Appendix 11: Dredge Modeling Report

Dredge Modelling Report

Aughinish Dredging

Aughinish Alumina Limited

November 2023

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1. Introduction

Malachy Walsh and Partners (MWP) were engaged by Aughinish Alumina Ltd. (AAL) for the provision of dredge plume dispersion modelling relating to a planned Dumping at Sea (DaS) permit and Marine Usage Licence application for the AAL jetty and its approaches.

This report presents the results of the numerical hydrodynamic modelling and dredge dispersion modelling that simulates the dispersion associated with proposed maintenance dredging and fate of the dredge material at the proposed dump sites and through the Lower Shannon Estuary.

The location of the dredge and dump sites are presented in **Figure 1.1.**

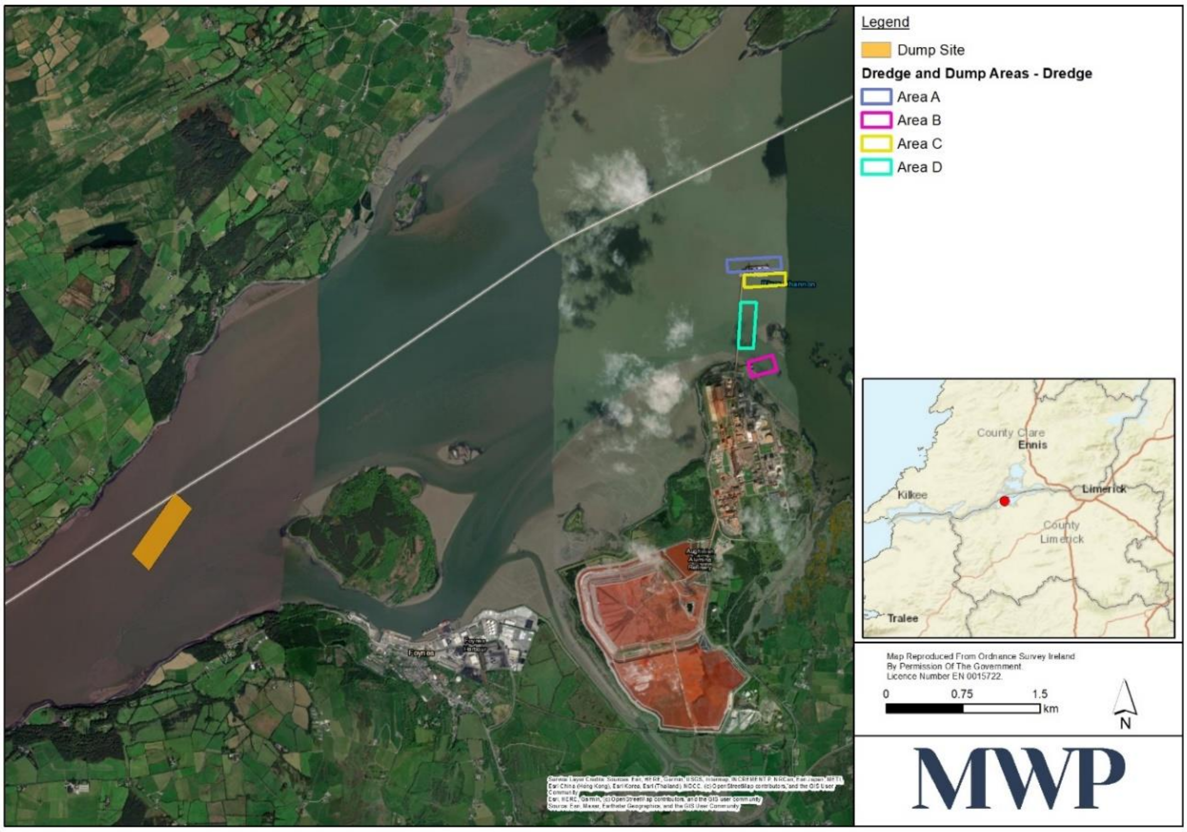

Figure 1.1 Proposed Dredge Areas and Dump Sites

2. Proposed Dredging Operations

2.1 Dredge Locations

As part of the 8- year dredge maintenance programme, The proposed dredging operations include 4 distinct locations, labelled A, B, C and D, **Figure 2.1**. that contain sediments suitable for dumping at sea. These sites are: A) outer berth of the main Jetty, B) an intertidal area (the cells), C) The inner berth of the main jetty and D) the approach arm.

2.2 Dump site

The proposed dump site is located off Foynes Island in the Shannon Estuary (see orange solid box in **Figure 2.1**. This is a dump site that the SFPC are already permitted to dump at (EPA DaS permit Nr. S0009-03). It is planned that a proportion of the dredge production in dredge areas A and C will be dumped here.

As each of the 4 dredge areas (A-D) will be potentially ploughed over the 8-year cycle, they can all be considered dump sites as well.

2.3 Dredge and Dump Methodology

The following methodological assumptions were used to inform the development of the modelling scenarios.

There will be 3 primary methods of dredging proposed over the 4 sites:

- Trailer Suction Hopper Dredger (TSHD)
- Long-arm Reach Excavator on a barge (LR/B)
- Plough Dredger.

Depending on access and tidal restrictions each area will undergo dredging by a combination of the three methods above.

The TSHD will operate on a 24hr basis and will be utilised in Area A (Outer berth) and Area C (inner berth). The TSHD dredge production rate is dependent on the individual vessel but for the purposes of this study a rate of 1500T/load was included in the assessment (Campaign 1) and separately a larger 3000T/load(Campaign 3) to capture a range of commercial dredge vessels suitable for such an project.

The TSHD travel time from the dredge site to the dumpsite is estimated at 1.5hrs including a sail under load time to dump site of 30 minutes, a dump time of 15 minute, a return sail empty time of 30 minutes and restationing time of 15 minutes. It is acknowledged this is an estimate and true travel time requires specific vessel speed which will vary as will ebb and flood currents to and from the dump site. However for the purposes of modelling this estimate is considered conservative. It is also noted that plough dredging is occurring during the TSHD travel time to and from the dump site.

The plough production rate is estimated at 100T/load. These figures are based on previous dredge campaigns undertaken at the proposed dredge locations. The LR/B is estimated at 200T/load.

All three dredge methods have associated sediment losses at the point of dredging termed the spillage rate. This spillage creates a plume due to the dispersion of suspended sediments which requires assessment. The rate of spillage varies from dredge methodology which is dealt with in Section 3.

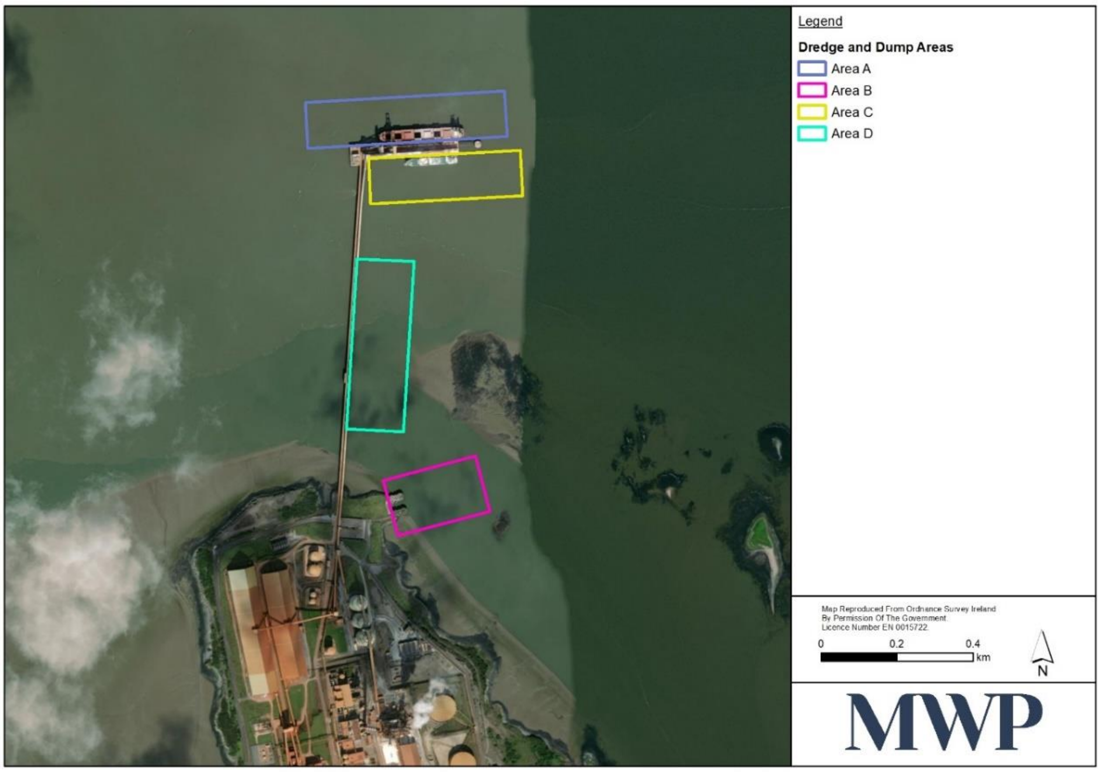

Figure 2.1 Proposed Dredge Areas

2.4 Representative Dredge Campaigns

Standard practise in determining the impact on the hydro and benthic environment due to multi annual dredge programmes requires that a series of dredge scenarios be developed, simulated and assessed. To adequately capture the variability of dredge and dumping operations year on year of the proposed programme at AAL, 3 campaigns were required. These campaigns represent the likely worst case scenarios in terms of dredge quantities, locations, sequencing and the combination of dredge methodologies as advised by AAL. In developing these campaigns, a conservative approach was taken to ensure the greatest potential impact in any one campaign is accounted for.

2.4.1 Campaign 1

Campaign 1 is based on a 21-day campaign outlined in Table 1. This included the use of a 1500 T/load TSHD which commences in area A and dredges continuously for 10 days. The Plough dredging alternates between the outer berth (A) (when the TSHD is under steam to the dump site) and the tidally restricted Area B (Cells), thereafter moving to the Area D (the approach arm). LR/B to occur at Area C from Day 9 onwards.

Table 1 Dredge Sections and Quantities Campaign 1

Area	Gross (t)	Dump Method	Period

A	45962	TSHD, Plough	TSHD for first 10 days Plough first 9 day intermittently
B	2520	Plough & LR/B	first 10 days intermittent
C	0		
D	1600	LR/B & Plough	From day 5 onwards
TOTAL	**64462**		

2.4.2 Campaign 2

Campaign 2 is also a 21-day campaign (see **Table 2**). The outer berth (Area A) is plough-dredged together with **LR/B**, while Area B (cells) is dredged in a similar method, but the **LR/B** starts at the outer berth and moves after Day 4 to the Cells (B) area. The approach arm (Area D) is then ploughed and mechanically dredged and at the end of this campaign the Inner berth Area C is ploughed. There is no TSHD used in this campaign.

Table 2 Dredge Sections and Quantities Campaign 2

Area	Gross (t)	Dump Method	Period
A	15000	Plough & LR/B	Plough first 10 days LR/B first 4 days
B	6500	Plough & LR/B	From day 4
C	5800	Plough	From day 17 onward
D	1600	LR/B & Plough	From day 5 onward
TOTAL	**4300**		

2.4.3 Campaign 3

This campaign is similar to Campaign 1 with the exception of a more intense TSHD operation (see **Table 3**). A production rate of 3000 T / load is utilised. This increases the discharge to the dump site in the first 5 days but thereafter no TSHD is simulated. It is effectively half the time (5 days) of the TSHD dredging in Campaign 1. This campaign is simulated to account for the availability of a higher production dredge being available over the course of the dredge programme.

Table 3 Dredge Sections and Quantities Campaign 3

Area	Gross (t)	Dump Method	Period
A	45962	TSHD, Plough	TSHD for first 5 days Plough first 9 days intermittent
B	2520	Plough & LR/B	First 10 days intermittent
C	0		
D	1600	LR/B & Plough	From day 5 onwards
TOTAL	**64462**		

3. Modelling

3.1 Relevant Software

In this study the MIKE21 suite of software were used, these related to River flow, tidal currents and sediment transport. To model the dredge dispersion in an estuarine environment, the hydrodynamics of the system must first be modelled and thereafter the simulation of sediment plume progression as a result of both dredging and dump operations. The model then estimates the amount of expected suspended concentration and deposition of sediment. A brief description of the capability of the software is provided below.

MIKE21 FM HD is used to model River and tidal currents and solves the vertically integrated equations for the conservation of energy, continuity and momentum, i.e. the Saint Venant equations on rectangular, flexible or curvilinear grids covering the area of interest, when provided with the bathymetry, bed resistance coefficients, wind field, hydrographic boundary conditions, etc. The HD module provides the basis for computations performed in many other modules but can also be used alone. It simulates the water level variations and flows in response to a variety of forcing functions on flood plains, in lakes, estuaries and coastal areas. Once the model has been validated, sediment transport characteristics in the model domain can be examined. The effects of sources and sinks like precipitation and evaporation, river discharge, intakes and outlets from power stations, etc. are included in the hydrodynamic equations. The impact of hydraulic structures (bridge piers or piles, weirs, etc.) on the flow conditions can also be included. A valuable facility in MIKE 21 is its capability to compute the flow in an area that sometimes floods and dries out such as tidal flats. The US Federal Emergency Management Agency (FEMA) has officially approved MIKE 21 HD for use in national flood insurance program studies (NFIS) for applications in both coastal and riverine environments.

The Mud Transport Module (MIKE21 MT). The MT module includes a state-of-the-art mud transport model that simulates the erosion, transport, settling and deposition of cohesive sediment in marine, brackish and freshwater areas. The module also takes into account fine-grained non cohesive material. The model is coupled with the Hydrodynamic solver HD to obtain forcing, the influence of waves on the erosion/ depositions patterns can also be simulated. The model includes a dynamic feedback between update of seabed and flow. The model calculates the rates of sedimentation/erosion and is mainly used to determine the impact of engineering works on a coastal system. In the case of simulating a dredge and dumping campaign, the MT module simulates dispersion of sediment factions due to the spillage associated with the dredging activity within the dredge area and the dispersal and deposition thickness due to the dumping of same such fractions at dump sites.

3.2 Hydrodynamic Model Setup

The model domain as developed for the simulation is shown in **Figure 3.1** The domain covers the entire Shannon Estuary from Western coastline of Kilbaha in Co. Clare, eastwards as far as north of Kings Island in Limerick. The domain is converted to a mesh with variable density. It increases in density from the western boundary towards the area of interest.

At areas of high dynamic flux, a local increase in mesh density is utilised to provide model stability. A high-density mesh was also implemented in the vicinity of AAL and the dump area to capture the dynamics at the sediment source locations. A quadrangular mesh is implemented further upstream in the riverine hydraulic regime toward and including Limerick City and out the eastern boundary of the domain.

The bathymetric data for the model has been extracted from a range of sources including Infomar data for the outer Estuary and digitised admiralty charts along the Shannon. The bed levels for the approaches to Limerick City was generated from bathymetry supplied by the Limerick Port Company. Hydrographic Surveys undertook high resolution bathymetry for the proposed dredge area and the licensed dump site.

3.3 Hydrodynamic Model Input Conditions

To adequately assess the impact of the proposed dredging activity it is necessary to simulate the most representative hydrodynamic conditions while also being conservative in terms of presenting the worst-case scenario impact.

Tidal boundary conditions were applied to the western extents of the domain. The tidal signal is generated utilising Mike DHI global tide model and represents the variation of water surface elevation along the boundary for an astronomic tide.

The eastern extent of the domain is forced by the River Shannon at Ardnacrusha. An analysis of the winter flows on the Shannon, **Figure 3.2**, (2009-2019) provides the following percentile flow:

- Shannon flow 25^{th} %-ile : 176.6 m^3/s
- Shannon flow 50^{th} %-ile : 301.9 m^3/s
- Shannon flow 75^{th} %-ile : 408.4 m^3/s

The model utilises the 25th percentile flow of 176.6m^3/s as an input condition as this represents the most conservative scenario in terms of bed deposition and suspended sediment diffusion. The model calibration and validation is presented in Appendix 1.

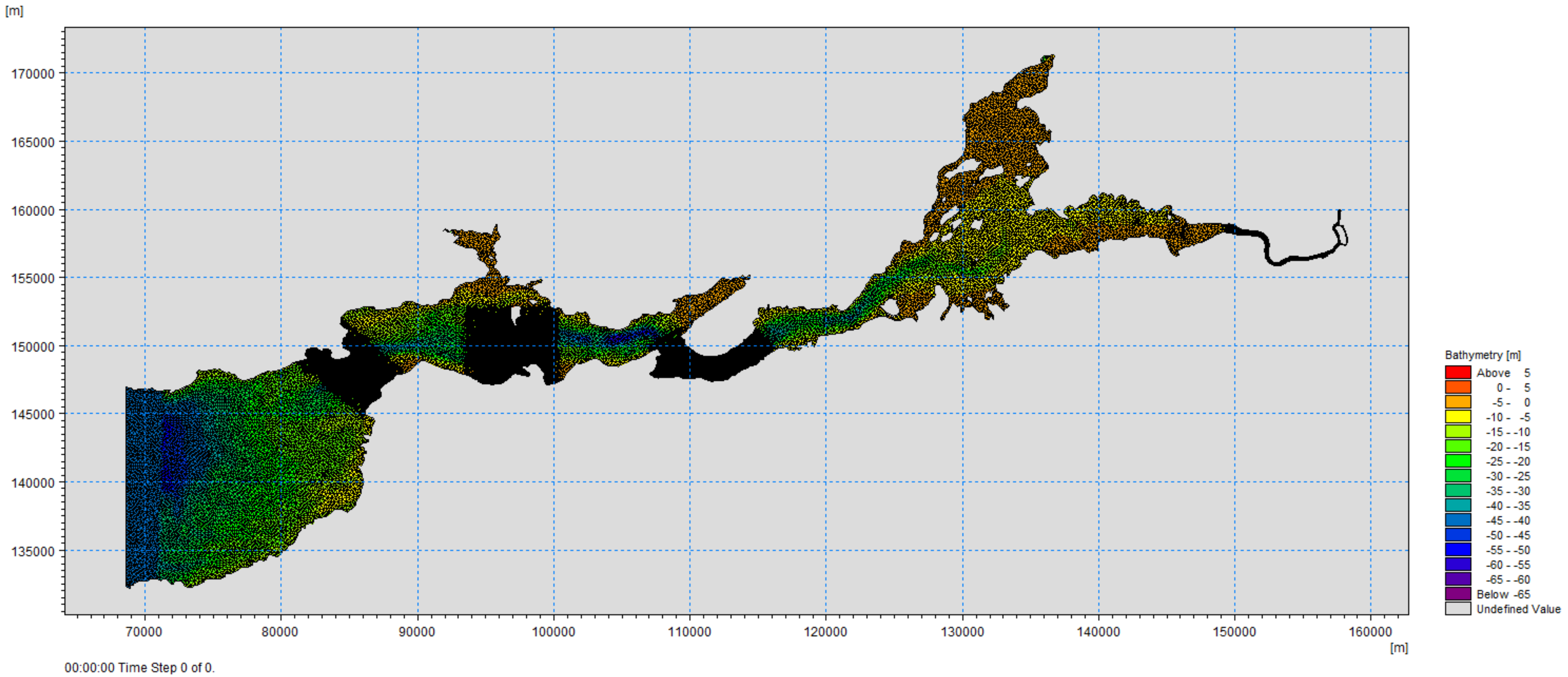

Figure 3.1 Model Domain

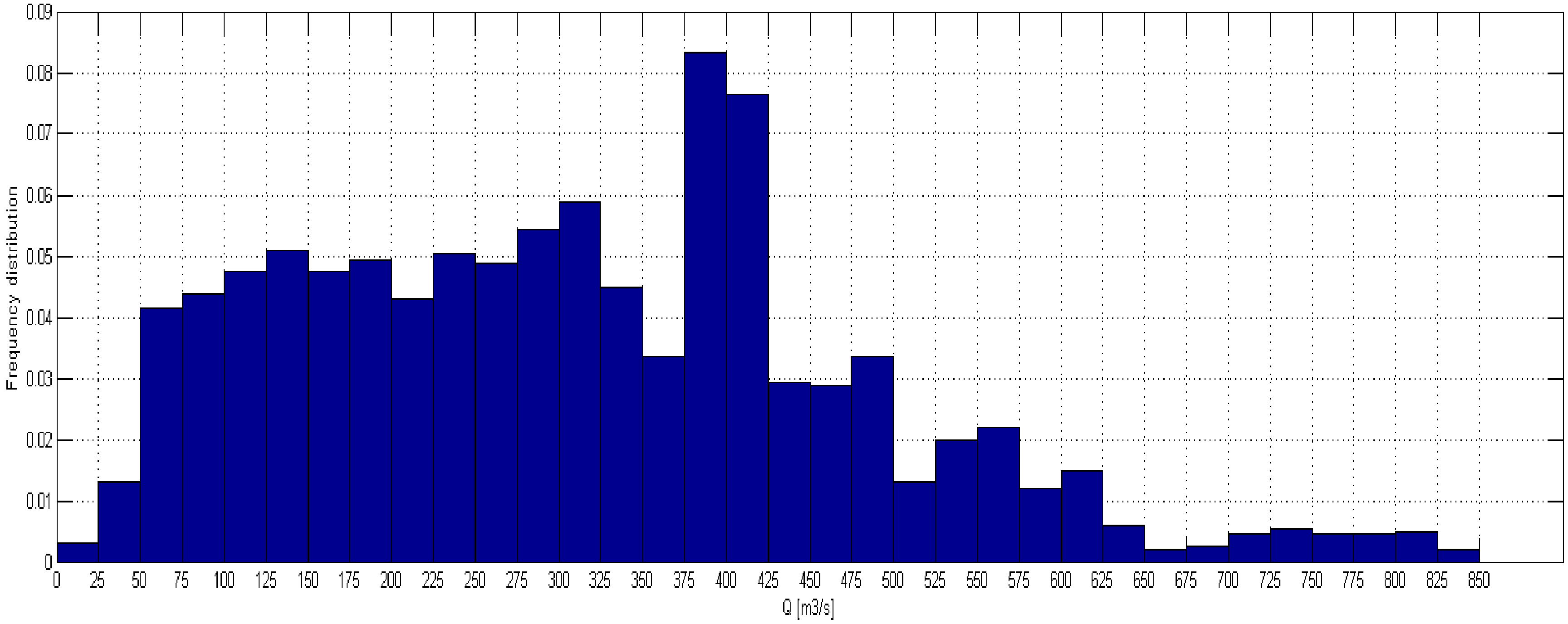

Figure 3.2 Winter Shannon Flows 2009 - 2019

3.4 Dredge Model Input Conditions

The sediment transport module is utilised for modelling both dispersion and deposition simulations.

The approach taken, based on the sediment grading, was to model two fractions: 1) fine sand and 2) silts. The percentage breakdown for each location is modelled as a contribution to the tidal discharge for each area (see **Table 4**).

Each of the methods of dredging have an associated spillage rate which was applied at the corresponding dredge locations during the dredging operation as per the dredging campaign programme **Table 4.** For plough dredging it is assumed that 100% of the dredge material is discharged into the water column. This conservative approach neglects the fact that any heavier fractions (pebbles, cobbles, etc.) will be taken by the suction dredger.

The dump rate applied to represent the emptying of the hopper barge is represented as a mass flow rate over 15 mins at the licensed dump site.

Table 4 Spill percentages

Dredge Methodology	Spillage %
TSHD	3
LR/B	5
Plough	100

The standard approach taken based on the sediment grading was to model two fractions: 1) fine sand and 2) silt. The percentage breakdown for each location is modelled as a contribution to the total discharge for each area (see **Table 5**). The dump site discharge is spilt based on the location of the original dredge material. The sediment fall velocity for each fraction is calculated based on the Stokes equation. For the fine sand component, a fall velocity of 0.0065 m/s and for the Silt of 0.0000236 m/s was utilised.

Table 5 Spill percentages (Area A - D)

Area	Fine sand	Silt
A	27.65	72.35
B	18.99	81.01
C	32.94	67.06
D	42.79	57.21

4. Dredge Simulation Results

The results of the dredge plume dispersion modelling are presented in two forms 1) suspended sediment concentration in kg/m^3, and 2) total bed thickness change from pre to post dredging and dump operations presented in mm. The contribution of both sediment fractions is combined in these plots to show the total suspended sediment concentration and total bed thickness. The three campaign scenarios are presented in the following sub sections.

4.1 Campaign 1

Campaign 1 comprises of dredging in all sections utilising plough, LR/Band a small capacity TSHD of 1500T. It represents the most likely case of dredging to occur in Year 1.

The peak deposition (Figure 4.1) occurs downstream of the dump site in particular on the south- western shore of Foynes Island and on the northern shore of the Shannon from Labasheeda to Shanahea in particular, and across the estuary on the southern shore around Loghill and Kilteery Pier. The maximum deposition of 120 mm is recorded in Foynes and the mud flat at Aillroe Beg.

The statistical maximum suspended sediment concentration (Figure 4.2), gives a worst case scenario for the entire domain. This plot shows, as expected, the peak suspended sediment concentration occurs at the dump site at approx. 0.5 kg/m^3. The is a peak of 0.7 kg/m^3 at the Dredge Area B, this is due to the extensive plough dredging at this location during Campaign 1. It should be noted that it is localised and restricted to within the dredge location as expected with plough dredging. The plume dissipates in concentration to 0.15 kg/m^3 within the immediate vicinity of the dredge site Area B.

4.2 Campaign 2

The total bed thickness is reduced in Campaign 2 compared with the other campaigns. The maximum deposition again occurs in Foynes Island south-west shore and at Aillroe beg. However, the quantum is much less than the other campaigns modelled at 60mm maximum bed thickness accruing in AillRoe beg and less that 40mm in Foynes Island.

The suspended sediment concentration is similar to the other campaigns simulated. The main peak being at dredge area C of 0.7 kg/m^3 and no visible peak concentration at the dump site. There is minor concentration increases in the Fergus Estuary around Feenish, Deer Island and Inish Tubbrid but at low levels of approx. 0.1kg /m^3.

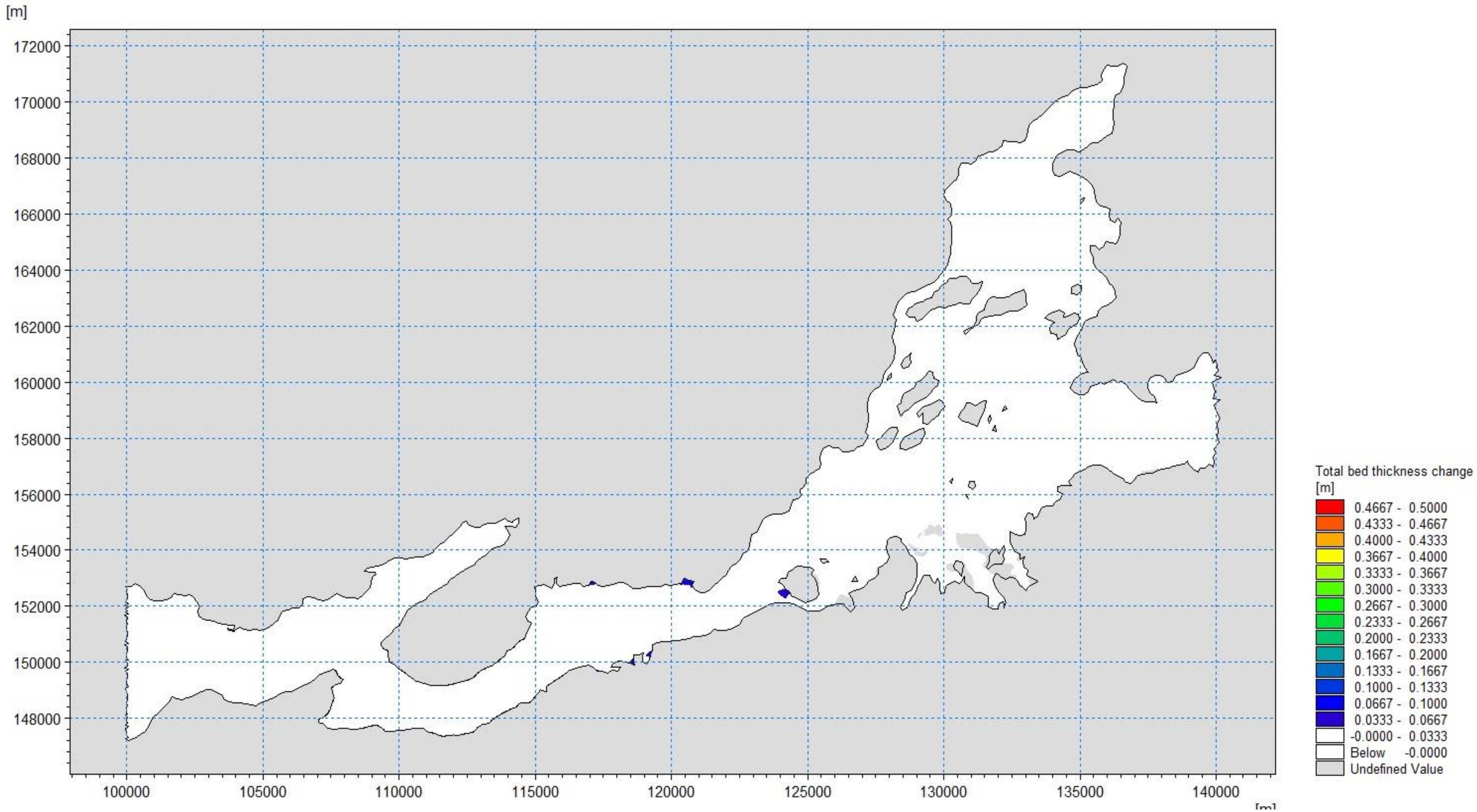

Figure 4.1 Total Bed Thickness Change Due to Scenario 1

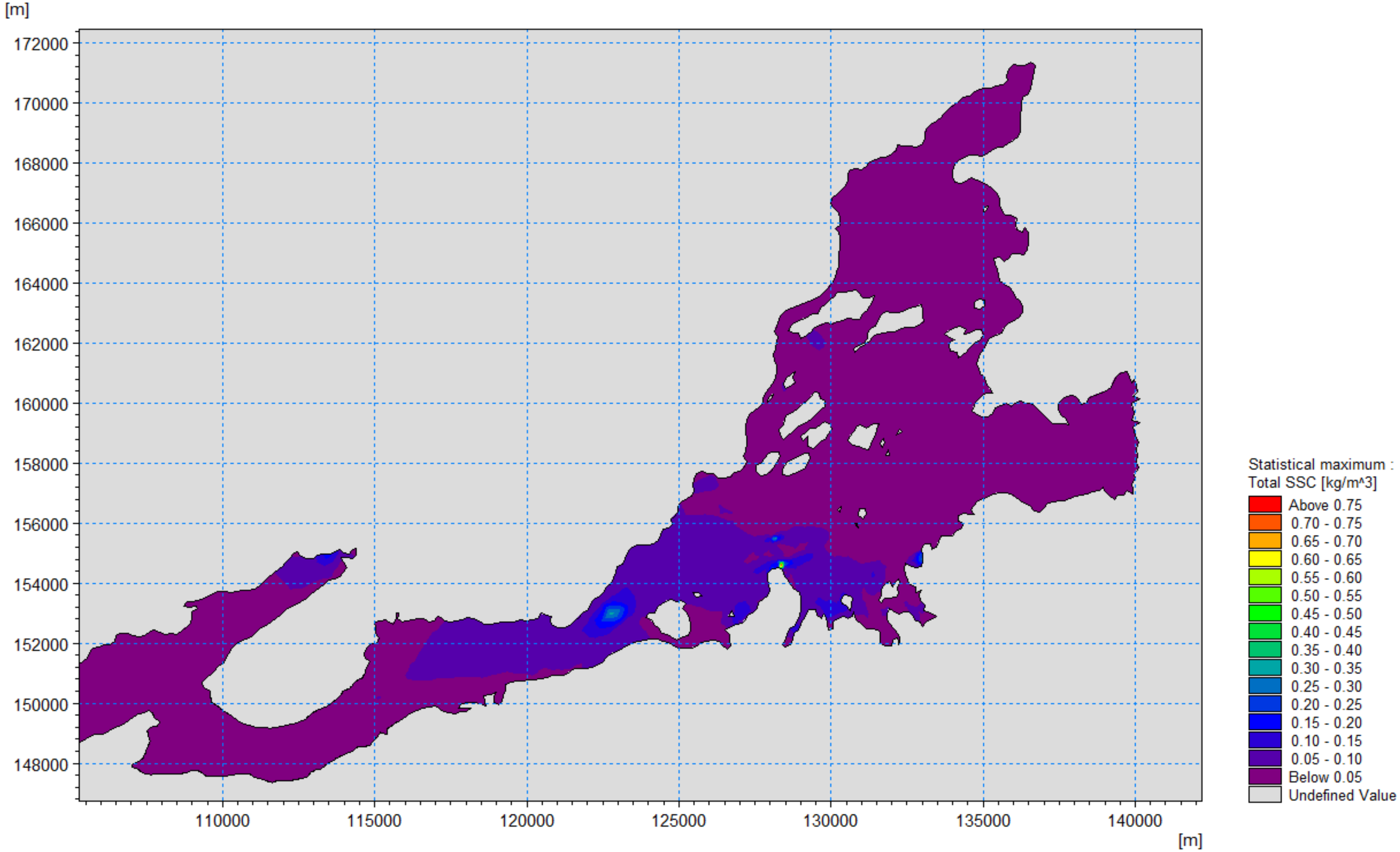

Figure 4.2 Statistical Maximum Suspended sediment concentration for all locations Campaign 1

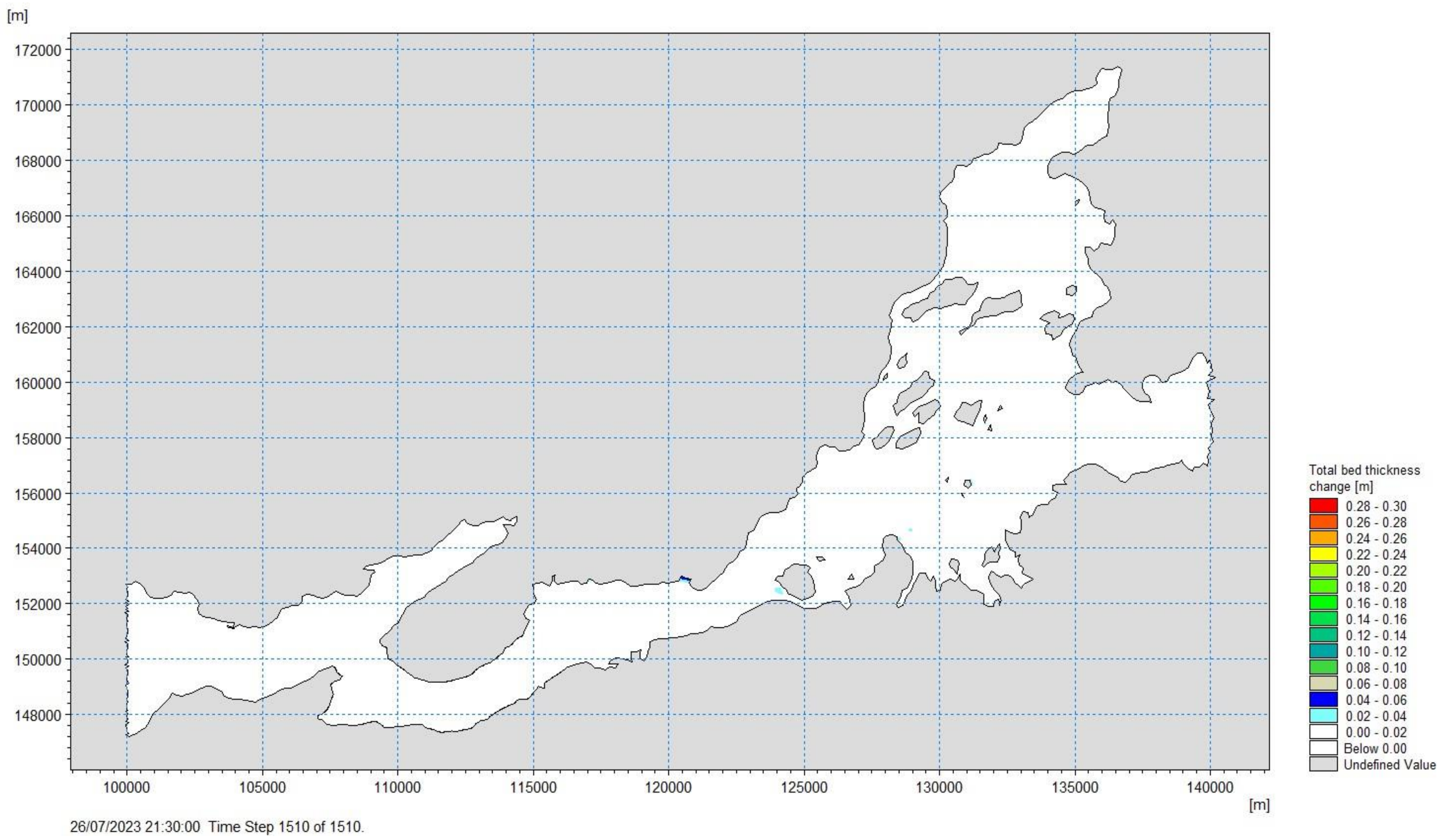

Figure 4.3 Total Bed Thickness Change Due to Scenario 2

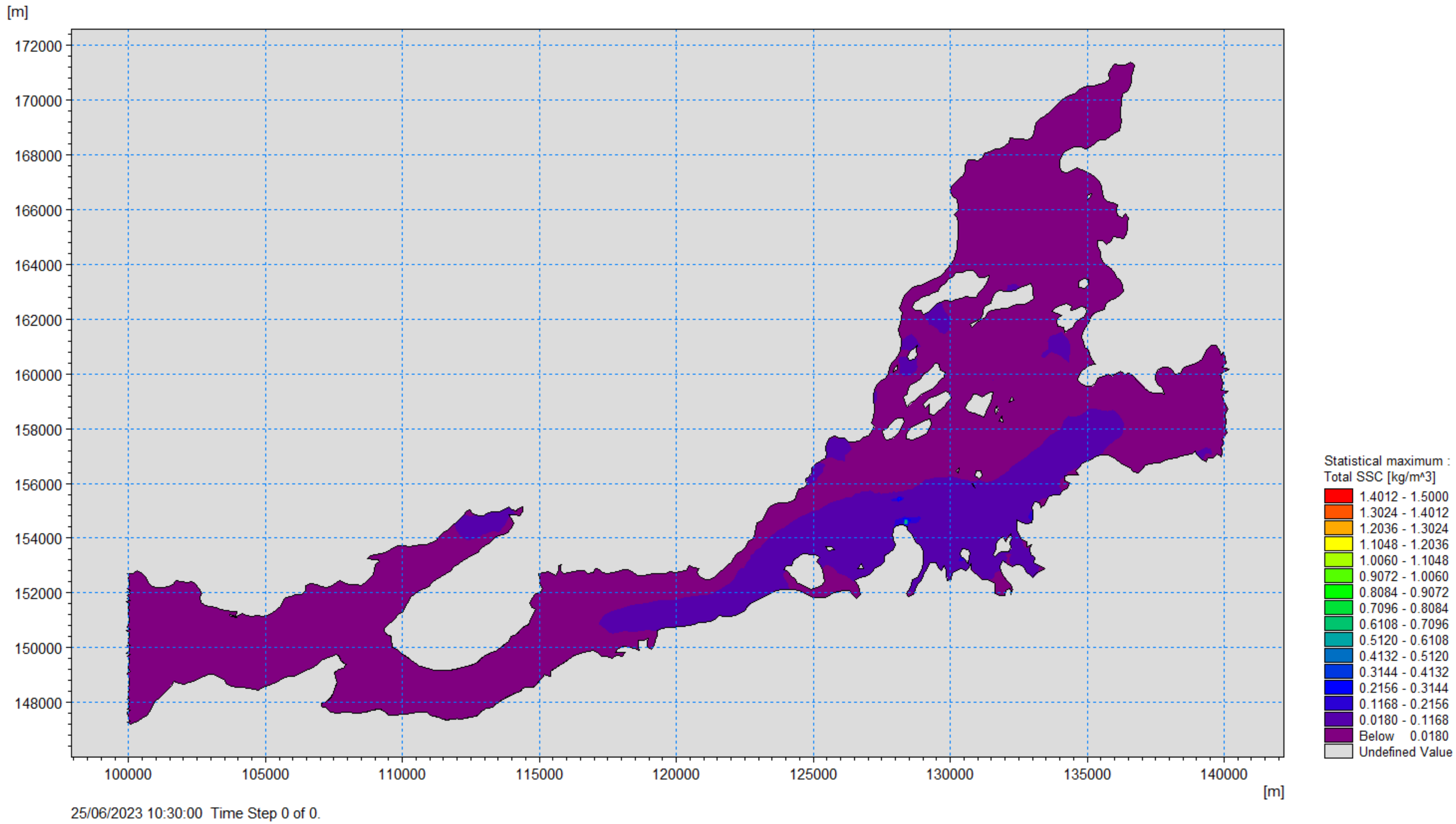

Figure 4.4 Statistical Maximum Suspended sediment concentration for all locations Campaign 2

4.3 Campaign 3

The final campaign modelled consists of the same components and overall volumes as Campaign 1 with the only difference being dredging via TSHD at a rate of 3000t / load. This effectively shortens the dredging in area B from 10 days to 5 days. It represents a scenario where a larger dredge vessel is contracted to undertake the dredging at the Jetty but still in combination with a plough similar to Campaign 1.

The impact of this increase in intensity of dump is not reflected in the increase in bed thickness, the maximum recorded for Campaign 3(see **Figure 4.5**) of the same order as Campaign 1 at maximum of 130 mm approximately.

The suspended sediment concentration is however increased (see **Figure 4.6**). This plot it should be noted represents the worst-case scenario for each grid point over the entire dredge campaign. As expected localised peaks at the dump site are the largest concentrations modelled for the dump site at 0.6 kg/m^3. A lower peak is observed at Area C (0.55kg/m^3,) which is lower than the peak SSC observed for the Campaign 2 simulation.

5. Summary and Conclusion

Three dredge campaign scenarios have been run for 21-day dredge and dump time frames to represent the most conservative individual dredging activities that would likely occur during the proposed 8-year licence.

5.1 Suspend Sediment Concentration Conclusions

It was found that peak suspended sediment concentration (SSC) overall occurs during Campaign 2 at the dredging site (0.7kg/m^3) while peak suspended sediment concentration at the dump site of Foynes Island occurs during Campaign 3 (0.6kg/m^3). It is noted that both these peaks are local to the dredge and dump locations and SSC diminishes rapidly outside these zones. Available background suspended sediment concentration would be in the region of 0.1 to 0.15 kg/m^3 but some peaks in excess of 0.25 kg/m^3 do occur (ref Aquafact report from 2016).

The numerical simulation of dredge dumping and plough dredging as presented herein requires a source location to discharge the dumped dredge material. This presents the worst-case scenario in terms of plume dispersion, as it does not include for localised advection or source movement to reduce initial SSC after dumping.

The dredging and dumping activities will temporarily increase turbidity levels in the River Shannon. However, given the overall naturally high levels of suspended solids throughout the estuary and the localised nature of high turbidity, it is unlikely that the additional turbidity resulting from the dredge disposal operations will have a significant negative impact on hydro environment i.e. the water column.

5.2 Bed Thickness Change Conclusions

The maximum bed thickness change which is an indication of potential habitat smothering, occurs equally and in the same locations for Campaigns 1 and 3 at a level of 130mm. The location of these depositions corresponds to natural mud flats which signifies the dredge material falls out of suspension and settles in the same manner as the natural sediment transport regime of the lower Shannon. This would indicate that adverse deposition in unsuitable areas will not occur as a result of these dredge campaigns. The quantity of 130mm bed thickness is considered insignificant and not likely to impact benthic ecology of these areas.

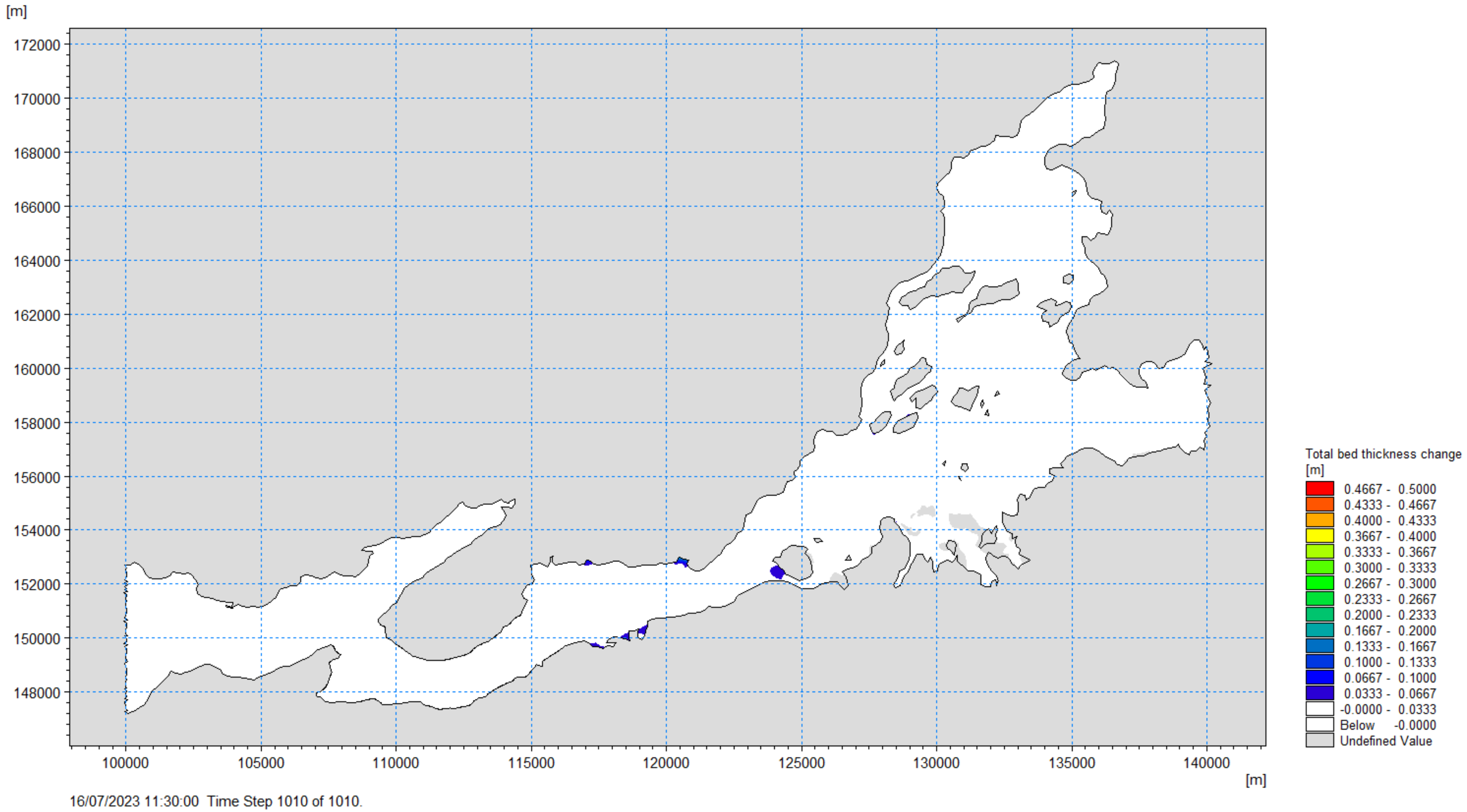

Figure 5.1 Total Bed Thickness Change Due to Scenario 3

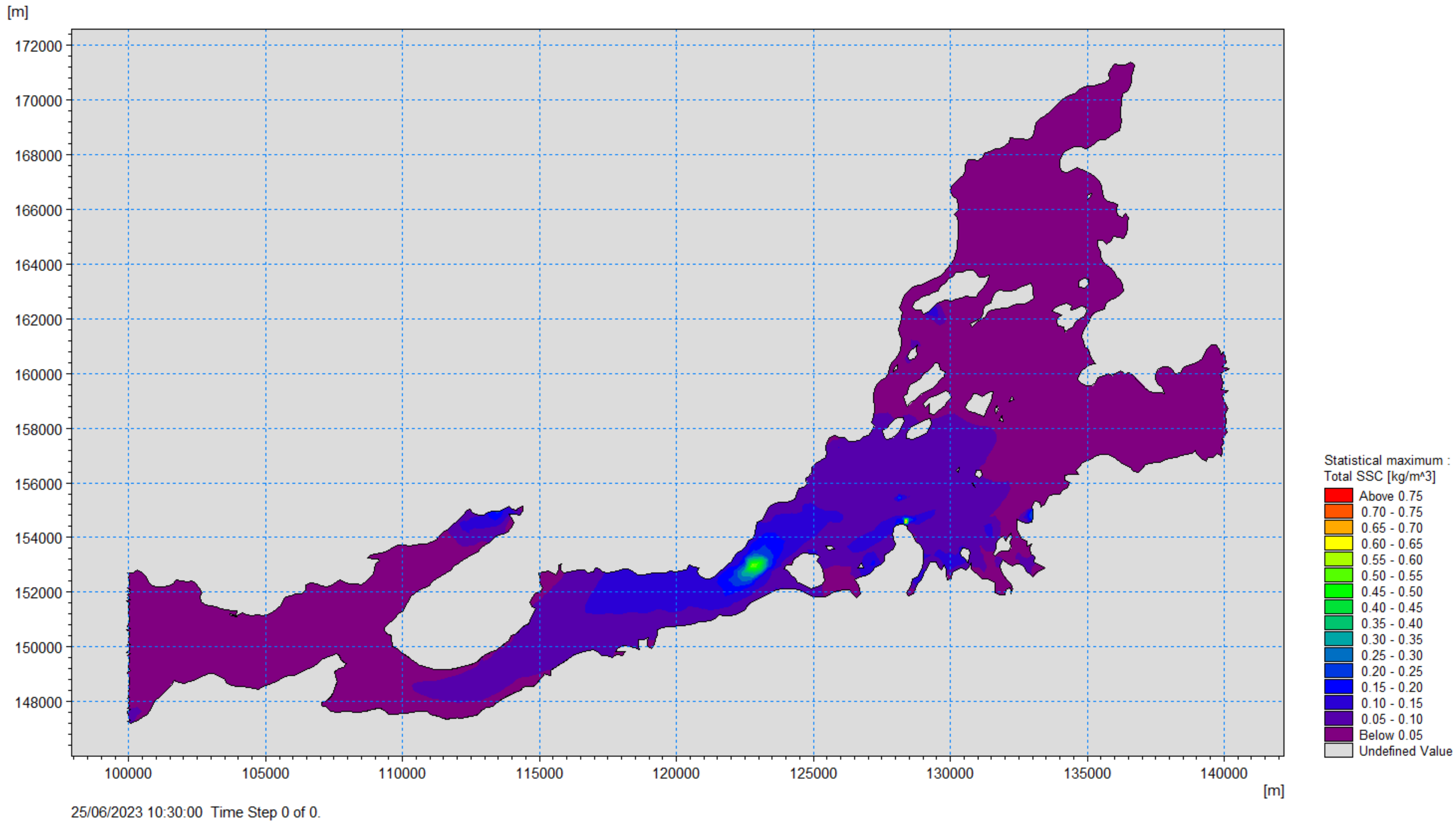

Figure 5.2 Statistical Maximum Suspended sediment concentration for all locations

APPENDIX 1 - MODEL CALIBRATION & VALIDATION

Site Specific Calibration

The hydrodynamic calibration of the model was undertaken by comparing current velocity and direction data recorded over a deployment period from June and July 2023 at Aughinish Jetty and at a location adjacent to Foynes Island in the vicinity of the proposed dumpsite, **Figure A1.** The hydrographic data recorded at Aughinish with a recording current meter (Valeport RCM 106 Series) while the data adjacent to Foynes was captured with a bottom mounted Acoustic Doppler Profiler.

The modelled current direction, **Figure A2**, and current speed, **Figure A3**, at Aughinish show good agreement in phase and magnitude with recorded data. . A localised damping of the measured neap peak daily current is observed, this is likely due to structural interference of the jetty where the gauge was installed. Such a feature is not picked up by the model due to its localised nature, the simulated current speed provides a more representative profile of the hydrodynamic regime at Aughinish. Similar agreement between modelled and measured is observed at the dumpsite for both parameters, **Figure A4** and **A5**

Figure A1 Location of Field measuring stations.

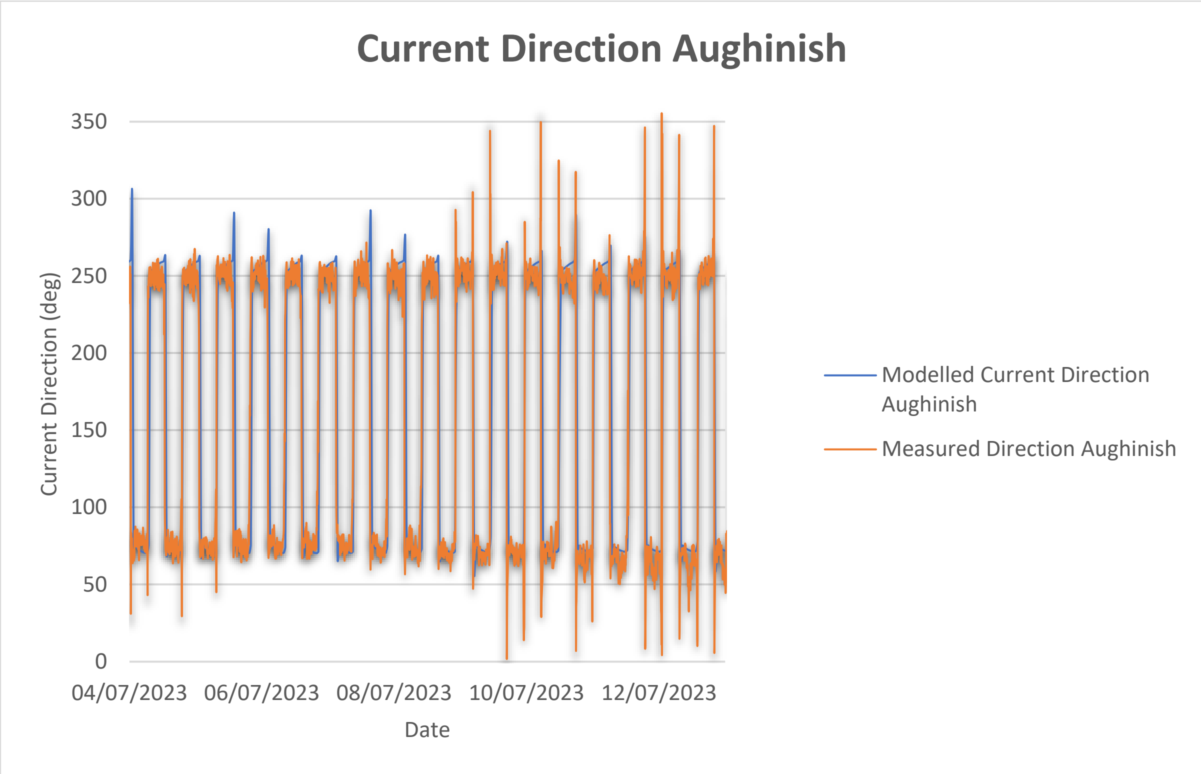

Figure A2 Current Direction Comparison at Aughinish

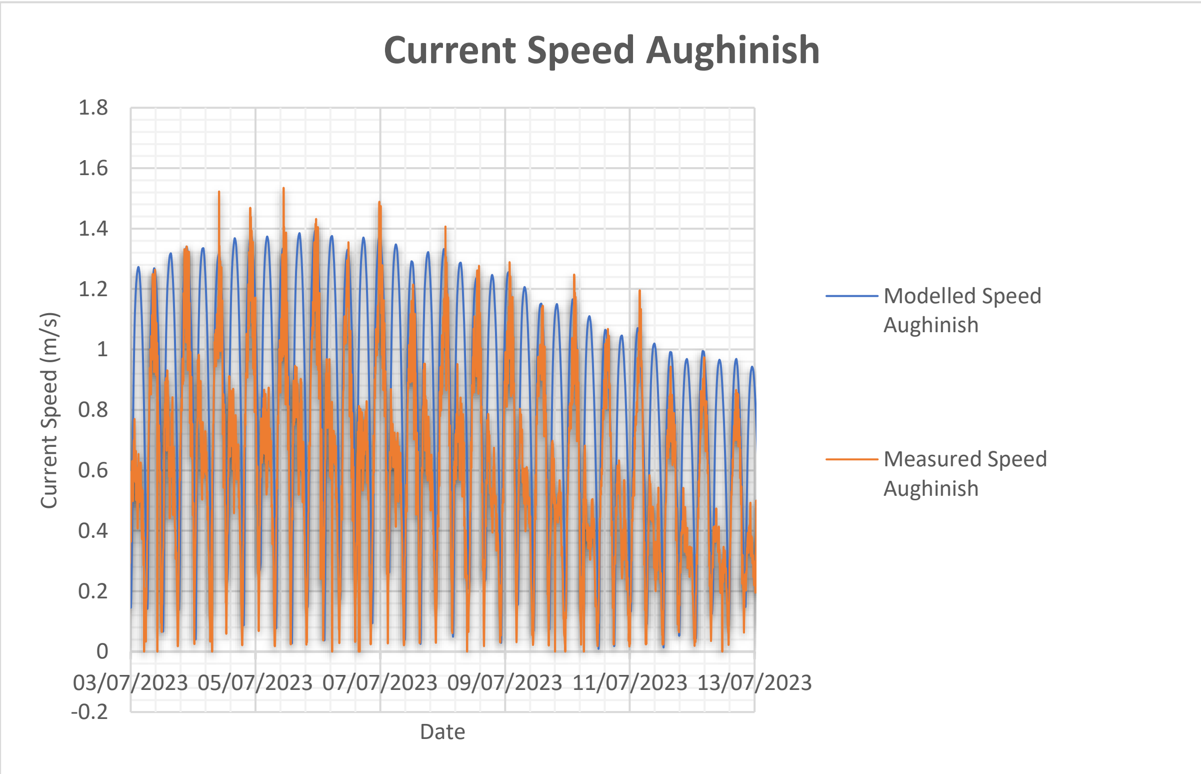

Figure A3 Current Speed Comparison at Aughinish

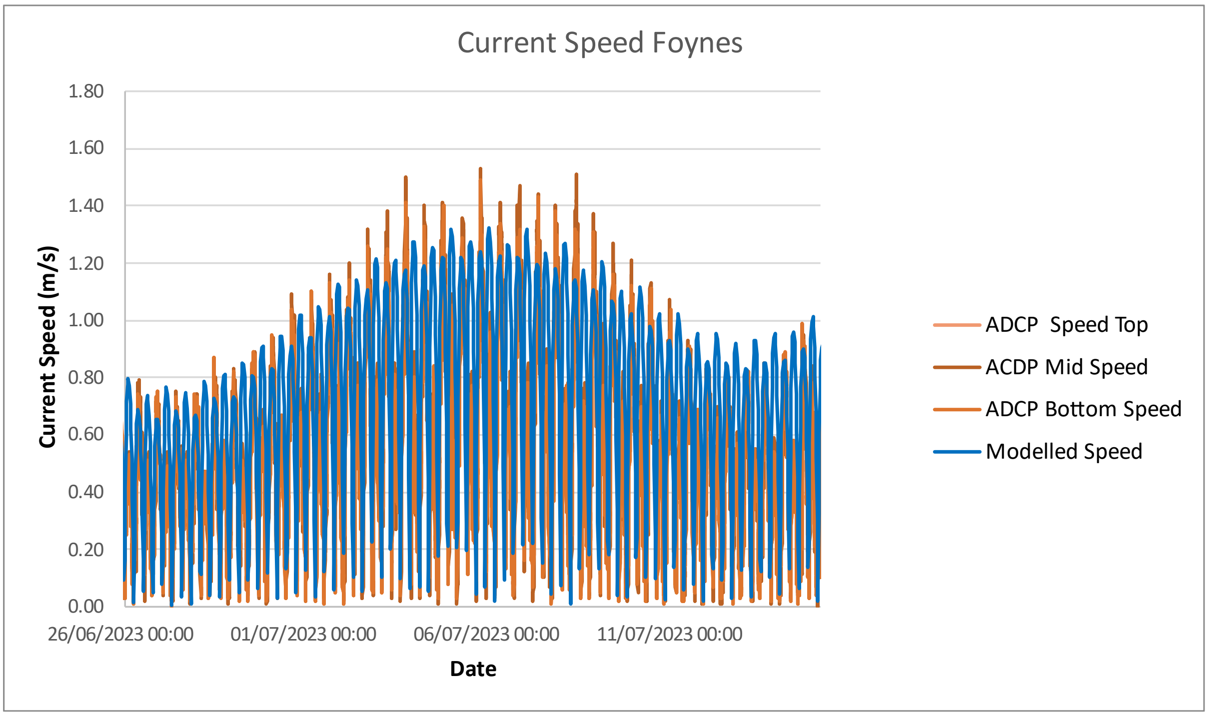

Figure A4 Current Speed Comparison at Dumpsite

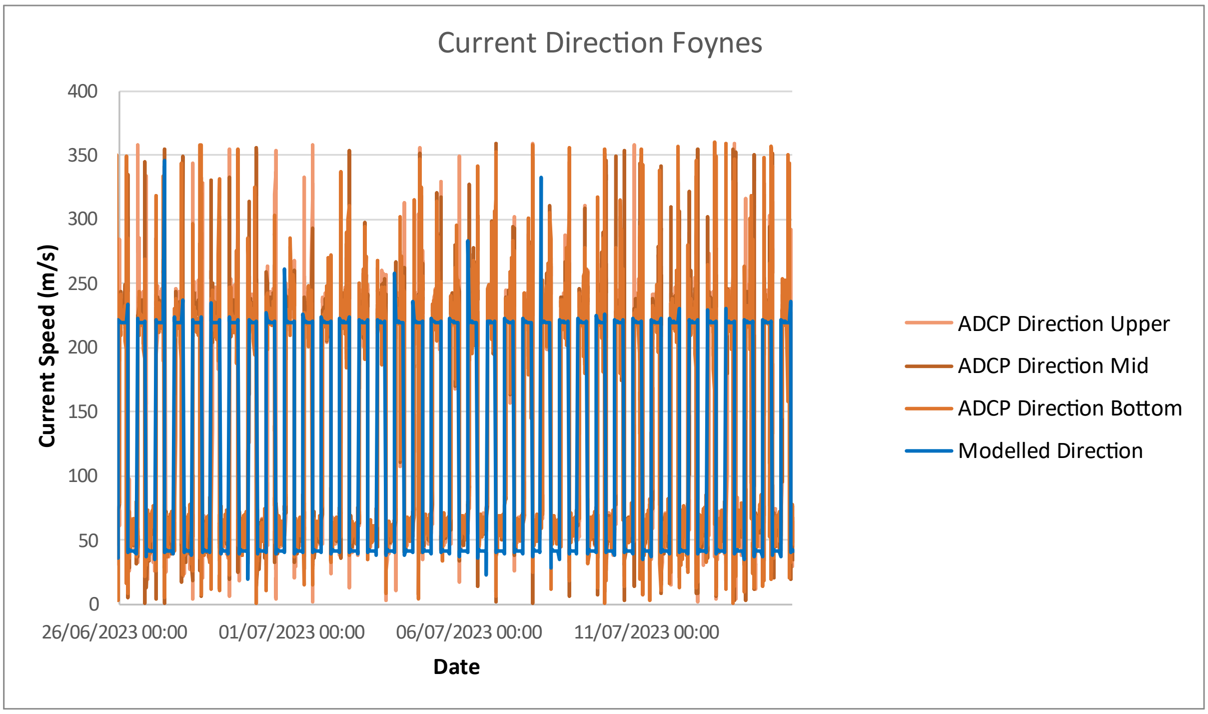

Figure A5 Current Speed Comparison at Dumpsite

Model Validation

The hydrodynamic module HD, output was compared with previous (2019) monitoring campaign upstream of the site at Bunratty. The model was validated for surface water level elevation against Hydrographic data collection undertaken by Aquafact Ltd in September 2019. The data collection included a location in the main Shannon channel at Bunratty The comparison of the simulated and recorded velocities at this location are shown in figure A6 . It should be noted that the simulated elevations are within 10% of the recorded high and low tides.

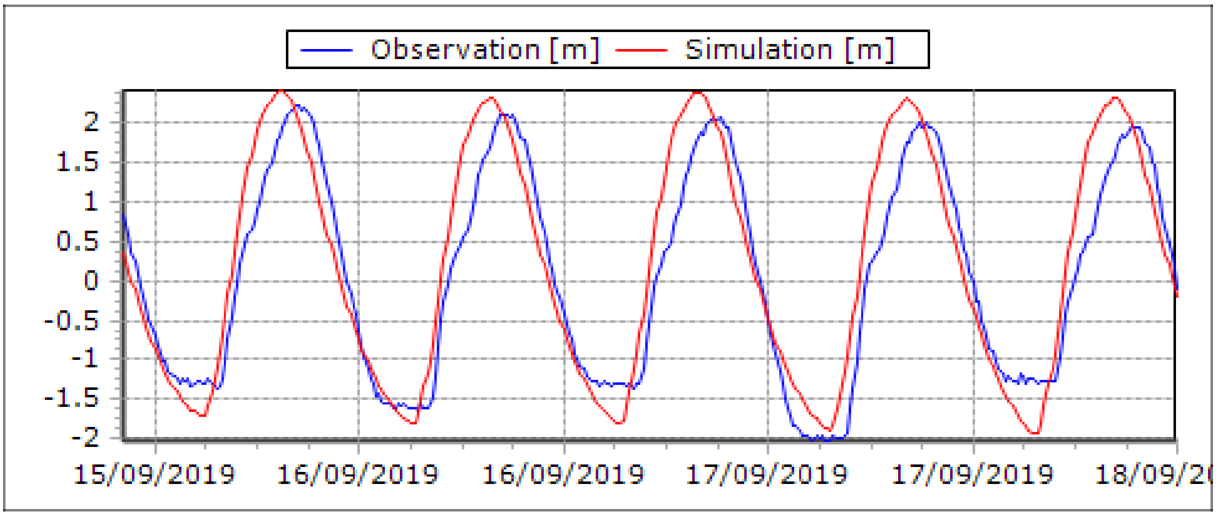

Figure A6 Water Surface Elevation Calibration Bunratty

Figure A7 Location of Recording gauge (2019)

APPENDIX 2 - INSTRUMENT CERTS

VALEPORT

CALIBRATION CERTIFICATE

This document certifies that the instrument detailed below has been calibrated according to Valeport Limited's Standard Procedures, using equipment with calibrations traceable to UKAS or National Standards.

Instrument	Model 106
Instrument Serial Number	85997
Calibrated By	[redacted]
Certificate Number	76388
Date	27/03/2023
Signed	[redacted]

This summary certificate should be kept with the instrument.

Valeport Limited
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sales@valeport.co.uk | **valeport.co.uk**

VAT No: GB 165 8753 67 | Registered in England No: 1950444

300 Series Instrument Calibration Record **Pressure** **© Valeport Limited**

Instrument Serial Number	85997
Sensor Type	Keller PAA-10
Sensor Serial Number	N292315
Sensor Range	200
Certificate Number	76388

Stage 1: Determine Local pressure conditions

Air temperature	22.5	°C
Grid reference	280657 East, 059840 North	
Height above sea level	5	metres
Local Gravity	9.81125	M/sec²
Gravity standard for barometer	9.80665	M/sec²
Atmospheric pressure	770.800	mmHg
	10.2436	dBar

Stage 2: Obtain Calibration data and Polynomial fit

Deadweight weight dBar	Deadweight pressure dBar	Atmospheric Pressure dBar	Counts (nnnn) nnnn	Total pressure dBarA	Polynomial fit for raw data: Order >>>> Parameter	2 Value	Polynomial calculations: Calc Pressure dBarA	Pressure Error [Calc - Actual] dBar	%FS	Acceptable Error	Pass/Fail
0	0.000	10.244	193	10.244	a0	1.367979E-01	10.23823997	-0.005	-0.003	±0.1	Pass
40	40.022	10.244	957	50.265	a1	5.232560E-02	50.27635497	0.011	0.006	±0.1	Pass
80	80.043	10.244	1719	90.287	a2	6.983451E-08	90.29086255	0.004	0.002	±0.1	Pass
120	120.064	10.244	2479	130.308			130.2811242	-0.027	-0.013	±0.1	Pass
160	160.086	10.244	3239	170.330			170.3520586	0.023	0.011	±0.1	Pass
200	200.107	10.244	3996	210.351			210.3450141	-0.006	-0.003	±0.1	Pass

Enter polynomial fit from graph in cell G30 $y = 6.983451E-08x^2 + 5.232560E-02x + 1.367979E-01$

Stage 3: Enter calibration string: #101 12 6.983451E-08 5.232560E-02 1.367979E-01

Stage 4: Post Calibration Check

Deadweight weight dBar	Deadweight pressure dBar	Atmospheric Pressure dBar	Measured pressure dBarA	Total pressure dBarA	Error [Reading - Actual] dBar	%FS	Acceptable Error	Pass/Fail
0	0.000	10.244	10.238	10.244	-0.006	-0.003	±0.1	Pass
40	40.022	10.244	50.276	50.265	0.011	0.005	±0.1	Pass
80	80.043	10.244	90.291	90.287	0.004	0.002	±0.1	Pass
120	120.064	10.244	130.332	130.308	0.024	0.012	±0.1	Pass
160	160.086	10.244	170.299	170.330	-0.030	-0.015	±0.1	Pass
200	200.107	10.244	210.345	210.351	-0.006	-0.003	±0.1	Pass

Calibration Equipment used

Instrument	Type	Serial No
DWT	Budenburg	31707/580DXA/965F/A5759
Barometer	DPM 7010	5194-001-0813

Name	[redacted]
Date	27 March 2023
Signed	[redacted]

85997_Press_230324.xlsx Calibrated to Valeport's procedures using test equipment with calibrations traceable to UKAS or national standards 31/03/2023 09:59

MWP

NORTEK

COMPANY WITH QUALITY SYSTEM CERTIFIED BY DNV GL = ISO 9001:2015 =

Certificate of Conformity

Certificate date: 25-05-2023

Customer: Hydrographic Survey Ltd

Customer PO number: 4718 Hydro Survey

Nortek SO number: 50229

Ship date: 25-05-2023

Country of Origin: Norway

Line	Part no.	Description	Qty.	Serial/batch number	Year of mfr.
1	906507	Eco system complete with tripod	2	Serial no.: 50229-1220 - 906507 Board Id: M E0 02473 Head Id: 520	2023

Nortek certifies that the item(s) herewith is (are) manufactured, tested and quality controlled in conformance with the requirements of the above Purchase Order and fully comply with applicable Nortek specifications and production documentation in effect at the date of manufacture. Nortek is certified against ISO 9001.

I hereby certify that the above statements are true and correct

(Nortek authorized representative)

NORTEK AS
Vangkroken 2,
N-1351 Rud, Norway
+47 67 17 45 00
www.nortekgroup.com

[redacted] Shipping Coordinator 25-05-2023

(Signature) (Title) (Date)

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