

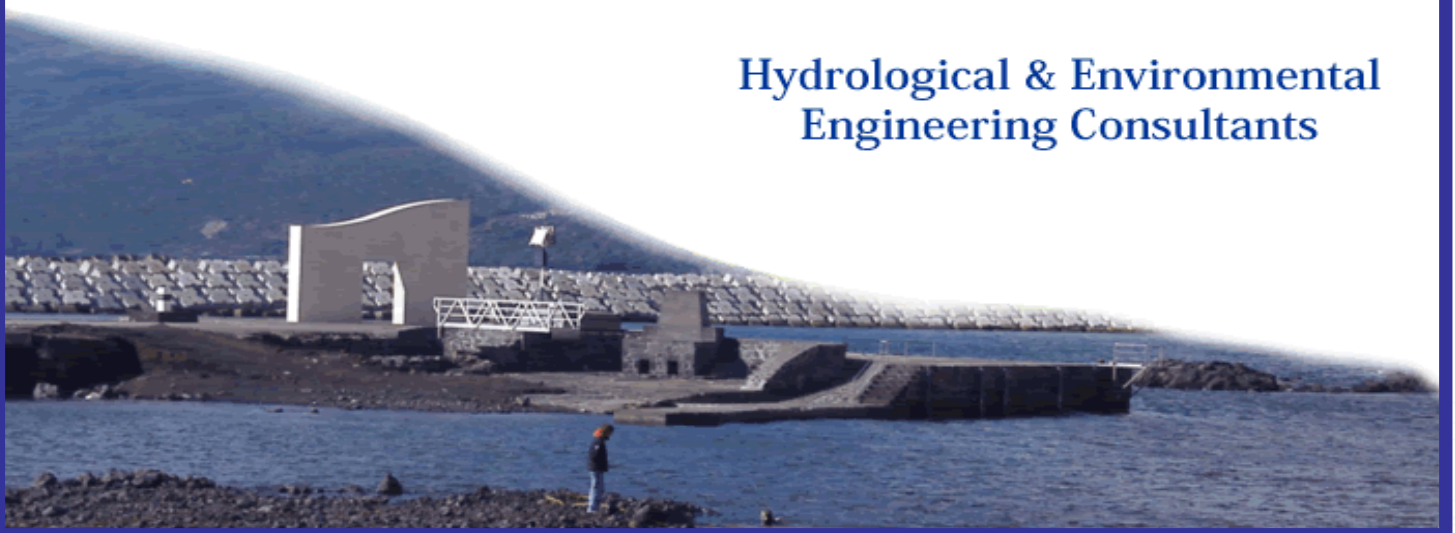


**Sediment Transport Modelling of Proposed
Maintenance Dredging of the Outer and Inner Berths
at the Aughinish Marine Terminal, Shannon Estuary**

**Prepared for
Malachy Walsh & Partners
On behalf of
Aughinish Alumina Ltd.**

February 2016

**Hydrological & Environmental
Engineering Consultants**



Sediment Transport Modelling of Proposed Maintenance Dredging of the Outer and Inner Berths at the Aughinish Marine Terminal, Shannon Estuary



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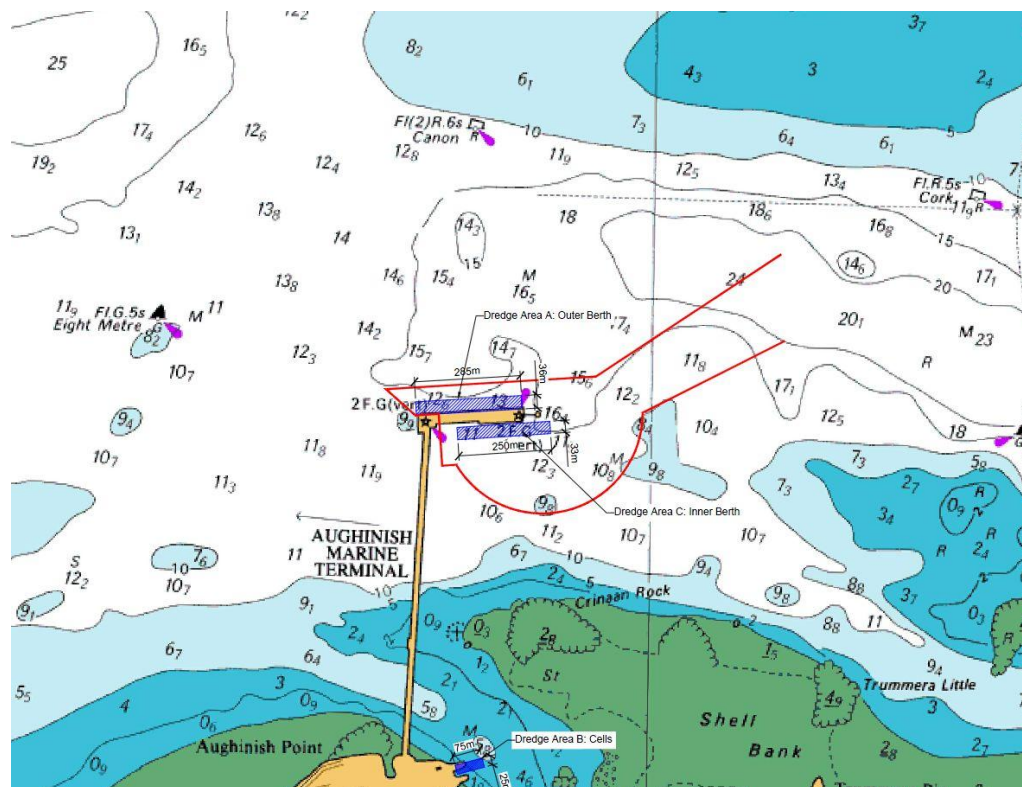
1. INTRODUCTION

1.1 Background

Hydro Environmental Ltd. was commissioned by Malachy Walsh & Partners on behalf of Aughinish Alumina Ltd. to carry out a preliminary sediment transport study to investigate the proposed dredging of the sea bed at Aughinish Marine Terminal in the Shannon Estuary. The intention is to plough the sea bed pulling the sediment along the sea floor into deeper waters away from the Berths. This ploughing has the potential to mobilise a portion of the sediment material into suspension which will then be transported and dispersed by the strong ambient tidal velocities that flow past the Jetty.

1.2 Proposed Dredging Works

It is proposed to plough dredge both the outer and inner berths at the Jetty having respective areas of 285m by 36m for the outer and 250m by 33m for the inner and also dredge at a third smaller nearshore site measuring 75m by 25m (refer to Figure 1). It is likely that occasional bed levelling may also occur within the red line area shown in Figure 1. The dredging will attempt to restore sea bed depths to approximately 12.2 to 14.3m below Chart Datum at the Jetty. The quantities to be dredged will be in the region of 4,000 tonnes with an unlikely maximum dredge of 16,000 tonnes. The dredging licence application will apply for an 8 year duration with a maximum of 16,000 tonnes per annum.



As the area will be plough dredged, the dredge site and surrounding sea bed will act as the dredge disposal site availing of the strong ambient velocities to disperse the sediment widely within the middle estuary through bedload and suspended load. It is proposed that the dredging would be carried out either in April 2016 or September 2016 when the berths are unoccupied or at a time where the need and opportunity arises. The anticipated plough dredging rate is likely to be of the order of 1m^3 of sediment per minute which represents a dredging rate of 31.25kg/sec or $2,700$ tonnes over a 24hour period. Typically a dredge event may take place over a four or five day period depending on quantity but could vary from 1000 to 4000m^3 .



Figure 2 *Bing Map view of Aughinish Jetty and the Surrounding Shannon Estuary*

Sediment sampling and sieve analysis of the bed material was carried out by Aquafact International Ltd. taken at eight locations in the estuary near Aughinish Island and the Marine Terminal (refer to Aquafact reports Dec 2015). Samples 2 and 3 at the berths and 5 and 7 in the channel both upstream and downstream of the berths are the most relevant to describing the characteristics of the sediment to be dredged. These show the sampled sediment at all four sites to consist of a fine to very fine sand and a silt/clay in almost equal proportions (refer to Table 1 and Figure 3 for locations). This description would indicate that the sediment would be very mobile once disturbed and suspended within the water column.

Table 1 Physical properties of sediment (taken from Aquafact Report (Dec 2015))

Station	% Gravel (>2mm)	% Sand (63-2mm)	Silt-Clay (<63mm)	Moisture %	Density (g/ml)	Description
ST 1	0	52.4	47.5	47.38	1.48	grey brown muddy sand, no smell
ST 2	0.1	51.3	48.7	45.09	1.30	soft mud, black, slight smell
ST 3	0	49.1	50.9	53.55	1.30	soft mud, grey, no smell
ST 4	0	55.2	44.7			soft mud, grey, no smell
ST 5	1.8	51	47.2			soft mud, grey, no smell
ST 6	0.5	50.8	48.6			soft mud, grey, no smell
ST 7	0.2	56.1	43.7			soft mud, grey, no smell
ST 8	0	89.5	10.5			grey brown muddy sand, no smell

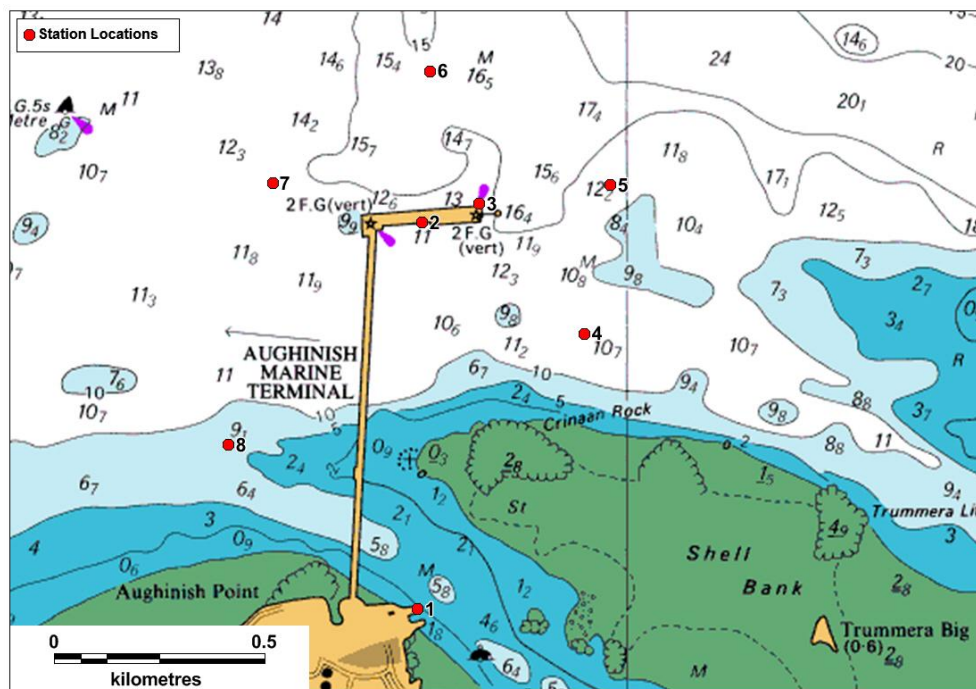


Figure 3 Bed Sediment Sampling Locations

2. Shannon Estuary Hydrodynamic Model

2.1 Model Description

The **TELEMAC** system and specifically **Telemac-2D** hydrodynamic module is the software of choice for modelling the complicated hydrodynamics of the Shannon Estuary. **TELEMAC** is a software system designed to study environmental processes in free surface transient flows. It is therefore applicable to seas and coastal domains, estuaries, rivers and lakes. Its main fields of application are in hydrodynamics, water quality, sedimentology and water waves.

The **TELEMAC** system is a powerful integrated modelling tool for use in the field of free-surface flows. Having been used in the context of very many studies throughout the world (several thousand to date), it has become one of the major standards in its field. The various simulation modules use high-capacity algorithms based on the finite-element method. Space is discretised in the form of an unstructured grid of triangular elements, which means that it can be refined particularly in areas of special interest. This avoids the need for systematic use of embedded models, as is the case with the finite-difference method. **Telemac-2D** is a two-dimensional computational code describing the horizontal velocities, water depth and free surface over space and time. In addition it solves the transport of several tracers which can be grouped into two categories, active and passive, with salinity and temperature being the active tracers which alter density and thus the hydrodynamics.

The horizontal coordinates are set as Cartesian Coordinates to Irish OS grid and the bathymetry specified at every finite element node is referred to Chart Datum which is c. 3m below OS Malin Datum.

A 2-dimensional depth averaged hydrodynamic model of the entire Shannon Estuary from Loop head to Corbally weir model was developed as part of the update to the Oil spill predictive modelling and GIS system for Shannon-Foynes Port Company. This model was run using **Telemac-2d** and had an unstructured finite element mesh of variable density depending on the geometry requirements, total number of nodes 10,294 and total finite elements 17,980 (representing an estuarine area of 561km²).

The hydrodynamics from Telemac are determined for springs and neap tides and inputted to a sediment transport model PSED.

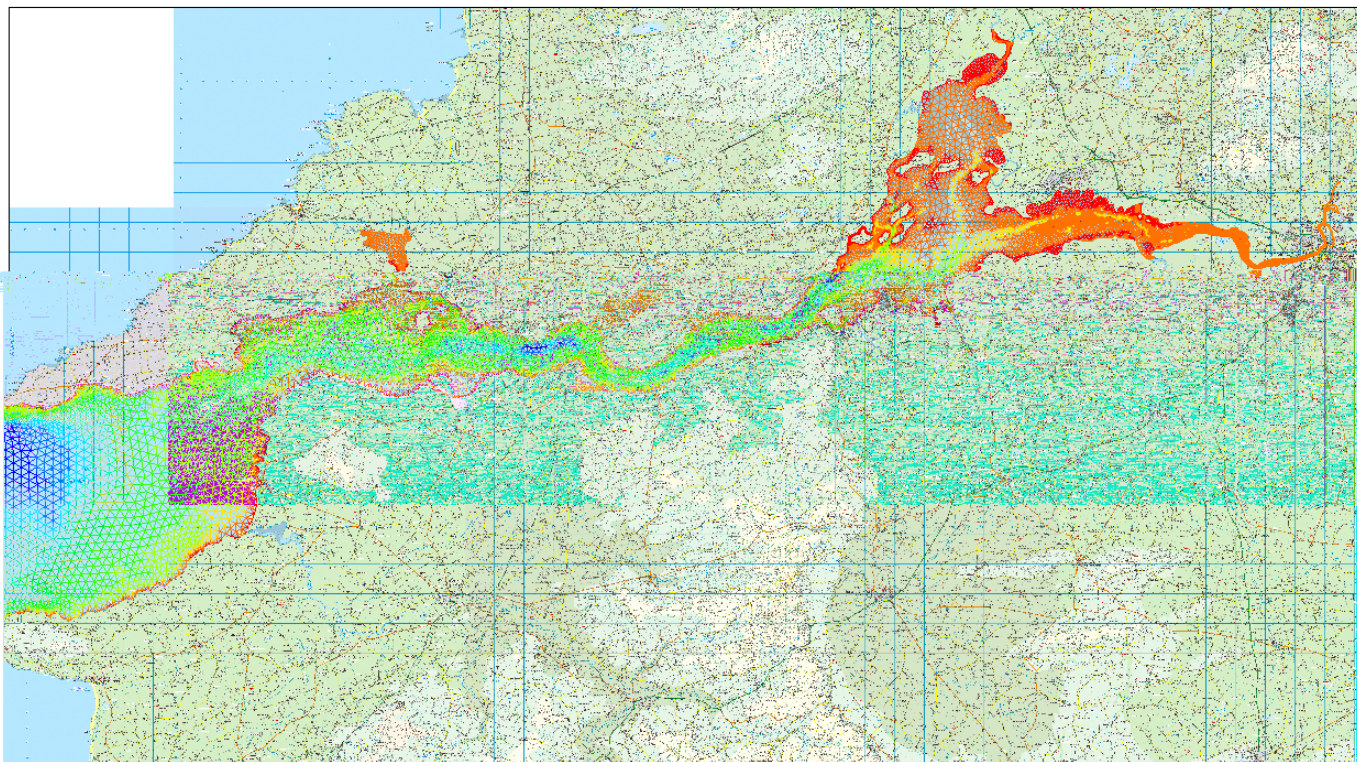


Figure 4 Shannon Estuary Hydrodynamic and Water Quality Model developed by Hydro Environmental Ltd.

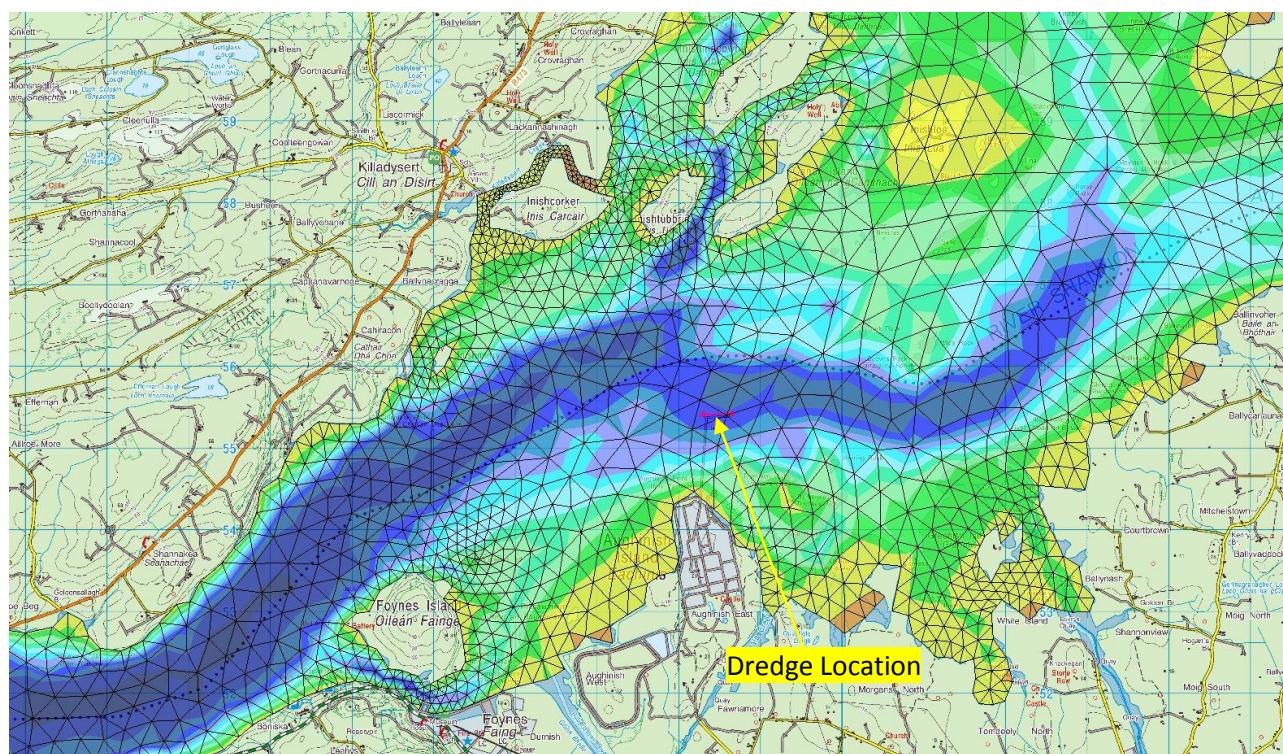


Figure 5 Location of dredge site at Aughinish Jetty and computational grid for hydrodynamics

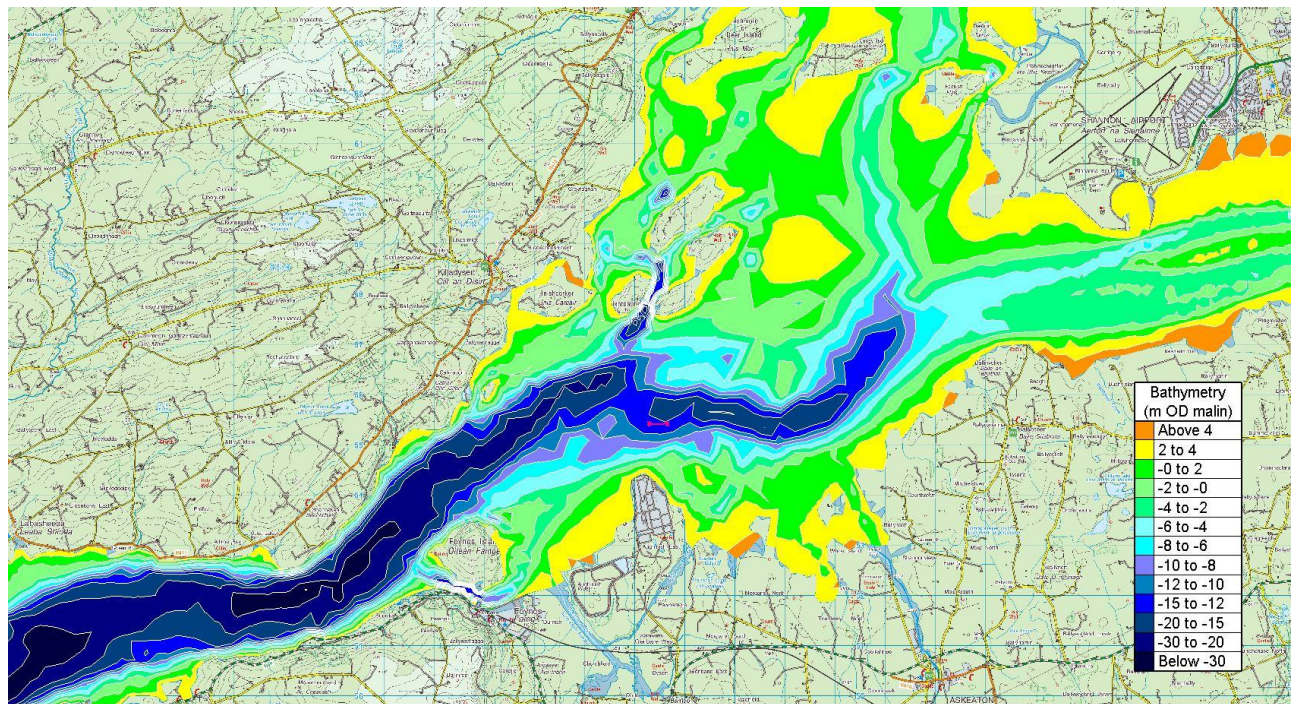


Figure 6 Model Bathymetry for the Middle Estuary near Aughinish

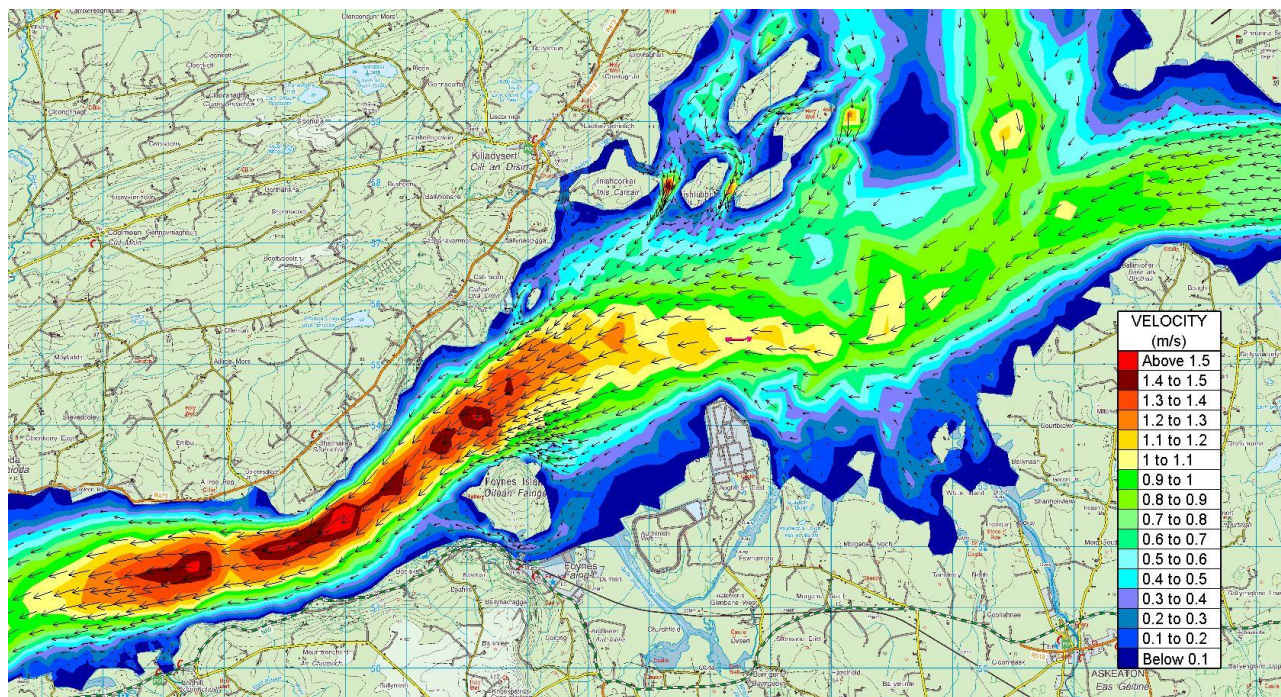


Figure 7 Modelled spring tide mid-ebb depth averaged velocities in the Shannon Estuary at Aughinish

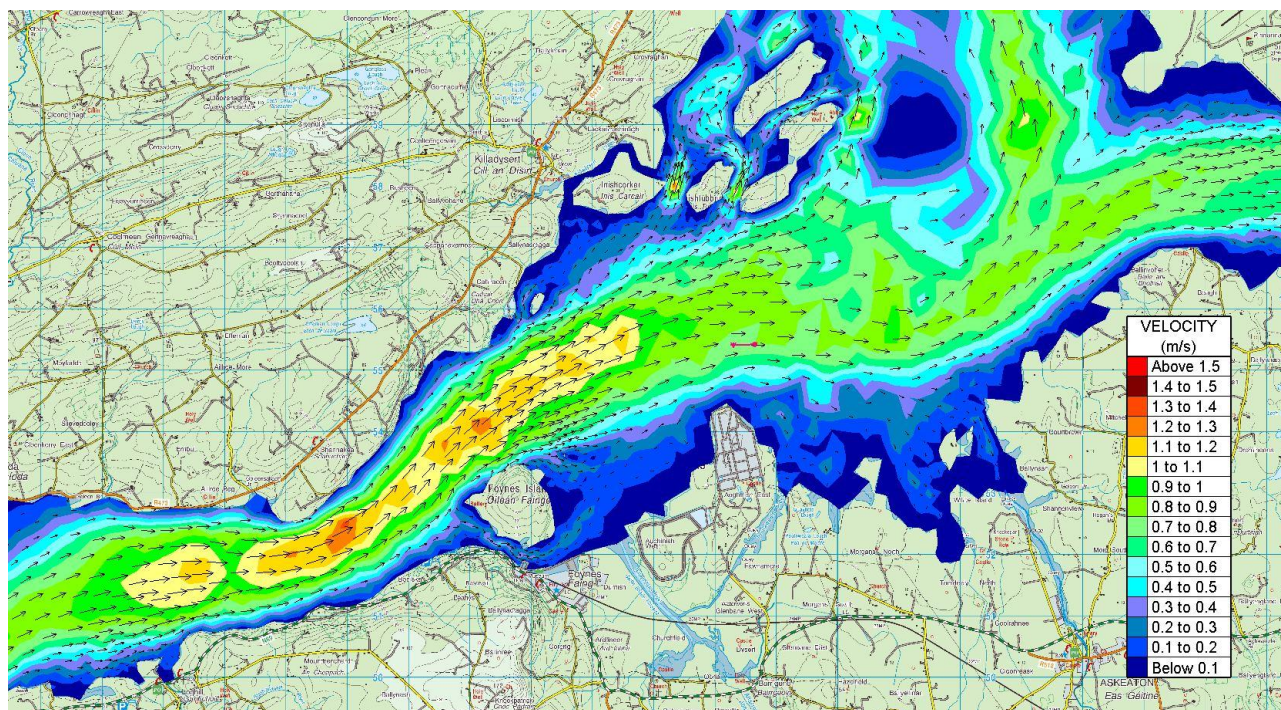


Figure 8 Modelled spring tide mid-flood depth averaged velocities in the Shannon Estuary at Aughinish

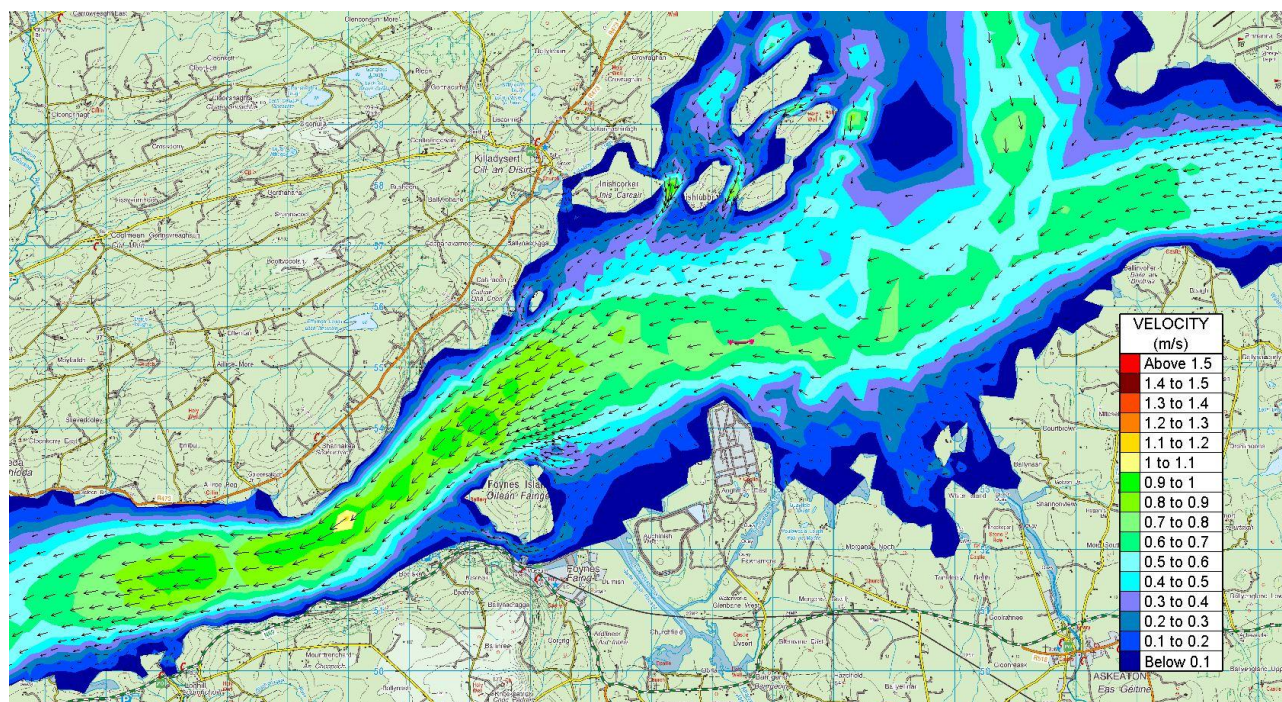


Figure 9 Modelled neap tide mid-ebb depth averaged velocities in the Shannon Estuary at Aughinish

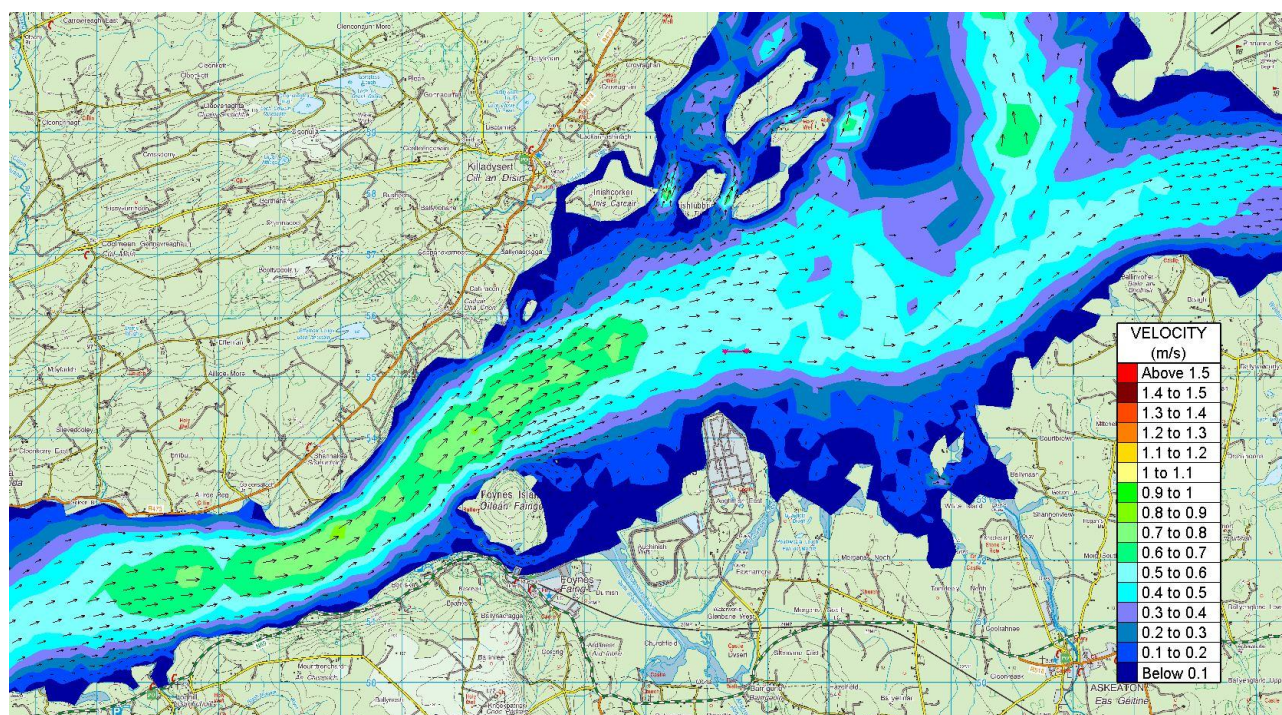


Figure 10 Modelled neap tide mid-flood depth averaged velocities in the Shannon Estuary at Aughinish

3. Shannon Estuary Sediment Transport Modelling

3.1 Sediment Transport Model Description Inputs

The hydrodynamics from Telemac are determined for springs and neap tides and inputted to a sediment transport model PSED. PSED is a Lagrangian particle tracking model for simulating non-cohesive sediments developed by the Canadian Hydraulics centre (CHC). The PSED model utilises the hydrodynamic output from the Telemac2d model requiring bathymetry, time varying water depths and velocities. PSED simulates the transport both suspended and bed load of a variety of non-cohesive sediment types from fine silts and sands to coarser sands and gravels. The model computes the mobility, entrainment, advection, dispersion and settling of sediments under steady and unsteady flows. The model allows for the re-suspension of the sediments once its critical shear stress is exceeded. Wave generated currents in combination with tidal and fluvial hydrodynamics can be input to the transport model.

3.2 Model Simulations

The granulometry results for the estuary show the sediment to be primarily a silt and a very fine sand. Dredging simulations were carried out for a continuous 4 day dredge over both spring and neap tidal cycles. A silt and very fine sand were modelled at a discharge rate to the water column of 31.25kg per second (2,700 tonnes per day or 10,800 tonnes continuously over the four days). At bed sediment density of 1800kg/m³ this represents mobilising 6,000m³ of sediment in a four day period. The simulation assumes all sediment is initially suspended into the water column during the plough dredging where it is mobilised by the ambient tidal currents inputted from the hydrodynamic model. This approach is likely to be very conservative as a large portion of the dredge material will remain on the sea floor where the plough dredging deposits it.

In the model simulations the dredge sediment material is modelled independent of the ambient sediments and suspended solids. The sediment fractions are modelled as non-cohesive sediments. The simulations show that once mobilised there is very little opportunity due to the high ambient velocities in the estuary near the dredge site for settlement of this very fine material through the stokes (non-cohesive) gravitational settlement velocities. The sediments in suspended form are transported in the main estuary flow channel back and forth with the ebbing and flooding tide being further dispersed with the tide over time. Longer term settlement would involve cohesive processes of coagulation of the fine particle through van-der-waals attractive forces between small particles. Suspended sediment concentrations are generated for the last tidal cycle of the 4-day dredge operation for both the spring and neap tides and these are presented in Figure 11 to 18. (highwater, mid-ebb, low water and mid flood for both spring and neap).

3.3 Discussion

The analysis indicated that all the plough material from fine sand to silt is easily suspended and transported away with the tidal velocities on both spring and neap tides. Due to the higher ebbing (outgoing) velocities the sediment Plume travels further westward than eastward. The simulations show the plume over a number of tidal excursions is transported up in to the lower Fergus Estuary where extensive mud flats already exist. The typical suspended sediment concentration in the dredge plume varies from 20 to 100 mg/l with an average concentration of approximately 40 to 60mg/l. Higher concentrations of 100 to 200mg/l are also present within in the plume path from the disposal site.

The Aquafact turbidity survey (December 2015) show that ambient concentration of suspended sediment as turbidity is high in the vicinity of the jetty berths with NTU values of 40 to 280. Often a factor of 3 is used to convert NTU's to suspended solid concentrations in mg/l, which suggests potential ambient suspended solid concentrations of 100 to 800mg/l in the receiving waters. These levels reflect the normal naturally high turbidity that exists in this estuary particularly in the middle and upper estuary reaches where mud flats are present and where the large river inflows and high turbulent tidal velocities mobilise such sediments.

Initial deposition of the dredge sediment through non-cohesive processes was found to be very minor and only for a very short interval at slack tides (change of tidal flow direction) and anything deposited was resuspended almost immediately and transported away by the strong ambient currents.

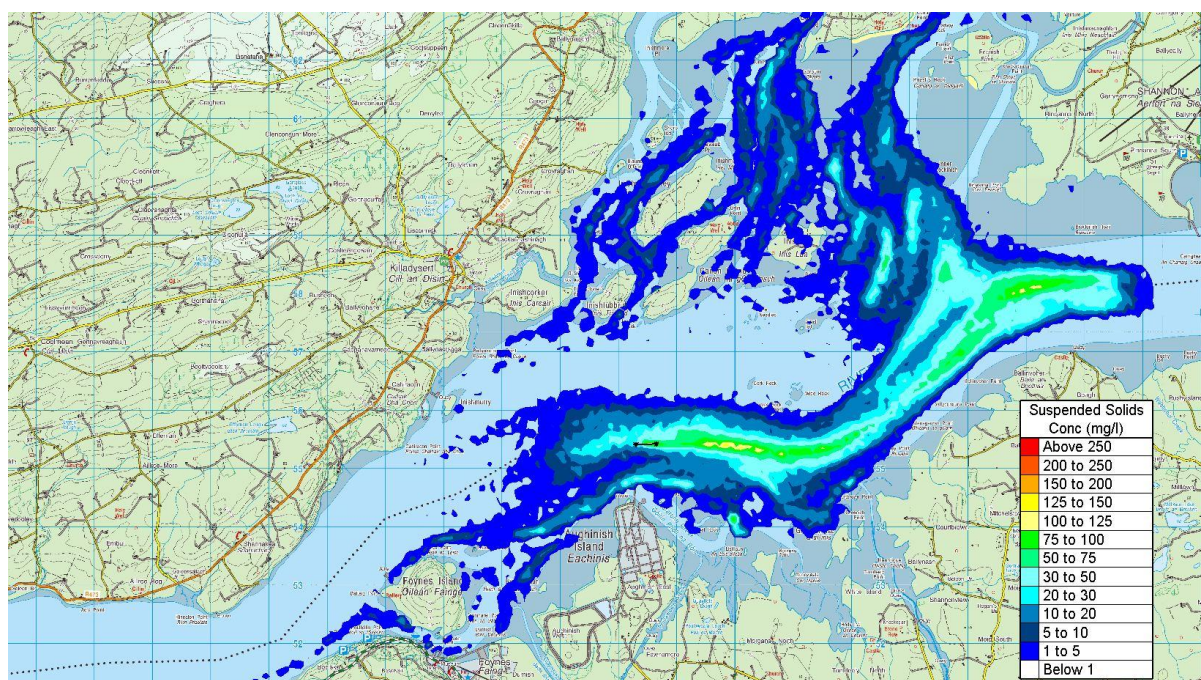


Figure 11 Predicted Suspended Sediment Concentrations from plough dredging activity at Highwater Spring Tides

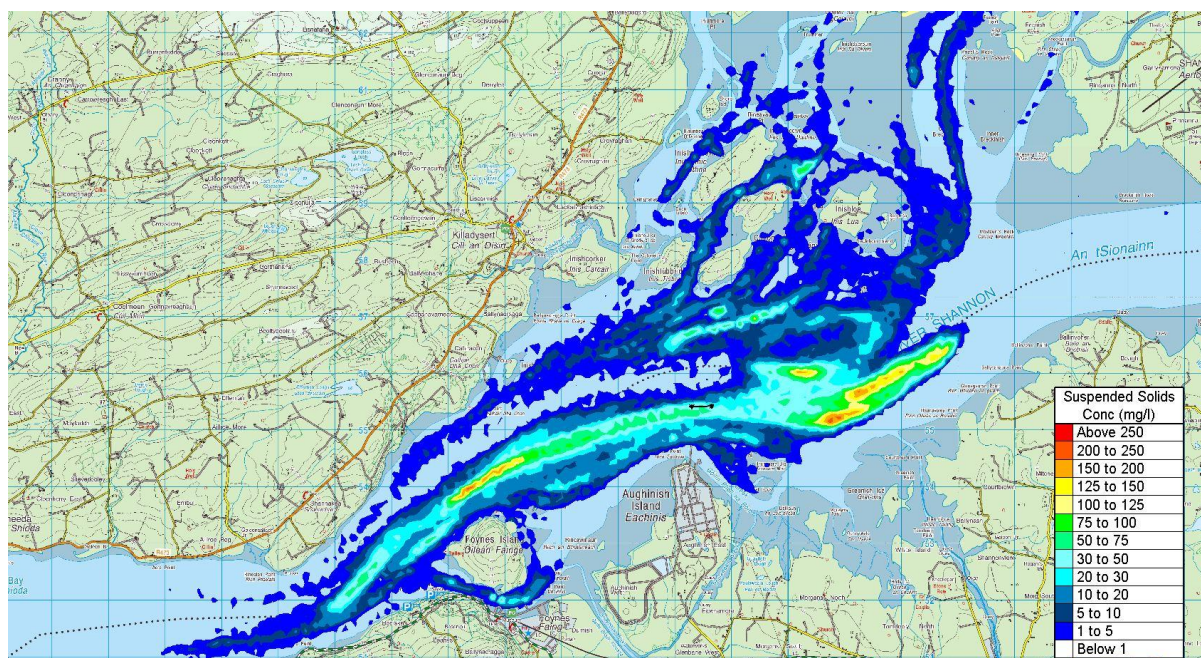


Figure 12 Predicted Suspended Sediment Concentrations from plough dredging activity at Mid-ebb Spring tide

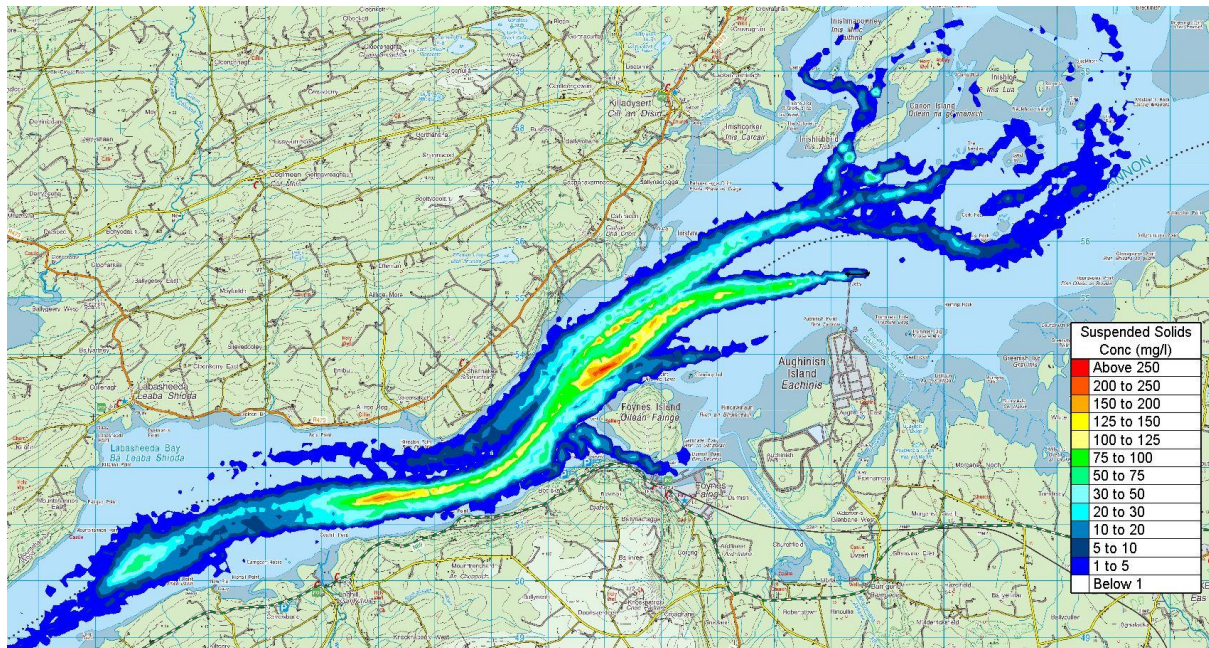


Figure 13 Predicted Suspended Sediment Concentrations from plough dredging activity at Low Water Spring Tide

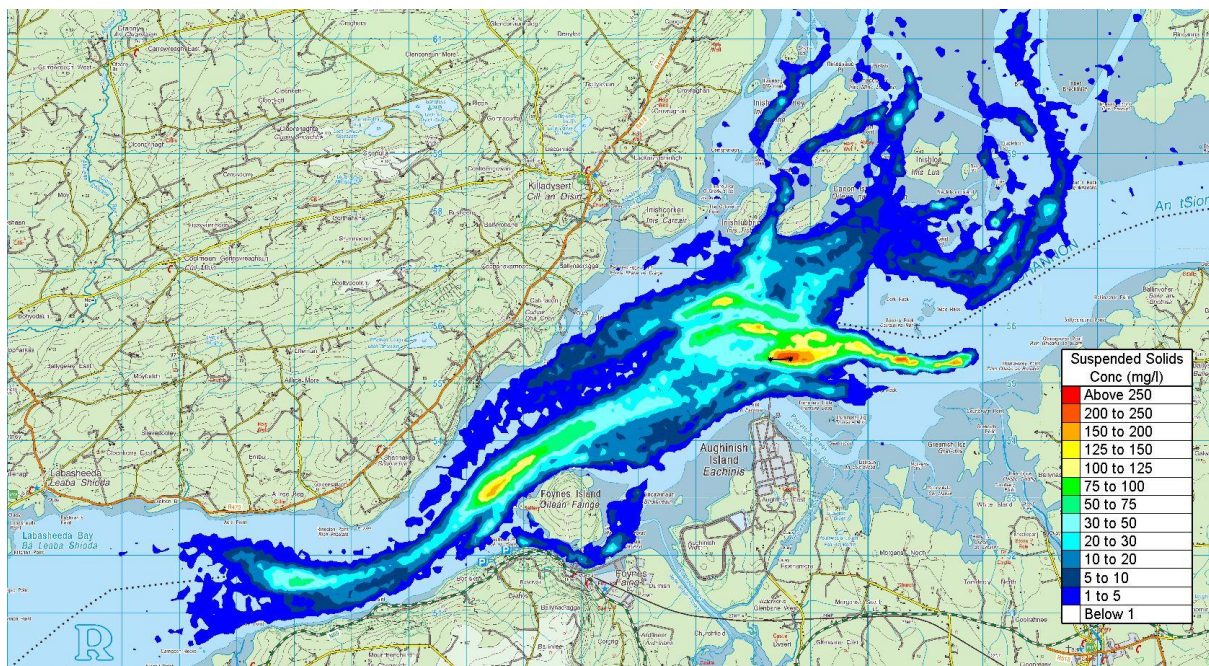


Figure 14 Predicted Suspended Sediment Concentrations from plough dredging activity at Mid-Flood Spring Tide

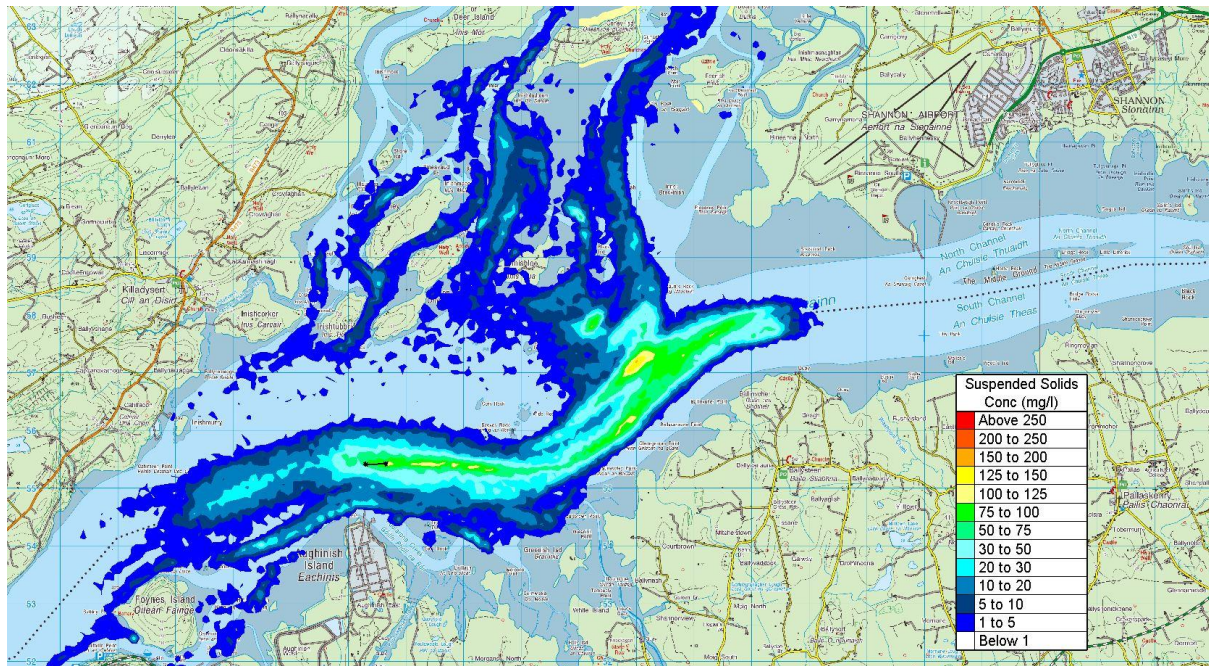


Figure 15 Predicted Suspended Sediment Concentrations from plough dredging activity at Highwater Neap tide

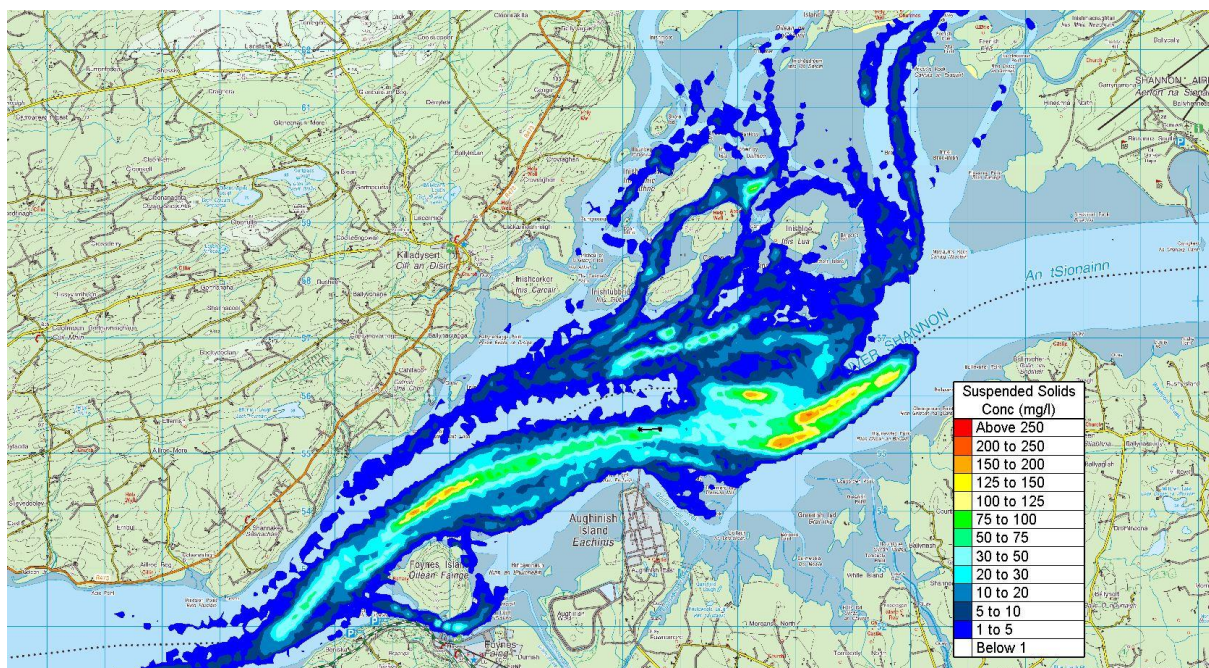


Figure 16 Predicted Suspended Sediment Concentrations from plough dredging activity at Mid-ebb Neap Tide

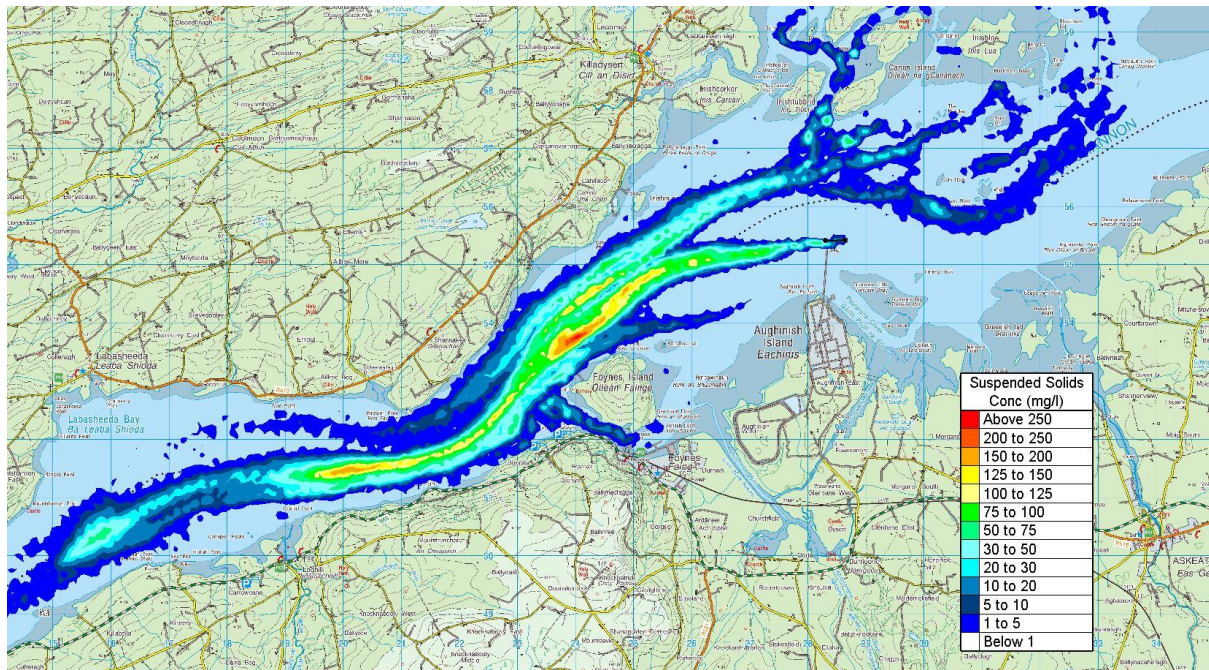


Figure 17 Predicted Suspended Sediment Concentrations from plough dredging activity at Low Water Neap Tide

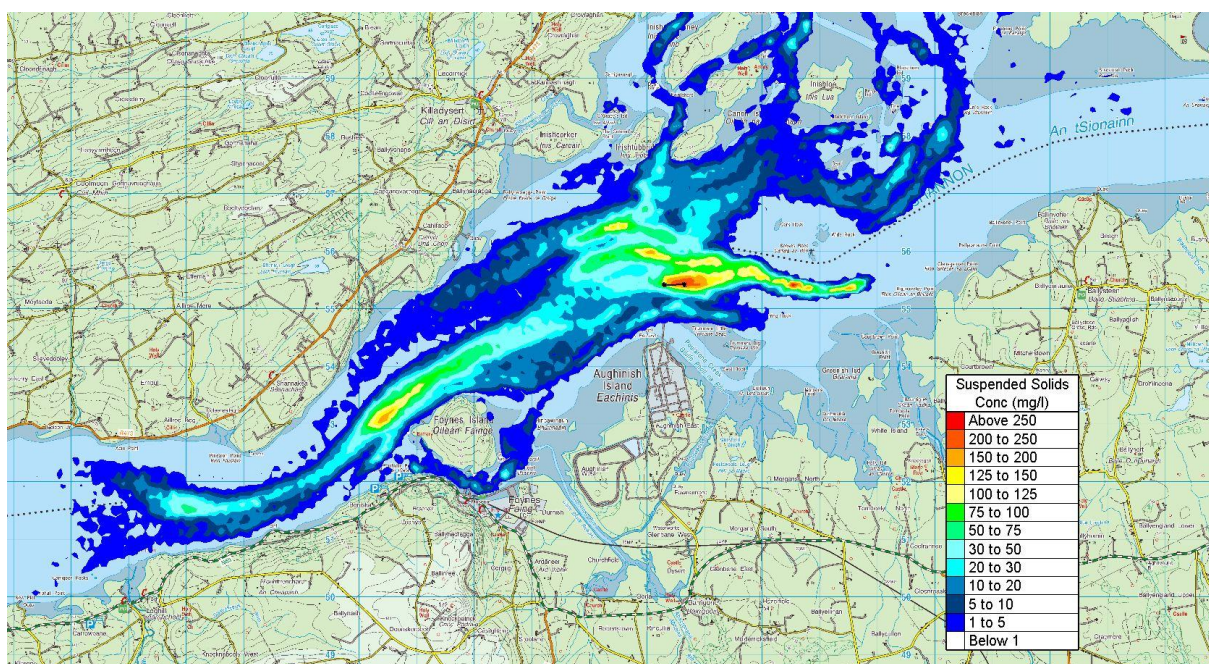


Figure 18 Predicted Suspended Sediment Concentrations from plough dredging activity at Mid-Flood Neap Tide

Appendix 1 Tide Velocity Survey Data

Hydrographic Surveys Ltd carried out Recent Neap Tide Current Metering Survey at Aughinish Marine Terminal Inner and Outer berths on the 20th January 2016.

Hydrographic Surveys Ltd.

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PH15014B - Aughinish Alumina Current Metering

Aughinish Alumina - Current Metering - 20 January 2016 - Neap Tides

Location Inside Pier - Upriver

Wind Strong Breeze SE, 15-20kn

Tidal Rang 3.3m

Lat 52°38.194 Lon 9°03.372

Time (hours)	1.5m Below Surface		Mid Water Depth		1.5m Above Seabed	
	Speed m/	Dir	Speed m/	Dir	Speed m/	Dir
-6	0.041	341.6	0.029	003.3	0.085	162.8
-5	0.222	124.2	0.261	115.6	0.092	139.8
-4	0.290	157.1	0.171	148.6	0.124	172.7
-3	0.422	117.7	0.246	137.8	0.225	143.2
-2	0.311	135.7	0.339	160.0	0.320	122.6
-1	0.460	146.7	0.561	140.1	0.322	166.3
HW	0.338	325.7	0.103	330.4	0.138	333.0
1	0.679	334.6	0.568	341.6	0.608	328.0
2	0.804	329.4	0.709	345.4	0.654	331.5
3	0.769	332.3	0.704	346.6	0.706	333.2
4	0.841	333.6	0.743	330.4	0.685	336.7
5	0.624	319.5	0.529	320.6	0.503	328.0
6	0.360	316.6	0.362	316.4	0.331	313.6



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PH15014B - Aughinish Alumina Current Metering

Aughinish Alumina - Current Metering - 20 January 2016 - Neap Tides

Location Inside Pier - Downrive **Wind** Strong Breeze SE, 15-20kn

Tidal Rang 3.3m Lat 52°38.261 Lon 9°03.451

Time (hours)	1.5m Below Surface		Mid Water Depth		1.5m Above Seabed	
	Speed m/	Dir	Speed m/	Dir	Speed m/	Dir
-6	0.170	108.0	0.132	153.7	0.169	137.2
-5	0.361	120.2	0.167	145.2	0.079	133.7
-4	0.393	125.1	0.434	151.1	0.383	139.1
-3	0.356	130.2	0.527	161.0	0.537	149.0
-2	0.422	121.0	0.524	131.8	0.481	125.6
-1	0.294	089.4	0.282	174.4	0.162	129.3
HW	0.508	320.5	0.123	275.3	0.240	124.8
1	0.702	333.7	0.654	331.1	0.618	329.0
2	0.806	327.3	0.736	341.5	0.689	335.3
3	0.806	327.3	0.736	341.5	0.689	335.3
4	0.944	322.0	0.791	325.6	0.783	328.3
5	0.604	321.0	0.608	320.7	0.596	328.1
6	0.305	320.4	0.136	314.9	0.111	328.1