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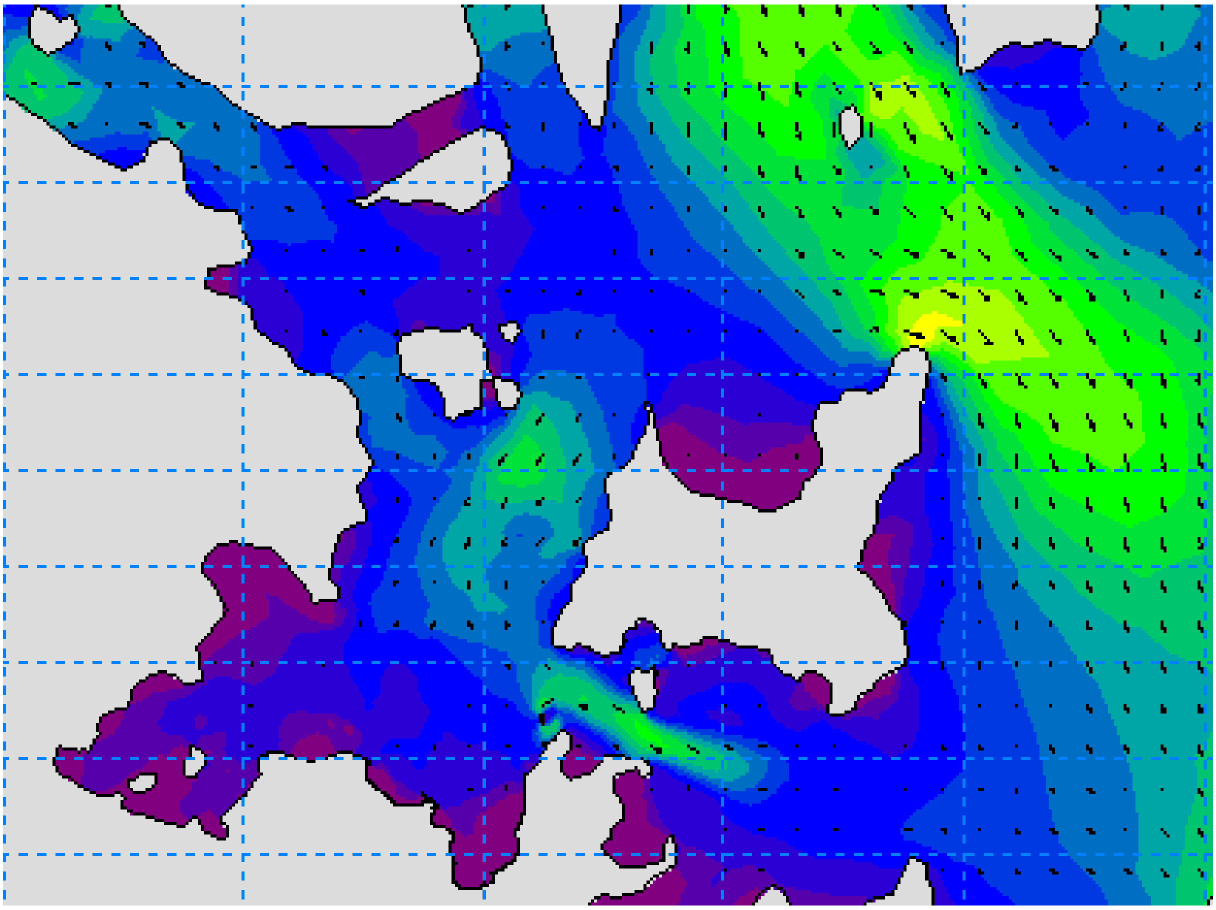
TECHNICAL APPENDIX 4.1

Orkney Logistics Base, Hatston
Coastal Hydrodynamic Modelling Study



May 2023

CONTROL SHEET

Client: Orkney Islands Council Harbour Authority
Project Title: Orkney Logistics Base, Hatston
Report Title: Coastal Hydrodynamic Modelling Study
Document number: 13283
Project number: 677674

Issue Record

Issue	Status	Author	Reviewer	Approver	Issue Date
1	Draft	MN	KMD	CGF	09/03/23
2	Issue	MN	KMD	CGF	05/05/23

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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 Coastal Hydrodynamic Modelling Study in support of the Environmental Impact Assessment (EIA) of the proposed expansion of the existing Hatston Ferry Terminal to create a Logistics Base (Refer to Appendix A).

1.2 Scope of Report

This study aims to develop a coastal hydrodynamic (HD) model of Bay of Kirkwall, approaches and surrounding coastal waters, to 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.

1.3 Report Usage

The information and recommendations contained within this report have been prepared in the specific context stated above and should not be utilised in any other context without prior written permission from EnviroCentre Limited.

If this report is to be submitted for regulatory approval more than 12 months following the report date, it is recommended that it is referred to EnviroCentre Limited for review to ensure that any relevant changes in data, best practice, guidance or legislation in the intervening period are integrated into an updated version of the report.

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2 BASELINE CONDITIONS

2.1 Site Location, Existing Infrastructure and Proposed Development

The proposed development site is located at Hatston Pier to the north of Kirkwall, Orkney Mainland, as shown in Figure 2-1 and Figure 2-2.

The development site is the location of Kirkwall Orkney Hatston Ferry Terminal, with an existing pier structure present, and associated deep water berth. The existing pier structure consists of a concrete deck positioned on tubular piles. A satellite image of the existing pier structure is shown in Figure 2-3

The proposed development includes an extension to the existing outer quay by 300m (with minimum water depth of -10m CD) which would also form a 125m inner berth. Additionally, circa 7.5 hectares of new land extending from the current shoreline outwards would be made available for harbour-related operations through reclamation. A small capital dredge will be required adjacent to the new quay face, to achieve required draft. The design includes a ship lift, additional link span and fuel facility. 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 metres relative to Chart Datum (mCD) at the shoreline to around -10mCD at the existing berth, on the outer face of Hatston Pier, and -13mCD further out in the centre of the Bay of Kirkwall. 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 Kirkwall as presented within the Admiralty tide tables are shown in Table 2-1[1]. The mean tidal range at Kirkwall is 2.4m for spring tides and 1.1m for neap tides.

Table 2-1: Tidal water levels at Kirkwall

	Chart Datum (mCD)	Ordnance Datum (mOD)
Highest Astronomical Tide (HAT)	3.5	2.1
Mean High Water Springs (MHWS)	3.0	1.6
Mean High Water Neap (MHWN)	2.4	1.0
Mean Sea Level (MSL)	1.8	0.4
Mean Low Water Neap (MLWN)	1.3	-0.1
Mean Low Water Springs (MLWS)	0.6	-0.8
Lowest Astronomical Tide (LAT)	-0.1	-1.5

*Chart datum correction for Ordnance Datum is -1.4 (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 Bay of Kirkwall shown by red dot

Figure 2-3: Satellite image of existing Hatston pier structure

2.4 Morphology and Geology

Tidal Currents along the nearshore within the Bay of Kirkwall near to Hatston are weak. The fetch lengths are restricted, so the wave conditions tend to be locally generated wind-waves. Within the Bay of Kirkwall waves lose their directional nature due to refraction effects within the bay. Much of the coastline near to Hatston is fronted by a rock platform with shingle and sand beaches. There is little littoral transport other than erosion caused by extreme events[2]. The European Nature Information System (EUNIS) seabed habitat map shows the dominant seabed habitat around the Hatston Pier to be infralittoral coarse sediment, present within a low energy environment[3].

Sandy gravel is shown immediately north and east of the existing pier[4], no seabed sediment is indicated to the west of the existing pier, whilst bedrock outcrop is visible on the surrounding shoreline. Due to the nature of the seabed substrate in the vicinity of the development site, and the lack of fine sediment, it is not anticipated that there are significant local active sediment transport processes.

Analysis of historical coastline alignments show that the major changes to the coastline since 1890 have been the addition of manmade structures such as Kirkwall pier and Hatston pier, whilst there has been no significant erosion observed[5].

[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] 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 Bay of Kirkwall, Wide Firth, Stronsay Firth, Westray Firth and North Sound, between the islands of Orkney Mainland, Westray, Sanday and Stronsay, as shown in Figure 3-1.

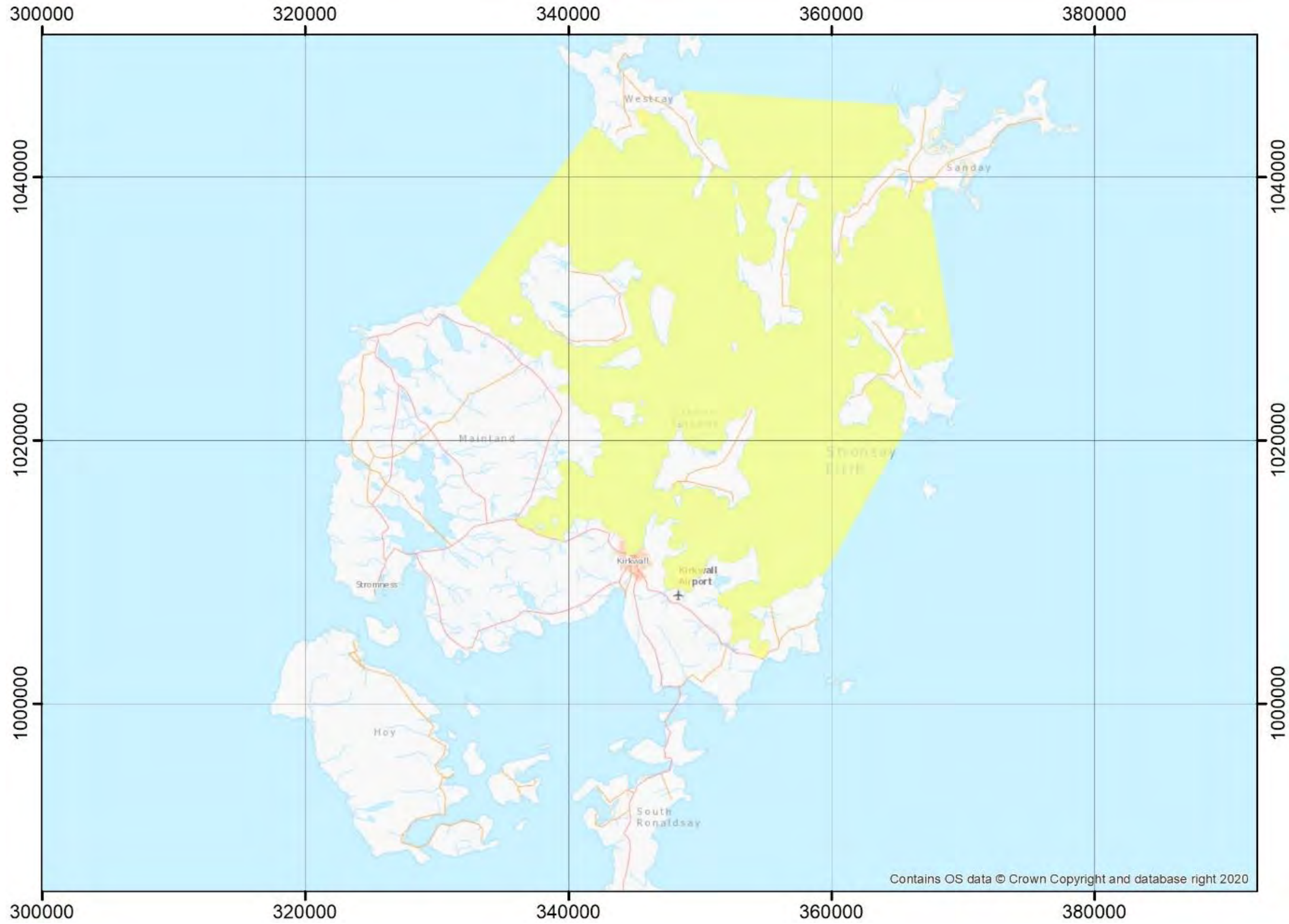


Figure 3-1: MIKE HD model extent (yellow polygon)

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[6]
    - Hatston Ferry Terminal (2020/2021);
    - Bay of Kirkwall (2009/2010);
    - Westray Firth to Stronsay Firth (2007); and
    - Sanday Sound to Westray Firth (2005)
- European Marine Observation and Data Network (EMODnet) Digital Bathymetry (DTM) - 2020[7]

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.

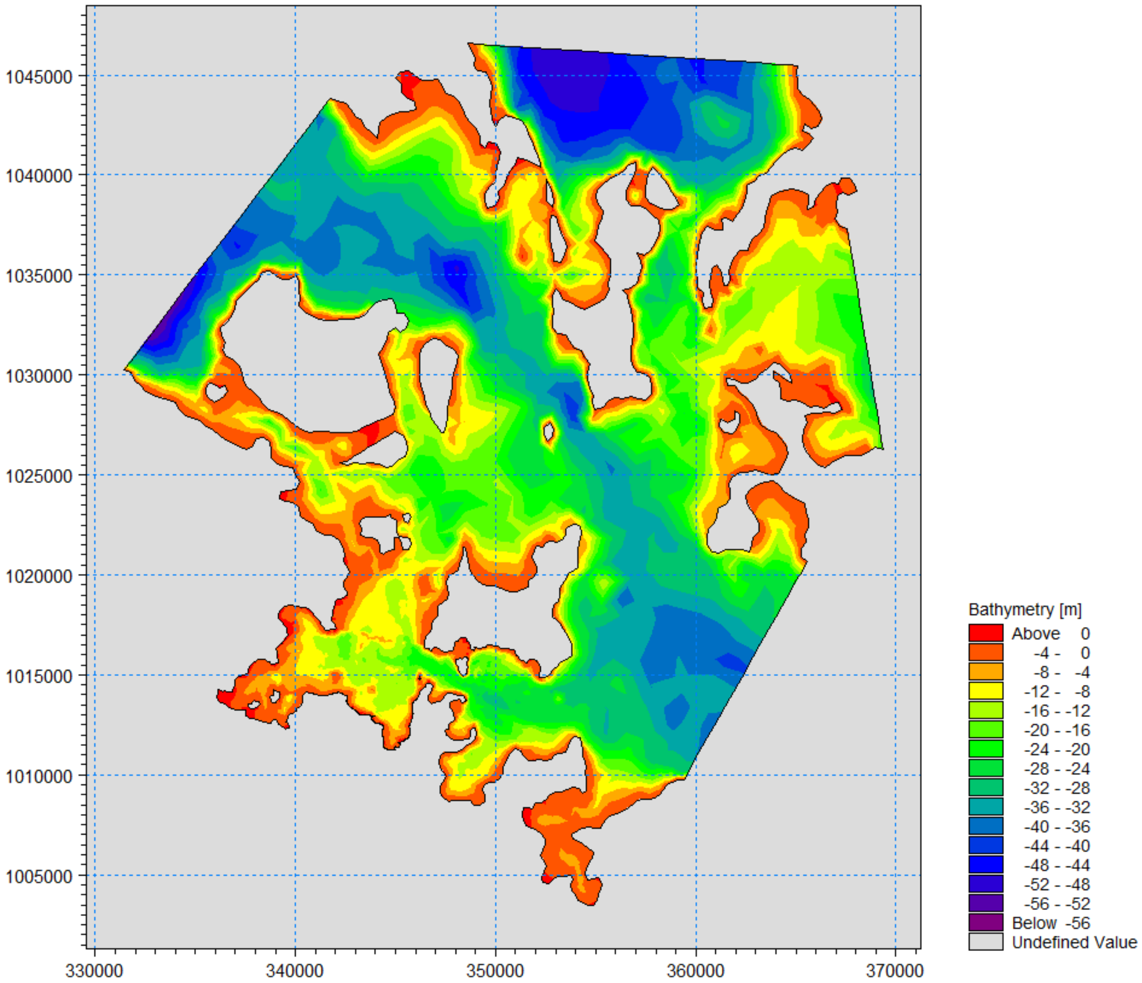


Figure 3-2: Bathymetry across model extent

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

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

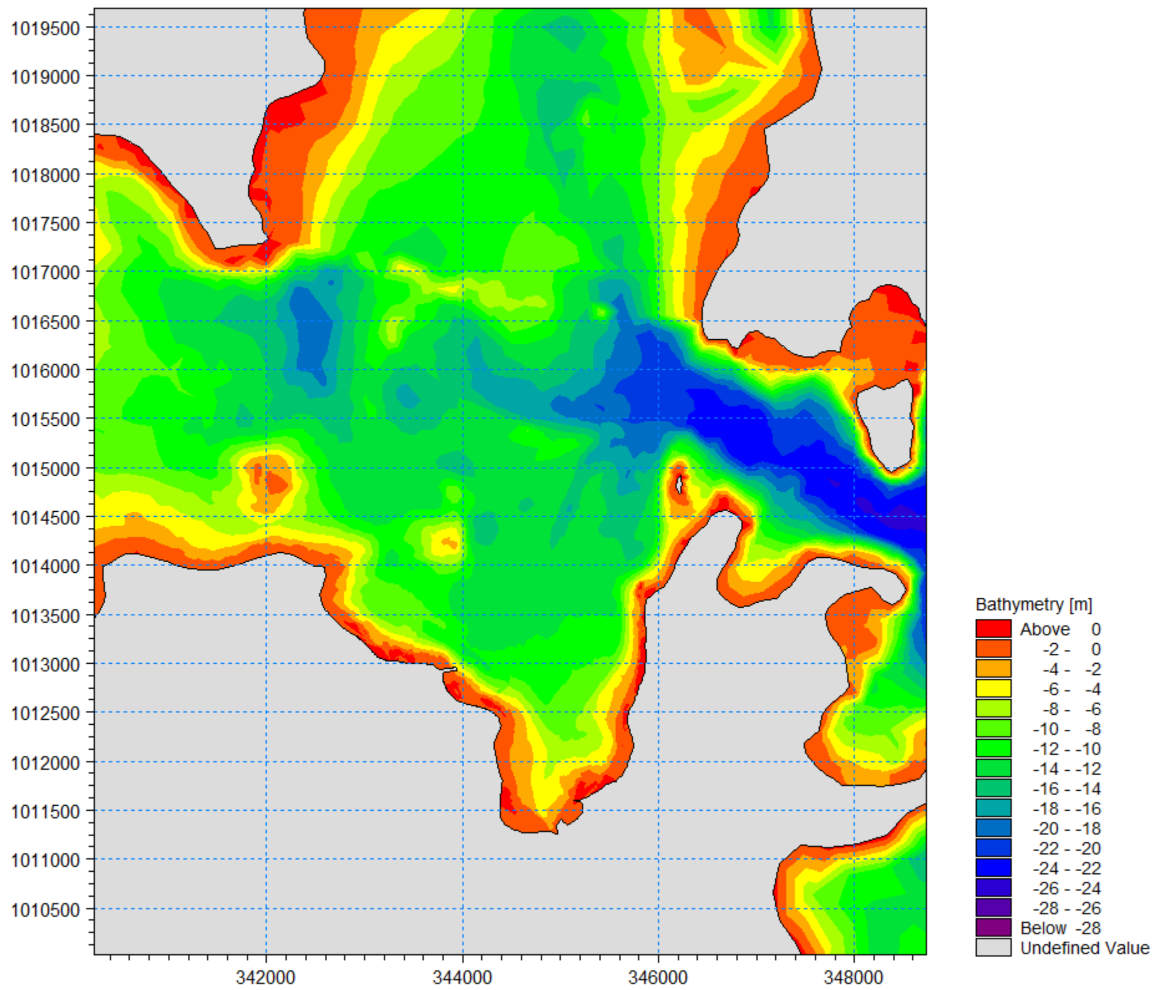


Figure 3-3: Bathymetry within Bay of Kirkwall and Wide Firth

3.3.2 Tidal Boundary Conditions

There are four tidal boundaries within the model extent, in the north-west from Orkney Mainland to Westray, in the north from Westray to Sanday, the north-east from Sanday to Stronsay, and a southern boundary from Stronsay to Orkney Mainland, 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.

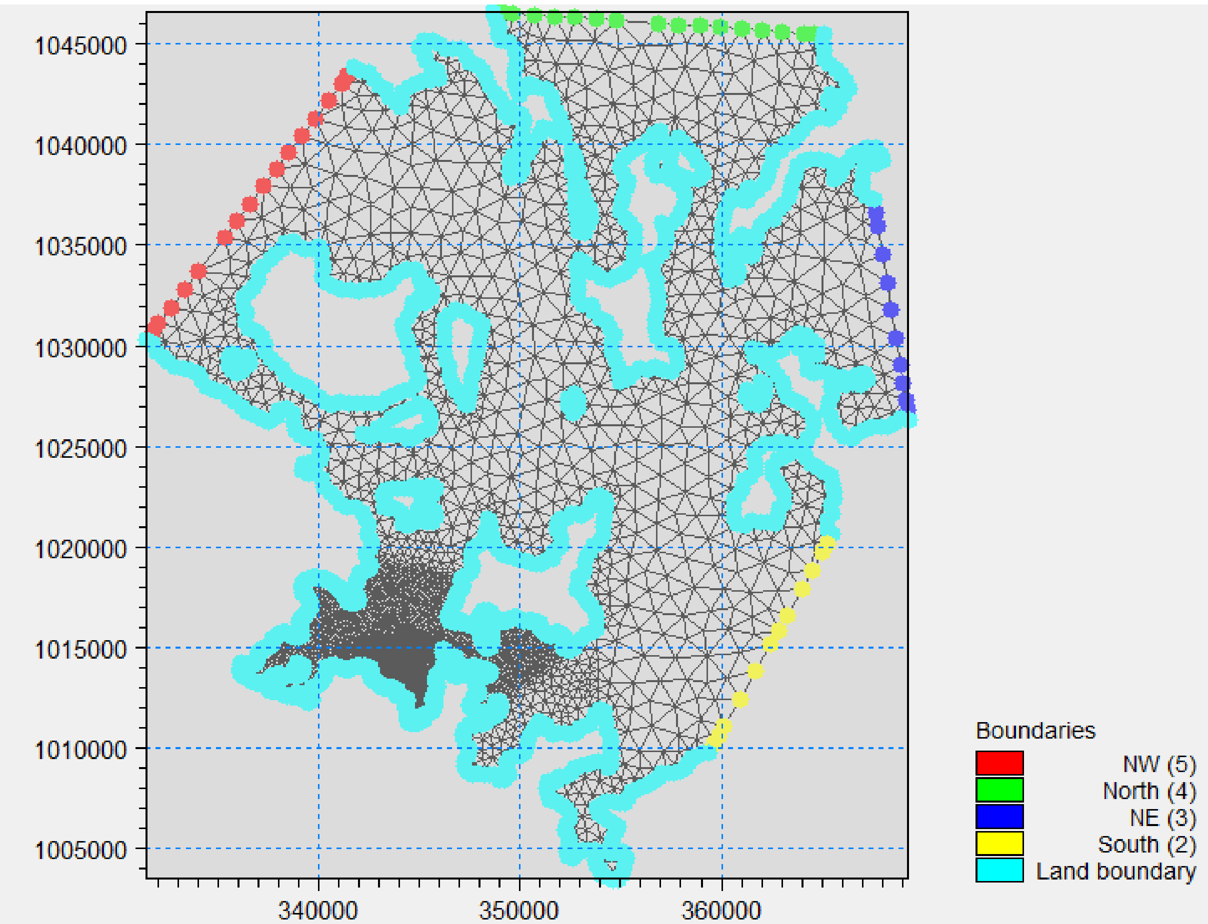


Figure 3-4: HD model boundaries

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 is 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 Bay of Kirkwall, becoming finer in the area of interest around Hatston Pier, as shown in Figure 3-6. 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	49,799
Number of nodes	25,849
Min. Z level (mCD)	-56.3
Max. Z level (mCD)	+1.99
Max triangular area at Hatston	75m^2 (approx. 8.5m resolution)

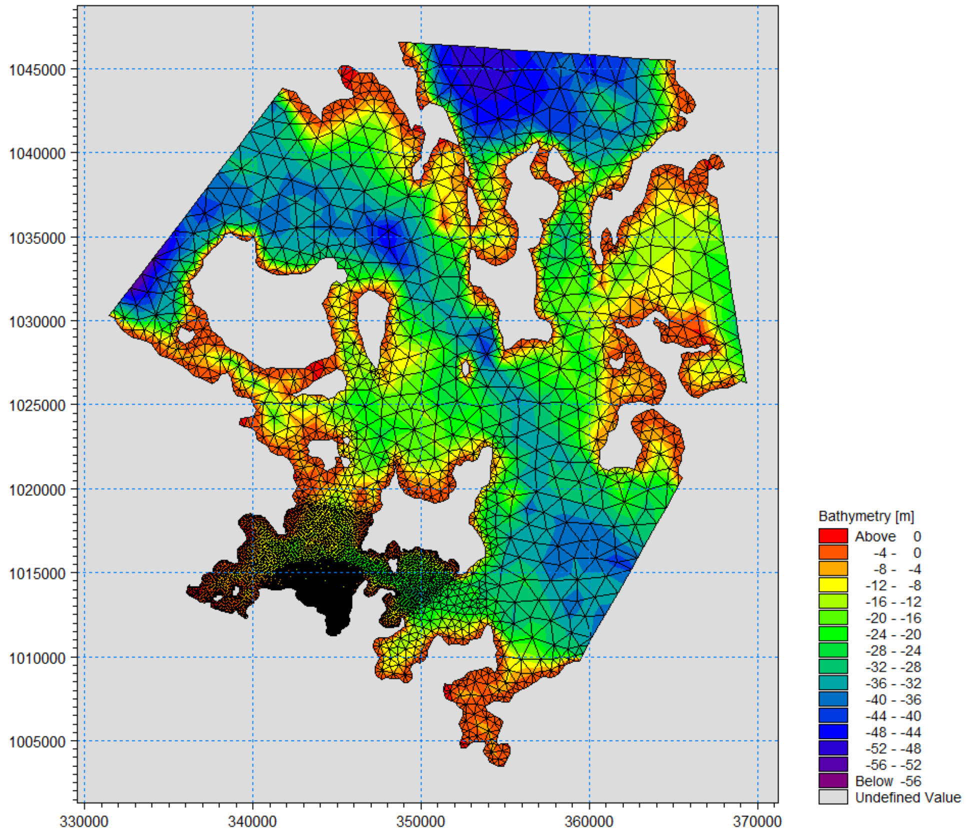


Figure 3-5: Baseline HD model mesh full extent

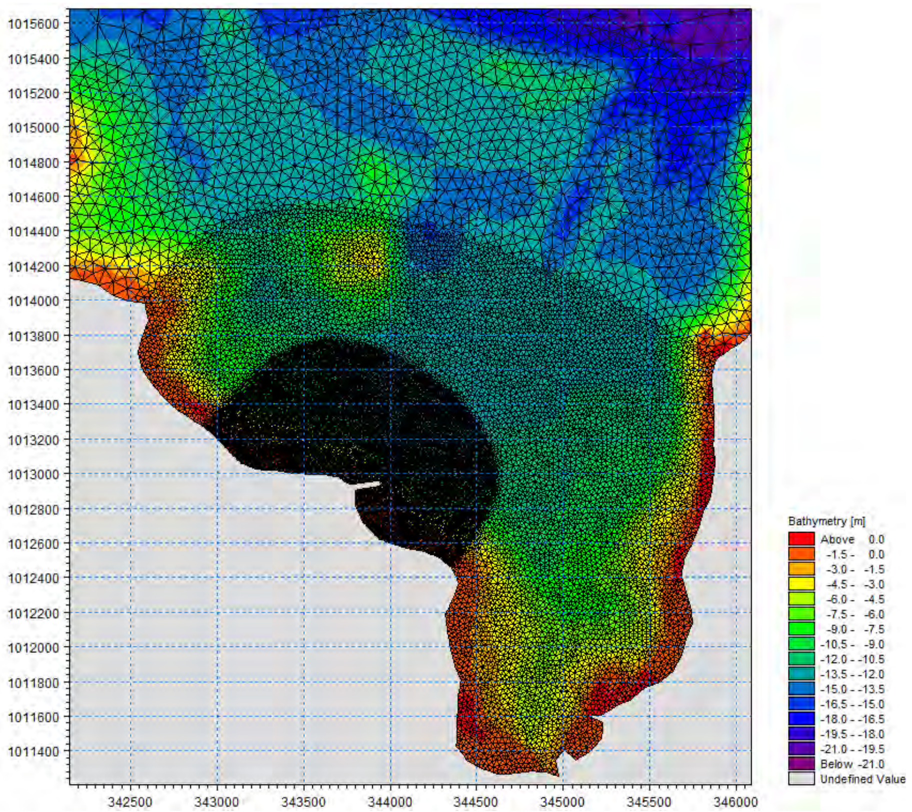


Figure 3-6: Baseline HD model mesh Bay of Kirkwall

A post-development version of the HD model mesh has been generated to include the proposed development footprint, and associated capital dredge, as shown in Figure 3-7.

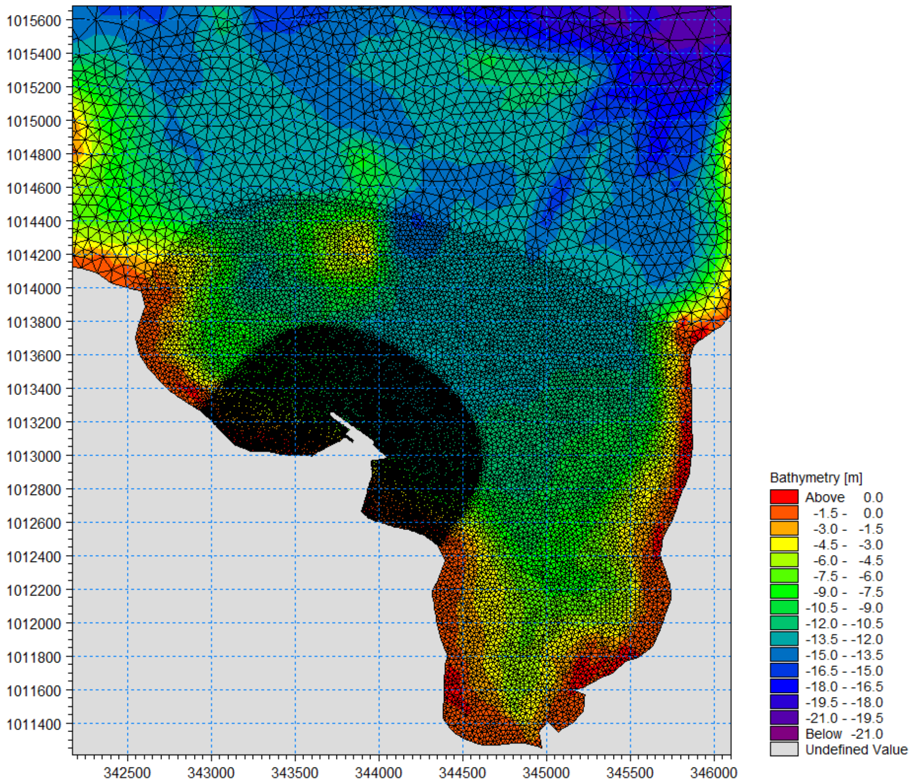


Figure 3-7: Post-development HD model mesh Bay of Kirkwall

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;
- Both baseline and post-development model runs include the existing Hatston Pier piles (no. 521) as shown in Figure 3-8 below;
- 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: $32m^{(1/3)}/s$

The model does not account for the impact of wind forcing or wave radiation, which may locally impact tidal currents.

The modelling has been undertaken with the following computing specification:

- Dell Precision 5820 Tower:

- 64GB RAM;
- Utilising 8 Cores – Intel Xeon CPU (2.5GHz);
- Windows 10 Pro 64-bit operating system.

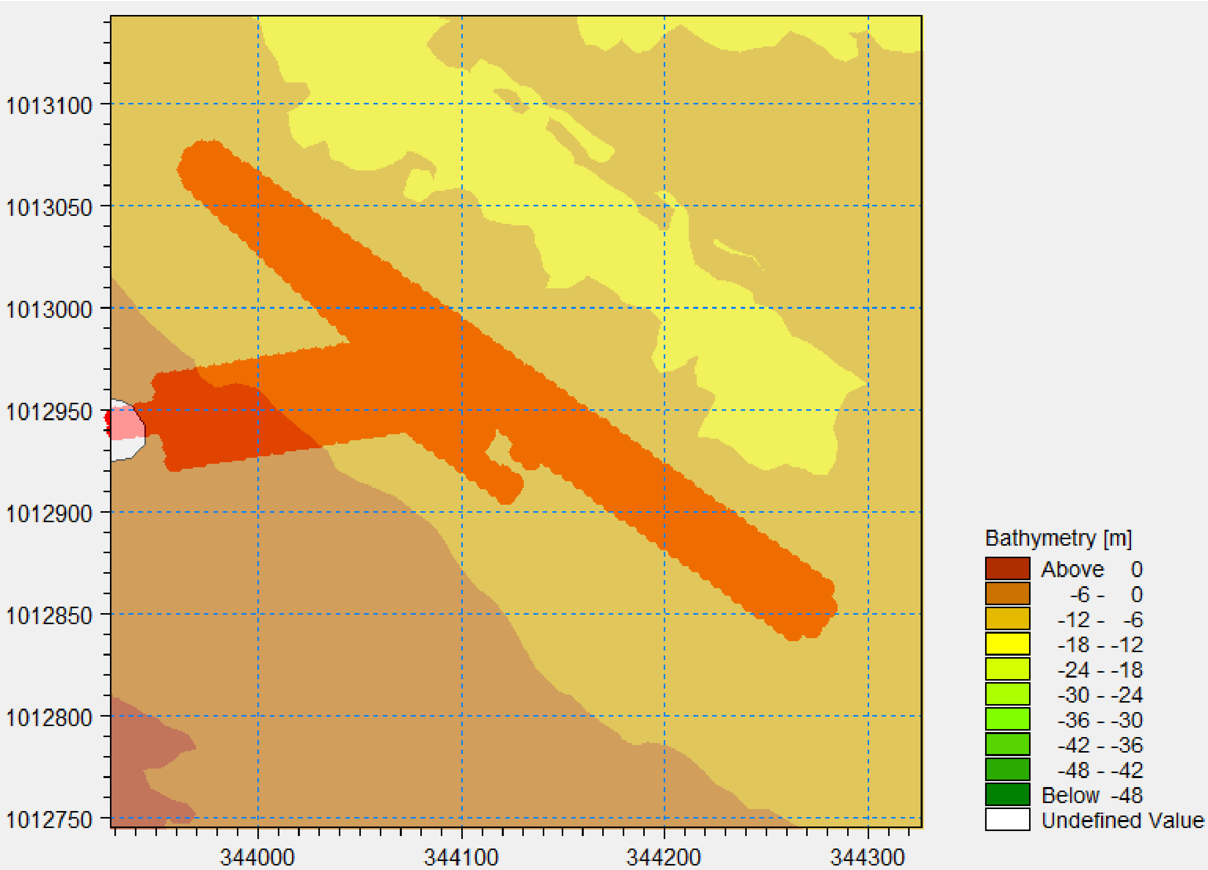


Figure 3-8: Existing Hatston Pier piles within model domain

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 12 identified locations within the model extent as detailed in Table 3-2. The locations of point outputs are situated within the immediate vicinity of Hatston, the wider Bay of Kirkwall, The String channel and Wide Firth, as shown in Figure 3-9. Point output locations have been selected to aid validation of the model and assessment of proposed development impact.

Table 3-2: HD Model point output locations

Point Output Location	Easting	Northing
Point 1	343600	1013198
Point 2	343600	1013400
Point 3	343800	1013300
Point 4	344000	1013150
Point 5	344200	1013050
Point 6	344400	1012900
Point 7	344200	1012750
Point 8	344000	1012700
Point 9	344500	1013700
Point 10	345000	1012400
Point 11	347000	1015200
Point 12	345500	1016000

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
FM HD 7	Baseline HD model simulating existing (pre-development) conditions. Run for January 2022 tidal cycle, including spring and neap tides.
FM HD 8	Post-development HD model 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 Kirkwall. This comparison highlights that the model predicts levels within 0.05m of the Admiralty predicted levels at high and low tide. Additionally, tidal current speeds predicted by the baseline model have been compared to annotated tidal stream speeds on UKHO hydrographic charts for Bay of Kirkwall 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.

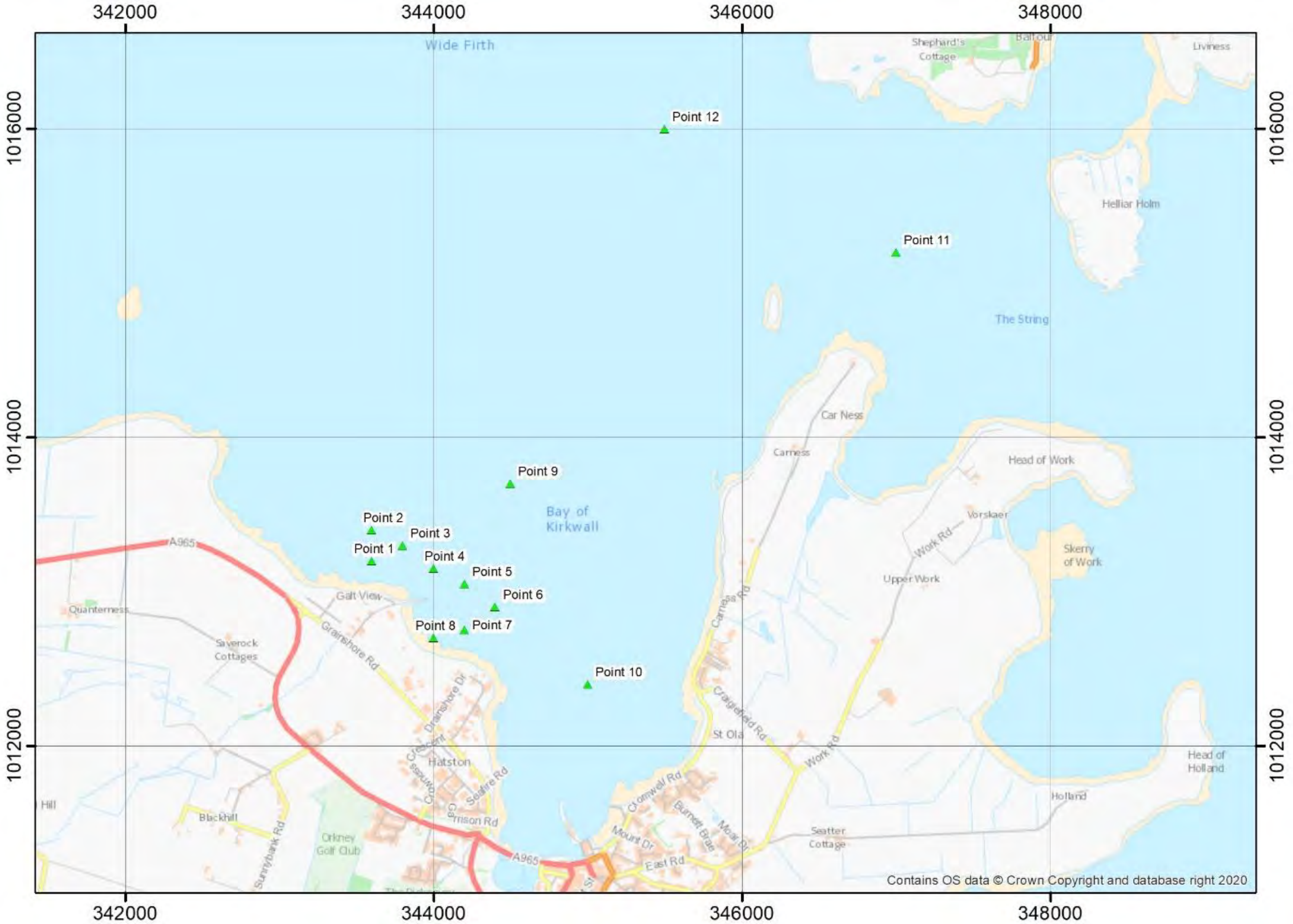


Figure 3-9: HD model point output locations

4 HYDRODYNAMIC MODEL RESULTS

A summary of the results from the existing (baseline) model run (FM HD 7) are presented in Section 4.1, whilst a summary of results from the post-development model run (FM HD 8) 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 7 simulates existing (baseline) tidal conditions at Hatston and surrounds during the month of January 2022. 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 1 and 9 (see Figure 3-9) are presented in Figure 4-1 for the full FM HD 7 run duration, and in Figure 4-2 for a selected spring and neap tidal cycle. 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 +3.25mCD during a spring tide on 4th January 2022, with a lowest tidal elevation prediction of +0.37mCD on the same day. These values are within 0.05m of the corresponding Admiralty Tide Tables[8] predictions for the same tide. Neap tides are also present within the simulated tidal curve. A neap high tide elevation of +2.35mCD is predicted on 11th January 2022, with a corresponding low tide elevation of +1.34mCD. Therefore the largest simulated spring tidal range at Hatston is 2.88m and with a simulated neap tidal range of 1.01m. Comparison with the mean tidal ranges for Kirkwall 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 4-3 presents spatial plots of predicted tidal water surface elevation across the HD model extent for key phases of a spring tide, whilst Figure 4-4 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.

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

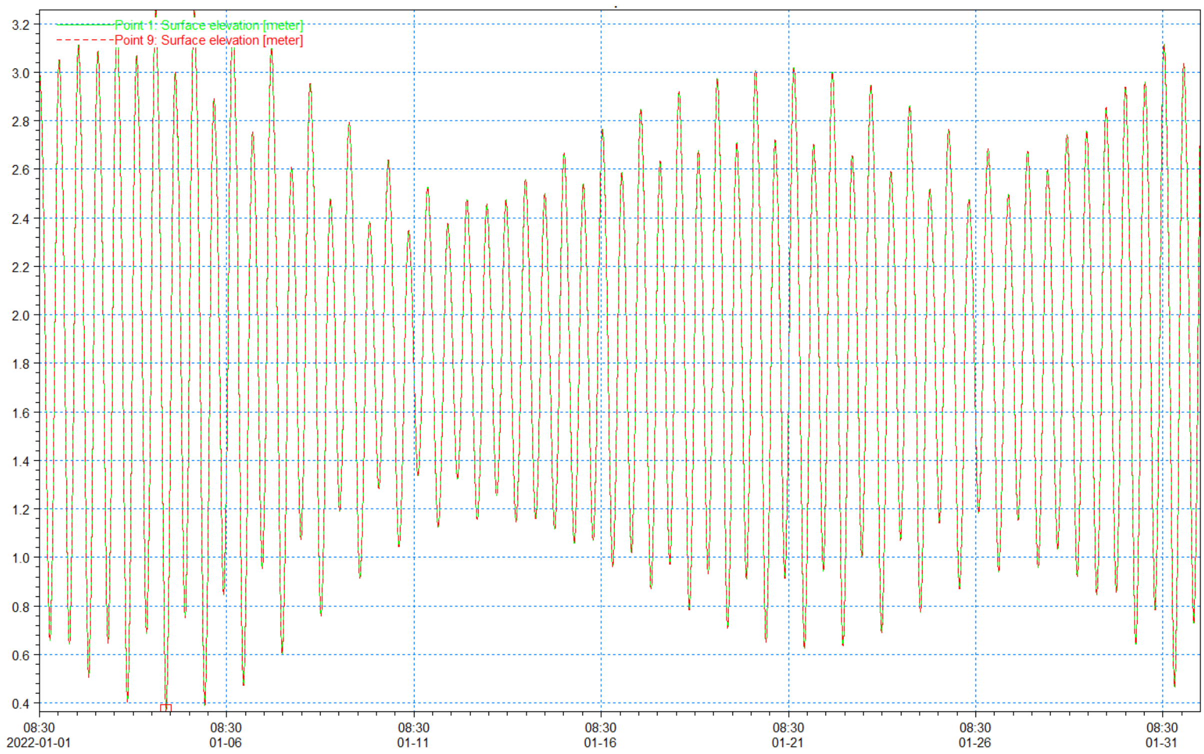


Figure 4-1: FM HD 7 tidal water surface elevation predictions at points 1 and 9 for run duration

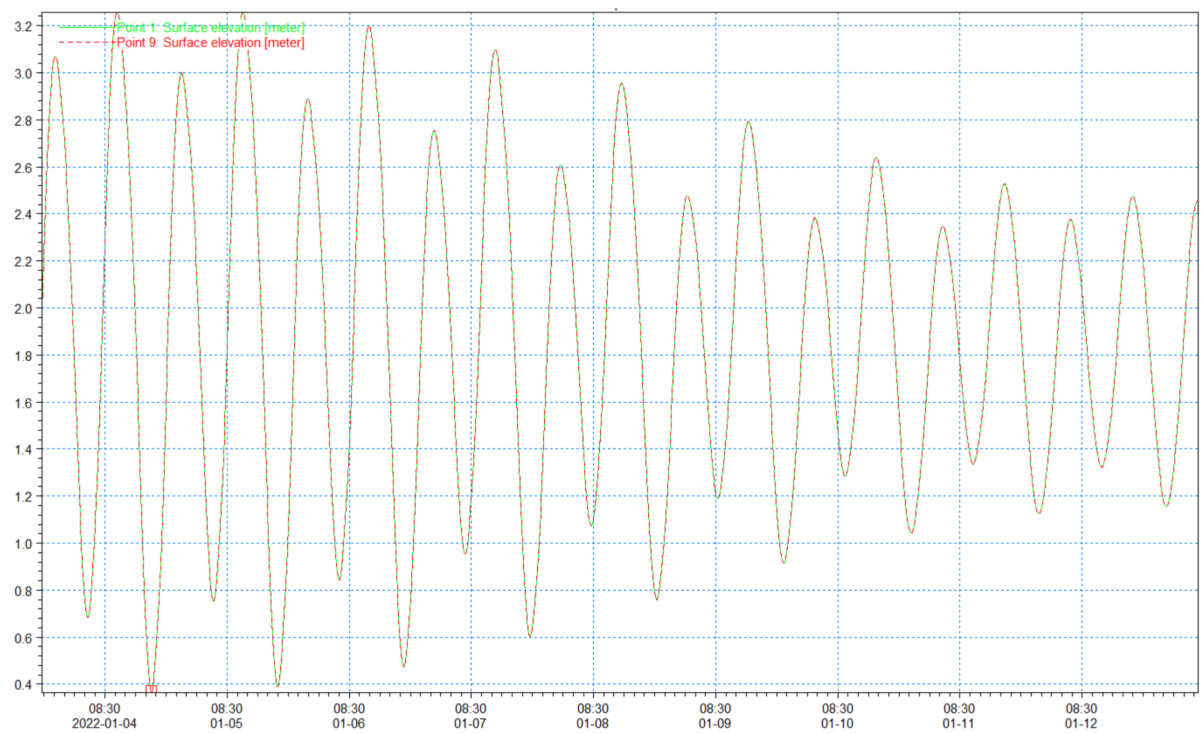


Figure 4-2: FM HD 7 tidal water surface elevation predictions at points 1 and 9 for spring and neap tidal cycle

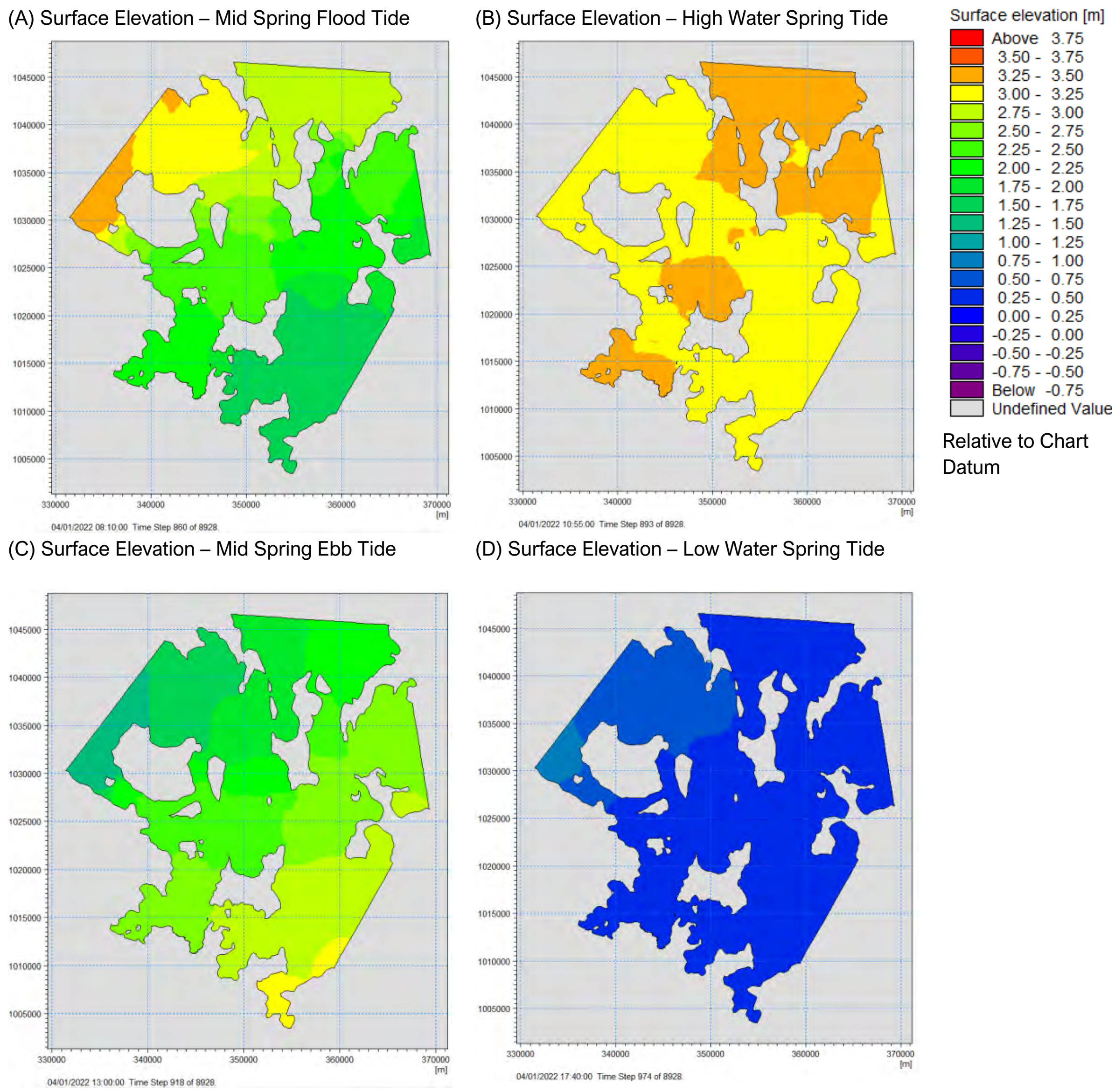


Figure 4-3: FM HD 7 model extent water surface elevation (A) mid-flood (B) high (C) mid-ebb (D) low spring tide

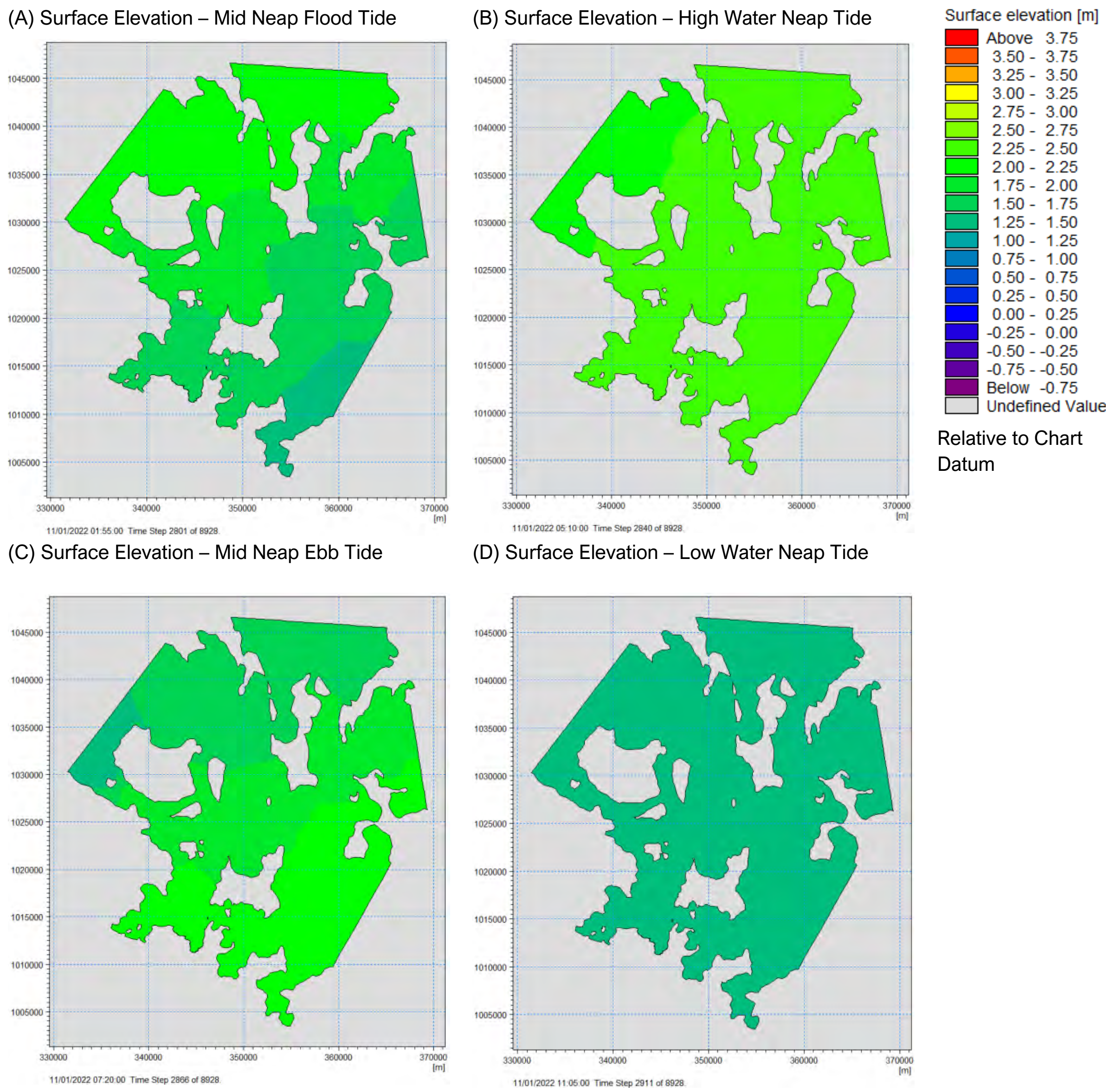


Figure 4-4: FM HD 7 model extent water surface elevation (A) mid-flood (B) high (C) mid-ebb (D) low neap tide

4.1.2 Tidal Currents

Tidal current speed predictions for point output locations 1, 9 and 11 are presented in Figure 4-5 for the full FM HD 7 run duration, and in Figure 4-6 for a selected spring and neap tidal cycle. Review of these figures highlights the relatively strong currents (>1.5m/s) present in The String channel to the north-west of Bay of Kirkwall (see Figure 3-9) during spring tides, and the weak currents which occur in Bay of Kirkwall (<0.2m/s) and at Hatston (<0.1m/s).

Figure 4-7 shows the spring tidal current predictions at locations 1, 9 and 11, along with the corresponding tidal water surface elevation at point 1. Review of this figure highlights the phasing of the tidal current speeds in relation to the tidal wave, with current speed peaks observed during mid-flood and ebb tides, and lowest speeds around high and low water. The phasing is more complex adjacent to Hatston, considered a result of local flow patterns and eddies, however, peak flood tide current speeds can be seen to be higher than corresponding ebb tide current speeds within Bay of Kirkwall and particularly around Hatston. At point 11 in The String channel peak flood and ebb tidal current speeds are more closely matched.

Figure 4-8 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 orientated north-west to south-east through the centre of the model extent, and other focused tidal streams through the narrow channels between islands. Weakest currents are observed to occur in sheltered tidal embayments outwith the main tidal streams.

Figure 4-9 to Figure 4-12 present similar plots focussed on Hatston, Bay of Kirkwall and surrounds, with current vector arrows shown to indicate tidal stream direction. Review of these figures highlights the position of the main local tidal stream through The String channel and Wide Firth around the south-western tip of Shapinsay. Current vectors highlight the direction of the flood tide from north-west to south-east, and the ebb tide in the opposite direction. The figures highlight the low current speeds outwith the main tidal stream within Bay of Kirkwall and adjacent to Hatston.

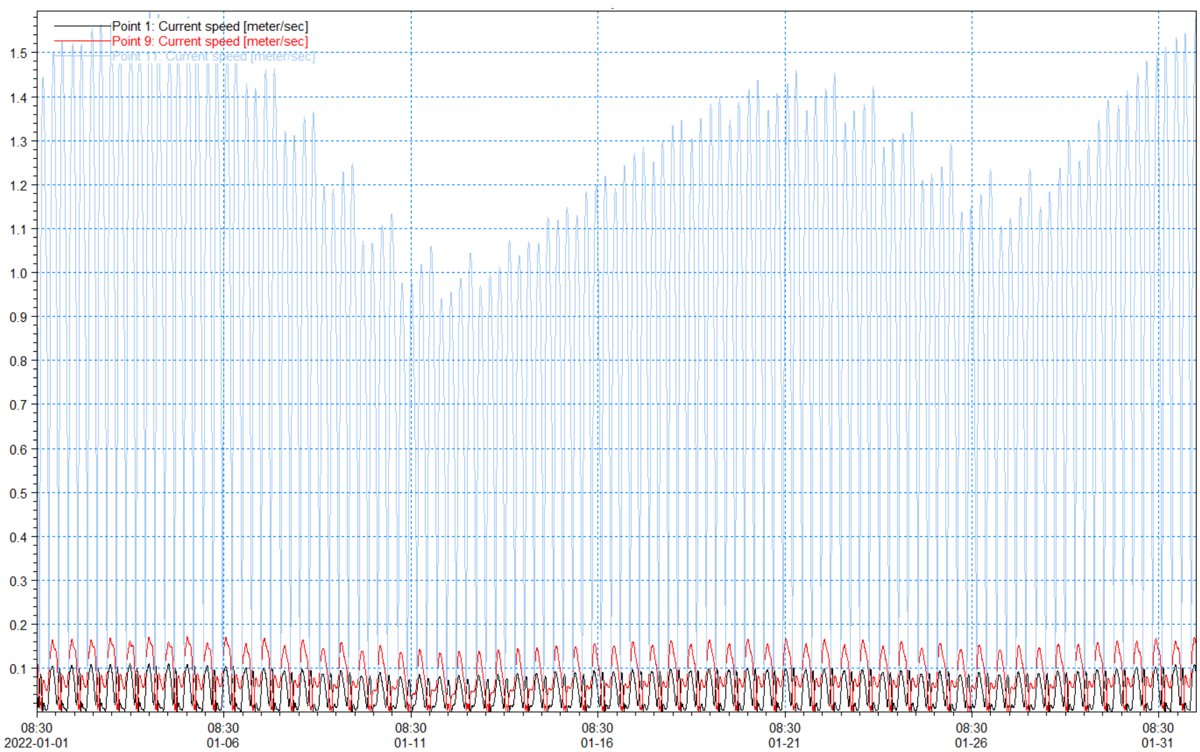


Figure 4-5: FM HD 7 current speed predictions at points 1, 9 and 11 for run duration

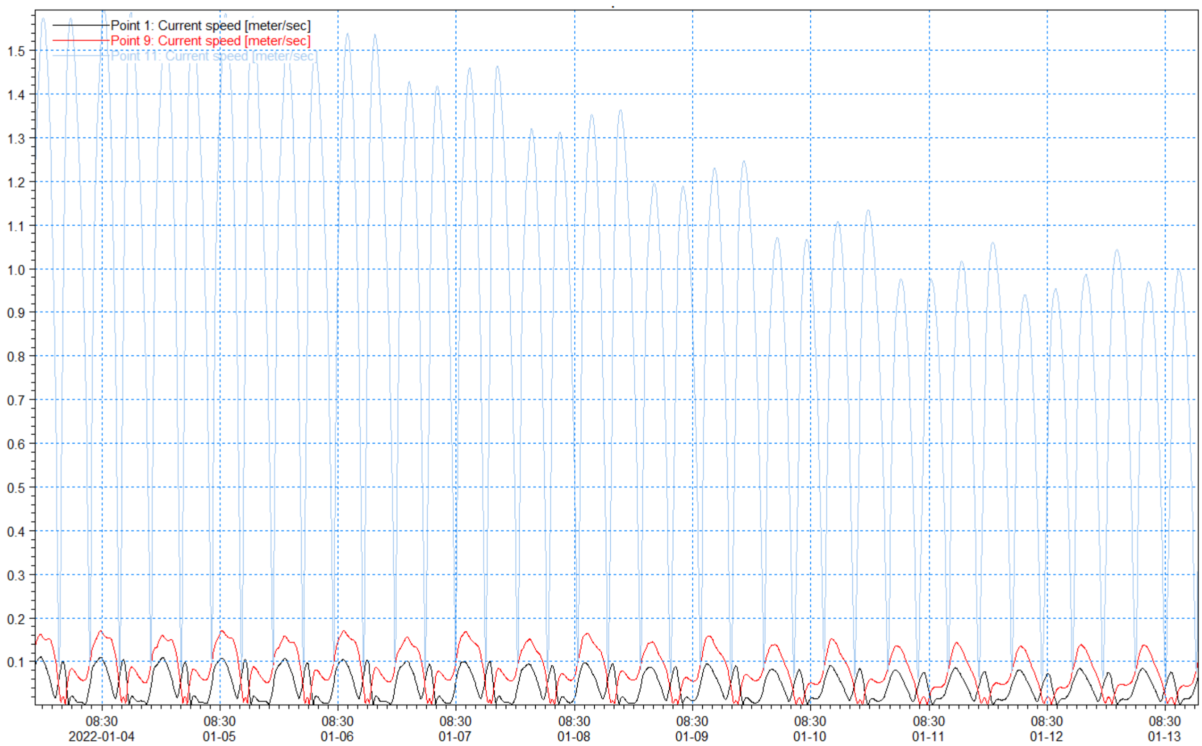


Figure 4-6: FM HD 7 current speed predictions at points 1, 9 and 11 for spring and neap tidal cycle

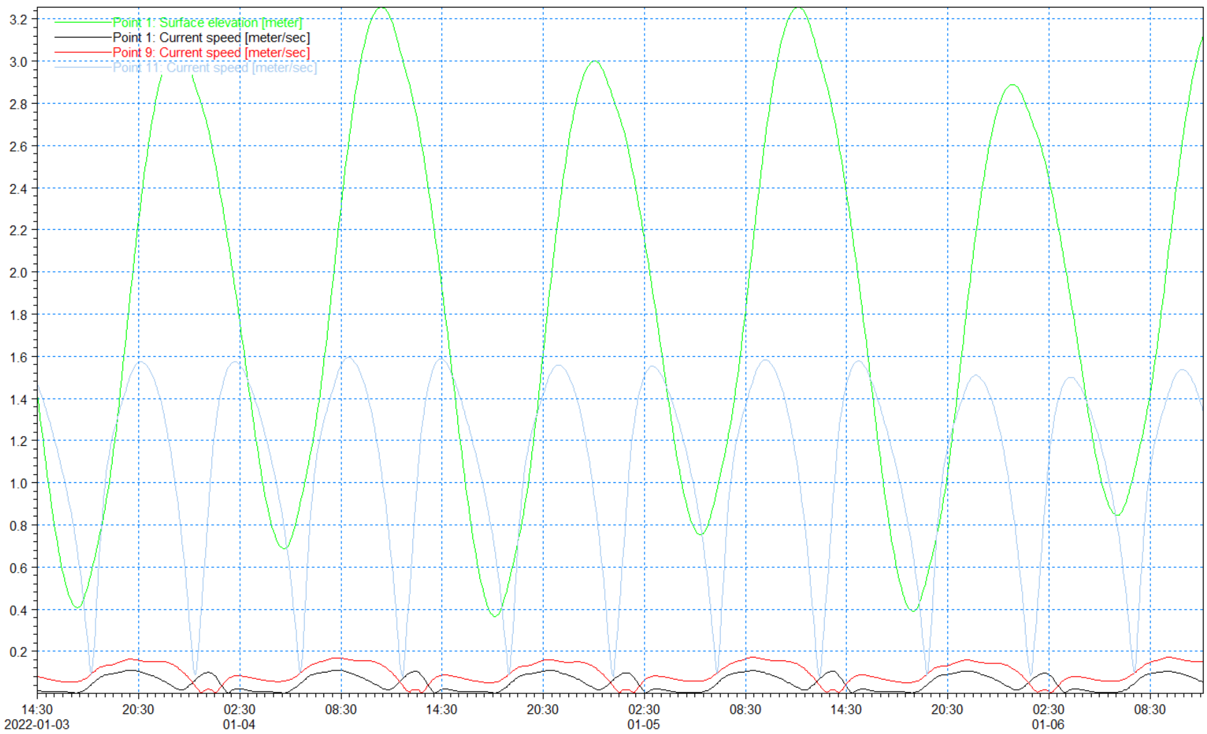


Figure 4-7: FM HD 7 water surface elevation (point 1) and current speed predictions (points 1, 9 and 11) for spring tidal cycle

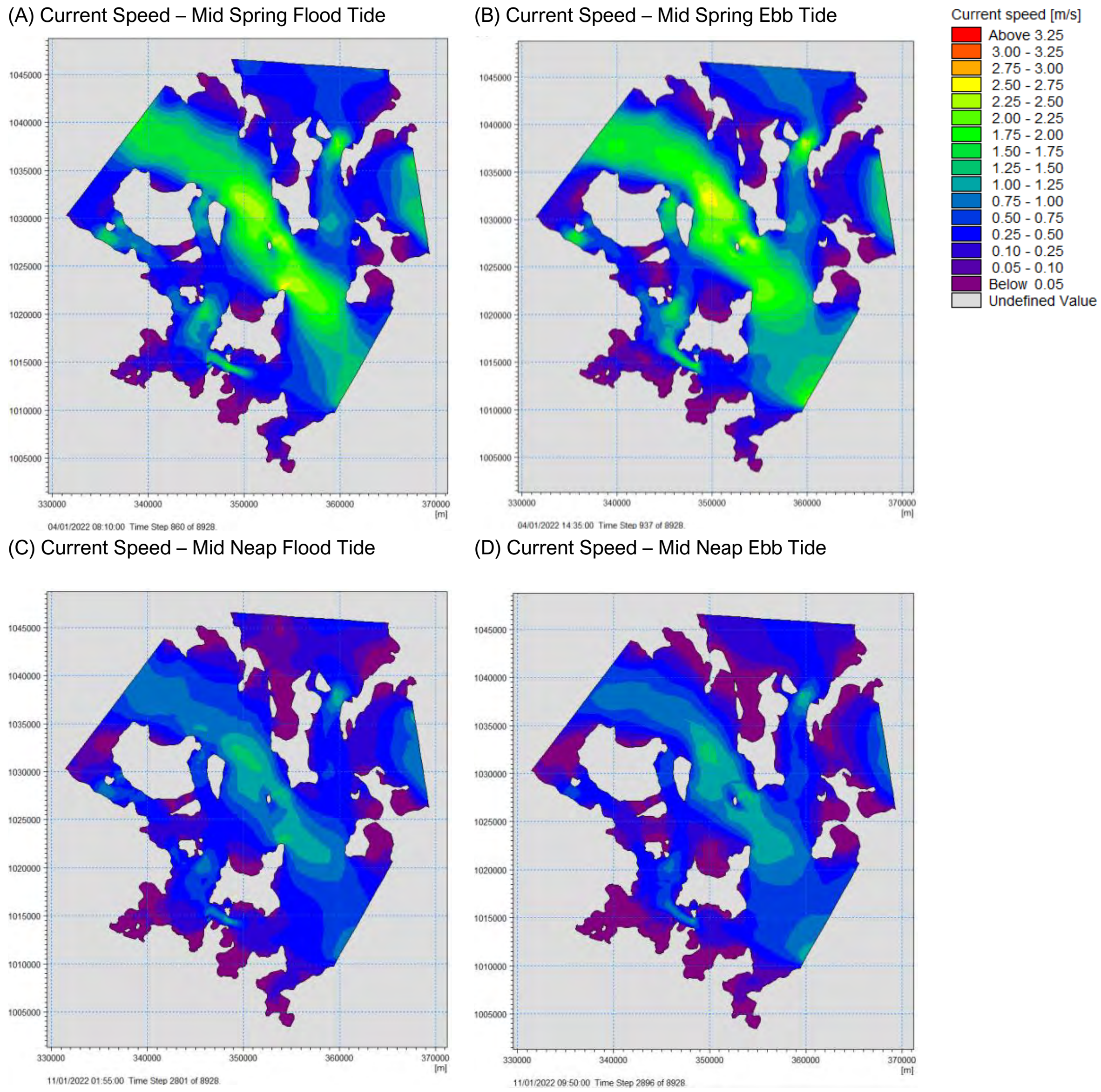


Figure 4-8: FM HD 7 model extent current speed (A) mid-flood spring (B) mid-ebb spring (C) mid-flood neap (D) mid-ebb neap tide

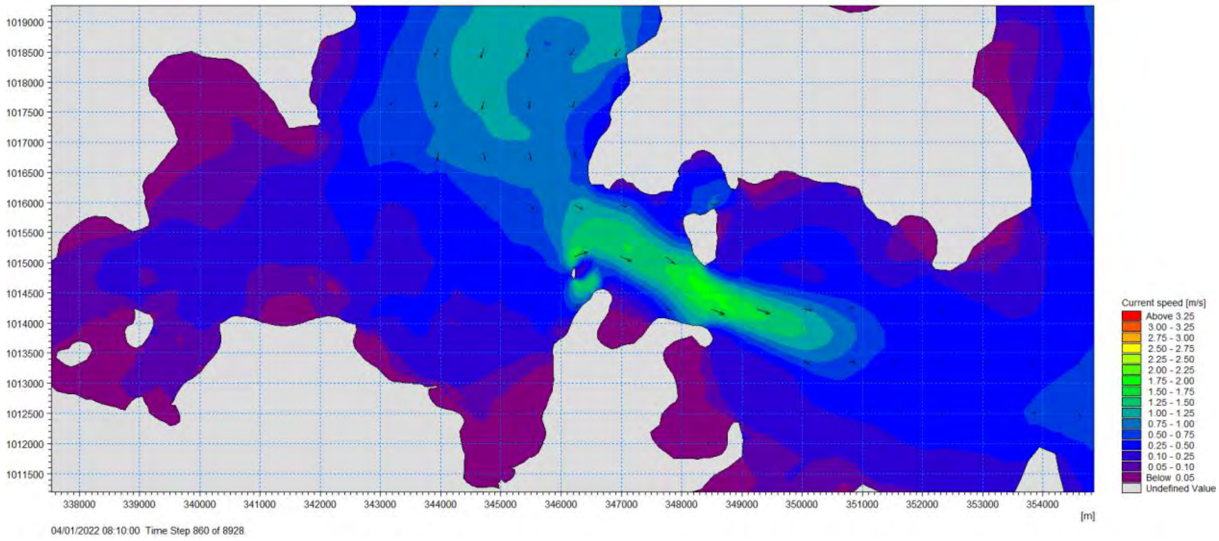


Figure 4-9: FM HD 7 Bay of Kirkwall and surrounds current speed mid-flood spring tide

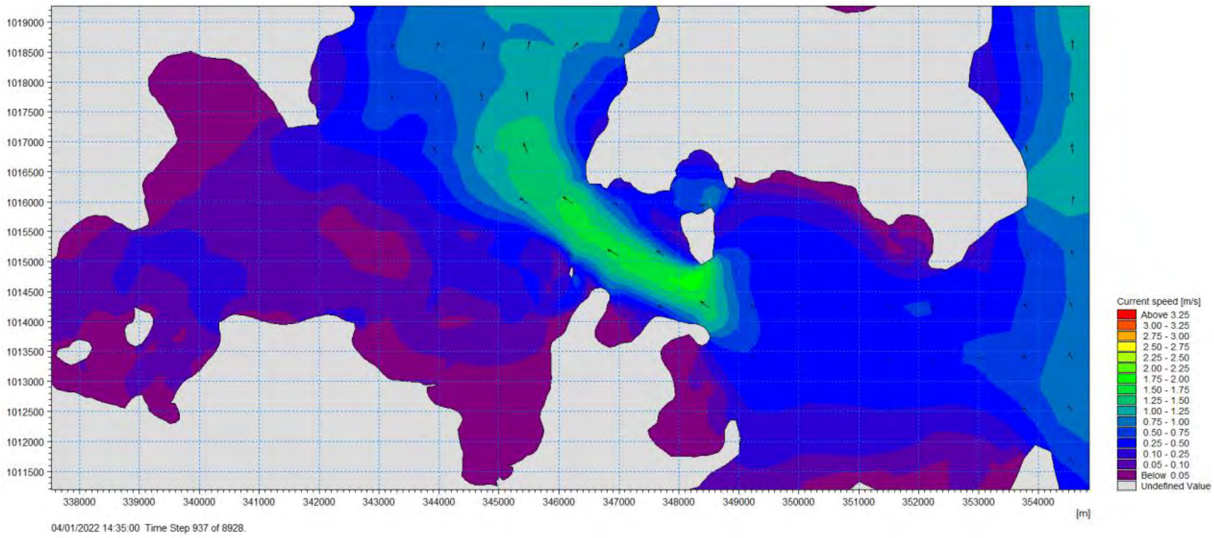


Figure 4-10: FM HD 7 Bay of Kirkwall and surrounds current speed mid-ebb spring tide

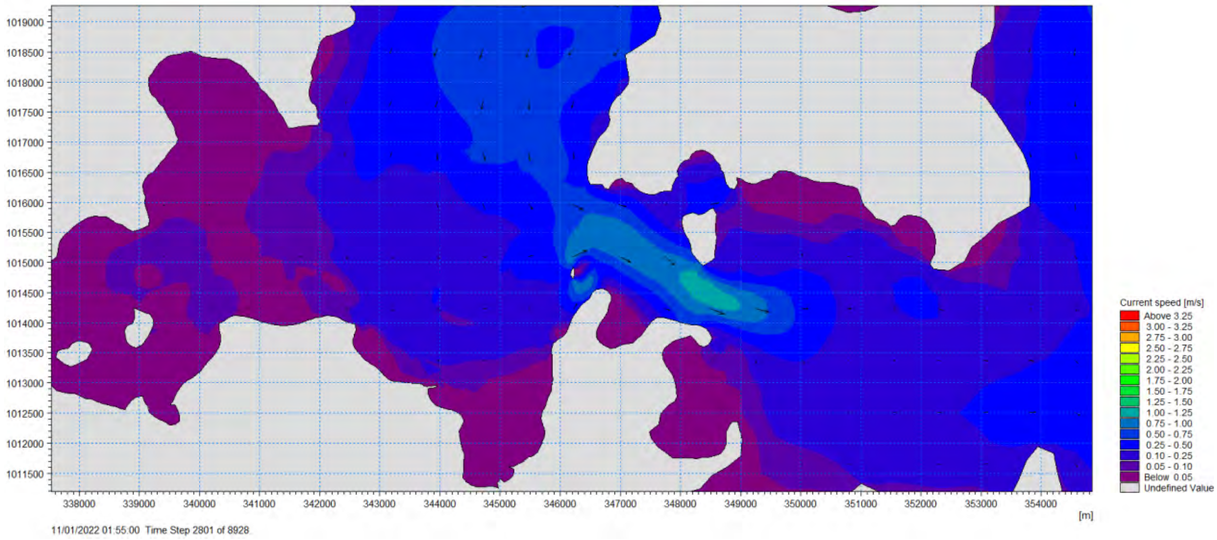


Figure 4-11: FM HD 7 Bay of Kirkwall and surrounds current speed mid-flood neap tide

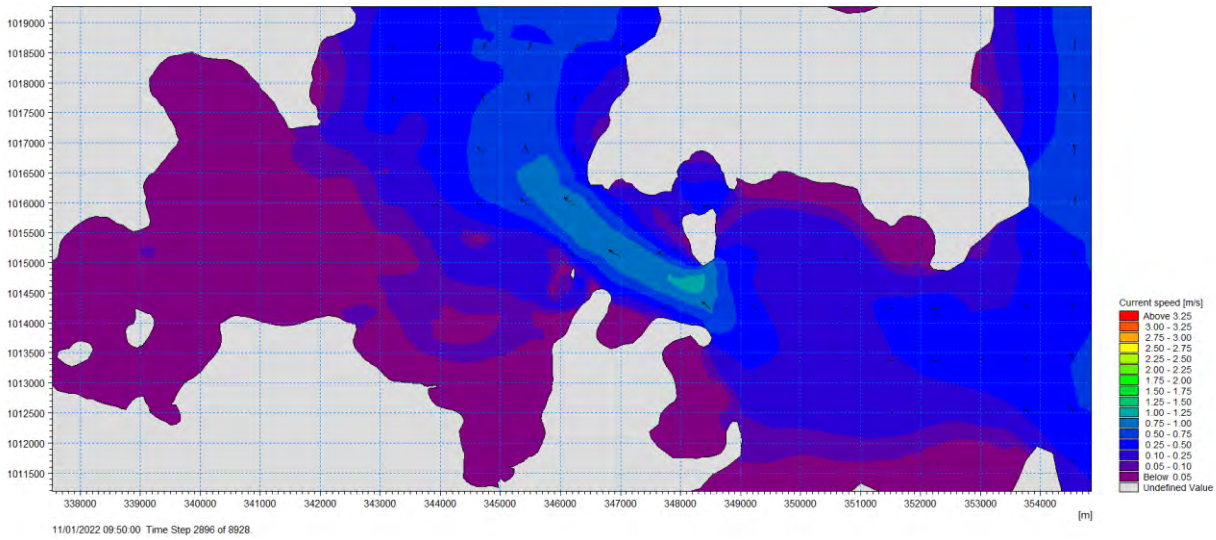


Figure 4-12: FM HD 7 Bay of Kirkwall and surrounds current speed mid-ebb neap tide

4.1.3 Bed Shear Stress

Figure 4-13 presents model predictions of bed shear stress during the selected spring and neap tidal cycle for point output locations 1 to 8 around Hatston. Review of this figure highlights that bed shear stress is strongly correlated with tidal current speed, with peak shear stress occurring with peak current speeds. 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 0.1N/m^2 during spring tides. The low current speeds and corresponding low bed shear stresses are considered indicative of a low energy environment, with no significant sediment transport by tidal currents predicted in the vicinity of Hatston.

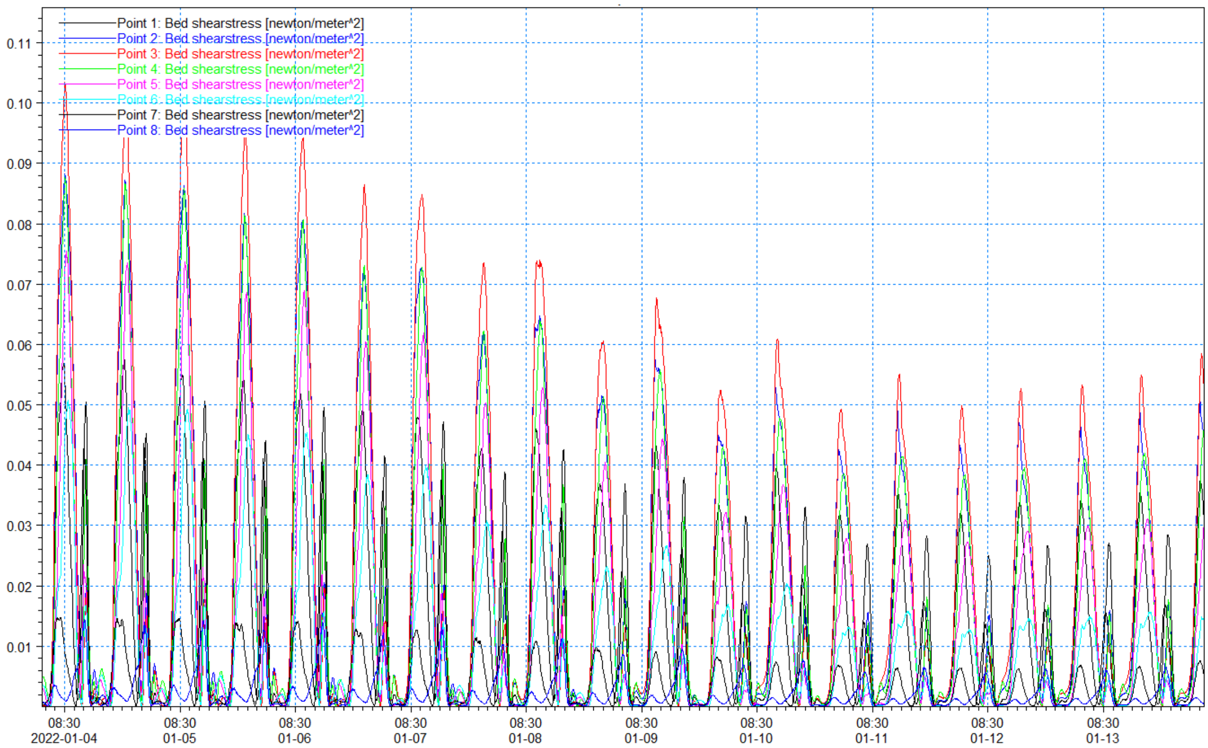


Figure 4-13: FM HD 7 bed shear stress at locations 1 – 8 through spring and neap tidal cycle

4.2 Post-Development Conditions

Model run FM HD 8 simulates post-development (see Appendix A for proposed development layout) tidal conditions at Hatston and surrounds during the month of January 2022. 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 7) 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 1 and 9 (see Figure 3-9) are presented in Figure 4-14 for the full FM HD 8 run duration, and in Figure 4-15 for the selected 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 7 under existing conditions.

Figure 4-16 presents a comparison of the full model run tidal curves for existing (FM HD 7) and post-development (FM HD 8) conditions at point output location 1. 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.

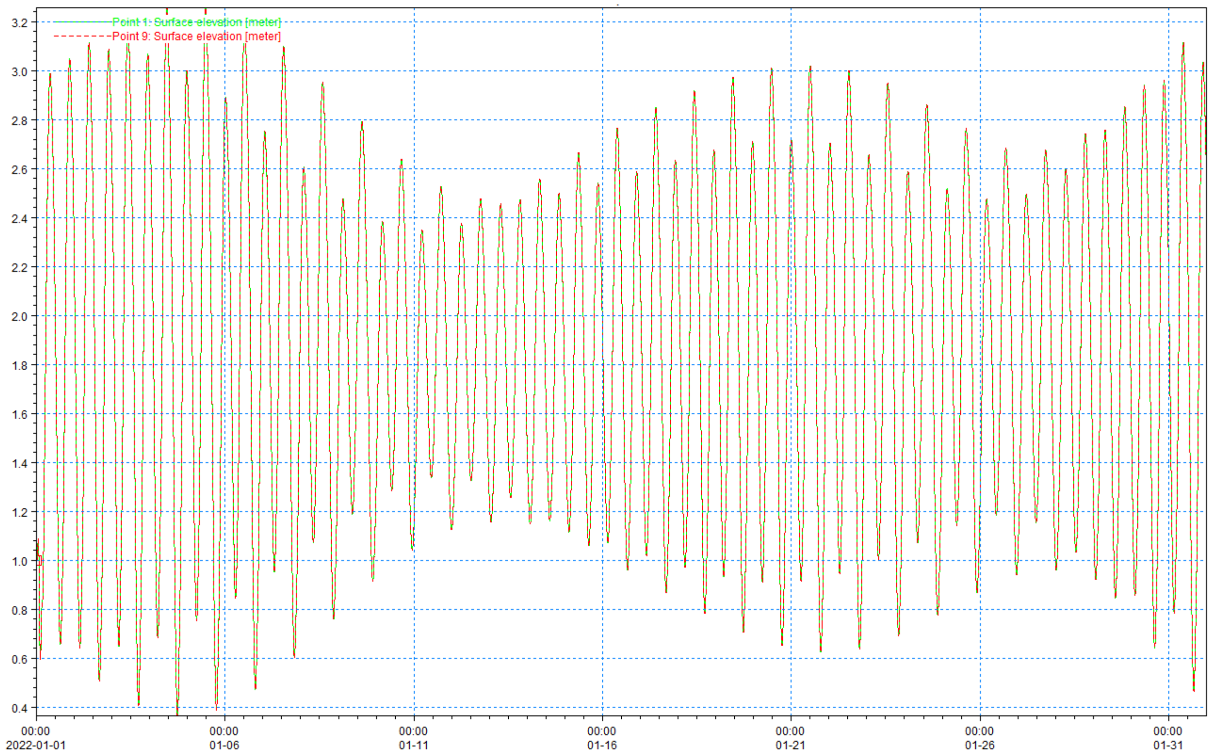


Figure 4-14: FM HD 8 tidal water surface elevation predictions at points 1 and 9 for run duration

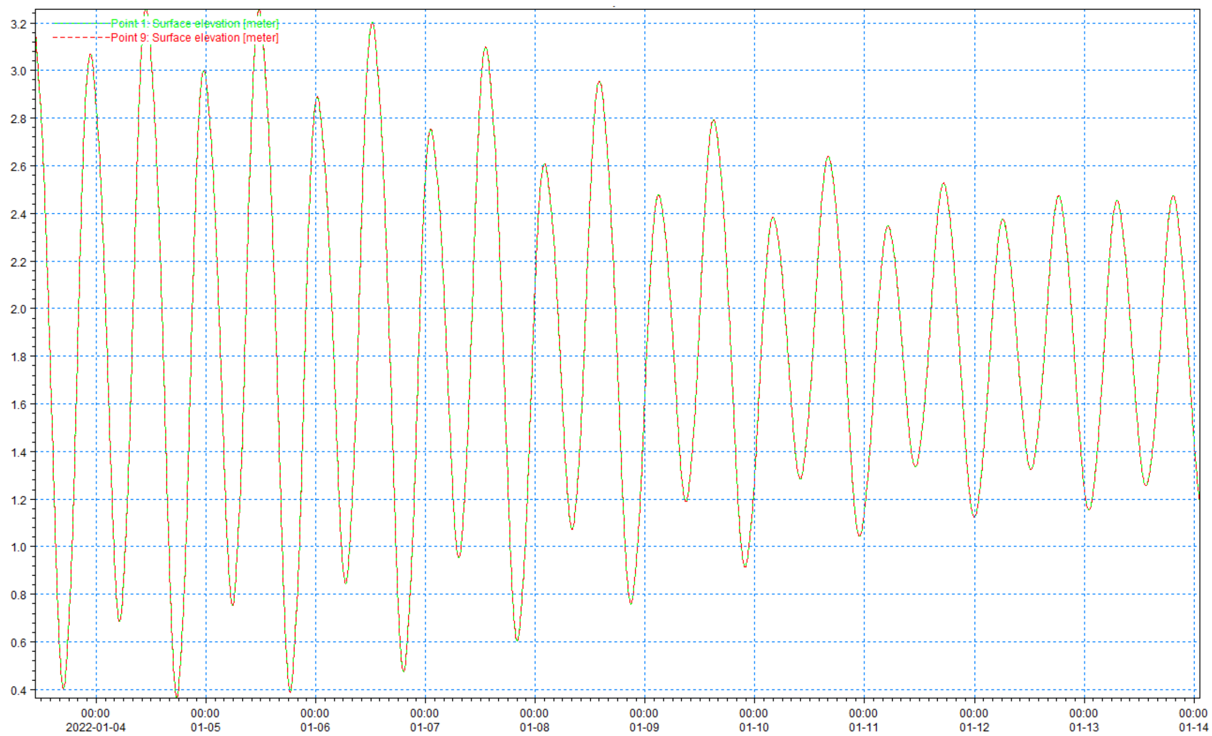


Figure 4-15: FM HD 8 tidal water surface elevation predictions at points 1 and 9 for spring and neap tidal cycle

Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 1: Surface elevati...	Point 1: Surface elevati...	Difference
	Item Unit	[m]	[m]	[m]
	Minimum	0.3648	0.3647	-0.0023
	Maximum	3.2565	3.2566	0.0015
	Average	1.8668	1.8669	-0.0001
	Std. deviation	0.6881	0.6881	0.0009

Figure 4-16: Comparison of FM HD 7 and FM HD 8 water surface elevation predictions at point 1

4.2.2 Tidal Currents

Tidal current speed predictions for point output locations 1, 9 and 11 are presented in Figure 4-17 for the full FM HD 8 run duration, and in Figure 4-18 for a selected spring and neap tidal cycle. Review of these figures highlights, as per the existing conditions run (FM HD 7), the relatively strong currents (>1.5m/s) present in The String channel to the north-west of Bay of Kirkwall during spring tides, and the weak currents which occur in Bay of Kirkwall (<0.2m/s) and at Hatston (<0.1m/s).

Figure 4-19 shows the spring tidal current predictions at locations 1, 9 and 11, along with the corresponding tidal water surface elevation at point 1. Review of this figure highlights the phasing of the tidal current speeds in relation to the tidal wave, with current speed peaks observed during mid-flood and ebb tides, and lowest speeds around high and low water, as per the results for existing conditions (FM HD 7).

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 (<0.06m/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 Hatston 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 generally higher current speeds during the flood tide, as well as the localised impact on current direction resulting from the new quay construction.

Figure 4-22 and Figure 4-23 present plots of current speed differential between post-development (FM HD 8) and existing (FM HD 7) 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. Minor increases in current speed are observed around the north-western end of the new quay during both flood and ebb tides, with minor decreases in current speed in the shelter of the proposed development, more extensively during the flood tide. Small local eddies are predicted during the ebb tide, resulting in localised areas of decreased current speed just offshore of the new quay.

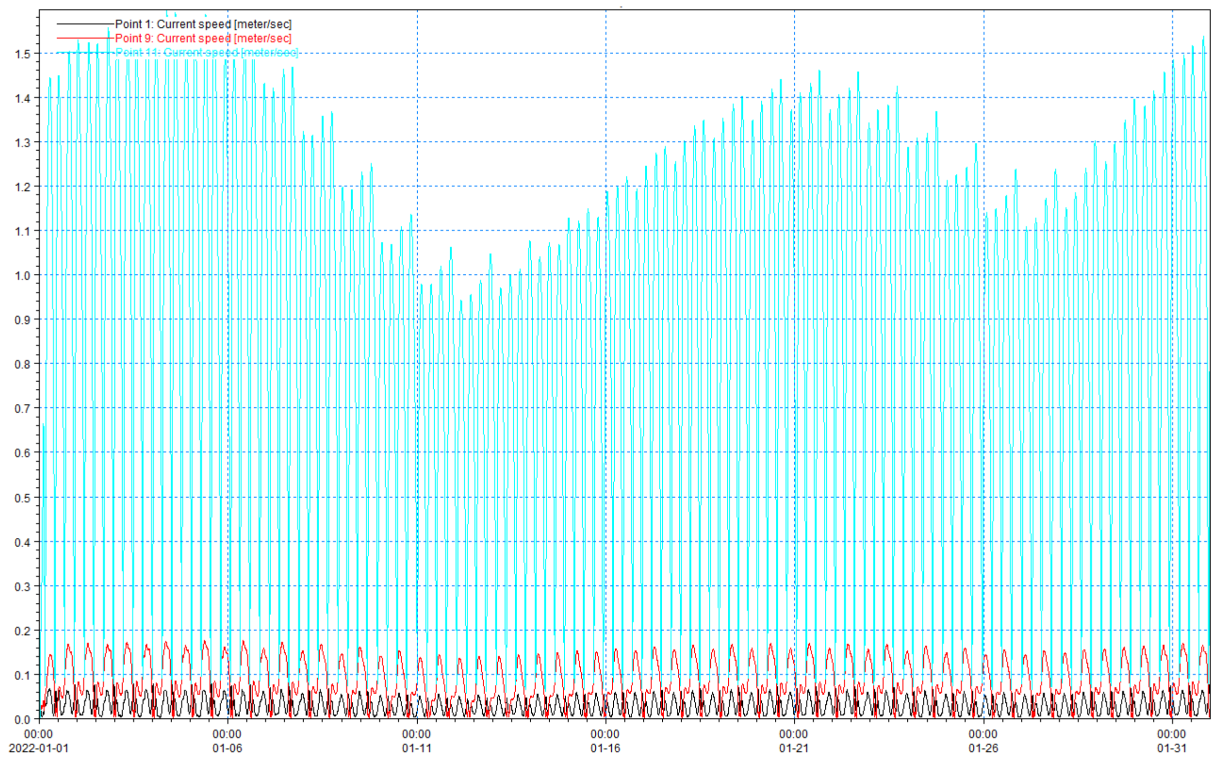


Figure 4-17: FM HD 8 current speed predictions at points 1, 9 and 11 for run duration

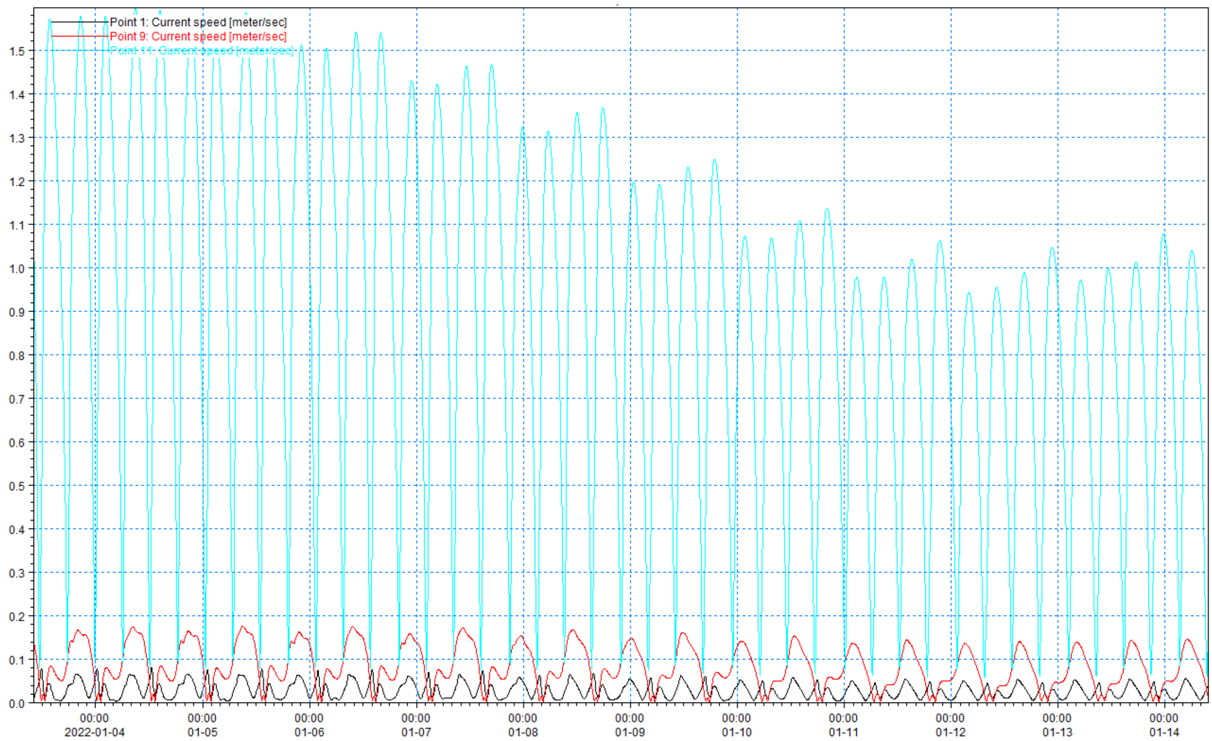


Figure 4-18: FM HD 8 current speed predictions at points 1, 9 and 11 for spring and neap tidal cycle

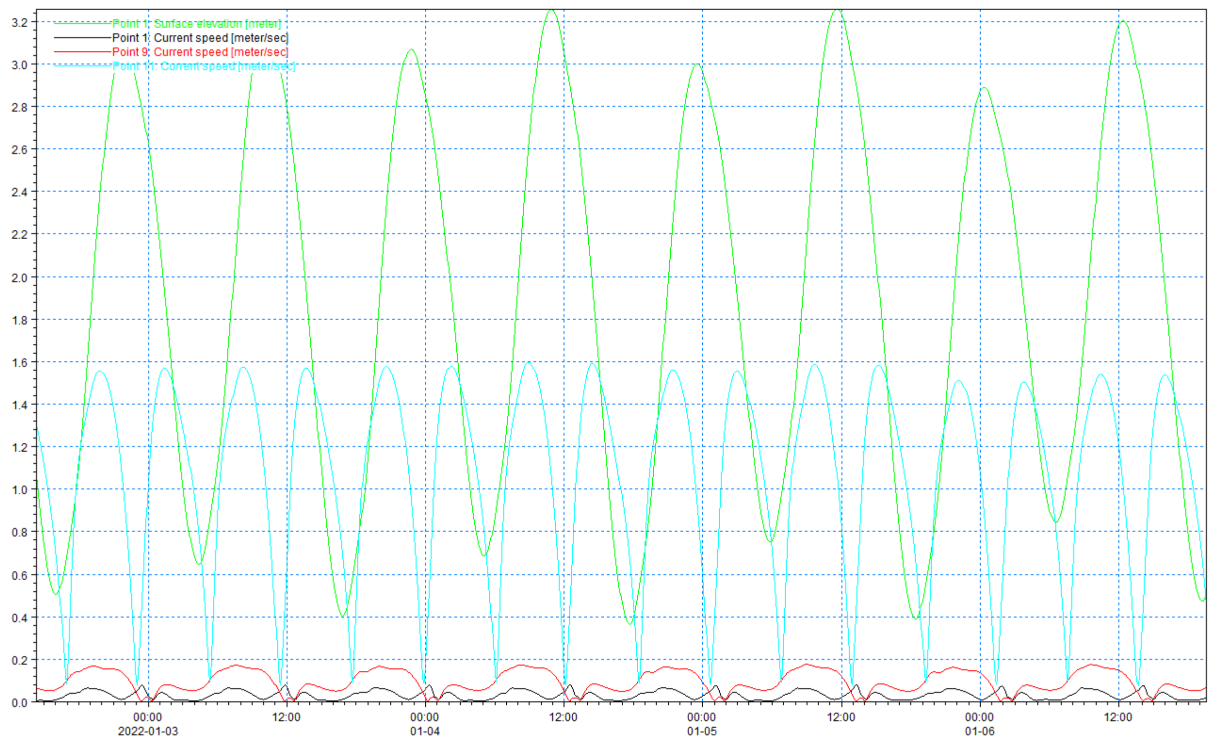


Figure 4-19: FM HD 8 water surface elevation (point 1) and current speed predictions (points 1, 9 and 11) for spring tidal cycle

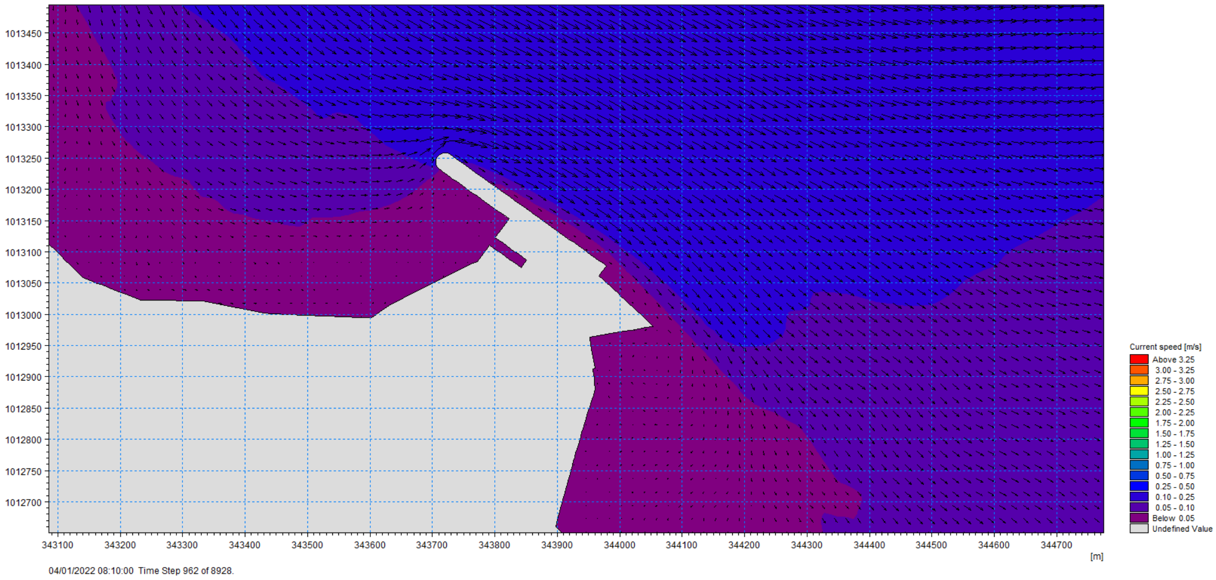


Figure 4-20: FM HD 8 current speed at Hatston during mid-flood spring tide

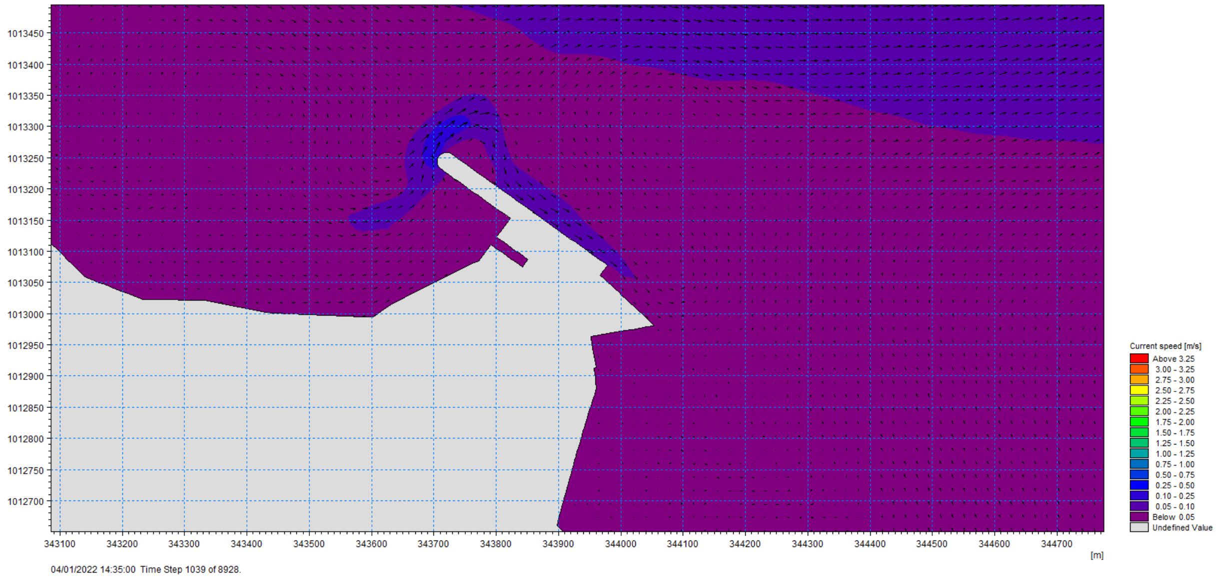


Figure 4-21: FM HD 8 current speed at Hatston during mid-ebb spring tide

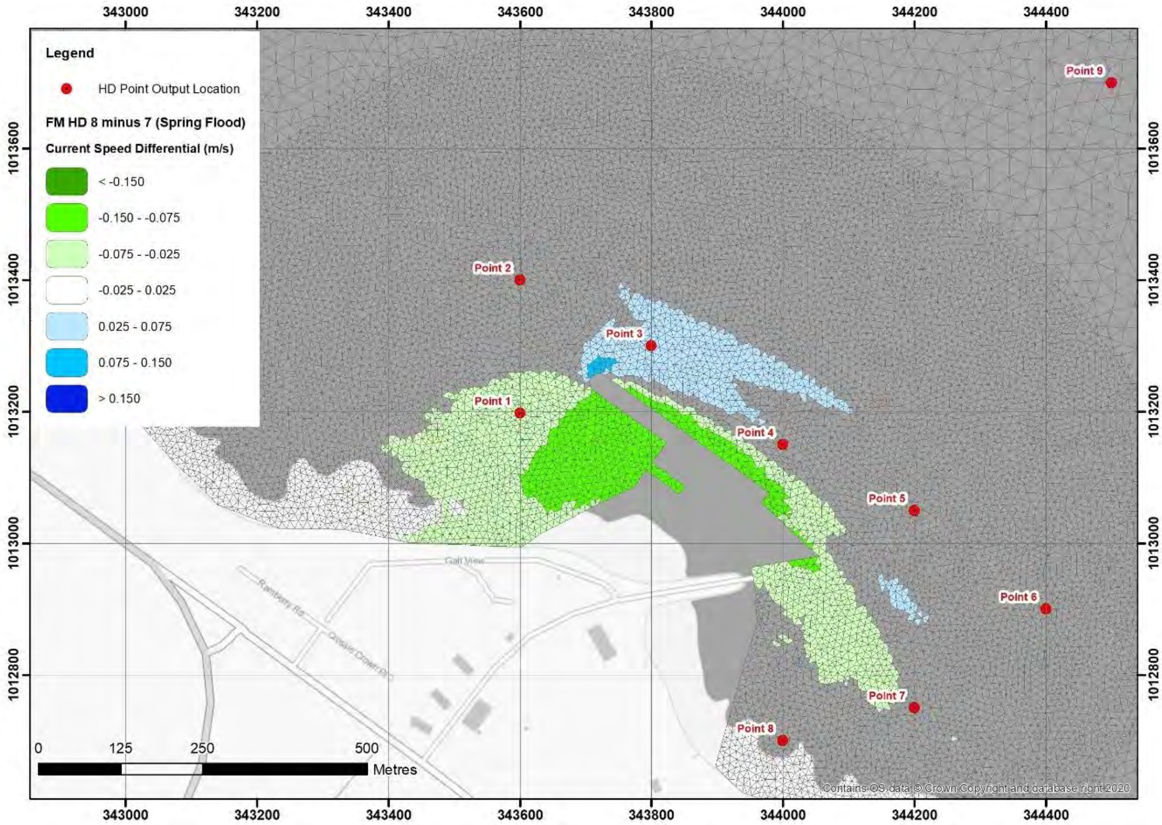


Figure 4-22: Post-development (FM HD 8) versus baseline (FM HD 7) current speed differential – spring flood tide

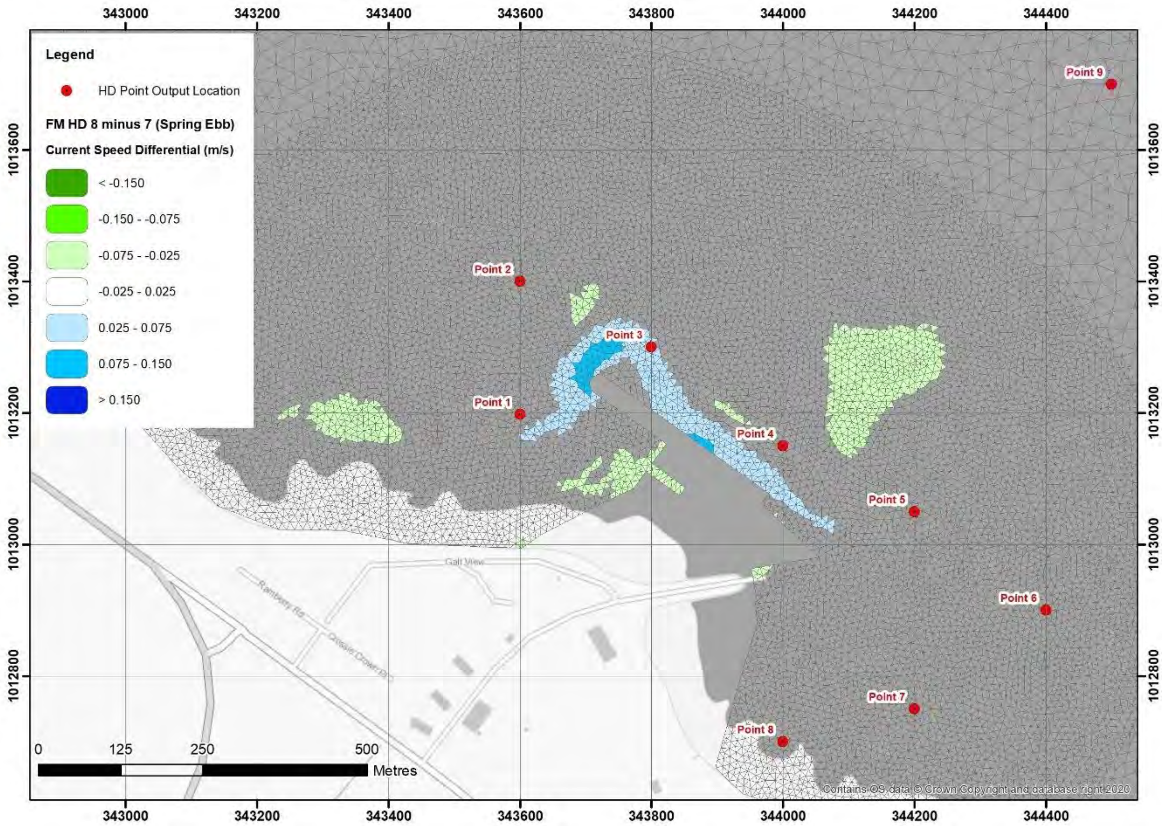


Figure 4-23: Post-development (FM HD 8) versus baseline (FM HD 7) current speed differential – spring ebb tide

4.2.3 Bed Shear Stress

Figure 4-24 presents post-development model predictions of bed shear stress during the selected spring and neap tidal cycle for point output locations 1 to 8 around Hatston. Review of this figure highlights that, as per existing conditions, bed shear stress is strongly correlated with tidal current speed, with peak shear stress occurring with peak current speeds. All locations again show generally low bed shear stress, as would be anticipated with the weak tidal currents observed. Peak bed shear stress predictions are around 0.15N/m^2 during spring tides.

Review of comparative analysis between existing and post-development bed shear stress model predictions presented in Table 2, Appendix B, and in Appendix C, highlights that minor changes in bed shear stress are predicted in a similar pattern to the changes in current speed described in the previous section.

However, in the post-development scenario it remains the case that the low current speeds and corresponding low bed shear stresses observed are considered indicative of a low energy environment, with no significant sediment transport by tidal currents predicted in the vicinity of Hatston.

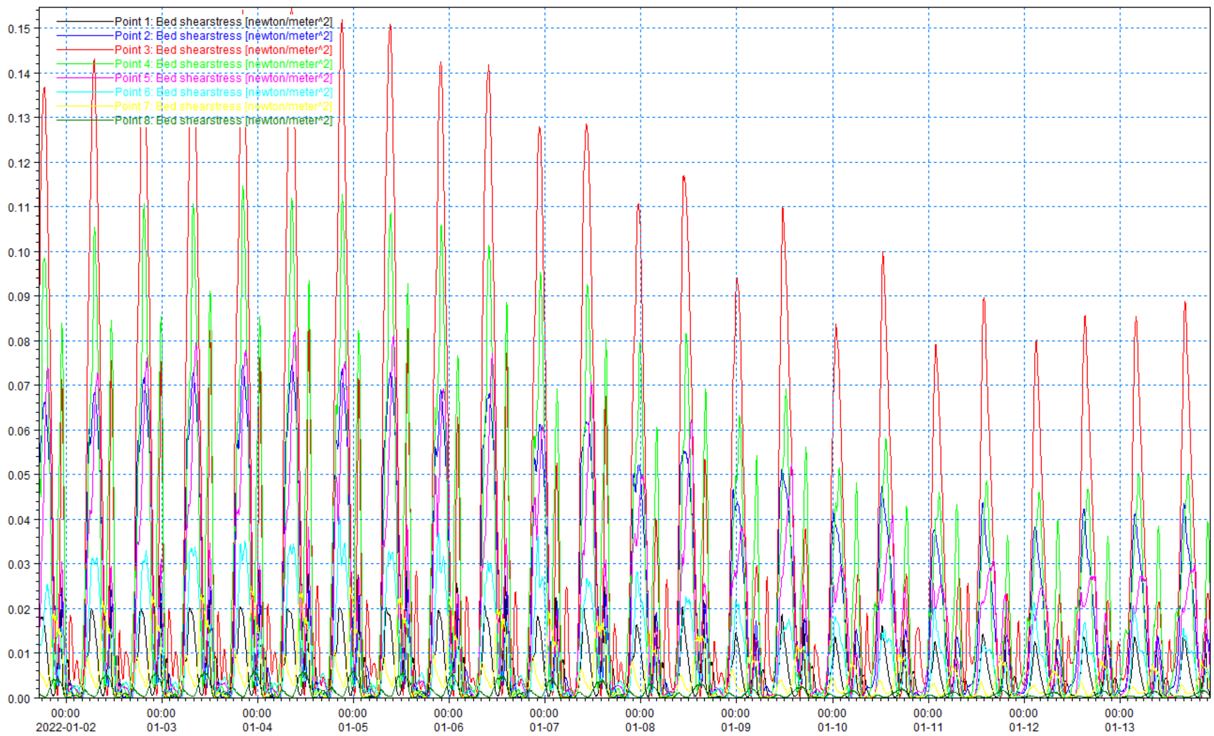


Figure 4-24: FM HD 8 bed shear stress at locations 1 – 8 through spring and neap tidal cycle

5 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 Bay of Kirkwall, Wide Firth, Stronsay Firth, Westray Firth and North Sound, between the islands of Orkney Mainland, Westray, Sanday and Stronsay.

There are four 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 Bay of Kirkwall, becoming finer in the area of interest around Hatston Pier. A post-development version of the HD model mesh has been generated to include the proposed development footprint, and associated capital dredge. The model has been run for both existing and post-development conditions, simulating the January 2022 tidal cycle, including a full spring and neap tidal cycle. 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 7) and the post-development model run (FM HD 8) 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 Hatston, 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 (<0.06m/s change), with no change observed in the wider surrounds. Review of current speed plots for the Hatston area highlights the localised spatial pattern of development impact on tidal current speed during each tidal state. Minor increases in current speed are observed around the north-western end of the new quay during both flood and ebb tides, with minor decreases in current speed in the shelter of the proposed development, more extensively during the flood tide. Small local eddies are predicted during the ebb tide, resulting in localised areas of decreased current speed just offshore of the new quay. Comparative analysis between existing and post-development bed shear stress model predictions highlights that minor changes in bed shear stress are predicted in a similar pattern to the changes in current speed.

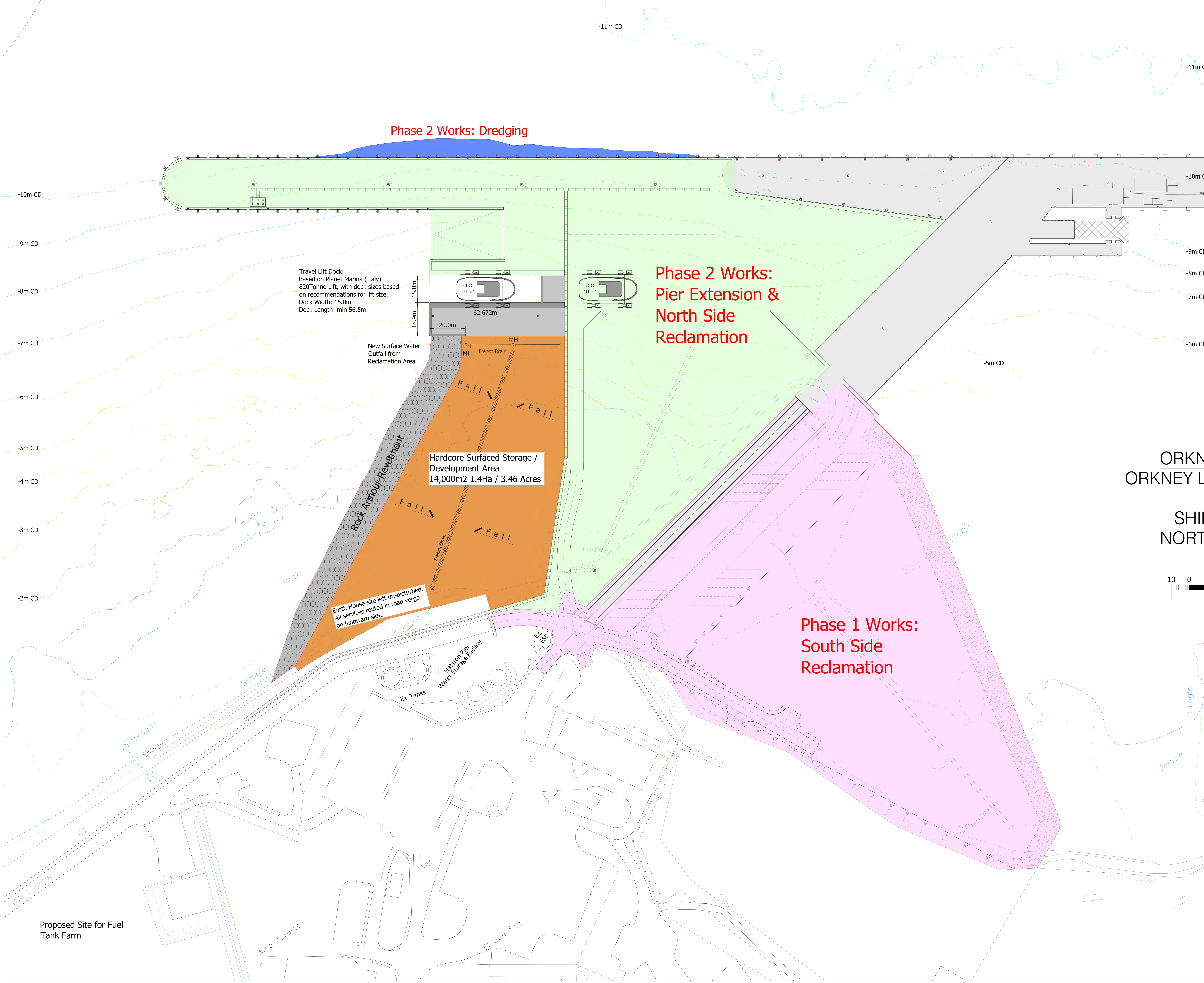
While the modelling results presented indicate that the proposed development will produce localised changes in tidal current speeds, it is considered that these variations are insignificant in terms of the wider hydrodynamic regime in and around Hatston Pier and Bay of Kirkwall, with predicted changes of very minor scale, and post development speeds of a very similar nature to those observed under existing conditions.

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

APPENDICES

A PROPOSED DEVELOPMENT LAYOUT

Chart Datum (Kirkwall)	Ordnance Datum (Newlyn)	Quay Heights and Tide Data Hatston Pier, Kirkwall
+6.40m	+5.00m	Quay Edge Level
+3.00m	+1.60m	Mean High Water Spring Tides
+1.40m	0.00m	Ordnance Datum (Newlyn)
+0.60m	-0.80m	Mean Low Water Spring Tides
0.00m	-1.40m	Chart Datum (Kirkwall)
-5.00m	-6.40m	
-7.50m	-8.90m	
-10.00m	-11.40m	



ORKNEY ISLANDS COUNCIL
ORKNEY LOGISTICS BASE, HATSTON
PHASE 3 WORKS
SHIP LIFT & ADDITIONAL NORTH SIDE RECLAMATION

Scale 1: 1000

10 0 10 20 30 40 50 60 70 80 90 100m

SCALE 1:1000 at A1

REV	DATE	REVISION	DRN	CHK
A	06:06:2023	Pier Approach Dredging Removed	JJM	
P1	21:02:2023	Preliminary Issue P1 for comment	JJM	

ORKNEY ISLANDS COUNCIL
Harbour Authority

Orkney Logistics Base, Hatston, Orkney

Consenting Process
Phase 3 Works: Ship Lift & Reclamation

Arch Henderson 1919
Civil Engineers
Structural Engineers
Architects
CDM Co-ordinators
Geotechnical services
Environmental services

Stewart Building, Lerwick, Shetland. ZE1 0LL.
Tel : 01595 695512
www.arch-henderson.co.uk - email : lerwick@arch-henderson.co.uk

Aberdeen; Dundee; Glasgow; Lerwick; Inverness; Thurso; Stromness; Southampton; Falkland Islands

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

SCALE : (A1) As Shown
DRAWING STATUS : Consents

DRAWING No : 202043/C- 30
REV : A

B TABULATED MODEL RESULTS

Table 1: FM HD 7 and FM HD 8 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/m²)
7	Mid-Flood Spring (TS 860) [04/01/22 08:10]	Point 1	2.13	0.11	1.94	0.0564
		Point 2	2.13	0.14	2.19	0.0845
		Point 3	2.13	0.16	2.04	0.0982
		Point 4	2.13	0.14	2.05	0.0814
		Point 5	2.13	0.13	2.11	0.0632
		Point 6	2.13	0.09	2.14	0.0361
		Point 7	2.13	0.05	2.39	0.0111
		Point 8	2.13	0.01	3.80	0.0012
		Point 9	2.13	0.17	1.70	0.1142
		Point 10	2.13	0.03	2.56	0.0047
		Point 11	1.95	1.50	1.99	7.5970
		Point 12	2.09	0.72	2.34	1.8373
	High Spring (TS 893) [04/01/22 10:55]	Point 1	3.25	0.02	2.74	0.0023
		Point 2	3.25	0.09	2.26	0.0302
		Point 3	3.25	0.08	2.06	0.0280
		Point 4	3.25	0.07	1.85	0.0170
		Point 5	3.25	0.07	1.80	0.0177
		Point 6	3.25	0.05	1.79	0.0112
		Point 7	3.25	0.01	5.26	0.0007
		Point 8	3.25	0.03	5.30	0.0063
		Point 9	3.25	0.13	1.67	0.0657
		Point 10	3.25	0.01	2.92	0.0004
		Point 11	3.20	0.99	1.94	3.2525
		Point 12	3.24	0.44	2.30	0.6911
	Mid-Ebb Spring (TS 937) [04/01/22 14:35]	Point 1	1.81	0.02	1.67	0.0021
		Point 2	1.81	0.04	1.76	0.0060
		Point 3	1.81	0.03	1.69	0.0030
		Point 4	1.81	0.03	1.77	0.0039
		Point 5	1.81	0.02	5.98	0.0016
		Point 6	1.81	0.02	5.79	0.0014
		Point 7	1.81	0.01	1.19	0.0008
		Point 8	1.81	0.01	1.46	0.0006
		Point 9	1.81	0.09	1.26	0.0308
		Point 10	1.82	0.02	6.10	0.0021
		Point 11	1.84	1.58	5.28	8.3583
		Point 12	1.81	1.24	5.41	5.5477
	Low Spring (TS 974) [04/01/22 17:40]	Point 1	0.37	0.00	2.59	0.0001
		Point 2	0.37	0.00	2.74	0.0001
		Point 3	0.37	0.00	4.14	0.0001
		Point 4	0.37	0.01	5.61	0.0003
		Point 5	0.37	0.00	4.50	0.0001
		Point 6	0.37	0.01	5.35	0.0006

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)
		Point 7	0.37	0.02	2.11	0.0018
		Point 8	0.37	0.01	2.78	0.0009
		Point 9	0.37	0.05	1.42	0.0124
		Point 10	0.37	0.00	4.71	0.0001
		Point 11	0.35	0.61	5.32	1.2968
		Point 12	0.37	0.49	5.32	0.9029
8	Mid-Flood Spring (TS 962) [04/01/22 08:10]	Point 1	2.13	0.06	1.50	0.0191
		Point 2	2.13	0.13	2.02	0.0716
		Point 3	2.13	0.19	1.95	0.1504
		Point 4	2.13	0.16	2.17	0.1042
		Point 5	2.13	0.12	2.31	0.0570
		Point 6	2.13	0.09	2.17	0.0340
		Point 7	2.13	0.03	3.07	0.0043
		Point 8	2.13	0.01	4.12	0.0004
		Point 9	2.13	0.17	1.72	0.1204
		Point 10	2.13	0.03	2.55	0.0046
		Point 11	1.95	1.51	1.99	7.6277
		Point 12	2.09	0.72	2.33	1.8379
	High Spring (TS 995) [04/01/22 10:55]	Point 1	3.25	0.02	3.71	0.0010
		Point 2	3.25	0.08	2.21	0.0242
		Point 3	3.25	0.08	1.90	0.0230
		Point 4	3.25	0.03	0.31	0.0026
		Point 5	3.25	0.04	1.35	0.0061
		Point 6	3.25	0.05	2.82	0.0108
		Point 7	3.25	0.07	5.16	0.0234
		Point 8	3.26	0.03	5.74	0.0055
		Point 9	3.25	0.13	1.70	0.0683
		Point 10	3.26	0.01	2.46	0.0005
		Point 11	3.20	0.99	1.94	3.2593
		Point 12	3.24	0.44	2.30	0.6914
	Mid-Ebb Spring (TS 1039) [04/01/22 14:35]	Point 1	1.81	0.03	1.62	0.0056
		Point 2	1.81	0.03	2.17	0.0036
		Point 3	1.81	0.07	2.12	0.0207
		Point 4	1.81	0.02	6.13	0.0011
		Point 5	1.81	0.02	6.21	0.0023
		Point 6	1.81	0.02	5.93	0.0017
		Point 7	1.81	0.02	1.73	0.0015
		Point 8	1.81	0.00	1.17	0.0002
		Point 9	1.81	0.08	1.31	0.0285
		Point 10	1.81	0.02	6.17	0.0020
		Point 11	1.84	1.58	5.28	8.3981
		Point 12	1.81	1.24	5.41	5.5723
	Low Spring (TS 1076) [04/01/22 17:40]	Point 1	0.37	0.01	1.76	0.0011
		Point 2	0.37	0.01	5.45	0.0002
		Point 3	0.37	0.02	3.18	0.0018
		Point 4	0.37	0.03	1.90	0.0037
		Point 5	0.37	0.01	5.39	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 6	0.37	0.01	5.41	0.0008
		Point 7	0.37	0.01	2.46	0.0007
		Point 8	0.37	0.01	2.90	0.0005
		Point 9	0.37	0.06	1.70	0.0146
		Point 10	0.37	0.00	4.69	0.0000
		Point 11	0.35	0.62	5.32	1.3047
		Point 12	0.37	0.49	5.32	0.9069

Table 2: Comparison of FM HD 7 and FM HD 8 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/m²)
FMHD7 minus FMHD8	Mid-Flood Spring [04/01/22 08:10]	Point 1	0.00	0.05	0.0372
		Point 2	0.00	0.01	0.0128
		Point 3	0.00	-0.04	-0.0522
		Point 4	0.00	-0.02	-0.0228
		Point 5	0.00	0.01	0.0061
		Point 6	0.00	0.00	0.0021
		Point 7	0.00	0.02	0.0069
		Point 8	0.00	0.01	0.0009
		Point 9	0.00	0.00	-0.0062
		Point 10	0.00	0.00	0.0001
		Point 11	0.00	0.00	-0.0307
		Point 12	0.00	0.00	-0.0006
	High Spring [04/01/22 10:55]	Point 1	0.00	0.01	0.0013
		Point 2	0.00	0.01	0.0060
		Point 3	0.00	0.01	0.0051
		Point 4	0.00	0.04	0.0144
		Point 5	0.00	0.03	0.0116
		Point 6	0.00	0.00	0.0004
		Point 7	0.00	-0.06	-0.0228
		Point 8	0.00	0.00	0.0009
		Point 9	0.00	0.00	-0.0026
		Point 10	0.00	0.00	-0.0001
		Point 11	0.00	0.00	-0.0068
		Point 12	0.00	0.00	-0.0003
	Mid-Ebb Spring [04/01/22 14:35]	Point 1	0.00	-0.01	-0.0035
		Point 2	0.00	0.01	0.0024
		Point 3	0.00	-0.04	-0.0177
		Point 4	0.00	0.01	0.0028
		Point 5	0.00	0.00	-0.0007
		Point 6	0.00	0.00	-0.0004
		Point 7	0.00	-0.01	-0.0007
		Point 8	0.00	0.00	0.0004
		Point 9	0.00	0.00	0.0022

HD Run Comp.	Tidal State [Date Time]	Output Location	Surface Elevation Difference (m)	Current Speed Difference (m/s)	Bed Shear Stress Difference (N/m²)
		Point 10	0.00	0.00	0.0001
		Point 11	0.00	0.00	-0.0398
		Point 12	0.00	0.00	-0.0246
	Low Spring [04/01/22 17:40]	Point 1	0.00	-0.01	-0.0010
		Point 2	0.00	0.00	-0.0001
		Point 3	0.00	-0.02	-0.0017
		Point 4	0.00	-0.02	-0.0034
		Point 5	0.00	0.00	-0.0002
		Point 6	0.00	0.00	-0.0002
		Point 7	0.00	0.01	0.0012
		Point 8	0.00	0.00	0.0004
		Point 9	0.00	0.00	-0.0022
		Point 10	0.00	0.00	0.0000
		Point 11	0.00	0.00	-0.0079
		Point 12	0.00	0.00	-0.0040

C MODEL RESULTS - GRAPHICAL COMPARISONS

Note: Observation = baseline model [FM HD 7] and Simulation = post-development model [FM HD 8]

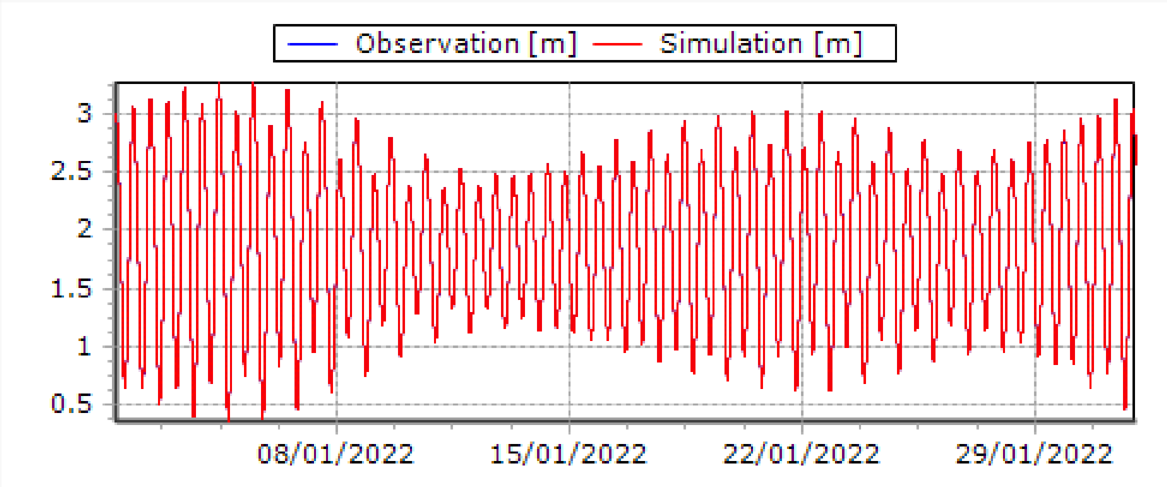
<u>Water Surface Elevation</u>

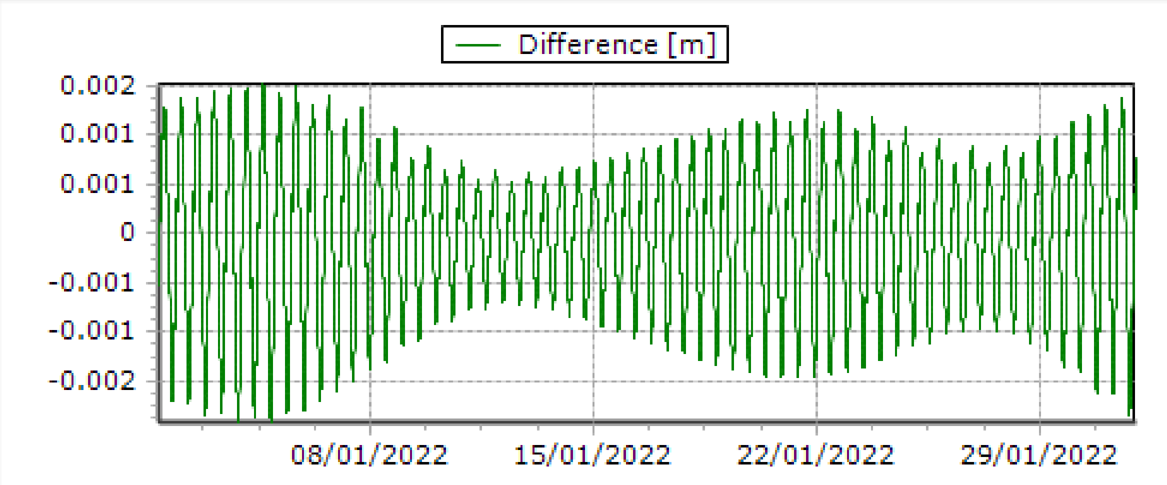
Time Series Plots

Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 1: Surface ele...	Point 1: Surface ele...	Difference
	Item Unit	[m]	[m]	[m]
	Minimum	0.3648	0.3647	-0.0023
	Maximum	3.2565	3.2566	0.0015
	Average	1.8668	1.8669	-0.0001
	Std. deviation	0.6881	0.6881	0.0009

Time Series Plots

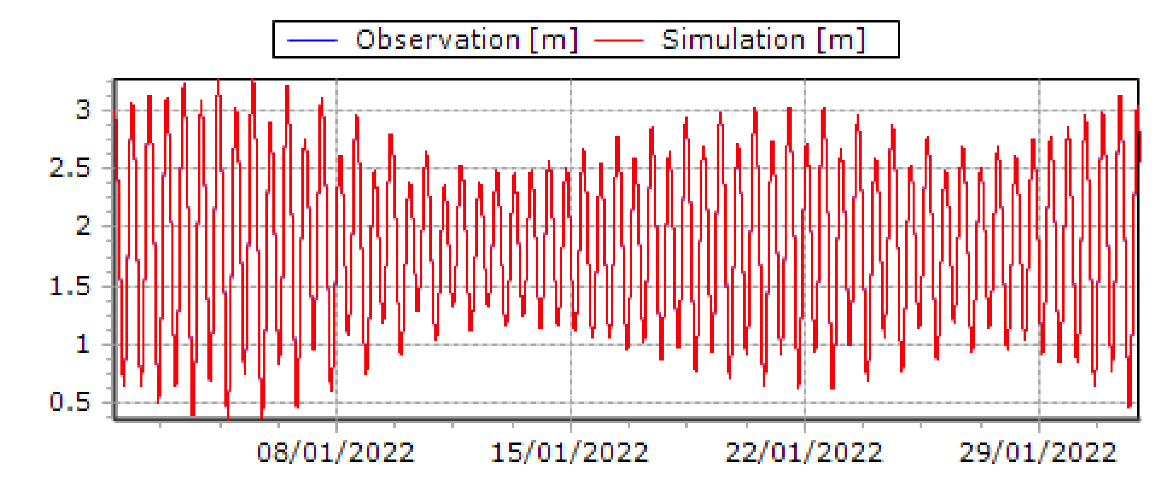


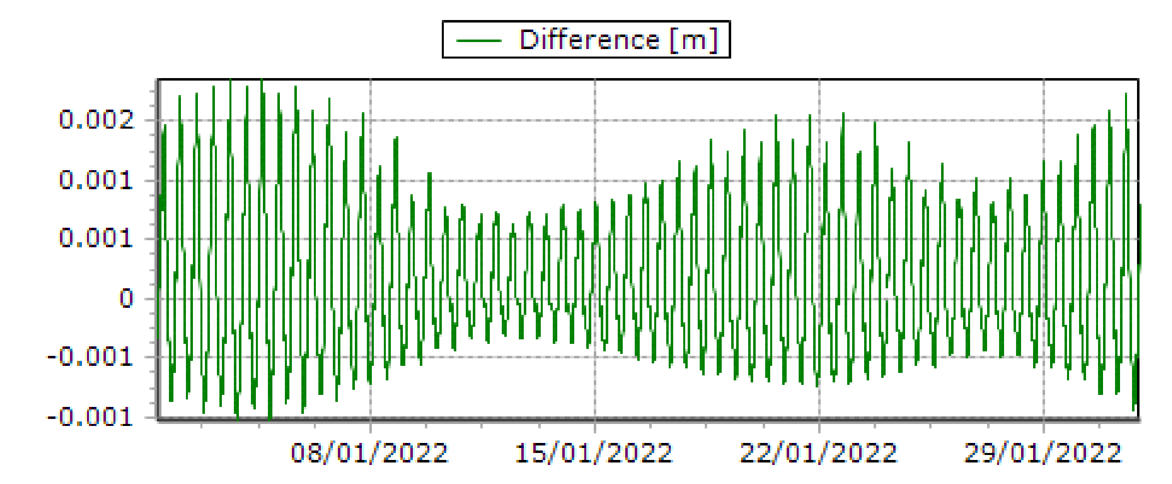


Statistics

	Observation	Simulation	Difference
Item Name	Point 2: Surface ele...	Point 2: Surface ele...	Difference
Item Unit	[m]	[m]	[m]
Minimum	0.3649	0.3648	-0.0019
Maximum	3.2562	3.2565	0.0015
Average	1.8668	1.8669	-0.0001
Std. deviation	0.6880	0.6881	0.0008

Time Series Plots

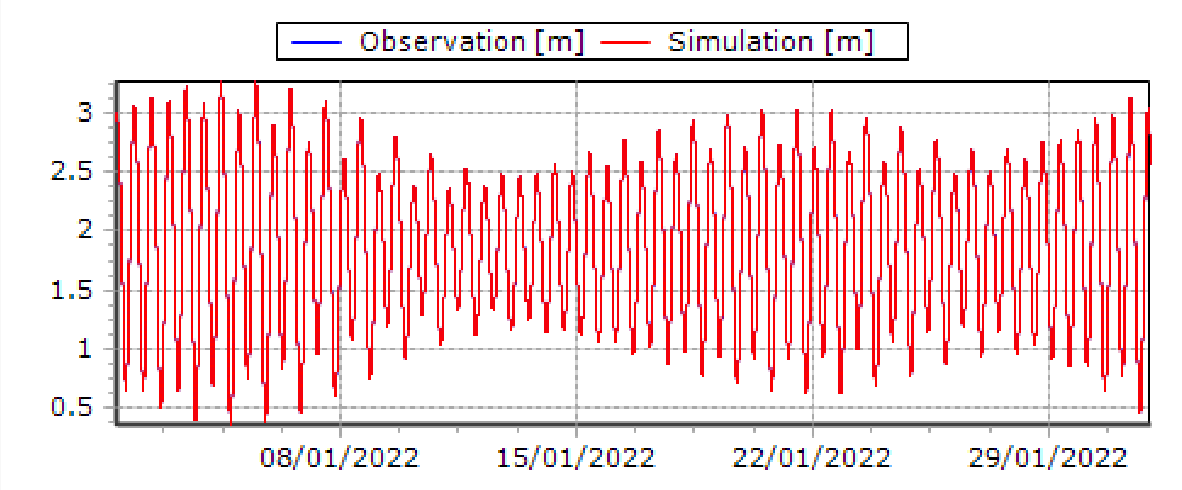


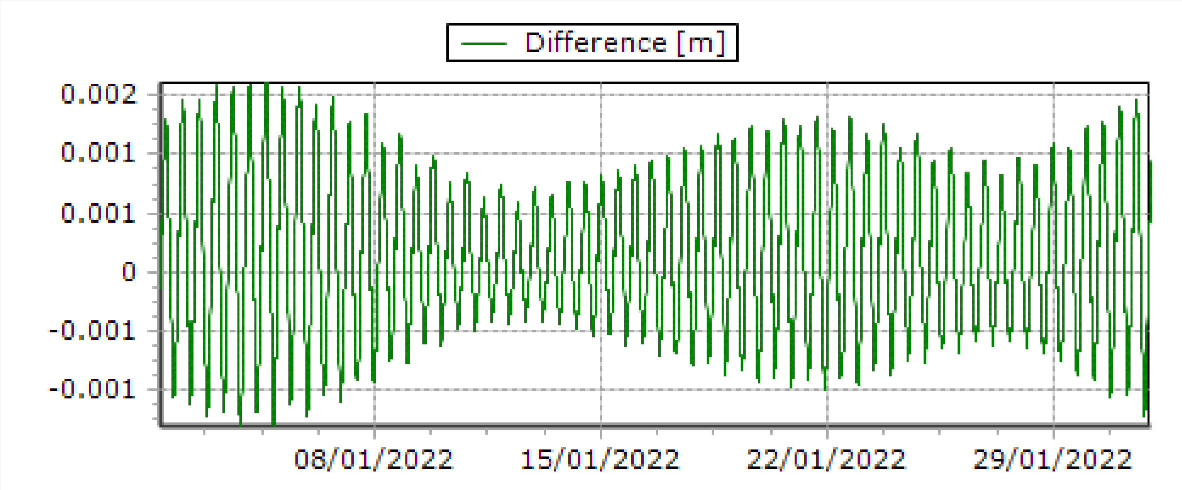


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 3: Surface ele...	Point 3: Surface ele...	Difference
	Item Unit	[m]	[m]	[m]
	Minimum	0.3647	0.3646	-0.0010
	Maximum	3.2567	3.2570	0.0019
	Average	1.8668	1.8666	0.0002
	Std. deviation	0.6881	0.6883	0.0006

Time Series Plots

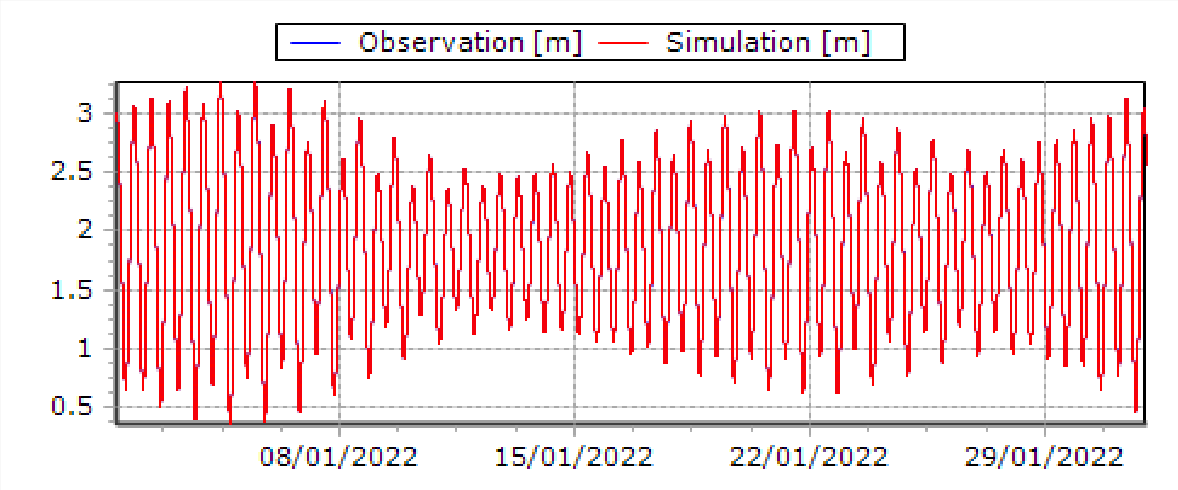


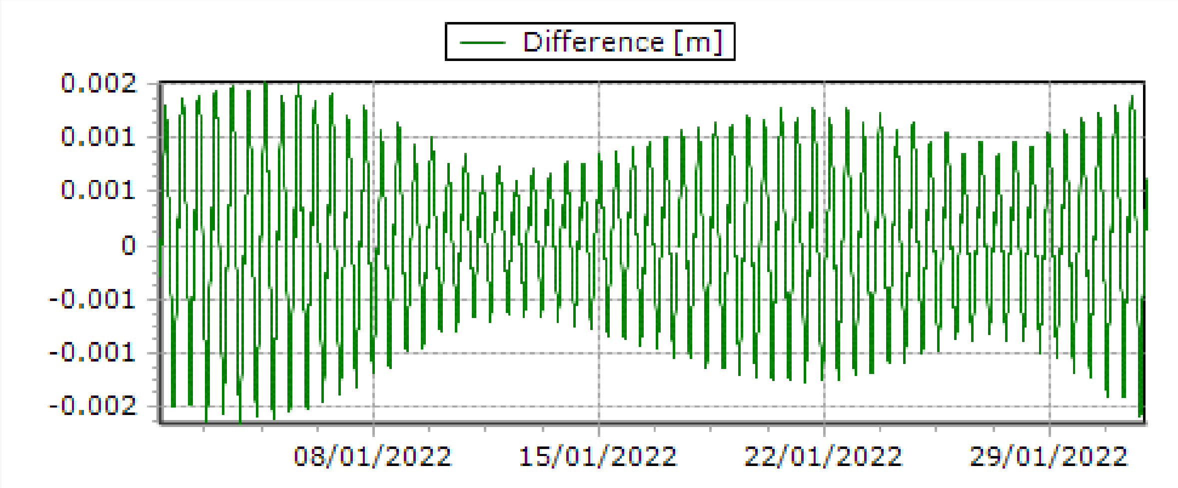


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 4: Surface ele...	Point 4: Surface ele...	Difference
	Item Unit	[m]	[m]	[m]
	Minimum	0.3644	0.3642	-0.0013
	Maximum	3.2572	3.2574	0.0016
	Average	1.8668	1.8666	0.0001
	Std. deviation	0.6883	0.6884	0.0007

Time Series Plots

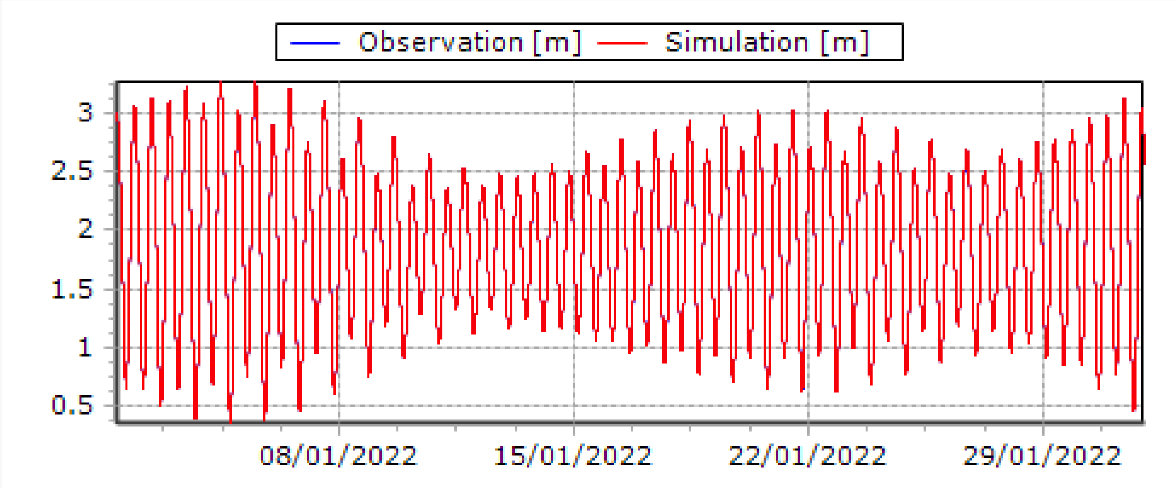


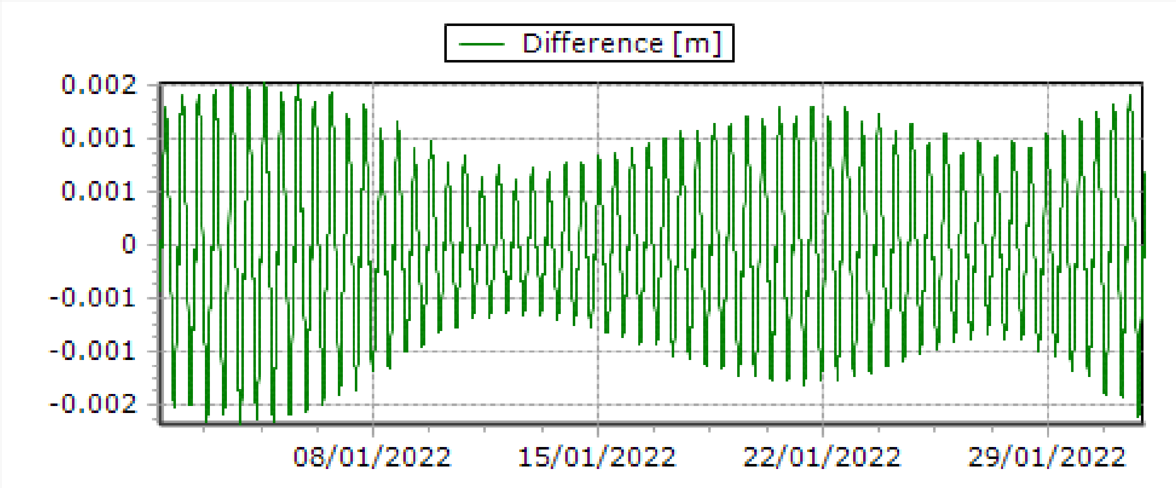


Statistics

	Observation	Simulation	Difference
Item Name	Point 5: Surface ele...	Point 5: Surface ele...	Difference
Item Unit	[m]	[m]	[m]
Minimum	0.3642	0.3641	-0.0017
Maximum	3.2576	3.2578	0.0015
Average	1.8668	1.8667	0.0000
Std. deviation	0.6884	0.6886	0.0007

Time Series Plots

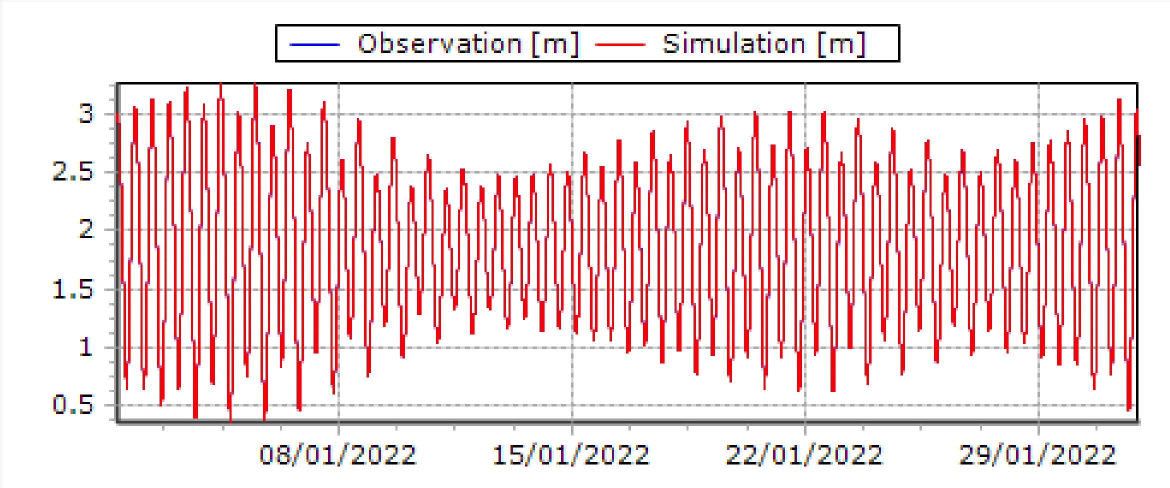


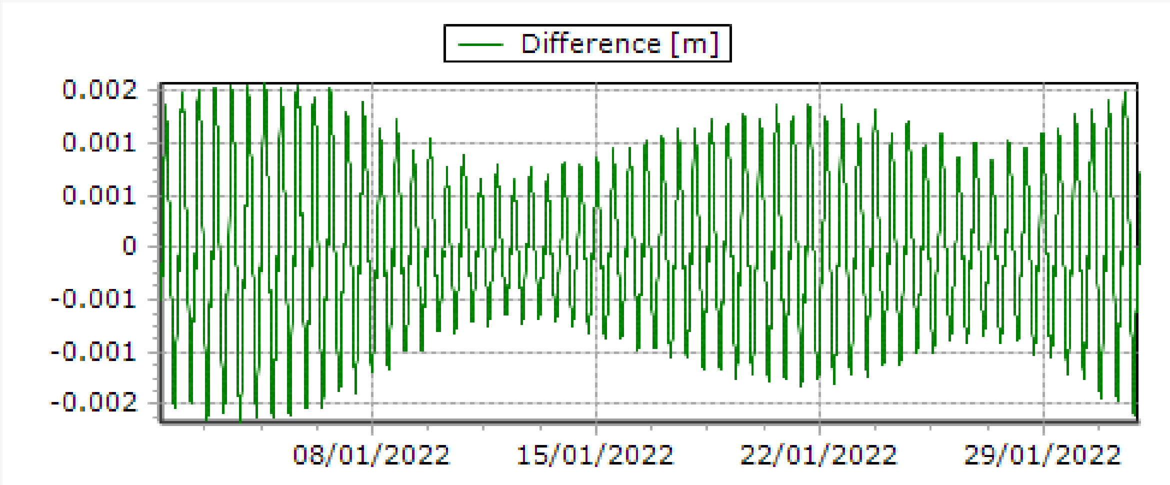


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 6: Surface ele...	Point 6: Surface ele...	Difference
	Item Unit	[m]	[m]	[m]
	Minimum	0.3640	0.3638	-0.0017
	Maximum	3.2579	3.2584	0.0015
	Average	1.8668	1.8668	0.0000
	Std. deviation	0.6885	0.6888	0.0008

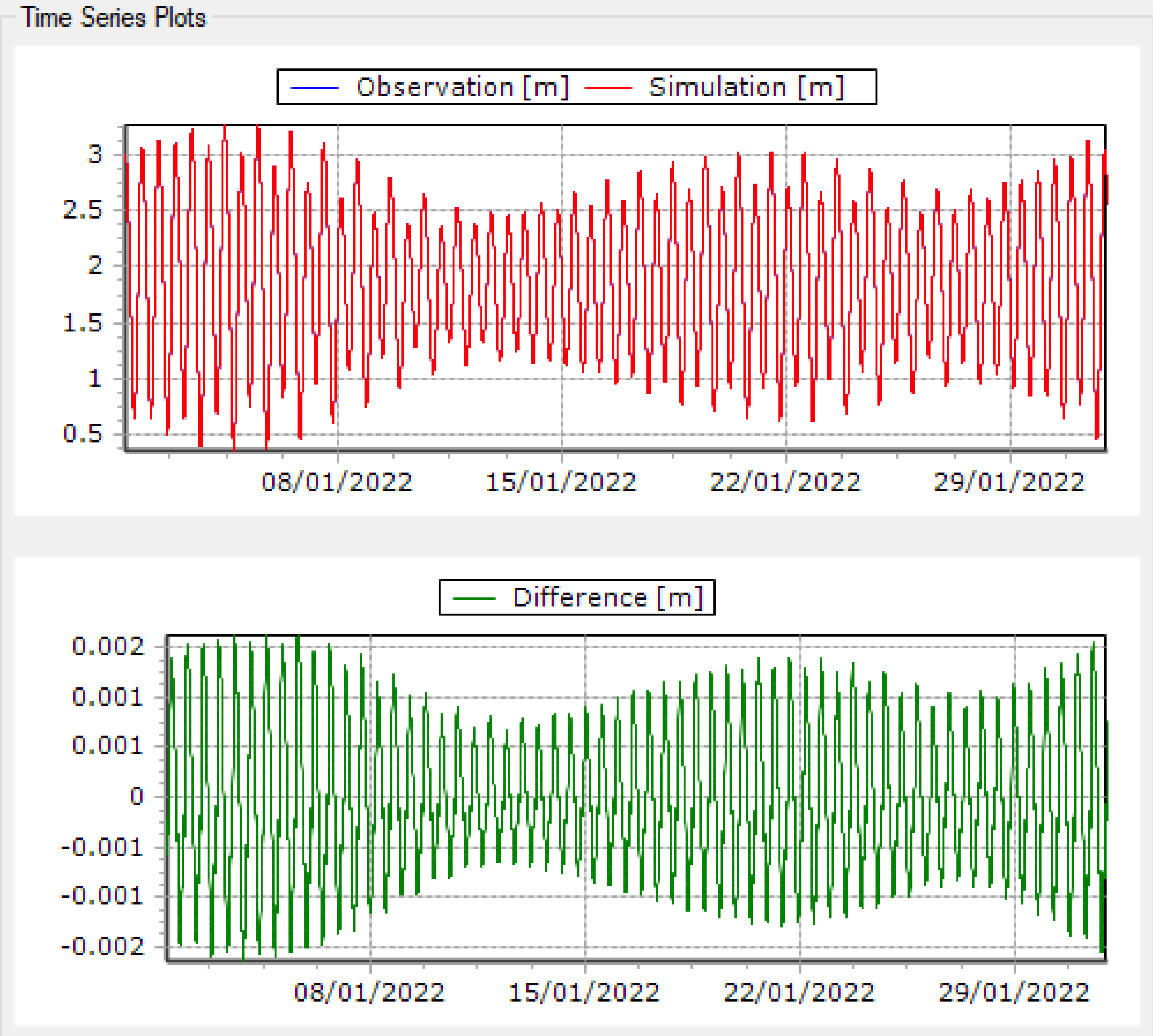
Time Series Plots





Statistics

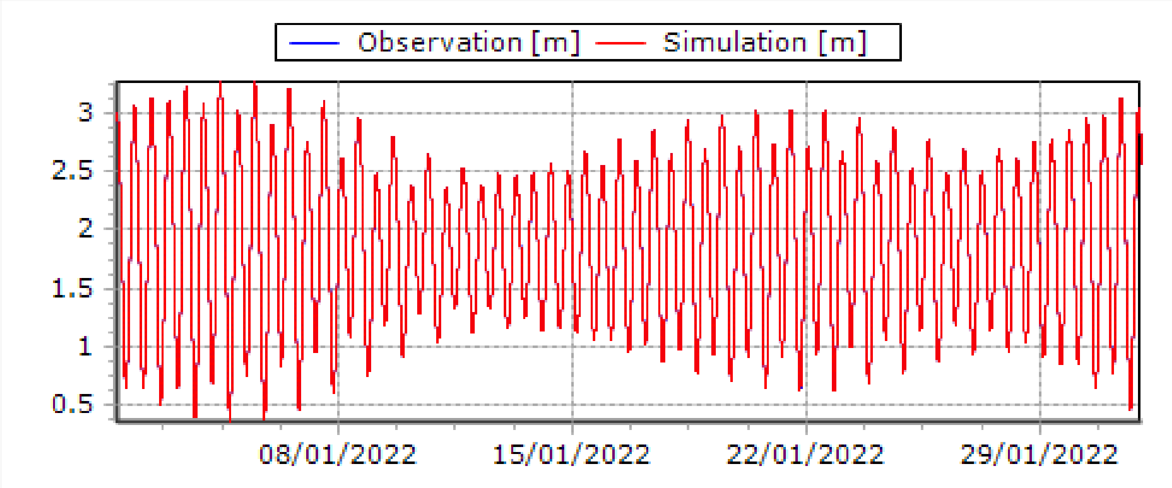
	Observation	Simulation	Difference
Item Name	Point 7: Surface ele...	Point 7: Surface ele...	Difference
Item Unit	[m]	[m]	[m]
Minimum	0.3640	0.3638	-0.0017
Maximum	3.2579	3.2584	0.0016
Average	1.8668	1.8668	0.0000
Std. deviation	0.6885	0.6888	0.0008

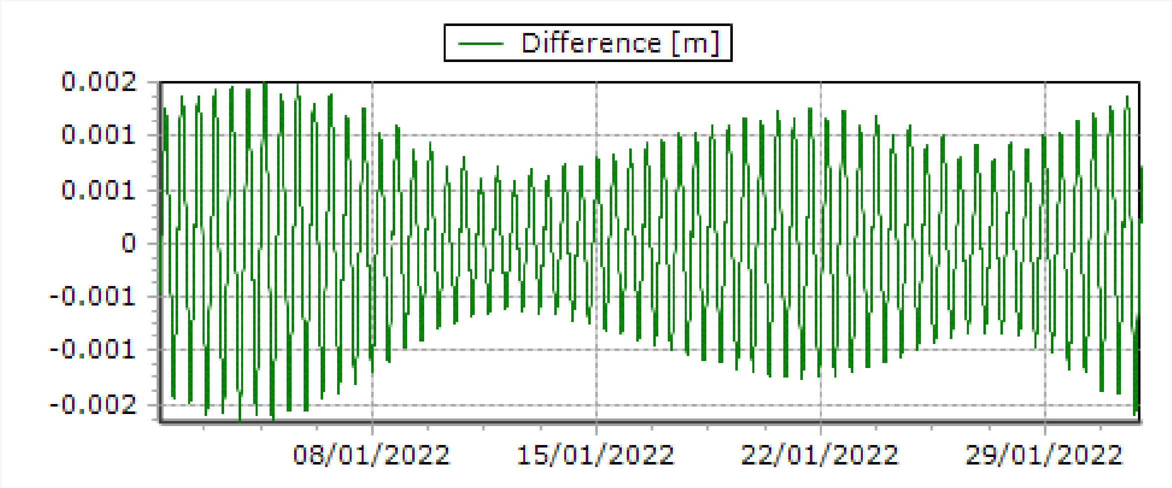


Statistics

	Observation	Simulation	Difference
Item Name	Point 8: Surface ele...	Point 8: Surface ele...	Difference
Item Unit	[m]	[m]	[m]
Minimum	0.3640	0.3638	-0.0016
Maximum	3.2579	3.2586	0.0016
Average	1.8668	1.8668	0.0000
Std. deviation	0.6885	0.6888	0.0008

Time Series Plots

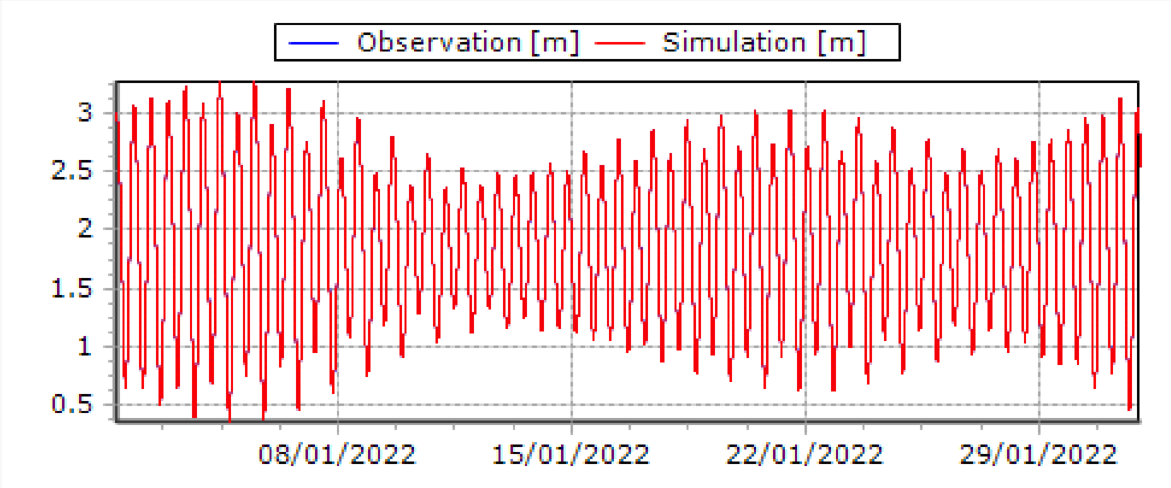


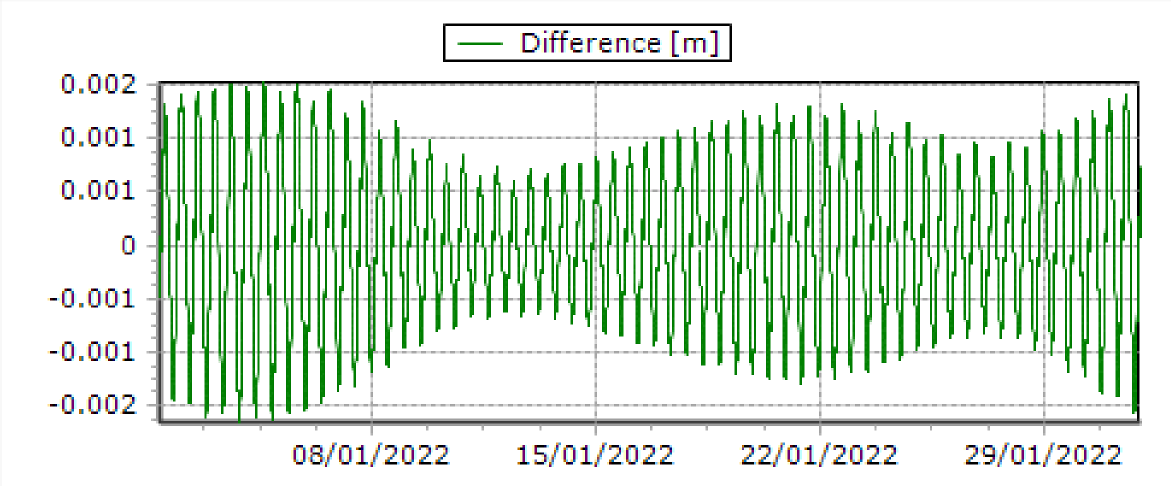


Statistics

	Observation	Simulation	Difference
Item Name	Point 9: Surface ele...	Point 9: Surface ele...	Difference
Item Unit	[m]	[m]	[m]
Minimum	0.3645	0.3643	-0.0017
Maximum	3.2567	3.2571	0.0015
Average	1.8665	1.8665	0.0000
Std. deviation	0.6883	0.6885	0.0007

Time Series Plots

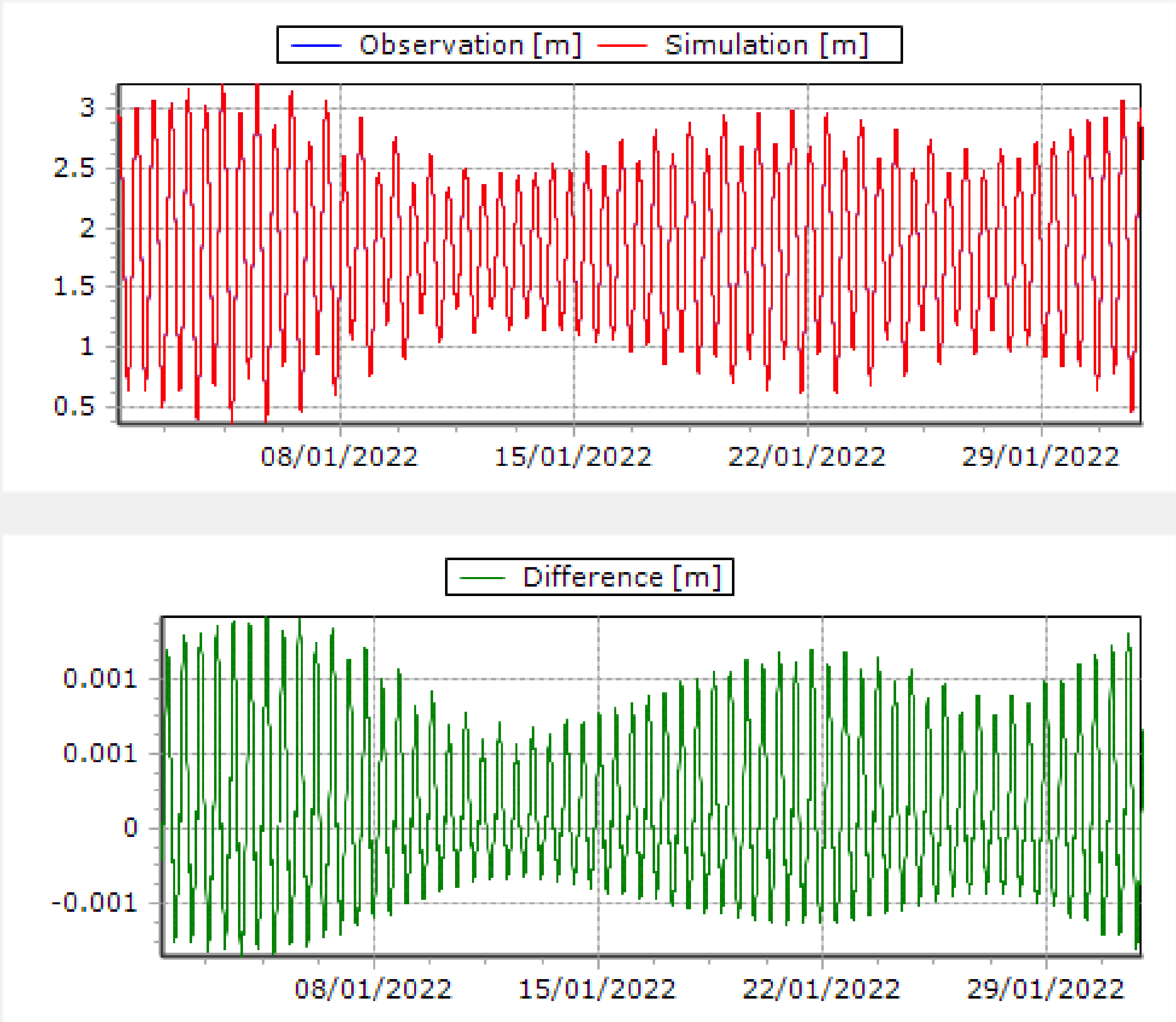




Statistics

	Observation	Simulation	Difference
Item Name	Point 10: Surface el...	Point 10: Surface el...	Difference
Item Unit	[m]	[m]	[m]
Minimum	0.3631	0.3630	-0.0017
Maximum	3.2594	3.2599	0.0015
Average	1.8669	1.8669	0.0000
Std. deviation	0.6889	0.6891	0.0007

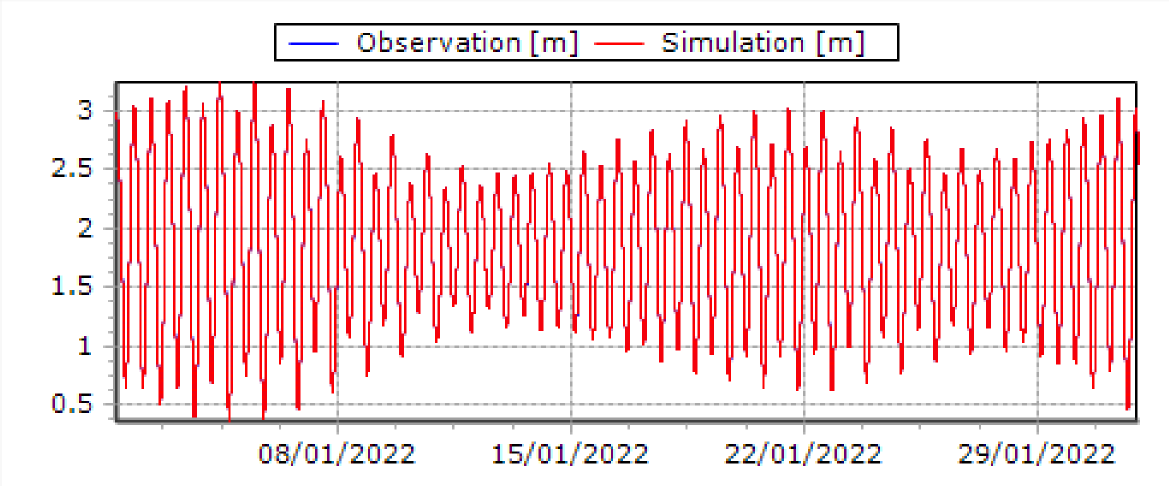
Time Series Plots

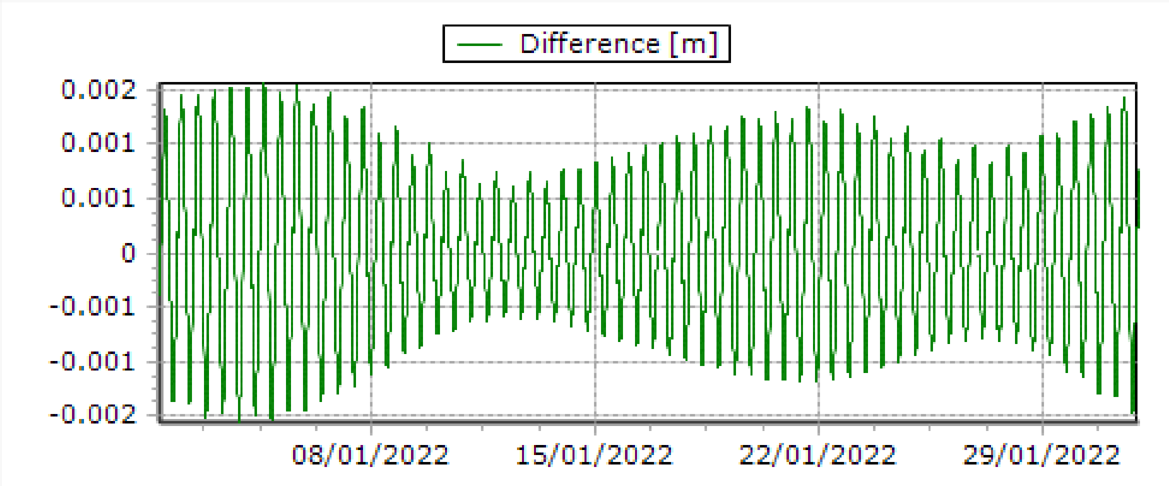


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 11: Surface el...	Point 11: Surface el...	Difference
	Item Unit	[m]	[m]	[m]
	Minimum	0.3548	0.3548	-0.0009
	Maximum	3.2110	3.2111	0.0014
	Average	1.8348	1.8347	0.0001
	Std. deviation	0.6836	0.6837	0.0005

Time Series Plots



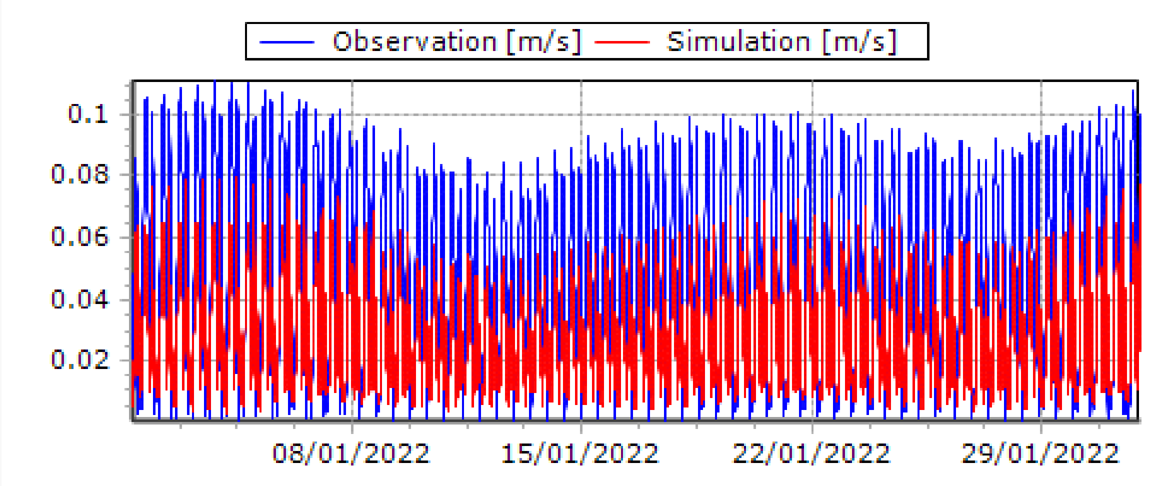


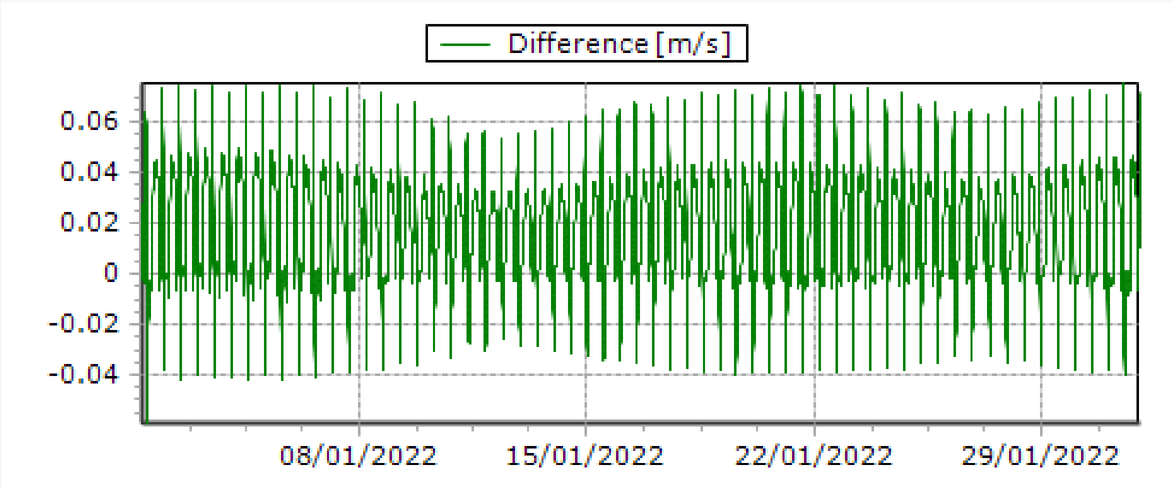
Statistics

	Observation	Simulation	Difference
Item Name	Point 12: Surface el...	Point 12: Surface el...	Difference
Item Unit	[m]	[m]	[m]
Minimum	0.3669	0.3667	-0.0016
Maximum	3.2394	3.2397	0.0016
Average	1.8583	1.8583	0.0000
Std. deviation	0.6843	0.6845	0.0007

Current Speed

Time Series Plots

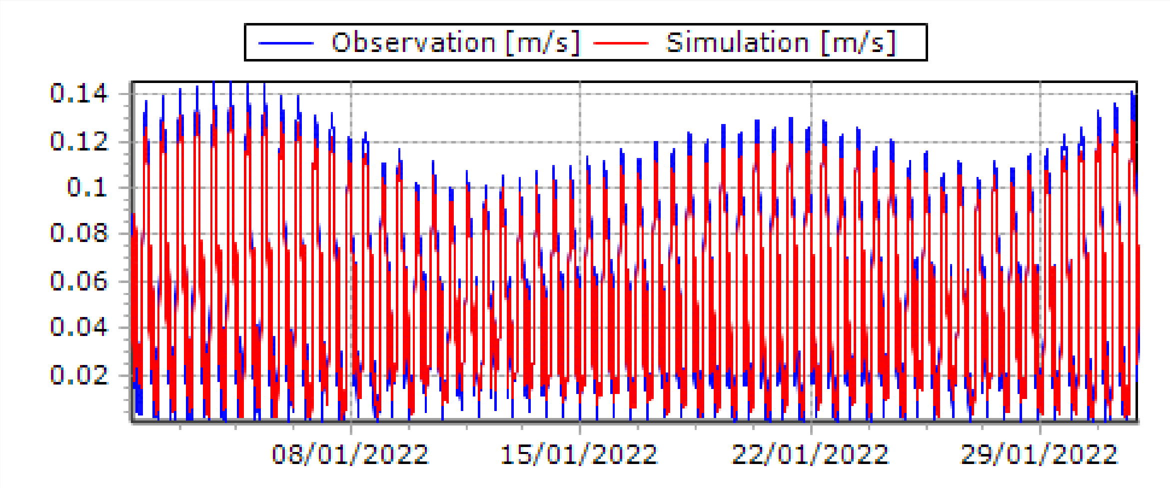


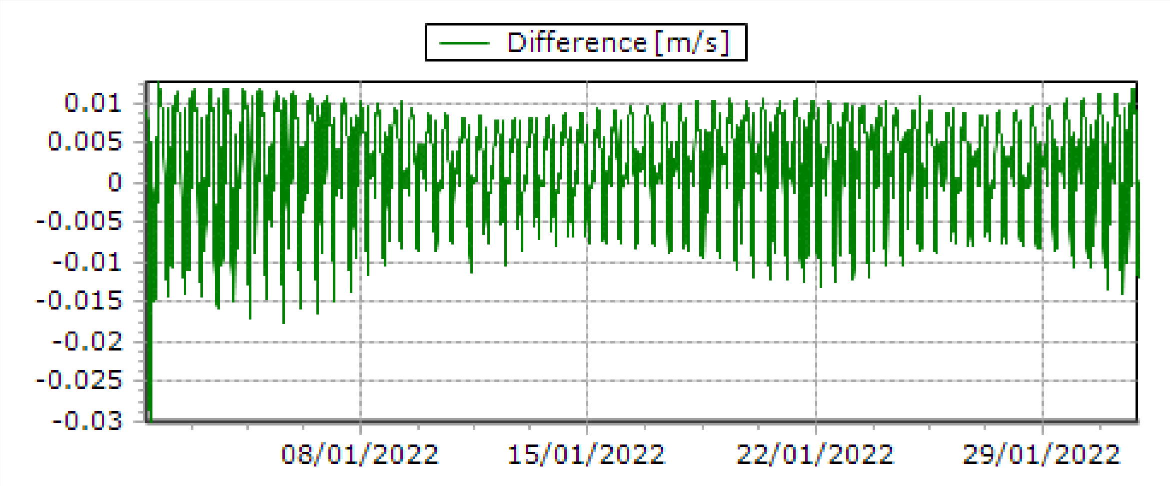


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 1: Current spe...	Point 1: Current spe...	Difference
	Item Unit	[m/s]	[m/s]	[m/s]
	Minimum	0.0007	0.0032	-0.0593
	Maximum	0.1105	0.0795	0.0754
	Average	0.0461	0.0288	0.0174
	Std. deviation	0.0322	0.0175	0.0225

Time Series Plots

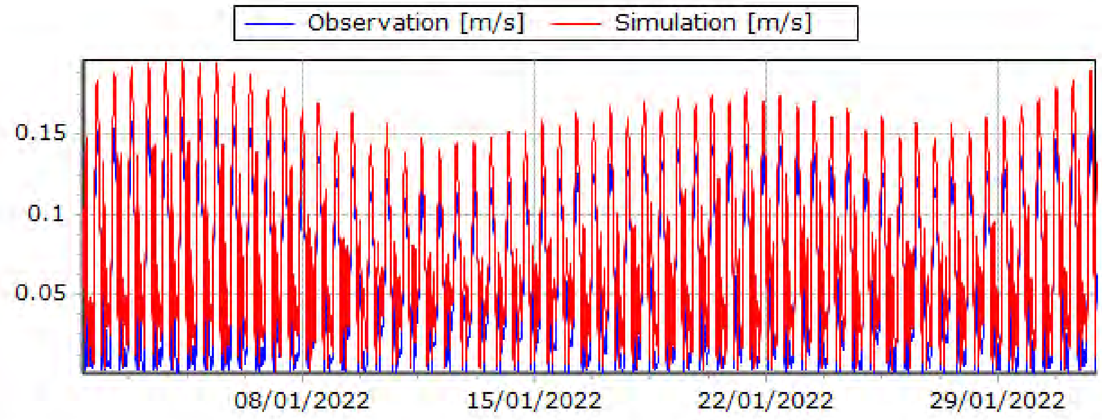


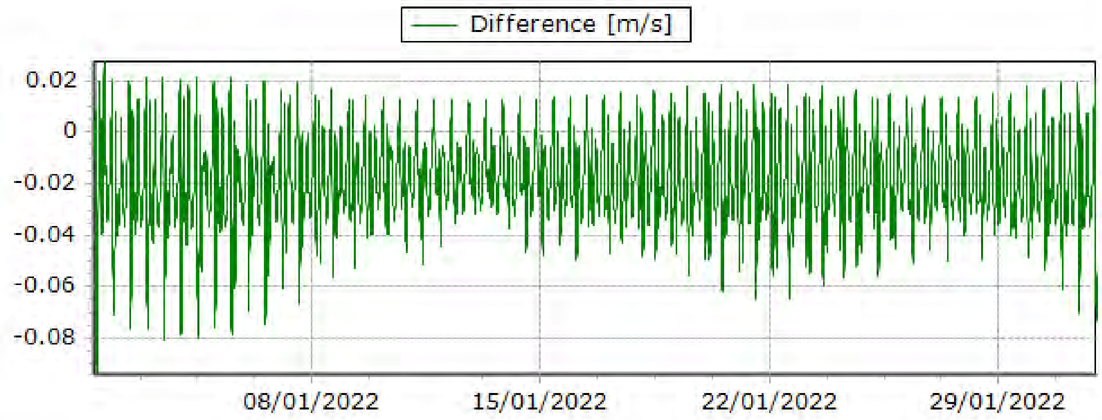


Statistics

	Observation	Simulation	Difference
Item Name	Point 2: Current spe...	Point 2: Current spe...	Difference
Item Unit	[m/s]	[m/s]	[m/s]
Minimum	0.0004	0.0019	-0.0301
Maximum	0.1452	0.1334	0.0127
Average	0.0572	0.0548	0.0024
Std. deviation	0.0411	0.0375	0.0061

Time Series Plots

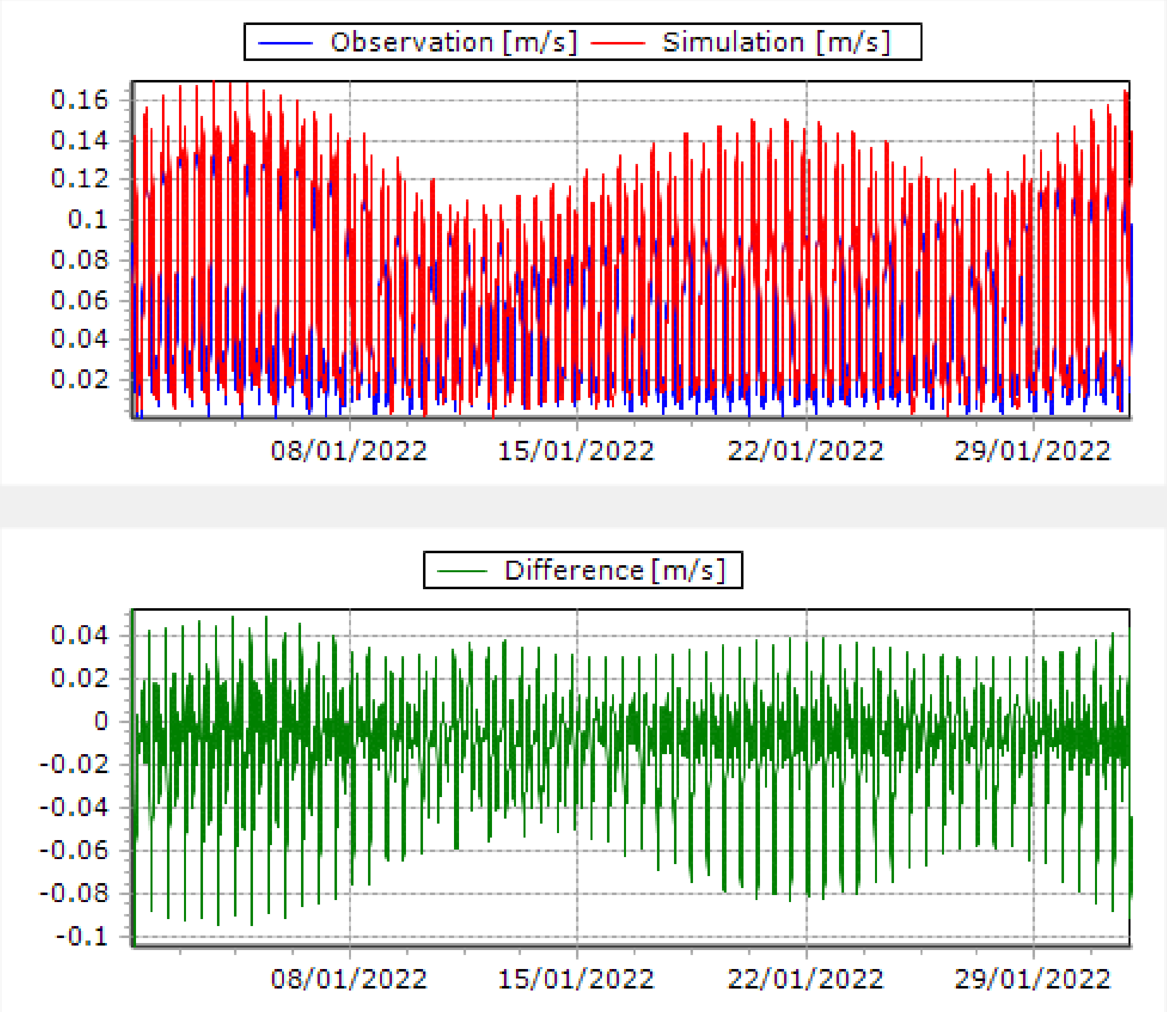




Statistics

	Observation	Simulation	Difference
Item Name	Point 3: Current speed	Point 3: Current speed	Difference
Item Unit	[m/s]	[m/s]	[m/s]
Minimum	0.0012	0.0023	-0.0941
Maximum	0.1601	0.1955	0.0275
Average	0.0595	0.0793	-0.0198
Std. deviation	0.0450	0.0500	0.0173

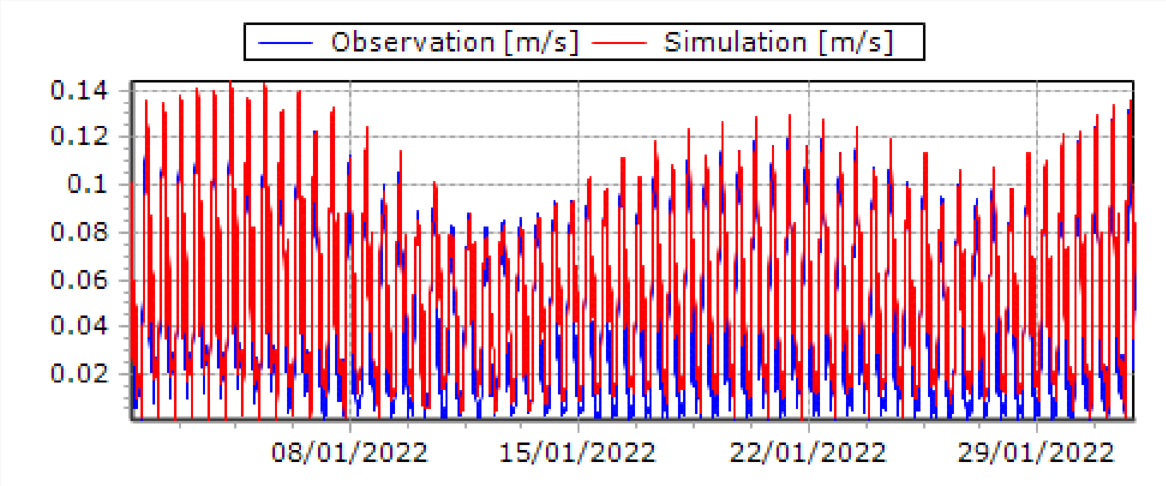
Time Series Plots

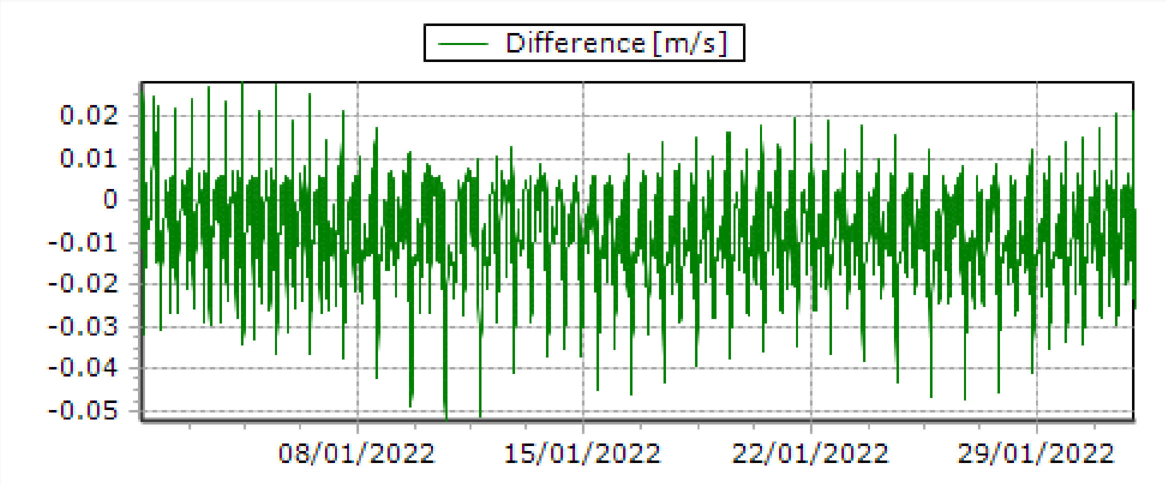


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 4: Current spe...	Point 4: Current spe...	Difference
	Item Unit	[m/s]	[m/s]	[m/s]
	Minimum	0.0012	0.0014	-0.1042
	Maximum	0.1484	0.1692	0.0518
	Average	0.0563	0.0665	-0.0102
	Std. deviation	0.0387	0.0440	0.0237

Time Series Plots

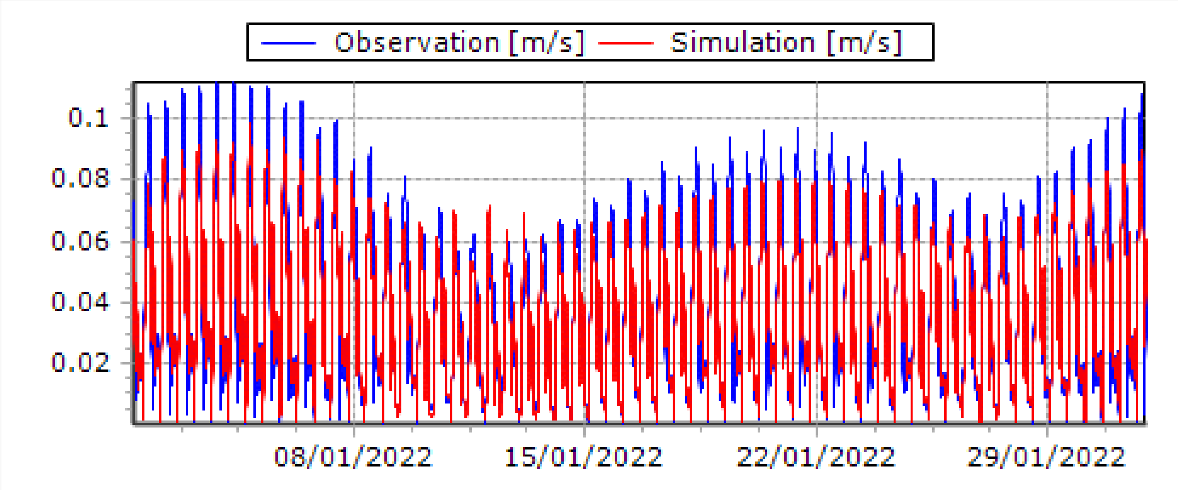


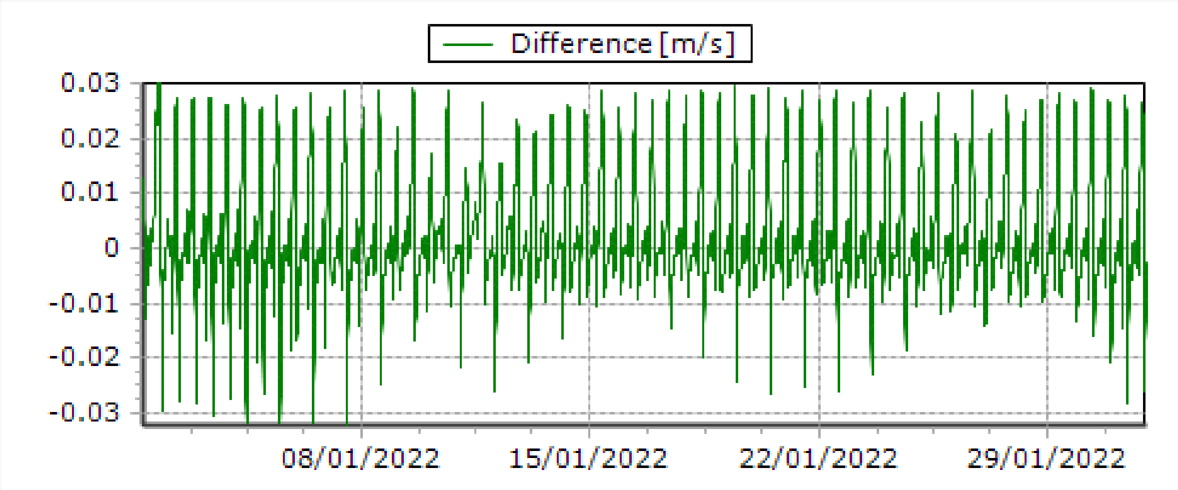


Statistics

	Observation	Simulation	Difference
Item Name	Point 5: Current spe...	Point 5: Current spe...	Difference
Item Unit	[m/s]	[m/s]	[m/s]
Minimum	0.0006	0.0007	-0.0523
Maximum	0.1376	0.1438	0.0282
Average	0.0462	0.0540	-0.0079
Std. deviation	0.0364	0.0351	0.0110

Time Series Plots

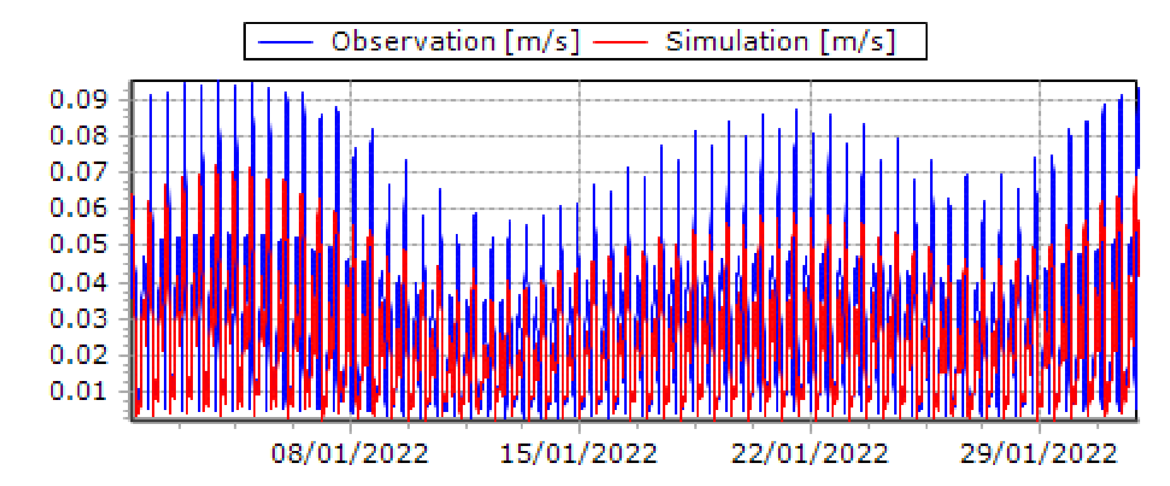


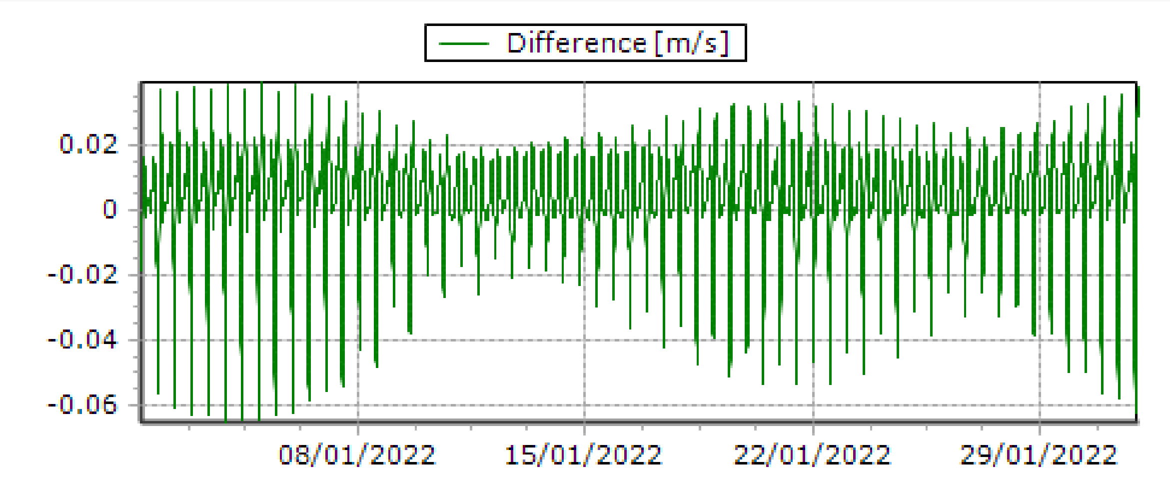


Statistics

		Observation	Simulation	Difference
▶	Item Name	Point 6: Current spe...	Point 6: Current spe...	Difference
	Item Unit	[m/s]	[m/s]	[m/s]
	Minimum	0.0003	0.0007	-0.0322
	Maximum	0.1120	0.0988	0.0300
	Average	0.0397	0.0369	0.0028
	Std. deviation	0.0277	0.0234	0.0104

Time Series Plots

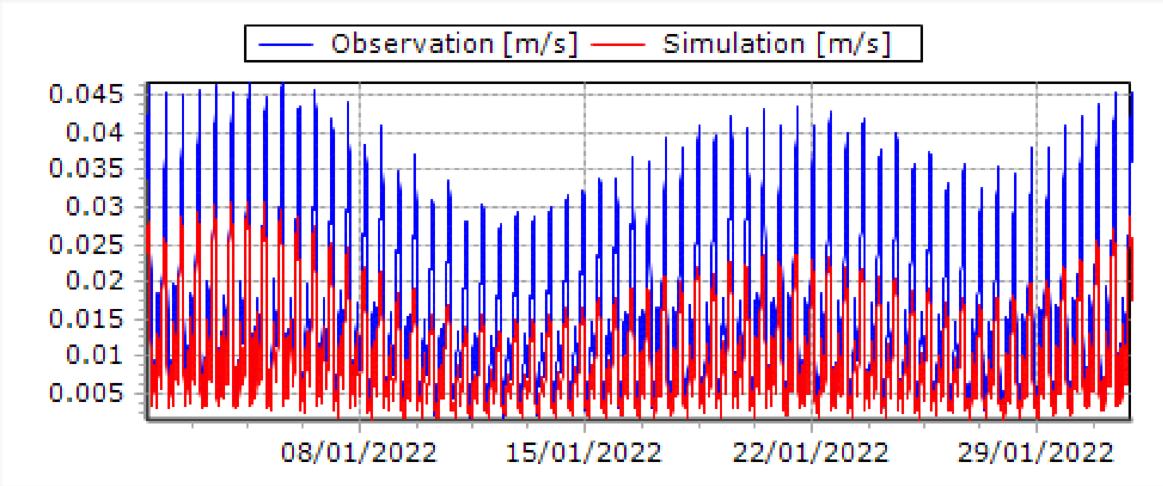


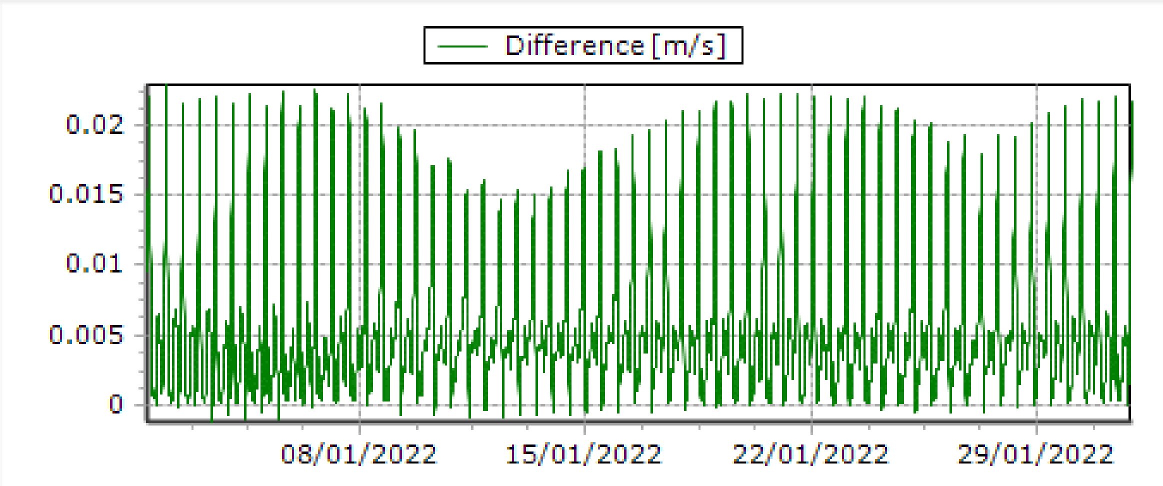


Statistics

	Observation	Simulation	Difference
Item Name	Point 7: Current spe...	Point 7: Current spe...	Difference
Item Unit	[m/s]	[m/s]	[m/s]
Minimum	0.0029	0.0024	-0.0649
Maximum	0.0950	0.0720	0.0393
Average	0.0287	0.0251	0.0036
Std. deviation	0.0206	0.0160	0.0165

Time Series Plots

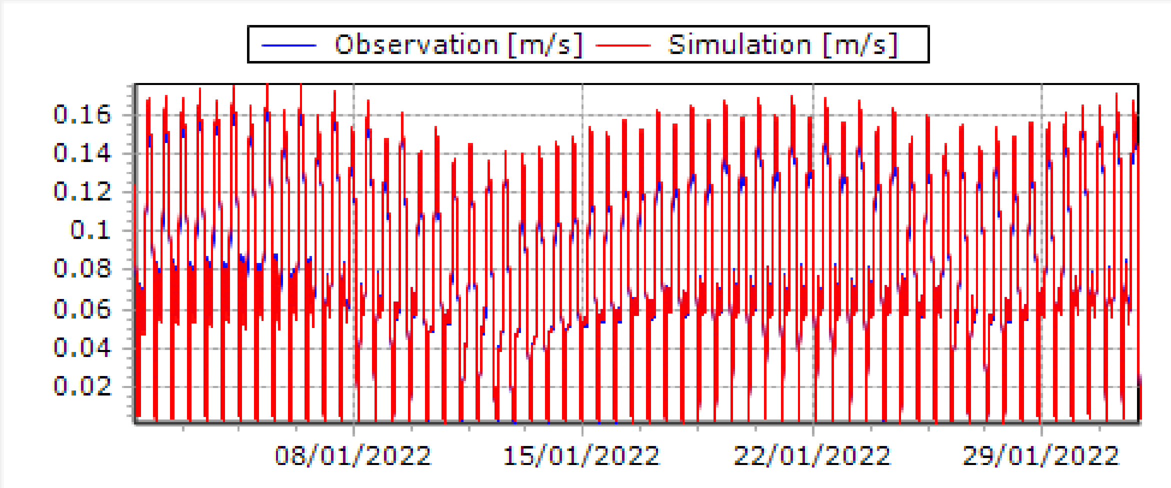


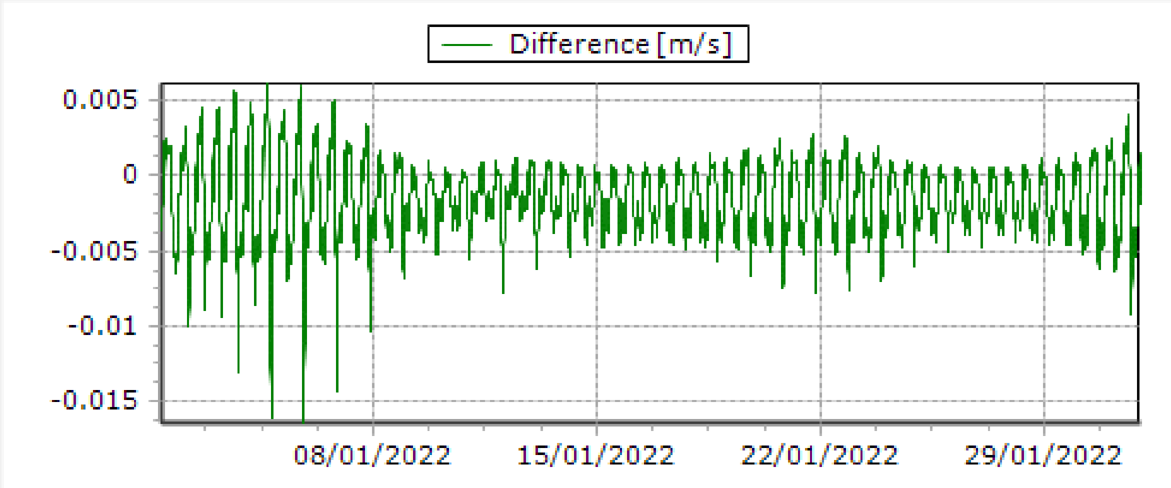


Statistics

	Observation	Simulation	Difference
Item Name	Point 8: Current spe...	Point 8: Current spe...	Difference
Item Unit	[m/s]	[m/s]	[m/s]
Minimum	0.0018	0.0015	-0.0012
Maximum	0.0467	0.0307	0.0228
Average	0.0157	0.0102	0.0055
Std. deviation	0.0102	0.0065	0.0051

Time Series Plots

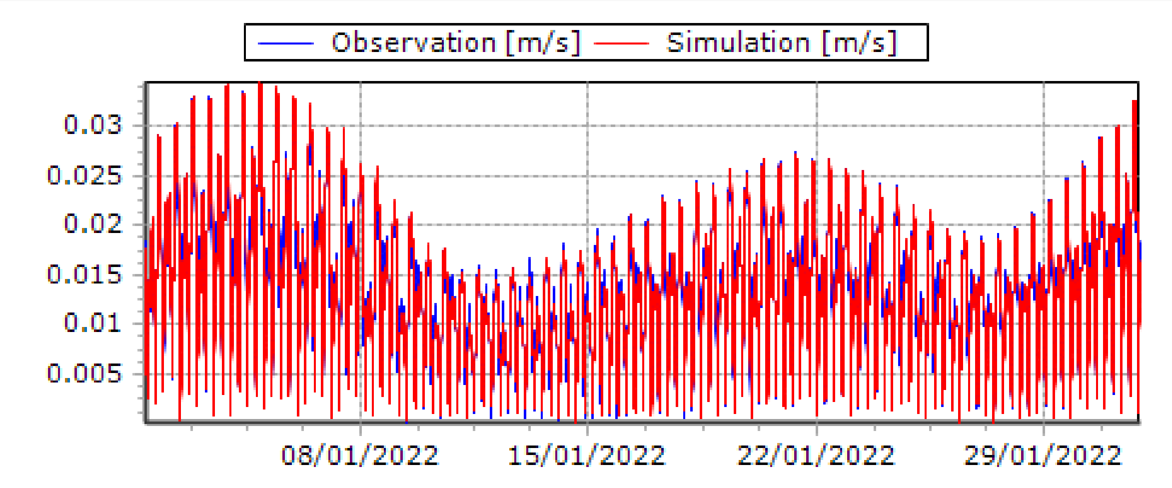


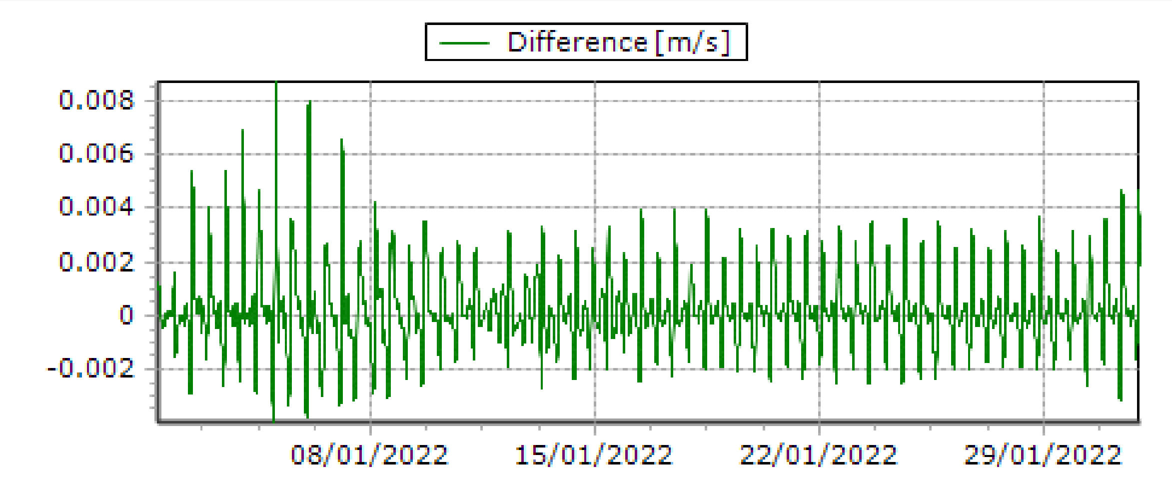


Statistics

	Observation	Simulation	Difference
Item Name	Point 9: Current spe...	Point 9: Current spe...	Difference
Item Unit	[m/s]	[m/s]	[m/s]
Minimum	0.0018	0.0015	-0.0164
Maximum	0.1714	0.1756	0.0062
Average	0.0838	0.0854	-0.0015
Std. deviation	0.0461	0.0477	0.0025

Time Series Plots

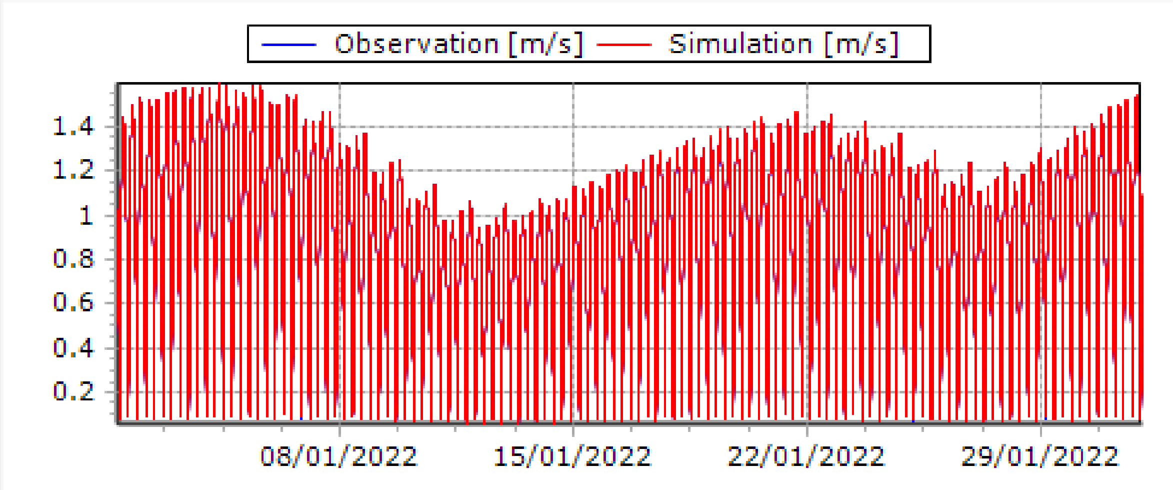


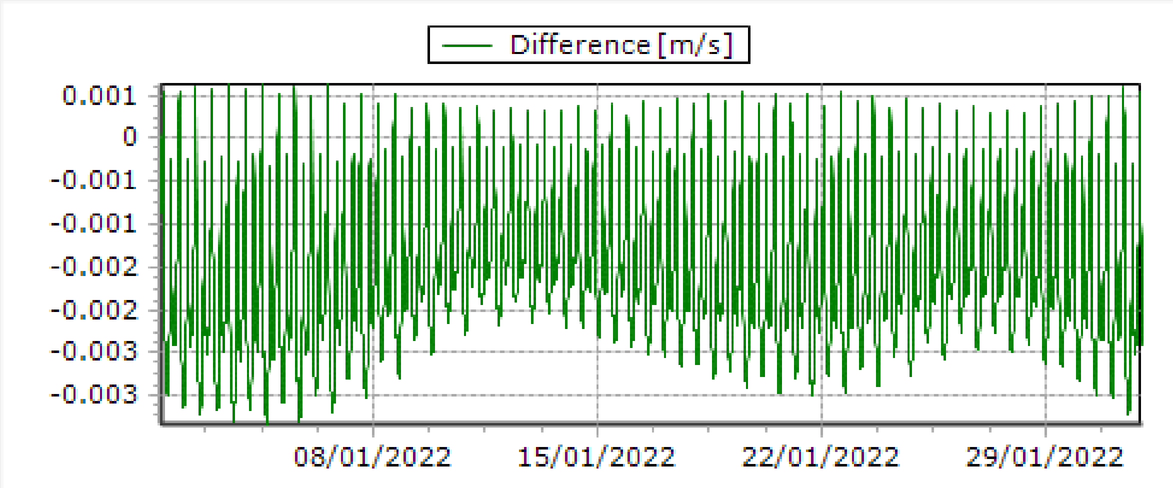


Statistics

	Observation	Simulation	Difference
Item Name	Point 10: Current sp...	Point 10: Current sp...	Difference
Item Unit	[m/s]	[m/s]	[m/s]
Minimum	0.0001	0.0001	-0.0040
Maximum	0.0340	0.0344	0.0087
Average	0.0139	0.0137	0.0002
Std. deviation	0.0068	0.0071	0.0015

Time Series Plots

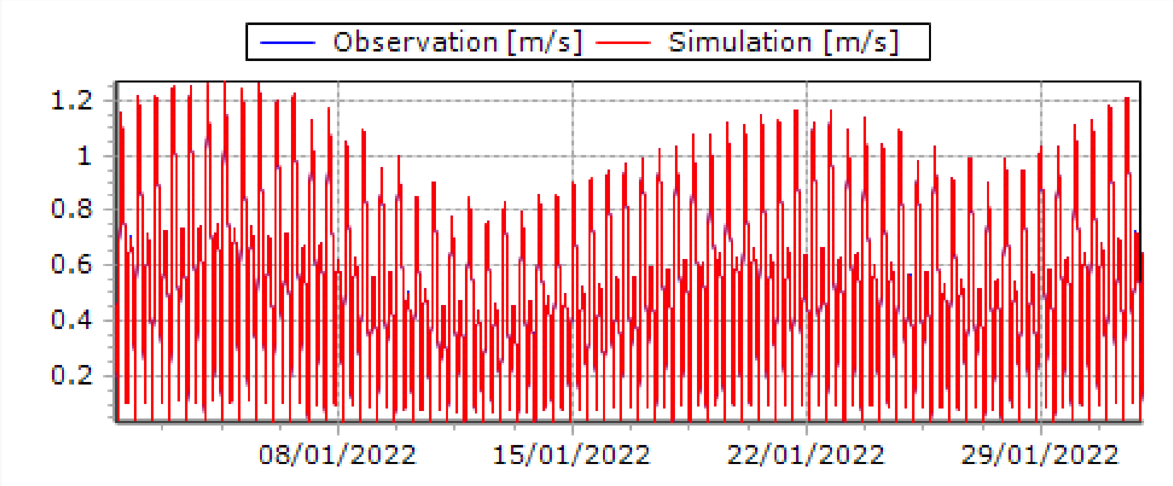


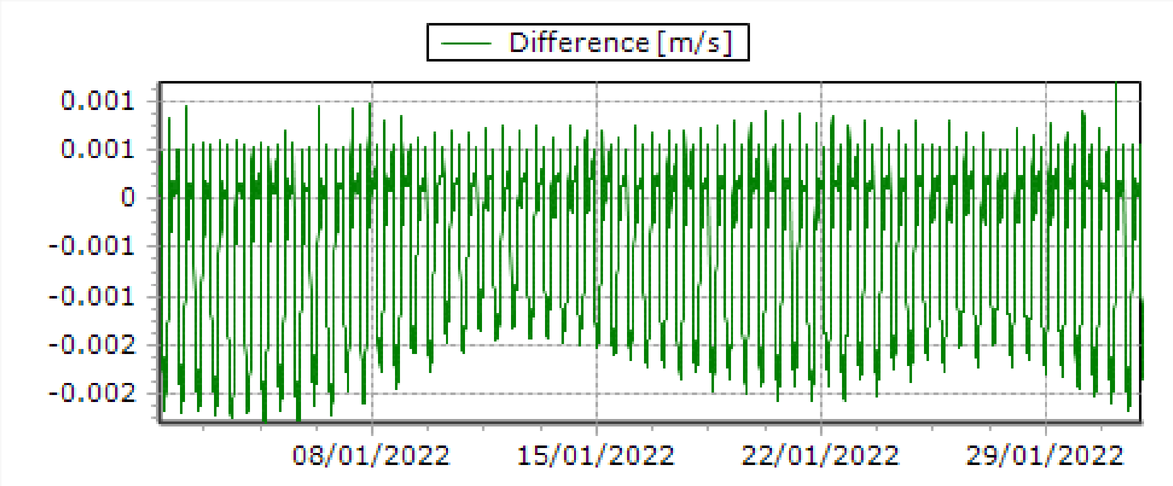


Statistics

	Observation	Simulation	Difference
Item Name	Point 11: Current sp...	Point 11: Current sp...	Difference
Item Unit	[m/s]	[m/s]	[m/s]
Minimum	0.0569	0.0569	-0.0033
Maximum	1.5945	1.5967	0.0006
Average	0.8992	0.9009	-0.0016
Std. deviation	0.3990	0.3996	0.0008

Time Series Plots



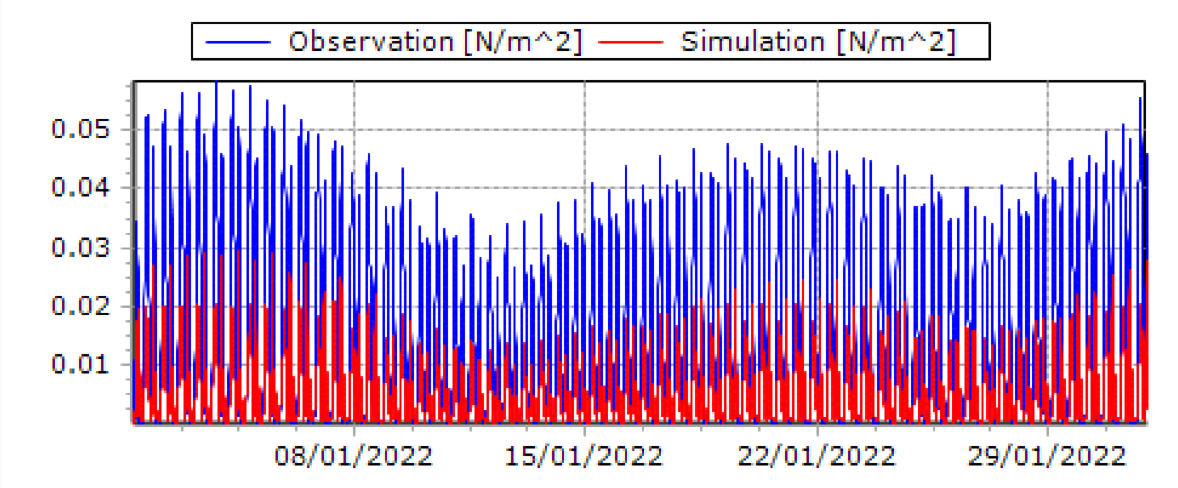


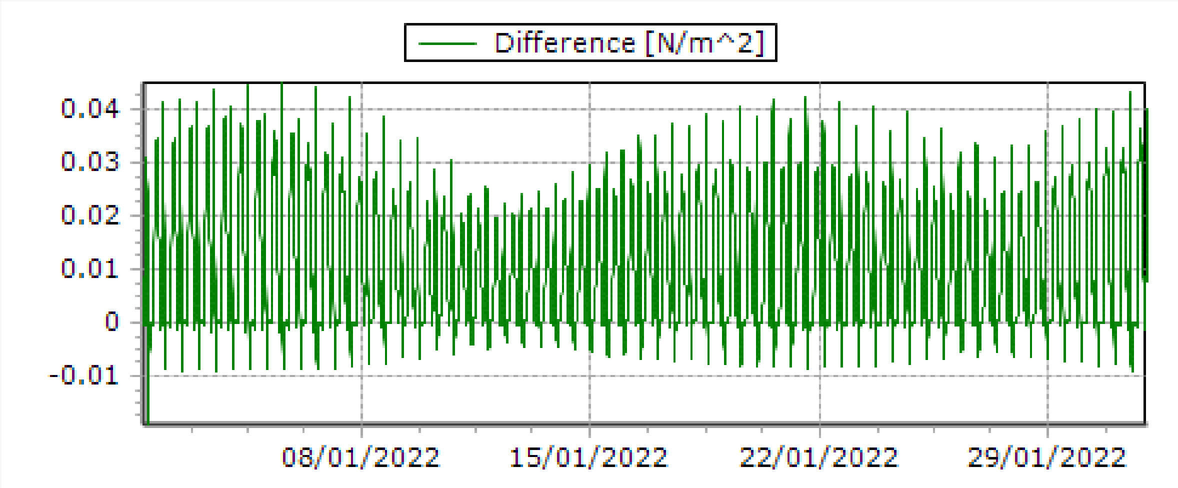
Statistics

	Observation	Simulation	Difference
Item Name	Point 12: Current sp...	Point 12: Current sp...	Difference
Item Unit	[m/s]	[m/s]	[m/s]
Minimum	0.0315	0.0316	-0.0023
Maximum	1.2656	1.2676	0.0012
Average	0.5378	0.5384	-0.0006
Std. deviation	0.2943	0.2949	0.0008

Bed Shear Stress

Time Series Plots

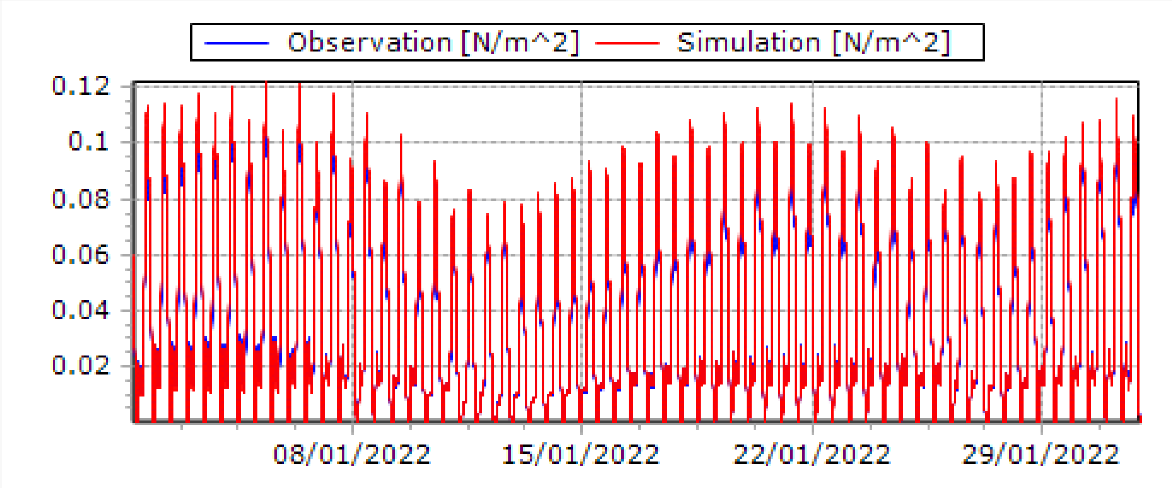


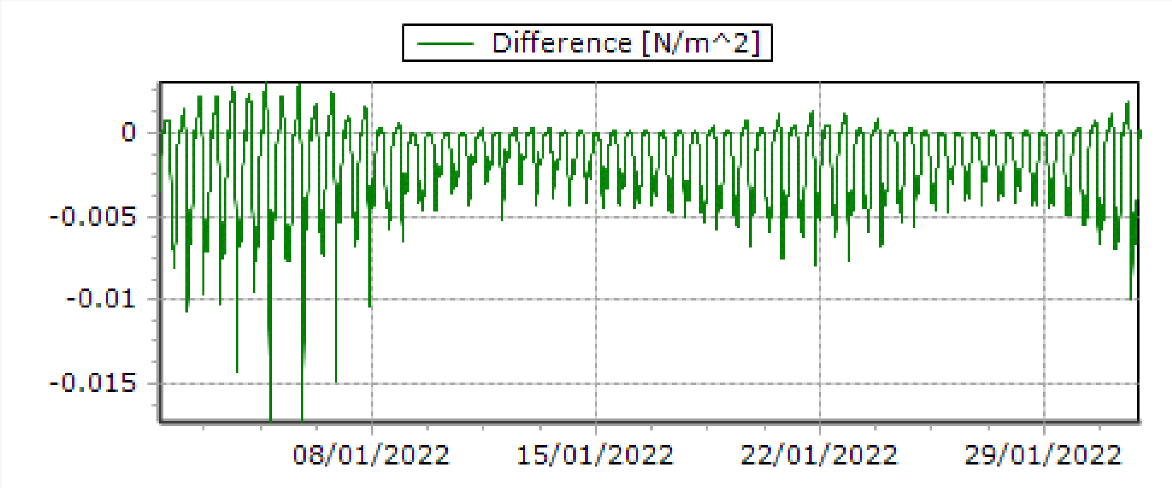


Statistics

	Observation	Simulation	Difference
Item Name	Point 1: Bed shearst...	Point 1: Bed shears...	Difference
Item Unit	[N/m^2]	[N/m^2]	[N/m^2]
Minimum	0.0000	0.0001	-0.0192
Maximum	0.0584	0.0292	0.0453
Average	0.0151	0.0054	0.0097
Std. deviation	0.0158	0.0056	0.0120

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	-0.0174
Maximum	0.1160	0.1220	0.0031
Average	0.0363	0.0380	-0.0017
Std. deviation	0.0320	0.0339	0.0024