Shannon Technology and Energy Park (STEP) Power Plant

Appendix A7A.5: Dispersion Modelling Report

Shannon LNG Limited

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Shannon Technology and Energy Park

Hydrodynamic and dispersion modelling
Of proposed development process and effluent discharges

Produced by

AQUAFACT International Services Ltd

for

Shannon LNG Ltd.

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1 INTRODUCTION

1.1 Background

AQUAFACT International Services Ltd. (AQUAFACT) were commissioned by consultants AECOM on behalf of Shannon LNG Ltd. (Shannon LNG) to undertake a 3D hydrodynamic study of the Shannon Estuary as part of the Environmental Assessment for the Shannon Technology and Energy Park development. The proposed development will be located near Ardmore Point located between Tarbert and Ballylongford in County Kerry.

1.2 General Description

The main components of the Shannon Energy Park are:

LNG Terminal

Power Plant

Gas transmission pipeline

The LNG Terminal will comprise

- A floating storage regasification unit (FSRU), which will have an LNG storage capacity of up to 180,000 m^3. The LNG vaporisation process equipment to regasify the LNG to natural gas shall be on-board the FSRU. The heat for LNG regasification shall be via seawater, supplemented by heat from gas fired heaters when the water temperature is inadequate. Loading of LNG onto the FSRU shall be via a ship-to-ship transfer from another LNG carrier (LNGC) berthed alongside.
- Jetty and access trestle, with the jetty comprising of an unloading platform, mooring dolphins and breasting dolphins.
- Four tugboats moored on the proposed jetty for FSRU and LNG carrier mooring operations.
- Onshore facilities including a nitrogen generation facility, a control room, a guard house, workshop and maintenance buildings, instrument air generator, fire water system.
- An Above Ground Installation (AGI) to include an odourisation facility, gas heater building, gas metering and pressure control equipment. The AGI facilitates the connection of the LNG terminal to the consented 26km Shannon Pipeline.

The Floating Storage Regassification Unit (FSRU) will be moored at a proposed LNG Jetty in the Shannon Estuary, refer to Figure 1.

The proposed on-shore Power Plant will comprise of:

- A flexible modular power plant design with up to three (3) blocks of Combined Cycle Gas Turbines (CCGT), each block with a capacity of *circa* 200 MW for a total installed capacity of up to 600 MW. The multishaft arrangement of the power plant provides fast acting response with very low minimum stable generation and is ideally suited to support increased intermittent renewable generation.

- Each block shall comprise of two (2) gas turbine generators, two (2) heat recovery steam generators and one (1) steam turbine generator and an air-cooled condenser.
- A 120 MW for 1 hour (120 MWhr) Battery energy storage facility (BESS). Due to its very fast response, the BESS supports intermittent renewable generation.

The hydrodynamic assessment documented herein was carried out with particular reference to possible adverse effects on the local flora and fauna. As part of the LNG development, it is intended to abstract seawater from the estuary, chlorinate that water, utilize the water as a source of heat for the LNG regasification onboard the FSRU, extract heat from the water and finally return the cooler water to the estuary.

For the Terminal Plant sanitary effluent (foul water) will be generated at three locations on the site: the workshop /warehouse building, the nitrogen package control room, and the main control room. For the Power Plant sanitary effluent will be generated at the following locations: the administration building, central control/operations building, storage/workshop/canteen building and each turbine building. All sanitary effluent from the development will be pumped or fall by gravity to a wastewater treatment plant (WWTP) on site, which is common to both the LNG Terminal and the power plant. This foul effluent will undergo secondary treatment and discharge to the Shannon Estuary in a marine outfall located close to the shoreline.

As part of this study, a computer based hydrodynamic and water quality model **Telemac** was used to assess the potential changes in water quality and temperature in the receiving waters due to chlorine residual and heated water discharges from the submarine outfall pipe. The purpose of the model simulations, the results of which are presented in this report, is to examine the dispersion pattern and concentration of the discharges from the outfall and to determine if they satisfy regulatory requirements as set out in the surface water regulations.

A description of the numerical model used to carry out the current study and the process of model calibration, are presented in Chapters 2. The results of the hydrodynamic and solute transport model are presented in Chapter 3. These results are discussed in relation to relevant water quality standards and conclusions based on the water quality model study are drawn and presented in Chapter 4.

Figure 1 ***Location of proposed LNG Terminal with FSRU near Ardmore Point***

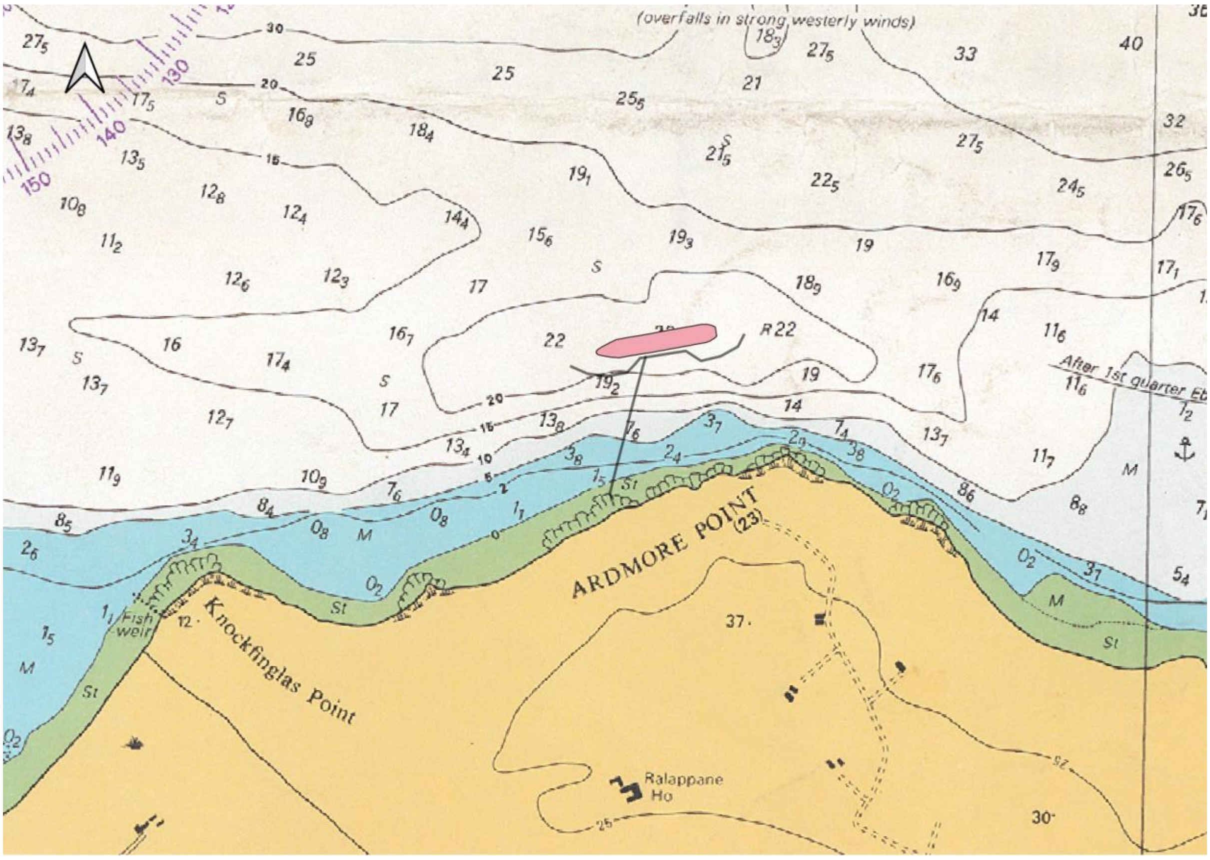

Figure 2 ***Location of proposed LNG Terminal and FSRU overlain onto admiralty chart***

2 MODEL DEVELOPMENT AND HYDRODYNAMICS

2.1 Model Background

The **TELEMAC** system and specifically **Telemac-2D** and **Telemac-3D** modules is the software of choice for modelling the complicated hydrodynamics of the Shannon Estuary off Ballylongford Co. Kerry and particularly given the very high computation refinement required to model accurately the three-dimensional flow in the vicinity of the proposed outfall discharge. **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.

TELEMAC is an integrated, user friendly software system for free surface waters. TELEMAC was originally developed by Laboratoire National d'Hydraulique of the French Electricity Board (EDF-LNHE), Paris. It is now under the directorship of a consortium of organisations including EDF-LNHE, HR Wallingford, SOGREAH, BAW and CETMEF. It is regarded as one of the leading software packages for free surface water hydraulic applications and with more than 1000 Telemac Installations Worldwide.

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 that alter density and thus the hydrodynamics.

Telemac-3D is a three-dimensional computational code describing the horizontal and vertical 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 that alter density and thus the hydrodynamics. It can be set to solve the barotropic (constant non-varying density conditions) and baroclinic pressure conditions where the active tracers of salinity and temperature influence density. The baroclinic approach is required to model the dispersion of cooled water discharge from the FSRU which initially will sink being denser than the ambient water.

The horizontal coordinates are set as Cartesian Coordinates to Irish OS grid and the vertical coordinates are transformed using a "σ" (sigma) vertical coordinate transformation allowing accurate representation of the vertical water column for representation of surface and bottom boundary processes. The bathymetry specified at every finite element node is referenced to Chart Datum which is c. 3m below OS Malin Datum.

2.2 Model Development

A 2-dimensional depth averaged model of the entire Shannon Estuary from Loop head to Corbally weir was developed previously to provide hydrodynamic input for Oil spill simulation by the Shannon-Foynes Harbour Company. This model was run using **Telemac-2d** and had an unstructured finite element mesh of variable density depending on the geometry requirements, the total number of nodes 10,294 and total finite elements 17,980 (representing an estuarine area of 561km^2).

The hydrodynamic output (time varying horizontal U and V velocities and water depth) from this model was used to drive the flow and elevation boundary conditions in a more refined local 3-D model of the middle estuarine reach. The output was also used to provide initial hydrodynamic conditions within the model domain for the simulation start period. This refined model extends from Kilcredaun Point Co. Clare and Kilconly Point Co. Kerry eastward to Mountshannon Co. Clare and Carraunbaur Pt. Co. Limerick. The computation mesh of the local 3-D model is a variable density mesh ranging in node spacing varying horizontally from 30m to 400m with the more refined 30m meshing being limited to the receiving waters near the outfall and intake locations. The vertical discretisation is 15 equal vertical layers using a sigma transformation relationship. The total node number for the 3D model is 74,475 and the total number of elements is 389,340 (Estuarine area 151km^2 and 1,848 million m^3 below chart datum).

The 3-Dimensional local model was developed using detailed bathymetry survey data obtained from the following sources: Irish Hydrodata, the GSI Infomar lidar seabed data and relevant Admiralty Charts for outside the survey areas. This bathymetry was interpolated and mapped to the finite element mesh nodes using mesh generator software refer to figures 3, 4 and 5.

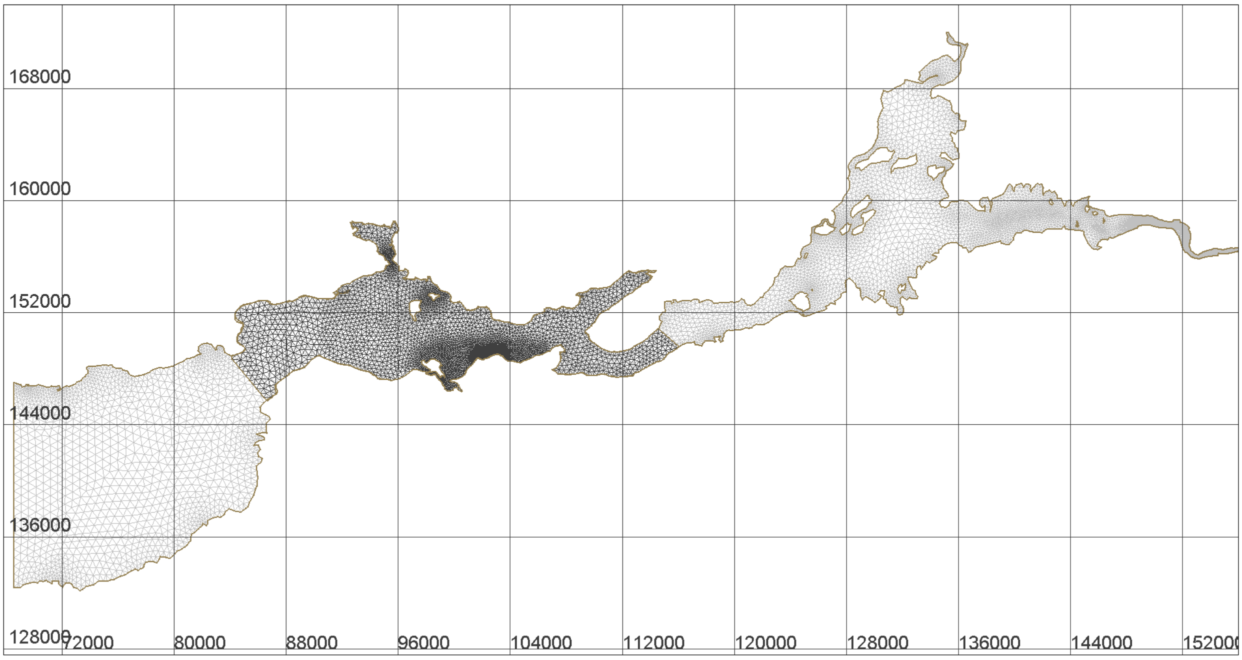

Figure 3 ***Shannon Estuary and refined LNG model Domain***

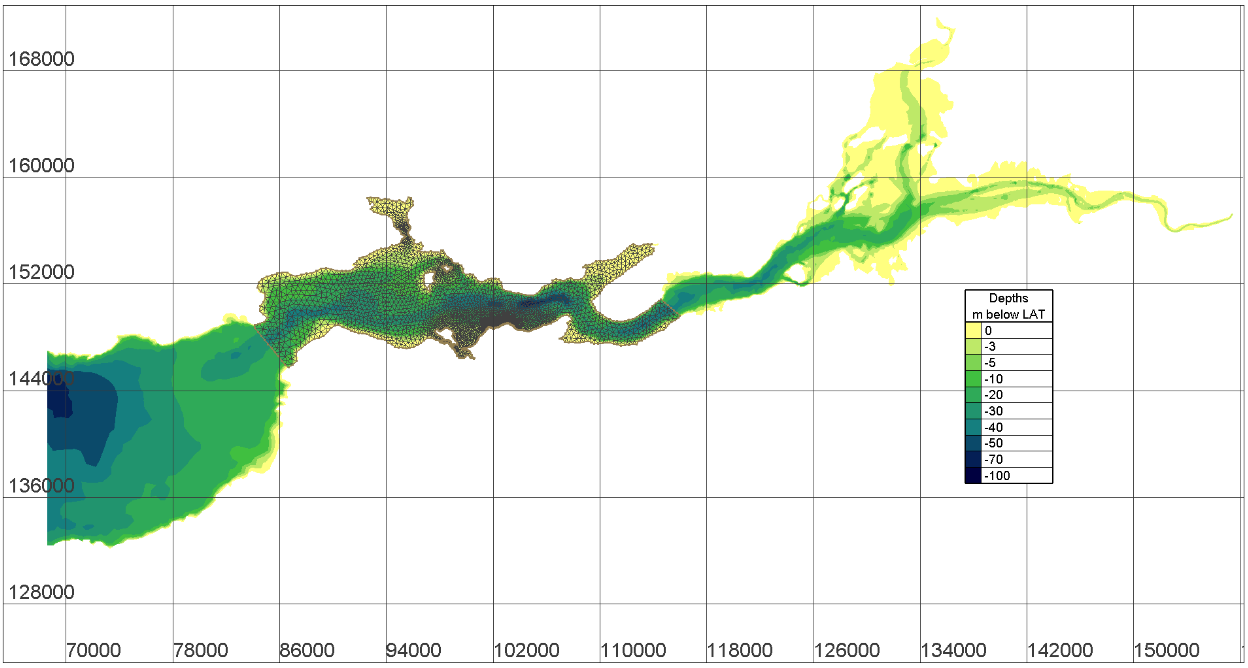

Figure 4 ***Shannon Estuary and refined LNG model Domain***

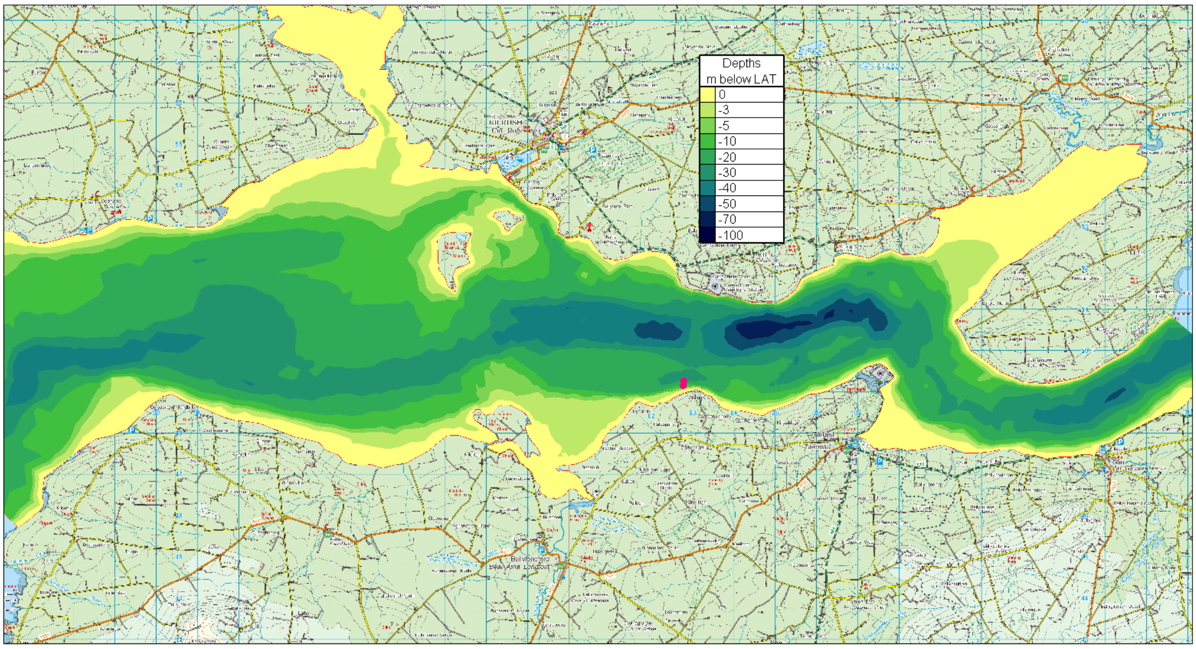

Figure 5 ***Bathymetric Contour Map from GSI lidar, Irish Hydrodata Survey and Admiralty Chart for model Domain.***

Boundary conditions specified are a tidal elevation boundary modelled with a Thompson Radiation condition along the western sea boundary and a flow boundary along the estuarine sea boundary representing the total tidal and fluvial flux from the estuarine area east of the model as computed by the 2-D model of the entire estuary, refer to figure 6. The tidal component of flow through the east boundary far outweighs the fluvial influence from the Shannon and other contributing rivers (Fergus, Maigue, Deal etc.) and is the dominant influence on hydrodynamics in the vicinity of the proposed outfall.

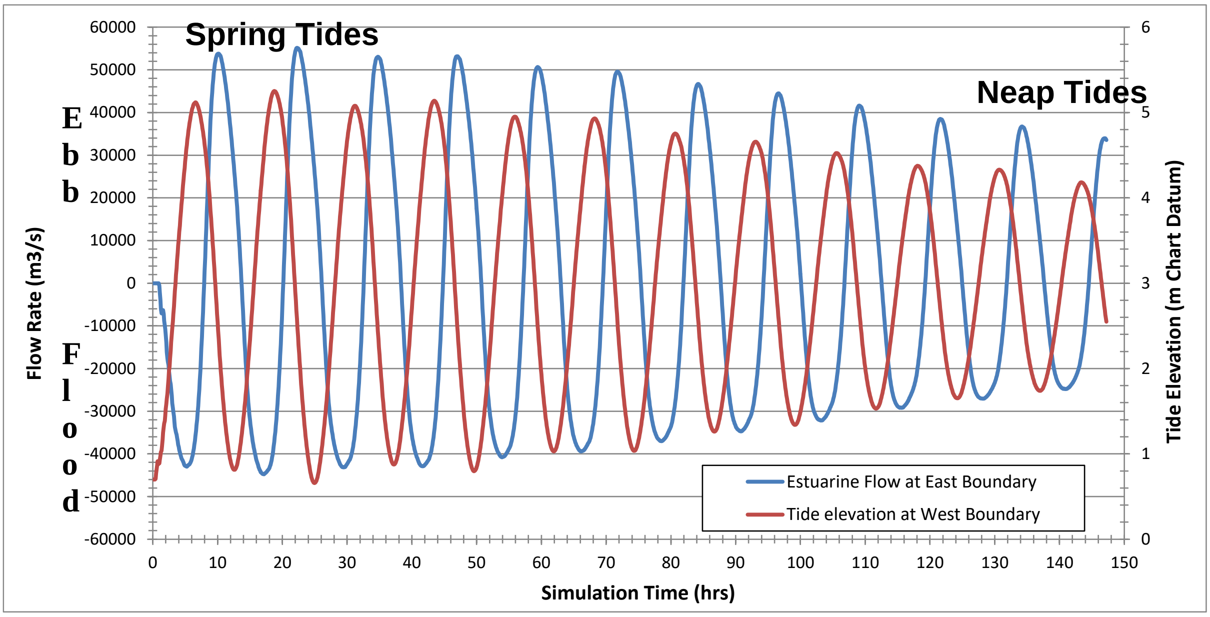

Figure 6 Tide and flow boundary hydrographs inputted to 3-D model Simulations

The first stage consisted of running the hydrodynamic model of the area surrounding Ballylongford to compute the hydrodynamic patterns and tidal elevations within the receiving water for prescribed environmental conditions. The second stage in the study was the calibration of this hydrodynamic model against field data. The solute transport model then uses the output from the hydrodynamic model to compute concentrations of residual chlorine and water temperature.

2.3 Hydrodynamic Simulation Results

The hydrodynamic model was run for mean spring to neap tides to examine the water circulation patterns and the variation of current velocities throughout the receiving estuarine waters. The results from the hydrodynamic model simulations are presented as vertically integrated snapshots in time of velocity vectors at each nodal point of the finite element mesh. The output is presented at eight different stages during the course of spring and neap tidal cycles: (i.e. high water, flood tide flows at 1.5hour intervals, low water and ebb tide flows at 1.5hour intervals). The mean spring and neap tidal ranges specified for these simulation runs were 4.6m and 2.2m respectively.

The current velocities calculated during the tidal cycle are considerably greater on the ebbing (out-going tide) tide than the returning flooding tide, such characteristics are also evident from the Irish Hydrodata 2006 current metering survey. As a result of the smaller tidal range for neaps, the predicted tidal velocities are considerably lower than the corresponding spring tide velocities. The maximum neap tide velocity in the vicinity of the outfall site is approximately 0.6m/s to 0.8m/s (flood and ebb flows), whereas the maximum spring tide velocity is 0.8 to 1.2m/s (flood and ebb flows), refer to Figure 9 (9.1 to 9.8) and 10 (10.1 to 10.8) below. The direction is predominantly rectilinear flowing predominantly east and west across the outfall.

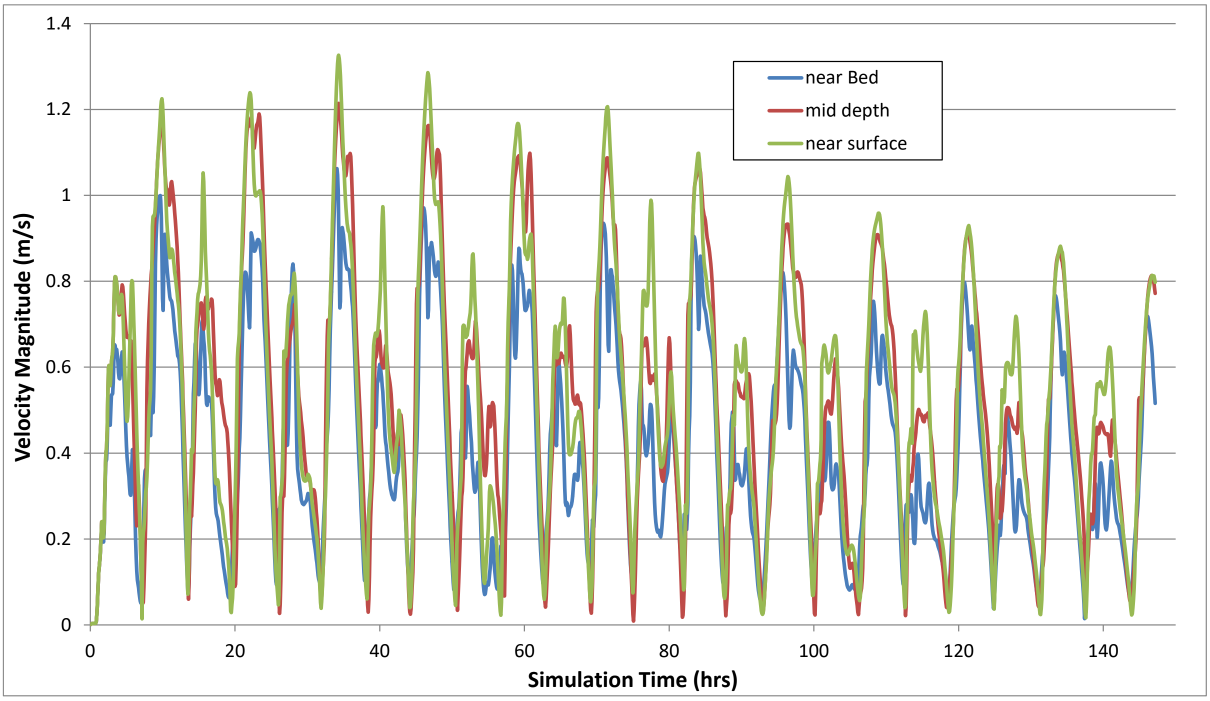

Figure 7 Computed Current Magnitudes at Outfall for layers 2, 6 and 11 (note these compare very well with the Irish Hydro Data 2006 ADCP current Survey information)

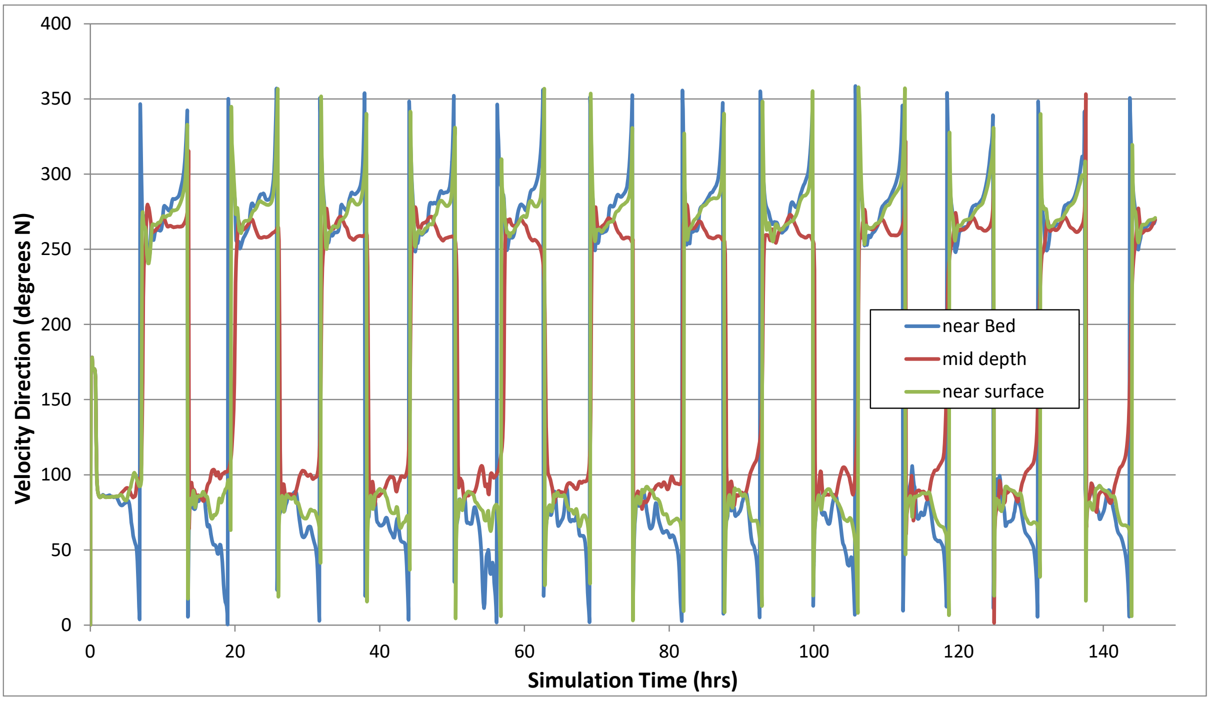

Figure 8 Computed Current Direction at Outfall for layers 2, 6 and 11 (note these compare very well with the Irish Hydro Data 2006 ADCP current Survey information)

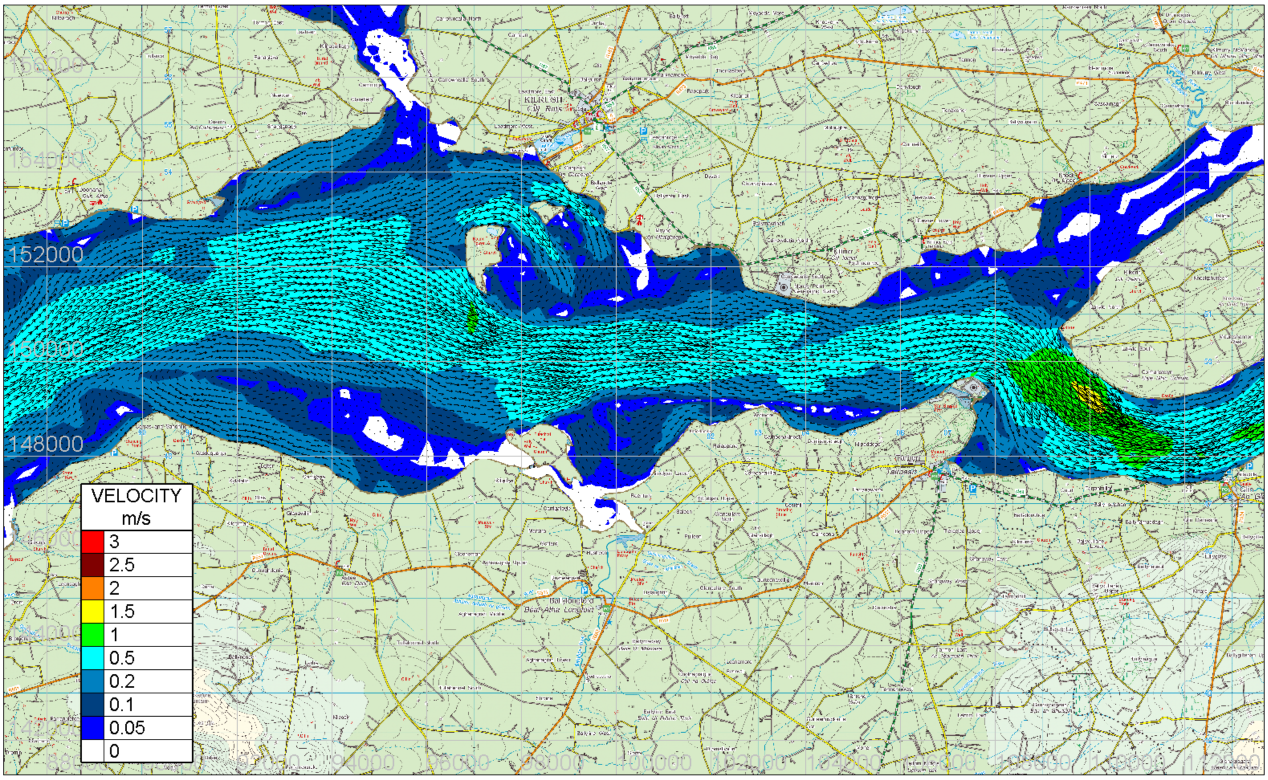

Figure 9.1 ***Spring tide velocities – High Water (simulation Time 19:00hrs)***

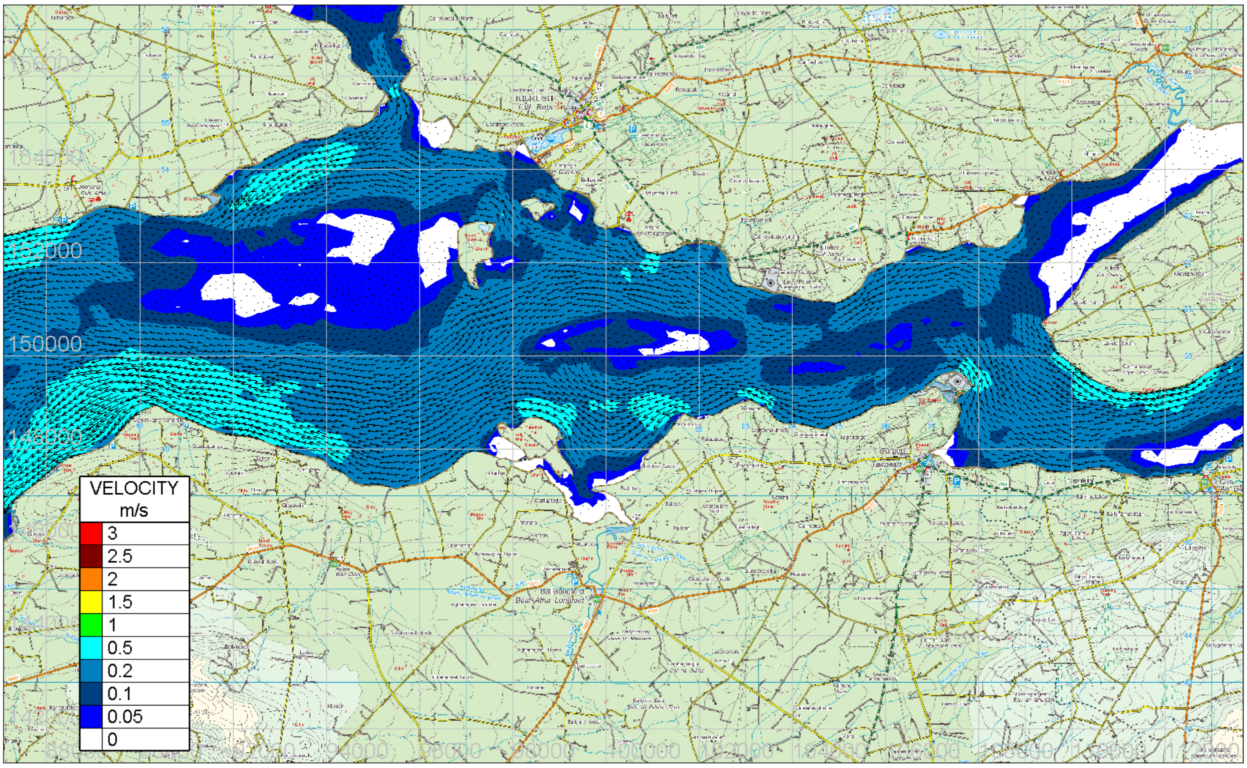

Figure 9.2 ***Spring tide velocities – 1.55hrs after High Water (simulation Time 20:35hrs)***

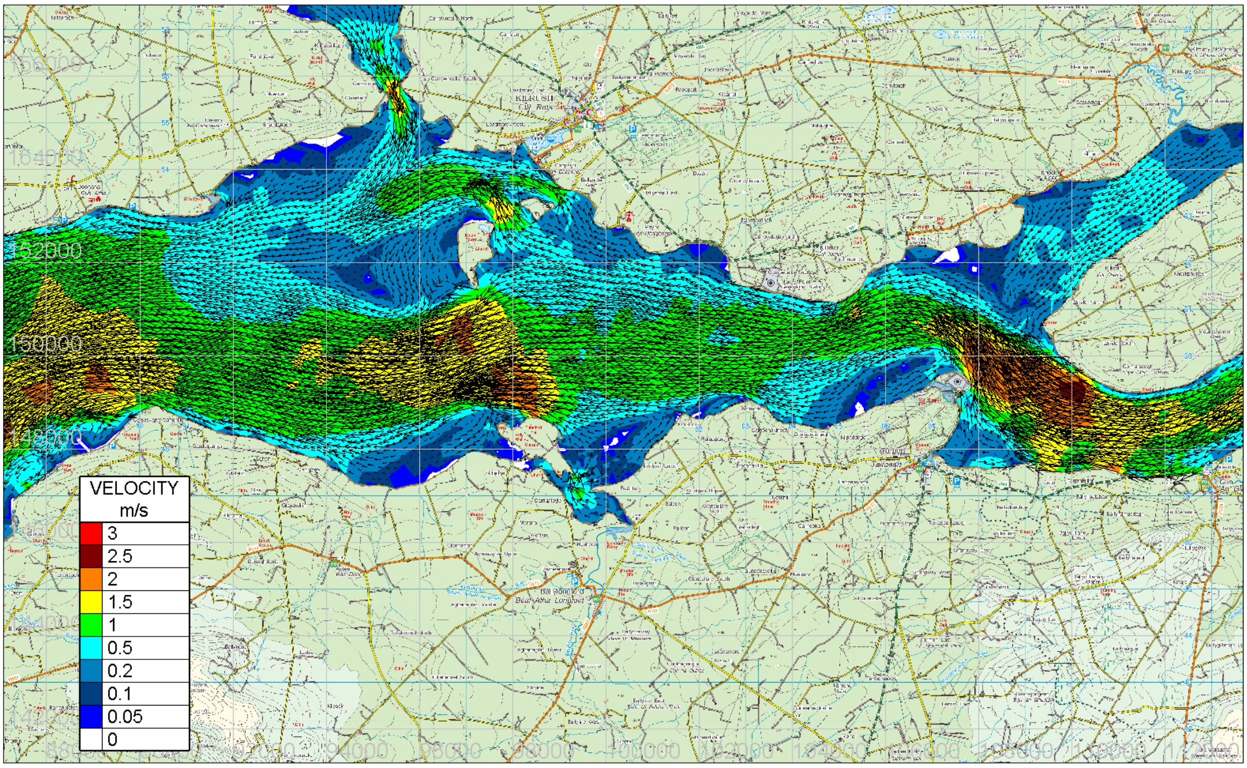

Figure 9.3 Spring tide velocities – Mid-Ebb Flow (simulation Time 22:10hrs)

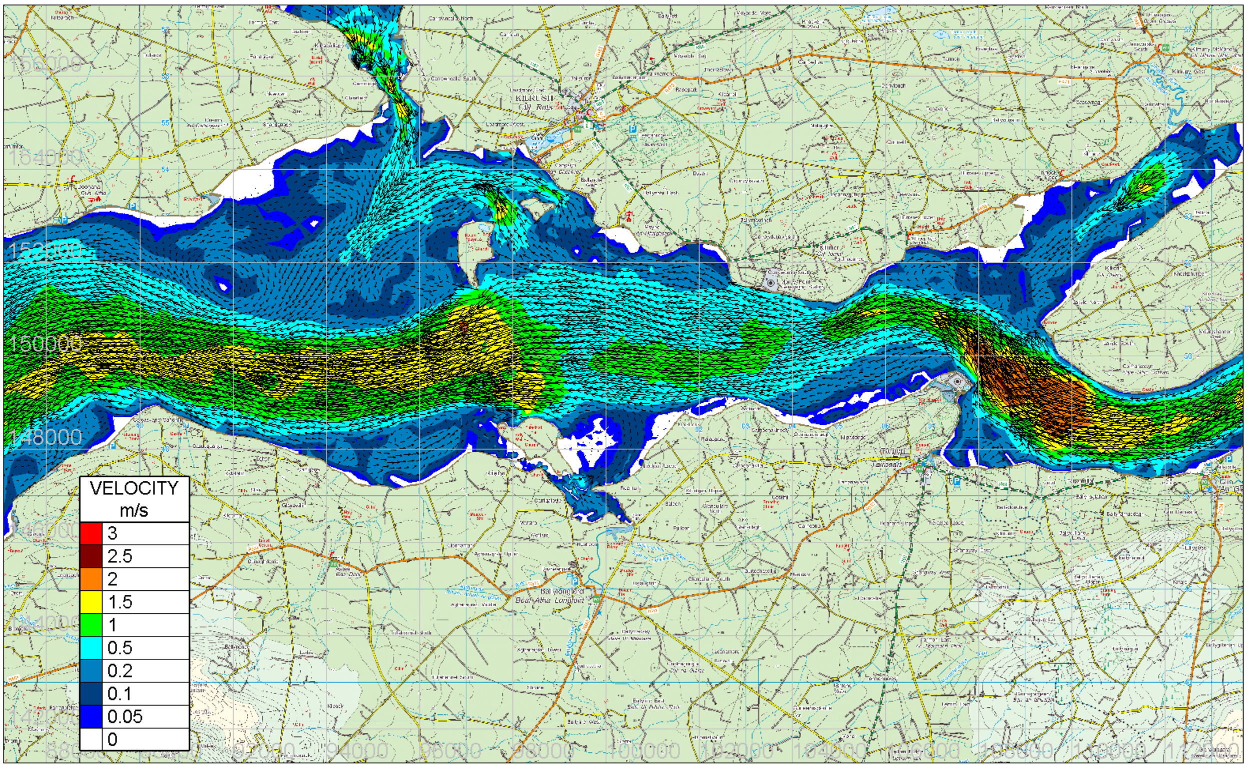

Figure 9.4 Spring tide velocities 1.5hrs before Low Water (Simulation Time 23:40hr)

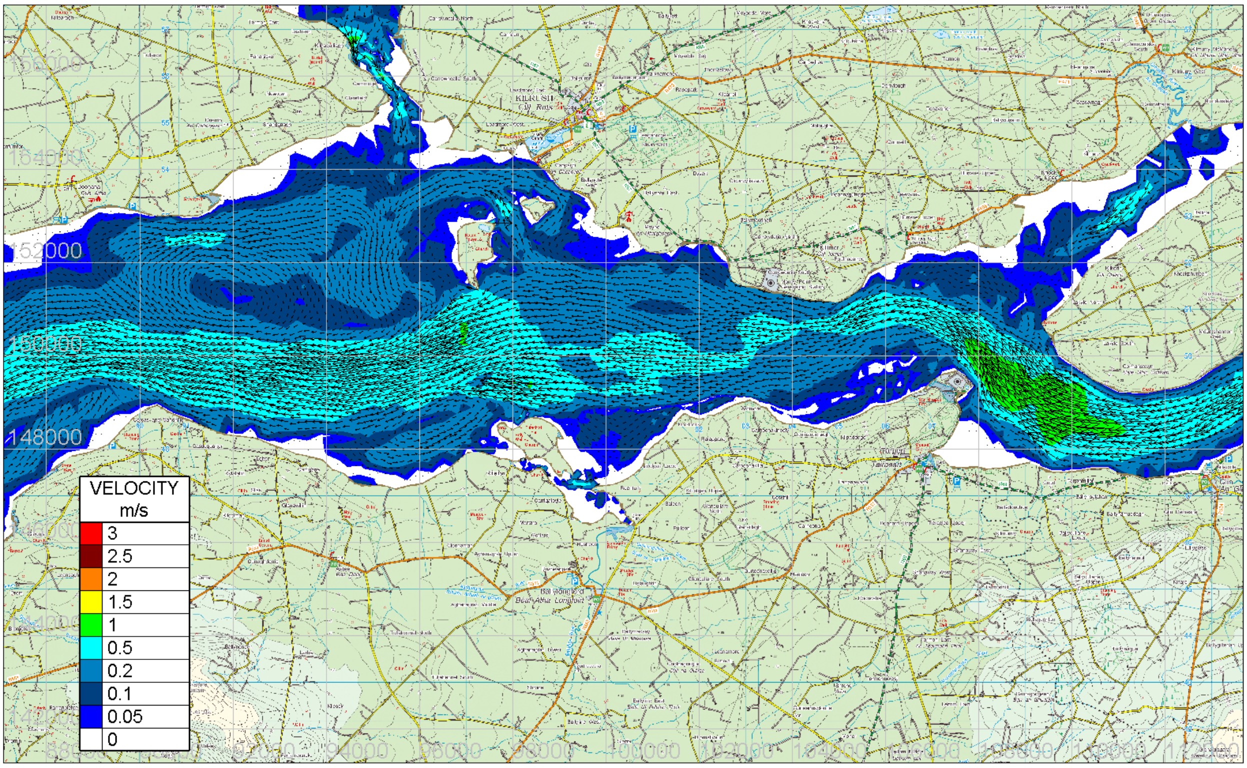

Figure 9.5 *Spring tide velocities Low Water (Simulation Time 25:10 hrs)*

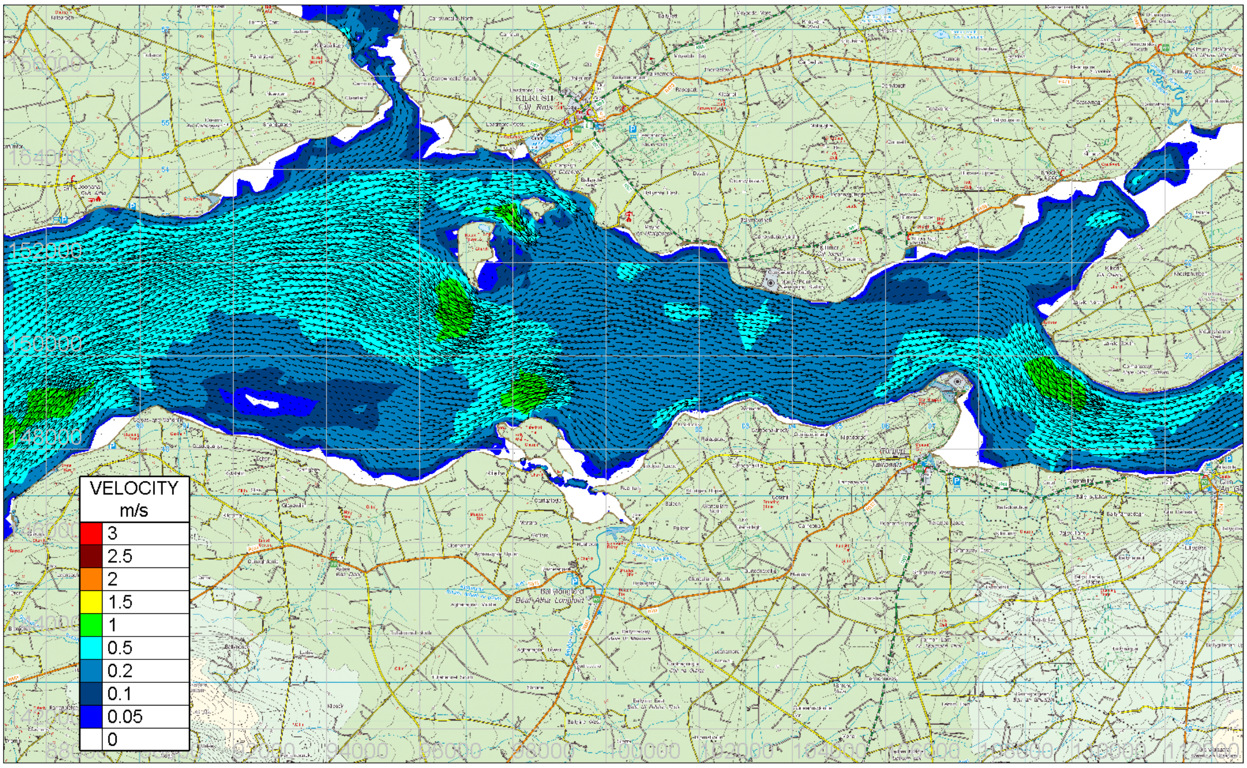

Figure 9.6 *Spring tide Velocities 1.5hr after Low Water (Simulation Time 26:40 hrs)*

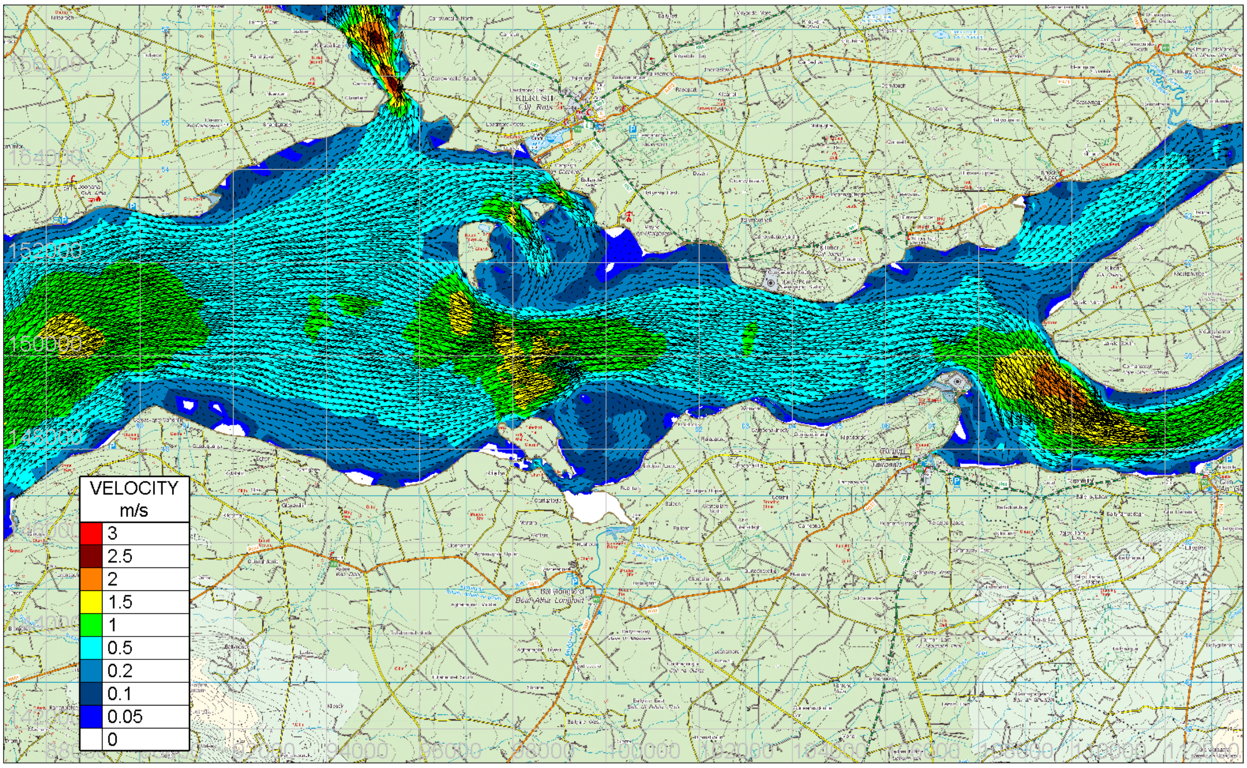

Figure 9.7 Spring tide velocities - Mid Flood (Simulation Time 28:20hrs)

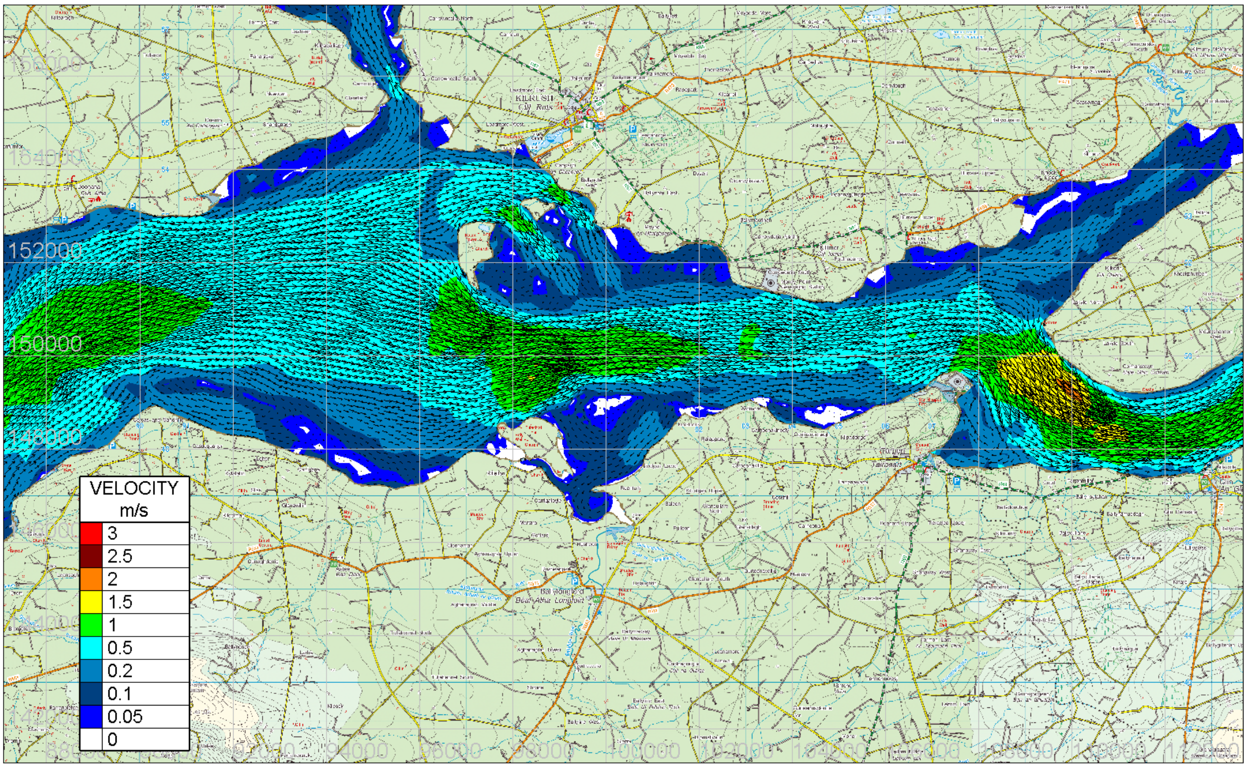

Figure 9.8 Spring tide velocities 1.5hr before High Water (Simulation Time 30:00 hrs)

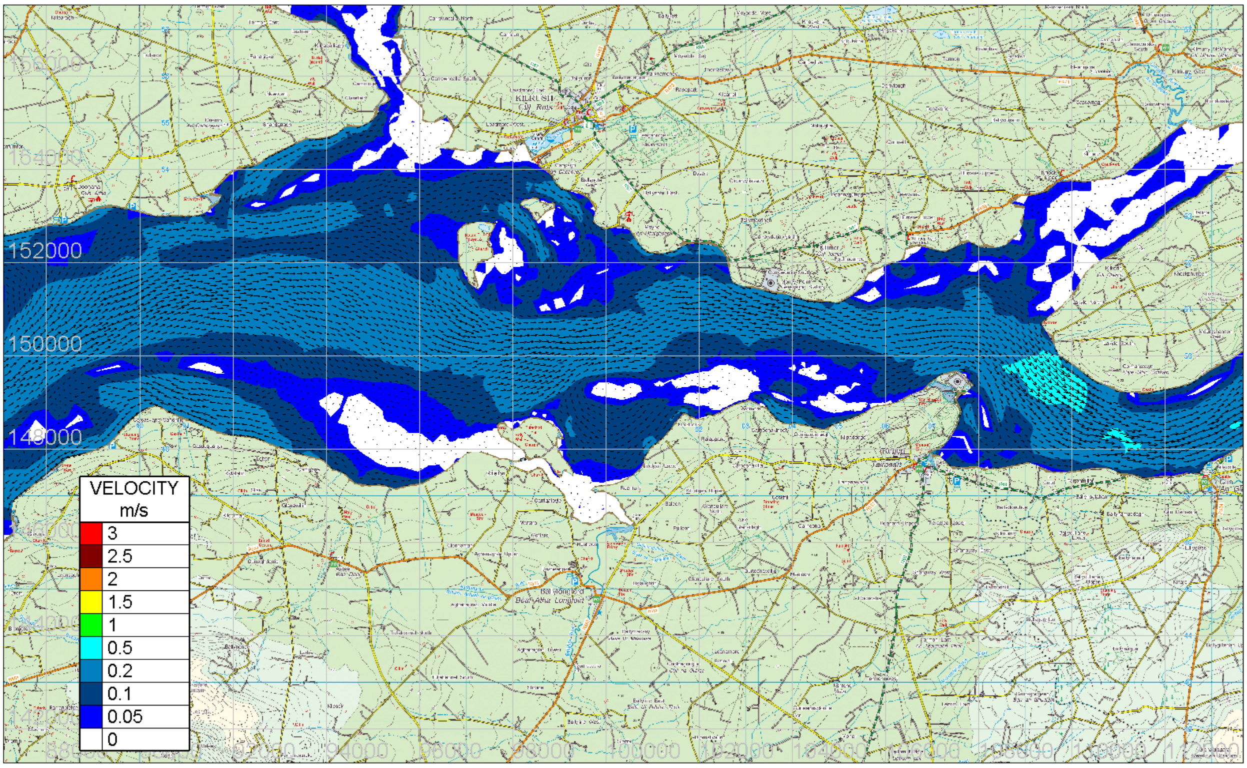

Figure 10.1 Neap tide velocities – High Water (simulation Time 19:00hrs)

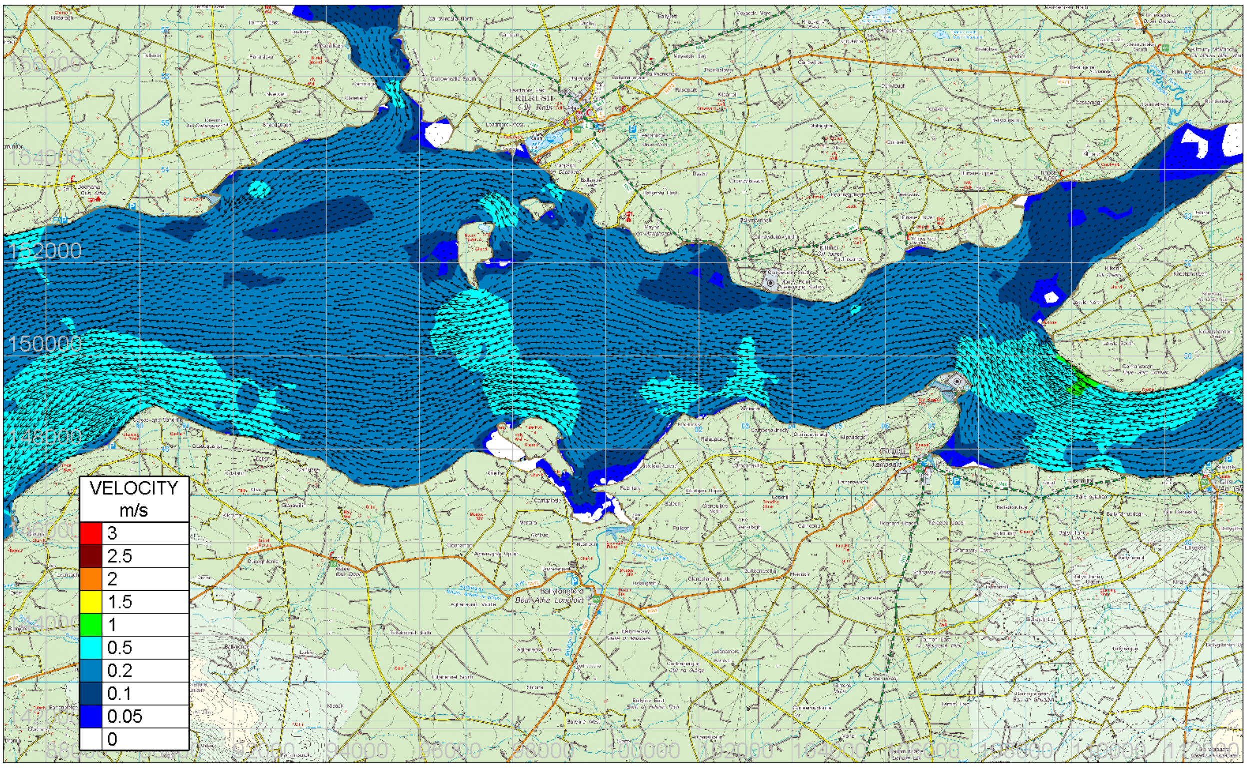

Figure 10.2 Neap tide velocities – 1.55hrs after High Water (simulation Time 20:35hrs)

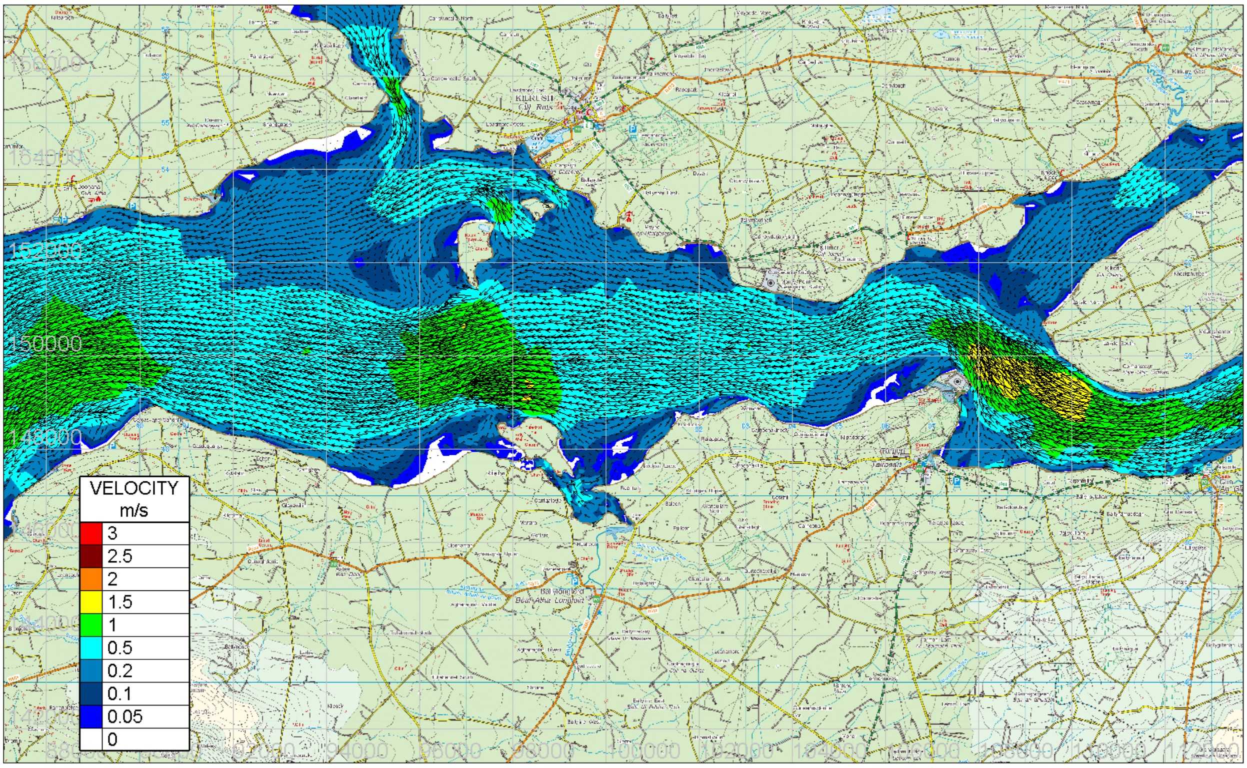

Figure 10.3 *Neap tide velocities – Mid-Ebb Flow (simulation Time 22:10hrs)*

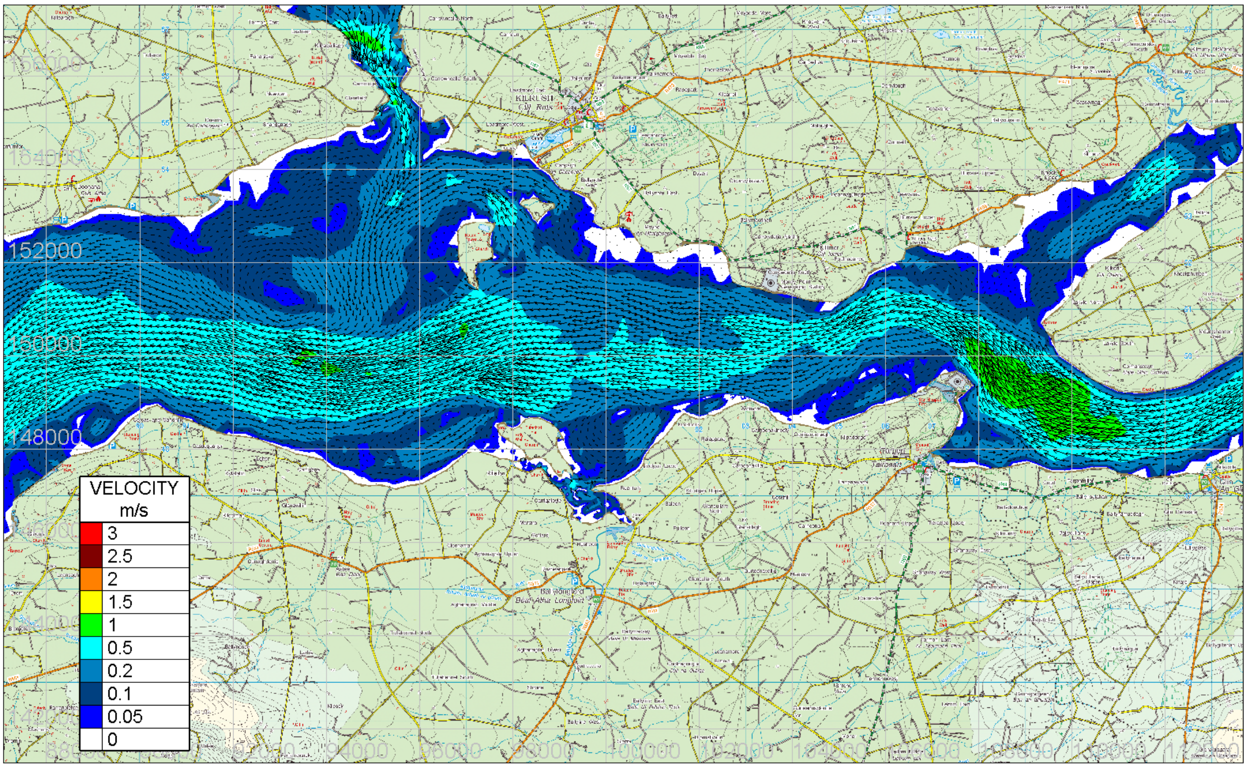

Figure 10.4 *Neap tide velocities 1.5hrs before Low Water (Simulation Time 23:40hr)*

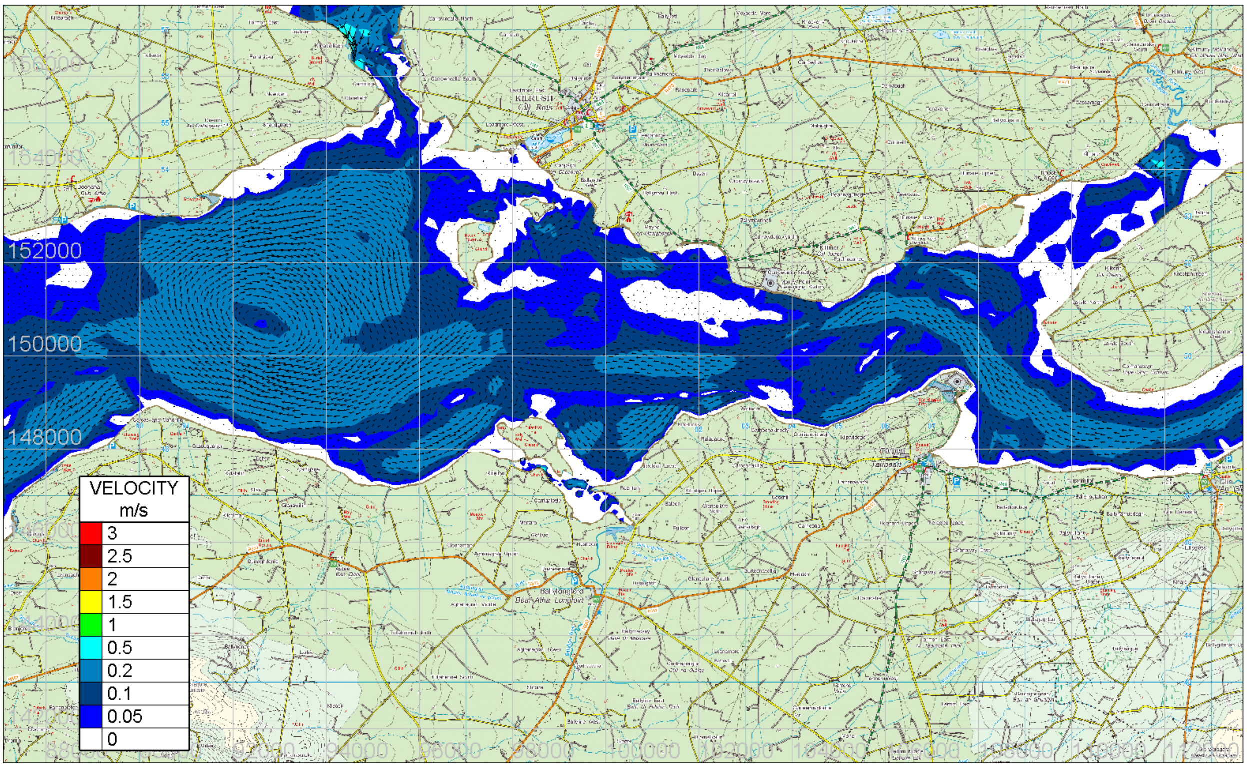

Figure 10.5 Neap tide velocities Low Water (Simulation Time 25:10 hrs)

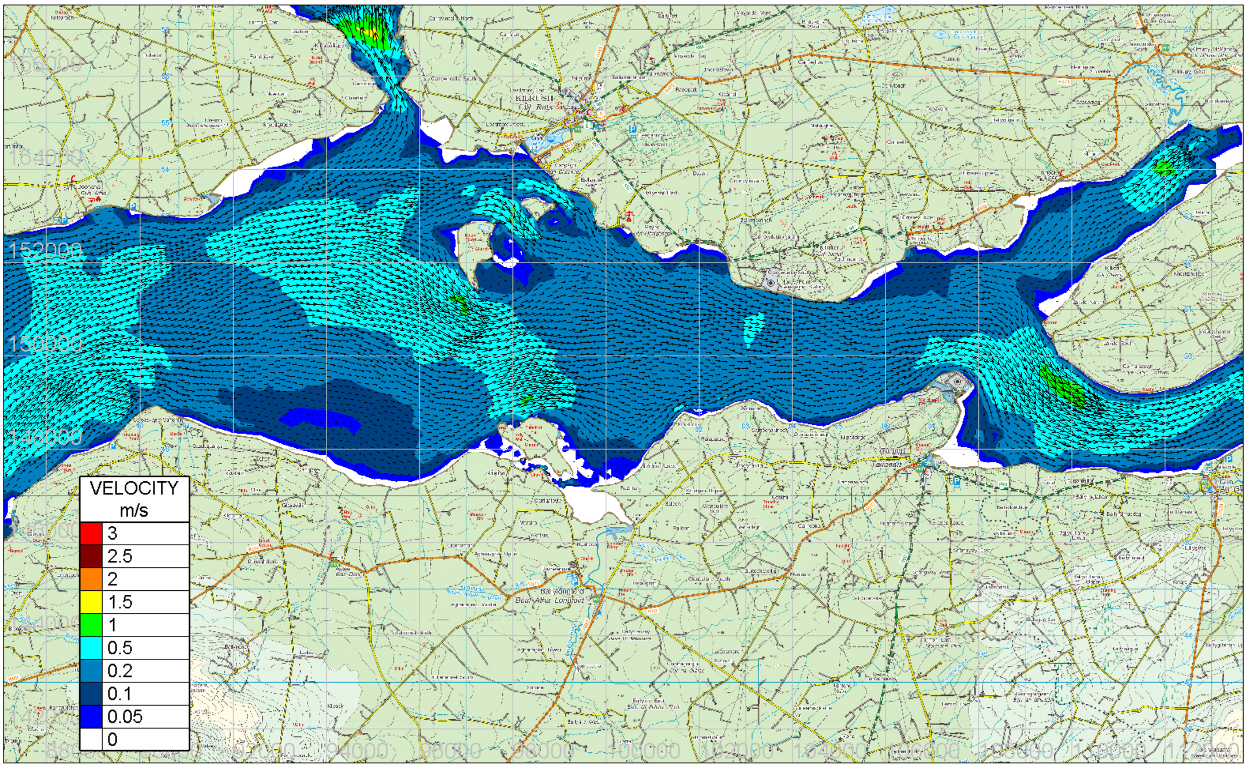

Figure 10.6 Neap tide Velocities 1.5hr after Low Water (Simulation Time 26:40 hrs)

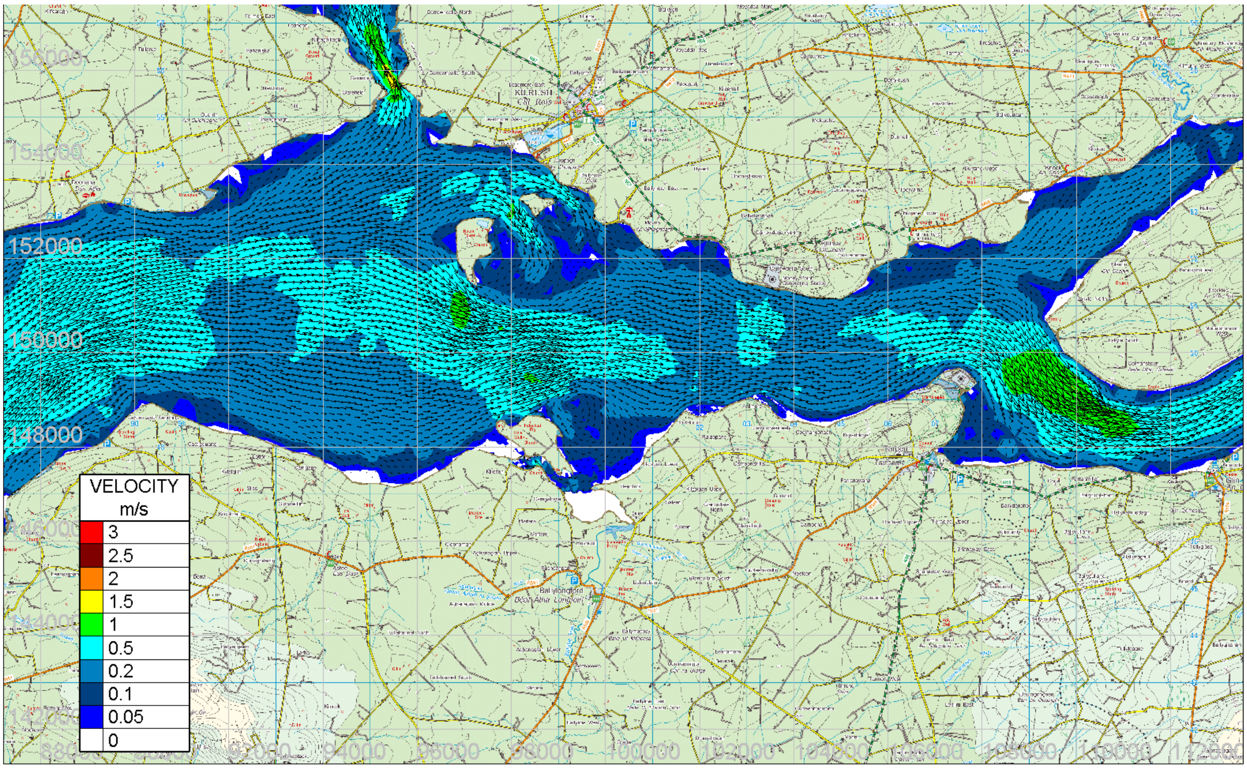

Figure 10.7 ***Neap tide velocities - Mid Flood (Simulation Time 28:20hrs)***

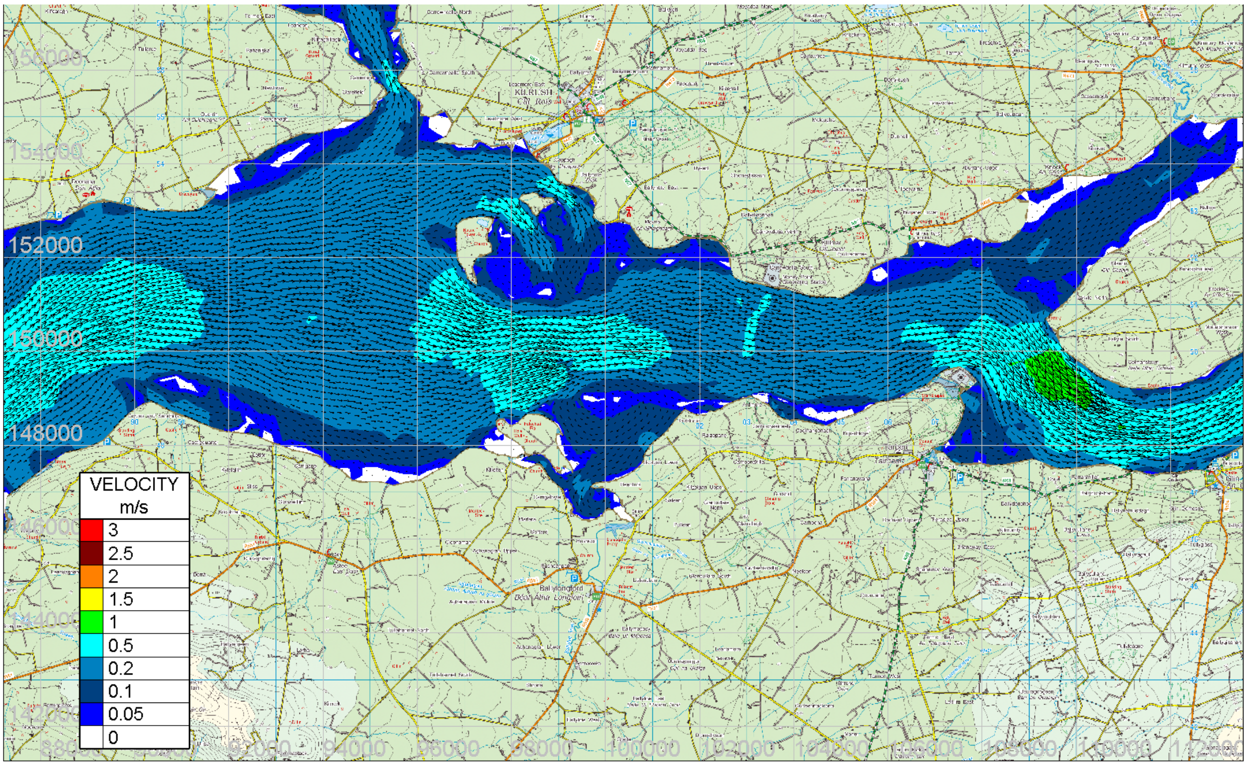

Figure 10.8 ***Neap tide velocities 1.5hr before High Water (Simulation Time 30:00 hrs)***

3 DISPERSION SIMULATIONS AND INPUTS

3.1 Discharge Characteristics

The characteristics of the cooled water to be discharged from the Floating Storage Regasification Unit are shown in table 1. The hydraulic load of 22,000m^3/hr is the peak loading from the FSRU and is equivalent to 6,111l/s (6.111 cumec). It was decided to model the peak flow so that a ‘worst case scenario’ could be observed in the receiving water. The modelling approach adopted in this study considers the background concentration of chlorine to be zero and that the differential change in temperature is 8^{o}C below ambient with ambient modelled at 12^{o}C so that the output represents solely the effect of discharging effluent in the receiving waters.

Table 1 Characteristics of the Cold Water Discharge from Outfall Pipe

Maximum Discharge rate (m^3/hr)	Maximum Residual Total Chlorine Concentration (mg/l)	Maximum Differential Temperature (^{0}C)
22,000	**0.50**	**-8.0**

3.2 Intake and Outfall Location of the Cooling Water

The seawater intake for the LNG regasification system will be on the side of the FSRU underwater. Screens will be installed to prevent debris in the sea water from entering the FSRU. The approach velocity at the screens will not be greater than 0.3 m/s to allow mobile marine biota to swim away. The screen mesh size will be approximately 5 mm x 5 mm. However, some small debris, leaves, plankton, and juvenile fish will be drawn in through the screens. It is expected that any silt entering the seawater circulating water system will remain in suspension and carry right through the system.

The regasification water outlet is also on the side of the FSRU underwater. The maximum projected change in water temperature is 8 °C below ambient seawater temperature. Other seawater inlet and exit points are at multiple locations. The FSRU regasification seawater discharge point is the largest discharge point from the FSRU.

Following the intake of seawater into the vessel, an electric current is passed through the seawater (a process known as electrolysis). Electrolysis breaks up the naturally occurring salt molecules (sodium chloride) in seawater and produces chlorine and hypochlorite, which prevents the growth of marine organisms in the internal piping system and the seawater heat exchangers of the FSRU. When the seawater is discharged from the vessel back into the marine environment, some short-lived residual chlorine would be present before mixing and decay. The concentration of residual chlorine at the discharge shall be monitored and shall not exceed the permissible limit of 0.5 mg/l.

In order to simulate the discharge from the outfall it was allocated a single finite element node location within the model domain at Irish Grid E102833, N149341 and the seawater intake was modelled at the node located at E102778, N149285.

3.3 Sanitary Effluent Discharge

Sanitary effluent will be generated by the LNG Terminal and by the Power Plant. All sanitary effluent will be pumped or fall by gravity to a common wastewater treatment plant (WWTP) on site. The effluent waste stream will be monitored for compliance with the licence limits and then discharged, via the storm water outfall pipe, to the Estuary.

A biological Wastewater Treatment System is proposed. It will be sized for a headcount of 67. Table 2 summarises the effluent stream generated from the WWTP and provides estimated quantities.

Effluent leaving the WWTP will be continuously monitored for pH before discharging to the estuary. The automatic control system associated with the WWTP will sound an alarm if pH falls outside of the expected range. This will alert the operator to take corrective action to remedy the problem. If the problem continues to go outside the pre-set range, this will automatically close the discharge valve and effluent will be diverted to a holding tank.

Table 2 Characteristic of WWTP Discharge

Parameter	Emission Limit Value
Volume	35 m^3/day
pH	6 – 10
BOD	25 mg/l
Suspended Solids	35 mg/l
Ammonia	5 mg/l as N
Total Phosphorous	2 mg/l as N

3.4 Power Plant Process Effluent

The Power Plant will generate several process water effluent streams. Some of the effluent streams will be collected and removed offsite and the remaining effluent streams will be pumped or fall by gravity to the effluent sump. Process water effluent leaving the effluent sump will be continuously monitored for pH before discharging to the estuary via the storm water outfall pipe.

The automatic control system associated with the effluent sump will sound an alarm if the pH goes outside a pre-set range – typically 6 to 9. This will alert the operator to take corrective action to remedy the problem. If the pH continues to go outside the pre-set range, this will automatically close the discharge valve and open the associated re-circulation valve and will then start the re-circulation process during which period the sump will be dosed with either acid or caustic soda to return the pH to between 7 and 8. At this stage, the automatic discharge valve will re-open and the re-circulation valve will close. A regular visual check on oils and greases will also be made in this sump to ensure that the discharge will be free of these contaminants before discharge. The process effluent in the sump will be monitored for compliance with the IE licence limits and then discharged, via the storm water outfall pipe, to the Shannon Estuary. Table 3 below summarises the Power Plant Process Effluent Sump Discharge.

All sanitary effluent from the FSRU will be retained onboard and discharged ashore via vacuum lorry.

Error! Reference source not found.**3 Power Plant Process Effluent Sump Discharge**

Parameter	Typical Range of Emissions (min to max)
Volume range	0 to 1,128m3/day
pH	6 – 9
Temperature range	25°C to 40°C
BOD	20 mg/l
Suspended Solids	30 mg/l
Total Dissolved Solids	5000 mg/l
Mineral Oil	20 mg/l
Total Ammonia (as N)	5 mg/l
Total Phosphorous (as P)	5 mg/l

3.5 Water Temperature Simulation Results

Using the maximum flow rate of 22,000m^3/hr, the Telemac-3D model was used to estimate the concentrations of the total residual Chloride and water temperature within the receiving waters of the Shannon Estuary from the regasification process. The process discharge was specified with a residual total chlorine concentration of 0.5mg/l and a maximum temperature decrease over the ambient temperature of 8^o C. The ambient temperature in the Shannon Estuary was set at 12^o C, and the discharging water temperature was set to 4^{o}C. The time step used in the model simulations was set to a time interval of 2 seconds because of the refined vertical spacing of 15 vertical layers. Full k – e vertical and horizontal turbulent modelling was performed. The model simulations were performed over a spring to neap tidal cycle for a simulation period of 360 hours. The duration of the simulation was sufficiently long enough to allow steady state conditions to be attained in the vicinity of the outfall and in the medium Field which includes Ballylongford Bay. This ensured that the minimum temperature and maximum concentration values, which would be reached throughout the water body, would be observed.

In order to analyse the model results similar to the hydrodynamics, snapshots of the predicted temperature plume within the study area were output at four principal stages of the tidal cycle over both a typical spring and neap tides and at four different layer depths vertically (layer 15 (surface), layer 10, layer 5, and layer 1 (bottom)) so as to demonstrate the extent and nature of the temperature plume, refer to figures 11.1 to 11.16. The minimum temperature envelope (representing maximum change in temperature) for the four selected vertical depths are shown in figures 11.17 to 11.20. To demonstrate the vertical mixing of the temperature plume time series of over two successive spring tides are presented in figure 11.21 and 11.22 at the proposed discharge site and also at 140m west of site for the four vertical layers. This shows the near field mixing of the temperature plume sinking towards the seabed due to its higher density with minimum temperatures of the discharge water towards the bottom layers at 130m from the site. At the site itself due to the elevation of the discharge port from the vessel minimum temperature is encountered at mid-depth. At the medium and far fields, the temperature change is small and is well mixed vertically and horizontally due to the high ebb and flood velocities. At the outfall site, the predicted minimum temperature is 10.38^{o}C representing a maximum temperature change over the ambient of 1.62^{o}C and occurs at layer 10. The maximum temperature change (decrease) in the bottom layer along the seabed is 0.76^{o} C. At 140m from the discharge site the minimum temperature which occurs on spring tides is 11.54^{o} C occurring in the bottom layer and representing a maximum decrease in ambient temperature of 0.46^{o} C.

The EPA proposal for estuarine waters states that the temperature measured downstream of a point of thermal discharge (at the edge of the mixing zone) must not exceed the unaffected temperature by more than 1.5^{o}C. The EPA have in previous discharge licenses allowed a regulatory mixing zone length of no greater than 10% of the channel width. In the case of the Shannon Estuary at Ardmore Point, the minimum estuary width is 2.3km indicating an allowable mixing zone of 230m. Figure 11.23 presents the maximum reduction in ambient temperature within the receiving water body. This plot shows that within 200m of the discharge the maximum reduction in ambient temperature is less than 0.5^{o} C and that within 3km it is less than 0.1^{o}C. The maximum reduction in temperature within the Ballylongford bay area is > 0.05^{o} C and < 0.1^{o}C which is insignificant.

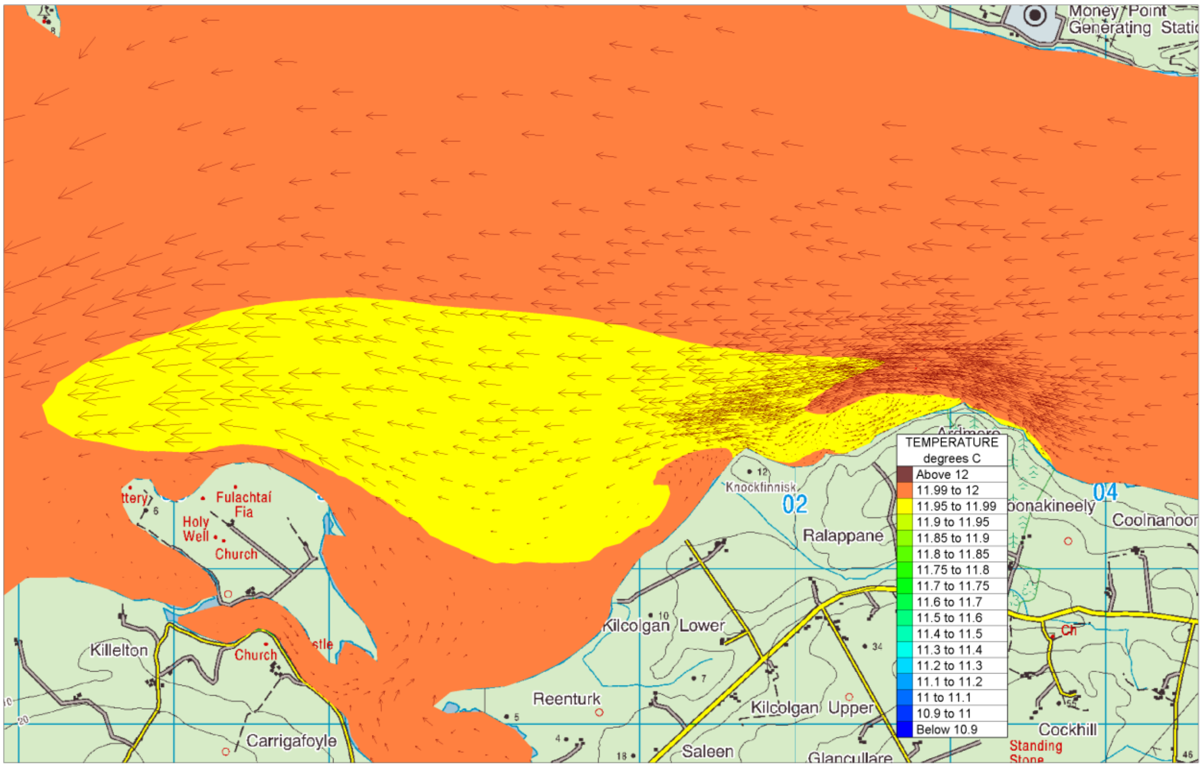

Figure 11.1 *Predicted Temperature in Surface Layer (15) at Mid-Ebb Spring Tide*

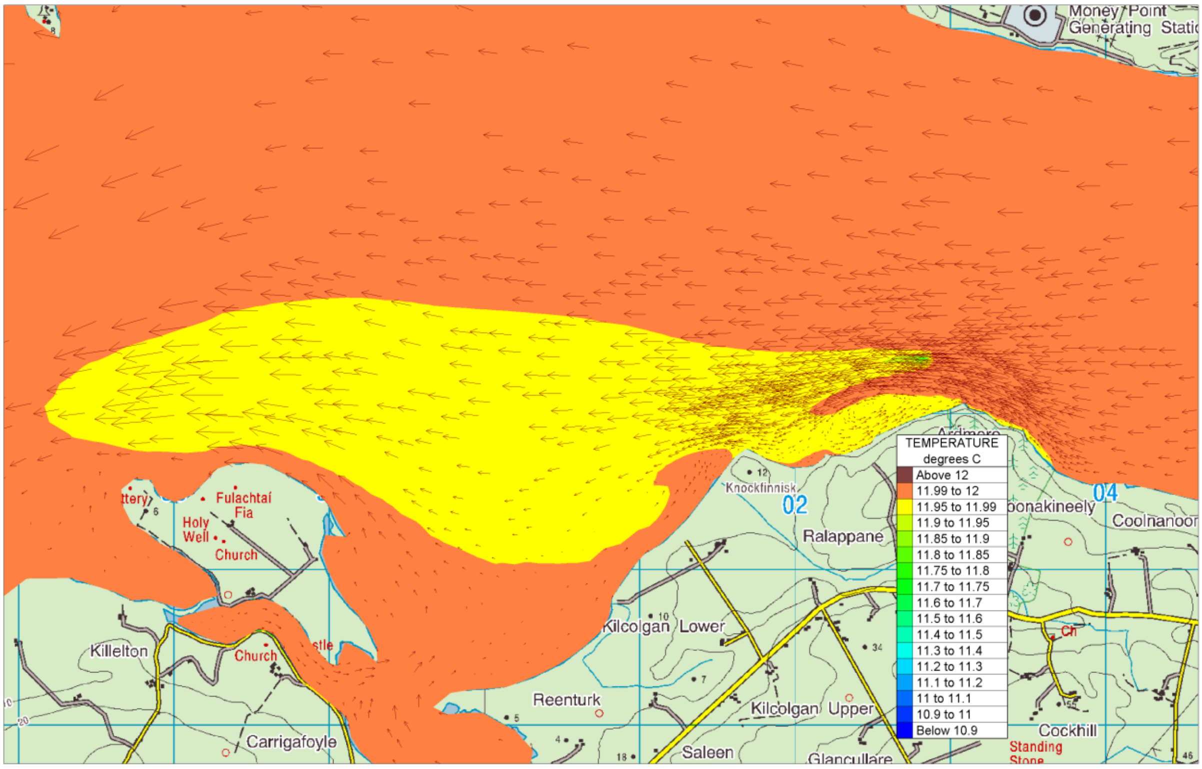

Figure 11.2 *Predicted Temperature in Vertical Layer (10) at Mid-Ebb Spring Tide*

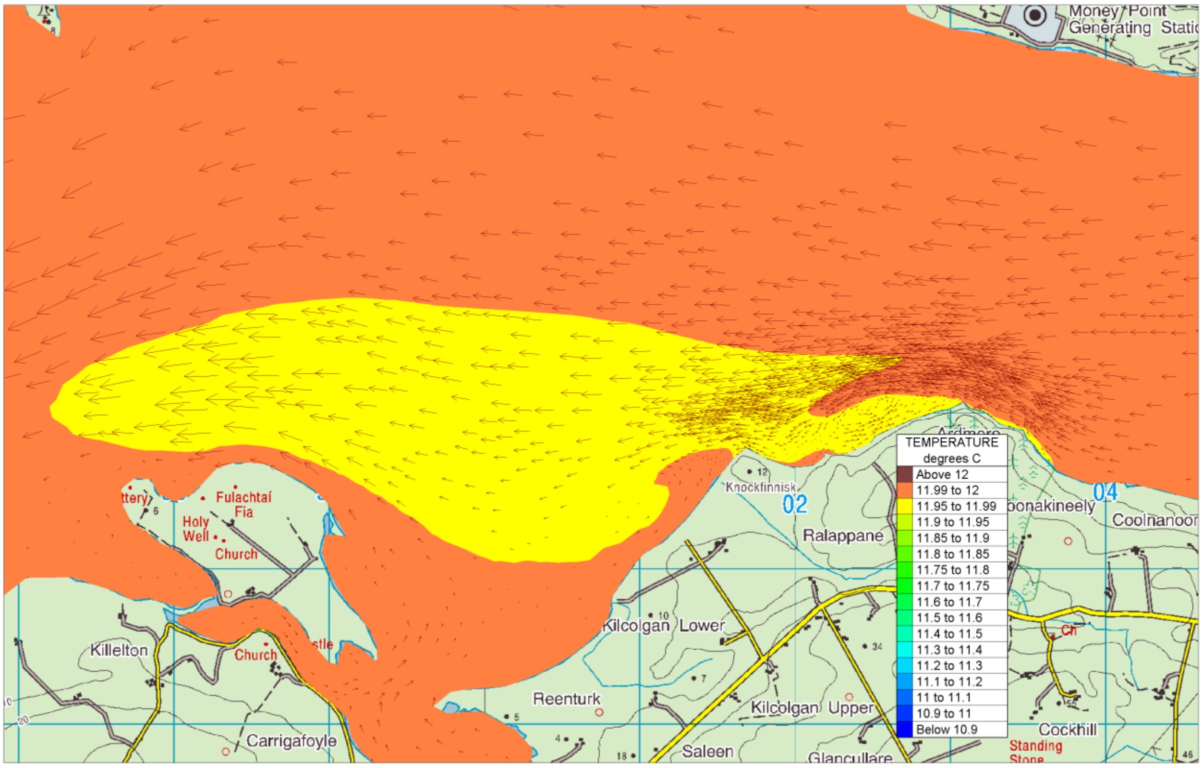

Figure 11.3 **Predicted Temperature in Vertical Layer (5) at Mid-Ebb Spring Tide**

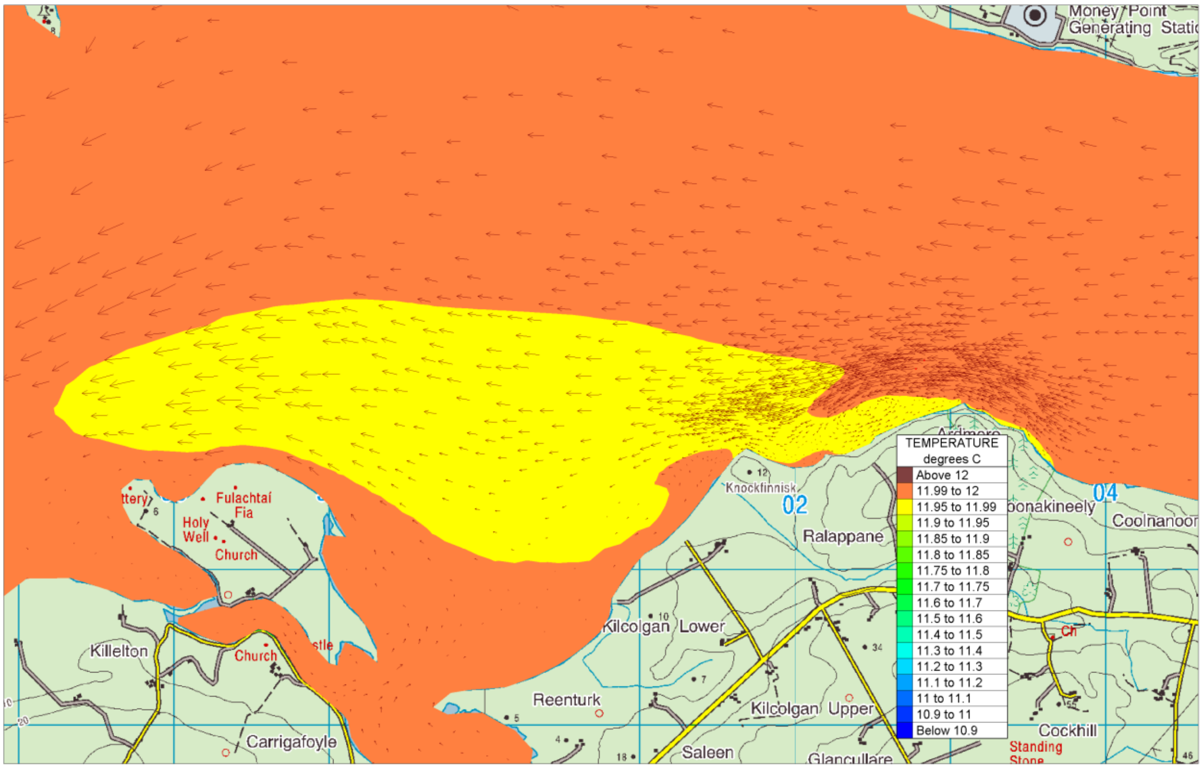

Figure 11.4 **Predicted Temperature in Bottom Layer (Layer 1) at Mid-Ebb Spring Tide**

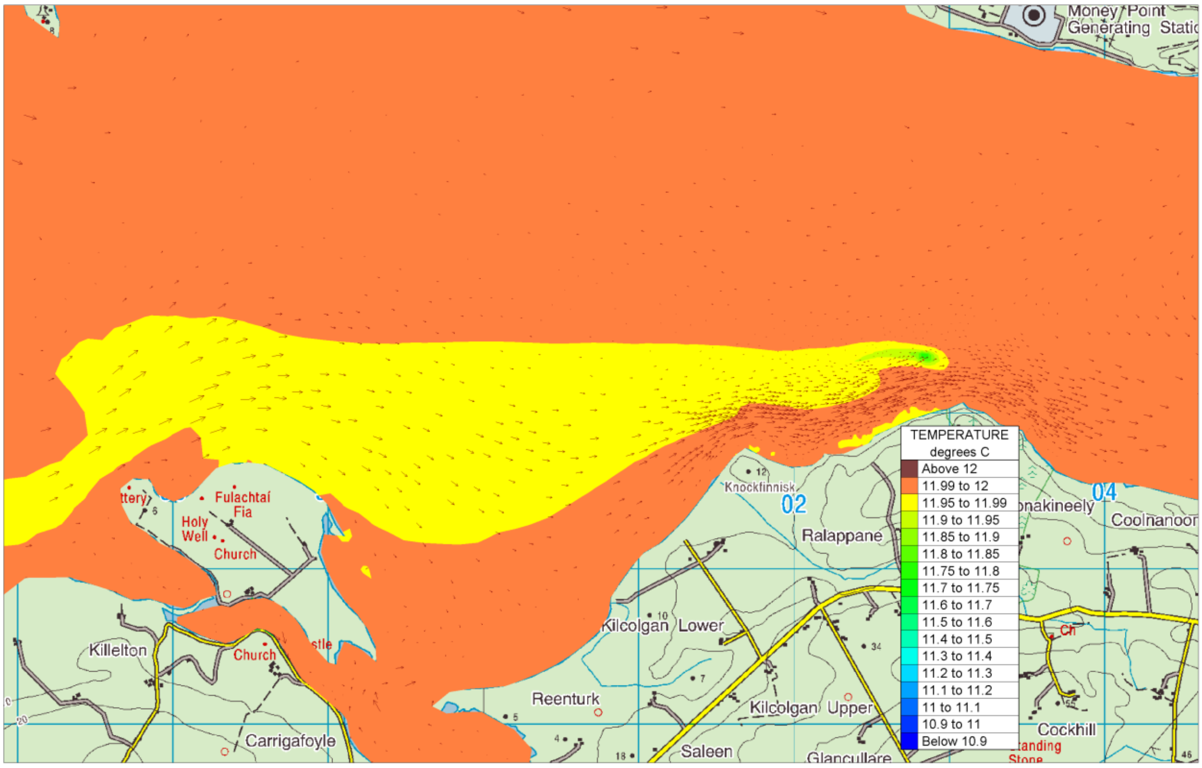

Figure 11.5 Predicted Temperature in Surface Layer (Layer 15) at Low Water Spring Tide

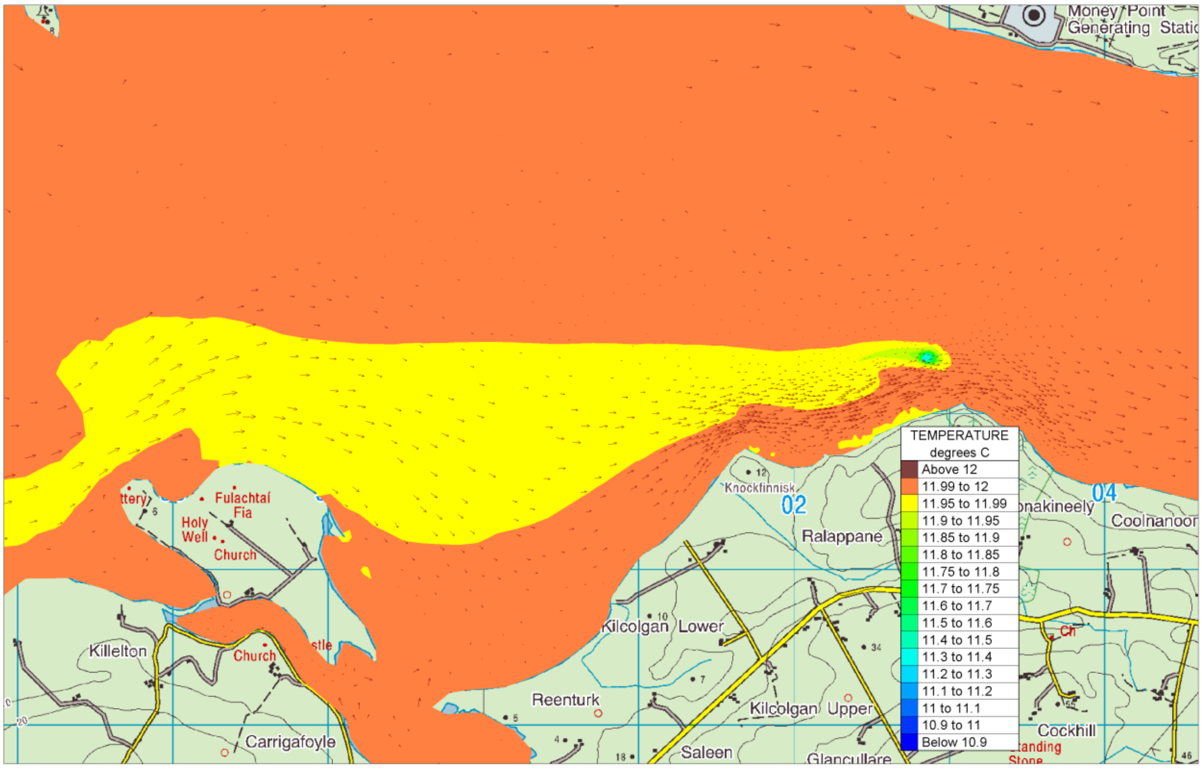

Figure 11.6 Predicted Temperature in Vertical Layer 10 at Low Water Spring Tide

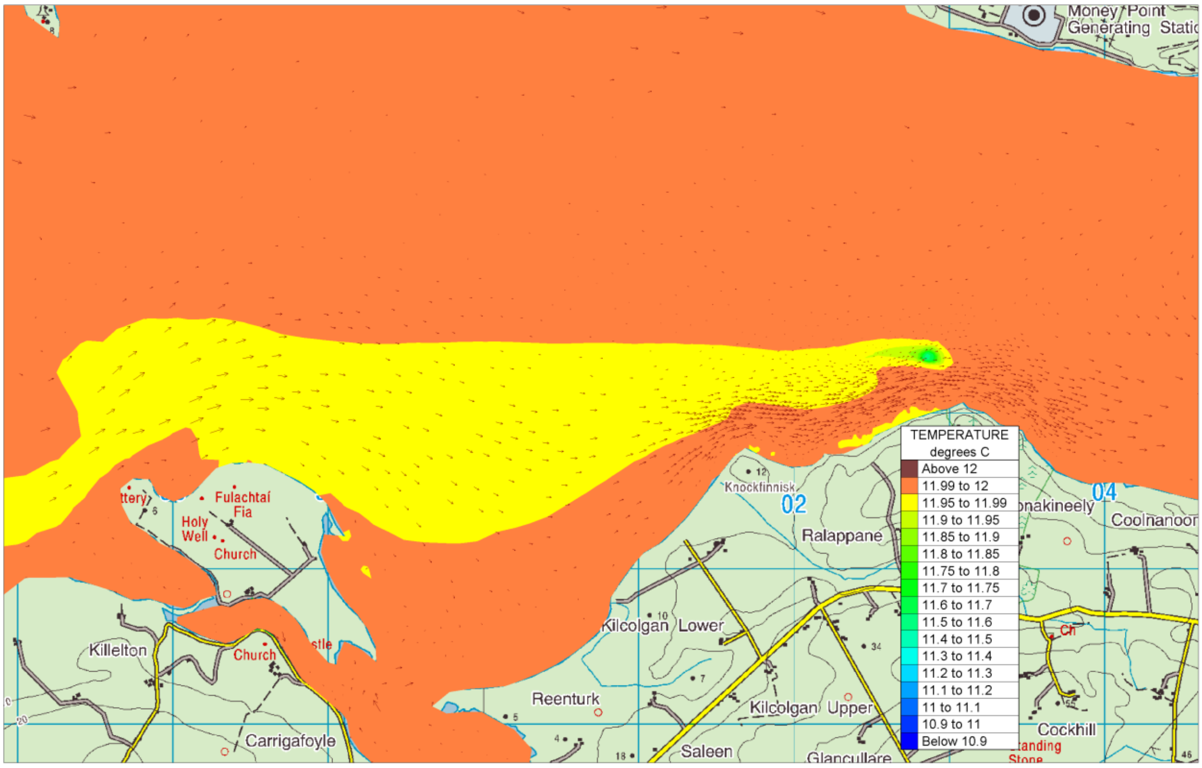

Figure 11.7 **Predicted Temperature in Vertical Layer 5 at Low Water Spring Tide**

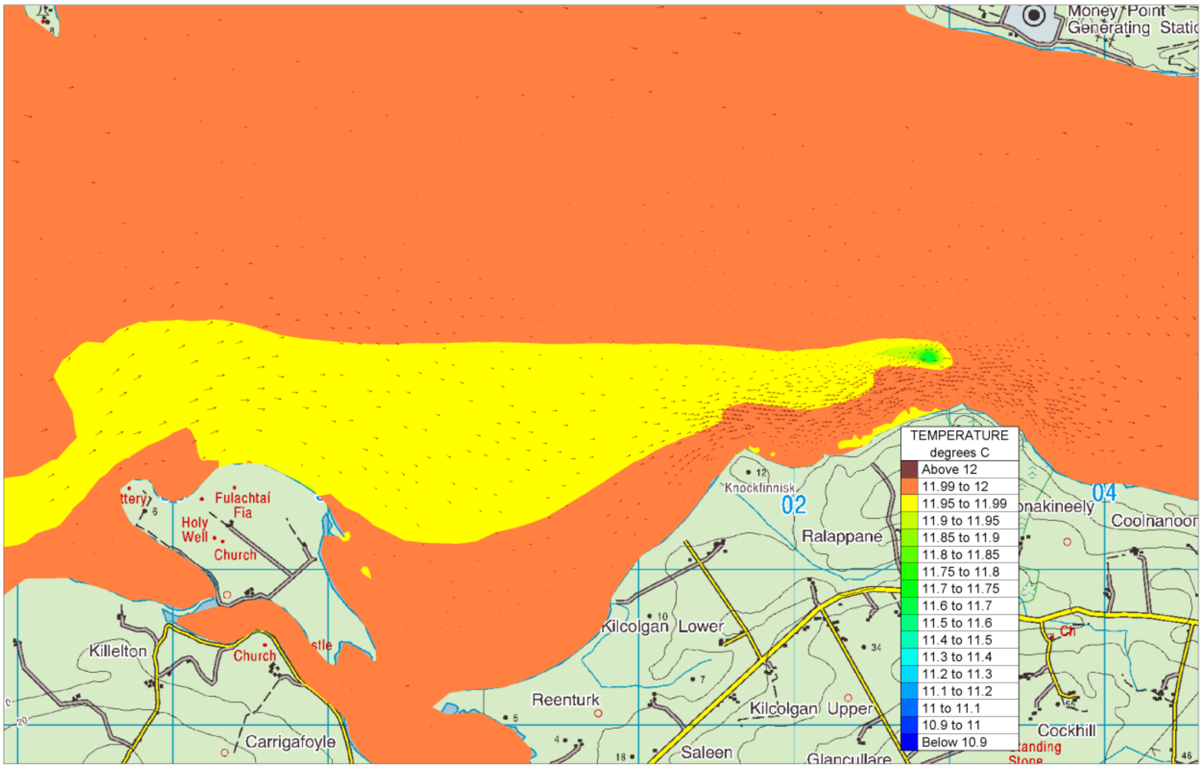

Figure 11.8 **Predicted Temperature in Bottom Layer (Layer 1) at Low Water Spring Tide**

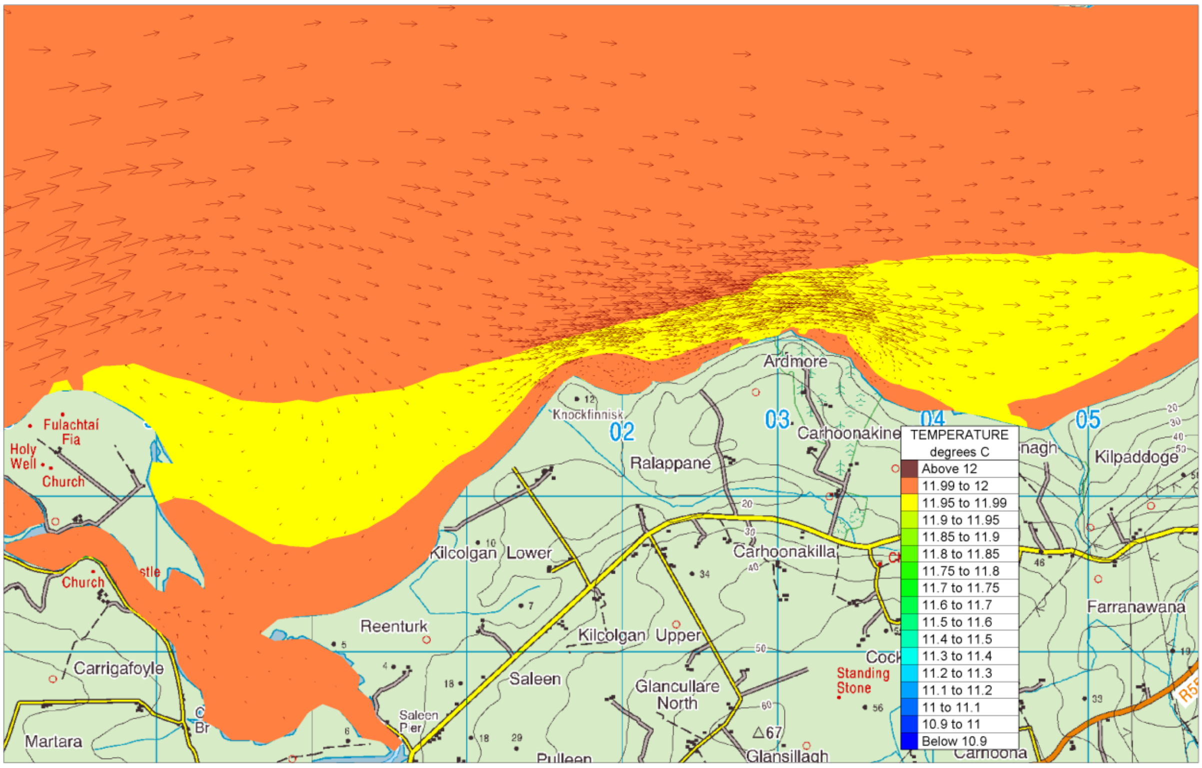

Figure 11.9 Predicted Temperature in Surface Layer (Layer 15) at Mid-flood Spring Tide

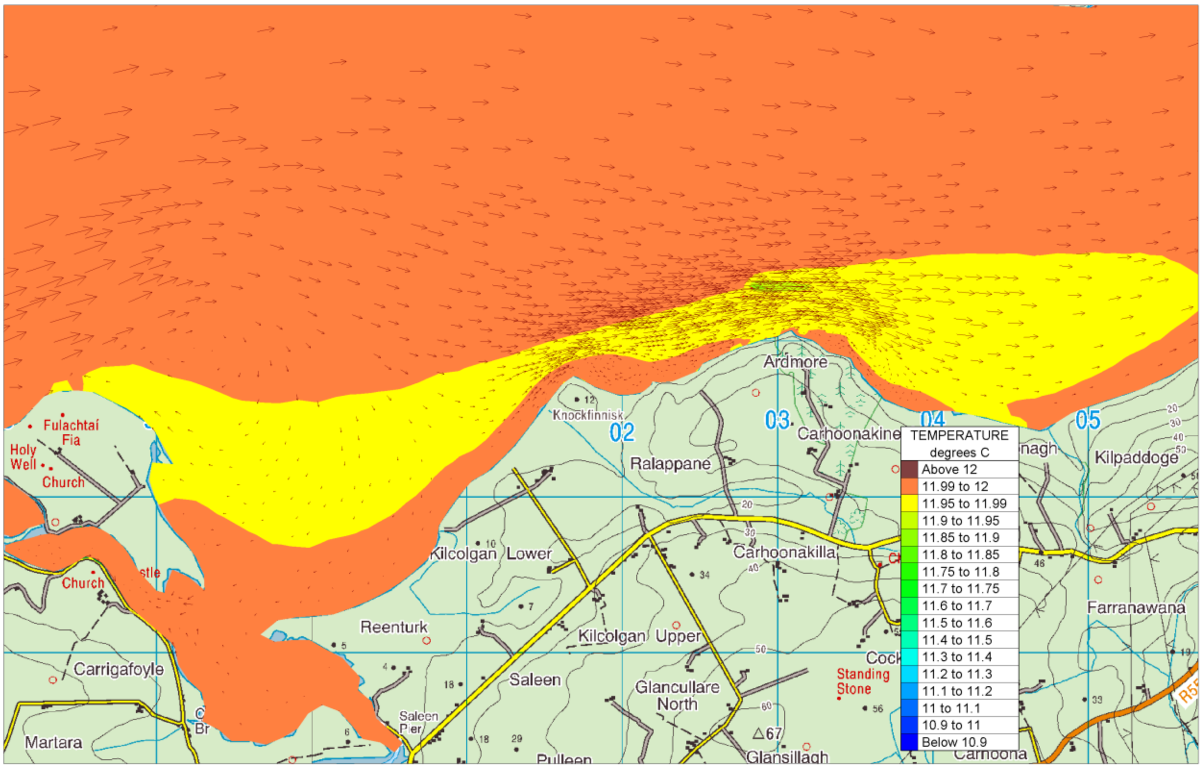

Figure 11.10 Predicted Temperature in Vertical Layer 10 at Mid-Flood Spring Tide

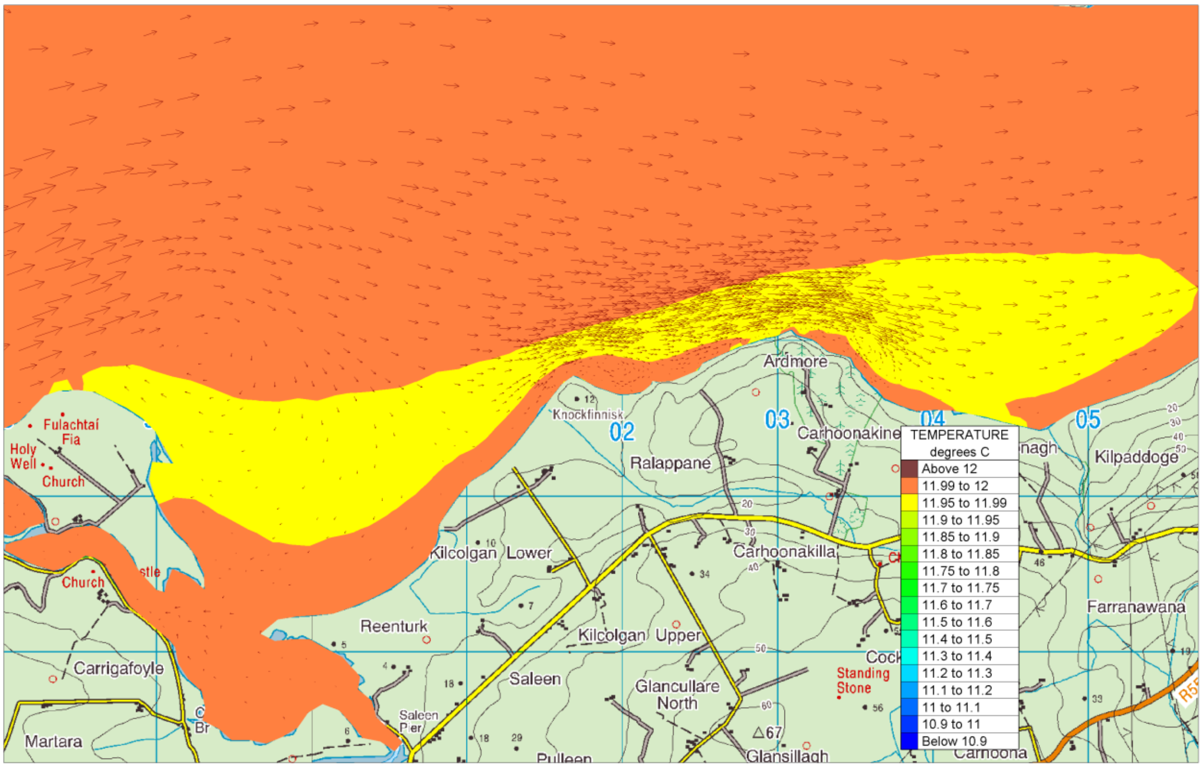

Figure 11.11 Predicted Temperature in Vertical Layer 5 at Mid-flood Spring Tide

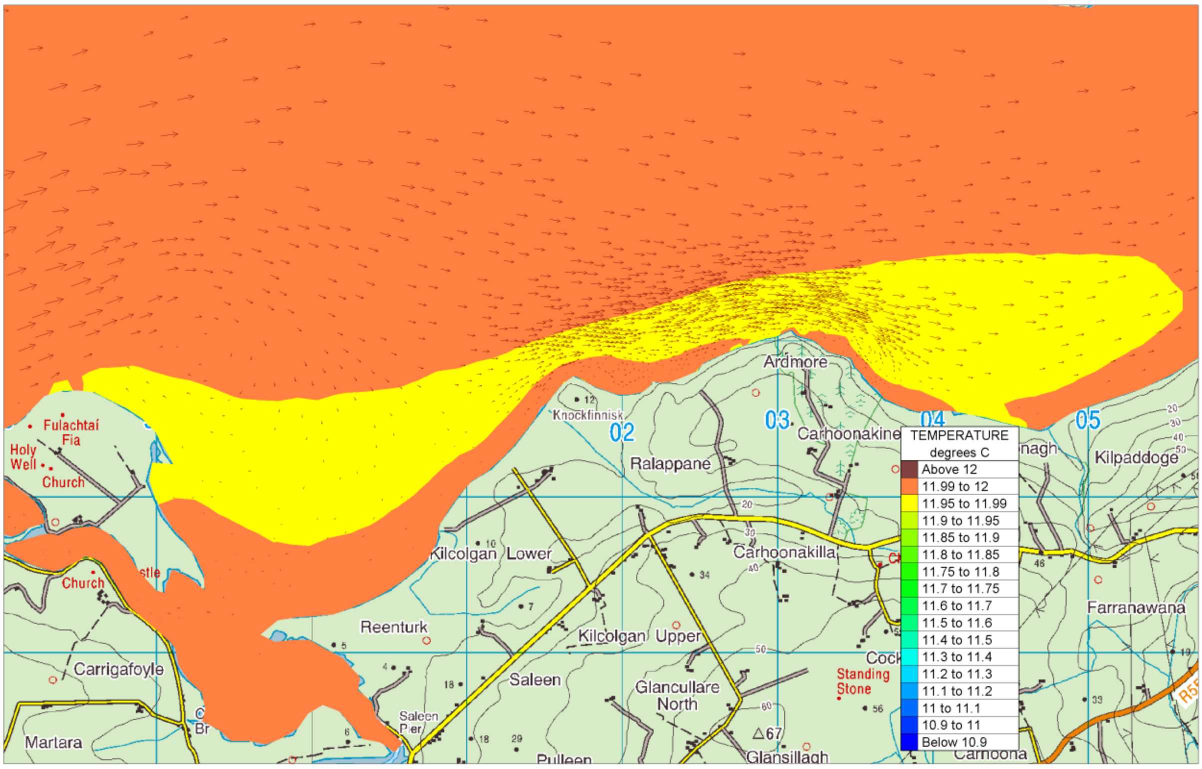

Figure 11.12 Predicted Temperature in Bottom Layer (Layer 1) at Mid-Flood Spring Tide

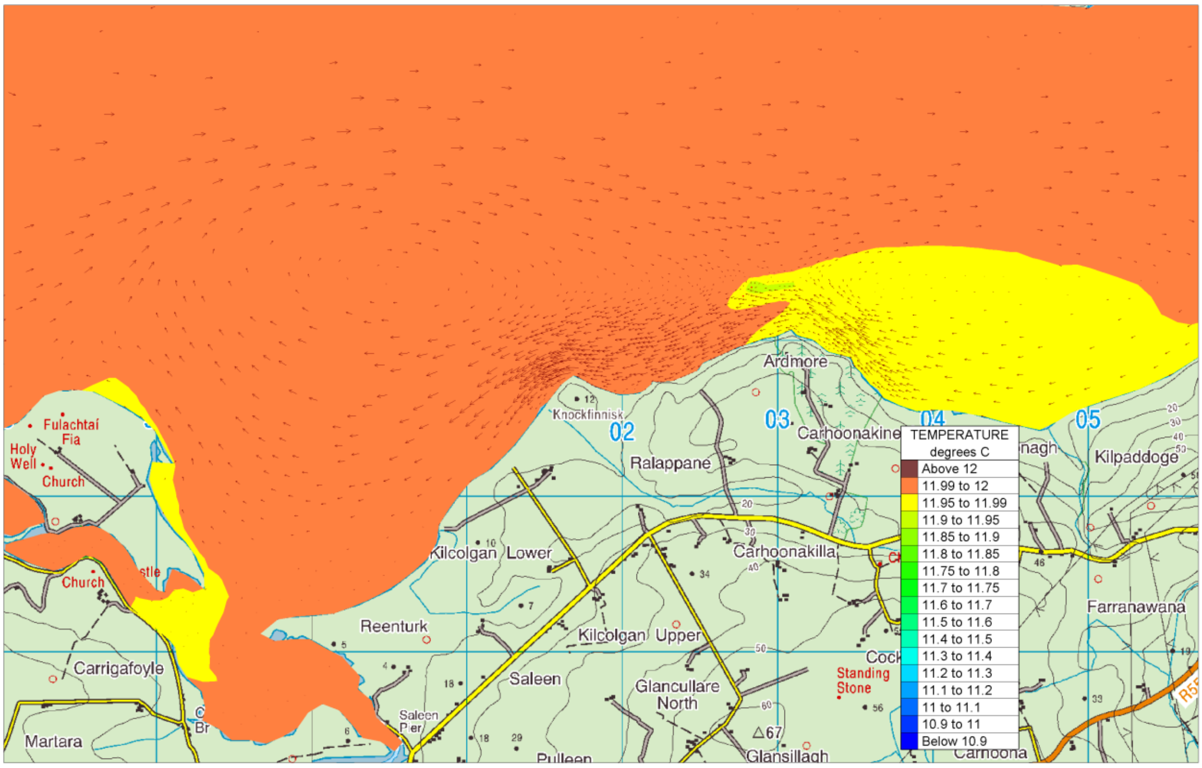

Figure 11.13 Predicted Temperature in Surface Layer (Layer 15) at High Water Spring Tide

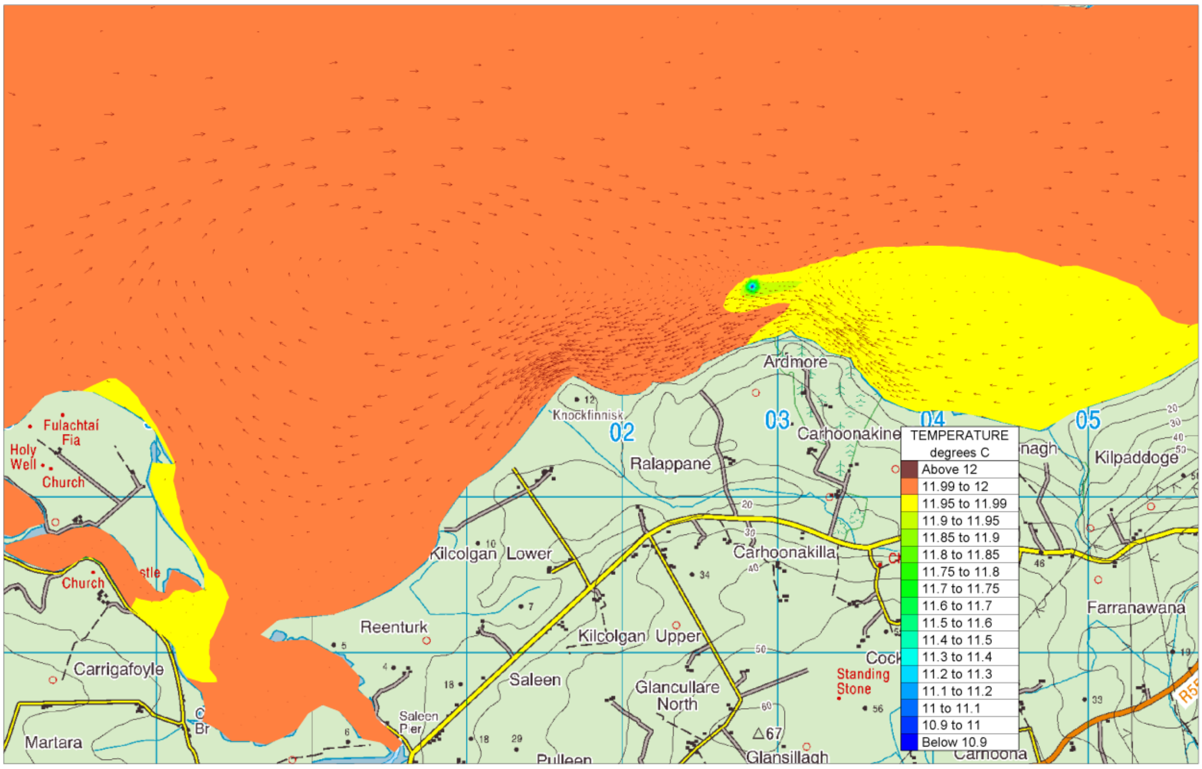

Figure 11.14 Predicted Temperature in Vertical Layer 10 at High Water Spring Tide

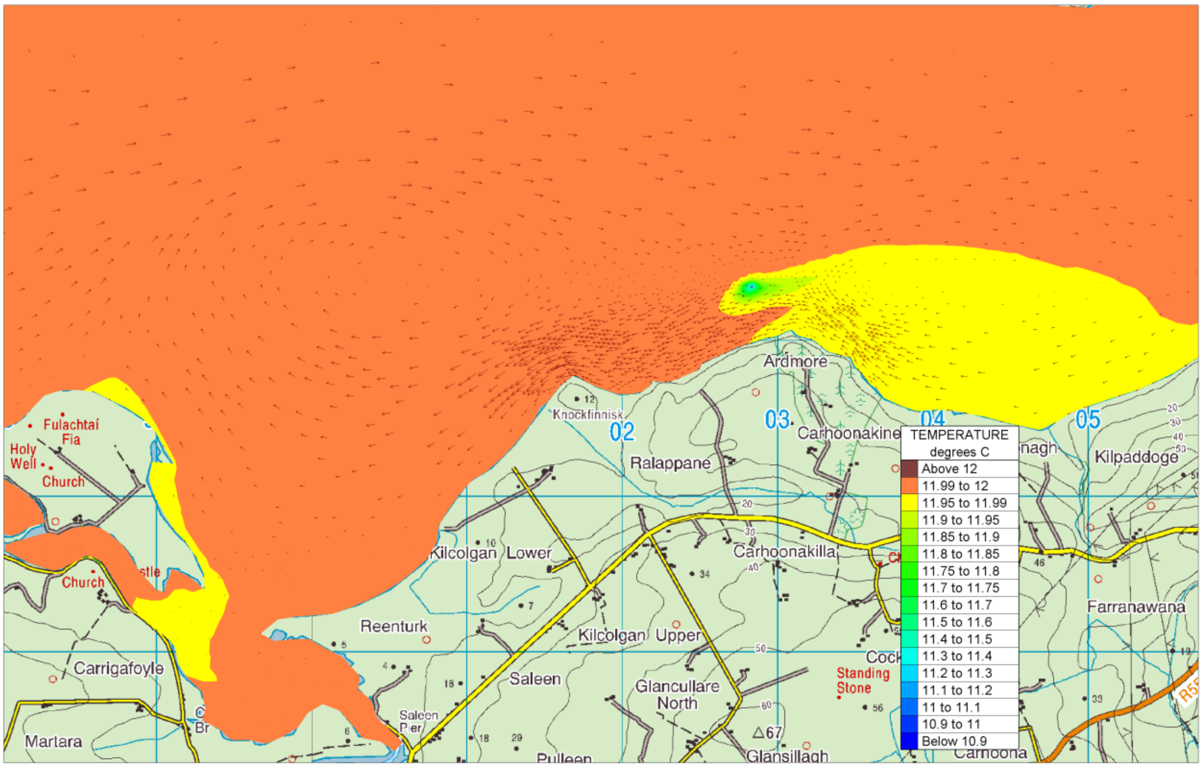

Figure 11.15 Predicted Temperature in Vertical Layer 5 at High Water Spring Tide

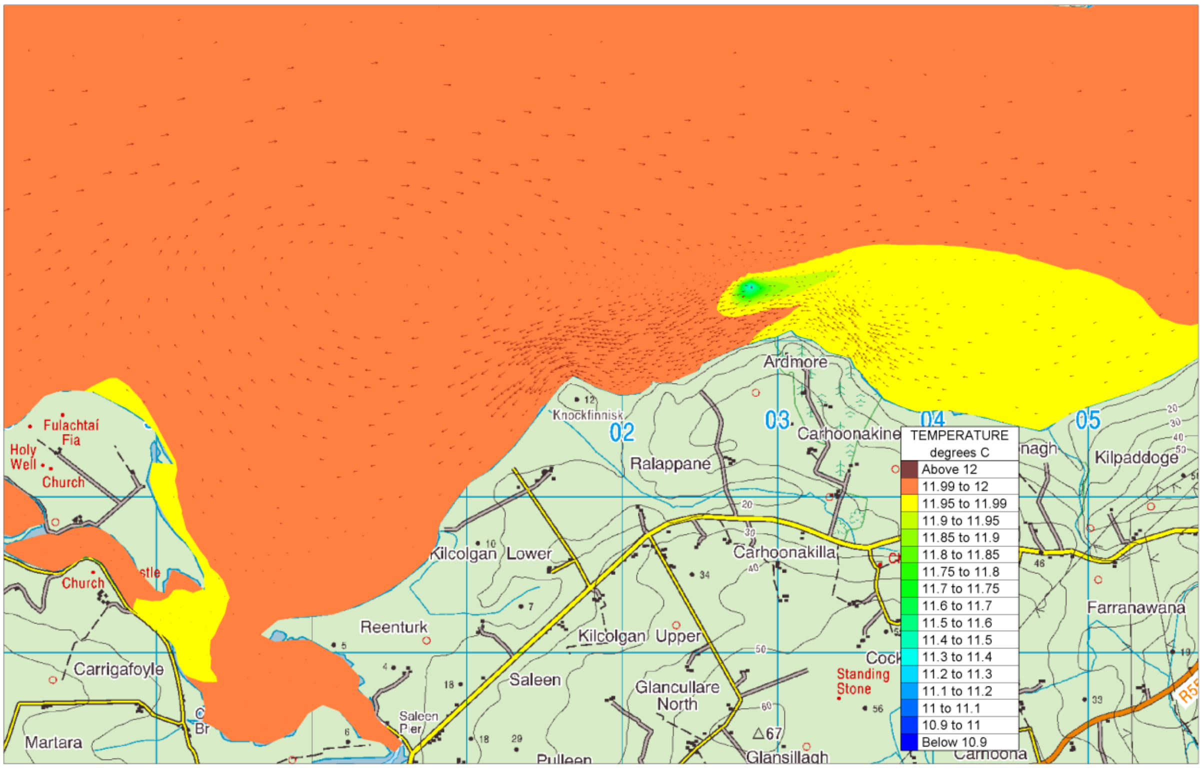

Figure 11.16 Predicted Temperature in Bottom Layer (Layer 1) at High Water Spring Tide

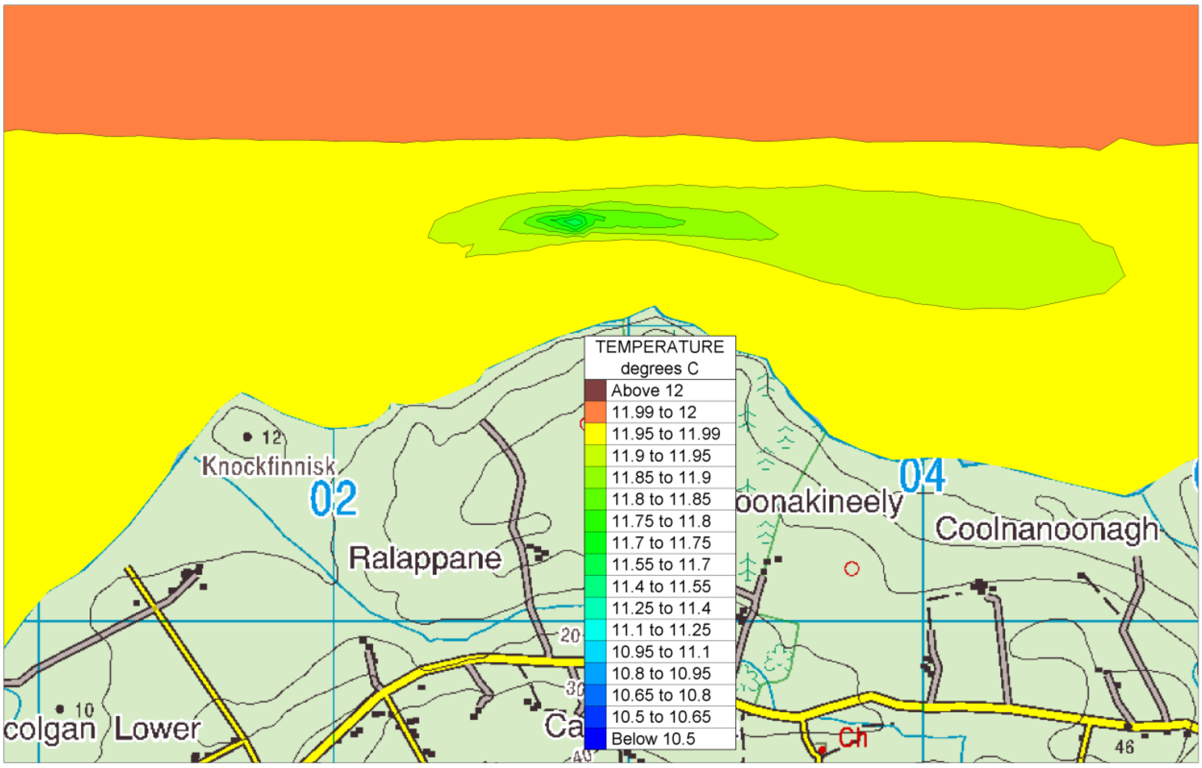

Figure 11.17 Predicted Minimum Temperature Envelope – Surface Layer (15) for spring-neap-spring 15day simulation

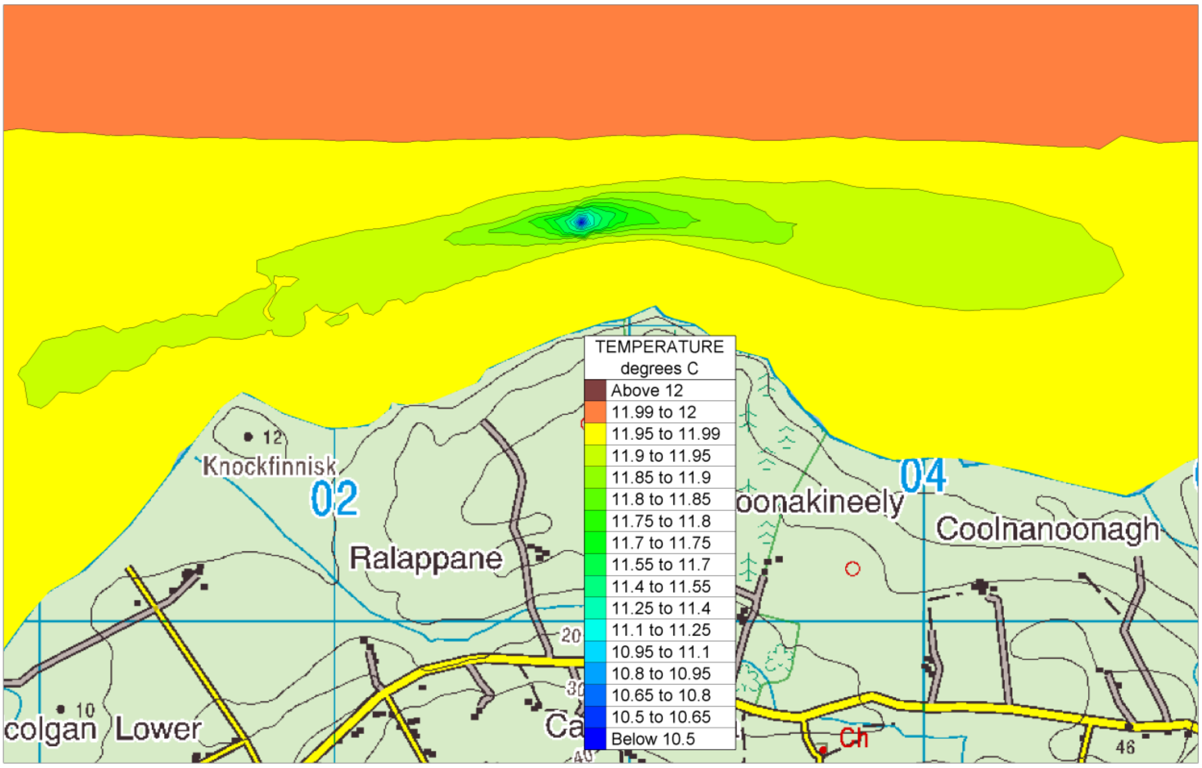

Figure 11.18 Predicted Minimum Temperature Envelope – Vertical Layer (10) for spring-neap-spring 15day simulation

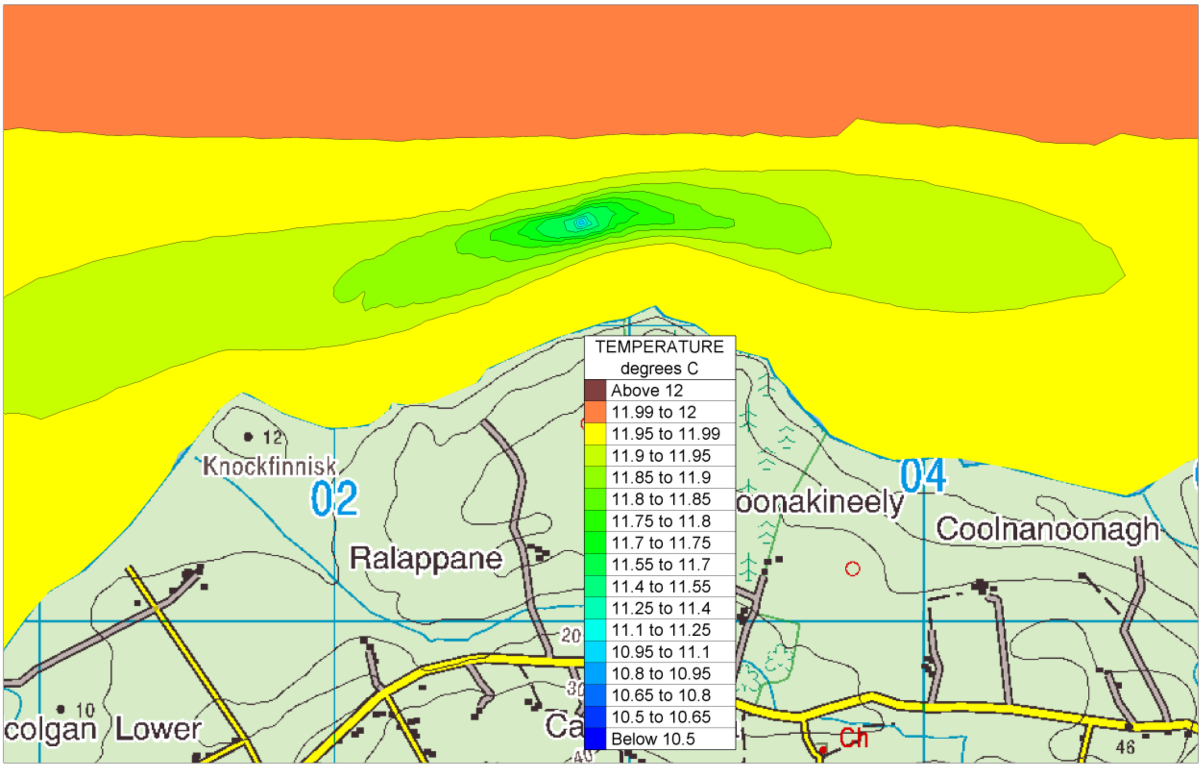

Figure 11.19 Predicted Minimum Temperature Envelope – Vertical Layer (5) for spring-neap-spring 15day simulation

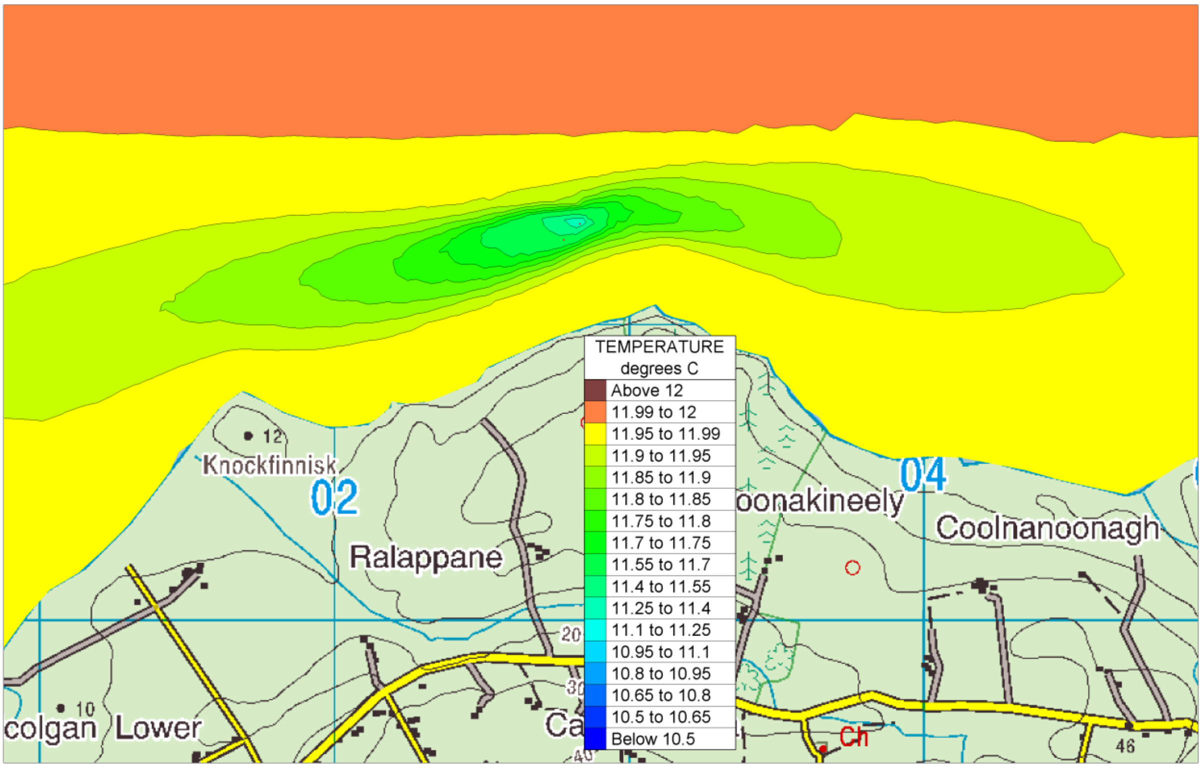

Figure 11.20 Predicted Minimum Temperature Envelope – Bottom Layer (1) for spring-neap-spring 15day simulation

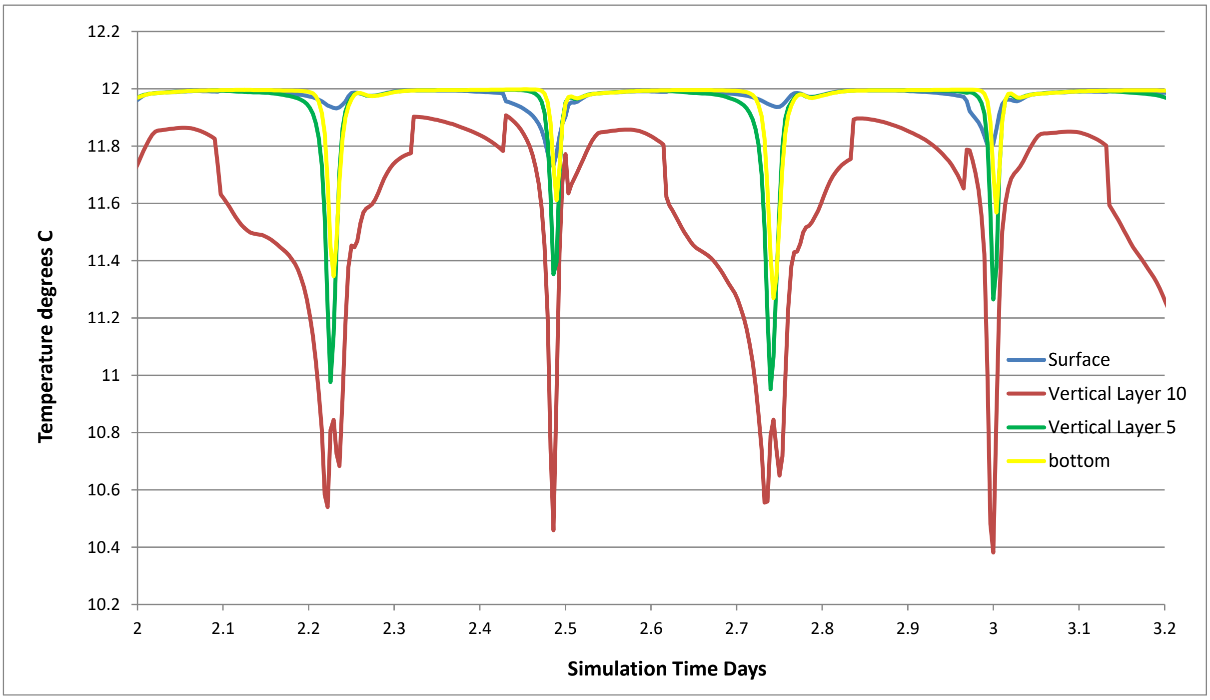

Figure 11.21 Temperature Time Series within receiving waters at FSRU outfall Node Point over sample spring tide

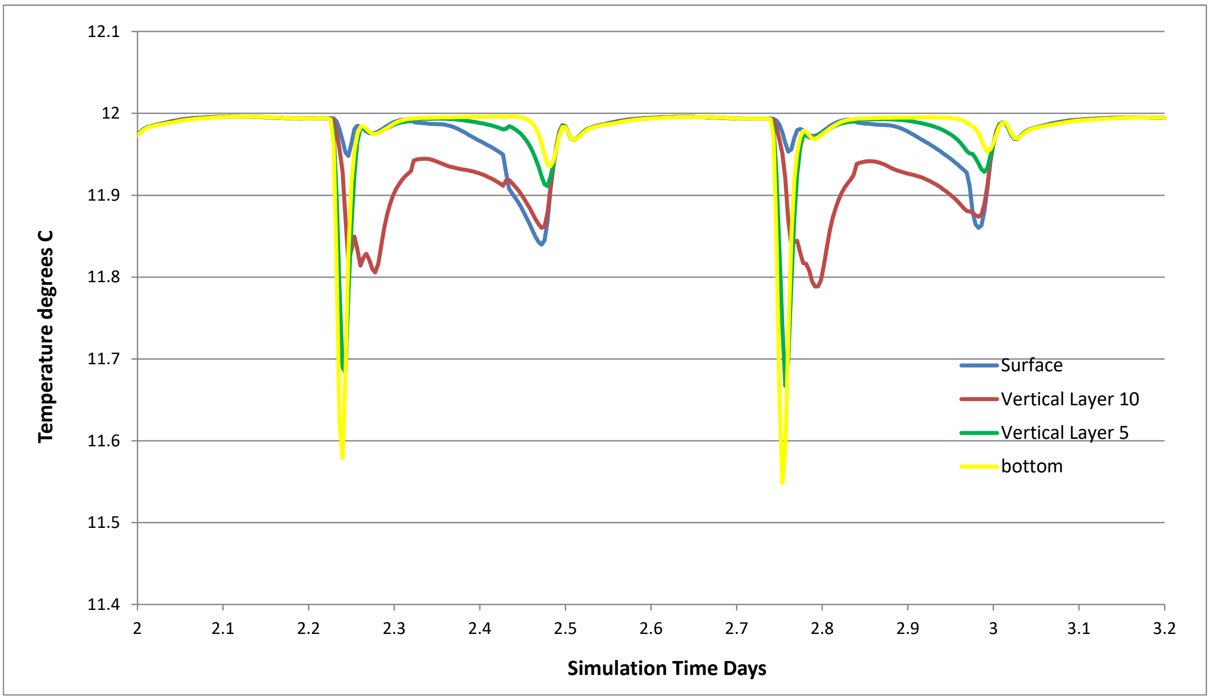

Figure 11.22 Temperature Time Series within receiving waters at 130m west of the FSRU Discharge Point over sample spring tide

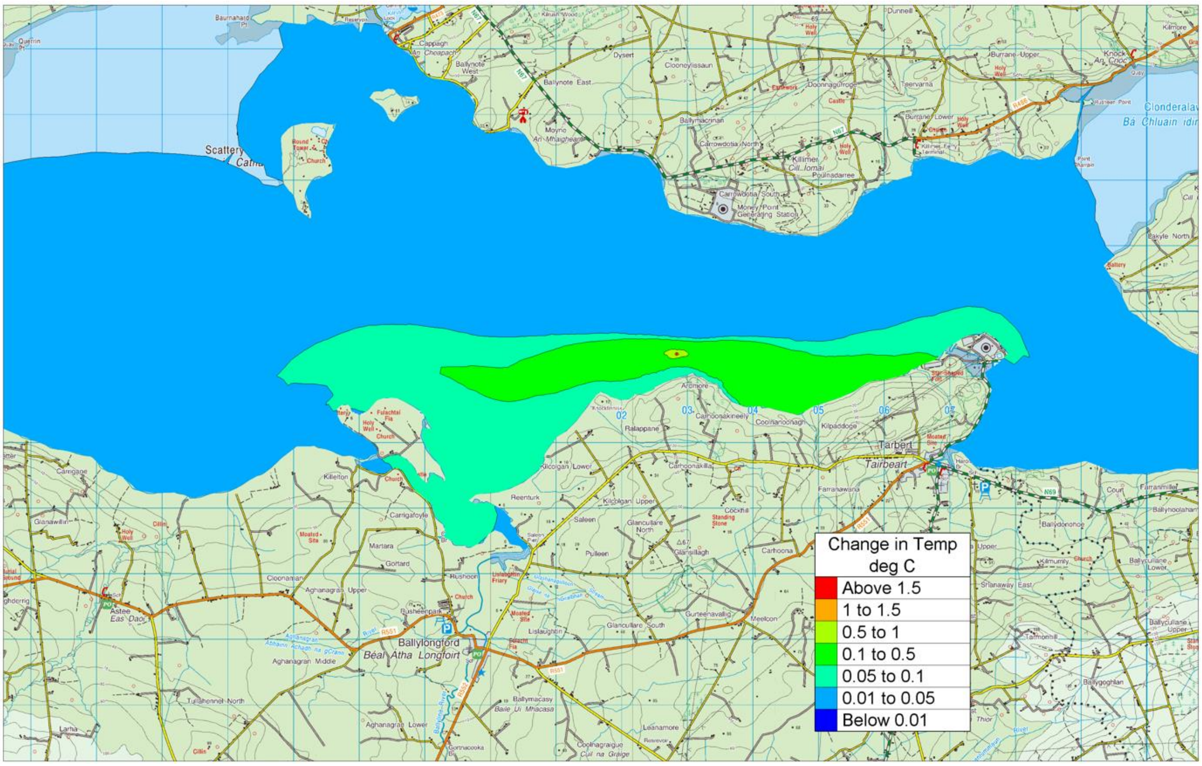

Figure 11.23 Maximum Temperature reduction envelope within receiving Shannon Estuary Water body over full 15-day simulation

3.6 Residual Chlorine Simulation Results

The residual Chlorine at 0.5mg/l and discharge rate of 6.111cumec was modelled in combination with the active tracer of temperature (i.e. includes the baroclinic hydrodynamic effects of density difference as a result of temperature).

The residual chlorine plume as maximum concentration envelopes for the selected four vertical layers (layers 15, 10, 5 and 1) are presented in Figures 12.1 to 12.4 for the spring-neap-spring simulation. The Residual Chlorine similar to the temperature mixing description sinks vertically at the discharge point and generally has maximum concentrations within a relatively short distance of the discharge point in the bottom (bed) layer due to the higher density of the colder discharge water over the ambient receiving waters. Within a reasonably short distance, the plume due to the high ebb and flood velocities and associated turbulence becomes well mixed vertically and horizontally.

Within 1.5km both East and West of the discharge point the predicted maximum Residual Chlorine concentration is less than 0.01mg/l, refer to Figure 12.5. Maximum concentrations above 0.1mg/l are shown to occur only within 20m of the discharge point and for a short period of time.

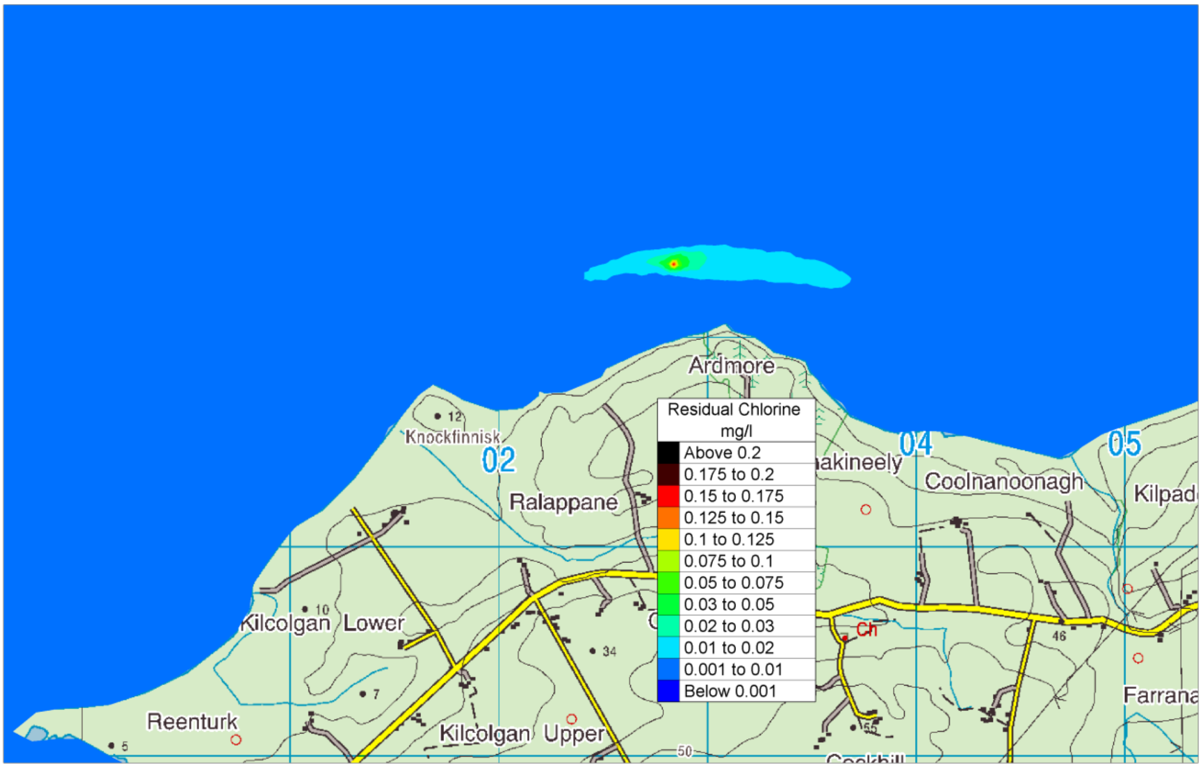

Figure 12.1 Maximum Concentration envelope in Surface Layer (layer 15) of Total Residual Chlorine

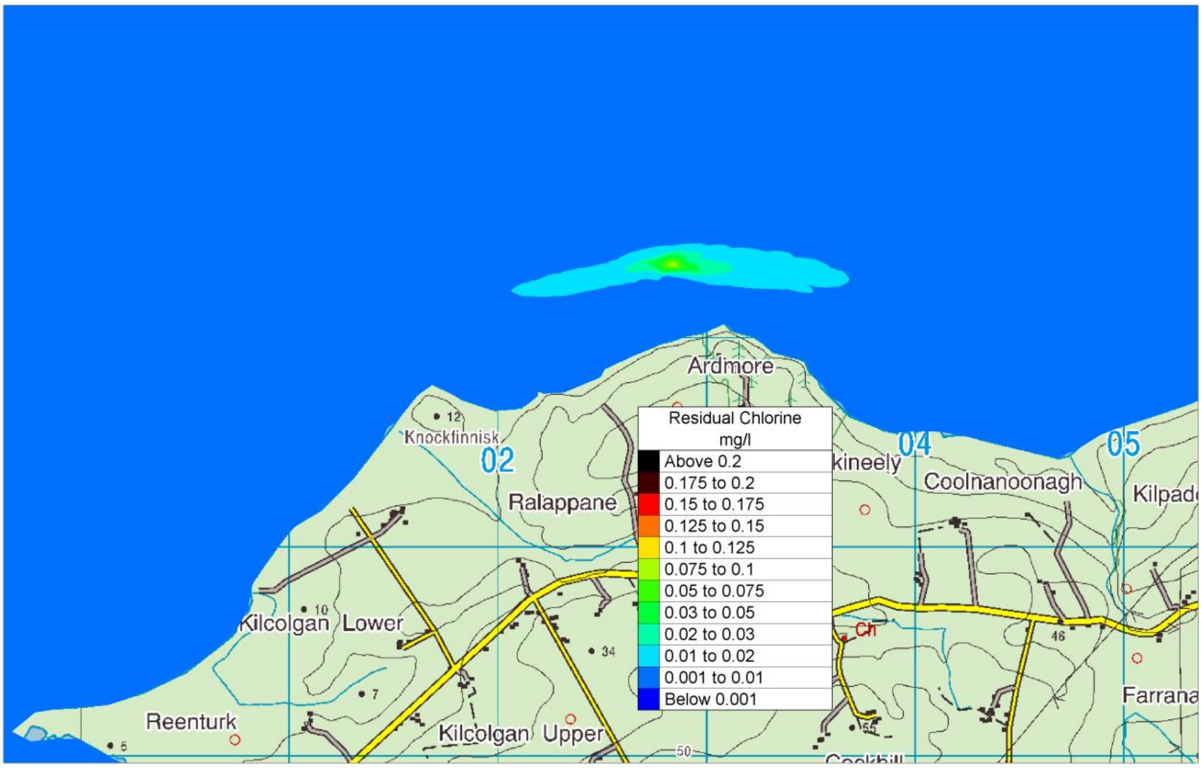

Figure 12.2 Maximum Concentration envelope in Layer 10 of Total Residual Chlorine

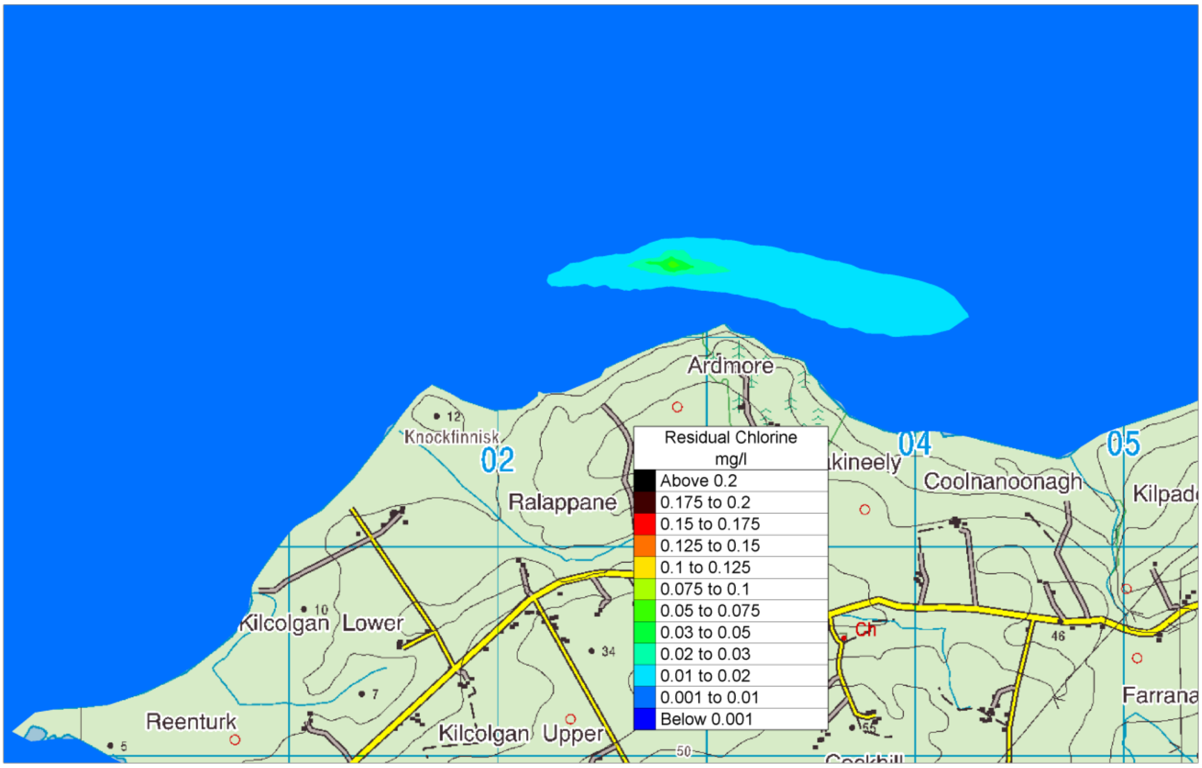

Figure 12.3 Maximum Concentration envelope in Layer 5 of Total Residual Chlorine

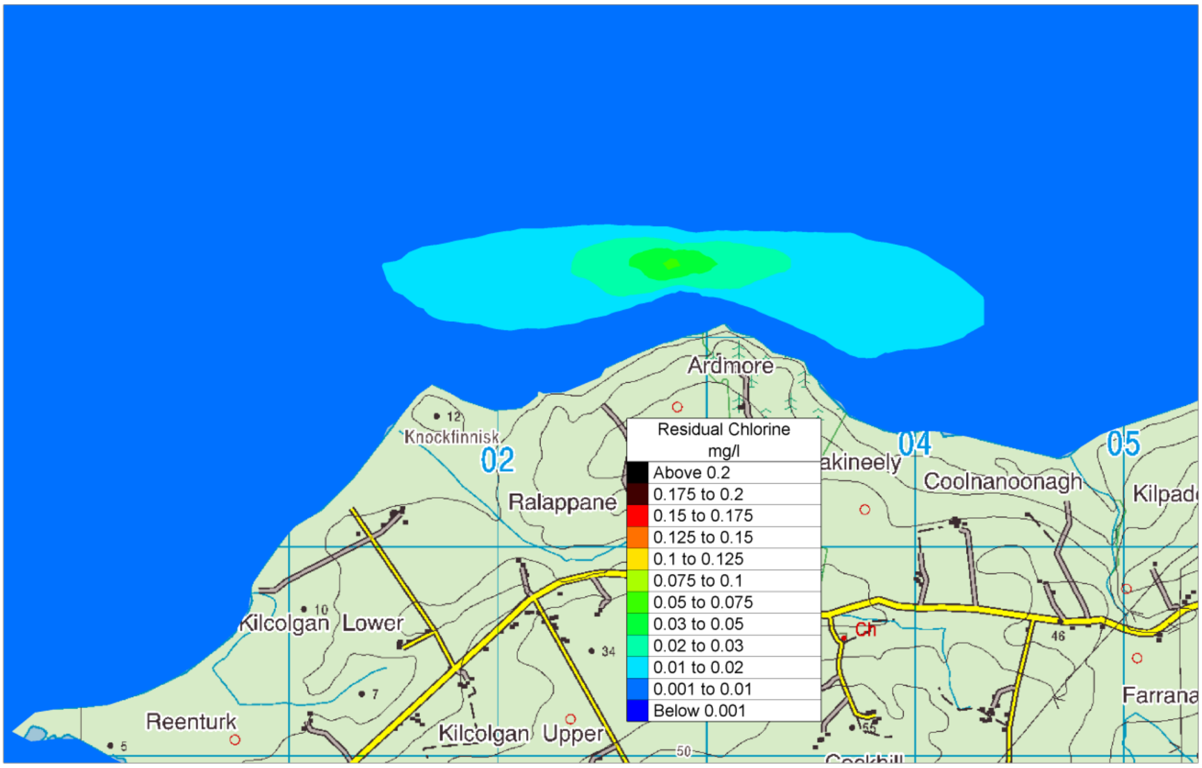

Figure 12.4 Maximum Concentration envelope in bottom Layer (Layer 1) of Total Residual Chlorine

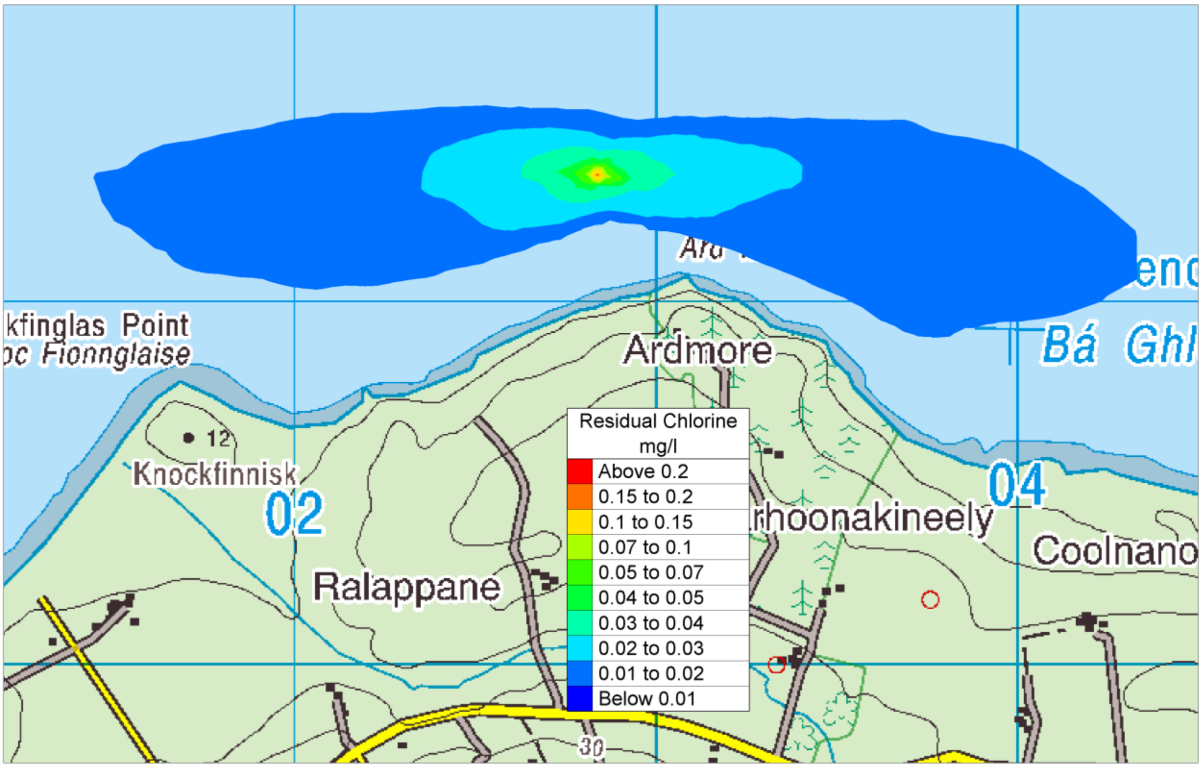

Figure 12.5 Maximum Residual Chlorine envelope within receiving Shannon Estuary Water body over full 15day simulation (all vertical layers)

3.7 Treated Sanitary Effluent Discharge

The proposed treated sanitary effluent discharge from development was modelled discharging from the proposed nearshore outfall pipe located on the sea bed at grid location E102554, N148936. The parameters of interest modelled are temperature, BOD, Ammonia, Total Phosphorous and *E.coli*.

The modelled effluent was a combination of the treated sanitary effluent of 35m^3/day and the process effluent at a mean daily discharge of 778m^3/day and an instantaneous maximum hydraulic load of 1,128 m^3/day. This was modelled as a thermal discharge at 40^{o}C with the receiving waterbody ambient temperature of 12^{o}C (effluent at 20^{o}C above ambient). The various treated effluent concentrations were specified based on tables 2 and 3 presented earlier.

The Heated discharge from the processed waters was modelled at 28^{o}C above ambient with the ambient at 12^{o}C. The maximum and mean temperature envelopes are presented in figures 13 and 14 over a full 15 day spring-neap-spring tidal period. These plots show a very local rise in temperature at the outfall site having a maximum increase of 0.9135^{o}C and a mean increase at the outfall site of 0.069^{o}C. The maximum temperature increase reduces within 100m of the discharge point to 0.171^{o}C which is an insignificant impact. The heated plume rises and mixes in the water column due to a lower density than the receiving waters. At the outfall site, the maximum temperature occurs at the sea bed but within a short distance, the plume is well mixed vertically.

E.coli was modelled from the sanitary discharge only using a conservative die-off rate of T_{90} = 36hours (winter conditions) at a secondary treated effluent concentration of 10^6 No./100ml and a discharge rate of 0.41l/s. The maximum and mean concentration envelopes for E.coli are presented in figures 15 and 16 over a complete spring-neap-spring tidal period. The predicted concentration plume shows no impact on Ballylongford and Glenclossagh Bays where shellfish activities areas are located. The highest concentration occurs in the receiving waters at the outfall site which is predicted to reach 1,458 No/100ml E.coli and within 100m (mixing zone) this has reduced to 279 No. / 100ml. The tidal mean concentration over 15 days of tides is 102 No./100ml at the outfall site and significantly lower elsewhere.

BOD concentration was modelled at 9l/s at a concentration of 20mg/l from the process effluent and at 0.41l/s at 25mg/l from the sanitary effluent discharge. The maximum and mean concentration envelopes for BOD are presented in figures 17 and 18 over a complete spring-neap-spring tidal period. The highest concentration occurs in the receiving waters at the outfall site at a concentration of 0.692mg/l BOD. The maximum BOD concentration within 100m of the outfall site is 0.132mg/l. The average BOD concentration in the receiving water at the outfall site is 0.048mg/l.

The total ammonia discharge from the treated process water and treated sanitary water produces a maximum ammoniacal nitrogen concentration within the receiving waterbody of 0.1513mg/l N and a mean concentration at the outfall site of 0.012mg/l N, refer to figures 19 and 20. The maximum ammoniacal nitrogen concentration within 100m of the outfall site is predicted to be 0.033mg/l N.

The dispersion simulations show that the total phosphorous concentration from the treated process water and treated sanitary water produce a maximum concentration within the receiving waterbody of 0.167mg/l P occurring at the outfall site and a mean concentration at the outfall site of 0.0117mg/l P, refer to figures 21 and 22. The maximum total phosphorous concentration at 100m from the outfall site is predicted to be 0.032mg/l P.

All of the above modelled water quality parameters are shown to easily satisfy the permissible limits set out in the surface water regulations and will not impact the water quality status of the receiving Shannon Estuary waters and will not impact the nearby shellfish waters in Ballylongford and Glenclossagh Bays.

Table 4 Predicted Maximum Concentrations within the receiving waters (note this occurred for all parameters at the proposed outfall site)

Parameter	Maximum	Average
Temperature difference	0.914°C	0.069°C
BOD	0.692 mg/l O2	0.049 m/l O2
Total Ammonia	0.1713 mg/l N	0.0120mg/l N
Total Phosphorous	0.1670mg/l P	0.0117mg/l P
E.coli	1458 No/100ml	102 No. / 100ml

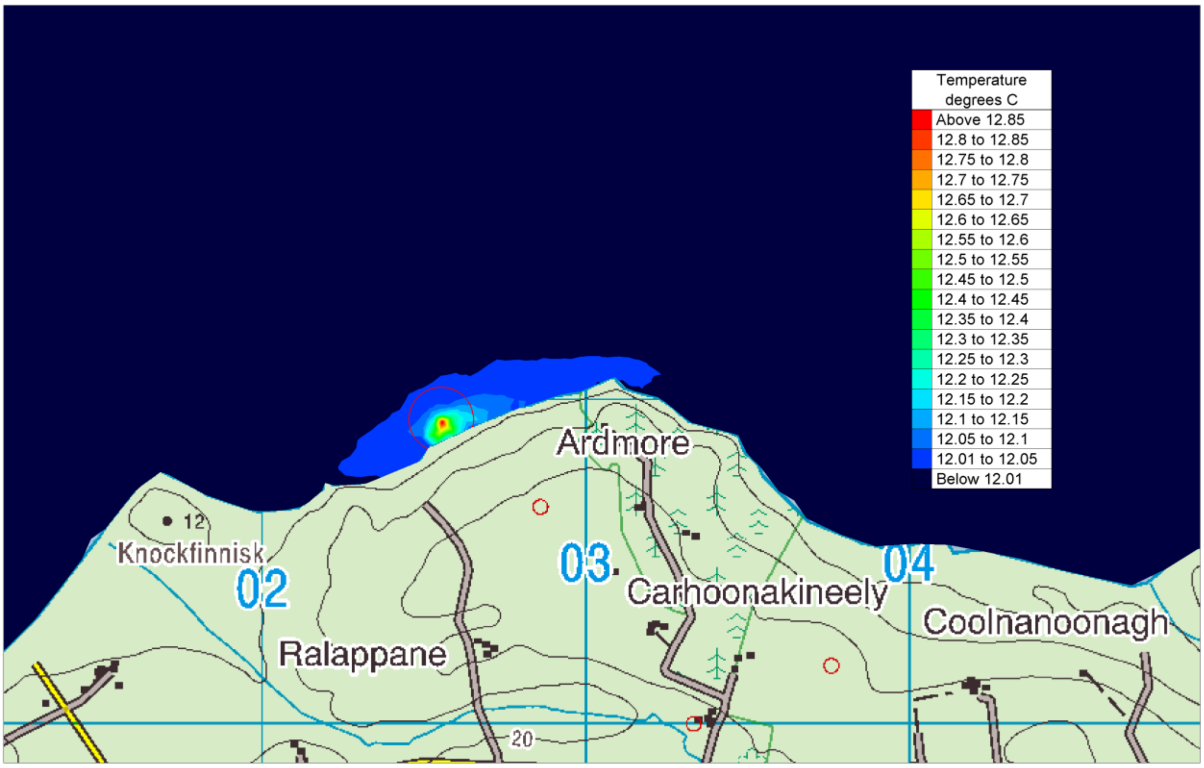

Figure 13 Predicted Maximum Temperature Envelope over 15-day for spring-neap-spring tide simulation modelling effluent at 40°C and ambient temperature at 12°C.

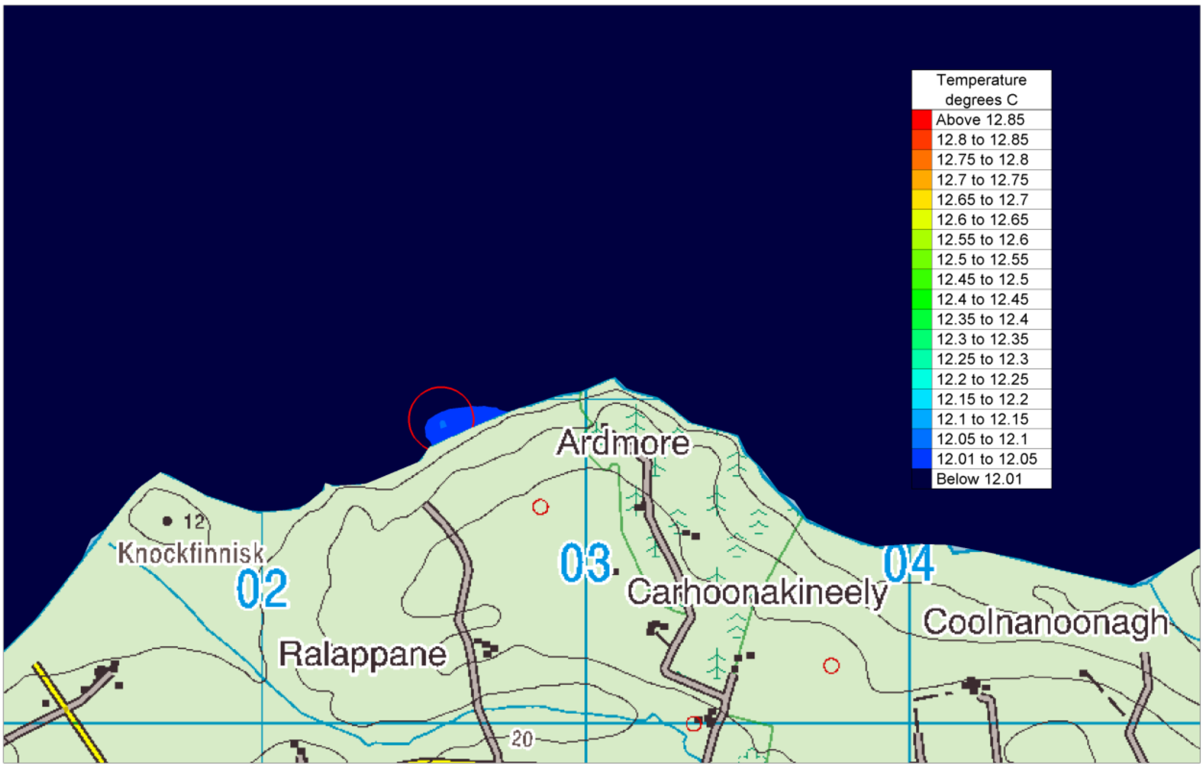

Figure 14 Predicted Mean Temperature Envelope over 15-day for spring-neap-spring tide simulation modelling effluent at 40°C and ambient temperature at 12°C.

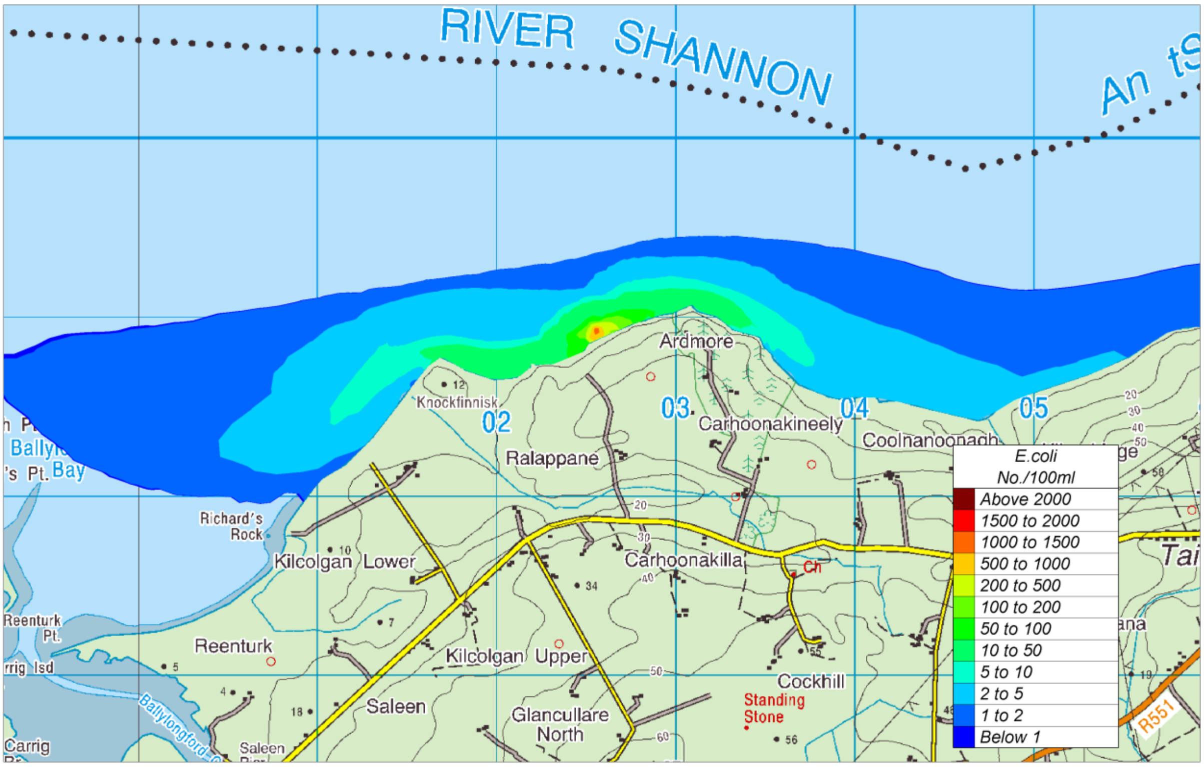

Figure 15 Predicted Maximum *E.coli* Concentration (No./100ml) Envelope over 15-day for spring-neap-spring tide simulation

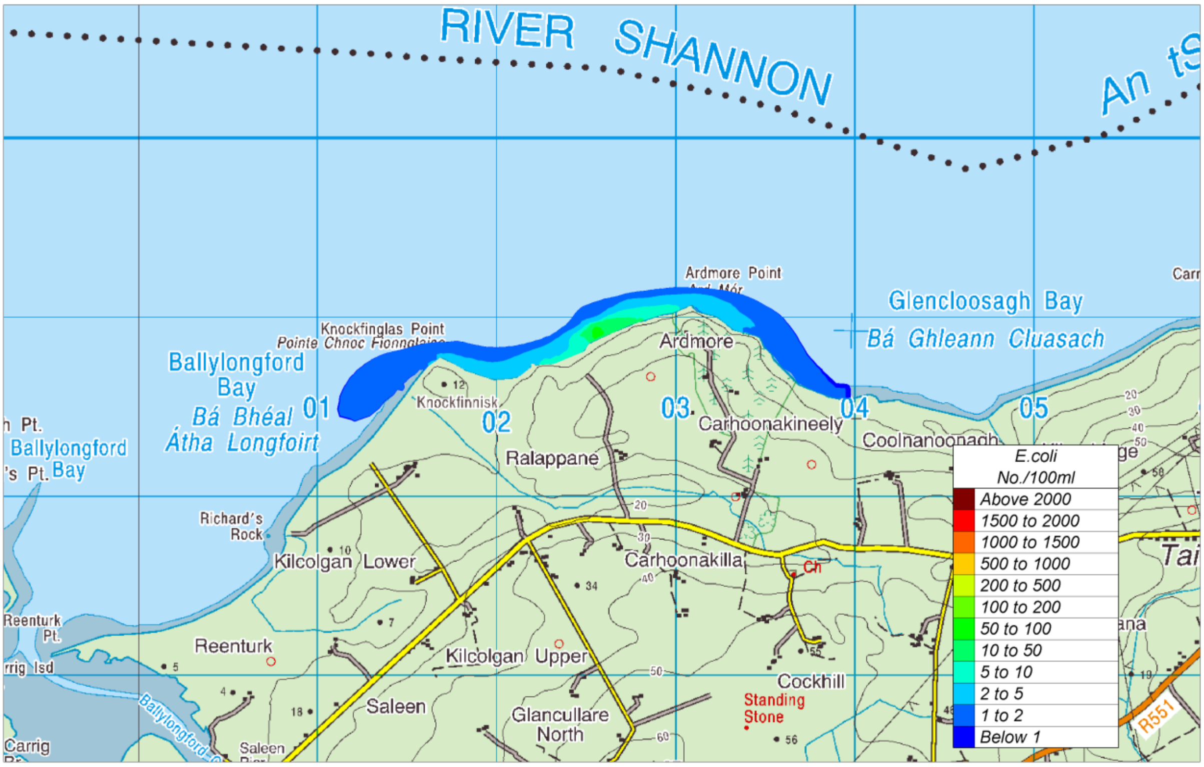

Figure 16 Predicted average *E.coli* Concentration (No./100ml) Envelope over 15-day for spring-neap-spring tide simulation

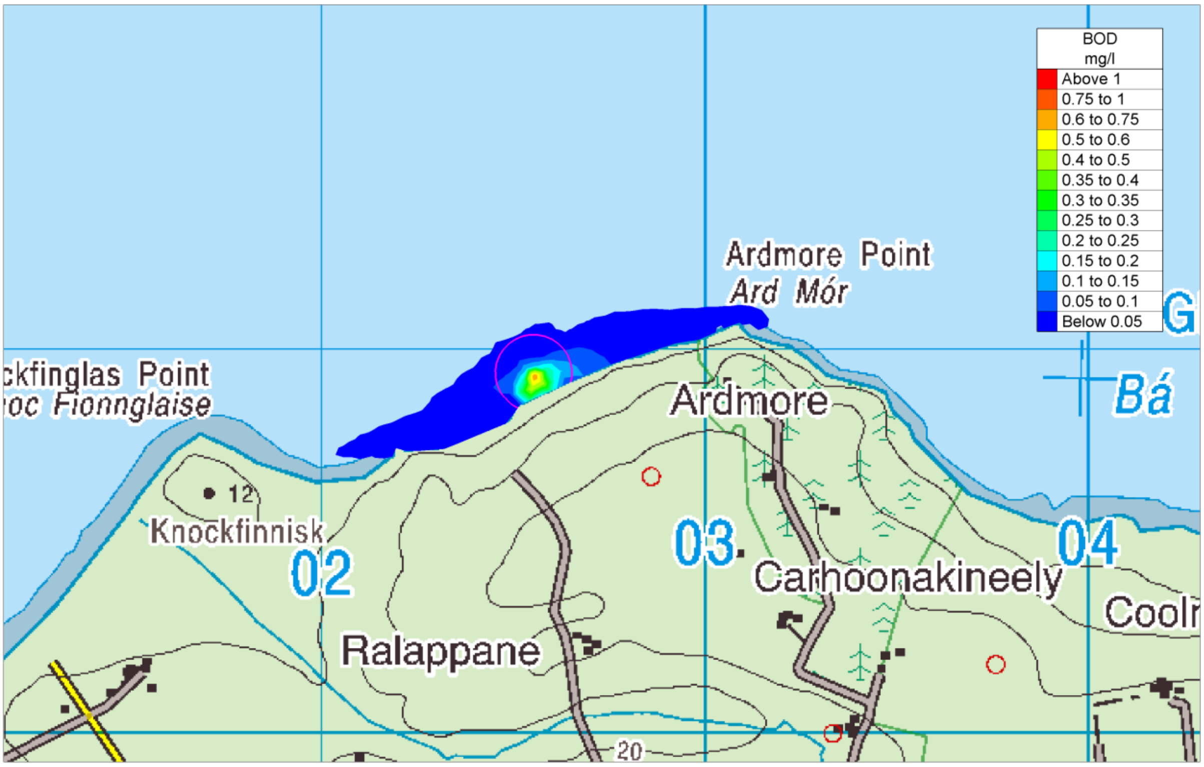

Figure 17 Predicted Maximum BOD Concentration (mg/l) Envelope over 15-day for spring-neap-spring tide simulation

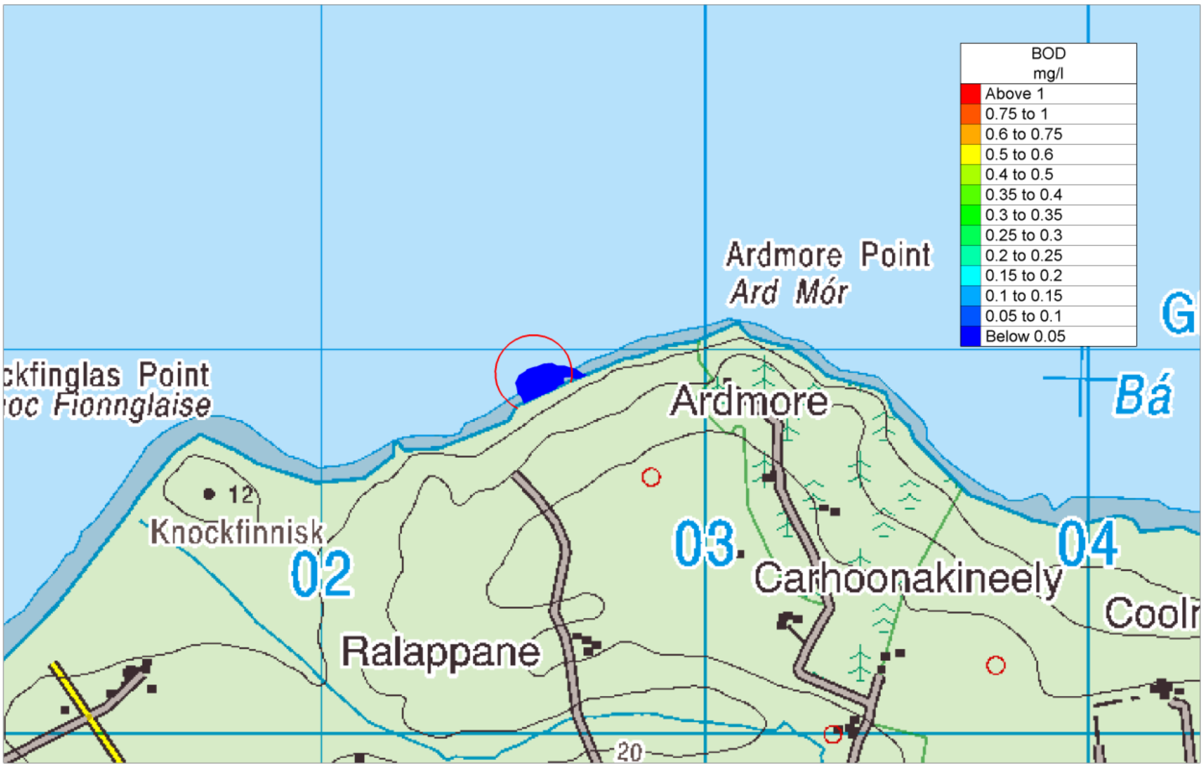

Figure 18 Predicted Mean BOD Concentration (mg/l) Envelope over 15-day for spring-neap-spring tide simulation

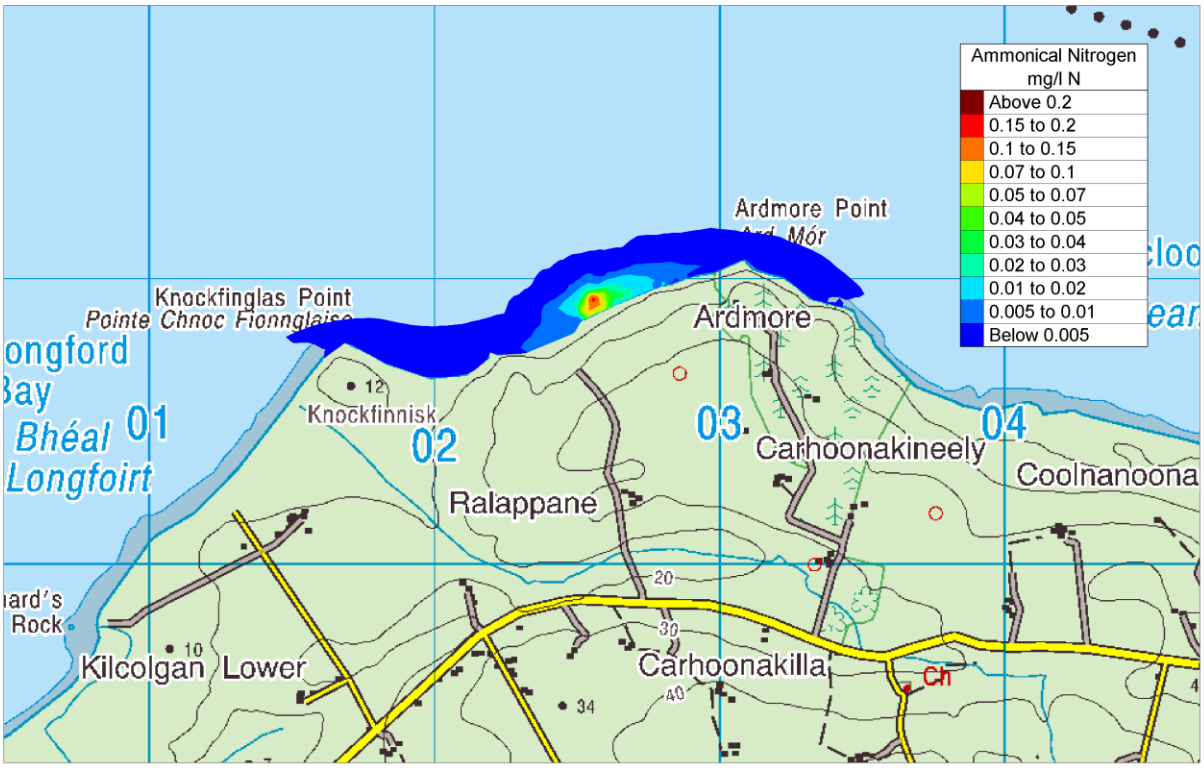

Figure 19 Predicted Maximum Ammoniacal Nitrogen Concentration (mg/l N) Envelope over 15-day for spring-neap-spring tide simulation

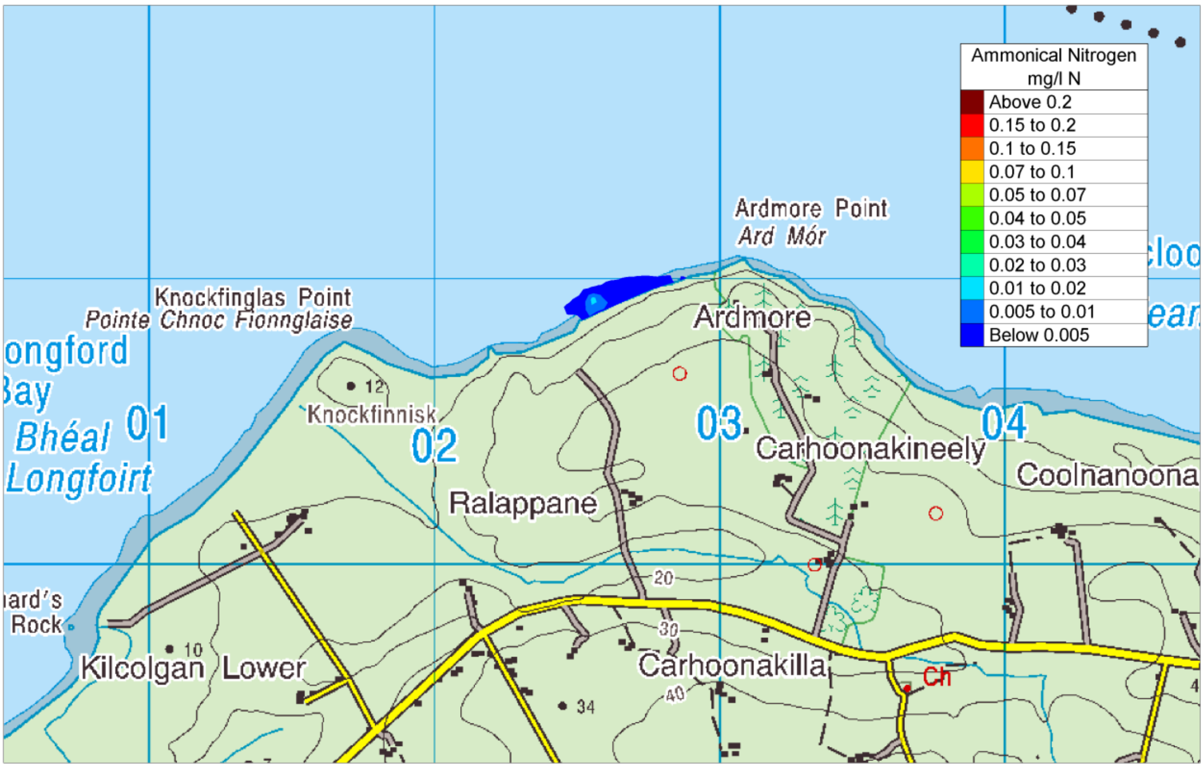

Figure 20 Predicted Mean Ammoniacal Nitrogen Concentration (mg/l N) Envelope over 15-day for spring-neap-spring tide simulation

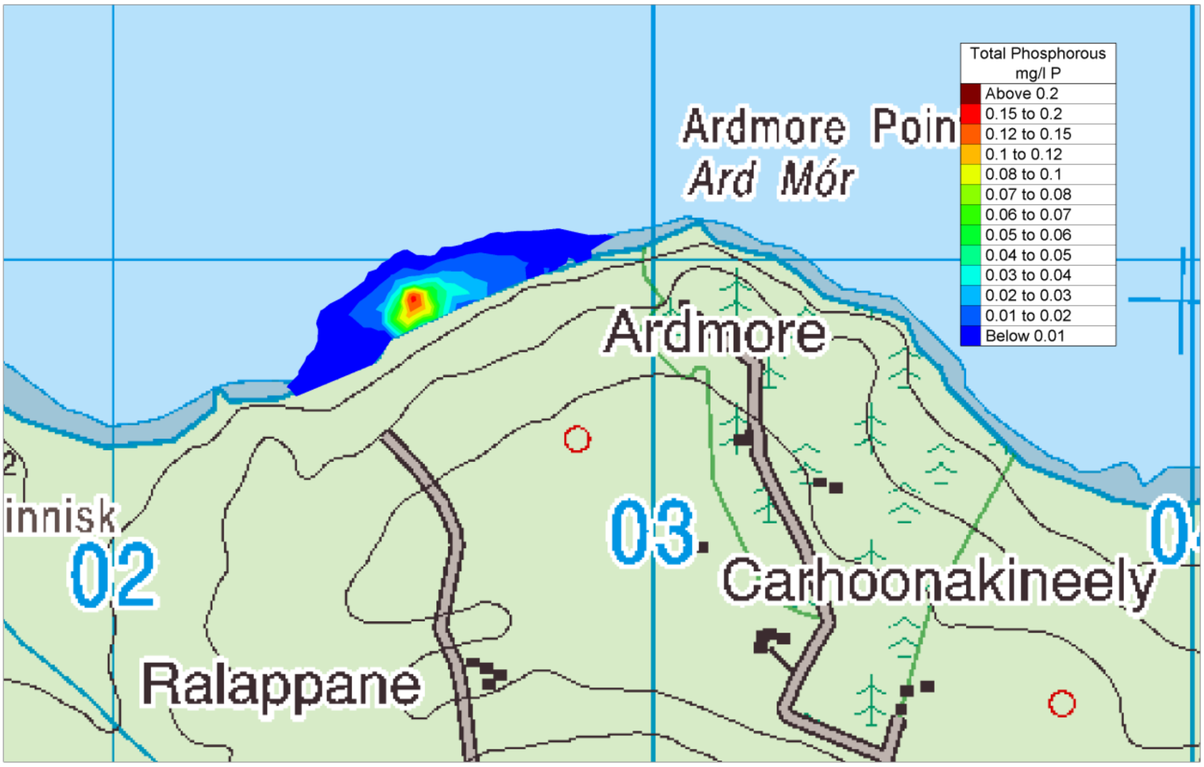

Figure 21 ***Predicted Maximum Total Phosphorous Concentration (mg/l P) Envelope over 15-day for spring-neap-spring tide simulation***

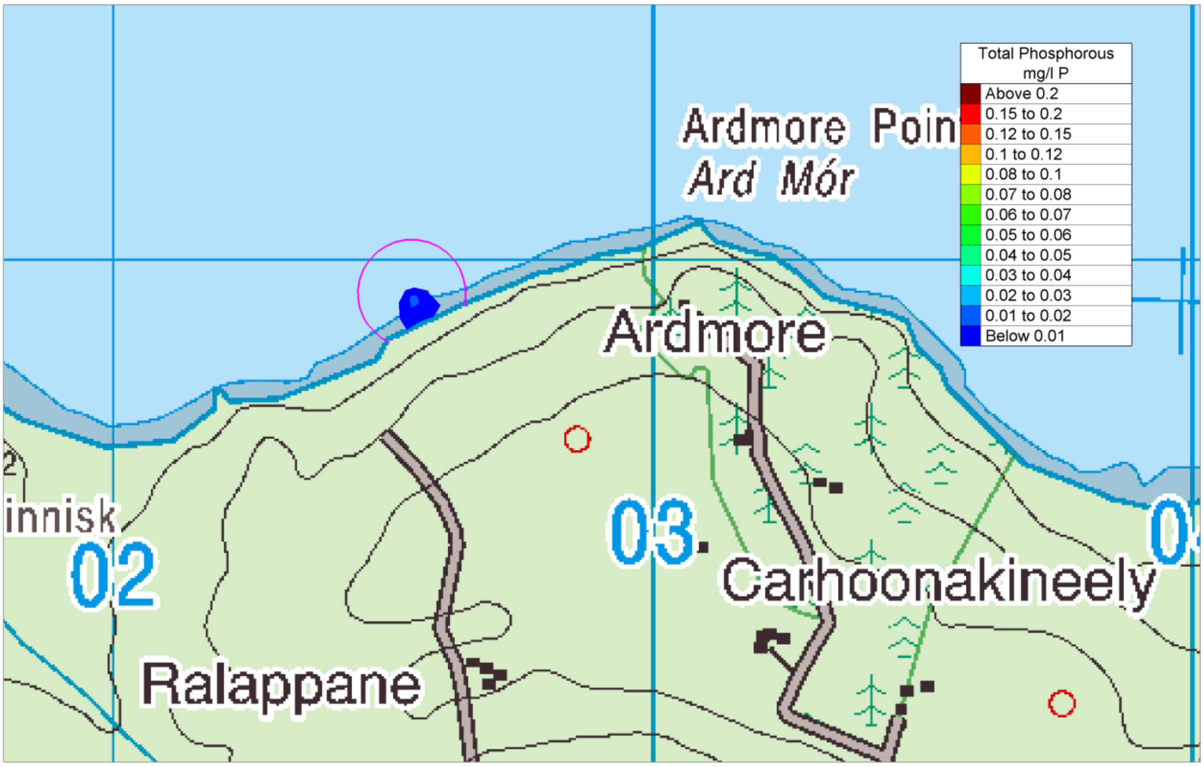

Figure 22 ***Predicted Mean Total Phosphorous Concentration (mg/l P) Envelope over 15-day for spring-neap-spring tide simulation***

4 SEDIMENT DEPOSITION FROM PROPOSED PILING ACTIVITIES

The proposed pilling activities associated with the construction of the proposed jetty, the piled access Trestle, Unloading Platform, Mooring Dolphin 1, Mooring Dolphin 2, Bresting Dolphin, Bent and Tugboat Berths and Moorings has the potential to disturb sediments.

The proposed piles are 76 No. 914mm diameter piles and 127 No. 1067mm Piles, of 92 will be concrete filled, at an average pile length of 20m representing a piling volume of 1,980m^3. At a porosity of 20%, the total mass of sediment removed by the pile drilling operation is estimated conservatively to be 5.5 million kg (5,500 tonnes).

It is proposed that piles will be prefabricated as much as possible to minimize in-water construction.

The majority of the piles supporting the jetty would be driven, with some piles drilled and socketed into the underlying rock to ensure stability of the jetty. This operation would require a jack-up platform supporting a large crane-mounted drill and a large barge-mounted support crane. Spoils from the drilling operation will be conveyed to the surface via reverse-circulation through the drill stem and contained within designated scows or other vessels.

Spoils from the drilling operation will be conveyed to the surface via reverse-circulation through the drill stem and contained within designated scows or other vessels. Approximately 1000m^3 pile arisings are anticipated from the socketed piles (approximately 80 no.), none of which will be from onshore piling operations. The spoils would be placed on a barge, dried, then transferred to shore for drying and reused in general earthworks or in landscaped bunds.

To allow for disturbance of sediments by the piling process and potential spillage of sediment via reverse circulation a conservative factor of 25% of the sediment removed is used as a spillage rate of sediment. Sediment transport simulations are carried out based on a fine to very fine sand as identified in the geotechnical investigations. An 18-day simulation was performed with 0.9kg/s of sediment releases continuously from the pilling site. On the final tidal cycle of the 18-day simulation, the sediment deposition rates in sediment depth (mm) at hourly intervals from Highwater are presented in figures 23.1 to 23.12. The maximum predicted sediment deposition rate envelope in mm per m^2 is presented in figure 23.14 and shows in the Ballylongford Bay area maximum rates from the piling operation are less than 0.2mm which is insignificant.

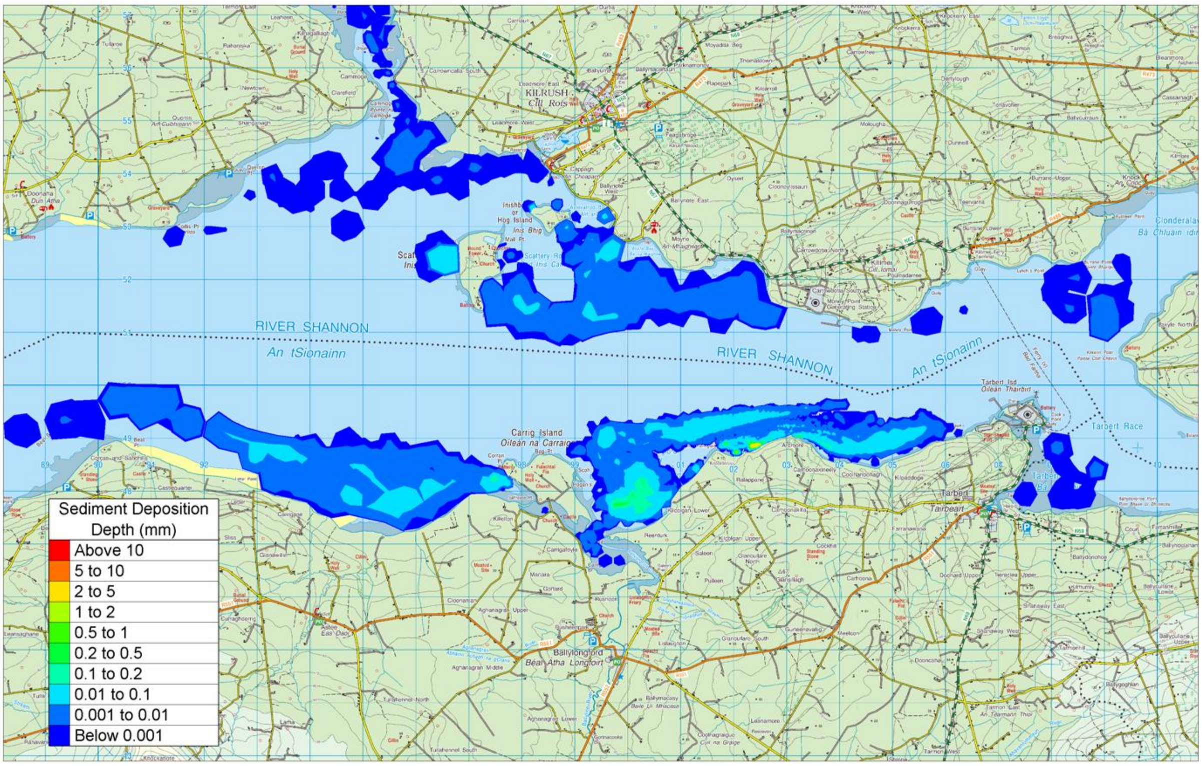

Figure 23.1 Sediment deposition at HW + 0.5hrs

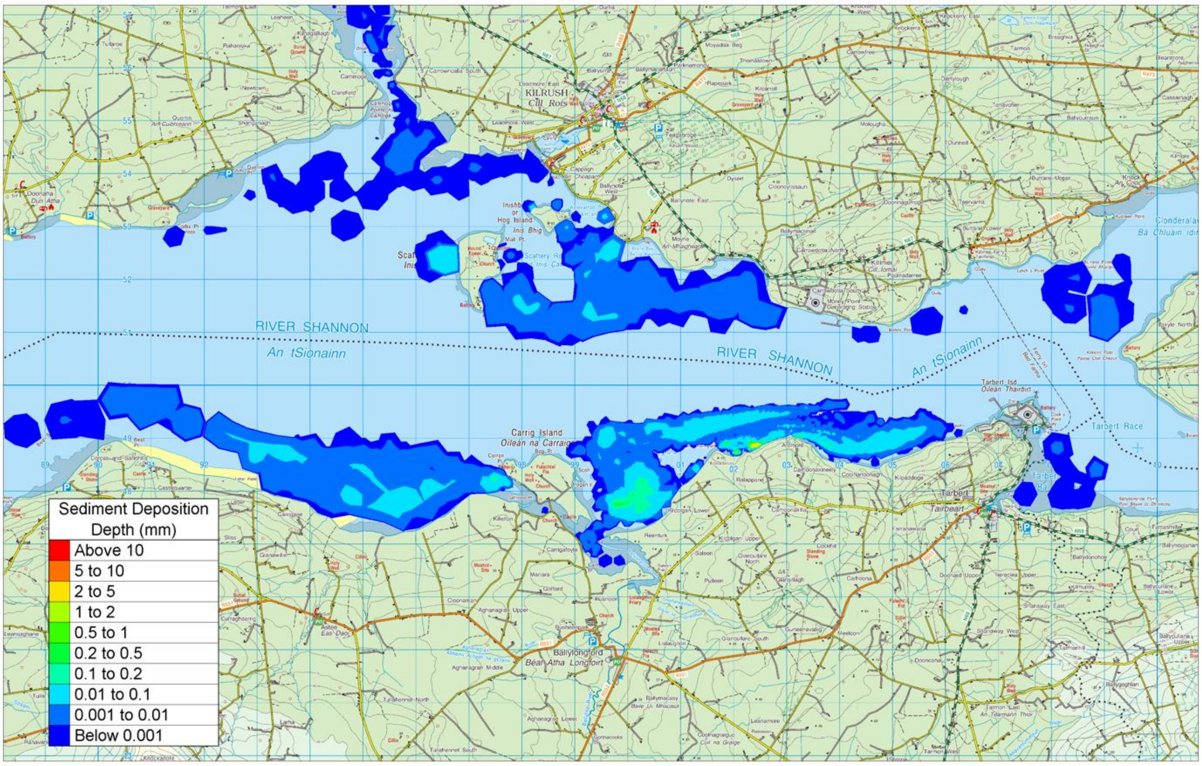

Figure 23.2 Sediment deposition at HW +1.5hrs

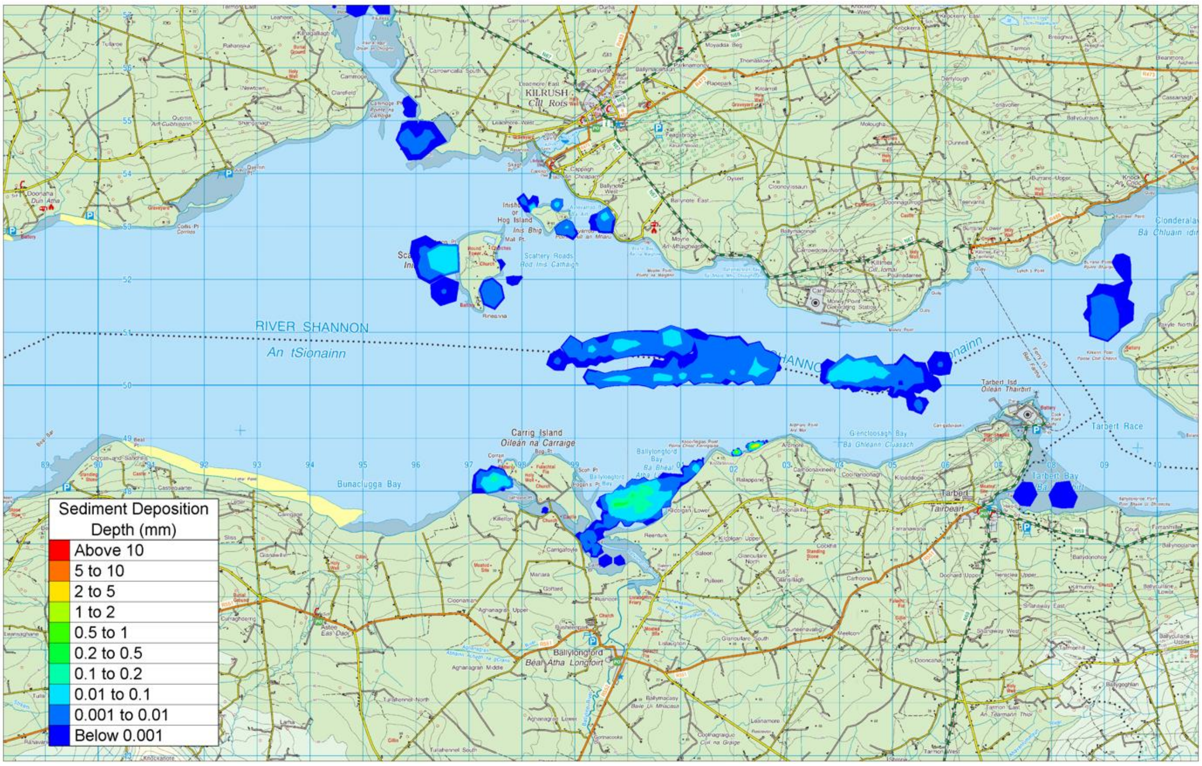

Figure 23.3 ***Sediment deposition at HW +2.5hrs***

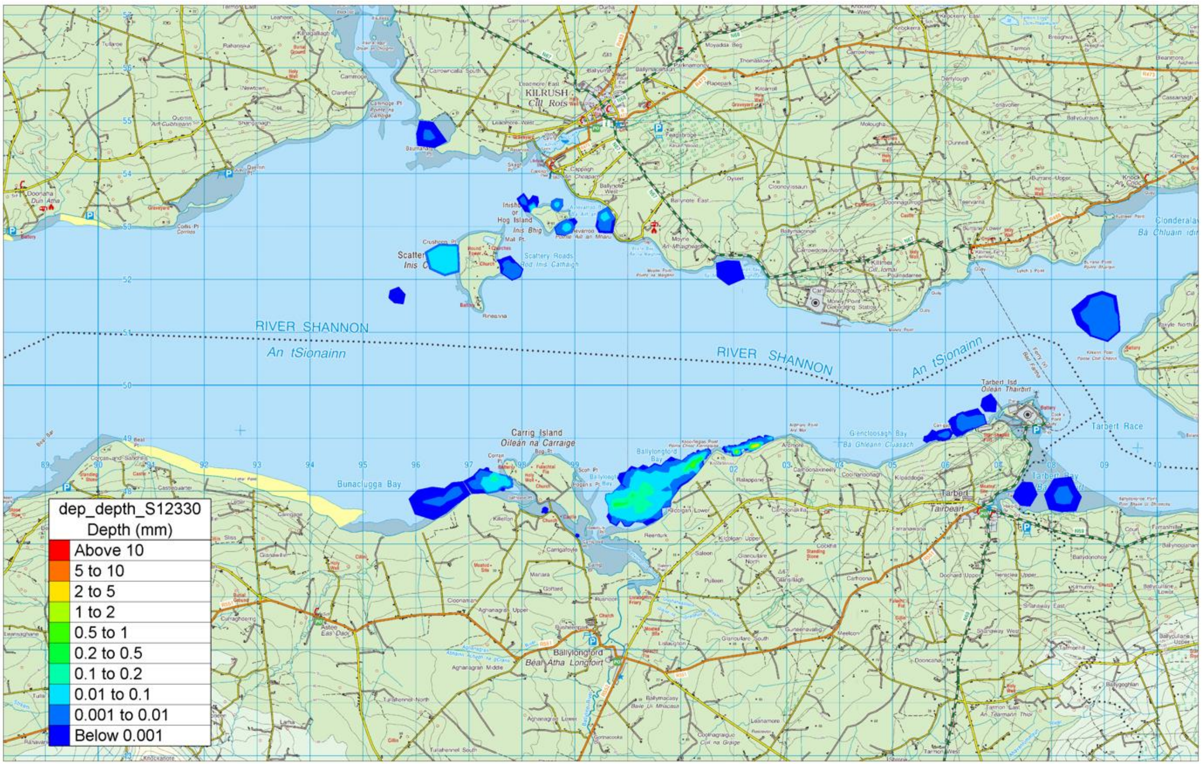

Figure 23.4 ***Sediment deposition at HW + Mid - ebb***

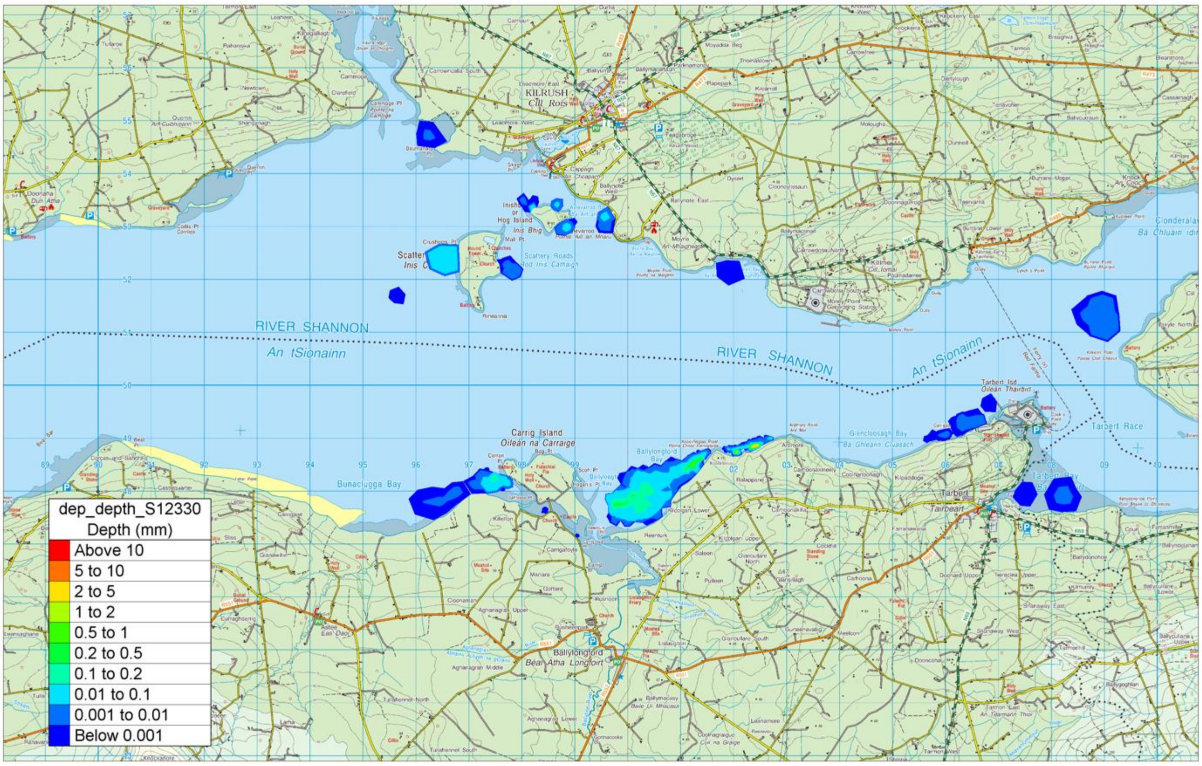

Figure 23.5 **Sediment deposition at LW - 2hrs**

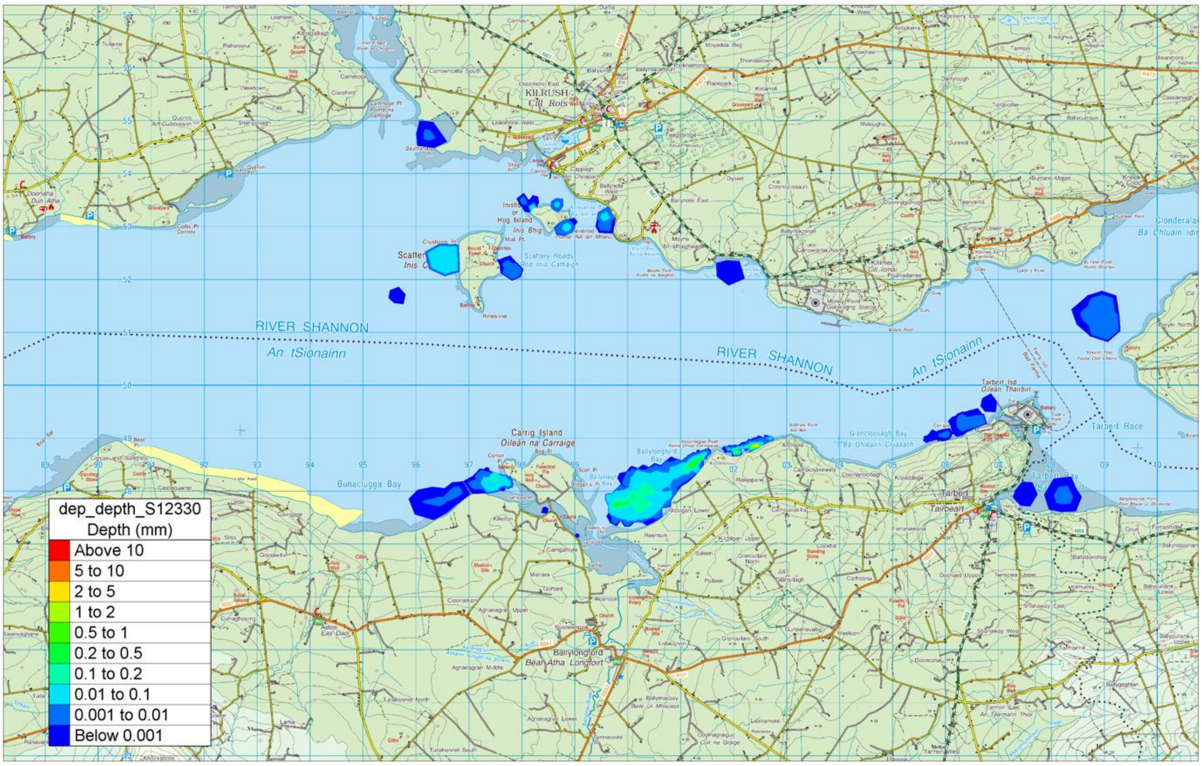

Figure 23.6 **Sediment deposition at LW – 1hr**

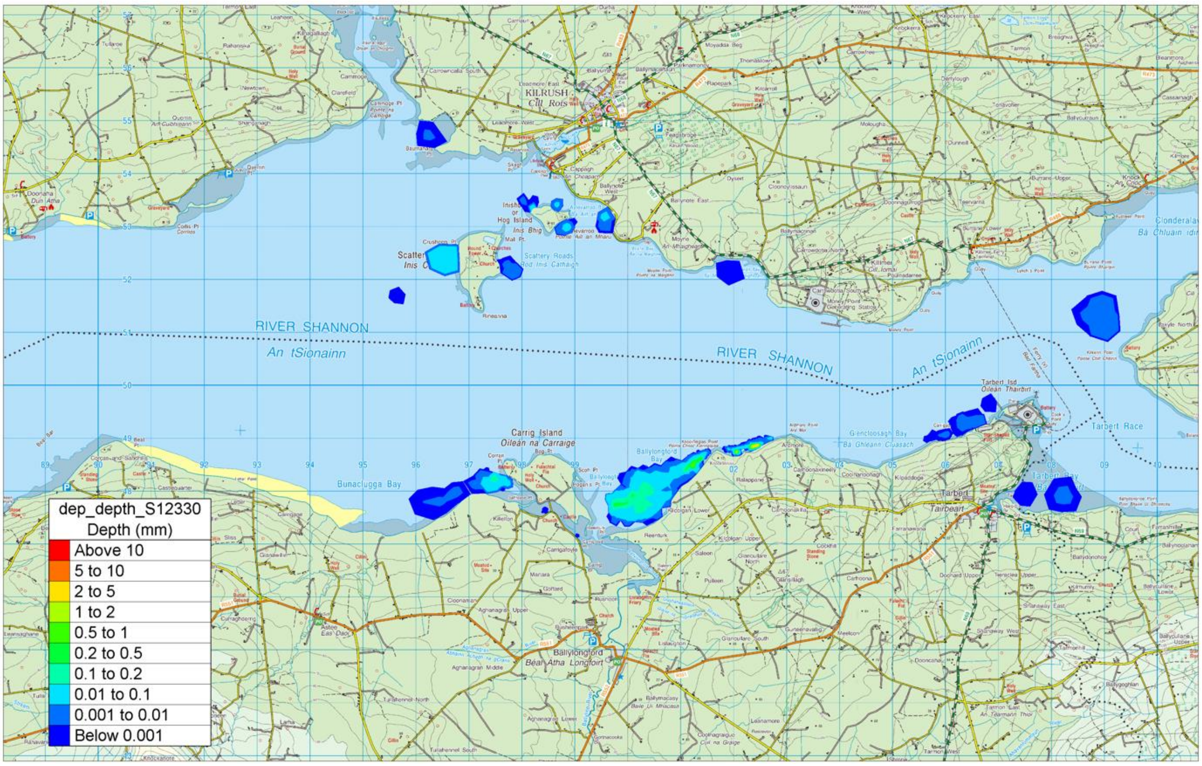

Figure 23.7 ***Sediment deposition at Low Water***

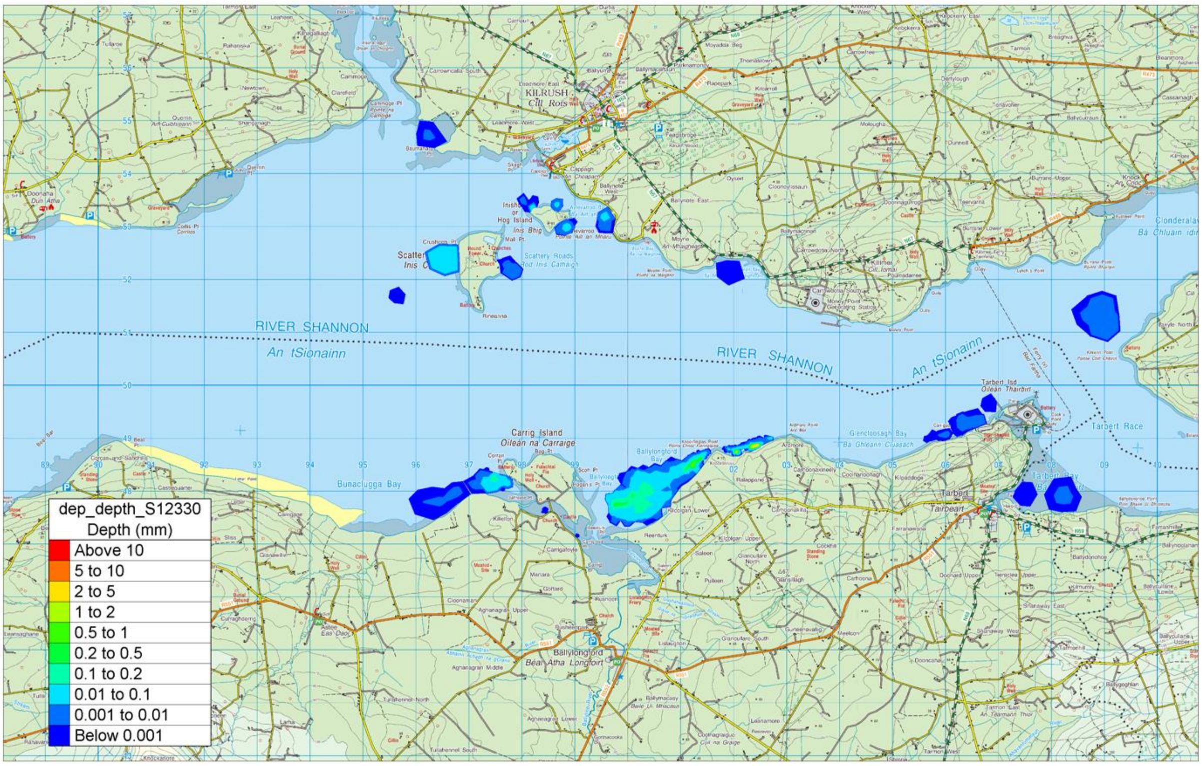

Figure 23.8 ***Sediment deposition at LW + 1***

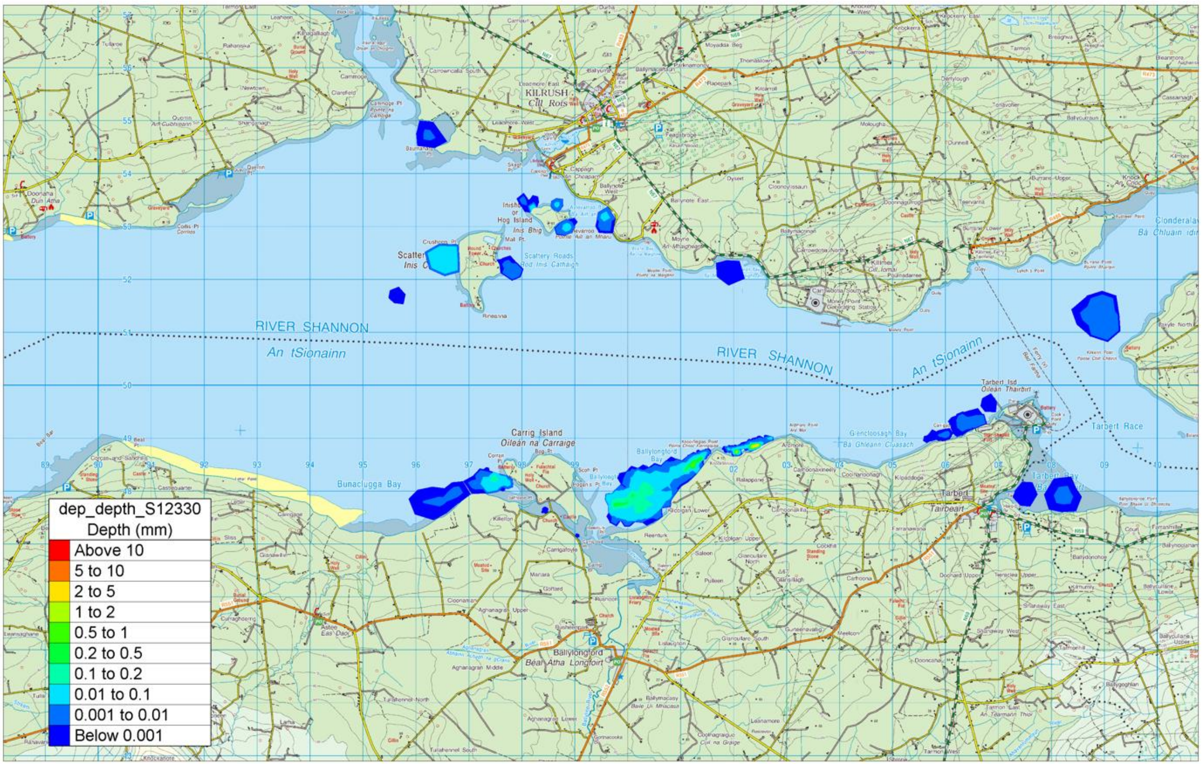

Figure 23.9 Sediment deposition at HW + 2hrs

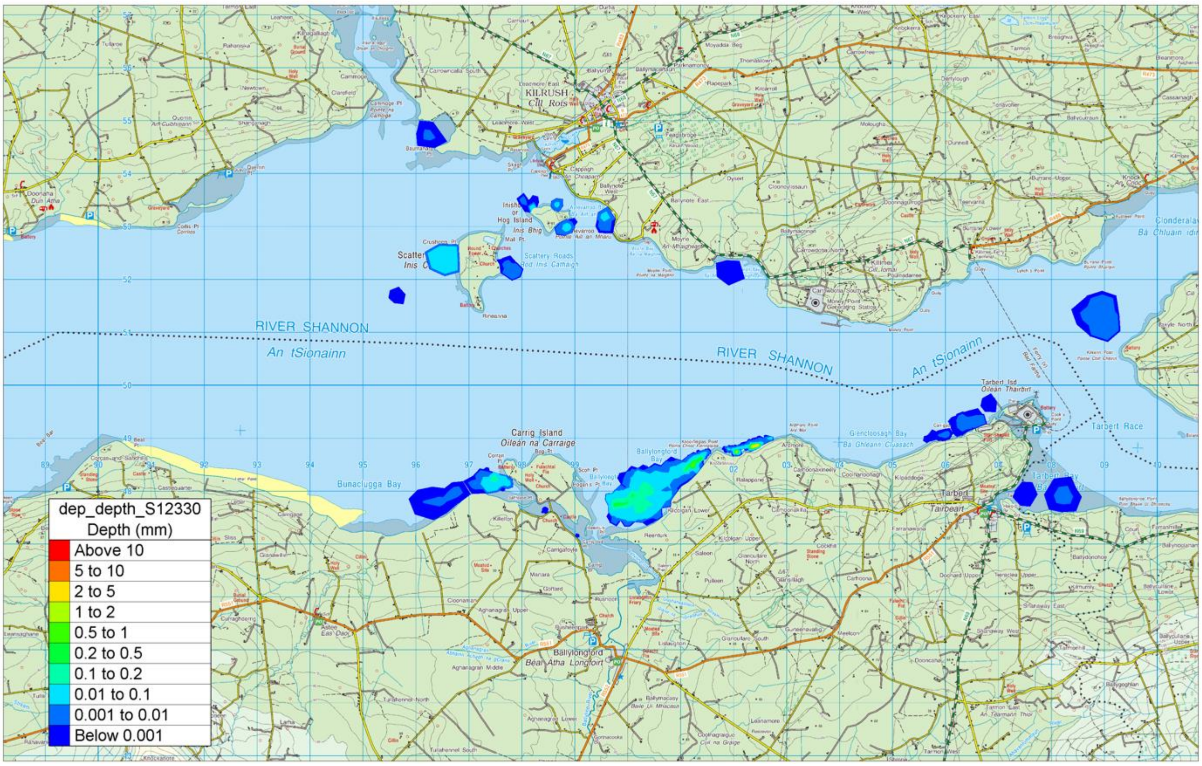

Figure 23.10 Sediment deposition at Mid-Flood

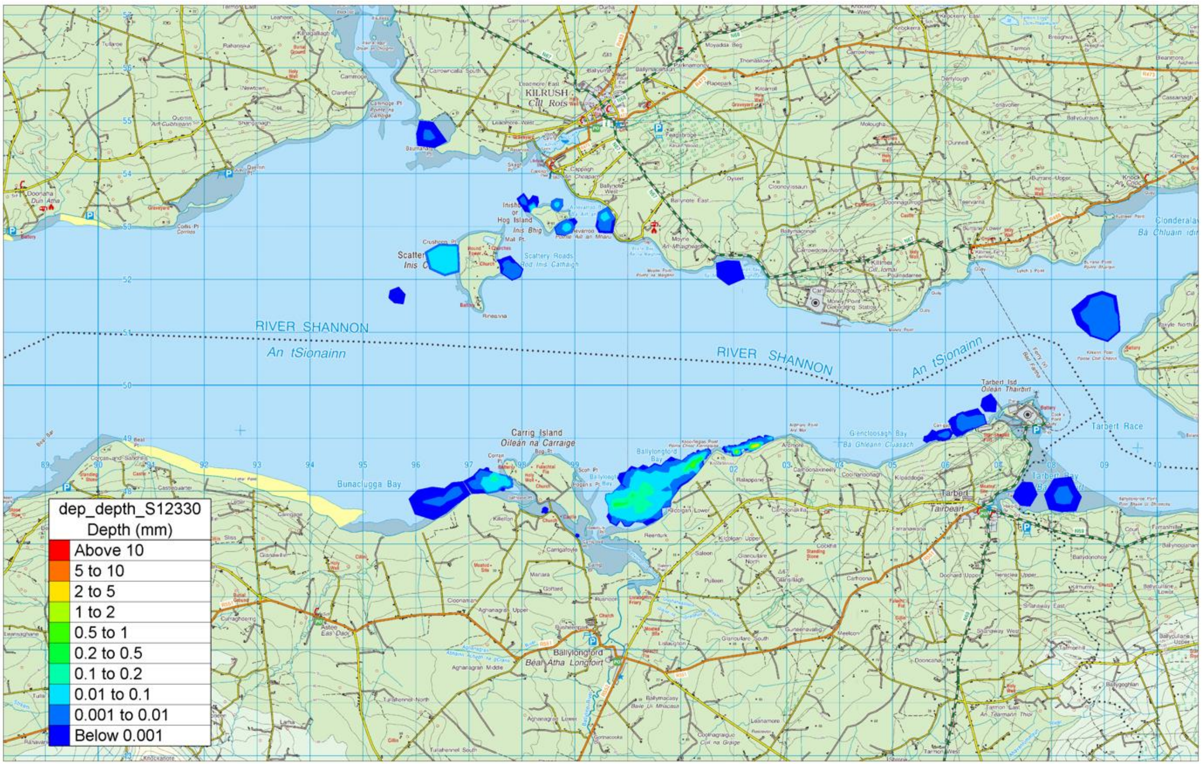

Figure 23.11 Sediment deposition at HW-2

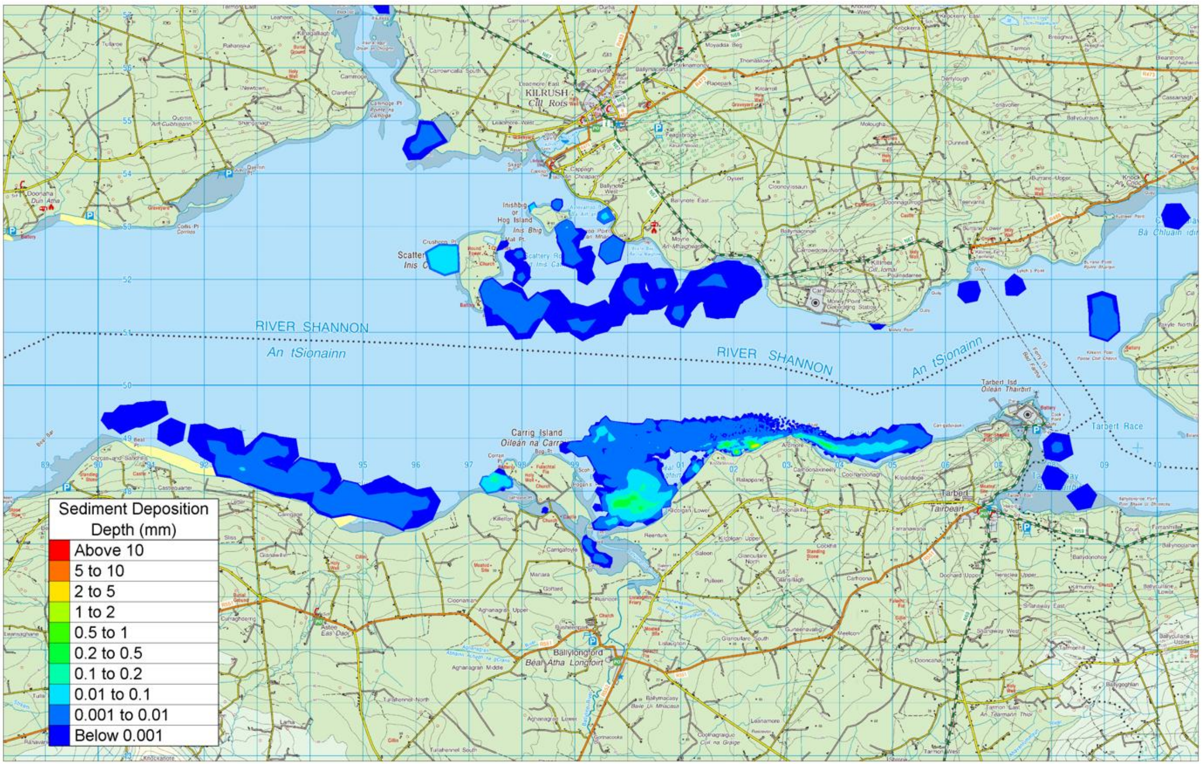

Figure 23.12 Sediment deposition at HW -1 hr

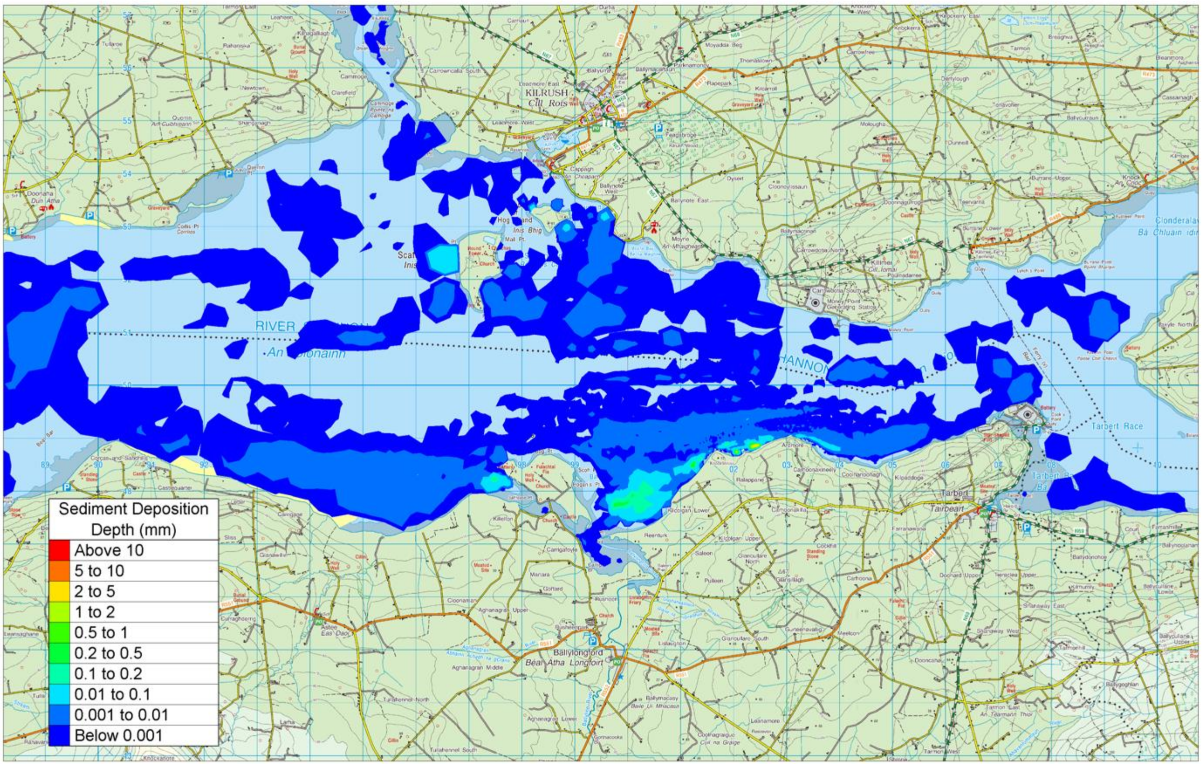

Figure 23.13 Mean tidal sediment deposition envelope

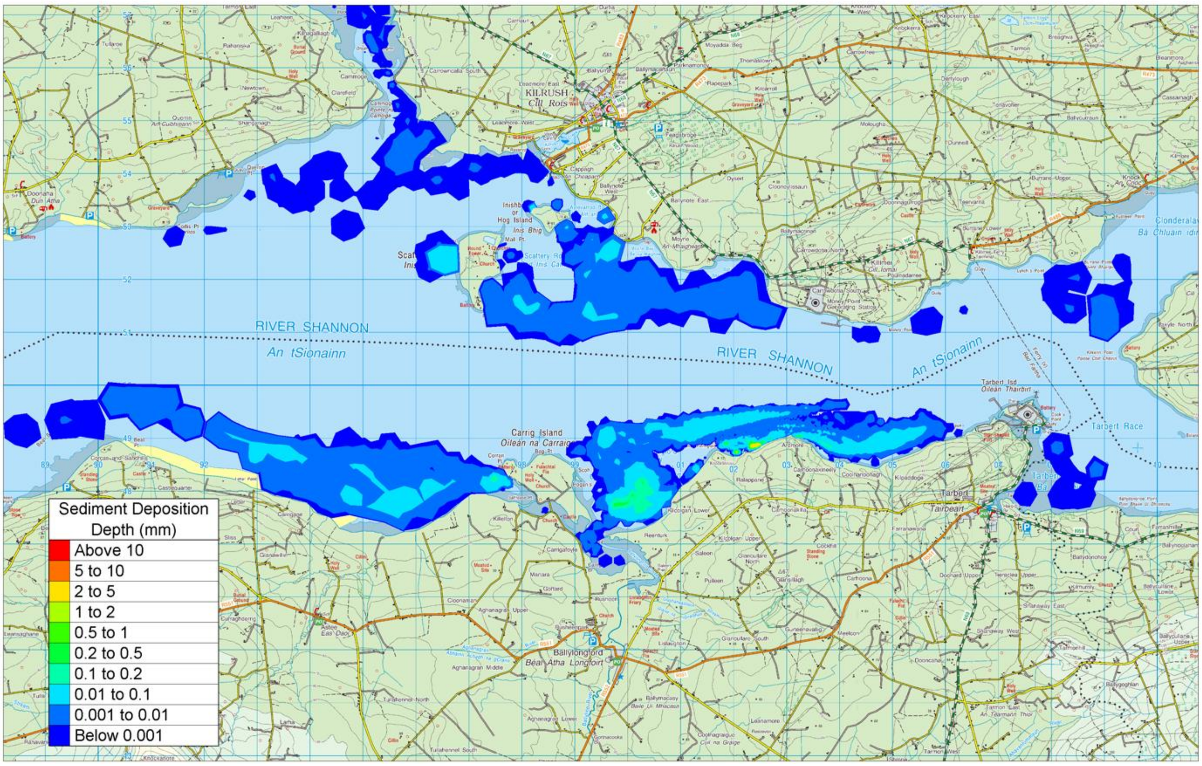

Figure 23.14 Maximum sediment deposition rate envelope