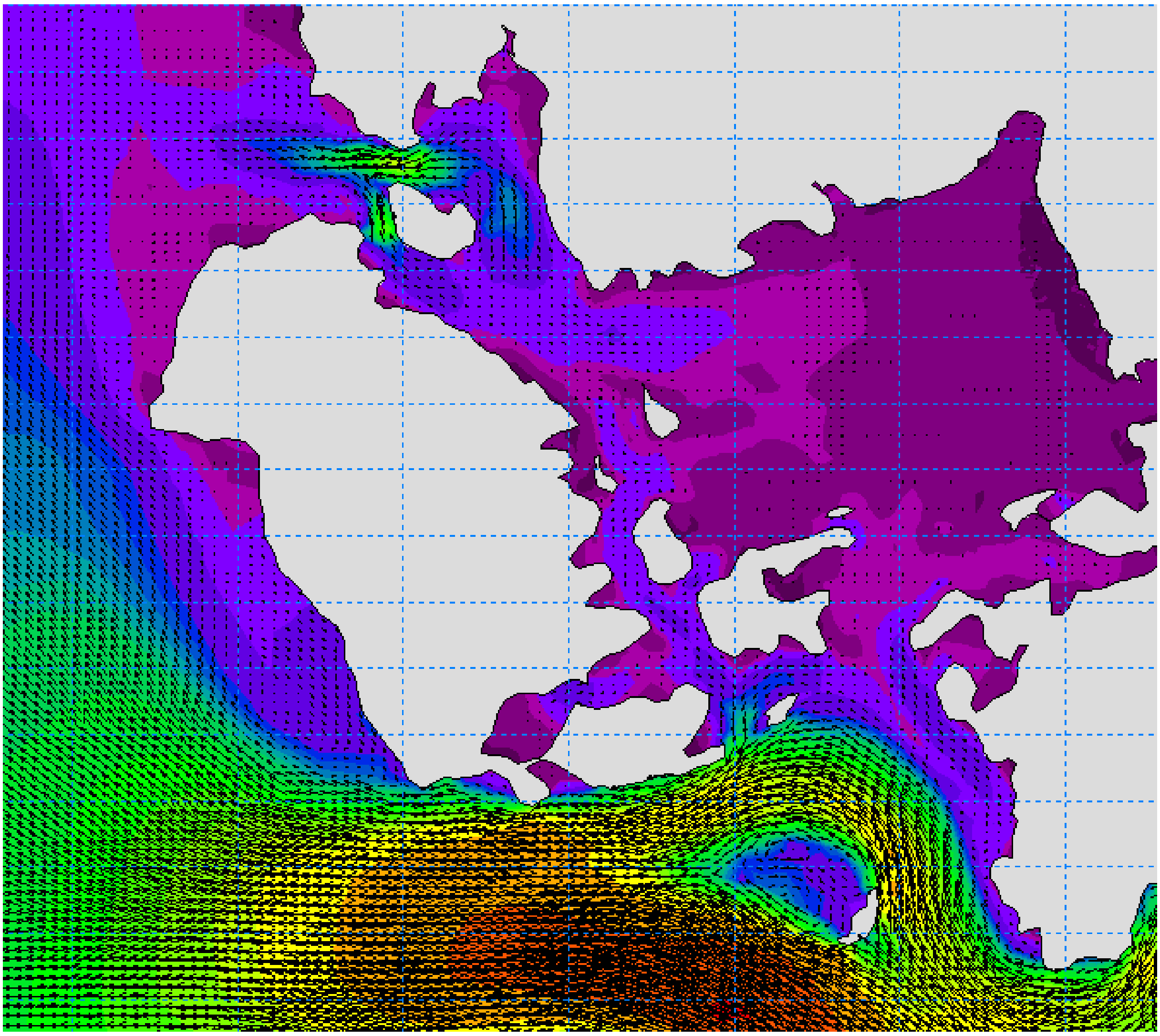
Scapa Flow Deep Water Quay
Coastal Hydrodynamic Modelling Study



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1 INTRODUCTION

1.1 Terms of Reference

EnviroCentre Ltd has been appointed by Orkney Islands Council Harbour Authority (OICHA) to undertake a Coastal Hydrodynamic Modelling Study in support of the Environmental Impact Assessment (EIA) of the proposed new deep water quay at Deepdale Bay, Scapa Flow, Orkney.

1.2 Scope of Report

This study aims to develop a coastal hydrodynamic (HD) model of Scapa Flow, to include Deepdale Bay as well as approaches and surrounding coastal waters. The model will enable simulation and characterisation of tidal flow under pre-development (baseline) and post-development conditions. This report will present details of the baseline coastal conditions at the development site, outline the HD model development, and describe the model simulations and results.

The study will also assess the potential dispersal of sediment plumes from the proposed capital dredging programme. The dredge plume dispersal assessment will involve the use of coupled HD and sediment transport modelling techniques.

1.3 Report Usage

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2 BASELINE CONDITIONS

2.1 Site Location, Existing Condition and Proposed Development

The proposed development site is located at Deepdale Bay, within Scapa Flow, to the south of Kirkwall, Orkney Mainland, as shown in Figure 2-1 and Figure 2-2 below.

The present-day site is undeveloped. The shoreline at the site consists of a rocky intertidal area with stretches of shingle along the upper beach. It lies below steep vegetated slopes, with short sections of vertical rocky cliffs, all less than 15 m high. Beyond the shoreline to the east is a mix of moorland and agricultural fields.

The development of Scapa Deep Water Quay comprises approx. 597m long main quayside berth with general -15m CD water depth, incorporating a 135m quayside pocket with -20m CD water depth. Further north tug (3No.) and pilot boat (2No.) berth approx. 180m long with depths between -6 and -9m CD. Laydown area directly behind quay face approx. 22.85 Hectares. There will also be an access road from the A961 to the site. The main purpose of this facility would be to undertake industrial activities that require both deep-water berthing and a large laydown area.

The proposed development layout is shown in Appendix A.

2.2 Topography and Bathymetry

Topographic and bathymetric survey data is available for the site and surrounds. Bathymetric levels slope from around +3.3 metres relative to Chart Datum (mCD) at the shoreline to around -11mCD at the western boundary of the proposed quay, and -40mCD further out in the centre of Scapa Flow. Bathymetric levels within the modelled extent of the Pentland Firth reach depths below -90mCD. Further information on wider bathymetry and data sources utilised within this modelling study is presented in section 3.3.1 of this report.

2.3 Tidal Water Levels

Tidal water levels at St Mary's, Scapa Flow as presented within the Admiralty tide tables are shown in Table 2-1[1]. The mean tidal range at St Mary's is 2.7m for spring tides and 1.7m for neap tides.

Table 2-1: Tidal water levels at St Mary's Scapa Flow

	Chart Datum (mCD)	Ordnance Datum (mOD)
Highest Astronomical Tide (HAT)	3.8	2.15
Mean High Water Springs (MHWS)	3.3	1.65
Mean High Water Neap (MHWN)	2.6	0.95
Mean Sea Level (MSL)	1.9	0.25
Mean Low Water Neap (MLWN)	1.4	-0.25
Mean Low Water Springs (MLWS)	0.6	-1.05
Lowest Astronomical Tide (LAT)	-0.1	-1.75

*Chart datum correction for Ordnance Datum is -1.65 (relative to OD at Newlyn)

[1] UK Hydrographic Office, 2023 (Admiralty Tide Tables – Volume 1B)

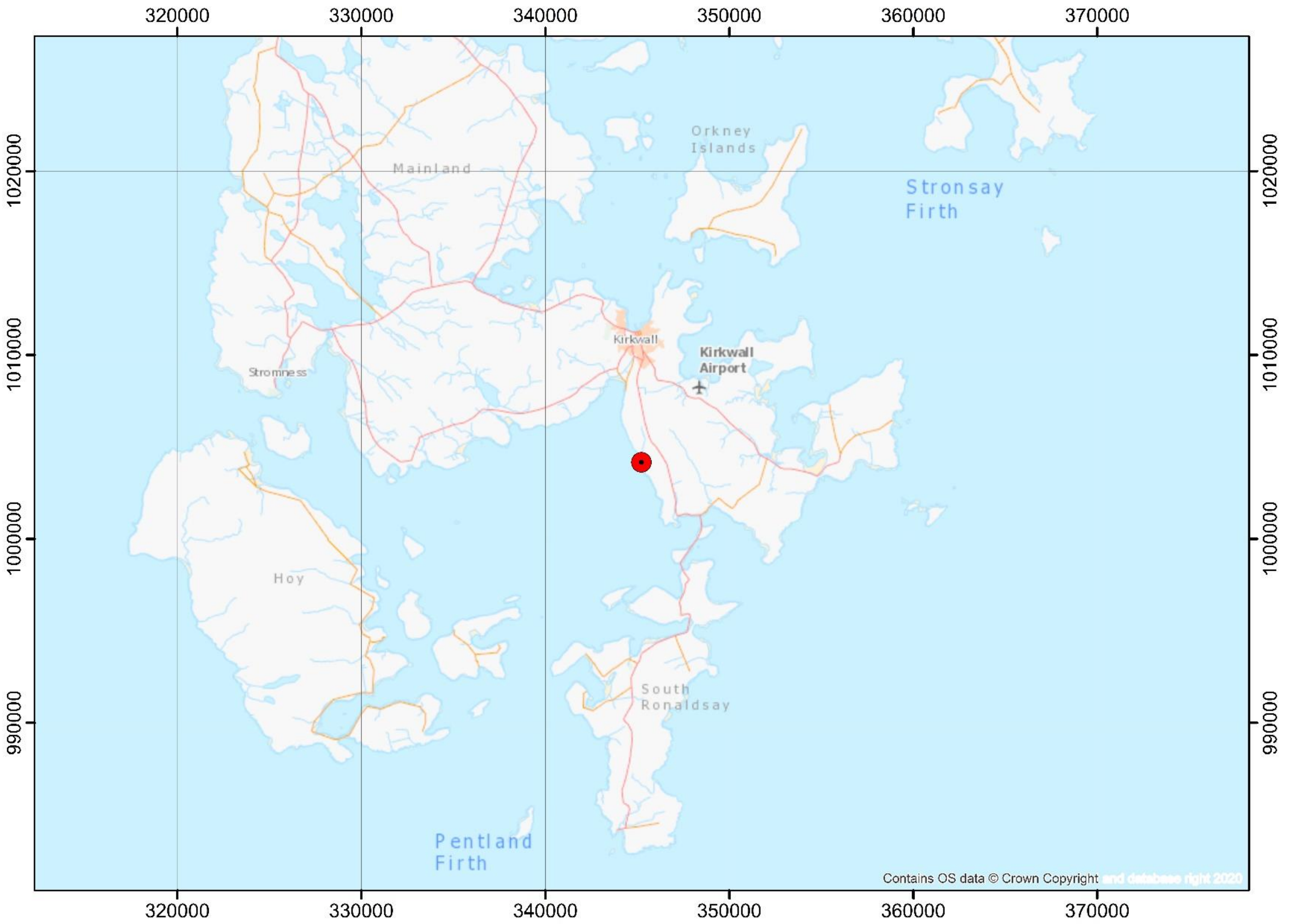

Figure 2-1: Site location shown by red dot

Figure 2-2: Site location within Scapa Flow shown by red dot

Figure 2-3: Satellite imagery of Deepdale Bay (2021)

2.4 Morphology and Geology

Tidal Currents are highest at the southern and western entrances to Scapa Flow, and rapidly dissipate into Scapa Flow, with currents generally weak, particularly so near to Deepdale bay. The relatively narrow openings to Scapa Flow restrict the penetration of swell and waves into Scapa Flow. The wave climate within Scapa Flow is therefore dominated by locally generated wind-waves[2].

Much of the coastline near to Deepdale Bay is fronted by shingle and sand beaches. The European Nature Information System (EUNIS) seabed habitat map shows the dominant seabed habitat around Deepdale Bay to be infralittoral mud and rock with biogenic reef[3]. Rock substrate is shown immediately west of the proposed development location, with gravelly muddy sand substrate located further into Scapa flow [4]. Sediment input to Scapa Flow is limited, with the Churchill Barriers preventing any sediment connectivity from the east. Due to the lack of sediment input, and weak tidal currents, there is therefore little littoral transport other than erosion of existing glacial deposits during extreme events[5].

Analysis of historical coastline alignments show that there have been no major changes to the coastline since 1890 and no significant erosion observed[6].

[2] Ramsay and Brampton, 2000. Coastal Cells in Scotland: Cell 10 – Orkney.
[3] EUNIS 2017 (https://emodnet.eu/en).
[4] Marine Scotland (https://marinescotland.atkinsgeospatial.com/nmpi/)
[5] Ramsay and Brampton, 2000. Coastal Cells in Scotland: Cell 10 – Orkney.
[6] Dynamic coast online map available at: http://www.dynamiccoast.com/webmap.html

3 HYDRODYNAMIC MODEL DEVELOPMENT

3.1 MIKE 21 Flow Model FM – Hydrodynamic (HD) Module

MIKE 21 Flow Model FM is a modelling package based on a flexible mesh (FM) structure, developed by the Danish Hydraulic Institute (DHI). The modelling system has been developed for applications within oceanographic, coastal and estuarine environments. The Hydrodynamic Module (HD) is the central computational component of the package, solving 2D shallow water equations. The module simulates unsteady flow taking account of bathymetry, sources and external forcing, it consists of continuity, momentum, temperature, salinity and density equations. The latest version of the software, MIKE 2023, has been used within this assessment.

3.2 Model Extent

A HD model has been developed, for which the model extent comprises the coastal waters of Scapa Flow, Hoy Sound, Hoy Mouth, the Sound of Hoxa, the Pentland Firth and North Atlantic as shown in Figure 3-1 below.

Initially the model extent included only the central channel of the Pentland Firth between Orkney and mainland Scotland. However, during the model validation process it was found that this did not sufficiently represent the complex inflow mechanisms into Scapa Flow through the Hoy Sound and the Sound of Hoxa. Expanding the model extents further to the west and east improved the accuracy of the model.

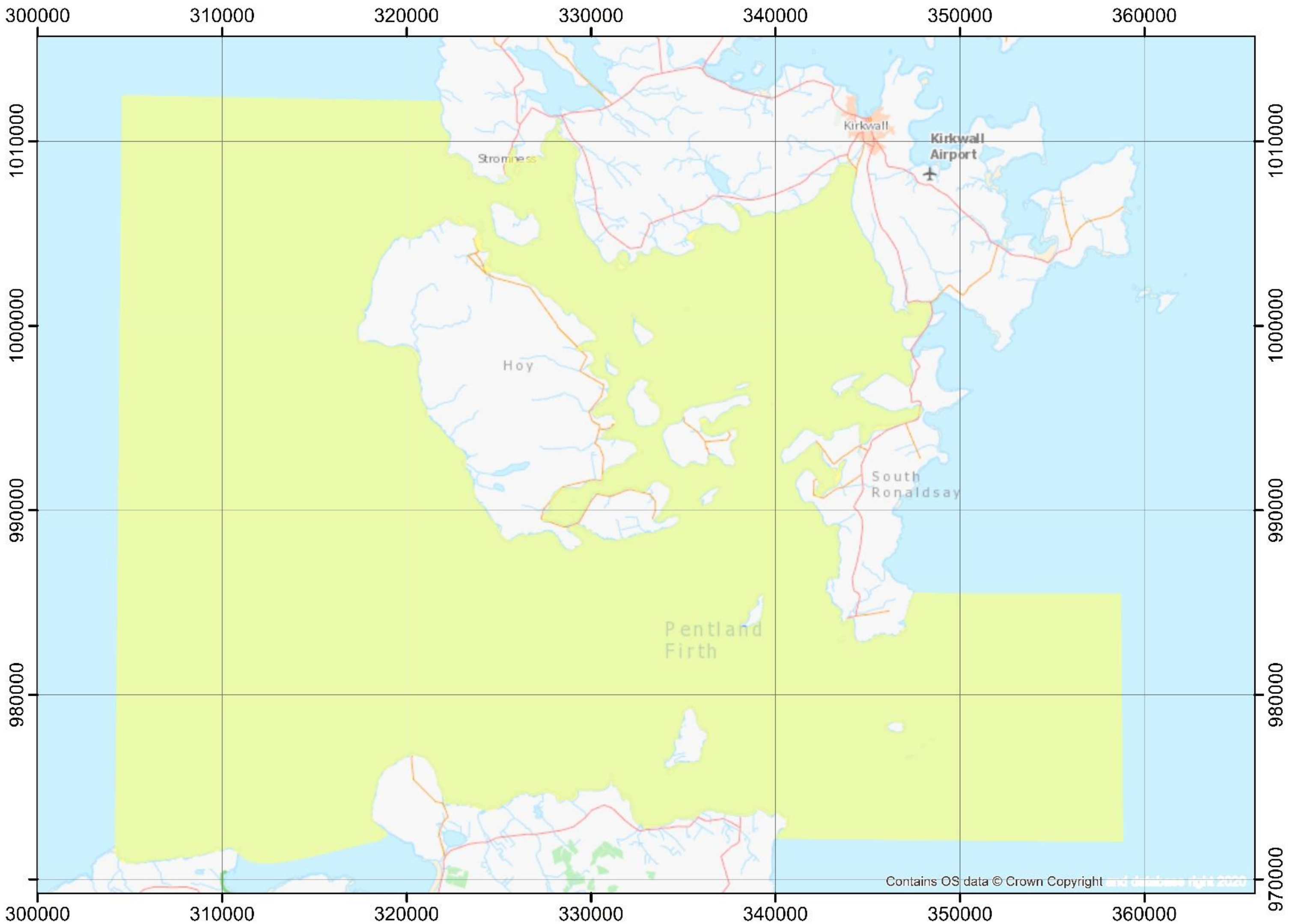

Figure 3-1: MIKE HD model extent (yellow polygon)

3.3 Input Data

3.3.1 Bathymetry

The following bathymetric data has been used within the modelling study:

- UK Hydrographic Office (UKHO) Bathymetric Survey[7]
  - Approaches to Lyness (2007);
  - Flotta (2022);
  - Longhope (2009 – 2010);
  - Scapa Bay 05 (2000 – 2006);
  - Scapa Bay 06 (2000 – 2006);
  - Scapa Flow Area 2a, 2m resolution (2009 – 2010);
  - Scapa Flow Area 2a, 4m resolution (2009 – 2010);
  - Scapa Flow Deepdale (2020 – 2021);
  - Scapa Flow Main Burra, 2m resolution (2009 – 2010).
- European Marine Observation and Data Network (EMODnet) Digital Bathymetry (DTM) - 2020[8]

The datasets have been used to create a combined Digital Terrain Model (DTM) for use within the hydrodynamic model. Snapshots of the DTM with bathymetry displayed relative to Chart Datum are presented in Figure 3-2 and Figure 3-3 below.

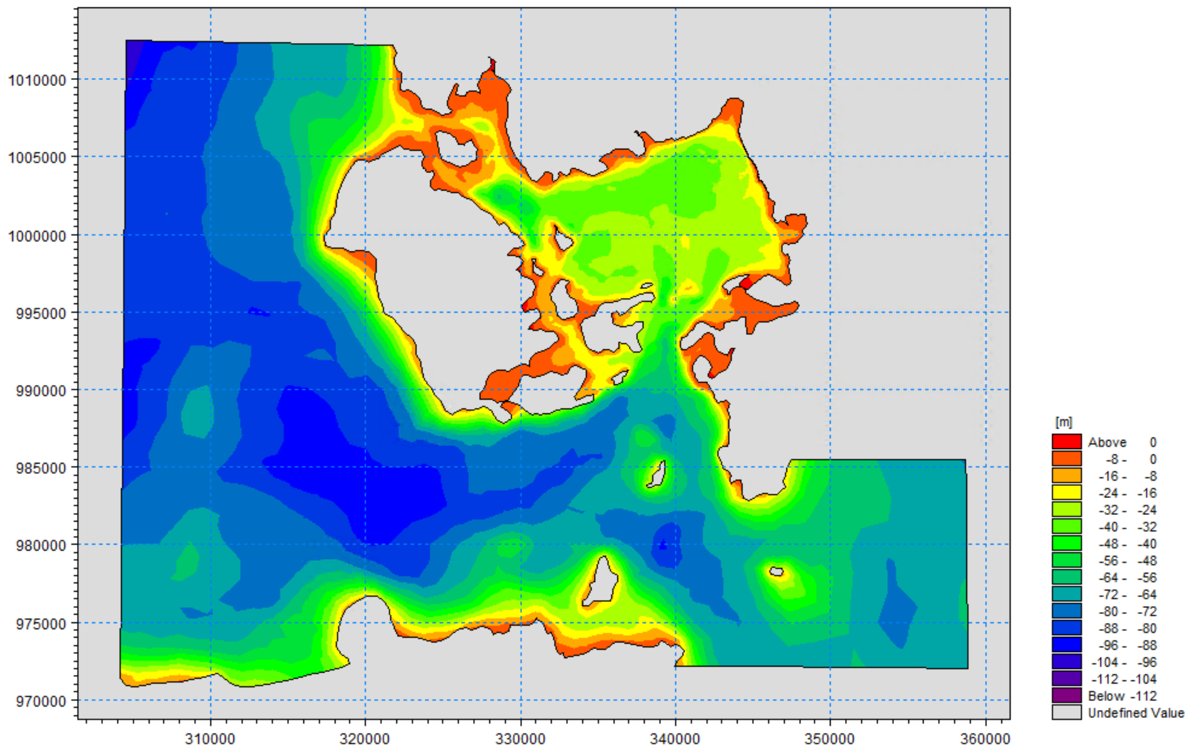

Figure 3-2: Bathymetry across model extent

[7] Admiralty Maritime Data Solutions: Seabed Mapping Service (https://seabed.admiralty.co.uk/?x=-331303.94&y=8185863.95&z=10.08)

[8] European Marine Observation and Data Network (EMODnet) Bathymetry (https://emodnet.ec.europa.eu/en/bathymetry)

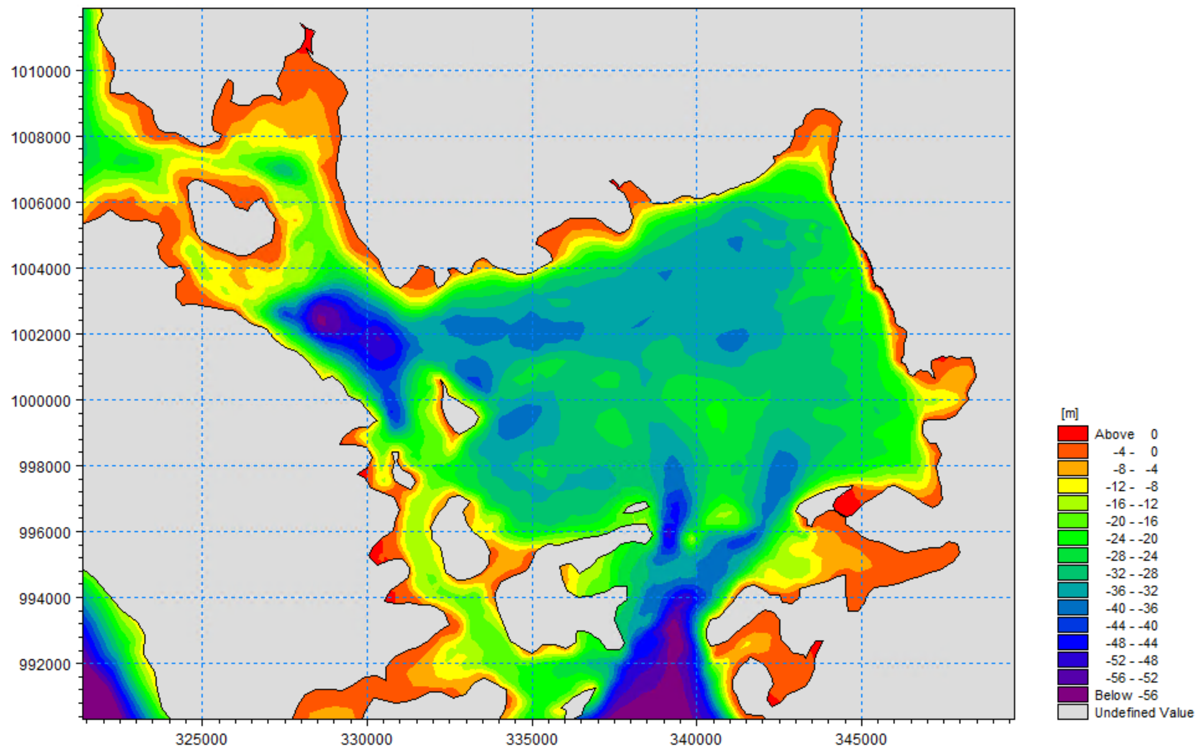

Figure 3-3: Bathymetry within Scapa Flow

3.3.2 Tidal Boundary Conditions

There are five tidal boundaries within the model extent. Two are in the west and north west which extend from the Orkney Mainland to the Scottish Mainland west of Thurso, and three are in the south east, linking the Orkney Mainland to the Scottish Mainland just south of John O'Groats, as shown in Figure 3-4.

Tidal boundary conditions for the HD model have been extracted from the DHI MIKE 21 Global Tide Model. This provides 0.125 x 0.125 degree resolution, 15 minute interval, tidal level data along the open model boundaries.

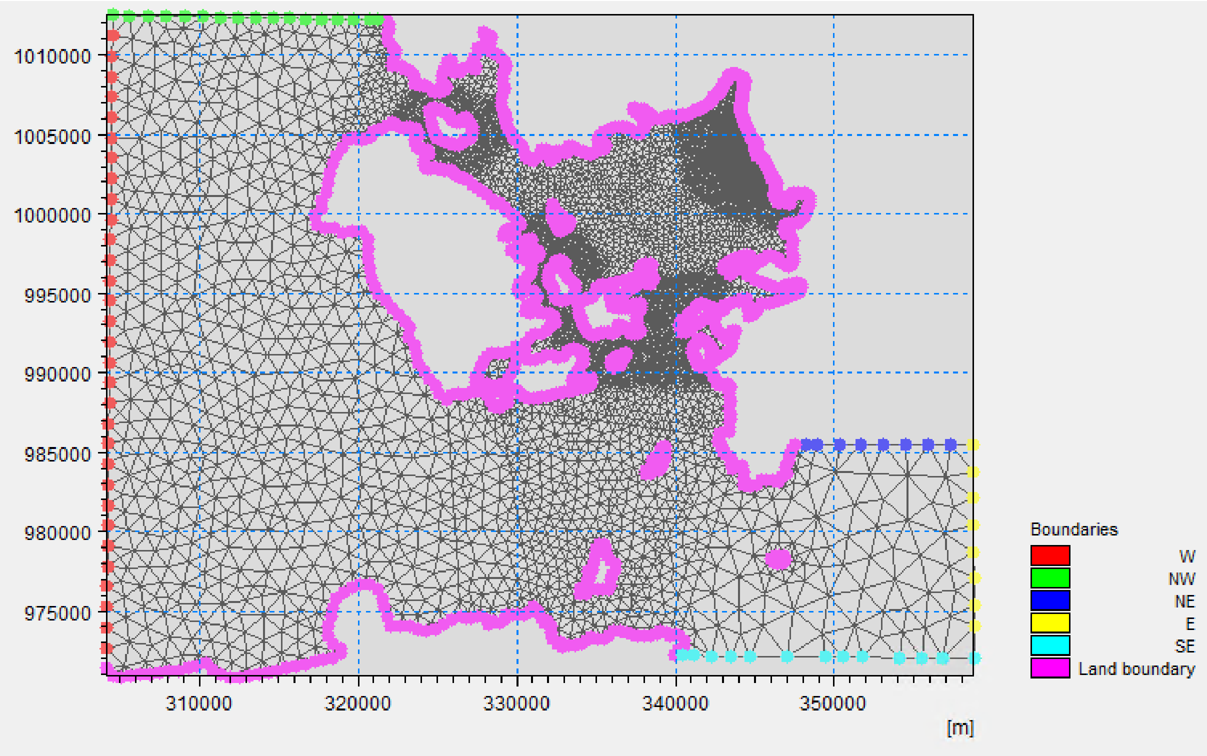

Figure 3-4: HD model boundaries

3.4 Model Mesh

The model utilises a flexible mesh to represent the offshore and coastal areas. The flexible mesh is composed of triangles of varying size and can therefore represent complex coastal alignments or bathymetry accurately.

The baseline model mesh extent and bathymetry are shown in Figure 3-5 below. The mesh has been generated using the bathymetric data described in section 3.3.1. The mesh has progressive refinement in resolution towards Deepdale Bay, becoming finer in the area of interest, as shown in Figure 3-6 and Figure 3-7. Finer mesh regions have also been used to represent areas near the Hoy Sound and Sound of Hoxa, where narrow channels and small islands influence coastal inflows into Scapa Flow. Key characteristics of the baseline mesh are summarised in Table 3-1.

Table 3-1: Baseline HD mesh characteristics

Mesh Characteristic	Value
Number of elements	46,424
Number of nodes	23,990
Min. Z level (mCD)	-100.59
Max. Z level (mCD)	+2.04
Max triangular area at Deepdale	75m^2 (approx. 8.5m resolution)

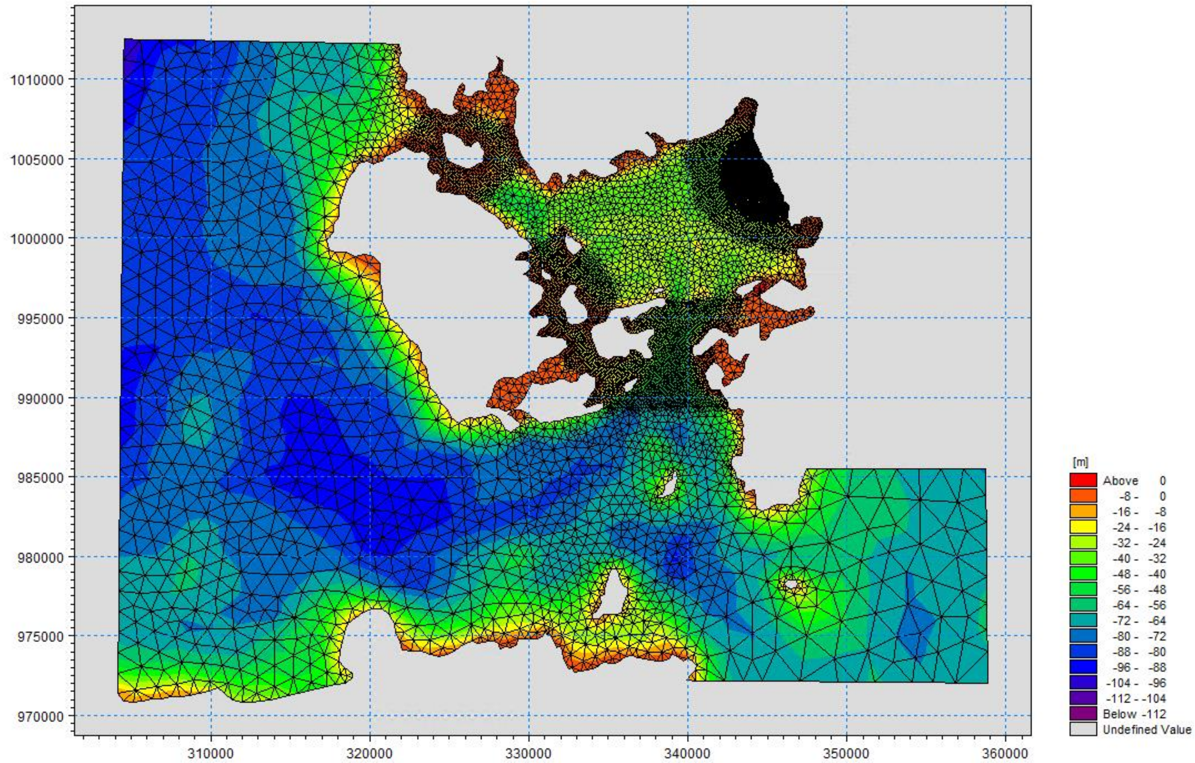

Figure 3-5: Baseline HD model mesh full extent

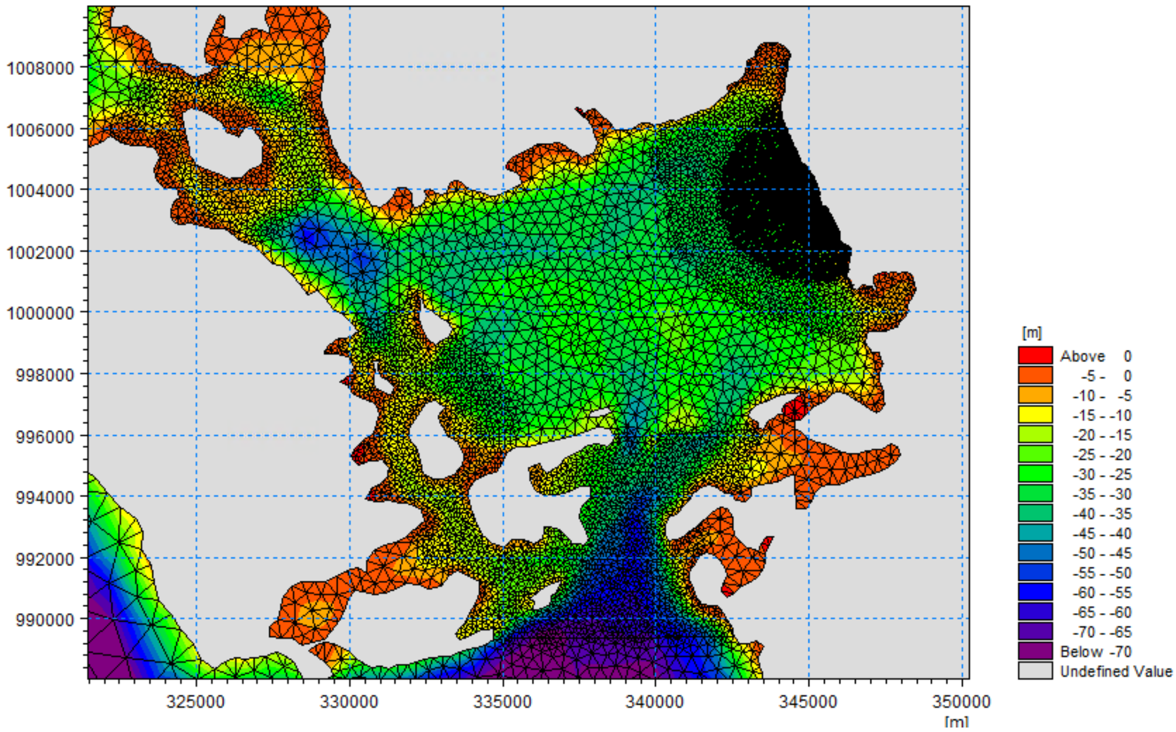

Figure 3-6: Baseline HD model mesh Scapa Flow

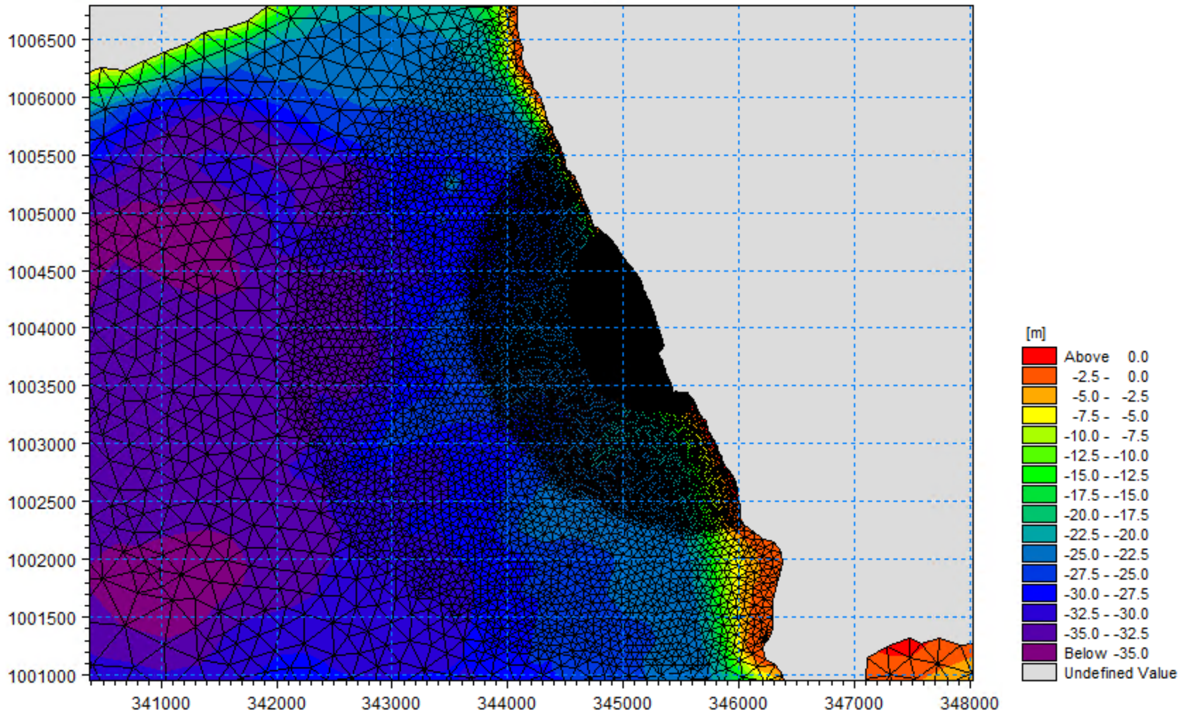

Figure 3-7: Baseline HD model mesh Deepdale Bay

A post-development version of the HD model mesh has been generated to include the proposed development footprint, as shown in Figure 3-8. The bathymetry for the post-development mesh was also updated to include the proposed dredge pockets. The proposed development layout is shown in Appendix A.

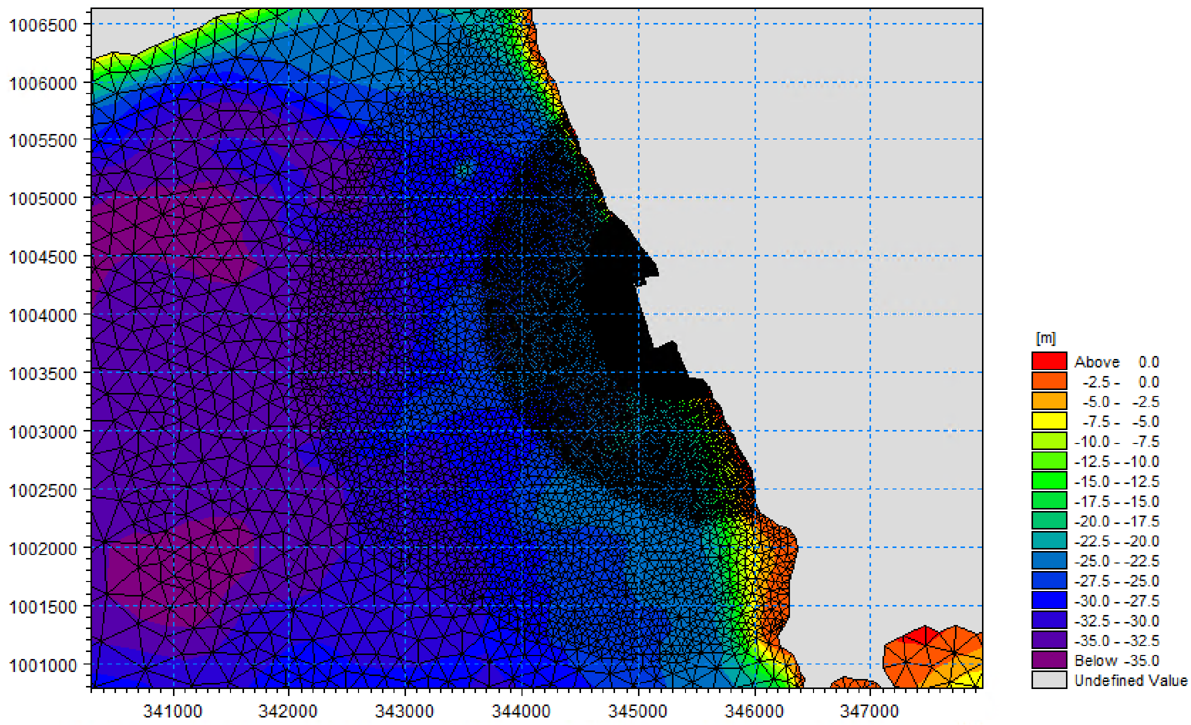

Figure 3-8: Post-development HD model mesh Deepdale Bay

3.5 Model Setup

Further details of the MIKE 21 FM HD model setup are provided below:

- For each model simulation the modelled extent includes the entire mesh as described in section 3.4;
- Open boundary time-varying tidal water level conditions have been derived from the DHI MIKE 21 Global Tide Model as described in section 3.3.2;
- Further model parameters are detailed below:
    - Simulation time-step interval: 300s
    - Model solution technique: Higher order shallow water equations
    - Model solution time-step: Minimum (0.01s) Maximum (30s)
    - Drying depth: 0.02m
    - Wetting depth: 0.1m
    - Bed resistance: 28.8m$^{(1/3)}$/s

A wind forcing sensitivity simulations were undertaken using wind data extracted from the COSMO Reanalysis 6km (CREA6) nonhydrostatic limited-area atmospheric prediction model via the DHI Metocean data portal[9]. For the sensitivity simulations the wind forcing data was applied as varying in time and constant across the model domain.

The modelling has been undertaken with the following computing specification:

- Dell Precision 5820 Tower:
    - 64GB RAM;
    - Utilising 14 Cores – Intel Xeon CPU (2.5GHz);
    - Windows 10 Pro 64-bit operating system.

3.6 Model Outputs

The MIKE 21 FM HD model simulations have been setup to produce results as both point and area outputs. The outputs include the following key parameters:

- Water surface elevation;
- Current speed;
- Current direction; and
- Bed shear stress

The area outputs are generated for the whole model extent, whilst point outputs have been generated at 20 identified locations within the model extent as detailed in Table 3-2. The locations of point outputs are situated within the immediate vicinity of Deepdale bay and the proposed development including the capital dredge pockets. Points are also situated out into the wider Scapa flow Area with a point at St Marys Bay to provide reference with Admiralty tide predictions. Point output locations are shown in Figure 3-9 and Figure 3-10.

[9] https://www.metocean-on-demand.com/metadata/waterdata-dataset-Europe_CREA6_V2

Table 3-2: HD Model point output locations

Point Output Location	Easting	Northing
Point 1	345014	1003771
Point 2	345123	1003631
Point 3	345064	1003833
Point 4	345013	1004005
Point 5	344962	1004173
Point 6	344925	1004296
Point 7	344949	1003980
Point 8	344896	1004149
Point 9	344859	1004287
Point 10	345065	1003566
Point 11	345154	1003560
Point 12	345248	1003594
Point 13	344914	1004381
Point 14	345028	1004417
Point 15	345180	1003110
Point 16	344363	1003771
Point 17	344586	1004687
Point 21	343093	1005047
Point 22	344343	1002099
Point 23	347449	1000234

Figure 3-9: HD model point output locations

Figure 3-10: HD model point output locations local to development site

3.7 Model Simulations

The key model simulations undertaken using the MIKE 21 FM HD model are presented in Table 3-3.

Table 3-3: HD model simulations

HD Model Simulation	Description
Scapa FM HD 16	Baseline HD model simulating existing (pre-development) conditions. Run for January 2022 tidal cycle, including spring and neap tides.
Scapa FM HD 17	Baseline HD model with wind forcing simulating existing (pre-development) conditions. Run for January 2022 tidal cycle, including spring and neap tides.
Scapa FM HD 19	Post-development HD model simulating conditions with proposed development in place. Run for January 2022 tidal cycle, including spring and neap tides.
Scapa FM HD 20	Post-development HD model with wind forcing simulating conditions with proposed development in place. Run for January 2022 tidal cycle, including spring and neap tides.

3.8 Model Validation

Validation of the model has been undertaken through comparison of baseline modelled tidal levels with Admiralty tide predictions (UKHO, 2022) for the same tide, at St Mary's. This comparison highlights that the model predicts levels within 0.05m of the Admiralty predicted levels.

Additionally, tidal current speeds predicted by the baseline model have been compared to annotated tidal stream speeds on UKHO hydrographic charts for Scapa Flow and surrounds, with model peak current speed predictions lying within the published range of current speed.

Given the results of the above validation exercise the model is therefore considered to perform well.

4 HYDRODYNAMIC MODEL RESULTS

A summary of the results from the existing (baseline) model run (FM HD 16) are presented in Section 4.1, whilst a summary of results from the post-development model run (FM HD 18) are presented in Section 4.2, along with comparative analysis versus the baseline model results. Appendix B contains tabulated model results under existing and post-development conditions for key tidal states, with relative change between both scenarios also tabulated. Appendix C contains graphical comparisons between existing and post-development results for the point output locations identified in Figure 3-9.

4.1 Existing (Baseline) Conditions

Model run FM HD 16 simulates existing (baseline) tidal conditions within Scapa Flow including at Deepdale Bay and surrounds from 1 January 2022 until 17 January 2022, capturing a full spring and neap tide cycle. The following sub-sections present the results of this simulation split by key outputs, tidal water surface elevation, tidal currents, and bed shear stress. Tabulated results are presented in Appendix B.

4.1.1 Tidal Water Surface Elevation

Tidal water surface elevation predictions relative to chart datum at point output locations 4 and 16 (see Figure 3-10) are presented in Figure 4-1 for the full FM HD 16 run duration. Review of these figures highlights that the same levels are predicted at both point output locations. The figures show a semi-diurnal tidal curve, with two high tides and two low tides each day, as is the case around the UK.

The highest predicted tidal elevation is +3.55mCD during a spring tide on 4th January 2022, with a lowest tidal elevation prediction of +0.42mCD on the same day. These values are within 0.05m and 0.02m of the corresponding Admiralty Tide Tables[10] predictions respectively for the same tide. Neap tides are also present within the simulated tidal curve. A neap high tide elevation of +2.54mCD is predicted on 11th January 2022, with a corresponding low tide elevation of +1.39mCD. Therefore the largest simulated spring tidal range at Deepdale Bay is 3.13m and with a simulated neap tidal range of 1.15m. Comparison with the mean tidal ranges for St Mary’s outlined in section 2.3, highlights that the simulated tidal curve includes spring tides larger, and neap tides smaller, than the mean spring and neap tides.

Figure 4-2 presents spatial plots of predicted tidal water surface elevation across the HD model extent for key phases of a spring tide, whilst Figure 4-3 presents the corresponding plots for a neap tide. Review of these figures shows the spatial variation across the model extent, highlighting the progression of the tidal wave approximately from north-west to south-east during the flood tide, and in reverse during the ebb tide.

[10] UK Hydrographic Office, 2022 (Admiralty Tide Tables – Volume 1B)

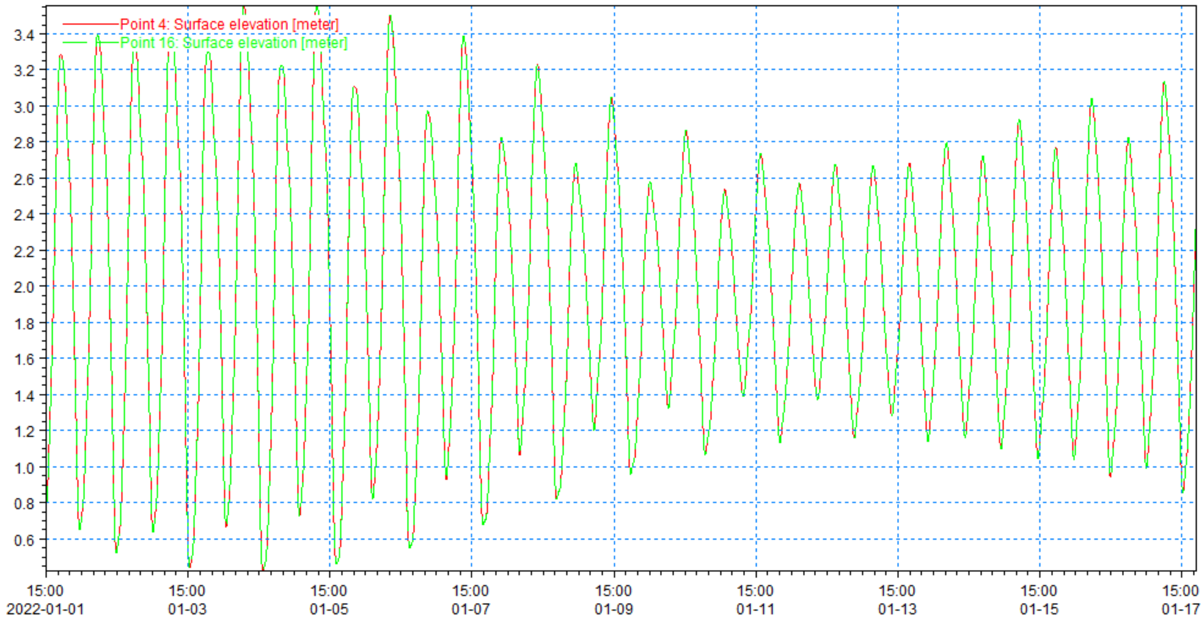

Figure 4-1: FM HD 16 water surface elevation predictions at points 4 and 16 for run duration.

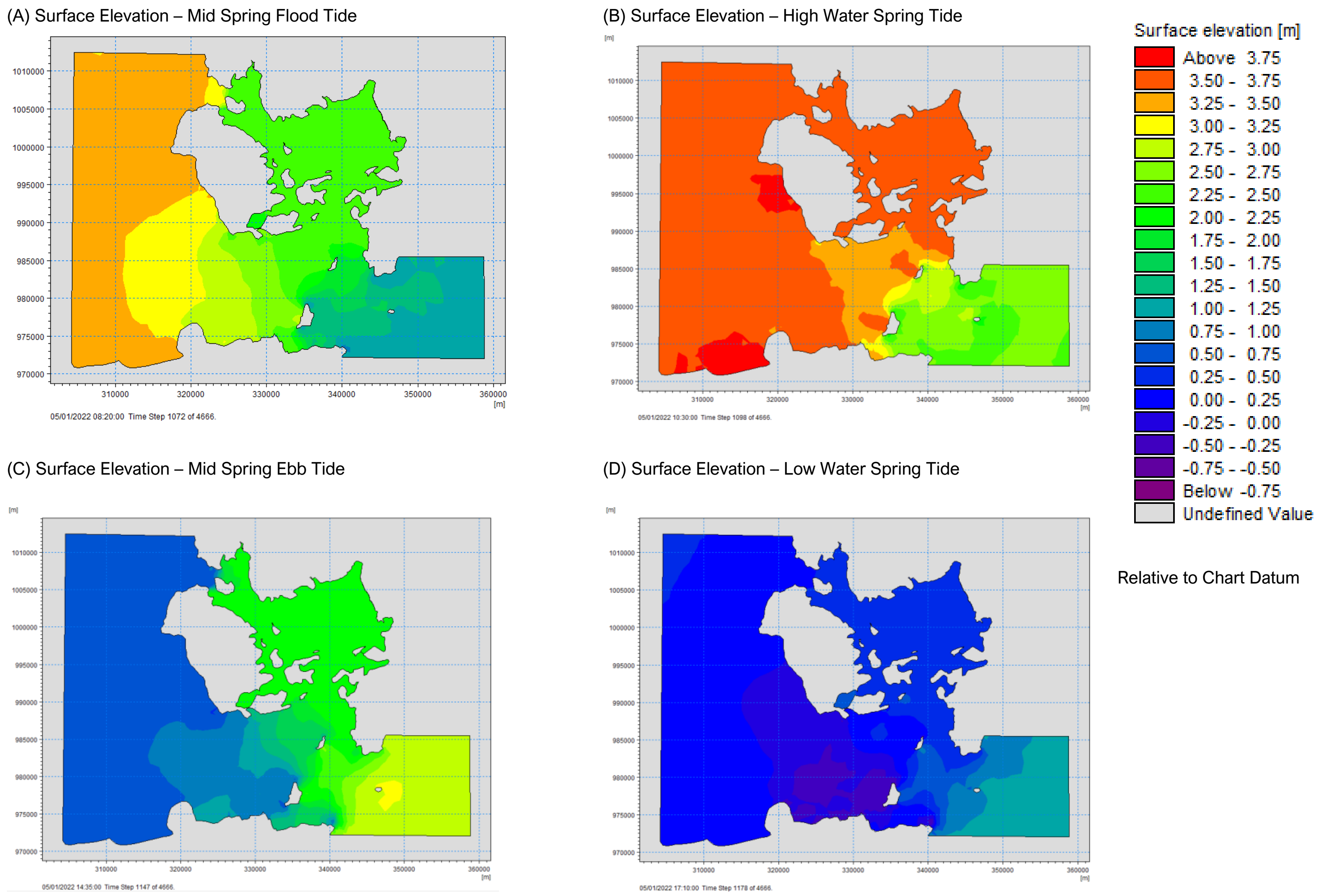

Figure 4-2: FM HD 16 water surface elevation (A) mid-flood (B) high (C) mid-ebb (D) low spring tide

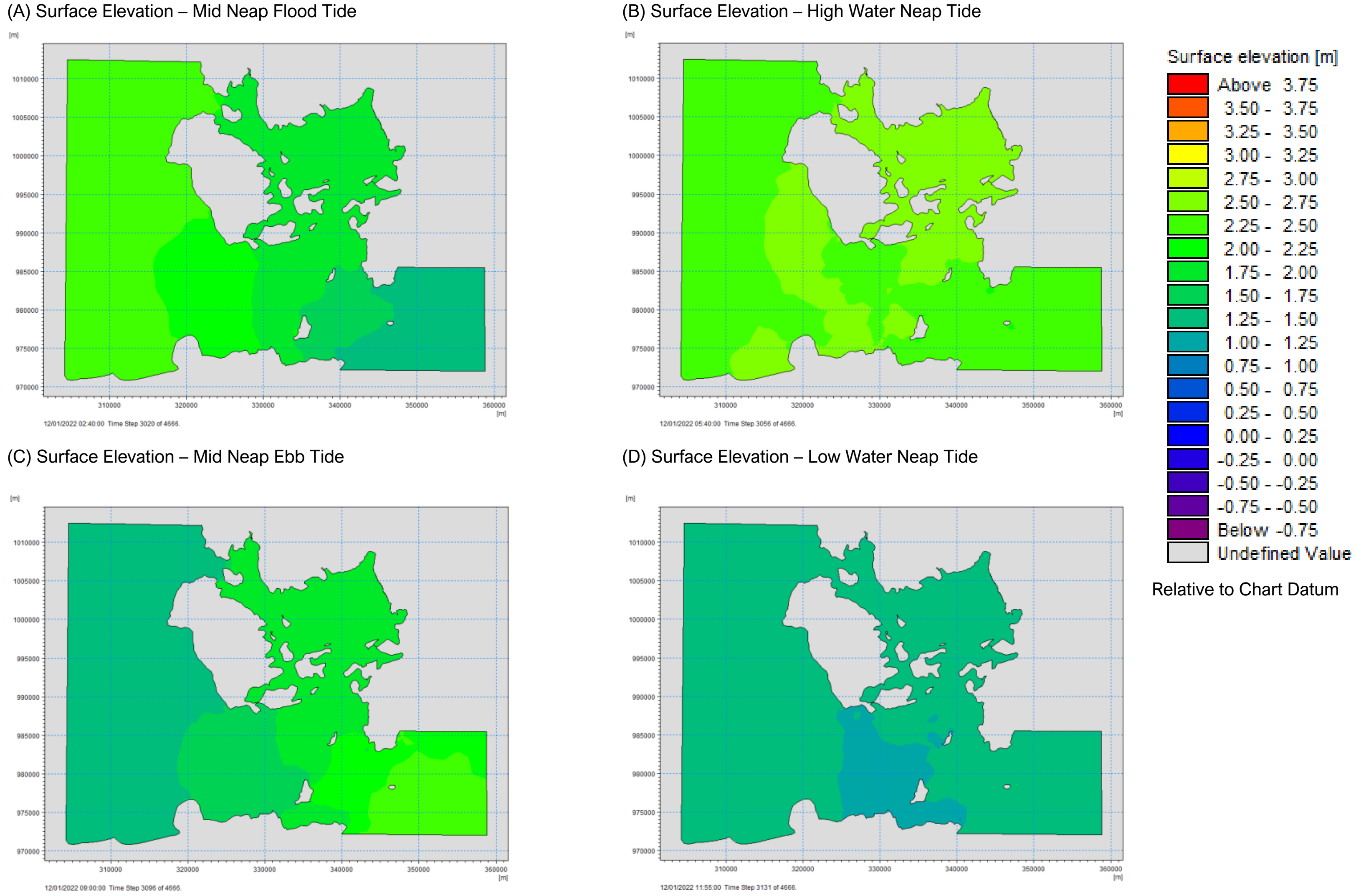

Figure 4-3: FM HD 16 water surface elevation (A) mid-flood (B) high (C) mid-ebb (D) low neap tide

4.1.2 Tidal Currents

Tidal current speed predictions for point output locations 4, 16 and 22 are presented in Figure 4-4 for the full FM HD 16 run duration including the spring and neap tide cycle, and in Figure 4-5 for a selected spring tidal cycle. Review of these figures highlights the relatively weak currents (<0.03m/s) present in throughout locations in Scapa Flow during spring tides.

Figure 4-5 shows the spring tidal current predictions at locations 4, 16 and 22. Review of this figure illustrates the complex and irregular phasing of tidal currents at Deepdale Bay. Whilst all currents are relatively weak, the strongest currents at these particular locations correlate with the incoming peak flood tides, whilst there is not such a clear correlation between tidal phase and current speed during the subsequent ebb tides. In other locations a stronger correlation is observed with the ebb tide. It is considered that due to the complex structure of Scapa Flow, with numerous bays and islands, that local flow patterns and eddies influence the position and speed of currents within Deepdale Bay.

Figure 4-6 presents model extent plots of tidal current speed for mid-flood and ebb conditions, during both spring and neap tides. Review of this figure highlights the spatial variation across the model extent, with the dominant tidal stream within the Pentland Firth travelling north-west to south-east through the model extent, and other focused tidal streams through the narrow channels between islands, for example at the Hoy Sound. Weakest currents are observed to occur the sheltered regions of Scapa Flow, including in the vicinity of the proposed development location of Deepdale Bay.

Figure 4-7 to Figure 4-10 present similar plots focussed on Deepdale Bay and surrounds, with current vector arrows shown to indicate tidal stream direction. Current vectors highlight the direction of the flood tide, circulating generally from north-west to south-east through Scapa Flow and parallel to the shore in the vicinity of Deepdale Bay, and the ebb tide circulating in the opposite direction. The figures further highlight the low current speeds within Scapa Flow, with slightly higher currents observed further out into the bay than at the nearshore locations. Figure 4-11 presents a residual current speed plot comparison between mid-ebb and mid-flood spring tidal currents in the vicinity of Deepdale Bay. Review of this figure highlights the marginal dominance of ebb currents, with the exception of the nearshore area where there is little difference observed.

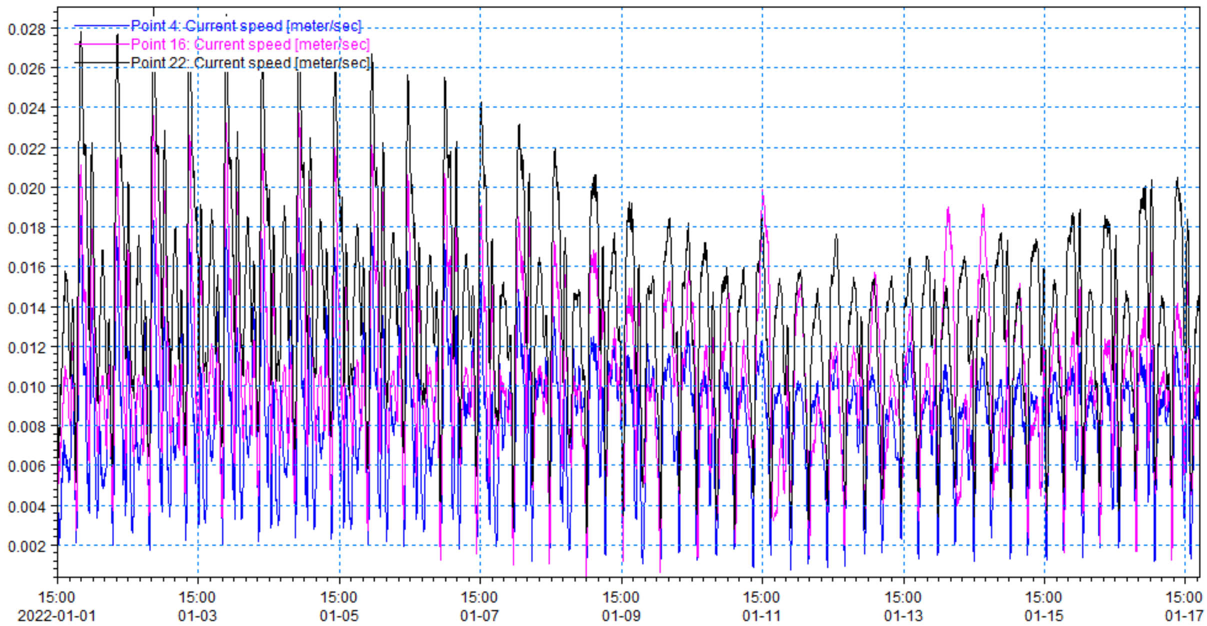

Figure 4-4: FM HD 16 current speed predictions at points 4, 16 and 22 for spring and neap cycle

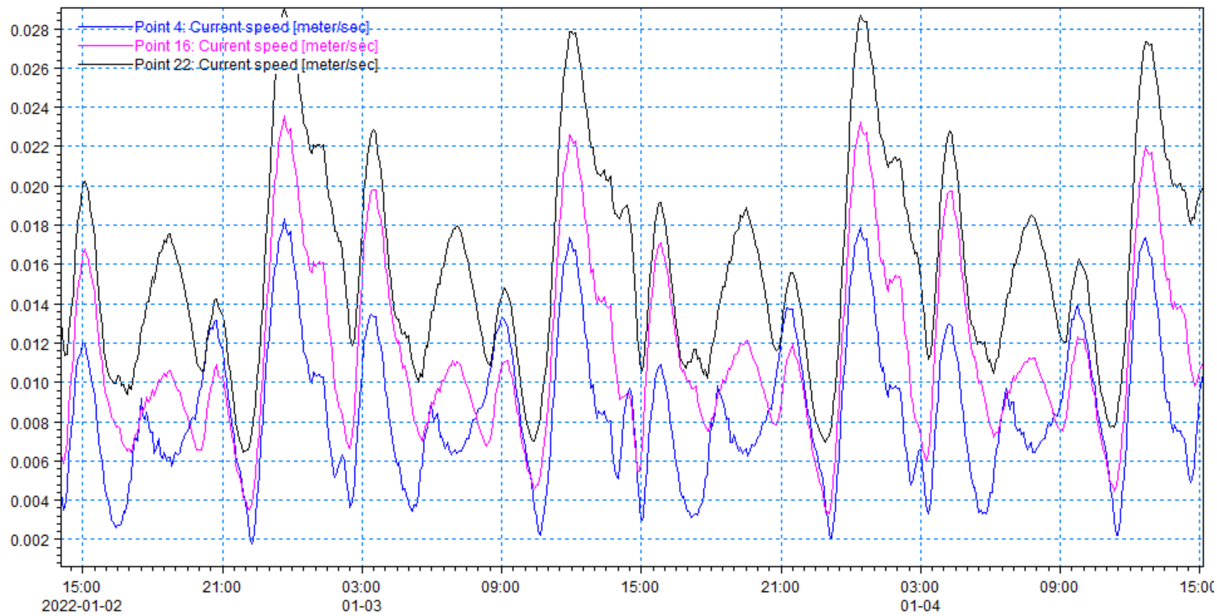

Figure 4-5: FM HD 16 current speed predictions for points 4, 16, 22 for spring tide

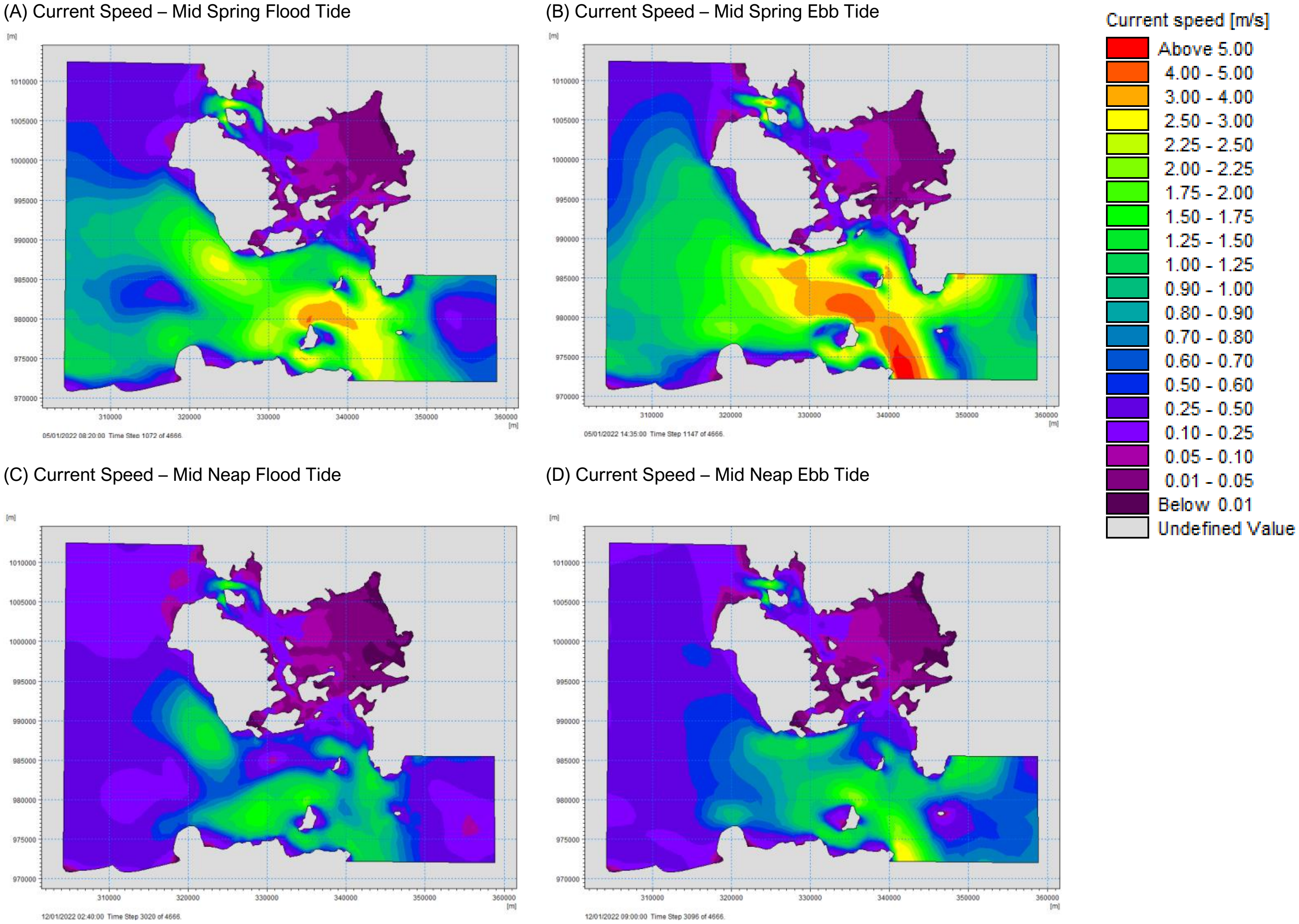

Figure 4-6: FM HD 16 current speed (A) mid-flood spring (B) mid-ebb spring (C) mid-flood neap (D) mid-ebb neap tide

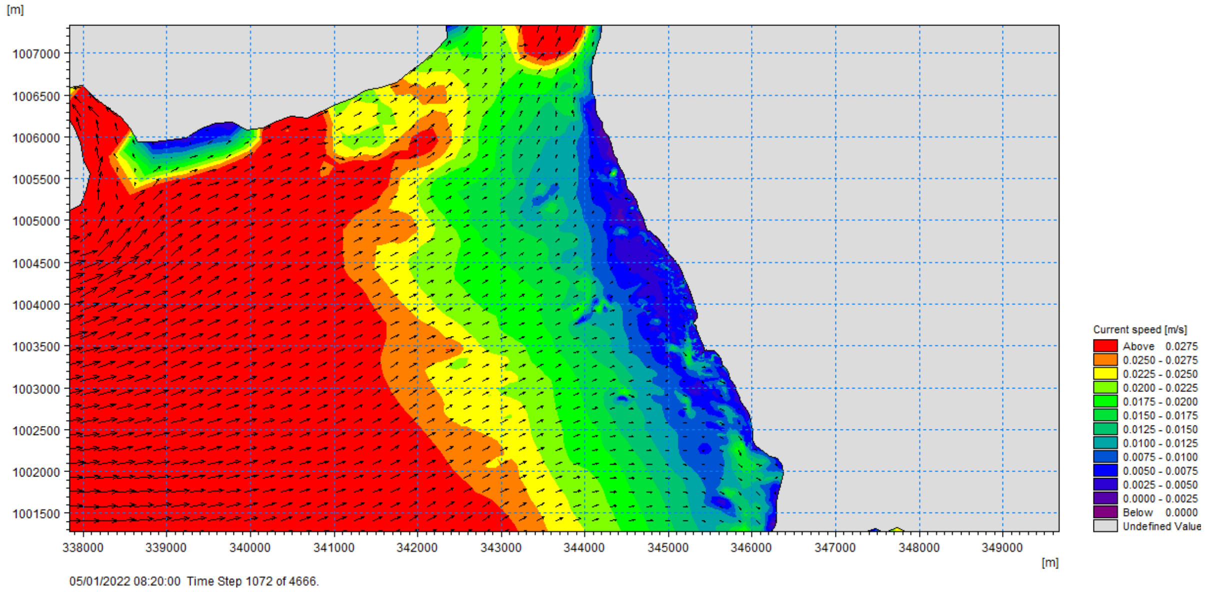

Figure 4-7: FM HD 16 Deepdale Bay and surrounds current speed mid-flood spring tide

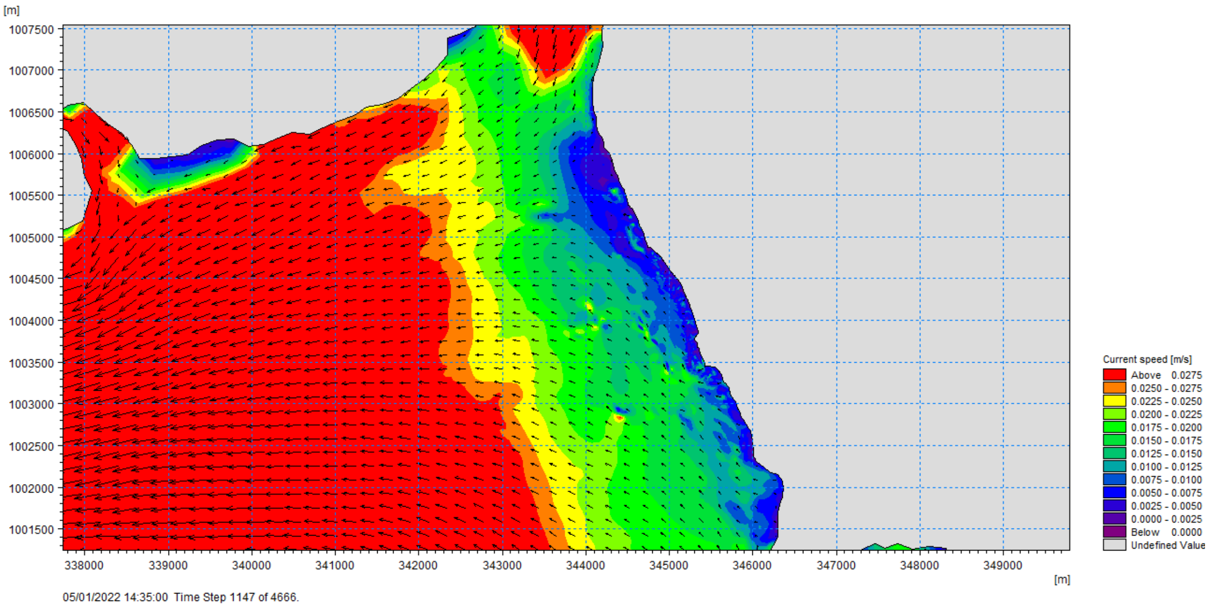

Figure 4-8: FM HD 16 Deepdale Bay and surrounds current speed mid-ebb spring tide

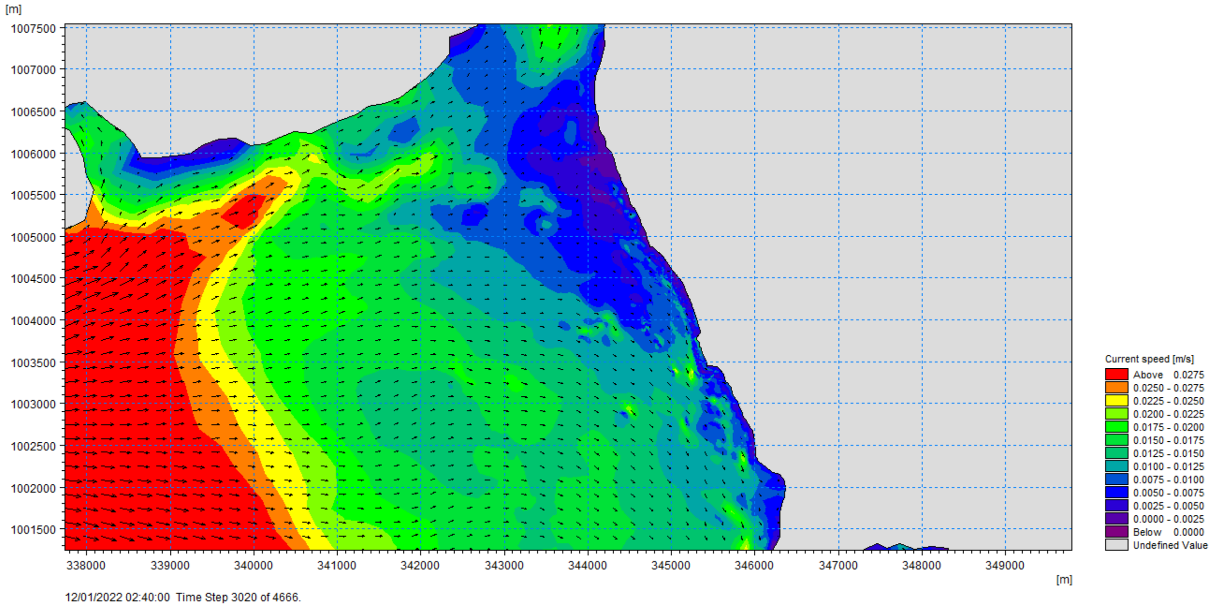

Figure 4-9: FM HD 16 Deepdale Bay and surrounds current speed mid-flood neap tide

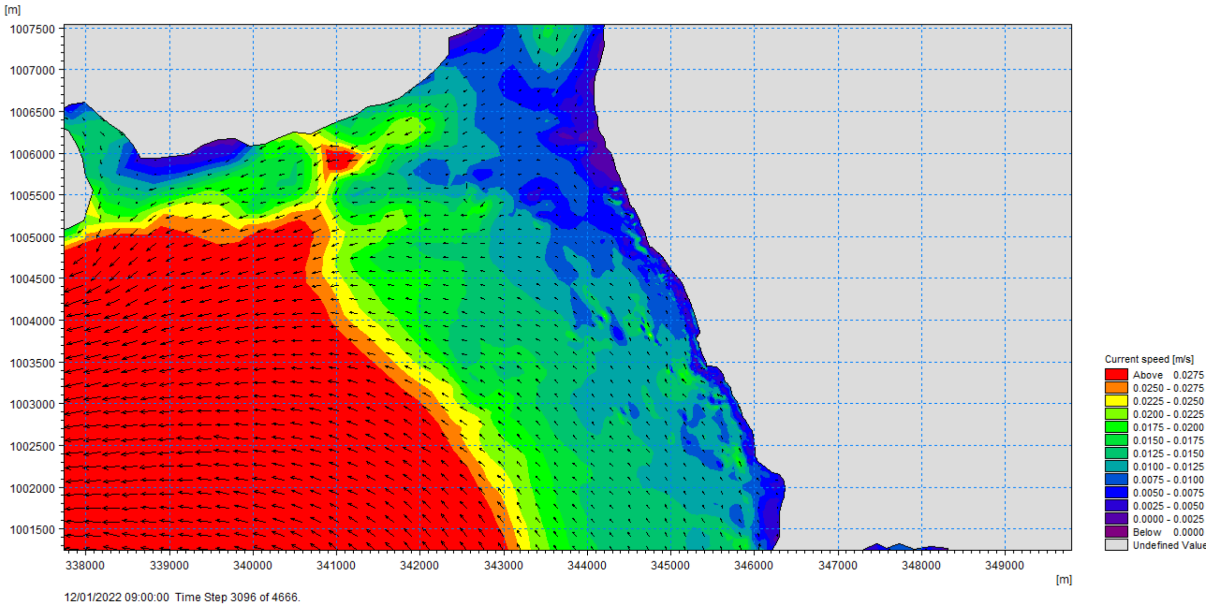

Figure 4-10: FM HD 16 Deepdale Bay and surrounds current speed mid-ebb neap tide

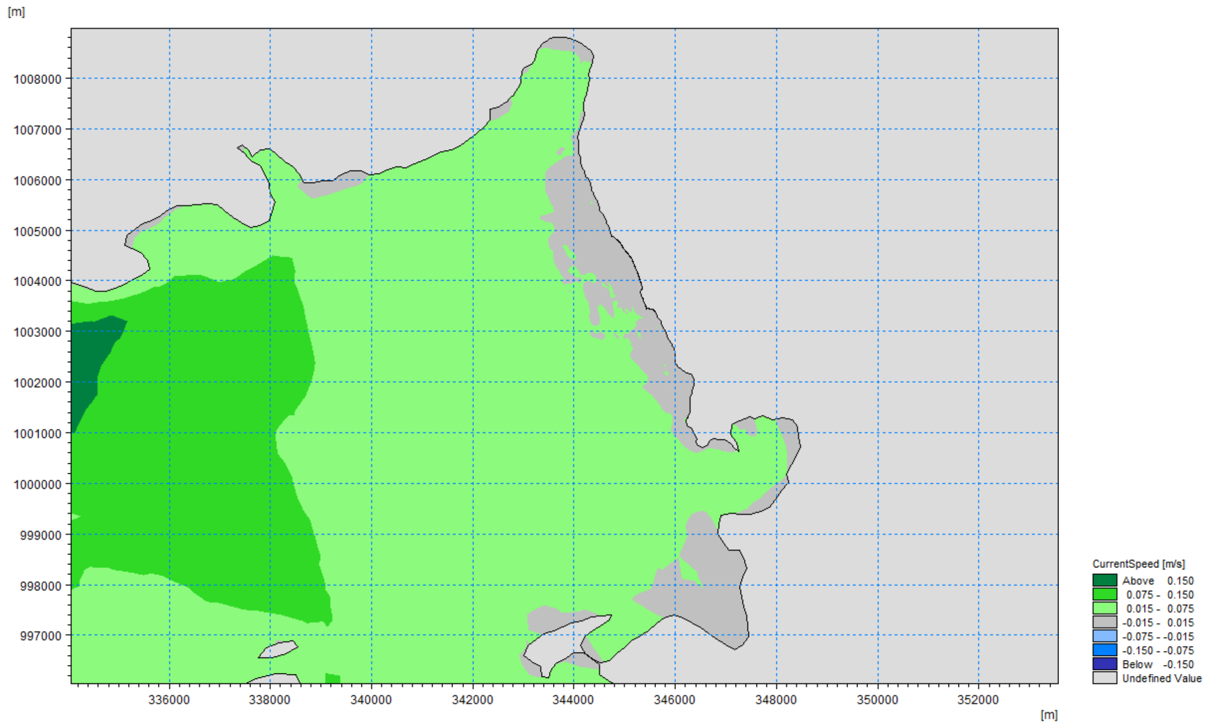

Figure 4-11: FM HD 16 spring tide residual current speed (mid-ebb minus mid-flood)

4.1.3 Bed Shear Stress

Figure 4-12 presents model predictions of bed shear stress during the spring and neap tidal cycle for point output locations 2, 4, 6, 7, 9 and 10 around the proposed development and Deepdale Bay. All locations show generally low bed shear stress, as would be anticipated with the weak tidal currents observed. Peak bed shear stress predictions are around 0.003 N/m^2 during spring tides.

Figure 4-13 shows bed shear stress alongside current speed for location 4. Review of this figure highlights that bed shear stress is correlated with tidal current speed, with peak shear stress occurring with peak current speeds. The low current speeds and corresponding low bed shear stresses are considered indicative of a low energy environment, given this and the absence of significant sediment inputs, no significant sediment transport by tidal currents predicted in the vicinity of Deepdale Bay.

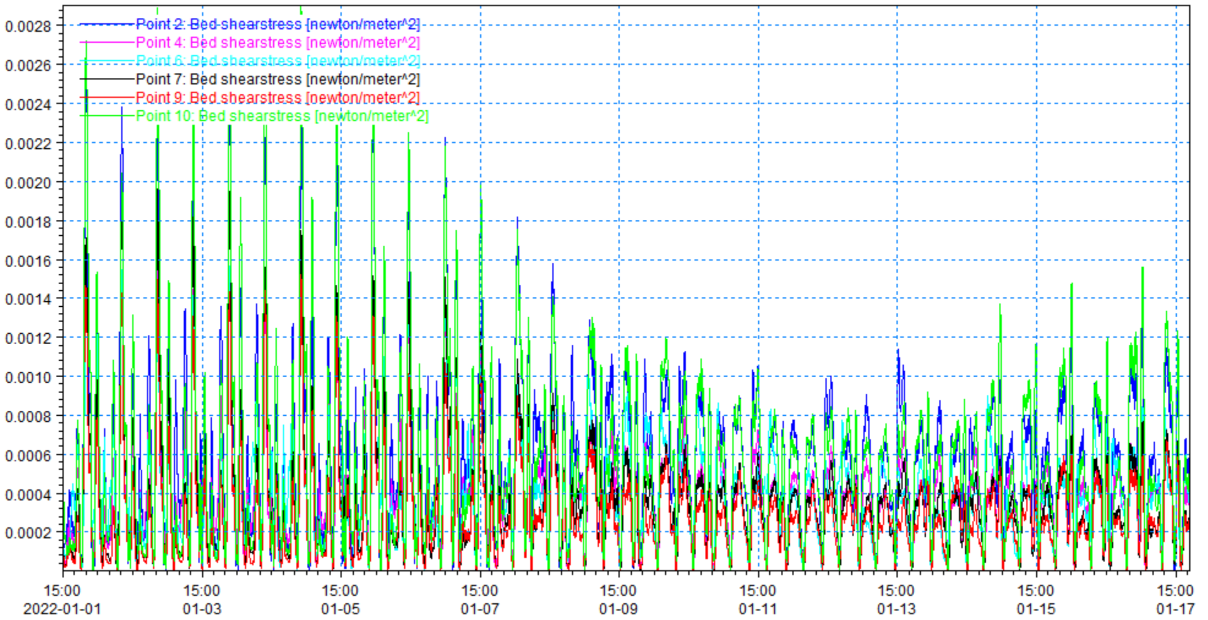

Figure 4-12: FM HD 16 bed shear stress at locations 2, 4, 6, 7, 9 and 10 through spring and neap tidal cycle

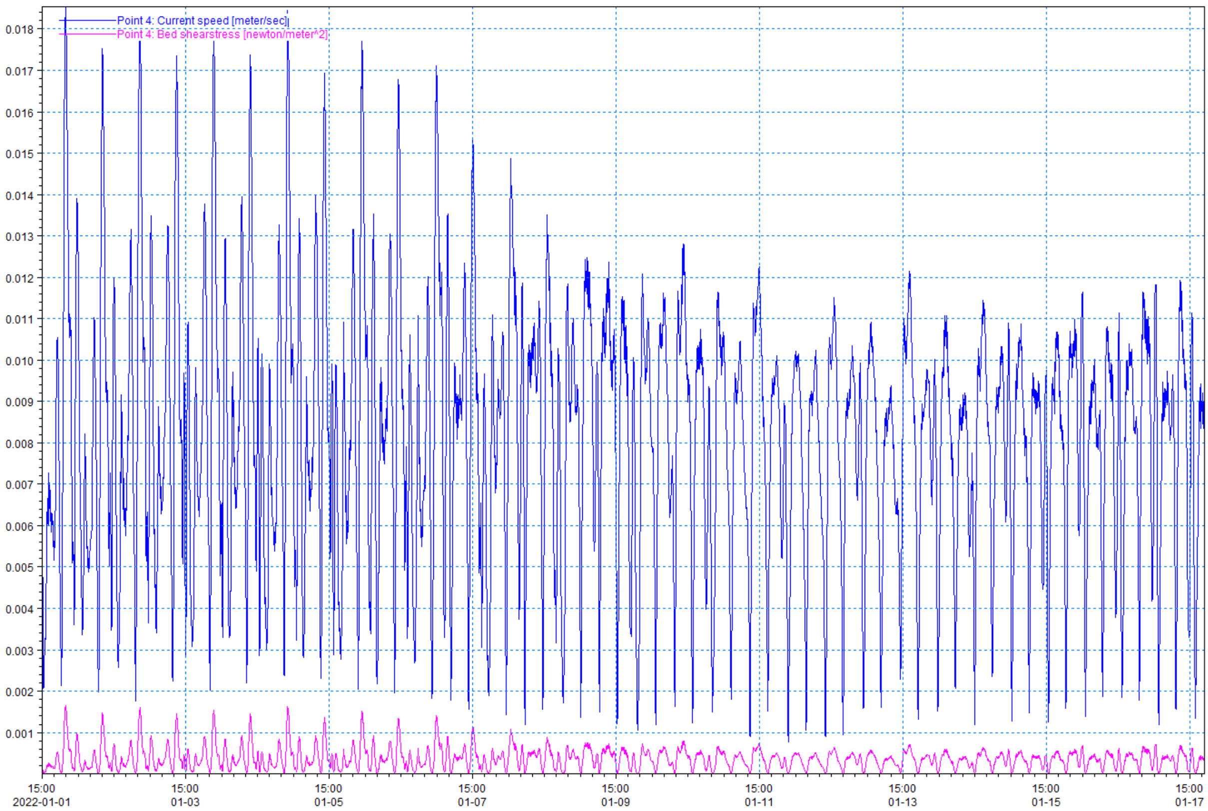

Figure 4-13: FM HD 16 bed shear stress and current speed at location 4

4.1.4 Wind Forcing Sensitivity

Given the low energy environment at Deepdale Bay and within the wider Scapa Flow area, it is considered that wind forcing could have a greater relative influence on current speeds and coastal processes than in more dynamic settings. A wind forcing sensitivity simulation was undertaken using wind data extracted from the COSMO Reanalysis 6km (CREA6) nonhydrostatic limited-area atmospheric prediction model via the DHI Metocean data portal[11]. The wind data used covered the period of January 2018, but is considered representative of general wind conditions in Scapa Flow during that time of year. A rose plot of the data showing wind speed and directional frequency is presented in Figure 4-14. The wind forcing data was applied as varying in time and constant across the model domain. Due to the unpredictability of wind forcing in terms of force, duration and direction, this scenario is only used to assess the model sensitivity to wind forcing. The wind forcing scenario has therefore not been adopted as the baseline case in later assessments.

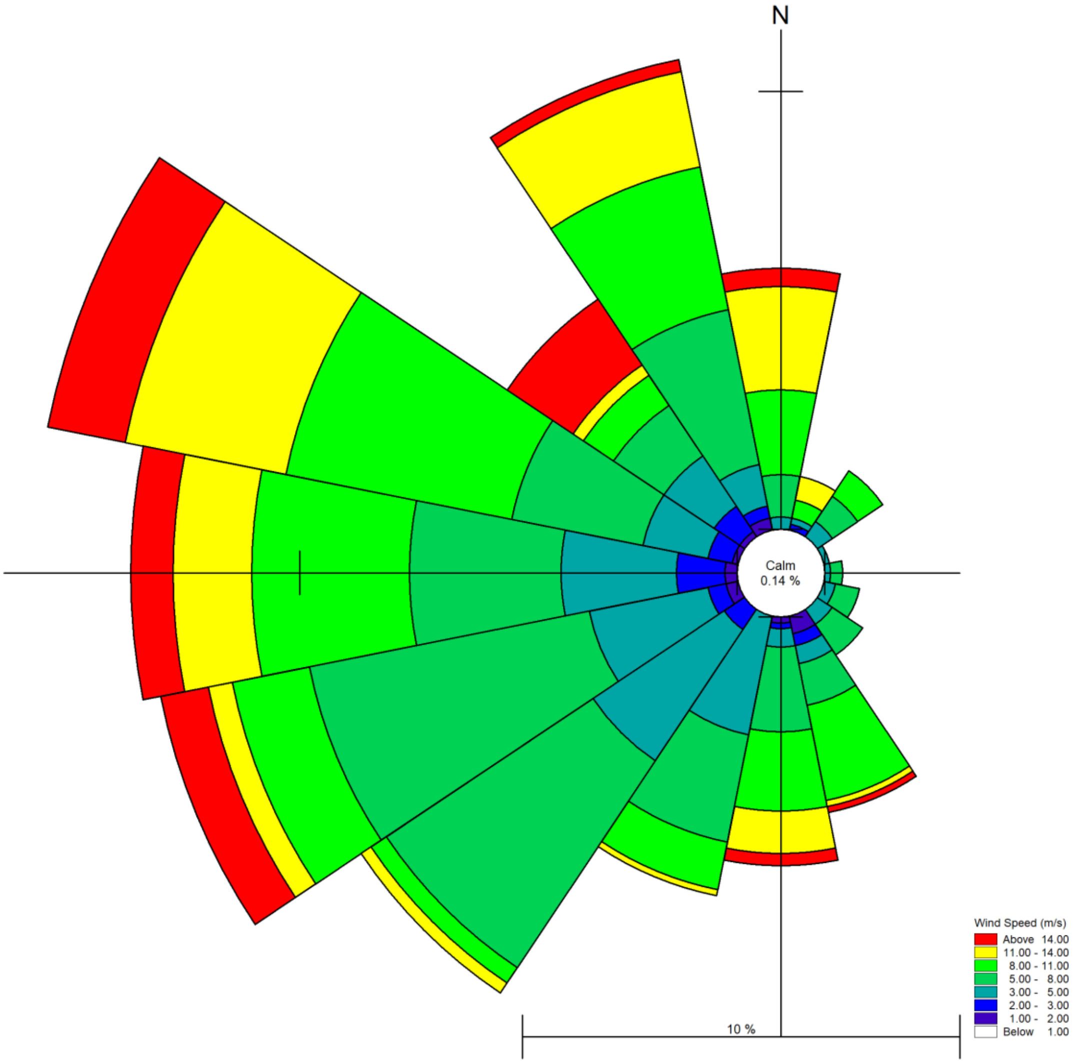

Figure 4-14: Wind rose plot – CREA6 model data (January 2018)

[11] https://www.metocean-on-demand.com/metadata/waterdata-dataset-Europe_CREA6_V2

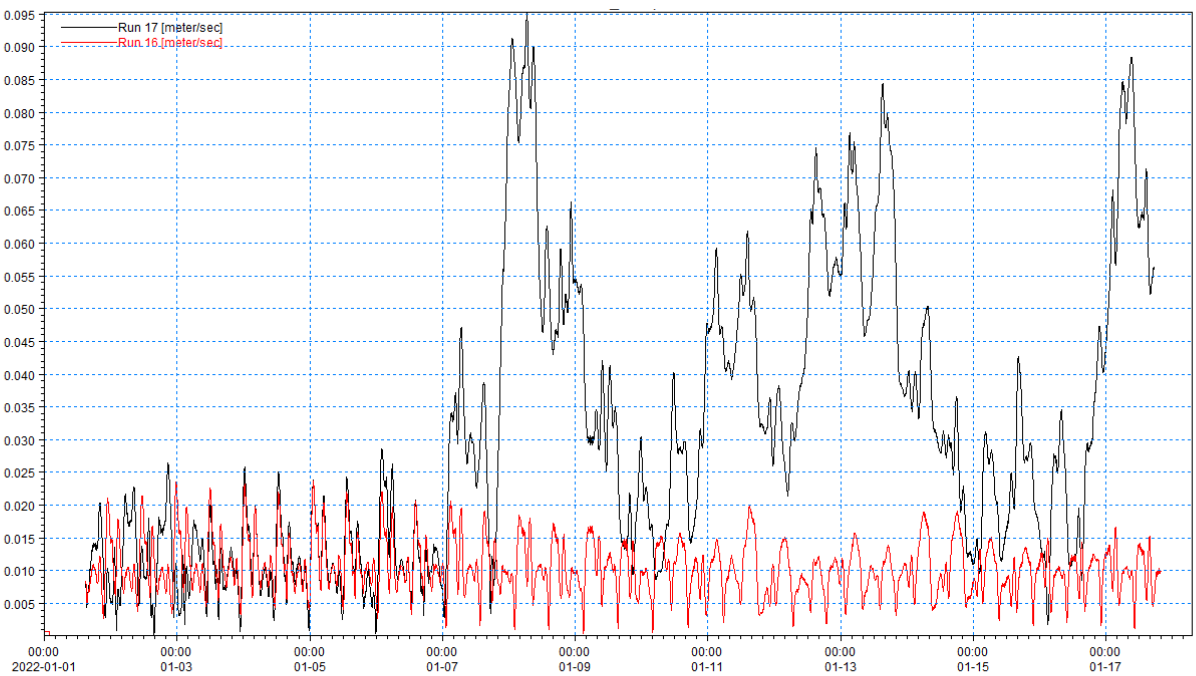

Figure 4-15: FM HD 16 and FM HD 17 current speed at location 16

Figure 4-15 illustrates the predicted current speeds at location 16 for the spring and neap tide cycle, both with (FM HD 17) and without (FM HD 16) wind forcing. The results show how the wind forcing has the potential to both increase and decrease current speeds within Scapa Flow, with peak modelled current speeds increasing from 0.025 m/s to 0.095 m/s. While such predicted relative increases are significant, current speeds within Scapa flow remain generally low in both scenarios, and it should be noted that wind forcing can also impact current direction.

4.2 Post-Development Conditions

Model run FM HD 19 simulates post-development (see Appendix A for proposed development layout) tidal conditions at Deepdale Bay and surrounds. The following sub-sections present the results of this simulation split by key outputs, tidal water surface elevation, tidal currents, and bed shear stress. Comparative analysis versus existing conditions (FM HD 16) is also presented through these sections. Tabulated results and comparisons are presented in Appendix B, whilst result comparisons are presented in graphical form in Appendix C.

4.2.1 Tidal Water Surface Elevation

Tidal water surface elevation predictions relative to chart datum at point output locations 4 and 16 (see Figure 3-9) are presented in Figure 4-16 for the spring and neap tidal cycle. Review of these figures highlights that the same levels are predicted at both point output locations, as per the results for FM HD 16 under existing conditions.

Figure 4-17 presents a comparison of the full model run tidal curves for existing (FM HD 16) and post-development (FM HD 19) conditions at point output location 4. This highlights that no significant change is observed in surface elevation predictions between the two model runs. Further comparative analysis presented in Table 2, Appendix B, and within figures in Appendix C, confirms this to be the case across the study area.

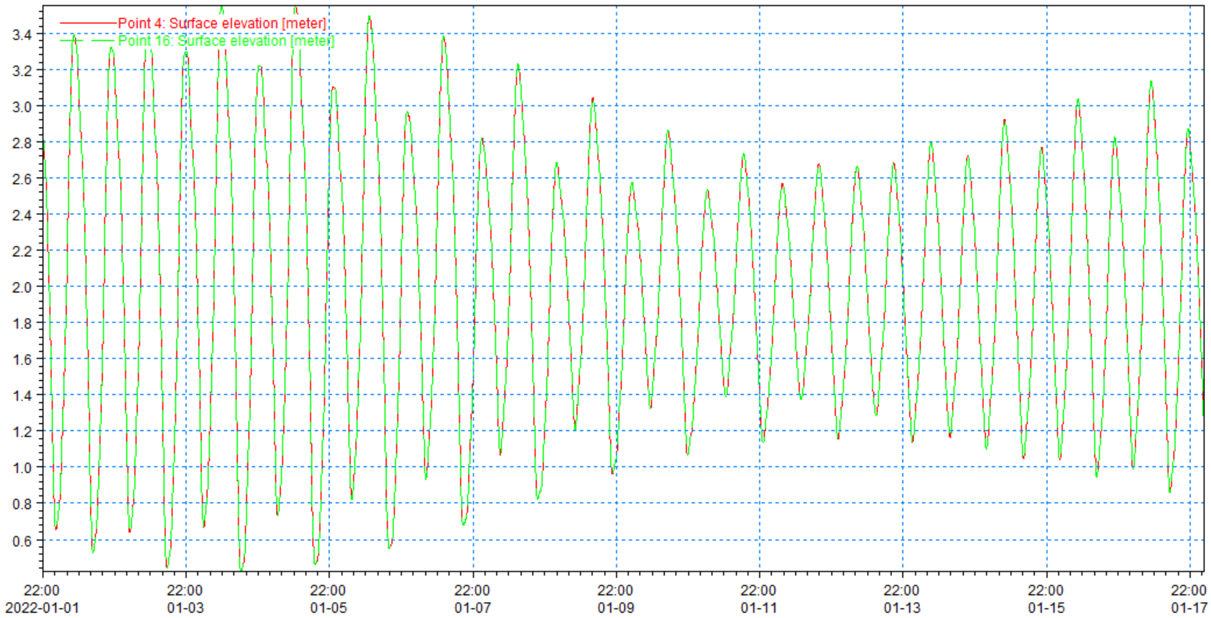

Figure 4-16: FM HD 19 water surface elevation predictions at points 4 and 16 for spring and neap tidal cycle

Statistics

	Observation	Simulation	Difference
Item Name	Point 1: Surface ele...	Point 1: Surface ele...	Difference
Item Unit	[m]	[m]	[m]
Minimum	0.4222	0.4231	-0.0019
Maximum	3.5556	3.5536	0.0023
Average	1.9935	1.9933	0.0002
Std. deviation	0.7521	0.7516	0.0007

Figure 4-17: Comparison of FM HD 16 & FM HD 19 water surface elevation predictions at point 4

4.2.2 Tidal Currents

Tidal current speed predictions for point output locations 4, 16 and 22 are presented in Figure 4-18 for the spring and neap tidal cycle and in Figure 4-19 for the spring tide cycle. Review of these figures highlights the relatively weak currents (<0.32 m/s) present throughout locations in Scapa Flow.

Whilst there is an identifiable increase in current speed at location 4 adjacent to the proposed development when compared with the existing conditions, the change is not considered significant in the local context, and values remain generally low. Comparison of post-development results with baseline values (Figure 4-4) shows increase in current speed at location 4 both on the spring and the neap tide, with peak current speed during the neap tide cycle increasing from approximately 0.012 m/s to 0.032 m/s. Point 4 is located in close proximity to the new quay, and within the dredging envelop, and it is predicted that the proposed development is locally influencing the position of tidal currents at this location.

Comparative analysis of predicted current speeds across the point output locations is presented in Table 2, Appendix B, and in graphical form in Appendix C. Review of this analysis highlights that minor changes in peak current speed are predicted at point output locations in the immediate vicinity of the proposed development (<0.02 m/s change), with no change observed in the wider surrounds.

Figure 4-20 and Figure 4-21 present plots of predicted post-development current speed at Deepdale Bay during mid-flood and mid-ebb spring tides respectively. These plots show interpolated current vectors highlighting the direction of tidal flow during these tidal states. Review of these plots highlights the localised impact on current direction resulting from the new deep water quay construction. Marginally higher current speeds and associated eddies are noted forming around the proposed dredge pocket, as highlighted by review of the time series data from point 4.

Figure 4-22 and Figure 4-23 present plots of current speed differential between existing (FM HD 16) conditions and post-development (FM HD 19) conditions, for mid-flood and mid-ebb spring tides respectively. Review of these figures highlights the localised spatial pattern of development impact on tidal current speed during each tidal state. Negative values equate to current speed increases in these plots, and a minor increase in current speed post-development is observed in close proximity to the quay face, particularly within the -20mCD dredge pocket, during both flood and ebb tides. During the ebb tide the area of increase extends slightly further north in the direction of flow, along the quay. It is considered that the proposed development concentrates and re-directs flows resulting in the slight increase observed. No significant impact on current speeds is predicted within the wider surrounds.

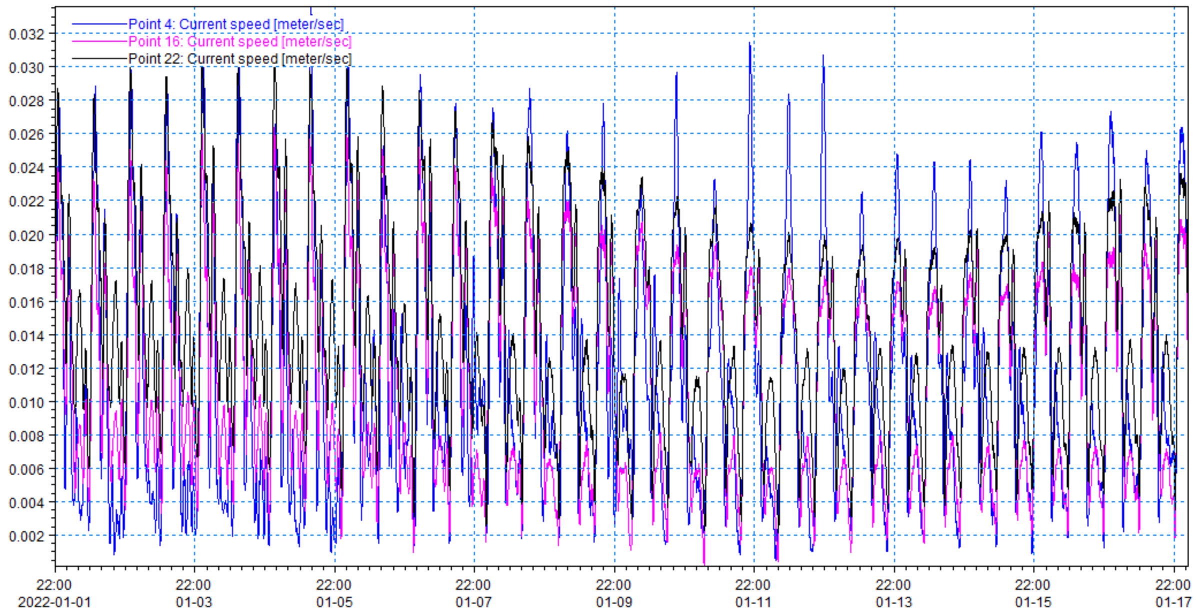

Figure 4-18: FM HD 19 current speed predictions at points 4, 16 and 22 for spring and neap tides

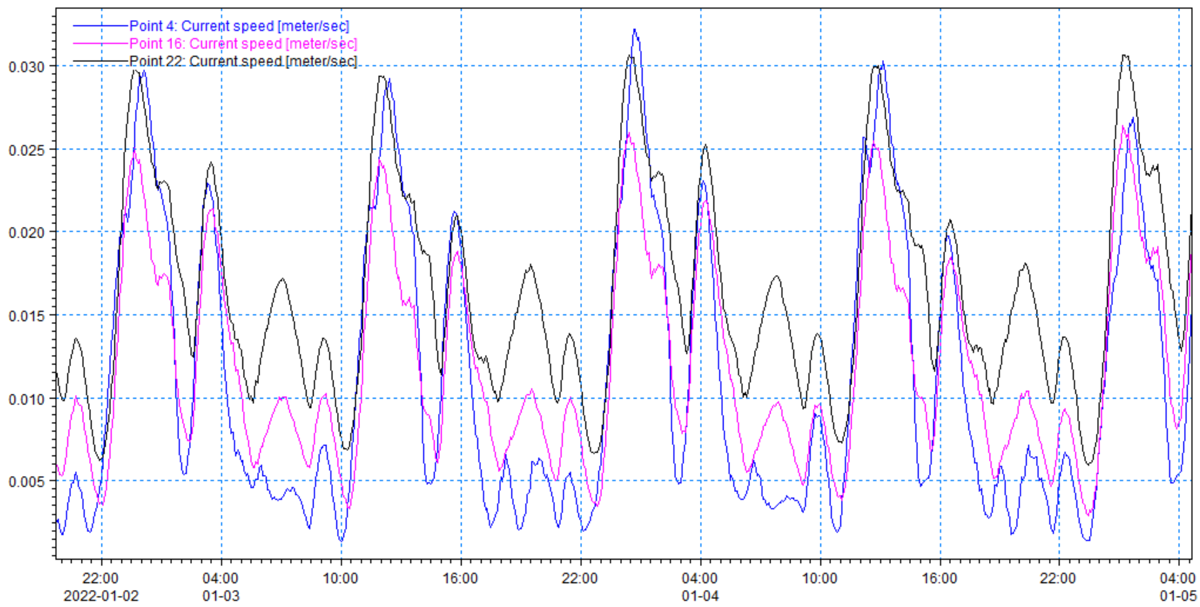

Figure 4-19: FM HD 19 current speed predictions for points 4, 16, 22 for spring tide

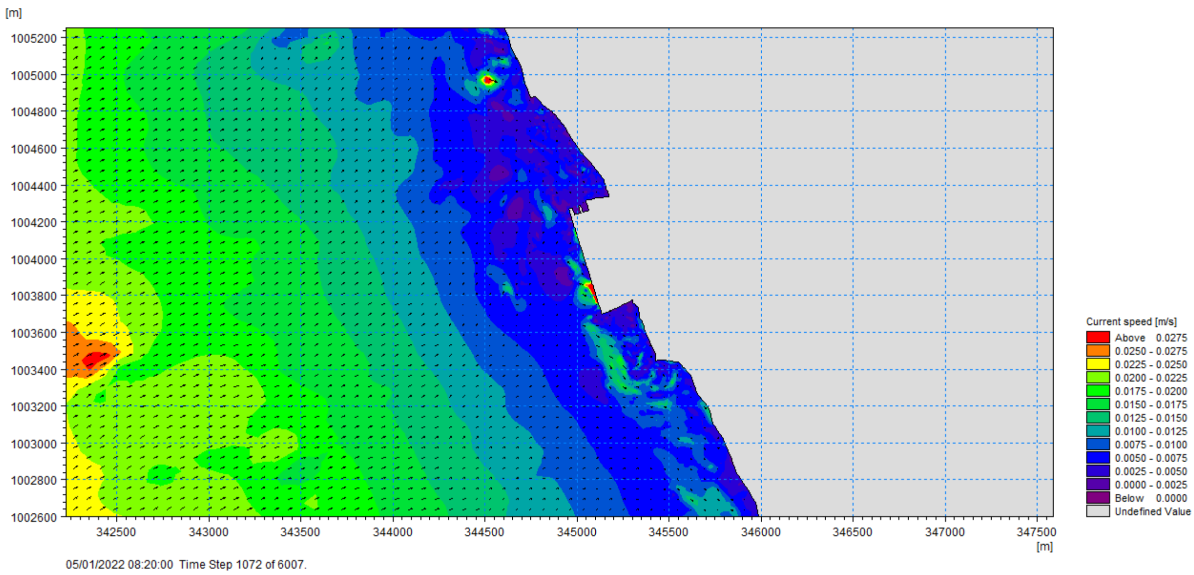

Figure 4-20: FM HD 19 current speed at Deepdale Bay during mid-flood spring tide

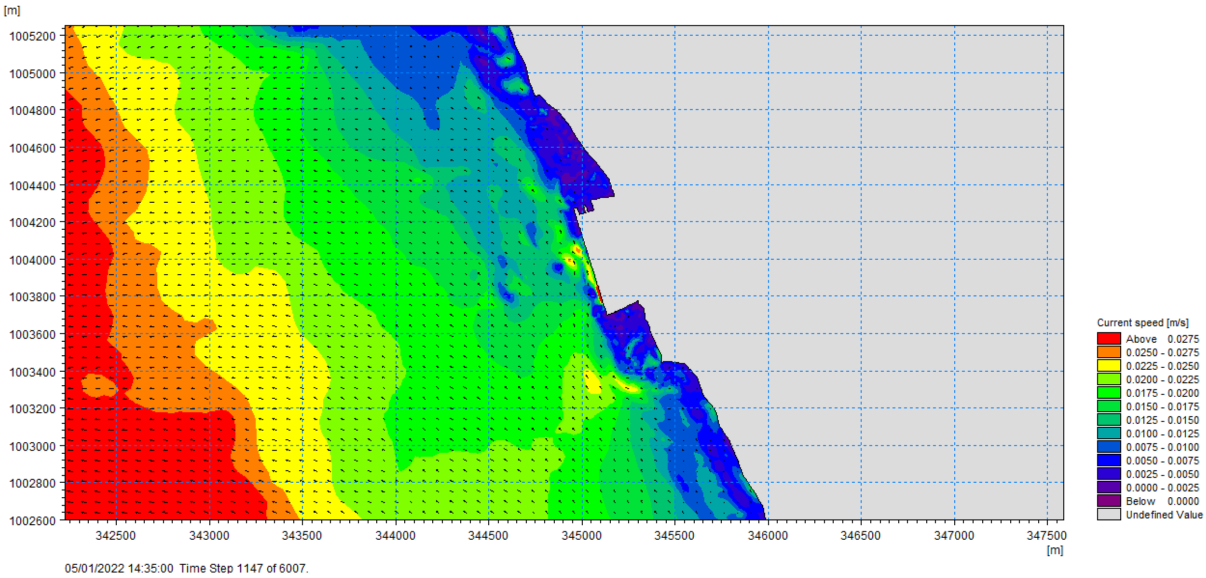

Figure 4-21: FM HD 19 current speed at Deepdale Bay during mid-ebb spring tide

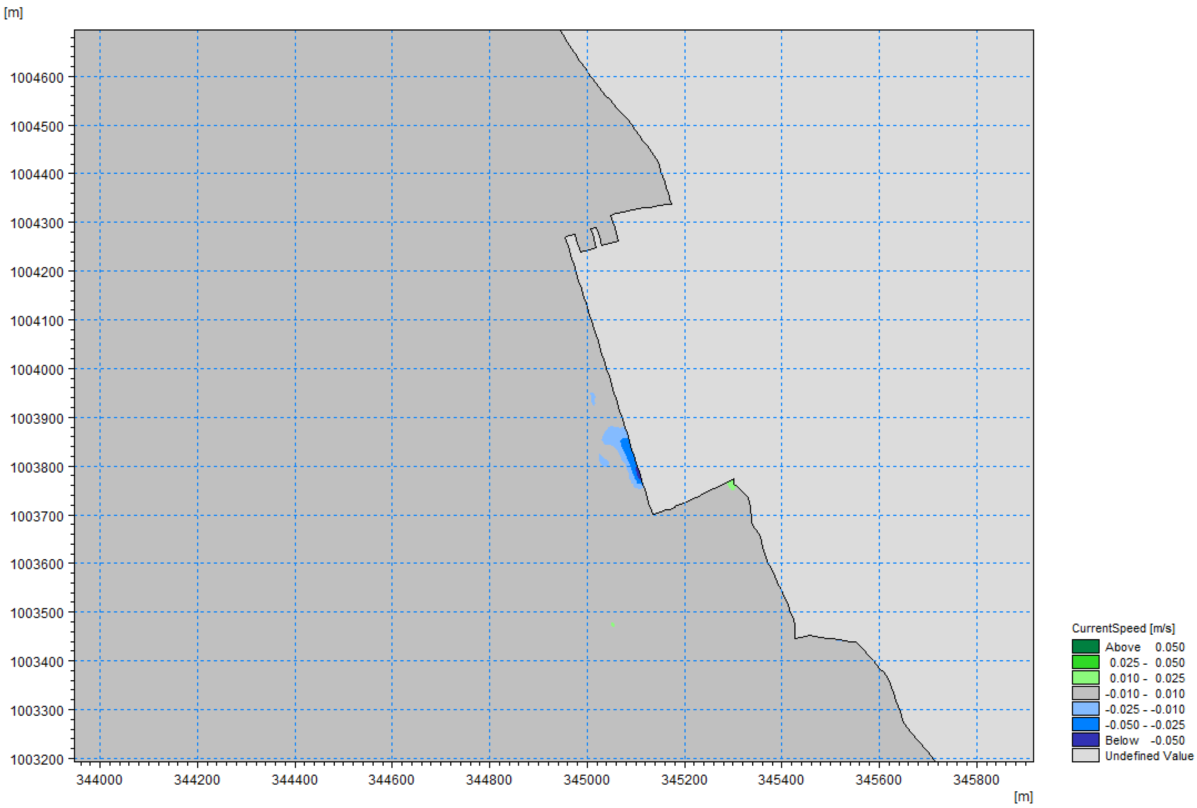

Figure 4-22: Baseline (FM HD 16) versus Post-development (FM HD 19) current speed differential – spring flood tide

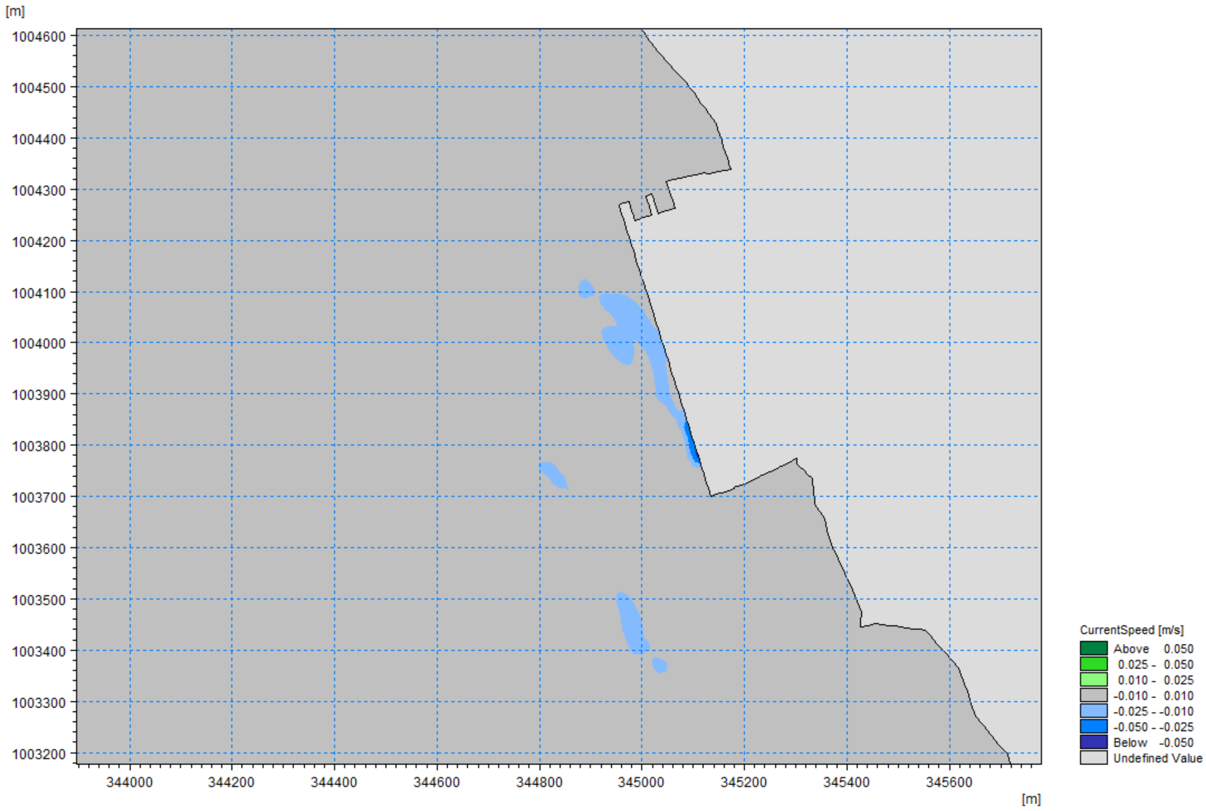

Figure 4-23: Baseline (FM HD 16) versus Post-development (FM HD 19) current speed differential – spring ebb tide

4.2.3 Bed Shear Stress

Figure 4-24 presents post-development model predictions of bed shear stress during the spring and neap tidal cycle for point output locations 2, 4, 6, 7, 9 and 10 around the proposed development and Deepdale Bay. As per existing conditions, all locations show generally low bed shear stress, as would be anticipated with the weak tidal currents observed. Peak bed shear stress predictions are around 0.005 N/m^2 during spring tides.

Whilst there is an identifiable increase in bed shear stress for locations adjacent to the proposed development when compared with the existing conditions, the change is not considered significant in the local context, and values remain generally low. The localised changes are visible when reviewing outputs for points 4 and 7. Figure 4-25 shows bed shear stress alongside current speed for location 4. Review of this figure shows that bed shear stress remains correlated with tidal current speeds despite local increases in shear stress post-development.

Despite local increases, in the post-development scenario it remains the case that the low current speeds and corresponding low bed shear stresses observed are considered comparable in magnitude to pre-development character, and indicative of a low energy environment.

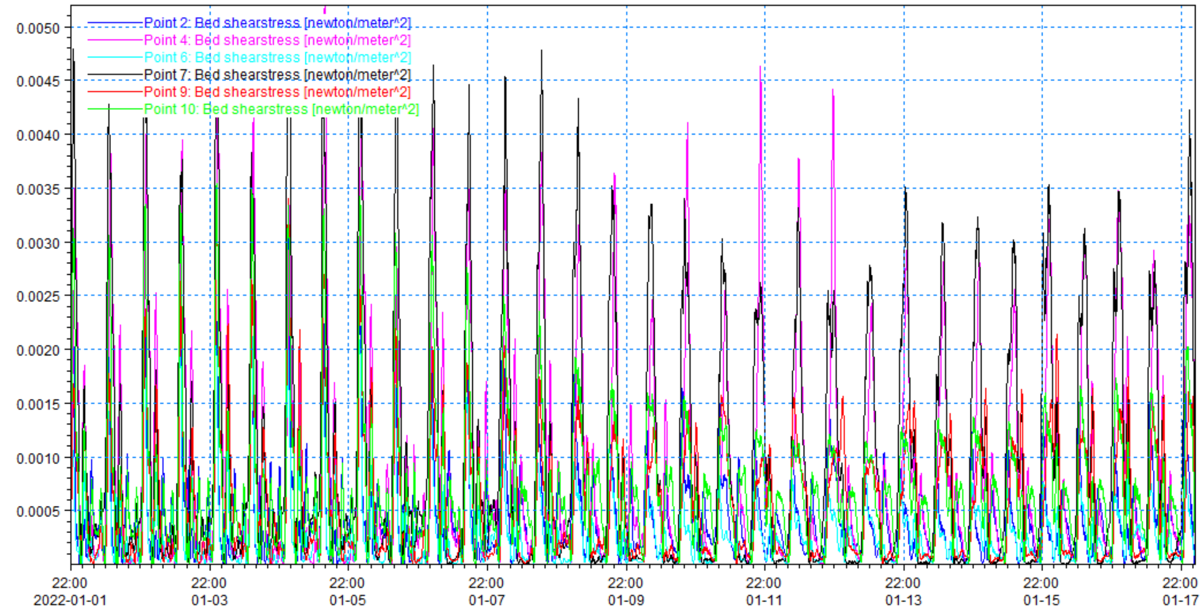

Figure 4-24: FM HD 19 bed shear stress at locations 2, 4, 6, 7, 9 and 10 through spring and neap tidal cycle

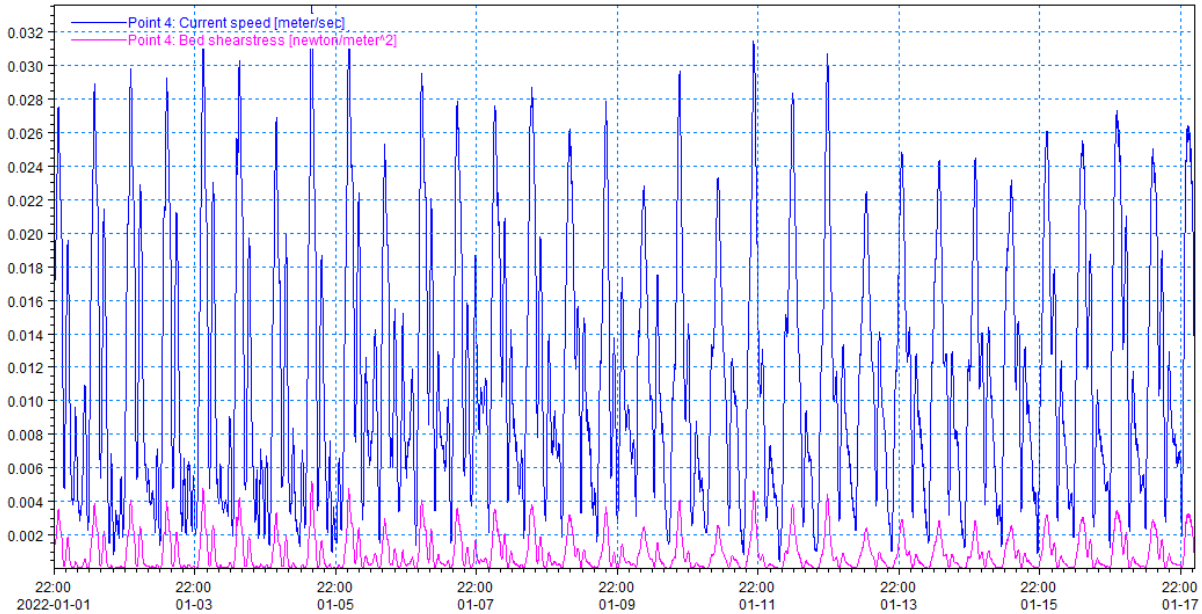

Figure 4-25: FM HD 19 bed shear stress and current speed at location 4

4.2.4 Wind Forcing Sensitivity

A wind forcing sensitivity simulation was undertaken using the post-development model and wind data as described in section 4.1.4. The wind forcing data was again applied as varying in time and constant across the model domain.

Figure 4-26 illustrates the post development current speeds at location 16 for the spring and neap tide cycle, both with and without wind forcing. Figure 4-27 shows the outputs for the same simulations at location 4, adjacent to the proposed development and dredging pocket. As is the case in the existing scenario, the results show how the wind forcing has the potential to increase current speeds within Scapa Flow, with peak current spends increasing from approximately 0.03 m/s to 0.095 m/s. While the relative increase is significant, current speeds within Scapa flow remain generally low.

Due to the unpredictability of wind forcing in terms of force, duration and direction, this scenario is only used to assess the model sensitivity to wind forcing. The wind forcing scenario has not been adopted as the design case in assessments and comparisons.

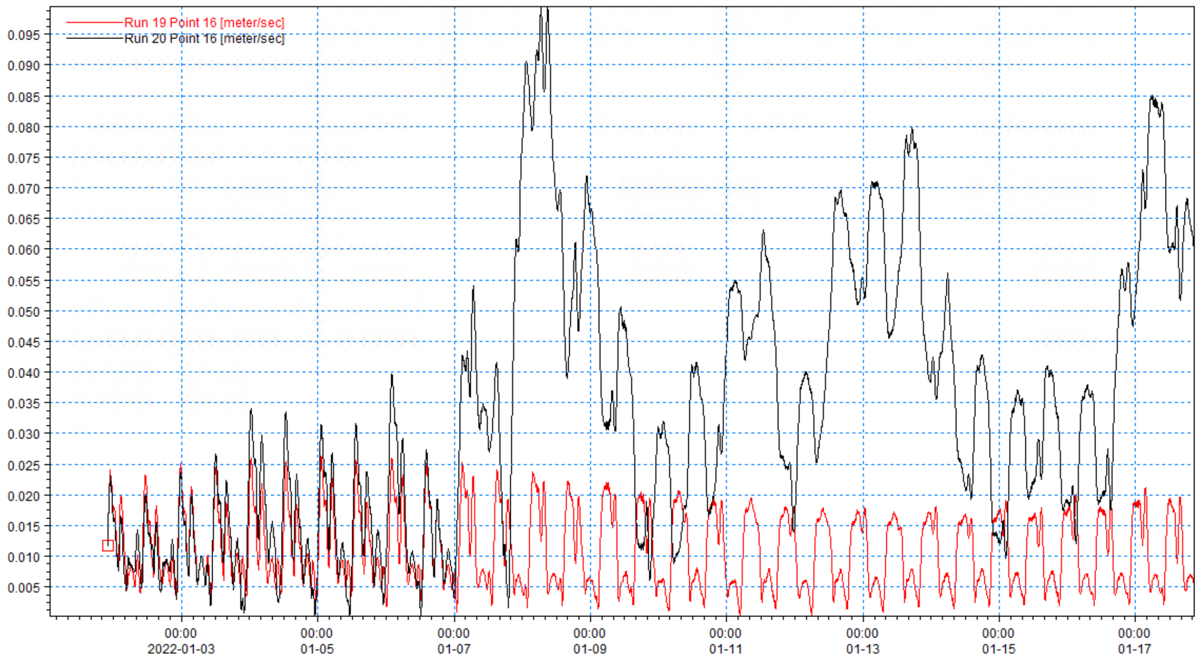

Figure 4-26: FM HD 19 and FM HD 20 current speed at location 16

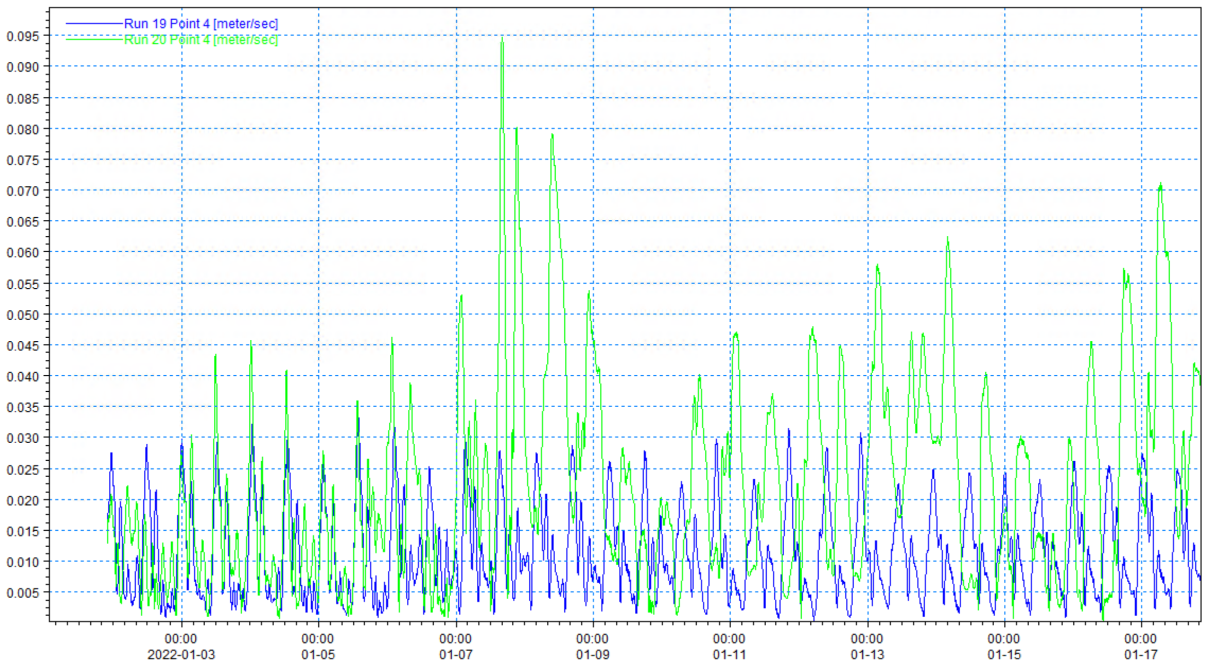

Figure 4-27: FM HD 19 and FM HD 20 current speed at location 4

5 DREDGE PLUME DISPERSAL MODEL

5.1 Context

5.1.1 Proposed Development Dredge

Dredging is required to facilitate the development of Scapa Deep Water Quay. The proposed harbour facility will include approx. 597m long main quayside berth with general -15m CD water depth, incorporating a 135m quayside pocket with -20m CD water depth. Further north tug (3No.) and pilot boat (2No.) berth approx. 180m long with depths between -6 and -9m CD. The proposed dredge budget is estimated at a total of 174,000m^3 across all three phase areas. The proposed dredge campaign would be undertaken by back-hoe dredger, with 24/7 operation over an estimated duration of just over 14 weeks. Dredging would take place following construction of the proposed quay walls. The dredge arisings are to be re-used predominantly as infill material within the proposed development footprint.

The proposed development layout, including dredge pocket locations and extents, are detailed in Appendix A.

5.1.2 Dredge Budget Character

The dredge budget has been assessed through site investigation, including borehole and washprobe sampling, to consist predominantly of sand with silt and gravel content. The average proportion of the dredge budget classified within the various identified particle sizes is presented in Table 5-1 below.

Table 5-1: Summary of dredge budget particle size data

Sediment Type (Grain Size)	Percentage of Dredge Budget
Silt and Clay (<0.063mm)	23.3%
Sand (> 0.063mm and <2mm)	59.7%
Gravel (>2mm)	17.0%

5.2 Dredge Dispersal Model Development

5.2.1 MIKE 21 Mud Transport (MT) Module

To simulate sediment plume dispersal from the proposed dredge campaign, the MIKE 21 Mud Transport (MT) module has been utilised. The mud transport module simulates the erosion and deposition of mud or sand/mud mixtures. It can be coupled with the MIKE 21 HD module, as described in section 3.1, to assess the dispersion of spilled sediment from a dredger by tidal forcing.

Amongst the key features of the MIKE 21 MT module are:

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

- Consolidation; and
- Capability to simulate morphological update of the seabed.

As MIKE 21 is a two-dimensional (depth-averaged) flow model, the simulation of the transport of material is averaged over depth.

5.2.2 MT Module Settings

A summary of the configuration of the general settings within the MT module for the dredge dispersal simulations is presented in Table 5-2 below. The assumed parameters of the dredge applied within the MT simulations are outlined in Table 5-3.

Table 5-2: General settings applied to MIKE 21 MT module

Setting	Description/Value	
Number of fractions	3 fractions: 1. Clay and silt 2. Sand 3. Gravel	
Number of bed layers	1	
Hydrodynamic conditions	2-dimensional flow from HD model (see chapters 3 and 4)	
Solution technique	Higher order	
Simulation period	105 days	
Output time interval	15 minutes	
Settling velocity	Fraction 1: Clay and silt	0.0007m/s
	Fraction 2: Sand	0.0395m/s
	Fraction 3: Gravel	0.0933m/s
Critical shear stress	Fraction 1: Clay and silt	0.136N/m^2
	Fraction 2: Sand	0.211N/m^2
	Fraction 3: Gravel	0.360N/m^2
Flocculation	Calculations included	
Wave forcing	Not included	
Dispersion	Scaled eddy viscosity formulation	
Initial conditions	Layer 1: No bed thickness	
Morphological update	Not included	

Table 5-3: Assumed parameters of dredge applied to MIKE 21 MT module

Variable	Quantity	Comments
Total dredge volume	174,000m^3	All 3 dredge phases
Dredger type	Backhoe	Nordic Giant or similar
Dredge campaign duration	102 days	24 hours operation
Dredge rate	1,694m^3/day	Assumed constant
Dredge sediment composition	Fraction 1 – 23.3%	Clay and silt
	Fraction 2 – 59.7%	Sand
	Fraction 3 – 17.0%	Gravel
Density of material	1,800kg/m^3	Assumed constant
Spill rate	5%	The proportion of dredged material lost to water column
Dredger path	-	As per Figure 5-1

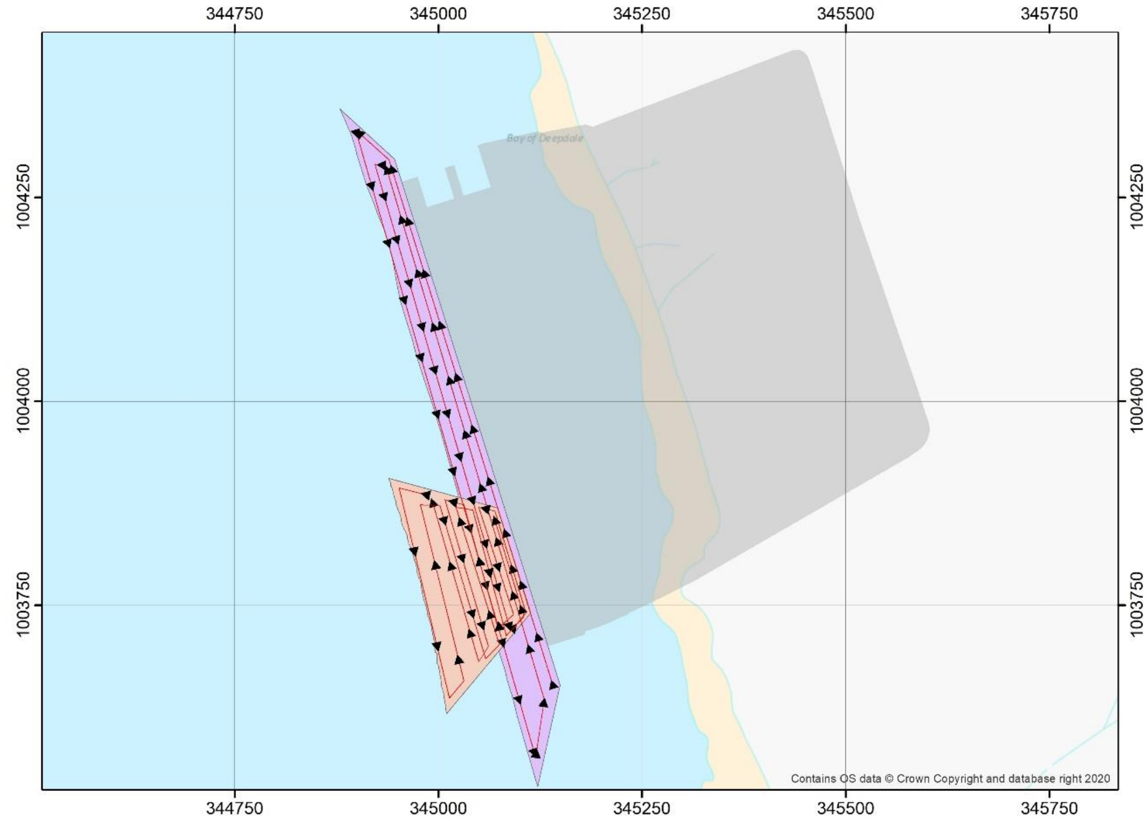

Figure 5-1: Assumed dredger path (red line with arrows) through dredge pockets for whole of dredge campaign

5.2.3 HD Module Settings

The HD module has been setup as described in Chapter 3, and specifically Section 3.5. A new version of the model mesh has been generated combining the post-development model mesh with the baseline bathymetry. This is considered reflective of the likely conditions at the commencement of the dredge campaign, and a conservative setup for assessing dredge plume dispersal.

5.2.4 Model Outputs

The MIKE 21 FM HD MT model simulations have been setup to produce results as both point and area outputs. The HD module outputs are as per those described in Section 3.6. The MT module outputs include the following key parameters:

- Total suspended solids (TSS);
- Bed thickness change; and
- Total net deposition accumulation.

The area outputs are generated for the whole model extent, whilst point outputs have been generated at 12 identified locations within the model extent as detailed in Table 5-4 and shown in Figure 5-2. The locations of point outputs are situated within the immediate vicinity of Deepdale Bay and the proposed development including one within the capital dredge pocket (Point 5), and one within the Westerbister fish farm extent (Point 12).

Table 5-4: MT module point output locations

Point Output Location	Easting	Northing
Point 1	344500	1004600
Point 2	344000	1004200
Point 3	344500	1003400
Point 4	345000	1003000
Point 5	345000	1003800
Point 6	344342	1002099
Point 7	345000	1001200
Point 8	342000	1003000
Point 9	342000	1005500
Point 10	344000	1006000
Point 11	346000	1002000
Point 12	345237	1002729

Figure 5-2: MT module point output locations

5.2.5 Model Simulations

The key MIKE 21 FM HD MT model simulations are described in Table 5-5. Simulations 2 and 4 have been run utilising the computing hardware specified in Section 3.6. Due to the length of required simulation, and the associated computational effort required, simulation 3 has been run utilising the DHI cloud simulation facility, with a PC including 64 CPU.

Table 5-5: MIKE 21 FM HD MT model simulations

Simulation	Description
Scapa FM HD MT Dredge 2	Initial 8 days of dredge campaign, model mesh includes pre-dredge bathymetry with development footprint. Run for January 2022 tidal cycle, with no wind forcing.
Scapa FM HD MT Dredge 3	Full dredge campaign, model mesh includes pre-dredge bathymetry with development footprint. Run for January to April 2022 tidal cycle, with no wind forcing.
Scapa FM HD MT Dredge 4	Wind forcing sensitivity scenario. Initial 8 days of dredge campaign, model mesh includes pre-dredge bathymetry with development footprint. Run for January 2022 tidal cycle, with wind forcing.

5.3 Dredge Dispersal Model Results

5.3.1 Dredge Plume Dispersal – Initial Days of Campaign

As outlined in Table 5-5, simulation Scapa FM HD MT Dredge 2 includes the first 8 days of the proposed dredge campaign, simulated with a January 2022 tidal cycle, and no consideration of wind forcing on hydrodynamics.

Due to the low current speeds present within the vicinity of the dredge, only clay and silt particles from the finest fraction (1) enter suspension to form a plume, whilst sands and gravel fractions immediately fall out of suspension to deposit within the dredge extent. Figure 5-3 presents the total suspended solids concentrations within the dredge plume following 8 days of the dredge campaign. Review of this figure highlights that the highest concentrations (0.0075 – 0.002 kg/m^3) of TSS occur within, and immediately adjacent to, the dredge pockets. TSS concentrations can be seen to rapidly reduce away from the dredge extents. The spatial extent of the plume is relatively restricted, however fingers of lower concentration TSS observed extending to the north-west along shore, highlight the marginal residual dominance of the ebb tide in that direction.

Figure 5-4 presents the total deposition thickness following 8 days of the dredge campaign. Review of this figure highlights that measurable thickness of deposition is limited to the immediate dredge footprint, primarily consisting of sands and gravels, with maximum deposit thickness of 0.015m. Figure 5-5 presents the total net deposition accumulation following 8 days of the dredge campaign. Review of this figure highlights that deposition accumulation primarily occurs within the immediate dredge extent (maximum accumulation ~8,000g/m^2), with accumulation rapidly decreasing away from this area.

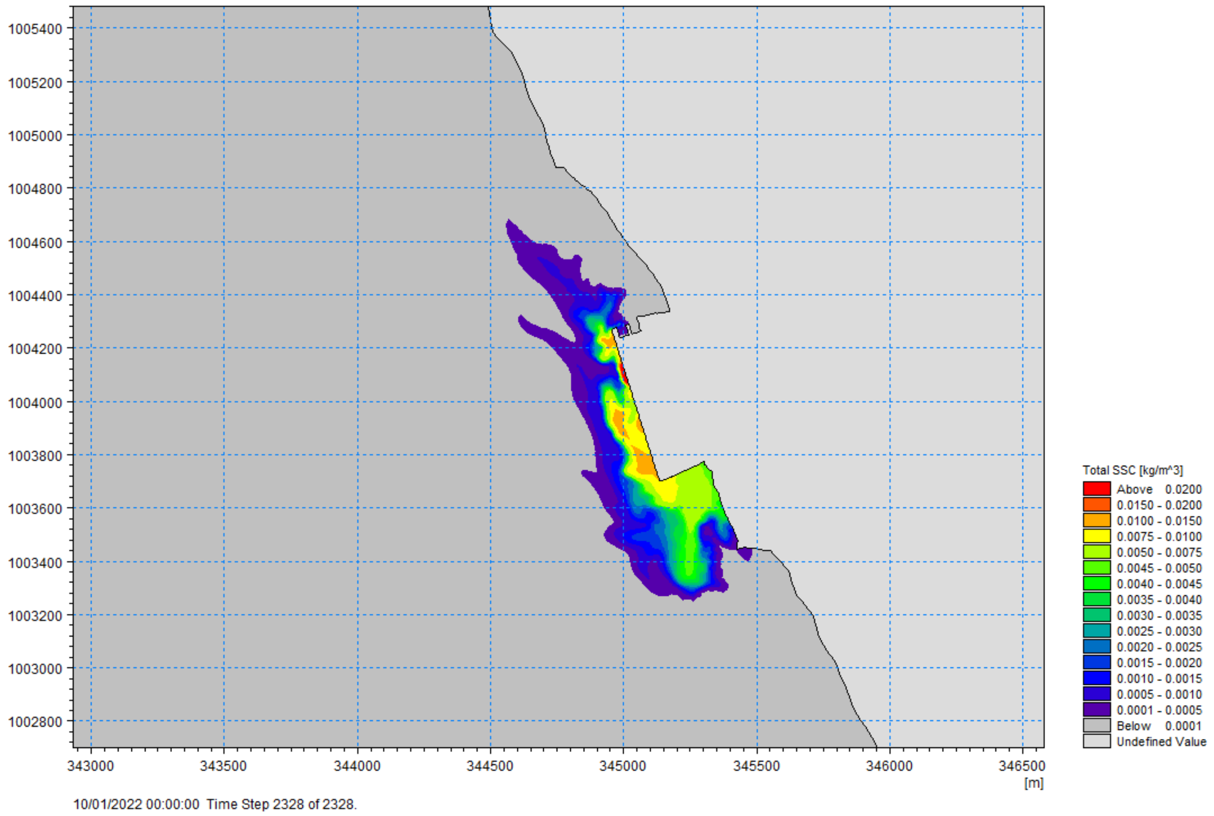

Figure 5-3: FM HD MT Dredge 2 – plume TSS following 8 days of dredge

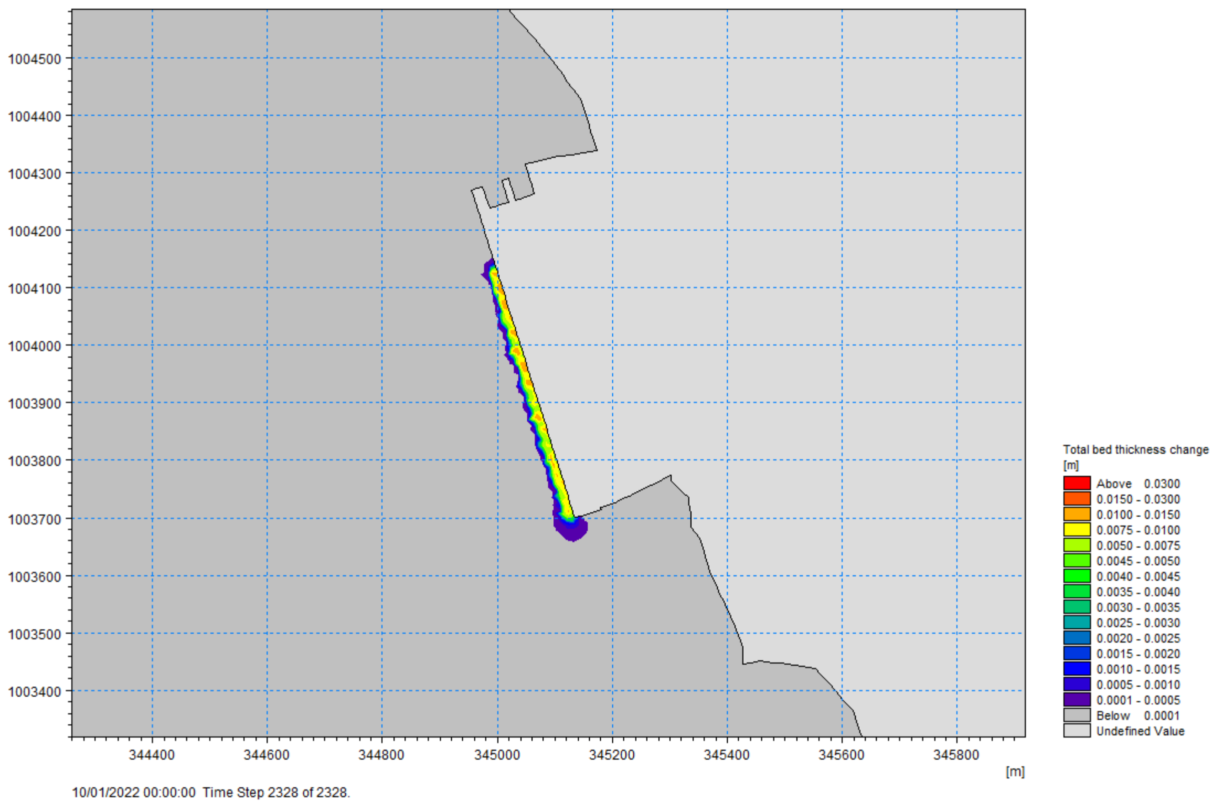

Figure 5-4: FM HD MT Dredge 2 – deposition thickness following 8 days of dredge

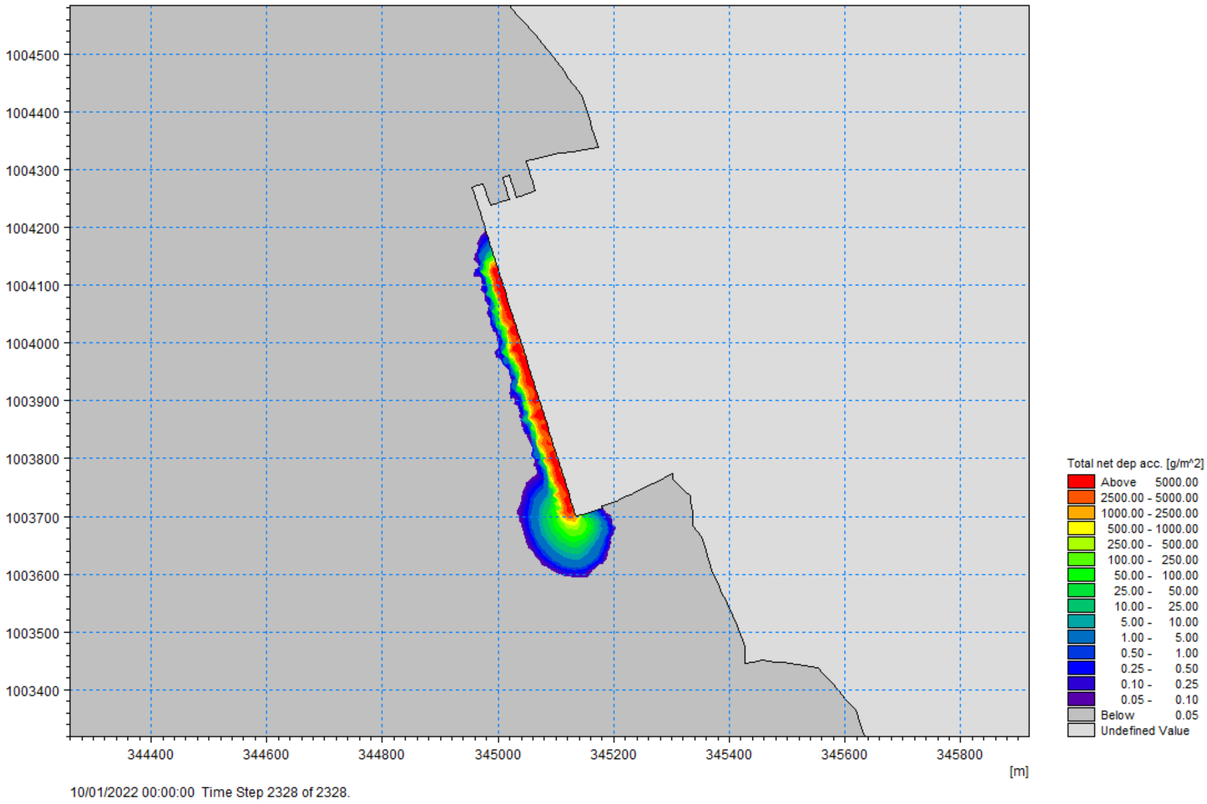

Figure 5-5: FM HD MT Dredge 2 – total net deposition accumulation following 8 days of dredge

5.3.2 Dredge Plume Dispersal – Full Campaign Duration

As outlined in Table 5-5, simulation Scapa FM HD MT Dredge 3 includes the full duration of the proposed dredge campaign, simulated with a January to April 2022 tidal cycle, and no consideration of wind forcing on hydrodynamics.

As described in section 5.3.1, due to the low current speeds present within the vicinity of the dredge, only clay and silt particles from the finest fraction (1) enter suspension to form a plume, whilst sands and gravel fractions immediately fall out of suspension to deposit within the dredge extent. Figure 5-6 presents the total suspended solids concentrations within the dredge plume at the end of the dredge campaign. Review of this figure highlights that the highest concentrations (0.0075 – 0.002 kg/m^3) of TSS occur within, and immediately adjacent to, the dredge pockets. TSS concentrations can be seen to rapidly reduce away from the dredge extents. The spatial extent of the plume, extending to the north-west along shore, highlights the marginal residual dominance of the ebb tide in that direction. Further westwards nearshore spread of very low concentration plume (<0.0005 kg/m^3) is also observed.

Figure 5-7 presents the total suspended solids concentrations within the dredge plume at the end of the simulation, 3 days after completion of dredging. Review of this figure versus Figure 5-6 highlights the reduction in plume extent, and reduction in observed TSS concentrations, over the 3 days since completion of dredging. Figure 5-8 presents a time-series of TSS concentrations at point output locations 1 (north of dredge zone), 5 (within dredge zone) and 12 (within Westerbister fish farm). Review of this figure highlights that point 5 exhibits higher relative TSS concentrations than point 1, and also generally longer duration of higher TSS concentrations throughout the dredge campaign. Point 12 within the fish farm does not return any significant TSS concentrations throughout the dredge campaign duration.

Figure 5-9 presents the statistical maximum TSS concentration across the full simulation. A similar pattern is observed to those described above, with highest TSS concentrations present within the dredge extent, and immediate surrounds, rapidly decreasing with distance away from the dredge zone. The dredge plume can again be observed to extend north-west along shore, with weaker concentrations of TSS observed extending further west into Scapa Flow within the nearshore zone.

Figure 5-11 presents the statistical mean TSS concentration across the full simulation. Review of this figure again highlights a similar pattern of plume dispersal as observed in previous figures. Highest mean TSS values within the dredge extent are <0.015 kg/m^3, whilst plume extents and concentrations are generally reduced in comparison to previous figures.

Figure 5-12 presents the total deposition thickness at the end of the simulation, following completion of the dredge campaign. Review of this figure highlights that measurable thickness of deposition is limited to the immediate dredge footprint, primarily consisting of sands and gravels, with maximum deposit thickness of 0.03m. Figure 5-13 presents the total net deposition accumulation at the end of the simulation, following completion of the dredge campaign. Review of this figure highlights that deposition accumulation primarily occurs within the immediate dredge extent (maximum accumulation ~30,000 g/m^2), with accumulation rapidly decreasing away from this area.

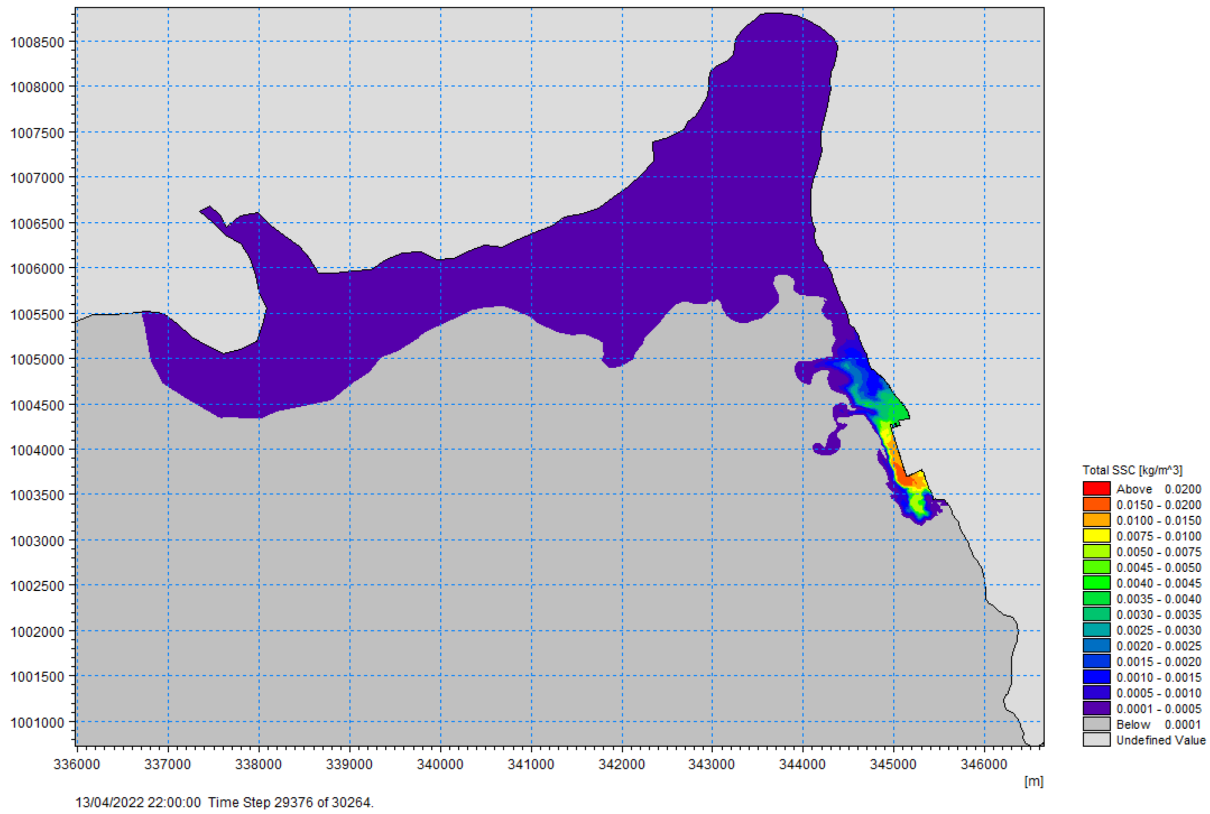

Figure 5-6: FM HD MT Dredge 3 – plume TSS at end of dredge campaign

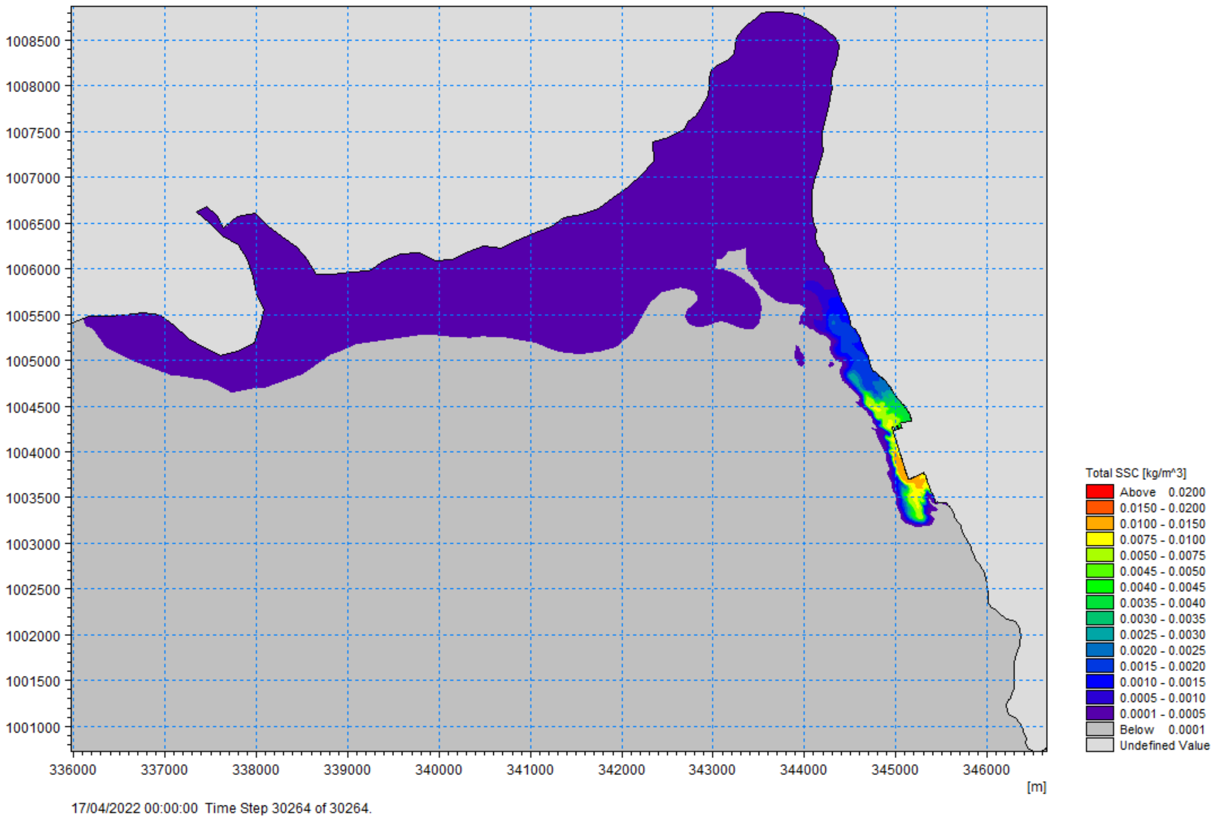

Figure 5-7: FM HD MT Dredge 3 – plume TSS at end of simulation

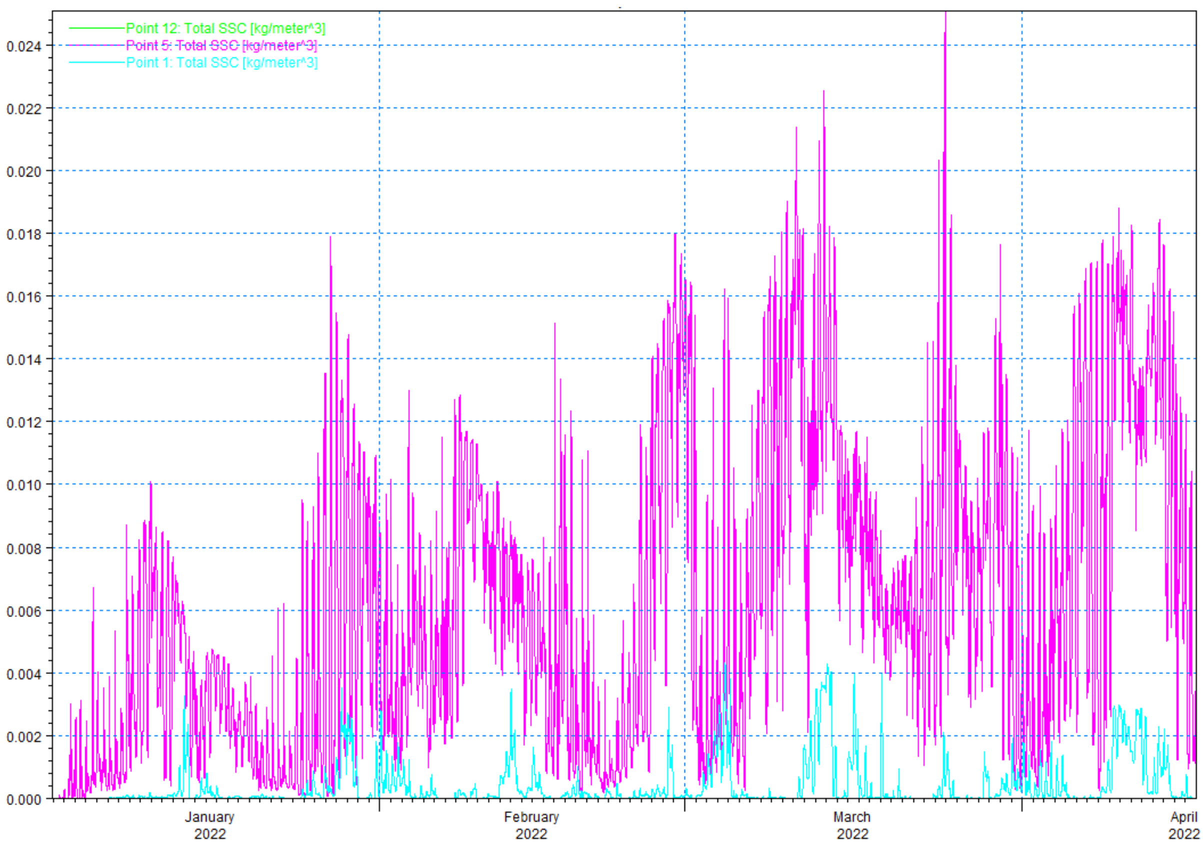

Figure 5-8: FM HD MT Dredge 3 – time-series TSS concentration (kg/m³) at locations 1, 5 & 12

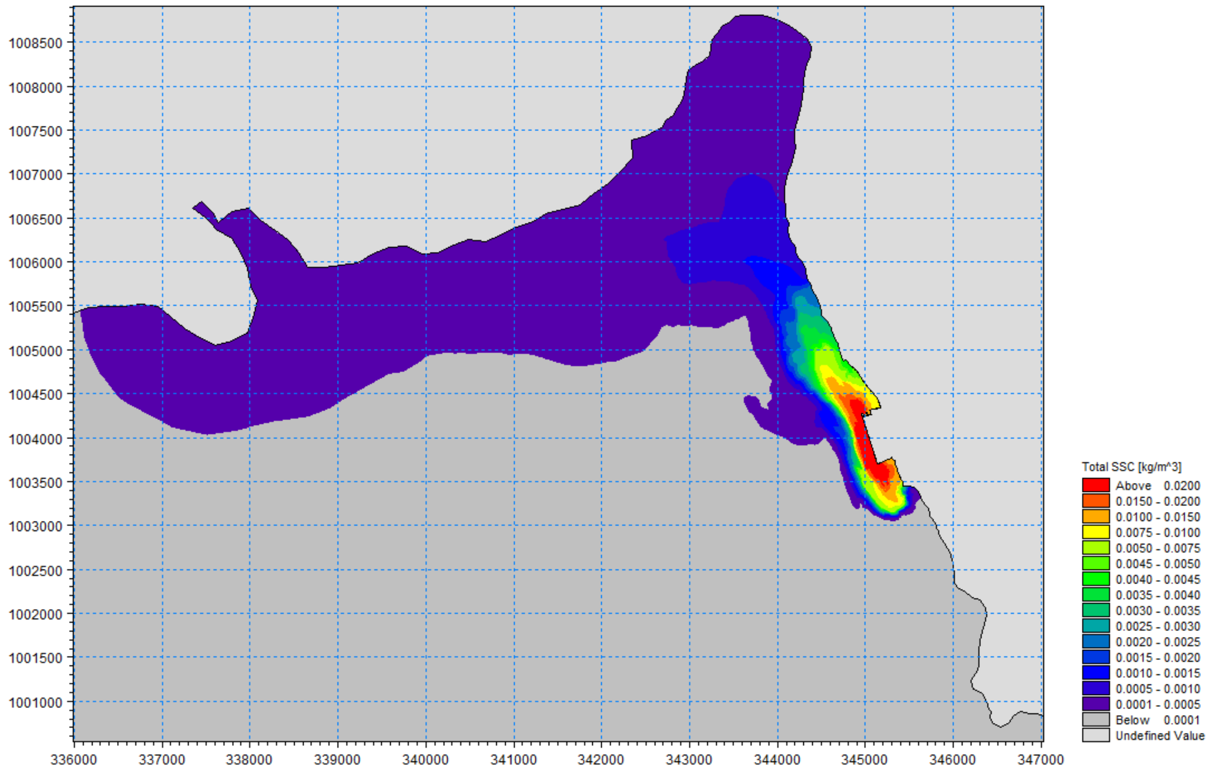

Figure 5-9: FM HD MT Dredge 3 – statistical maximum plume TSS (full dredge campaign)

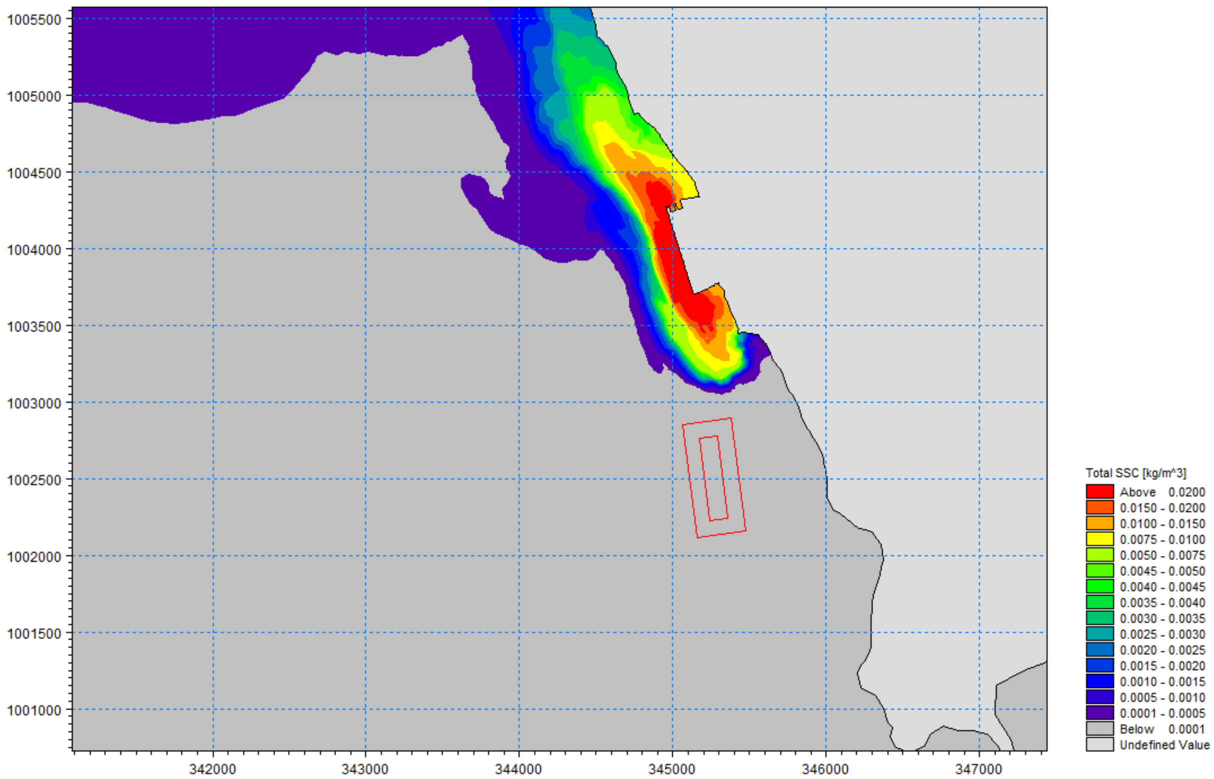

Figure 5-10: FM HD MT Dredge 3 – statistical maximum plume TSS (full dredge campaign zoom view Westerbister Fish Farm (red polygons))

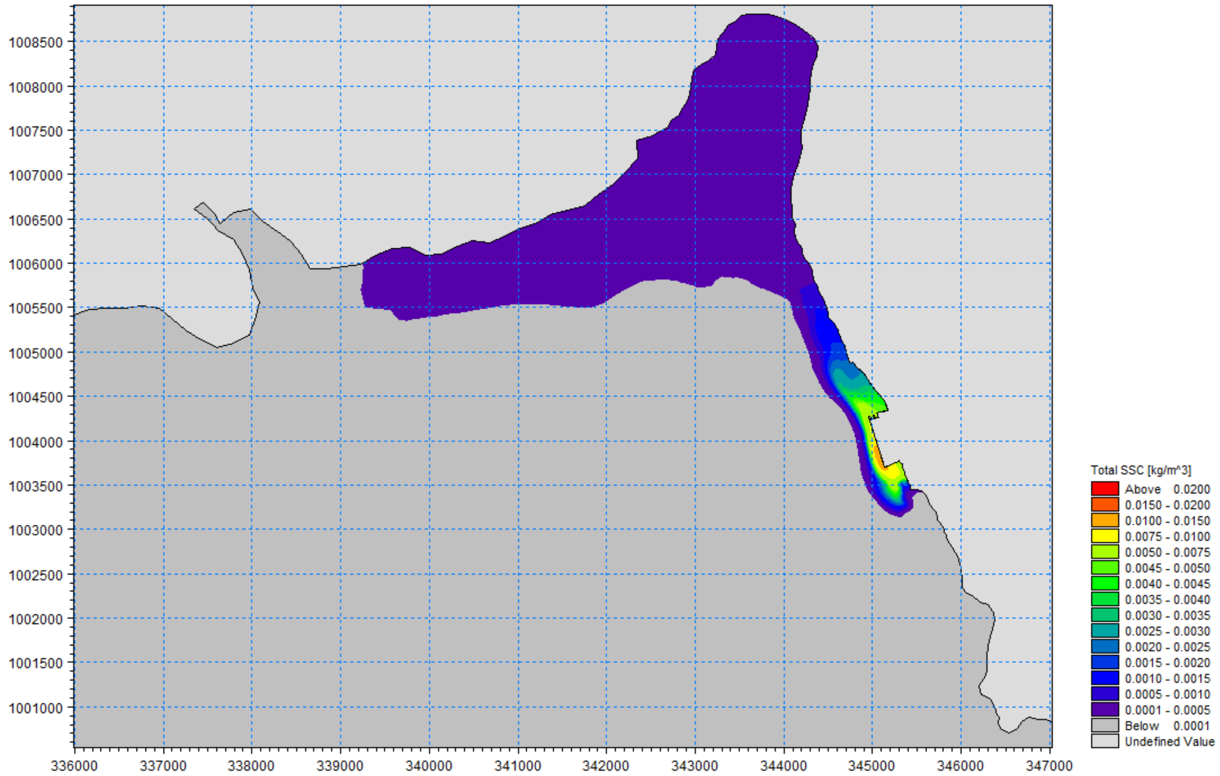

Figure 5-11: FM HD MT Dredge 3 – statistical mean plume TSS (full dredge campaign)

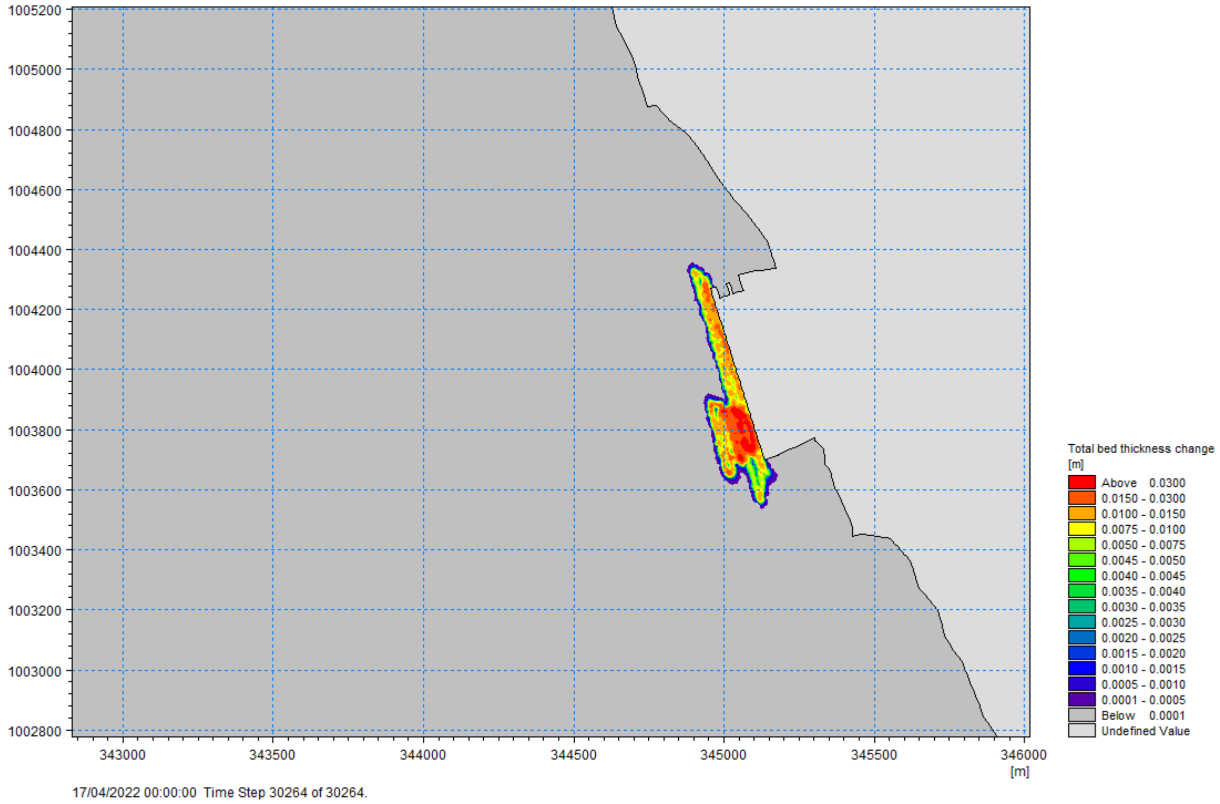

Figure 5-12: FM HD MT Dredge 3 – deposition thickness at end of simulation

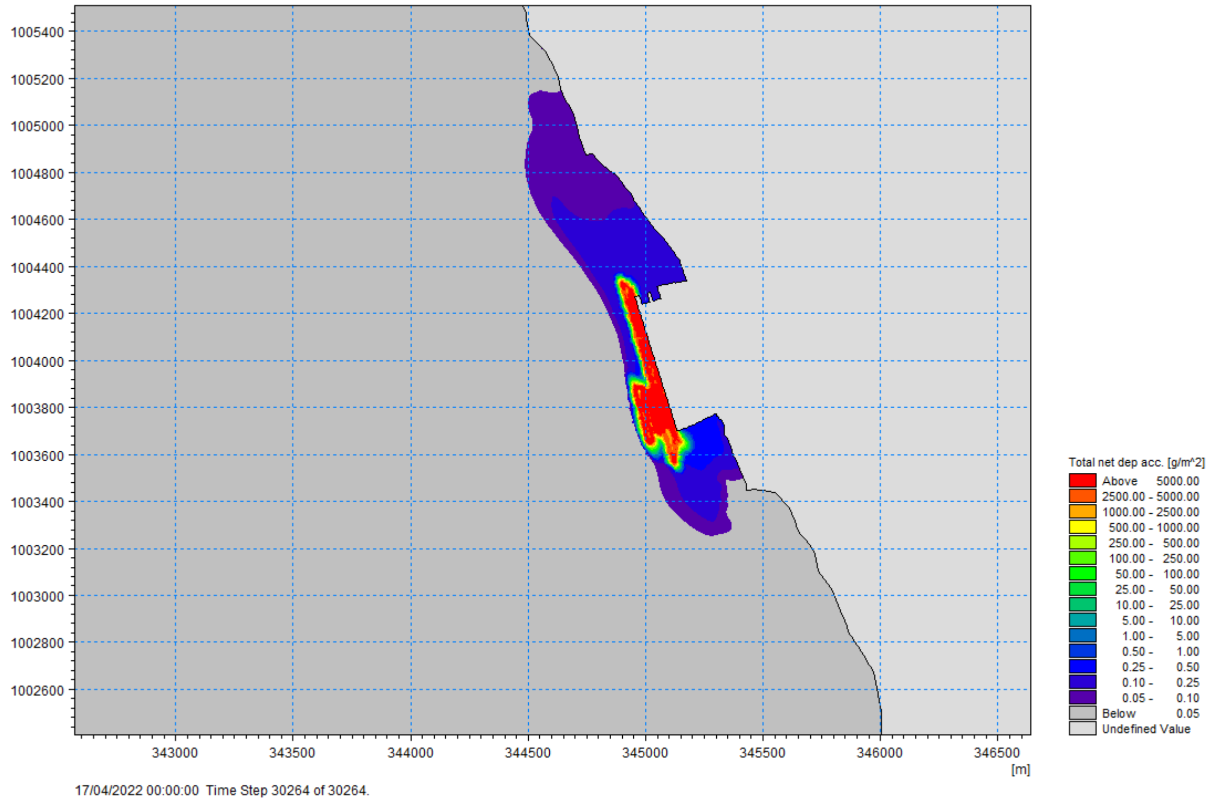

Figure 5-13: FM HD MT Dredge 3 – total net deposition accumulation at end of simulation

5.3.3 Wind Forcing Sensitivity

As outlined in Table 5-5, simulation Scapa FM HD MT Dredge 4 includes the first 8 days of the proposed dredge campaign, simulated with a January 2022 tidal cycle, and including consideration of wind forcing on hydrodynamics, as a model sensitivity scenario. The wind forcing applied in this simulation is constant across the model domain, but varying in time, as described in section 4.1.4. A rose plot showing input wind speed and directional frequency during the simulation period is presented in Figure 5-14, and during the final 50 hours of the simulation in Figure 5-15. Due to the unpredictability of wind forcing in terms of force, duration and direction, this scenario is only used to assess the model sensitivity to wind forcing.

Figure 5-17 and Figure 5-16 present the total suspended solids concentrations within the dredge plume following 8 days of the dredge campaign, with wind forcing included. Comparison of these figures with the results presented in Figure 5-3 highlights the impact of wind forcing on plume extents and placement, as well as observed TSS concentrations. The wind forcing effect on tidal currents acts to reduce the north-western dispersal of the dredge plume, driving the plume towards shore in the east, and extending further along shore to the south-east. Observed TSS concentrations are generally lower than those presented in Figure 5-3, with lower TSS within the dredge pocket, and with values reducing rapidly away from this area.

Figure 5-18 presents a time-series of TSS concentrations at point output locations 1 (north of the dredge zone), 5 (within the dredge zone) and 12 (within the Westerbister fish farm). Review of this figure highlights that point location 5 exhibits the most frequent relative elevations in TSS, and generally highest levels. Point 1 shows less frequent occurrence of elevated TSS, occurring later in the simulation, whilst point 12 shows relatively low (<0.0002 kg/m^3) elevated concentrations of TSS only towards the end of the simulation. The elevation in TSS levels at point 12 is concurrent with prevalence of wind from the north-west and north (Figure 5-15).

Figure 5-19 presents the total deposition thickness following 8 days of the dredge campaign. Review of this figure highlights that, as per simulation FM HD MT Dredge 2, measurable thickness of deposition is limited to the immediate dredge footprint, primarily consisting of sands and gravels, with maximum deposit thickness of 0.015m. Figure 5-20 presents the total net deposition accumulation following 8 days of the dredge campaign. Review of this figure highlights that deposition accumulation primarily occurs within the immediate dredge extent (maximum accumulation ~10,000 g/m^2), with accumulation rapidly decreasing away from this area.

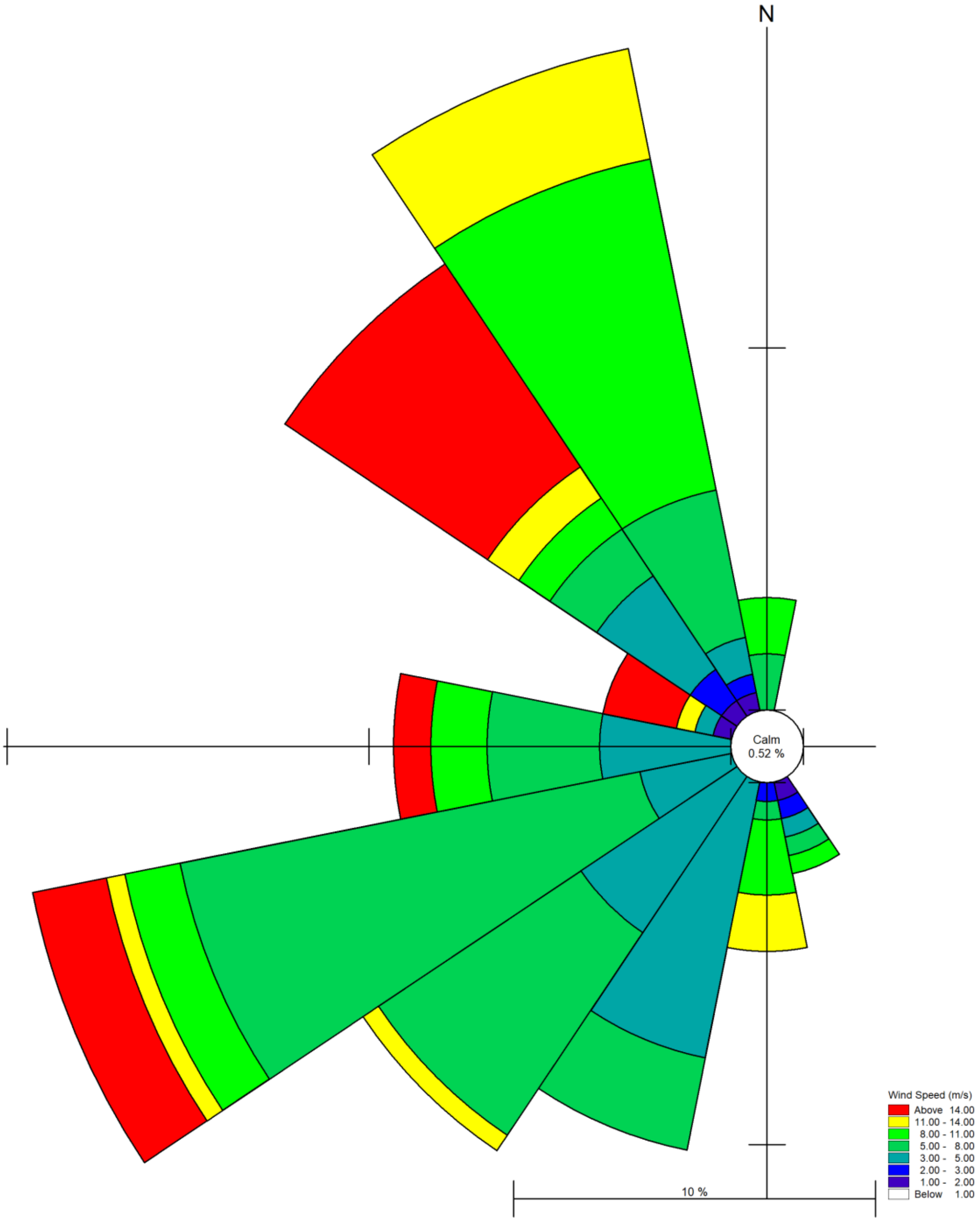

Figure 5-14: Wind rose plot – CREA6 model data for full duration of Scapa FM HD MT Dredge 4

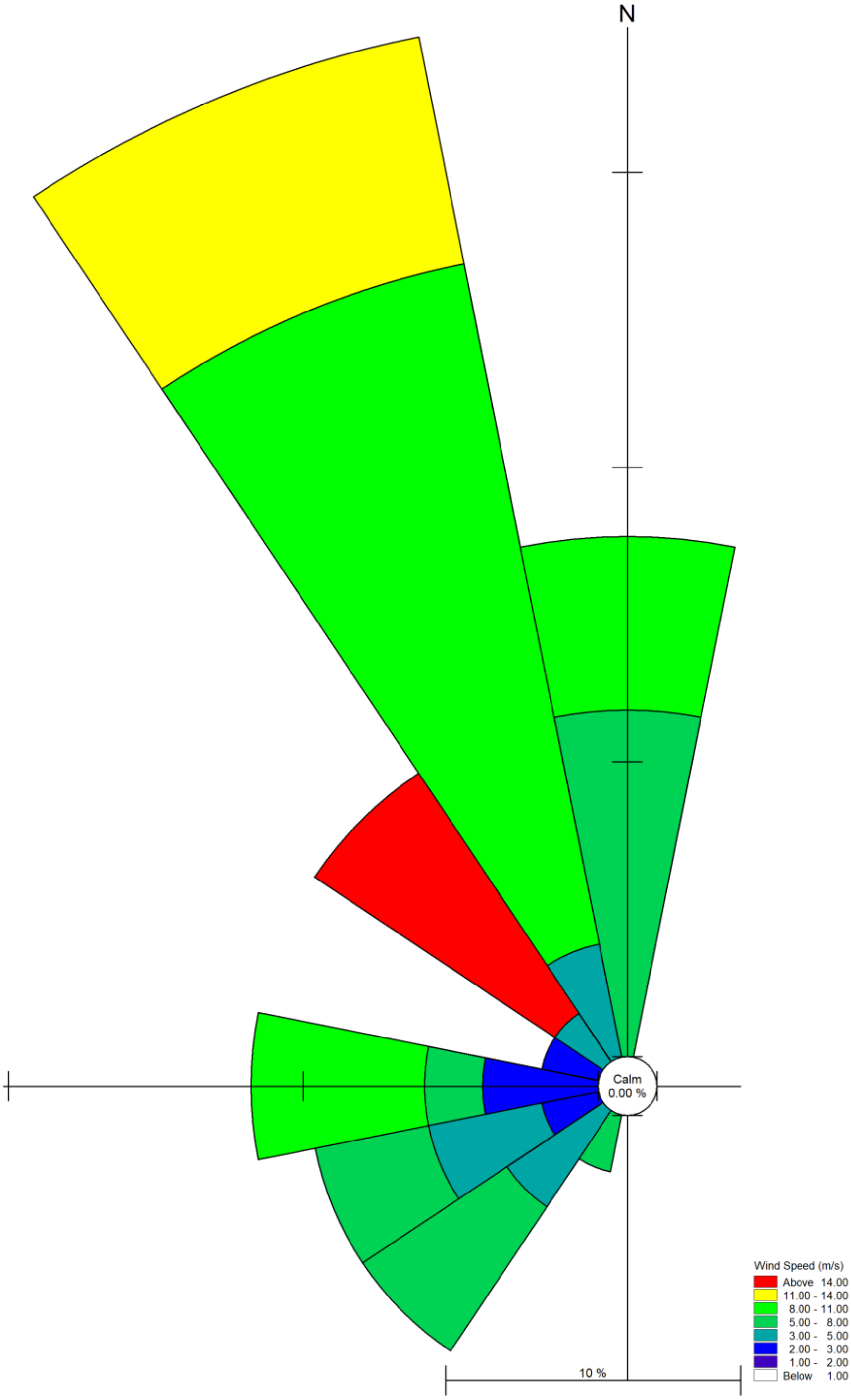

Figure 5-15: Wind rose plot – CREA6 model data for final 50 hours of Scapa FM HD MT Dredge 4

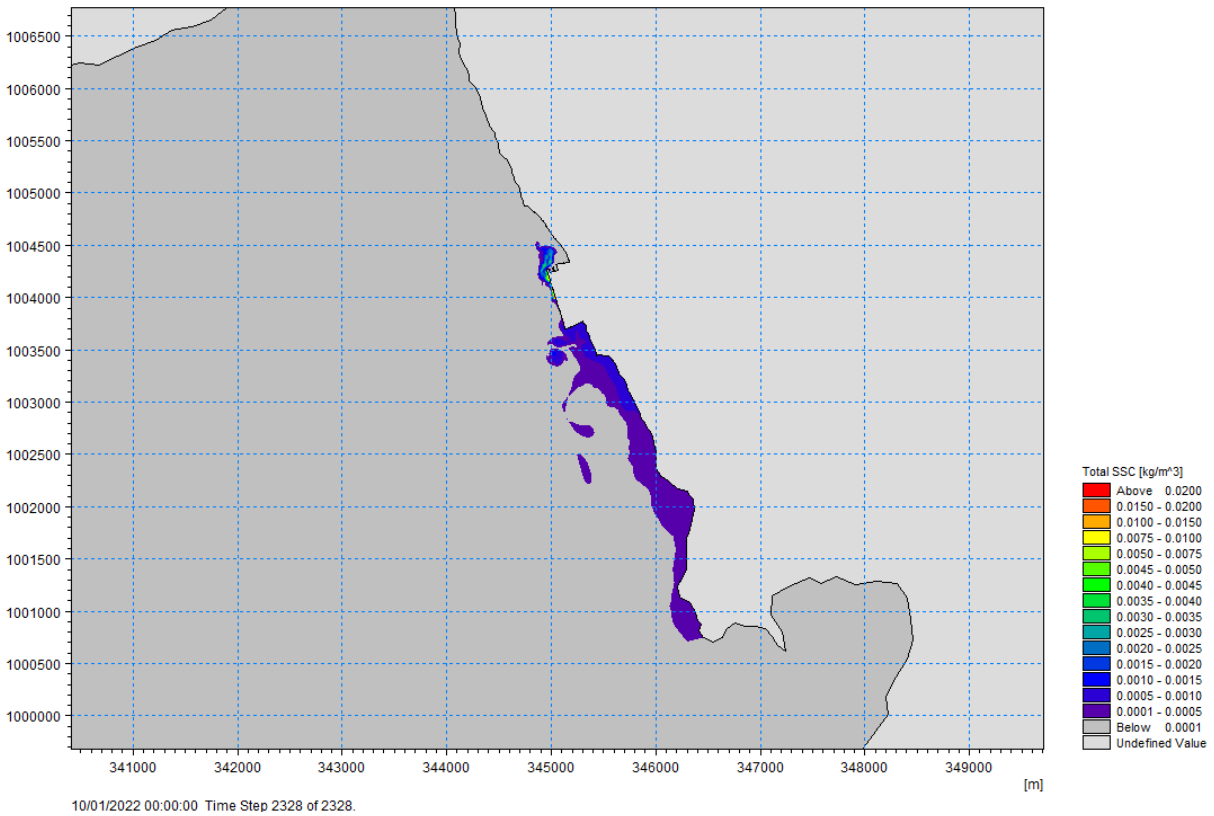

Figure 5-16: FM HD MT Dredge 4 – plume TSS following 8 days of dredge with wind forcing (wider view)

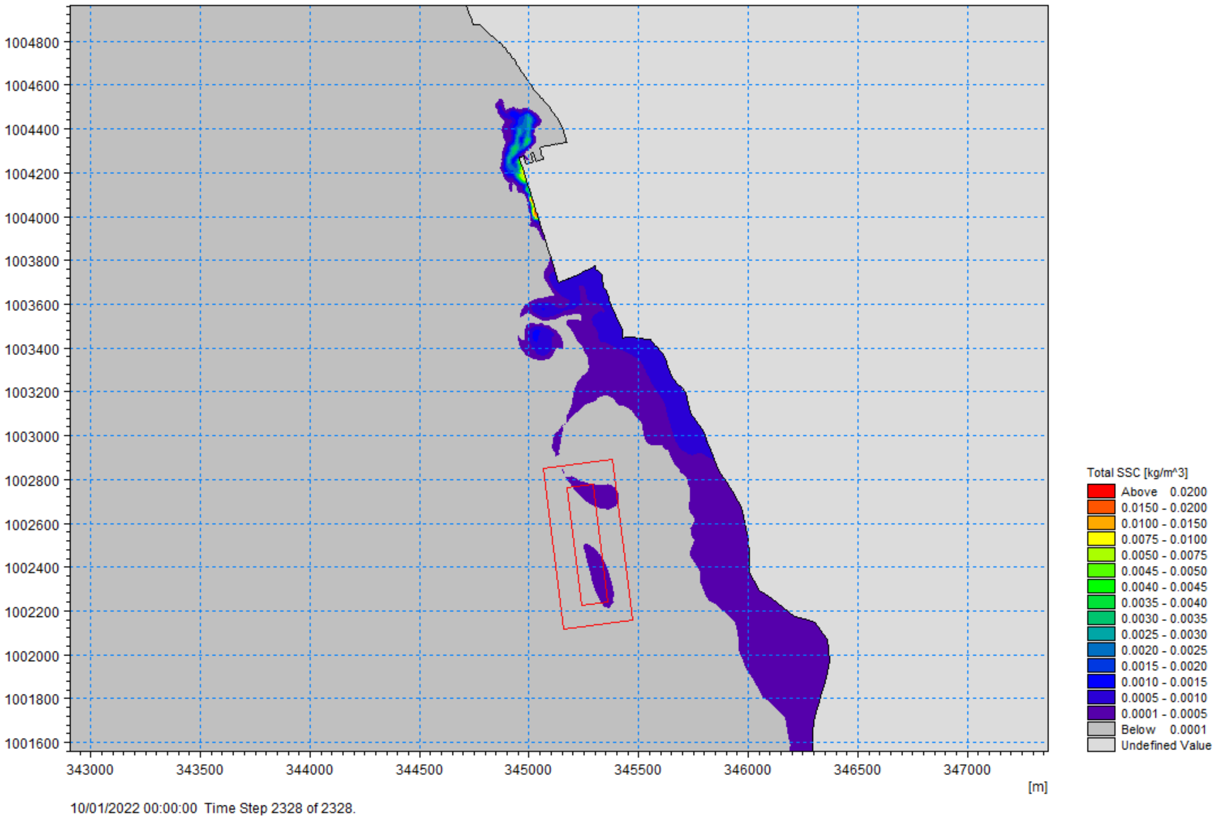

Figure 5-17: FM HD MT Dredge 4 – plume TSS following 8 days of dredge with wind forcing (zoom view Westerbister Fish Farm (red polygons))

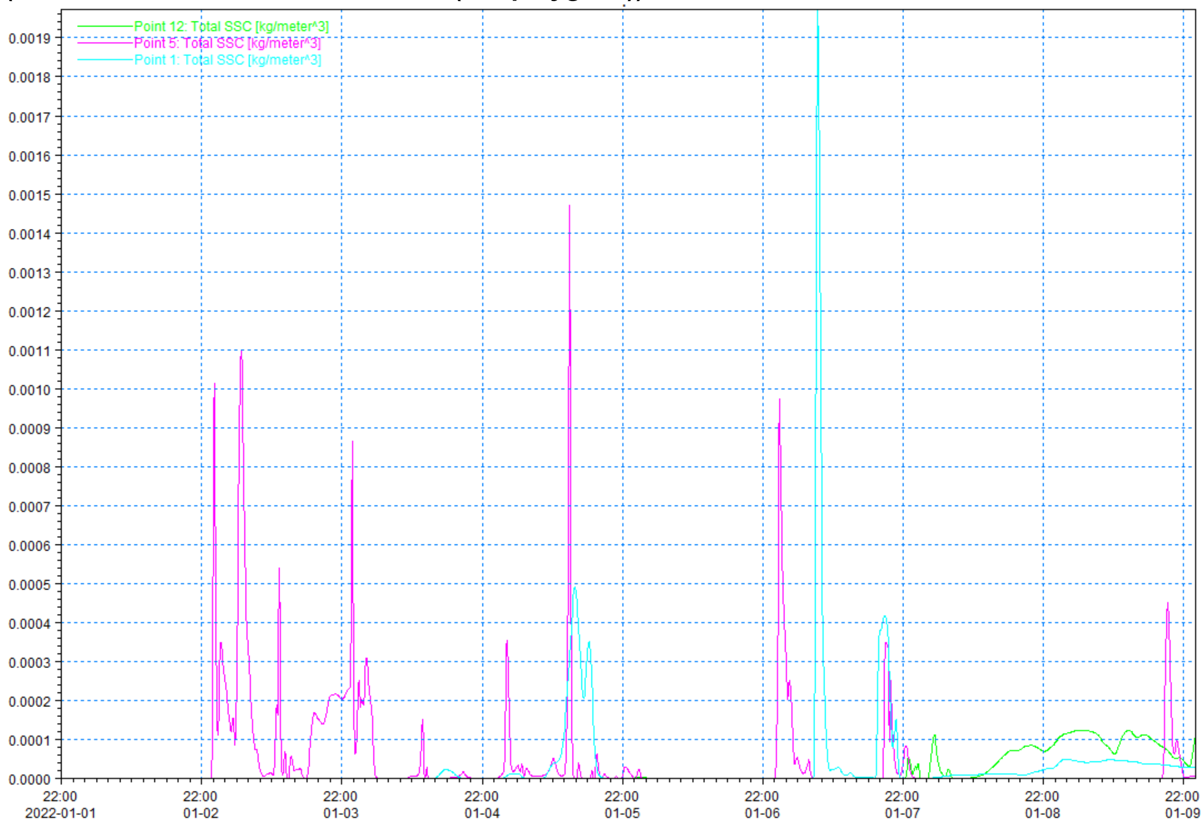

Figure 5-18: FM HD MT Dredge 4 – time-series TSS concentration (kg/m^3) at locations 1, 5 & 12

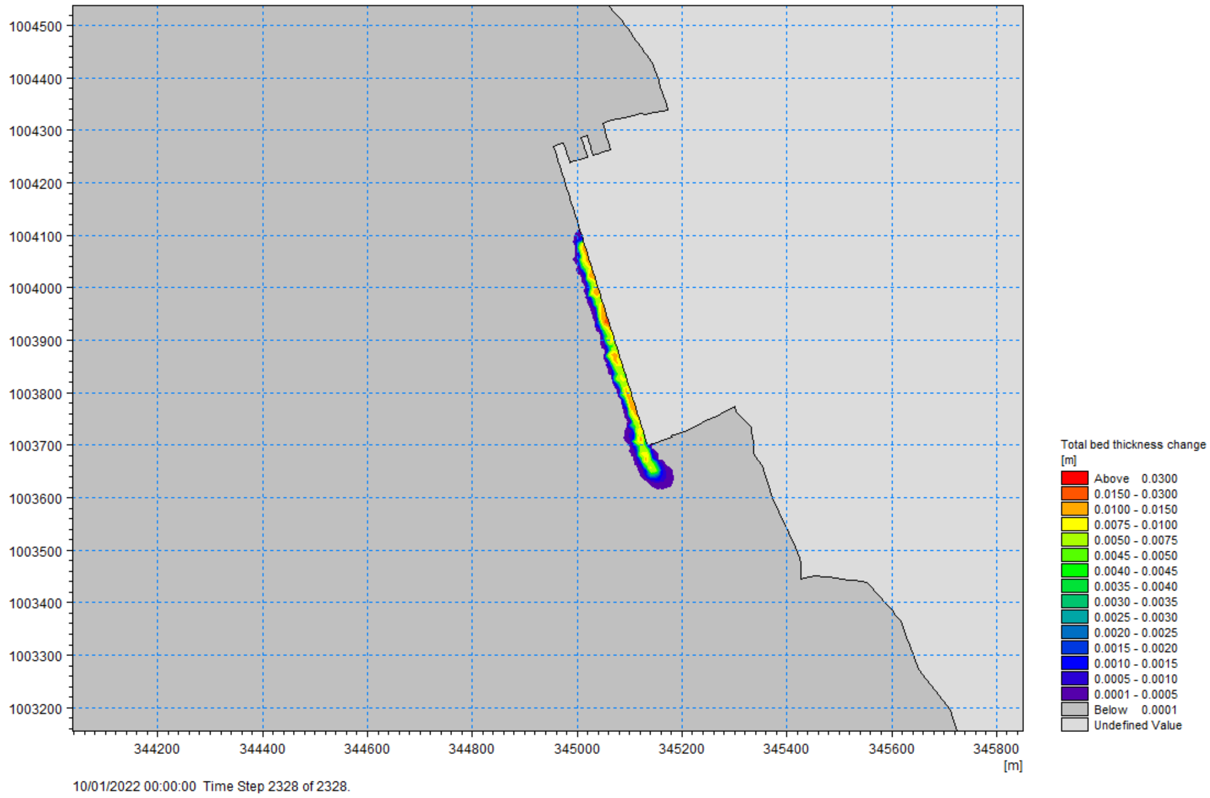

Figure 5-19: FM HD MT Dredge 4 – deposition following 8 days of dredge with wind forcing

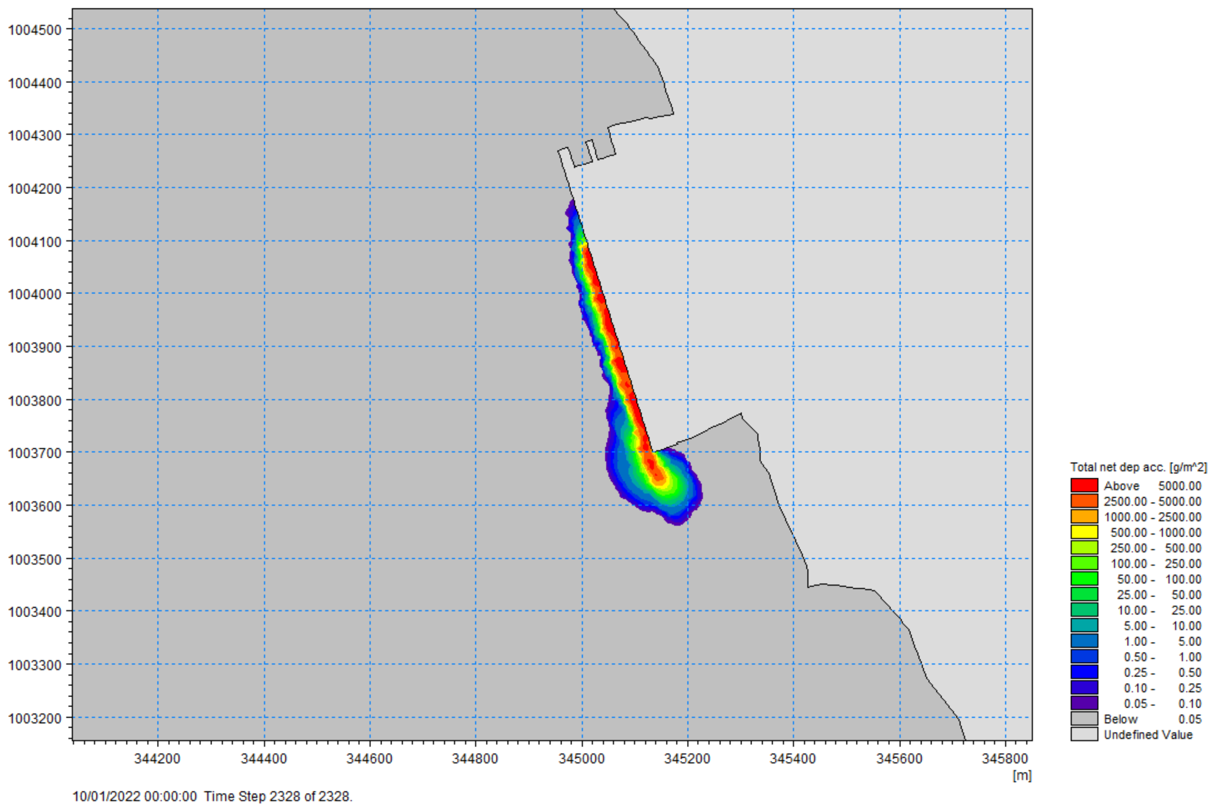

Figure 5-20: FM HD MT Dredge 4 – total net deposition accumulation following 8 days of dredge with wind forcing

6 CONCLUSIONS

A coastal hydrodynamic model has been developed utilising the MIKE by DHI software platform, specifically the MIKE 21 FM HD module. The model extent comprises the coastal waters of Scapa Flow, Scapa Bay, the Hoy Sound, Hoy Mouth, the Sound of Hoxa, the Pentland Firth and North Atlantic.

There are five tidal boundaries within the model extent, with boundary conditions extracted from the DHI MIKE 21 Global Tide Model. UKHO and EMODnet bathymetric survey data have been combined to create a Digital Terrain Model (DTM) for use within the hydrodynamic model. The model utilises a flexible mesh to represent the offshore and coastal areas. The mesh has progressive refinement in resolution towards Deepdale Bay, becoming finer in the area of interest. The mesh has also been refined in locations where complex flow paths influence predictions within Scapa Flow, including around islands, and across the Sound of Hoxa and Hoy Sound. A post-development version of the HD model mesh has been generated to include the proposed development footprint, and associated capital dredge pockets. The model has been run for both existing and post-development conditions, simulating the January 2022 spring and neap tidal cycle. Additional model sensitivity simulations including wind forcing have also been run for both existing and post-development conditions. Validation of the model has been undertaken through comparison of baseline modelled tidal levels with Admiralty tide predictions, and tidal current speeds predicted by the baseline model have been compared to annotated tidal stream speeds on UKHO hydrographic charts. The results of the validation exercise indicate that the model performs well.

The results from the existing (baseline) model run (FM HD 16) and the post-development model run (FM HD 19) have been presented and analysed. Both models predict a semi-diurnal tidal curve, with two high tides and two low tides each day, as is the case around the UK. Tidal elevation predictions are within 0.05m of the corresponding Admiralty Tide Tables predictions for the same tide. The models predict low current speeds and corresponding low bed shear stresses in the vicinity of Deepdale Bay, considered indicative of a low energy environment, with no significant sediment transport by tidal currents predicted.

Comparison of existing and post-development results highlights that no significant change is observed in surface elevation predictions between the two model runs. Comparative analysis of predicted current speeds across the point output locations highlights that minor changes in peak current speed are predicted at point output locations in the immediate vicinity of the proposed development (<0.02m/s change), with no change observed in the wider surrounds. Review of current speed plots highlights that the predicted development impact on tidal current speed is greatest in the vicinity of the -20mCD dredge pocket. Whilst the modelling results presented indicate that the proposed development will produce localised changes in tidal current speeds, it is considered that these variations are insignificant in terms of the wider hydrodynamic regime in and around Deepdale Bay, with predicted changes of very minor scale, and post development speeds of a very similar nature to those observed under existing conditions.

This hydrodynamic modelling study concludes that there will be no significant impact from the proposed development on tidal levels or current speeds.

Additionally, to simulate sediment plume dispersal from the proposed dredge campaign, the MIKE 21 Mud Transport (MT) module has been utilised, in combination with the HD model. Model results show that due to the low current speeds present within the vicinity of the dredge, only clay and silt particles from the finest fraction (1) enter suspension to form a plume, whilst sands and gravel fractions immediately fall out of suspension to deposit within the dredge extent. Highest modelled TSS concentrations are present within the dredge extent, and immediate surrounds, rapidly decreasing with distance away from the dredge zone. The main dredge plume is predicted to extend north-west along shore, with weaker concentrations of TSS predicted to extend further west into Scapa Flow, within the nearshore zone. Model sensitivity scenarios highlight that wind forcing can impact tidal currents and dredge plume dispersal in the vicinity of the proposed development. Wind direction and magnitude will impact the scale and spatial extent of any impact arising from wind forcing.

APPENDICES

A PROPOSED DEVELOPMENT LAYOUT

Chart Datum (Scapa Flow)	Ordnance Datum (Newlyn)	Quay Heights and Tide Data Scapa Deep Water Quay
+7.00m	+5.31m	Quay Edge Level
+3.60m	+1.91m	Mean High Water Spring Tides
+1.69m	0.00m	Ordnance Datum (Newlyn)
+0.70m	-0.99m	Mean Low Water Spring Tides
0.00m	-1.69m	Chart Datum (Scapa Flow)
-5.00m	-6.69m	
-10.00m	-11.69m	
-15.00m	-16.69m	
-20.00m	-21.69m	

ORKNEY ISLANDS COUNCIL
SCAPA DEEP WATER QUAY
PROPOSED SITE LAYOUT
WORKS - FINAL PHASED OPTIONS

20 0 20 40 60 80 100 120 140 160 180 200m

SCALE 1: 2000 at A1

REV	DATE	REVISION	DRN	CHK
P1	03.02.2023	Preliminary Issue P1 for comment	JJM	

ORKNEY ISLANDS COUNCIL
Harbour Authority

Scapa Deep Water Quay Proposal

Works - Final Phased Option Layout

Arch Henderson 1919

Civil Engineers
Structural Engineers
Architects
CDM Co-ordinators
Geotechnical services
Environmental services

Stewart Building, Lerwick, Shetland. ZE1 0LL.
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Aberdeen; Dundee; Glasgow; Lerwick; Inverness; Thurso; Stromness; Southampton; Falkland Islands

DRAWN :	DATE :	CHECKED :	APPROVED :
JJM	February 2023	APS	APS

SCALE : (A1)	DRAWING STATUS :
As Shown	Preliminary

DRAWING No :	REV :
212089-SK-030223	P1

B TABULATED MODEL RESULTS

Table 1: FM HD 16 and FM HD 19 selected point output results for key tidal states

HD Run	Tidal State (Timestep) [Date Time]	Output Location	Surface Elevation (mCD)	Current Speed (m/s)	Current Direction (Radian)	Bed Shear Stress (N/m^2)
16	Mid-Flood Spring (TS 1072) [05/01/22 08:20]	Point 2	2.329	0.006	2.153	0.0002
		Point 4	2.329	0.007	1.968	0.0002
		Point 6	2.329	0.005	2.135	0.0001
		Point 7	2.329	0.005	1.765	0.0001
		Point 9	2.329	0.004	1.735	0.0001
		Point 10	2.329	0.004	2.057	0.0001
		Point 15	2.329	0.007	1.917	0.0002
		Point 16	2.329	0.011	1.187	0.0005
		Point 17	2.329	0.003	1.462	0.0000
		Point 22	2.329	0.018	1.437	0.0013
		Point 23	2.327	0.038	0.948	0.0079
	High Spring (TS 1098) [05/01/22 10:30]	Point 2	3.556	0.016	2.838	0.0012
		Point 4	3.556	0.014	2.647	0.0009
		Point 6	3.556	0.013	2.780	0.0009
		Point 7	3.556	0.012	2.729	0.0007
		Point 9	3.556	0.011	2.636	0.0005
		Point 10	3.556	0.016	2.811	0.0010
		Point 15	3.555	0.015	2.575	0.0009
		Point 16	3.556	0.012	2.557	0.0006
		Point 17	3.556	0.010	2.703	0.0004
		Point 22	3.555	0.017	2.639	0.0011
		Point 23	3.555	0.005	5.270	0.0002
	Mid-Ebb Spring (TS 1147) [05/01/22 14:35]	Point 2	2.126	0.011	5.736	0.0006
		Point 4	2.126	0.008	5.363	0.0003
		Point 6	2.126	0.009	5.197	0.0004
		Point 7	2.126	0.009	5.519	0.0004
		Point 9	2.126	0.009	5.482	0.0003
		Point 10	2.126	0.014	5.673	0.0008
		Point 15	2.126	0.015	5.297	0.0010
		Point 16	2.126	0.014	5.284	0.0008
		Point 17	2.126	0.008	5.337	0.0002
		Point 22	2.126	0.020	5.123	0.0015
		Point 23	2.122	0.032	4.294	0.0060
	Low Spring (TS 1178) [05/01/22 17:10]	Point 2	0.461	0.013	6.079	0.0009
		Point 4	0.461	0.010	5.860	0.0005
		Point 6	0.461	0.009	5.876	0.0004
		Point 7	0.461	0.010	5.940	0.0005
		Point 9	0.461	0.010	5.870	0.0004
		Point 10	0.461	0.016	5.972	0.0012
		Point 15	0.461	0.016	5.625	0.0010
		Point 16	0.461	0.016	5.875	0.0010
		Point 17	0.461	0.009	5.768	0.0003

HD Run	Tidal State (Timestep) [Date Time]	Output Location	Surface Elevation (mCD)	Current Speed (m/s)	Current Direction (Radian)	Bed Shear Stress (N/m²)
		Point 22	0.461	0.017	5.875	0.0012
		Point 23	0.462	0.006	1.890	0.0002
19	Mid-Flood Spring (TS 988) [05/01/22 08:20]	Point 2	2.328	0.008	1.899	0.0003
		Point 4	2.328	0.003	3.494	0.0000
		Point 6	2.328	0.004	1.764	0.0001
		Point 7	2.328	0.009	5.088	0.0003
		Point 9	2.328	0.006	5.517	0.0002
		Point 10	2.328	0.009	1.925	0.0004
		Point 15	2.328	0.007	1.502	0.0002
		Point 16	2.328	0.009	0.915	0.0003
		Point 17	2.328	0.005	6.236	0.0001
		Point 22	2.328	0.017	1.274	0.0011
		Point 23	2.327	0.039	1.067	0.0089
	High Spring (TS 1014) [05/01/22 10:30]	Point 2	3.554	0.011	2.528	0.0006
		Point 4	3.554	0.007	2.639	0.0002
		Point 6	3.554	0.011	3.405	0.0006
		Point 7	3.554	0.014	3.850	0.0009
		Point 9	3.554	0.009	3.372	0.0004
		Point 10	3.554	0.014	2.340	0.0008
		Point 15	3.554	0.011	2.415	0.0005
		Point 16	3.554	0.009	2.614	0.0003
		Point 17	3.554	0.004	2.698	0.0001
		Point 22	3.553	0.014	2.684	0.0007
		Point 23	3.554	0.006	0.601	0.0002
	Mid-Ebb Spring (TS 1063) [05/01/22 14:35]	Point 2	2.128	0.005	5.276	0.0001
		Point 4	2.128	0.023	5.917	0.0025
		Point 6	2.128	0.005	4.499	0.0002
		Point 7	2.128	0.021	6.138	0.0019
		Point 9	2.128	0.015	5.466	0.0010
		Point 10	2.128	0.015	5.637	0.0010
		Point 15	2.128	0.018	5.402	0.0013
		Point 16	2.128	0.017	5.384	0.0012
		Point 17	2.128	0.014	5.443	0.0008
		Point 22	2.127	0.022	5.225	0.0020
		Point 23	2.124	0.034	4.373	0.0067
	Low Spring (TS 1094) [05/01/22 17:10]	Point 2	0.462	0.008	5.637	0.0003
		Point 4	0.462	0.019	5.928	0.0017
		Point 6	0.462	0.014	6.257	0.0010
		Point 7	0.462	0.018	6.102	0.0015
		Point 9	0.462	0.016	5.735	0.0011
		Point 10	0.462	0.013	5.922	0.0008
		Point 15	0.462	0.017	5.644	0.0012
		Point 16	0.462	0.019	5.822	0.0014
		Point 17	0.462	0.015	5.713	0.0010
		Point 22	0.462	0.020	5.882	0.0017
		Point 23	0.463	0.008	3.777	0.0005

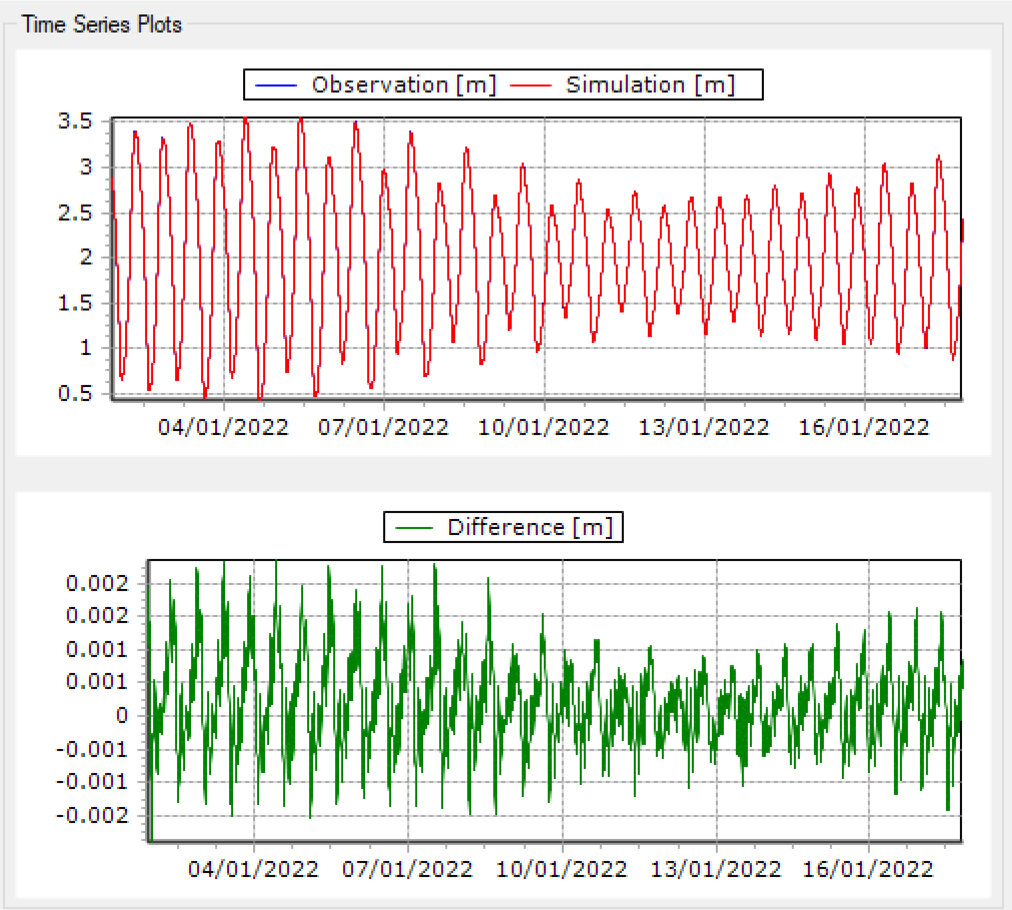
Table 2: Comparison of FM HD 16 and FM HD 19 selected point output results for key tidal states

HD Run Comp.	Tidal State [Date Time]	Output Location	Surface Elevation Difference (m)	Current Speed Difference (m/s)	Bed Shear Stress Difference (N/m^2)
FMHD16 minus FMHD17	Mid-Flood Spring [05/01/22 08:20]	Point 2	0.00	0.00	-0.0001
		Point 4	0.00	0.00	0.0002
		Point 6	0.00	0.00	0.0000
		Point 7	0.00	0.00	-0.0002
		Point 9	0.00	0.00	-0.0001
		Point 10	0.00	-0.01	-0.0003
		Point 15	0.00	0.00	0.0000
		Point 16	0.00	0.00	0.0001
		Point 17	0.00	0.00	-0.0001
		Point 22	0.00	0.00	0.0002
		Point 23	0.00	0.00	-0.0009
	High Spring [05/01/22 10:30]	Point 2	0.00	0.00	0.0007
		Point 4	0.00	0.01	0.0007
		Point 6	0.00	0.00	0.0003
		Point 7	0.00	0.00	-0.0002
		Point 9	0.00	0.00	0.0000
		Point 10	0.00	0.00	0.0002
		Point 15	0.00	0.00	0.0004
		Point 16	0.00	0.00	0.0003
		Point 17	0.00	0.01	0.0003
		Point 22	0.00	0.00	0.0004
		Point 23	0.00	0.00	-0.0001
	Mid-Ebb Spring [05/01/22 14:35]	Point 2	0.00	0.01	0.0005
		Point 4	0.00	-0.02	-0.0022
		Point 6	0.00	0.00	0.0002
		Point 7	0.00	-0.01	-0.0015
		Point 9	0.00	-0.01	-0.0007
		Point 10	0.00	0.00	-0.0001
		Point 15	0.00	0.00	-0.0003
		Point 16	0.00	0.00	-0.0004
		Point 17	0.00	-0.01	-0.0005
		Point 22	0.00	0.00	-0.0005
		Point 23	0.00	0.00	-0.0007
	Low Spring [05/01/22 17:10]	Point 2	0.00	0.01	0.0006
		Point 4	0.00	-0.01	-0.0012
		Point 6	0.00	-0.01	-0.0006
		Point 7	0.00	-0.01	-0.0010
		Point 9	0.00	-0.01	-0.0007
		Point 10	0.00	0.00	0.0004
		Point 15	0.00	0.00	-0.0002
		Point 16	0.00	0.00	-0.0004
		Point 17	0.00	-0.01	-0.0006
		Point 22	0.00	0.00	-0.0005
		Point 23	0.00	0.00	-0.0002

C MODEL RESULTS - GRAPHICAL COMPARISONS

Note: Observation = baseline model [FM HD 16] and Simulation = post-development model [FM HD 19]

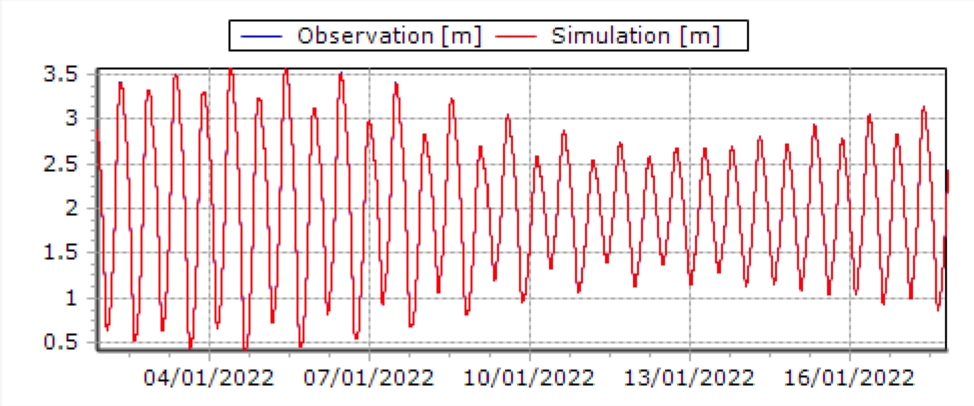
<u>Water Surface Elevation</u>

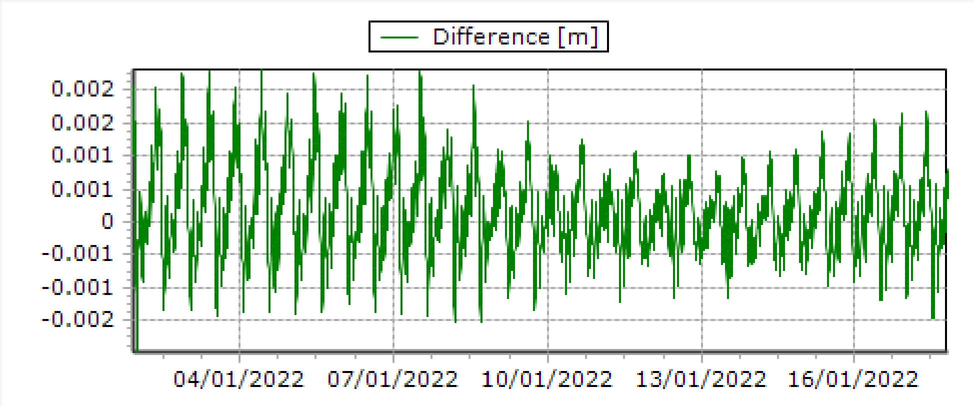


Statistics

	Observation	Simulation	Difference
Item Name	Point 2: Surface ele...	Point 2: Surface ele...	Difference
Item Unit	[m]	[m]	[m]
Minimum	0.4223	0.4231	-0.0019
Maximum	3.5555	3.5536	0.0024
Average	1.9935	1.9933	0.0002
Std. deviation	0.7521	0.7517	0.0007

Time Series Plots

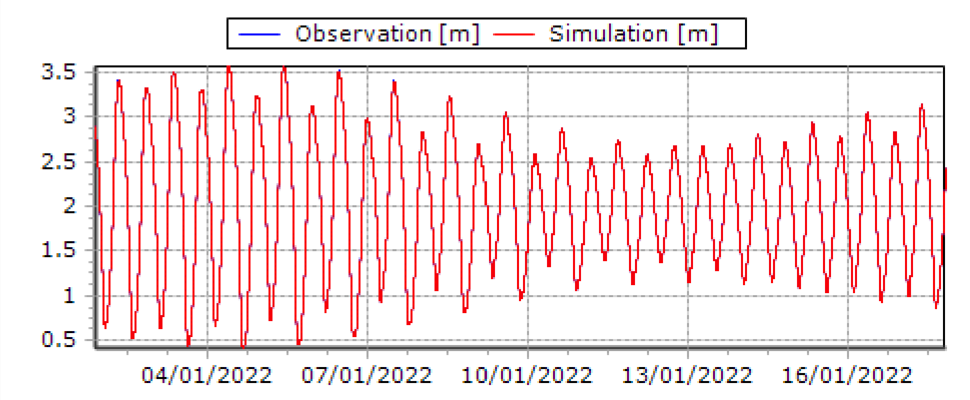


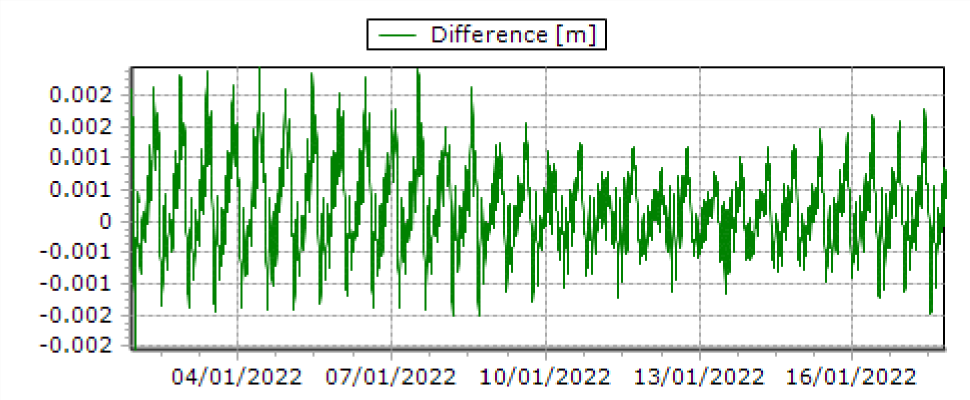


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 4: Surface ele...	Point 4: Surface ele...	Difference
	Item Unit	[m]	[m]	[m]
	Minimum	0.4222	0.4231	-0.0020
	Maximum	3.5556	3.5537	0.0023
	Average	1.9935	1.9933	0.0002
	Std. deviation	0.7521	0.7516	0.0007

Time Series Plots

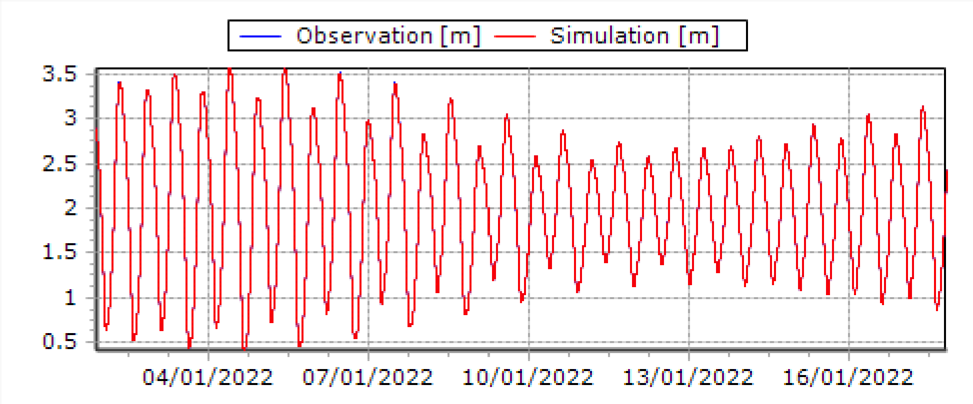


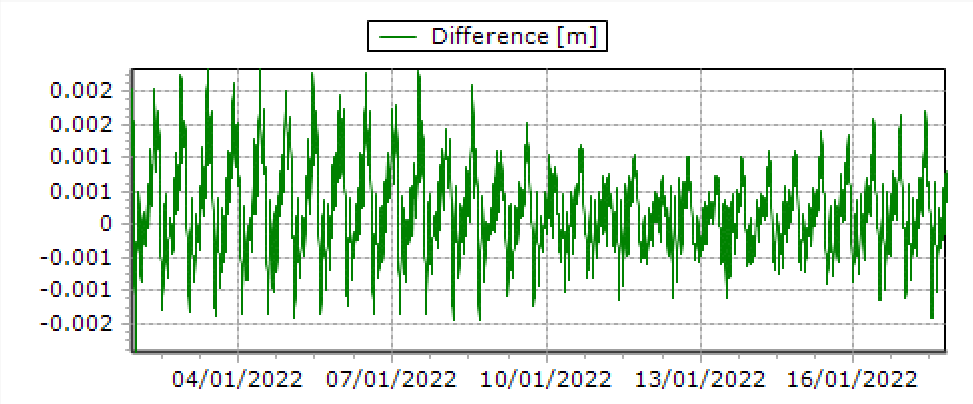


Statistics

	Observation	Simulation	Difference
Item Name	Point 6: Surface ele...	Point 6: Surface ele...	Difference
Item Unit	[m]	[m]	[m]
Minimum	0.4221	0.4230	-0.0021
Maximum	3.5557	3.5536	0.0024
Average	1.9935	1.9933	0.0002
Std. deviation	0.7521	0.7516	0.0007

Time Series Plots

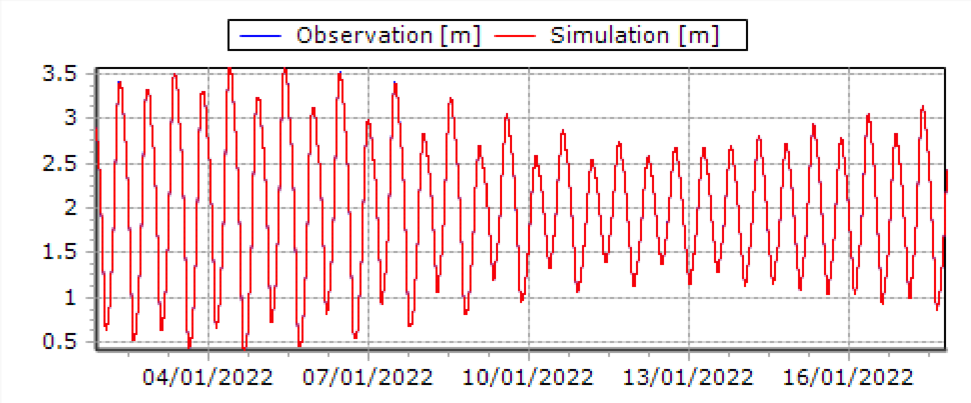


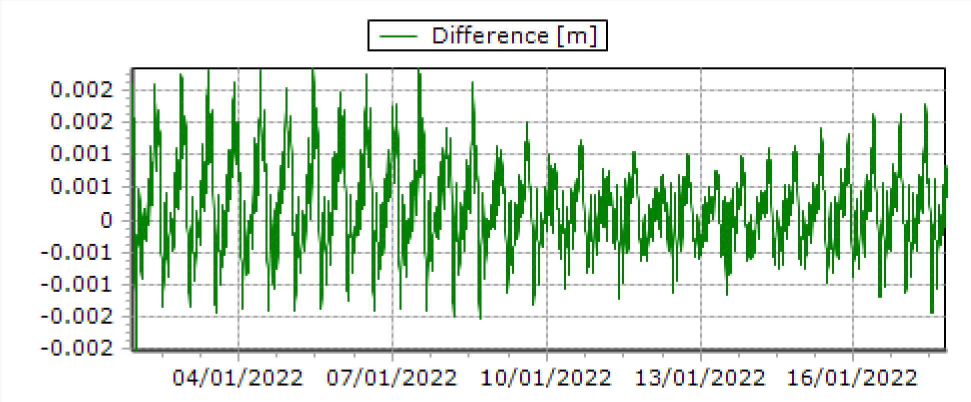


Statistics

	Observation	Simulation	Difference
Item Name	Point 7: Surface ele...	Point 7: Surface ele...	Difference
Item Unit	[m]	[m]	[m]
Minimum	0.4222	0.4231	-0.0019
Maximum	3.5556	3.5536	0.0023
Average	1.9935	1.9933	0.0002
Std. deviation	0.7521	0.7516	0.0007

Time Series Plots

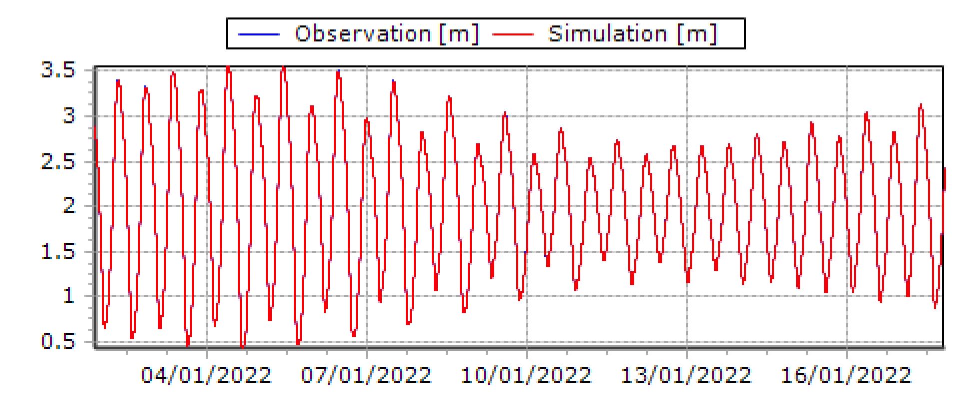


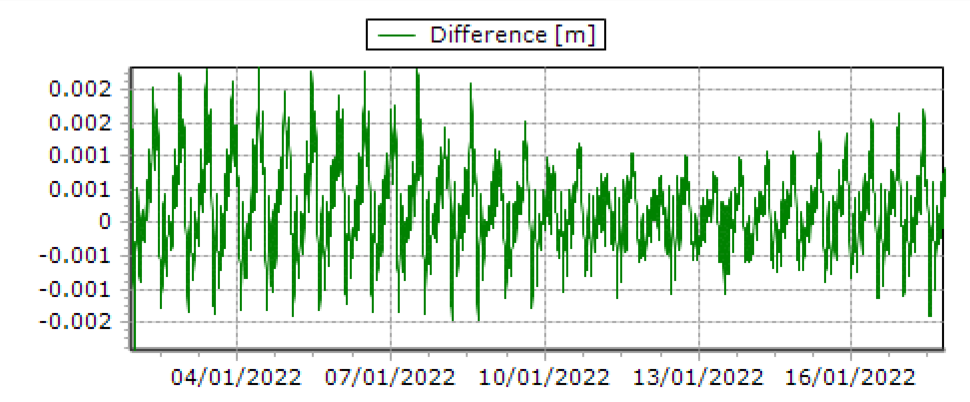


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 9: Surface ele...	Point 9: Surface ele...	Difference
	Item Unit	[m]	[m]	[m]
	Minimum	0.4221	0.4230	-0.0020
	Maximum	3.5556	3.5537	0.0023
	Average	1.9935	1.9933	0.0002
	Std. deviation	0.7521	0.7516	0.0007

Time Series Plots

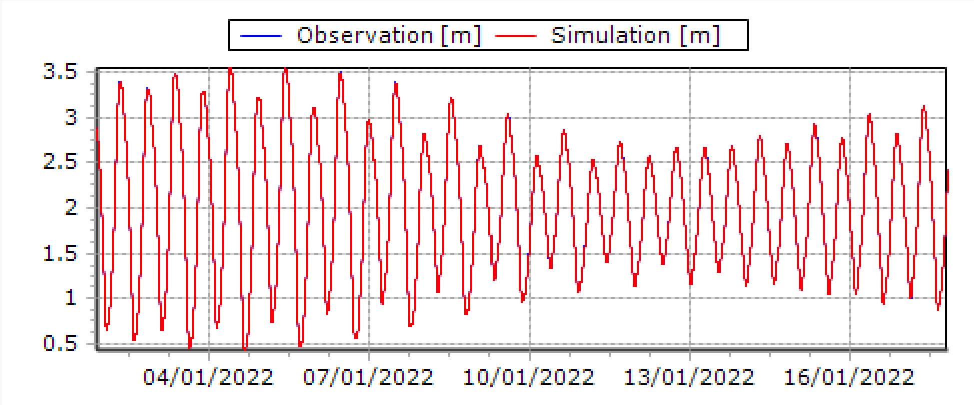


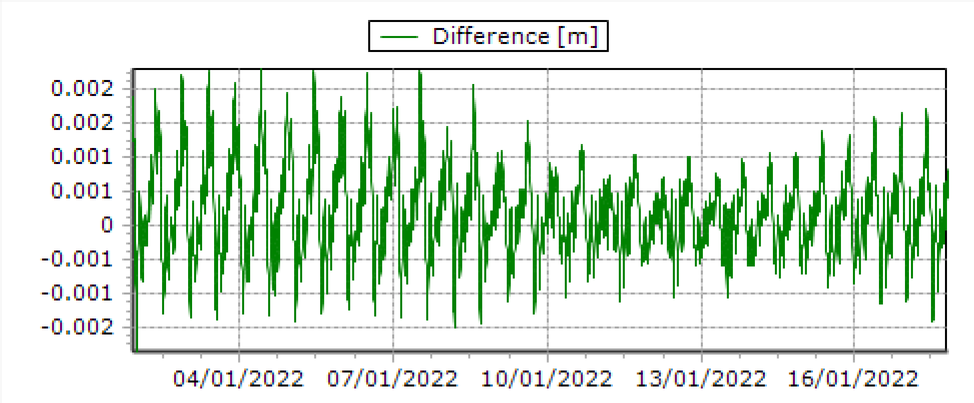


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 10: Surface el...	Point 10: Surface el...	Difference
	Item Unit	[m]	[m]	[m]
	Minimum	0.4223	0.4232	-0.0019
	Maximum	3.5555	3.5536	0.0023
	Average	1.9935	1.9933	0.0002
	Std. deviation	0.7521	0.7517	0.0007

Time Series Plots

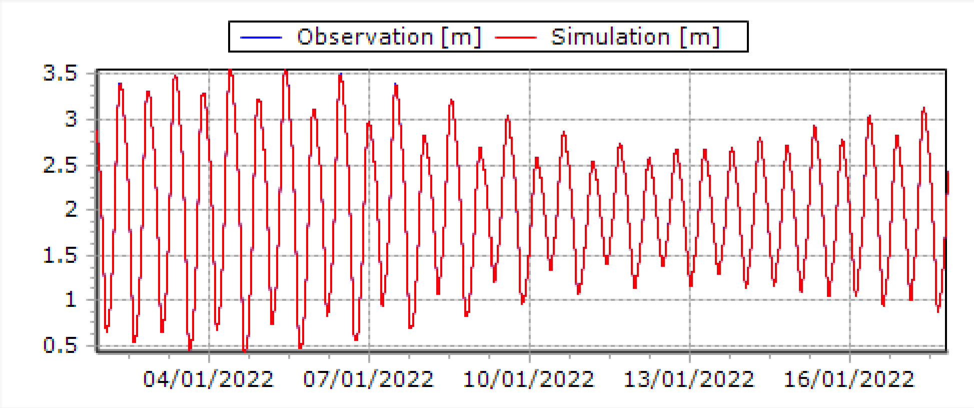


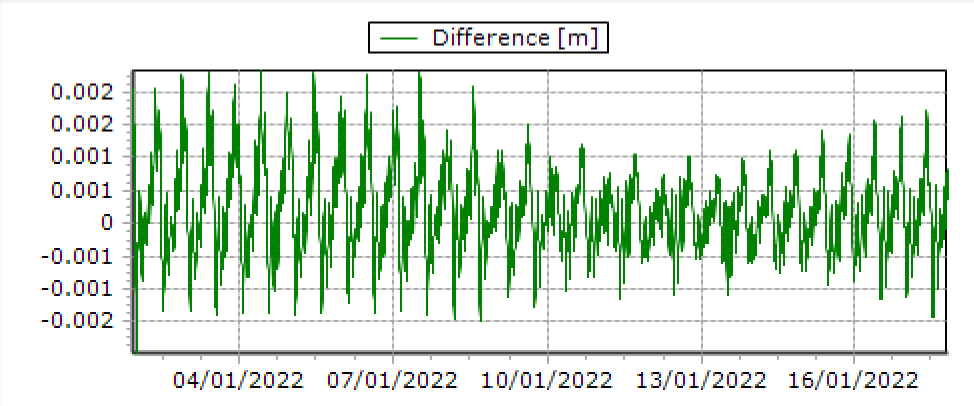


Statistics

	Observation	Simulation	Difference
Item Name	Point 15: Surface el...	Point 15: Surface el...	Difference
Item Unit	[m]	[m]	[m]
Minimum	0.4224	0.4233	-0.0019
Maximum	3.5554	3.5536	0.0023
Average	1.9935	1.9933	0.0002
Std. deviation	0.7522	0.7517	0.0007

Time Series Plots

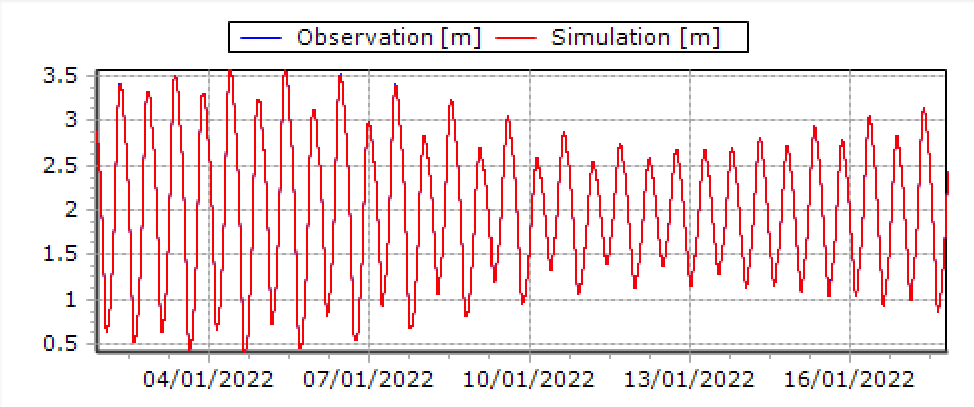


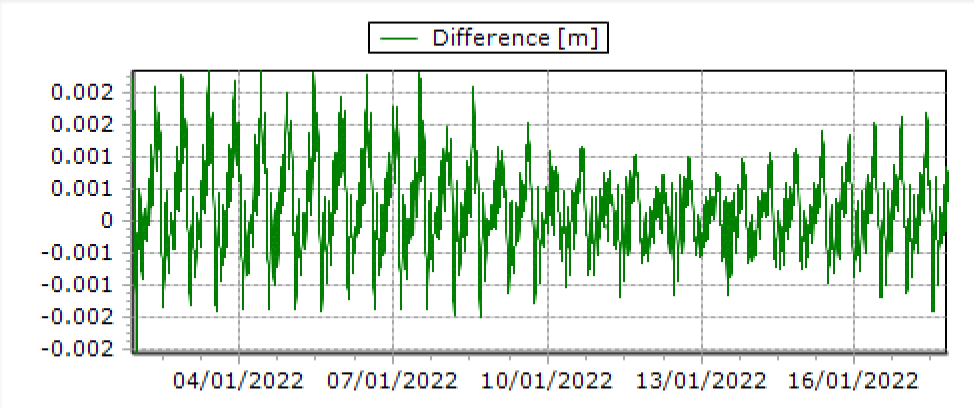


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 16: Surface el...	Point 16: Surface el...	Difference
	Item Unit	[m]	[m]	[m]
	Minimum	0.4222	0.4231	-0.0020
	Maximum	3.5556	3.5536	0.0023
	Average	1.9935	1.9933	0.0002
	Std. deviation	0.7520	0.7516	0.0007

Time Series Plots

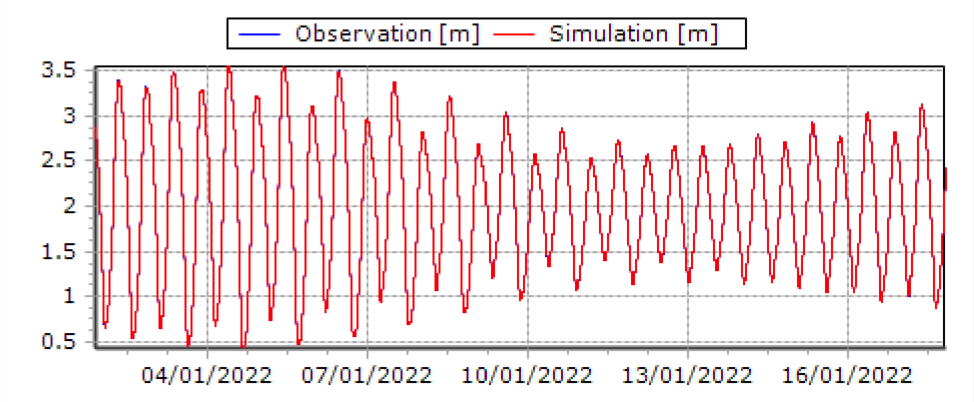


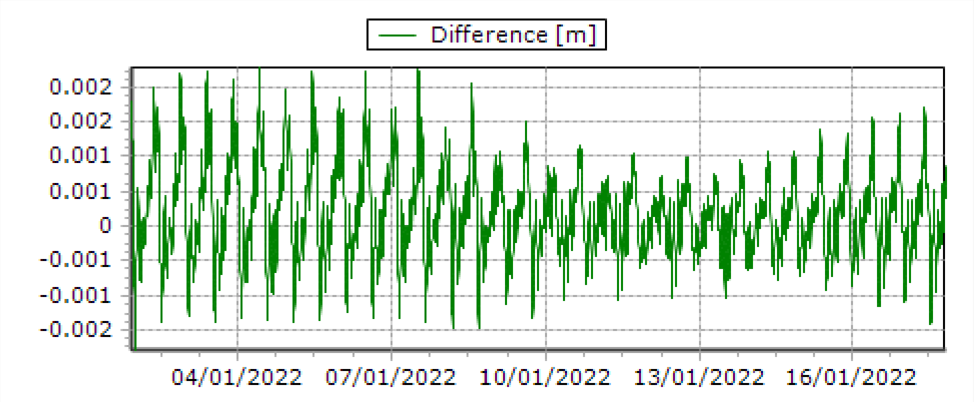


Statistics

	Observation	Simulation	Difference
Item Name	Point 17: Surface el...	Point 17: Surface el...	Difference
Item Unit	[m]	[m]	[m]
Minimum	0.4220	0.4229	-0.0021
Maximum	3.5557	3.5537	0.0024
Average	1.9935	1.9933	0.0002
Std. deviation	0.7520	0.7516	0.0007

Time Series Plots

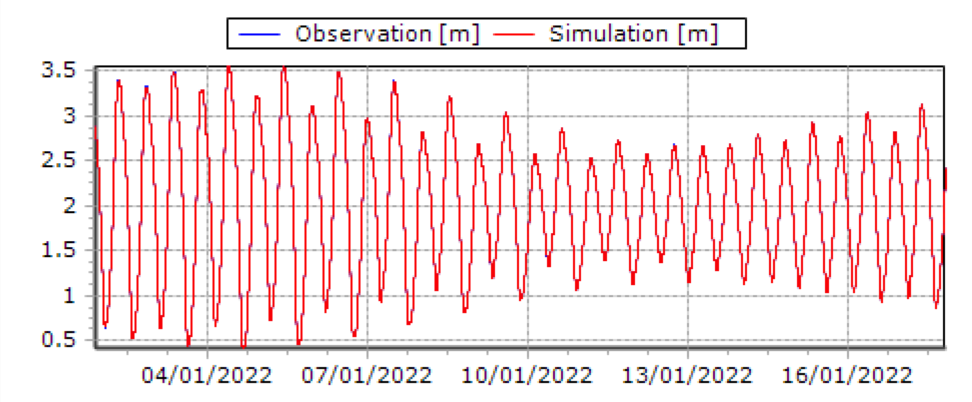


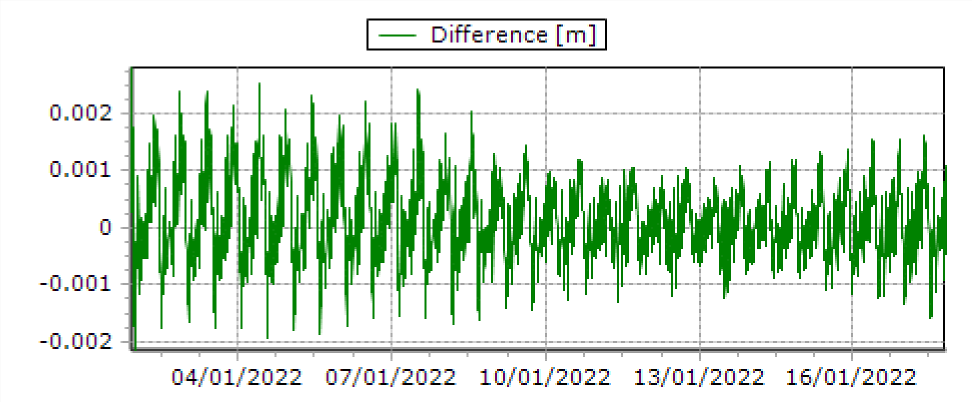


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 22: Surface el...	Point 22: Surface el...	Difference
	Item Unit	[m]	[m]	[m]
	Minimum	0.4227	0.4235	-0.0018
	Maximum	3.5552	3.5534	0.0023
	Average	1.9935	1.9933	0.0002
	Std. deviation	0.7521	0.7517	0.0007

Time Series Plots



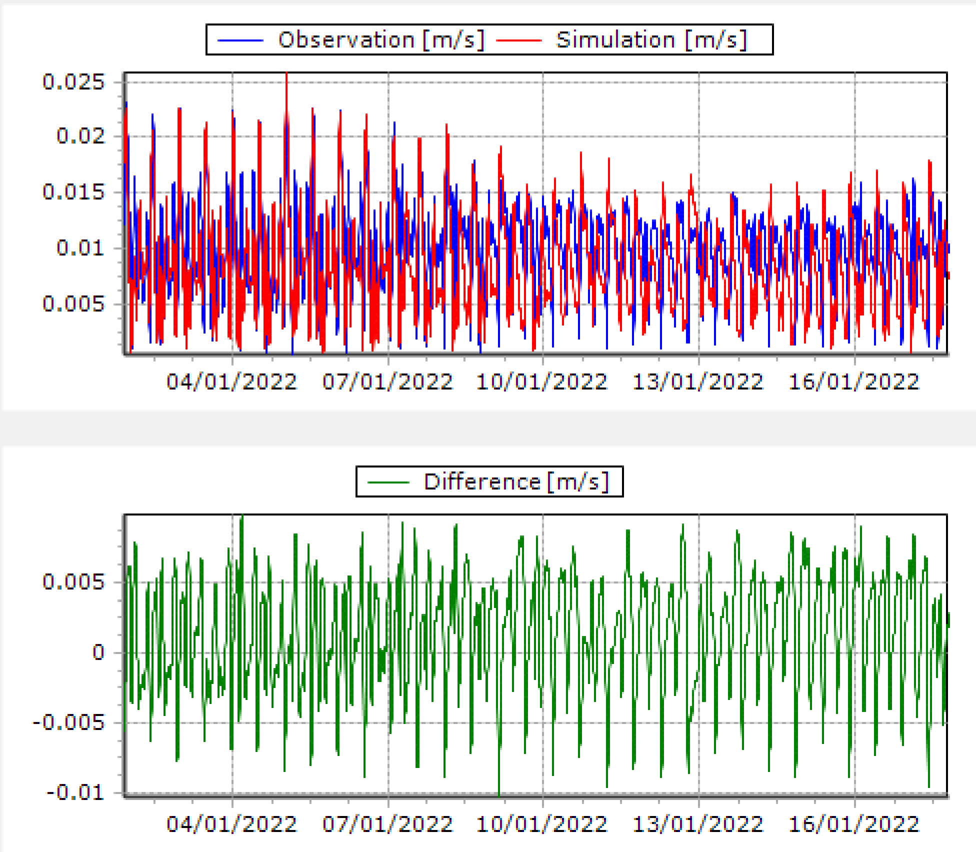


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 23: Surface el...	Point 23: Surface el...	Difference
	Item Unit	[m]	[m]	[m]
	Minimum	0.4219	0.4230	-0.0022
	Maximum	3.5550	3.5537	0.0028
	Average	1.9934	1.9933	0.0001
	Std. deviation	0.7528	0.7524	0.0007

Current Speed

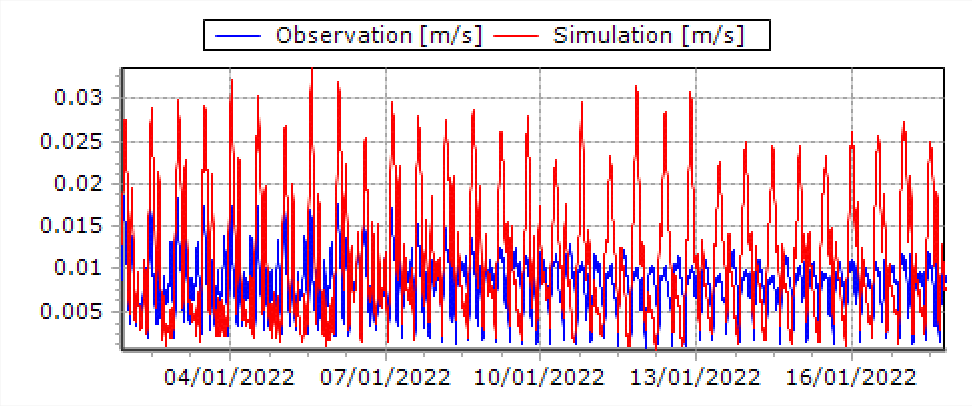
Time Series Plots

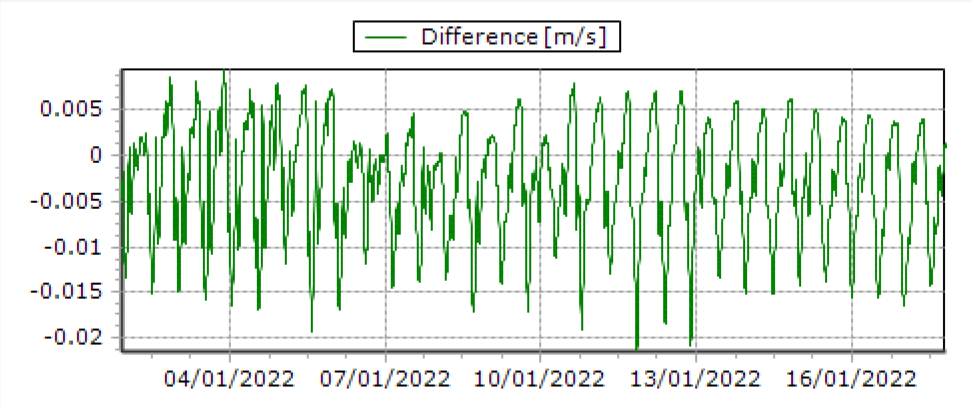


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 2: Current spe...	Point 2: Current spe...	Difference
	Item Unit	[m/s]	[m/s]	[m/s]
	Minimum	0.0006	0.0007	-0.0103
	Maximum	0.0232	0.0258	0.0099
	Average	0.0101	0.0087	0.0015
	Std. deviation	0.0040	0.0044	0.0041

Time Series Plots

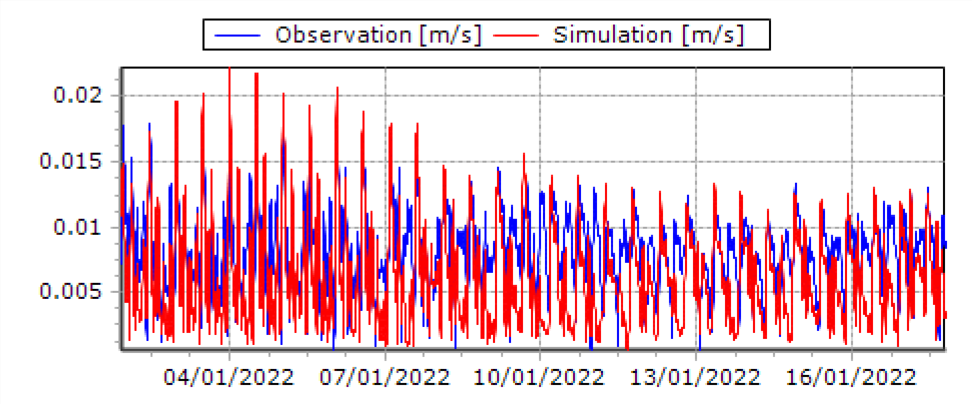


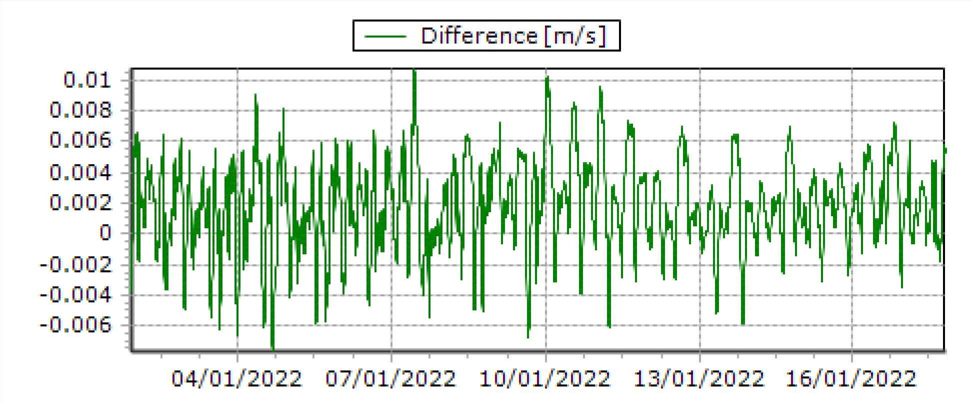


Statistics

	Observation	Simulation	Difference
Item Name	Point 4: Current spe...	Point 4: Current spe...	Difference
Item Unit	[m/s]	[m/s]	[m/s]
Minimum	0.0008	0.0004	-0.0215
Maximum	0.0185	0.0336	0.0095
Average	0.0082	0.0114	-0.0032
Std. deviation	0.0031	0.0074	0.0062

Time Series Plots

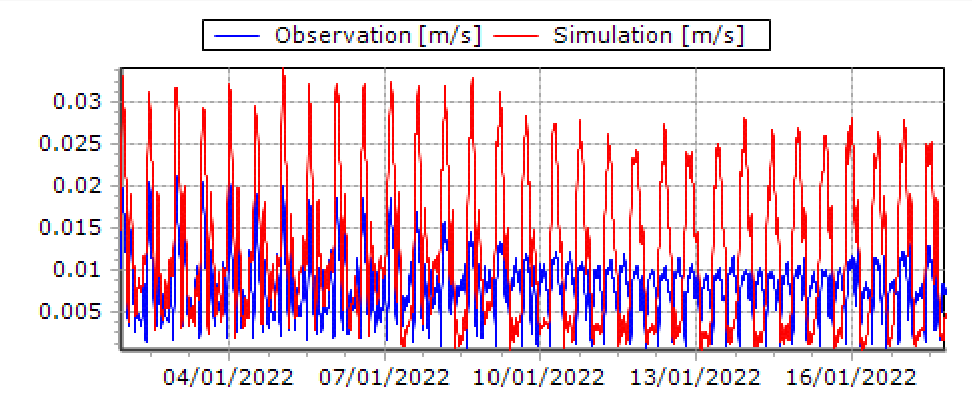


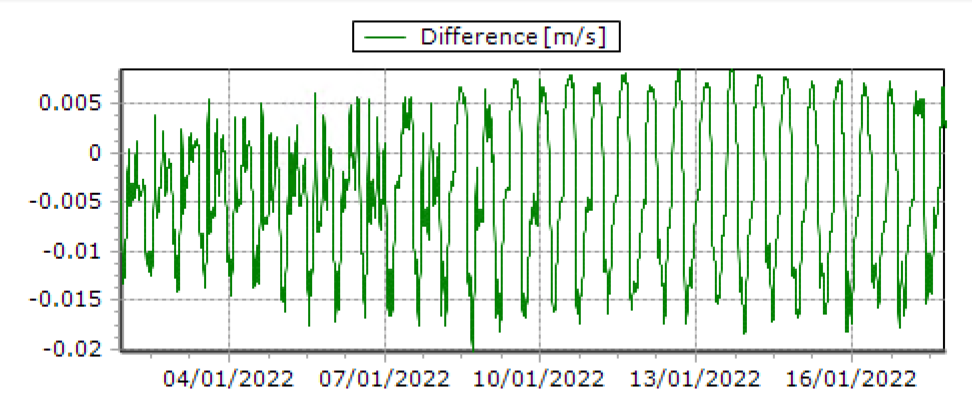


Statistics

	Observation	Simulation	Difference
Item Name	Point 6: Current spe...	Point 6: Current spe...	Difference
Item Unit	[m/s]	[m/s]	[m/s]
Minimum	0.0006	0.0007	-0.0076
Maximum	0.0186	0.0221	0.0107
Average	0.0081	0.0063	0.0018
Std. deviation	0.0031	0.0038	0.0029

Time Series Plots

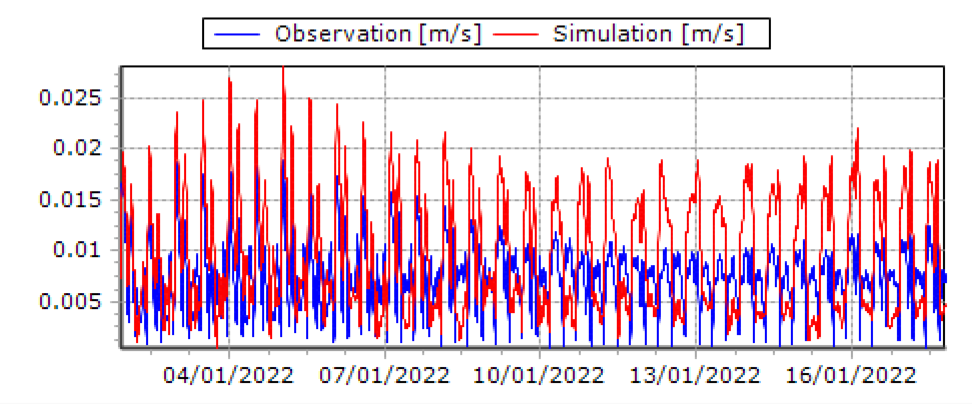


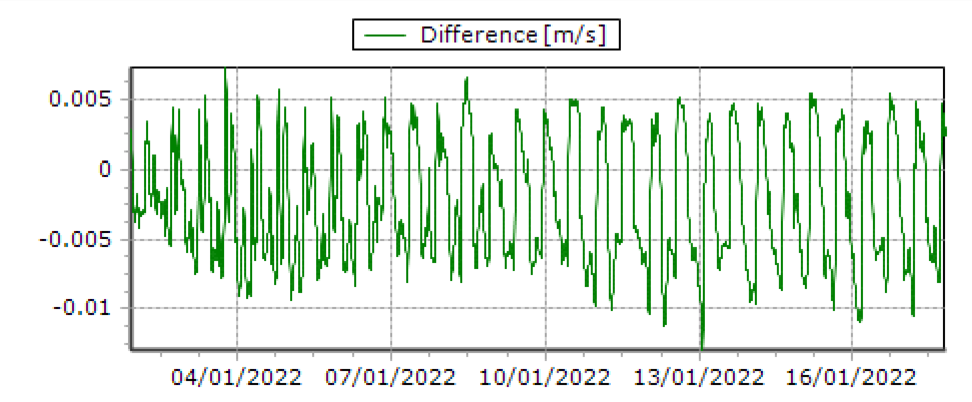


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 7: Current spe...	Point 7: Current spe...	Difference
	Item Unit	[m/s]	[m/s]	[m/s]
	Minimum	0.0005	0.0003	-0.0202
	Maximum	0.0212	0.0342	0.0085
	Average	0.0080	0.0124	-0.0044
	Std. deviation	0.0035	0.0087	0.0073

Time Series Plots

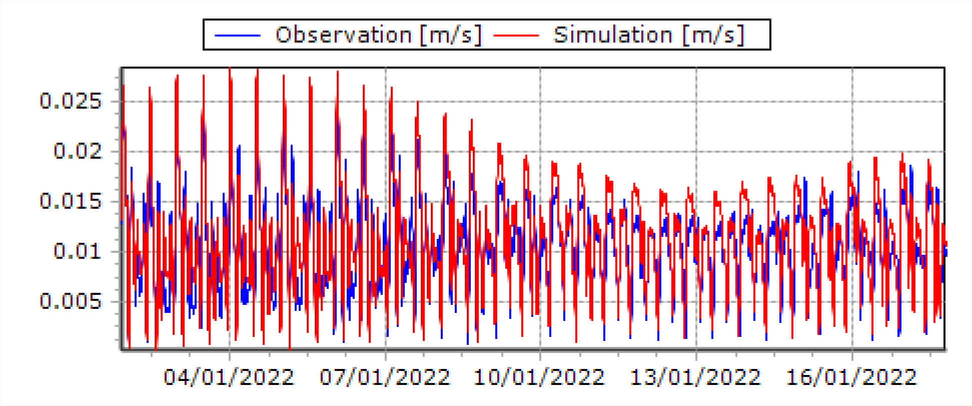


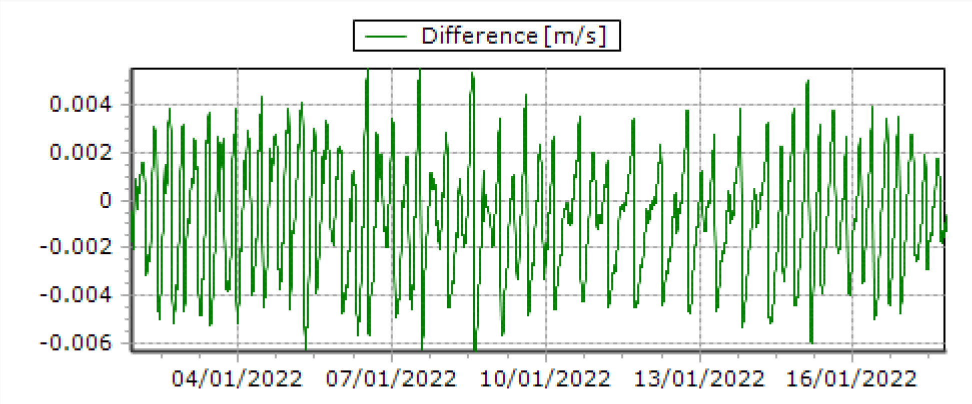


Statistics

	Observation	Simulation	Difference
Item Name	Point 9: Current spe...	Point 9: Current spe...	Difference
Item Unit	[m/s]	[m/s]	[m/s]
Minimum	0.0005	0.0004	-0.0130
Maximum	0.0187	0.0280	0.0074
Average	0.0073	0.0097	-0.0024
Std. deviation	0.0032	0.0056	0.0044

Time Series Plots

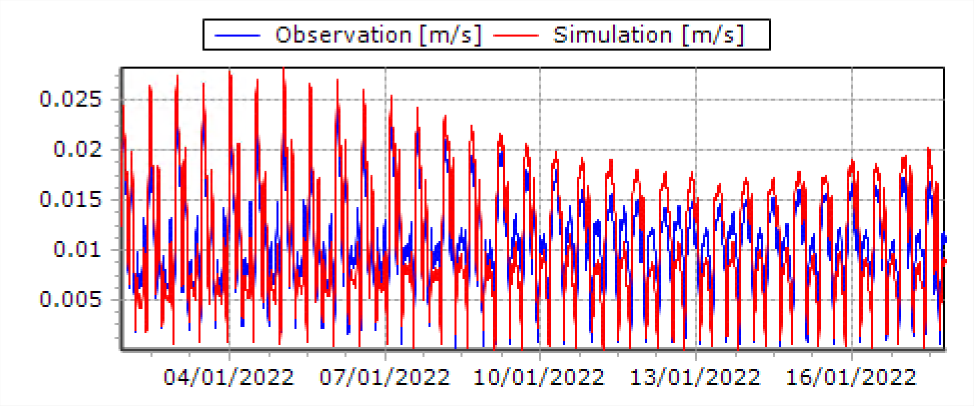


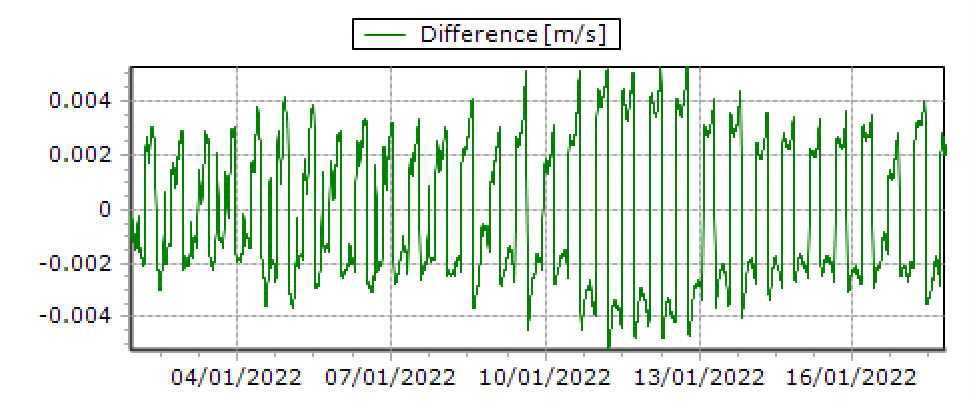


Statistics

	Observation	Simulation	Difference
Item Name	Point 10: Current sp...	Point 10: Current sp...	Difference
Item Unit	[m/s]	[m/s]	[m/s]
Minimum	0.0009	0.0003	-0.0063
Maximum	0.0257	0.0284	0.0055
Average	0.0106	0.0114	-0.0008
Std. deviation	0.0045	0.0052	0.0025

Time Series Plots

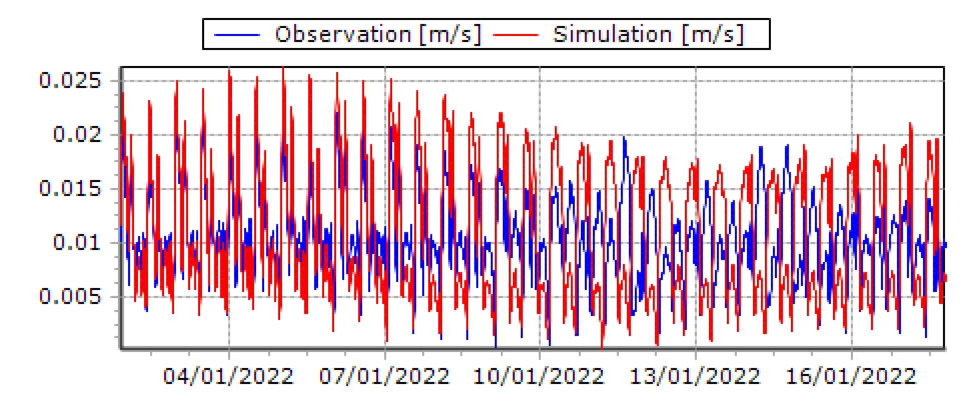


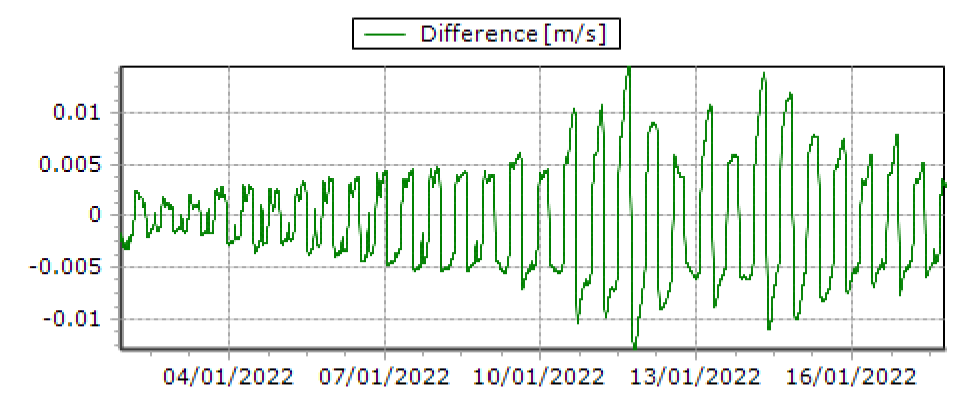


Statistics

	Observation	Simulation	Difference
Item Name	Point 15: Current sp...	Point 15: Current sp...	Difference
Item Unit	[m/s]	[m/s]	[m/s]
Minimum	0.0003	0.0001	-0.0053
Maximum	0.0258	0.0281	0.0053
Average	0.0109	0.0111	-0.0002
Std. deviation	0.0047	0.0059	0.0026

Time Series Plots

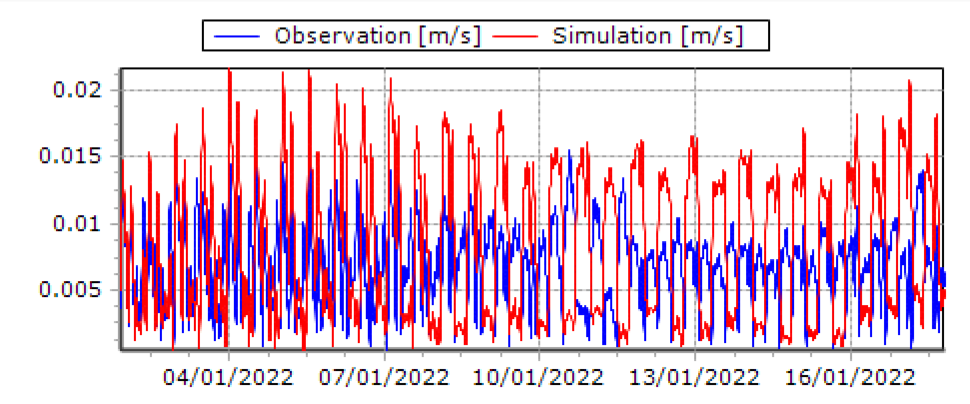


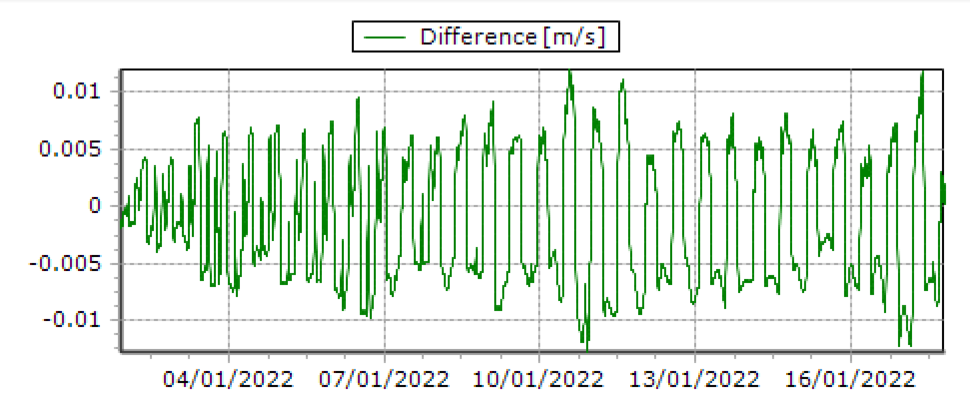


Statistics

	Observation	Simulation	Difference
Item Name	Point 16: Current sp...	Point 16: Current sp...	Difference
Item Unit	[m/s]	[m/s]	[m/s]
Minimum	0.0004	0.0001	-0.0130
Maximum	0.0237	0.0264	0.0145
Average	0.0105	0.0111	-0.0006
Std. deviation	0.0040	0.0061	0.0053

Time Series Plots

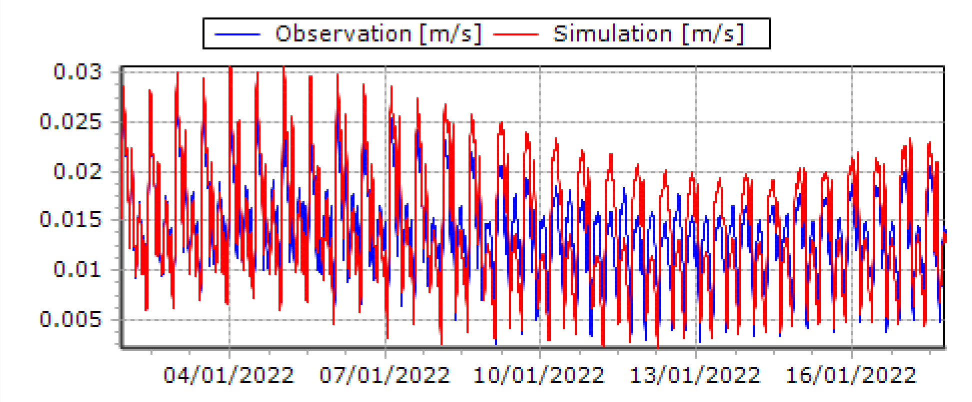


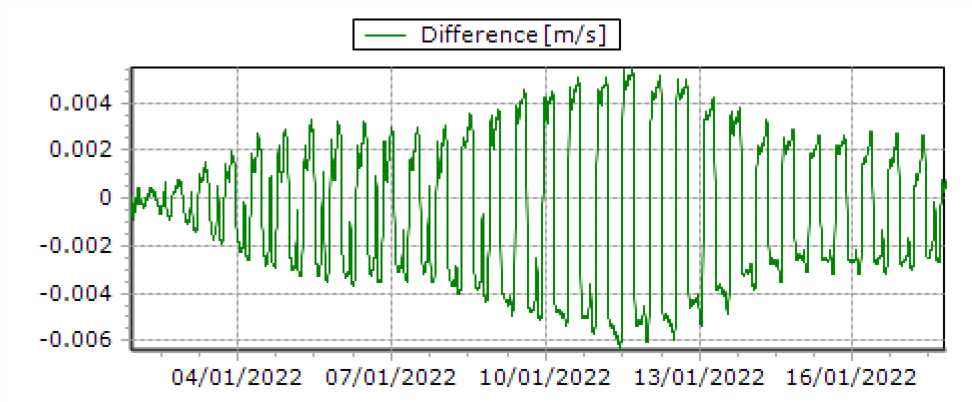


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 17: Current sp...	Point 17: Current sp...	Difference
	Item Unit	[m/s]	[m/s]	[m/s]
	Minimum	0.0006	0.0005	-0.0127
	Maximum	0.0158	0.0216	0.0120
	Average	0.0069	0.0084	-0.0015
	Std. deviation	0.0029	0.0054	0.0057

Time Series Plots

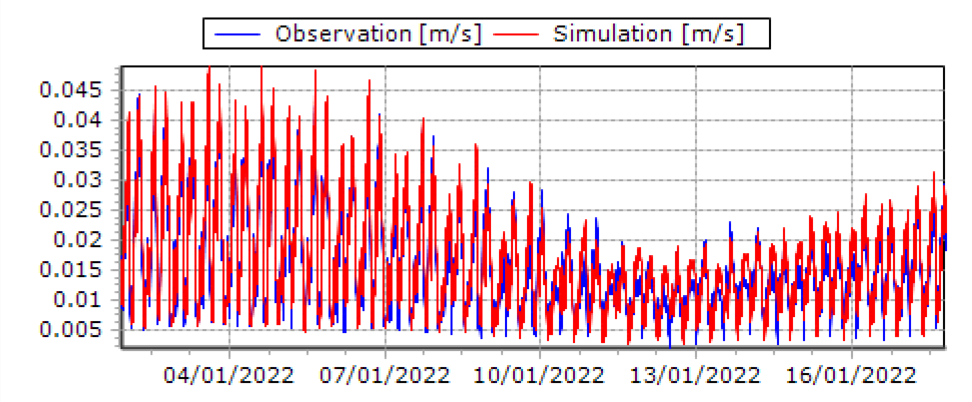


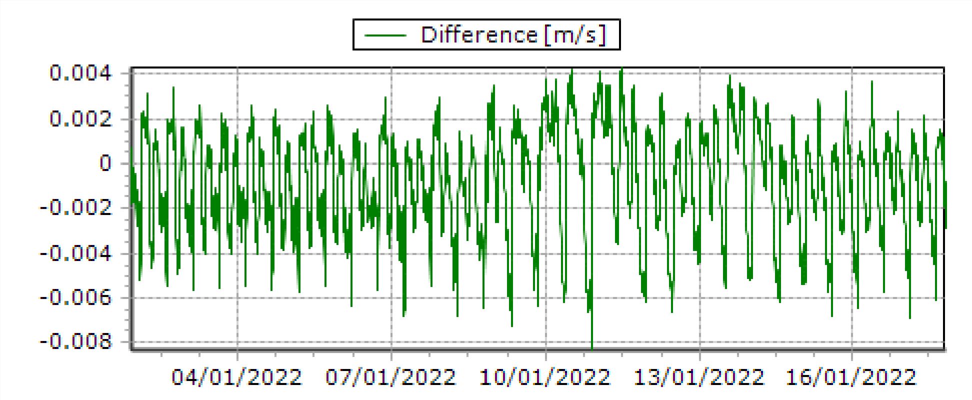


Statistics

	Observation	Simulation	Difference
Item Name	Point 22: Current sp...	Point 22: Current sp...	Difference
Item Unit	[m/s]	[m/s]	[m/s]
Minimum	0.0026	0.0021	-0.0064
Maximum	0.0291	0.0307	0.0055
Average	0.0139	0.0145	-0.0006
Std. deviation	0.0047	0.0059	0.0030

Time Series Plots

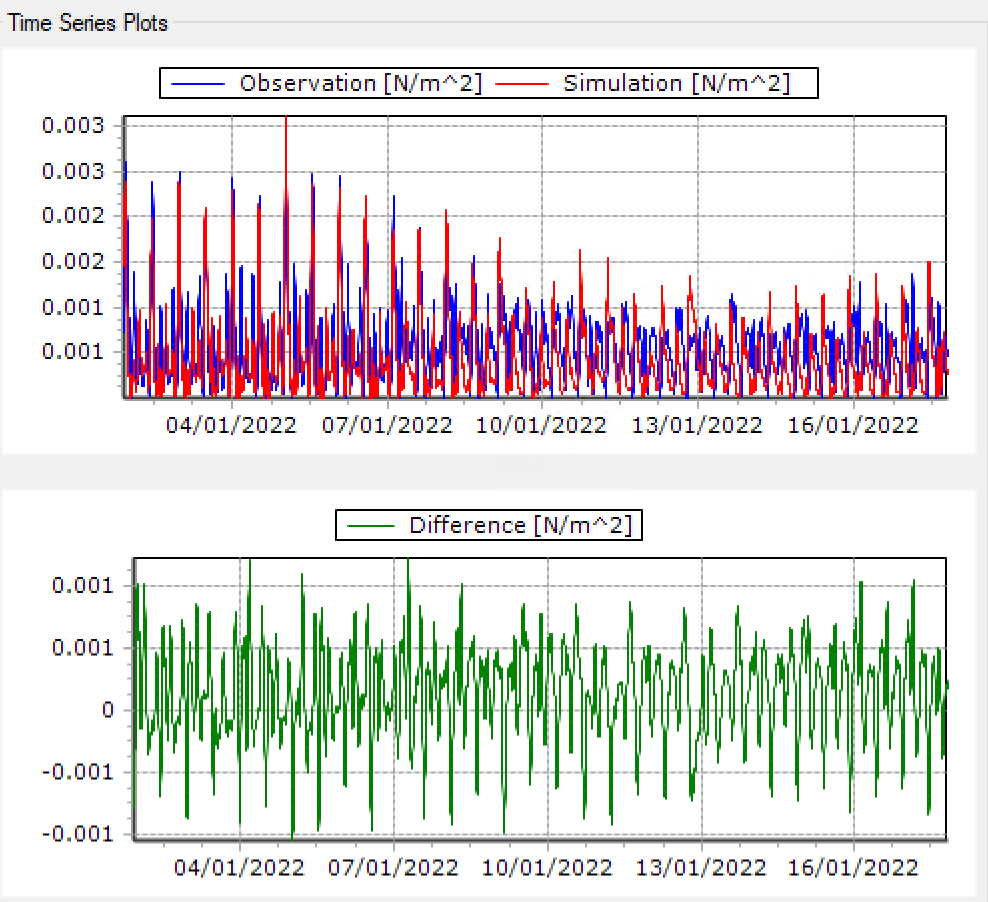




Statistics

	Observation	Simulation	Difference
Item Name	Point 23: Current sp...	Point 23: Current sp...	Difference
Item Unit	[m/s]	[m/s]	[m/s]
Minimum	0.0021	0.0026	-0.0083
Maximum	0.0478	0.0491	0.0043
Average	0.0158	0.0166	-0.0008
Std. deviation	0.0086	0.0090	0.0024

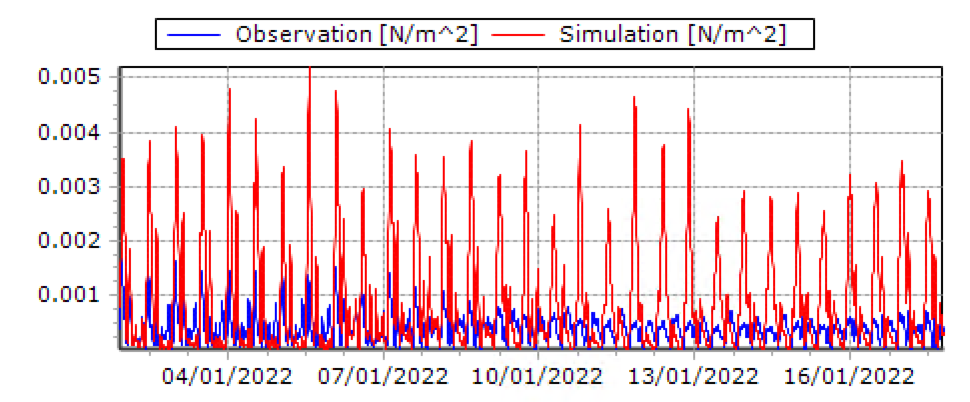
Bed Shear Stress

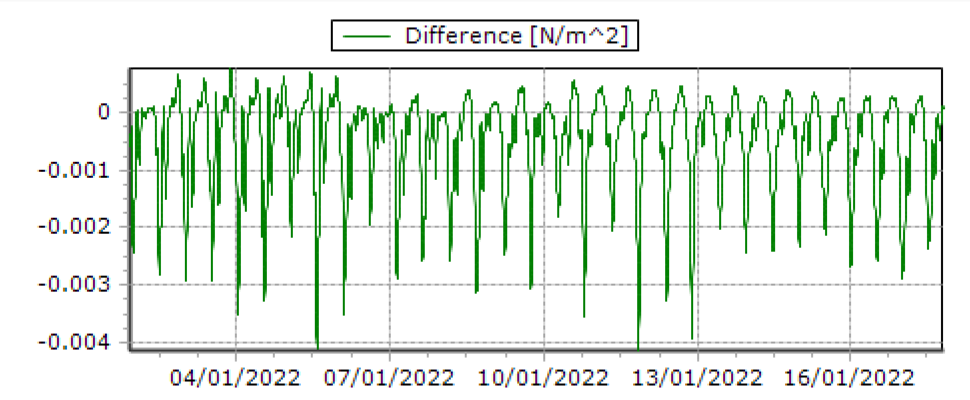


Statistics

	Observation	Simulation	Difference
Item Name	Point 2: Bed shearst...	Point 2: Bed shears...	Difference
Item Unit	[N/m^2]	[N/m^2]	[N/m^2]
Minimum	0.0000	0.0000	-0.0011
Maximum	0.0026	0.0031	0.0012
Average	0.0006	0.0004	0.0001
Std. deviation	0.0004	0.0004	0.0004

Time Series Plots

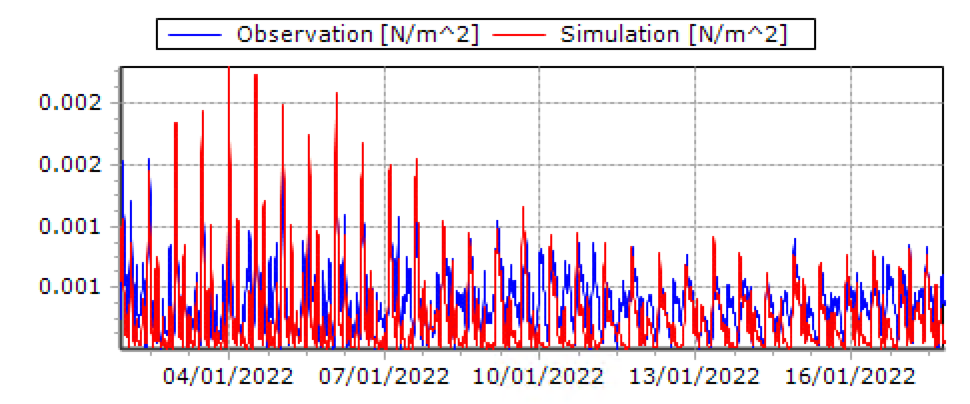


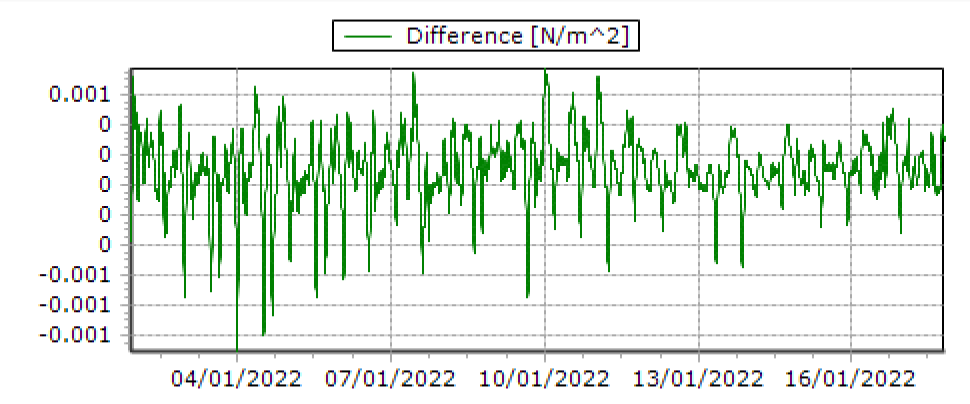


Statistics

	Observation	Simulation	Difference
Item Name	Point 4: Bed shearst...	Point 4: Bed shears...	Difference
Item Unit	[N/m^2]	[N/m^2]	[N/m^2]
Minimum	0.0000	0.0000	-0.0041
Maximum	0.0017	0.0052	0.0008
Average	0.0004	0.0009	-0.0005
Std. deviation	0.0003	0.0010	0.0009

Time Series Plots

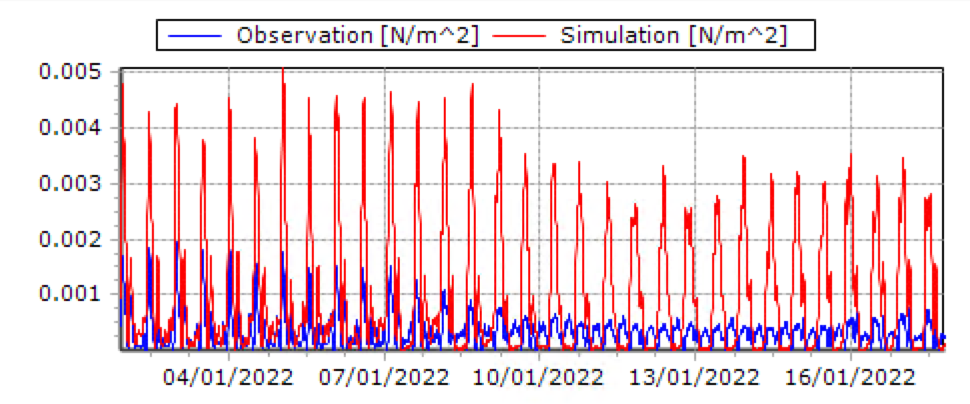


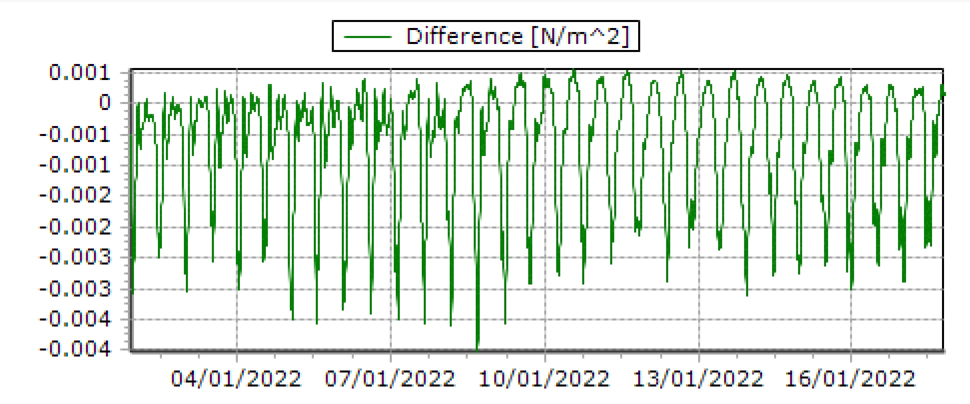


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 6: Bed shearst...	Point 6: Bed shears...	Difference
	Item Unit	[N/m^2]	[N/m^2]	[N/m^2]
	Minimum	0.0000	0.0000	-0.0011
	Maximum	0.0017	0.0023	0.0008
	Average	0.0004	0.0003	0.0001
	Std. deviation	0.0003	0.0003	0.0002

Time Series Plots

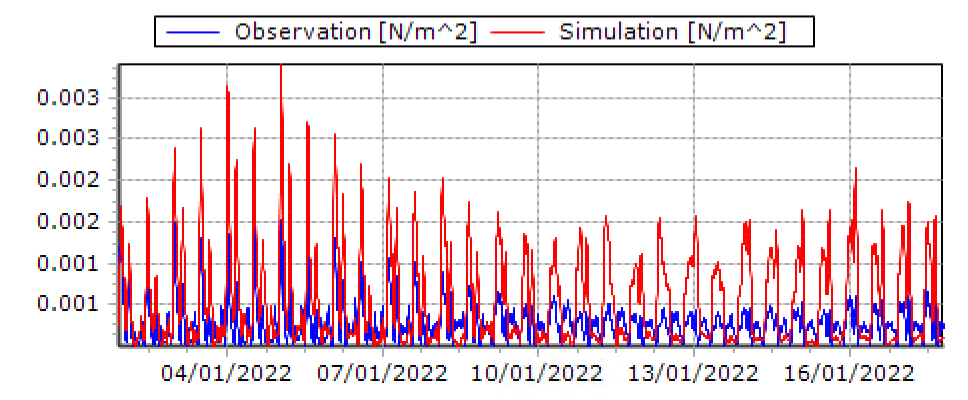


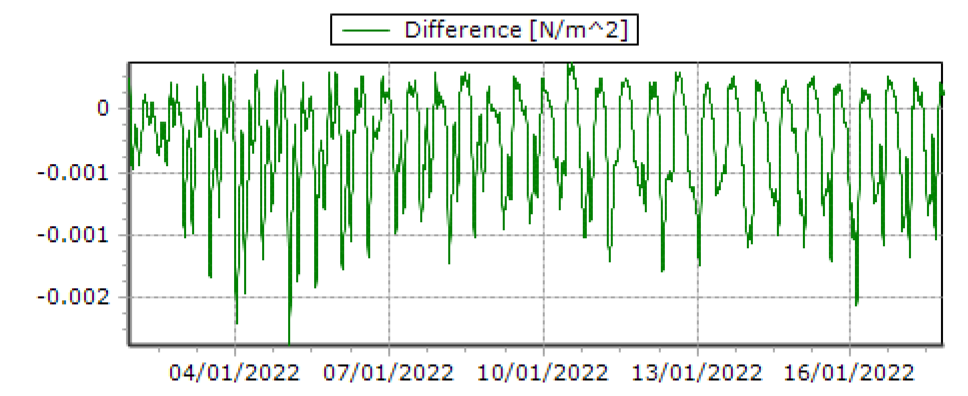


Statistics

	Observation	Simulation	Difference
Item Name	Point 7: Bed shearst...	Point 7: Bed shears...	Difference
Item Unit	[N/m^2]	[N/m^2]	[N/m^2]
Minimum	0.0000	0.0000	-0.0040
Maximum	0.0020	0.0051	0.0006
Average	0.0003	0.0010	-0.0007
Std. deviation	0.0003	0.0012	0.0010

Time Series Plots

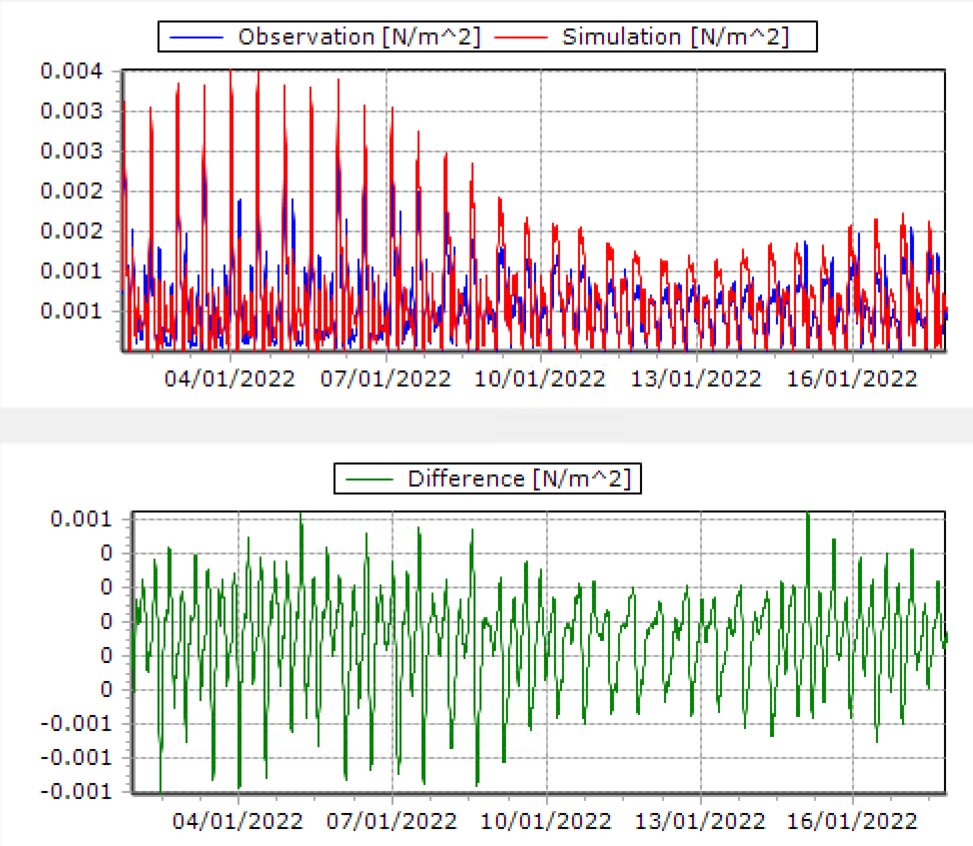




Statistics

	Observation	Simulation	Difference
Item Name	Point 9: Bed shearst...	Point 9: Bed shears...	Difference
Item Unit	[N/m^2]	[N/m^2]	[N/m^2]
Minimum	0.0000	0.0000	-0.0019
Maximum	0.0015	0.0034	0.0004
Average	0.0003	0.0006	-0.0003
Std. deviation	0.0002	0.0006	0.0004

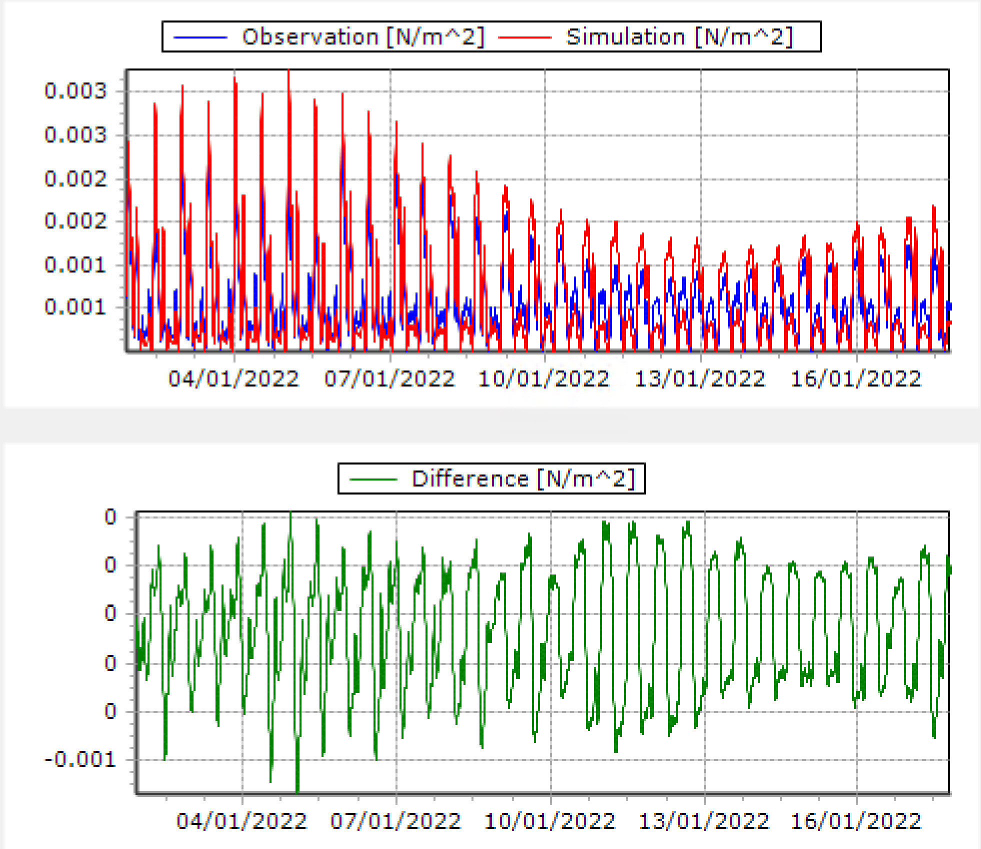
Time Series Plots



Statistics

	Observation	Simulation	Difference
Item Name	Point 10: Bed shear...	Point 10: Bed shear...	Difference
Item Unit	[N/m^2]	[N/m^2]	[N/m^2]
Minimum	0.0000	0.0000	-0.0010
Maximum	0.0029	0.0035	0.0006
Average	0.0006	0.0007	-0.0001
Std. deviation	0.0005	0.0006	0.0003

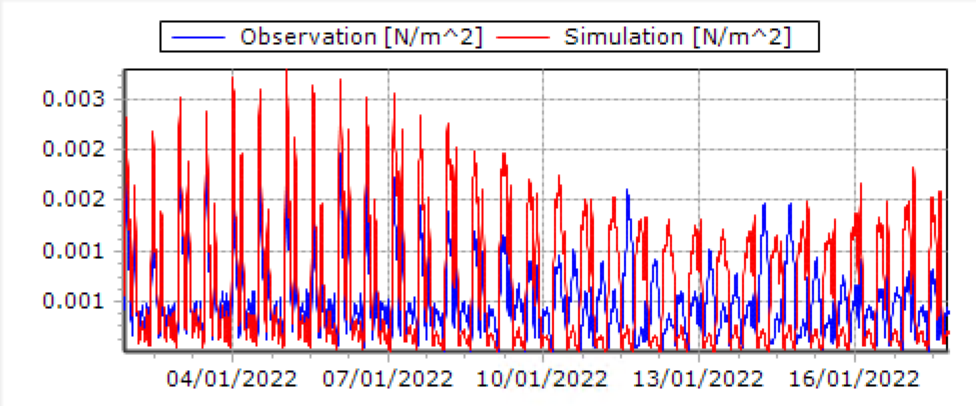
Time Series Plots

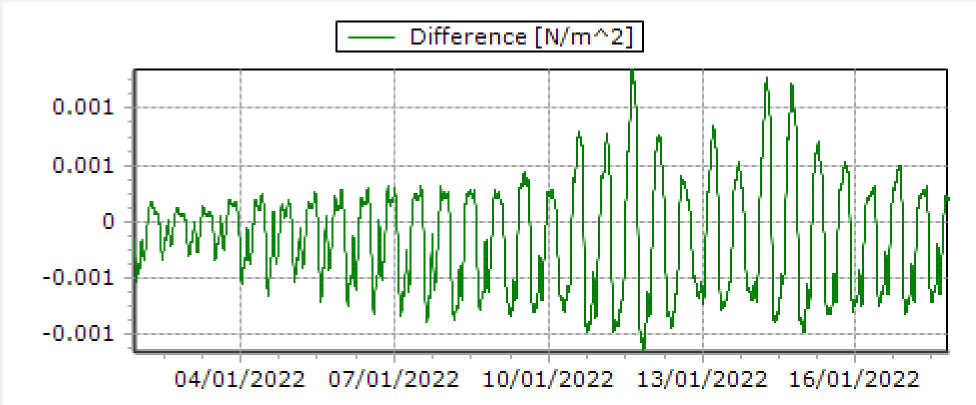


Statistics

	Observation	Simulation	Difference
Item Name	Point 15: Bed shear...	Point 15: Bed shear...	Difference
Item Unit	[N/m^2]	[N/m^2]	[N/m^2]
Minimum	0.0000	0.0000	-0.0007
Maximum	0.0028	0.0033	0.0004
Average	0.0006	0.0007	-0.0001
Std. deviation	0.0005	0.0006	0.0002

Time Series Plots

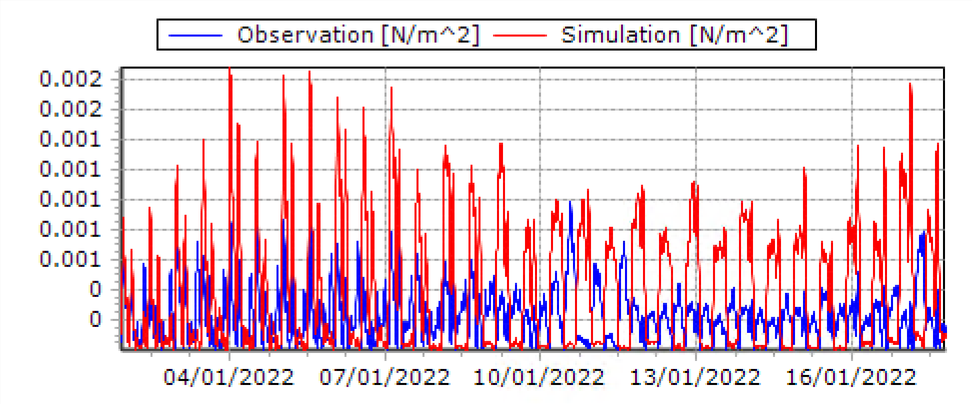


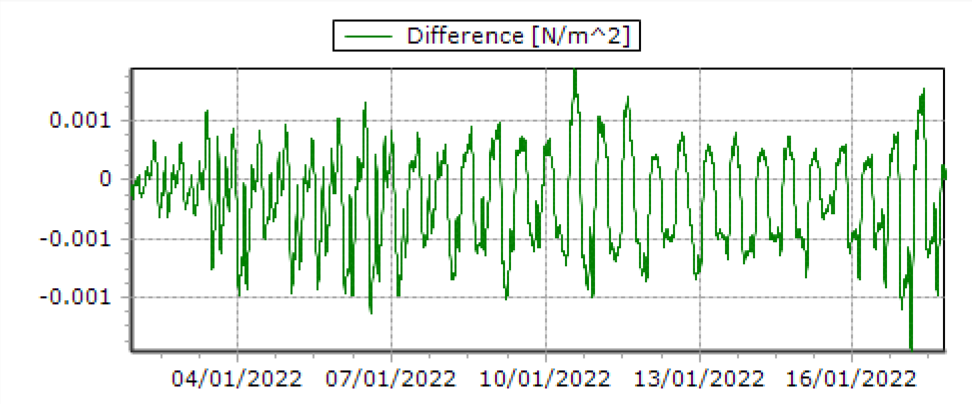


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 16: Bed shear...	Point 16: Bed shear...	Difference
	Item Unit	[N/m^2]	[N/m^2]	[N/m^2]
	Minimum	0.0000	0.0000	-0.0012
	Maximum	0.0023	0.0028	0.0013
	Average	0.0005	0.0007	-0.0001
	Std. deviation	0.0004	0.0006	0.0005

Time Series Plots

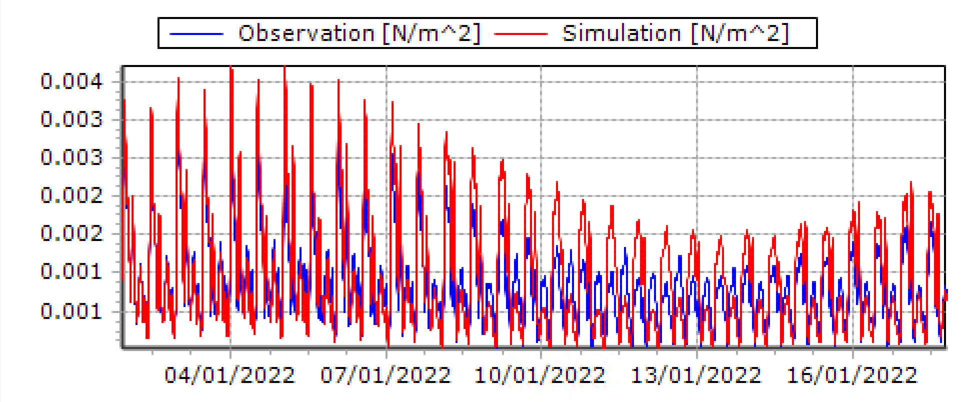


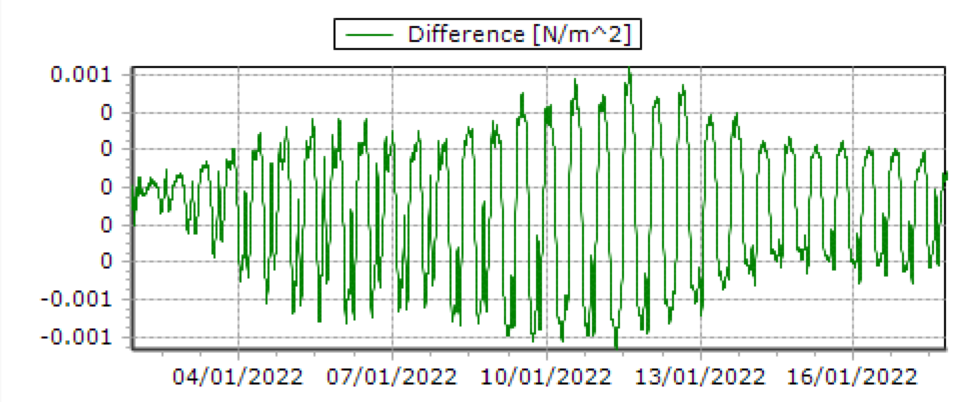


Statistics

	Observation	Simulation	Difference
Item Name	Point 17: Bed shear...	Point 17: Bed shear...	Difference
Item Unit	[N/m^2]	[N/m^2]	[N/m^2]
Minimum	0.0000	0.0000	-0.0015
Maximum	0.0010	0.0019	0.0009
Average	0.0002	0.0004	-0.0002
Std. deviation	0.0002	0.0004	0.0004

Time Series Plots

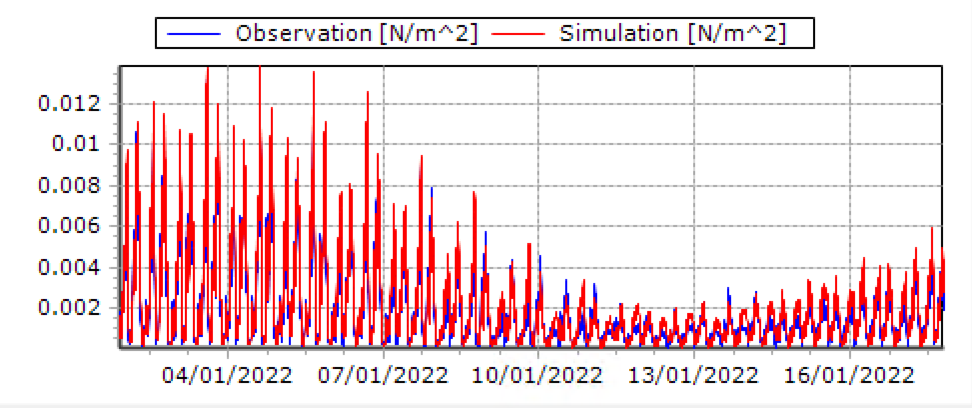


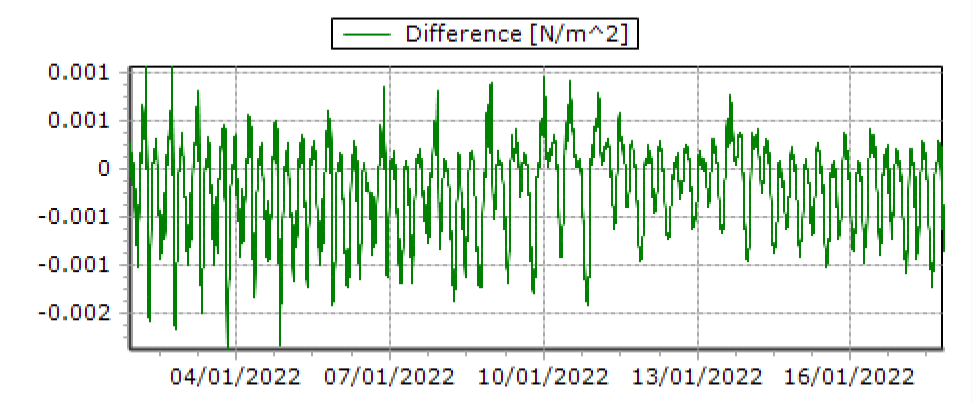


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 22: Bed shear...	Point 22: Bed shear...	Difference
	Item Unit	[N/m^2]	[N/m^2]	[N/m^2]
	Minimum	0.0000	0.0000	-0.0009
	Maximum	0.0033	0.0037	0.0006
	Average	0.0009	0.0010	-0.0001
	Std. deviation	0.0006	0.0007	0.0003

Time Series Plots





Statistics

	Observation	Simulation	Difference
Item Name	Point 23: Bed shear...	Point 23: Bed shear...	Difference
Item Unit	[N/m^2]	[N/m^2]	[N/m^2]
Minimum	0.0000	0.0000	-0.0019
Maximum	0.0135	0.0139	0.0011
Average	0.0019	0.0021	-0.0002
Std. deviation	0.0021	0.0023	0.0005