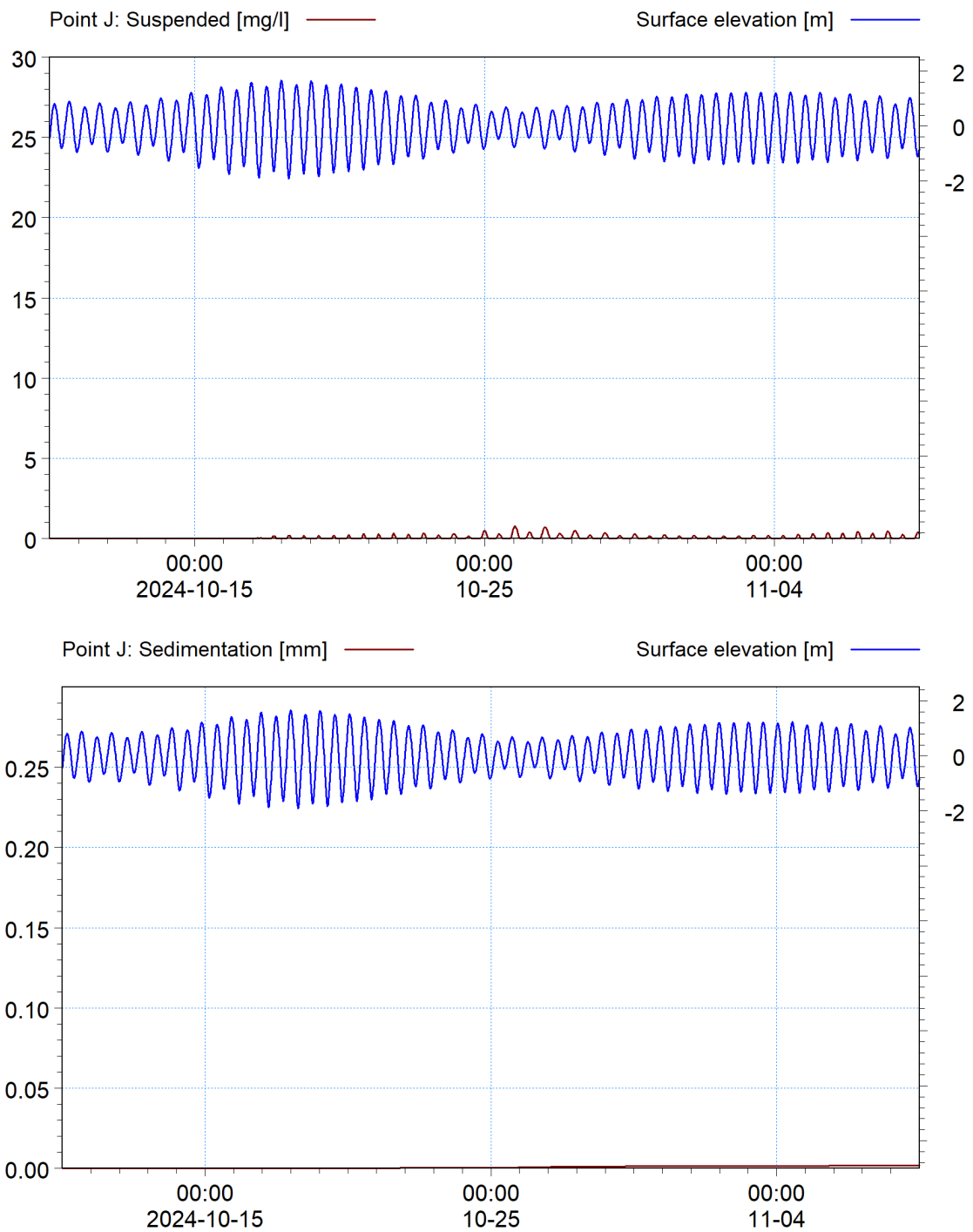
Figure 7-60: Scenario 2 - SSC (upper) & Sedimentation (lower) Location G for the Simulation Period



**Figure 7-61: Scenario 2 - SSC (upper) & Sedimentation (lower) at Location H for the Simulation Period**



**Figure 7-62: Scenario 2 - SSC (upper) & Sedimentation (lower) at Location I for the Simulation Period**



**Figure 7-63: Scenario 2 - SSC (upper) & Sedimentation (lower) at Location J for the Simulation Period**