Galway Harbour Company

Galway Harbour Extension

Appendices to NIS Addendum / Errata

Note : This Section has been taken directly from Section 4 of the RFI

Appendix No. 3.3 – Marine Hydrology Issues

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Appendices to NIS Addendum / Errata

Appendix No. 3.3

Appendix No. 1 – Sediment Transport / Morphology Modelling

4 MARINE HYDROLOGY ISSUES

4.1 SEDIMENT TRANSPORT:

Query:

4.1.1 Morphology Modelling

Section 8.4.2.6 of the EIS is a discussion of changes in the sedimentation patterns. These changes are partly due to the creation of a dredged access channel, and also due to the change in the flow direction of the Corrib in-and outflow. The discussion is based on considering changes in the computed bed shear stresses for a number of different scenarios. These bed shear stresses are compared with a table (8.4.1), from which it can be evaluated whether different fractions of the bed sediment can be moved or not.

Deposition can occur in many places on a live bed (a bed on which sediment transport occurs). In section 8.4.2.6, it is stated “the bed shear stress indicates the rate of erosion and susceptibility of a location for deposition”. This may apply to cohesive sediment like clay, but not necessarily apply to fine sand, which will settle as soon as the transport capacity (or bed shear stresses) decreases. The applicant is requested to comment on this.

According to section 8.4.2.2, the model system contains a sediment transport module SISYPHE, but whether it has been applied to account for the morphological changes within the bay is not clear. In the EIS, “Marine Ecology and Modelling”, it is stated that the mathematical modeling will include “Sediment transport modeling to include erosion and deposition rates, changes to morphology etc.”.

Applying the sediment transport module, as an example, the impact of the harbour extension on the morphology west of the extension should be evaluated applying all the information contained in the plots 8.4.16 to 8.4.39. Similarly, the deposition pattern from the spill from Capital Dredging should be evaluated from figures 8.4.42 to 8.4.57. Please comment on the above, and identifying where deposition / erosion could cause a problem.

Response:

4.1.1 Introduction

In order to address the issues raised in Item 1 above a number of morphological modelling simulations using the SISPHYE sediment transport and bed evolution model were run. These simulations attempt to quantify the longer term depositional and erosional characteristics in the vicinity of the Harbour area and the potential impact of the proposed development over the existing case.

SISYPHE is a sediment transport and morphodynamic model which is part of the TELEMAC System. In SISYPHE, sediment transport rates, split into bedload and suspended load, are calculated at each node as a function of flow (velocity, depth, wave height, etc.) and sediment (grain diameter, relative density, settling velocity, etc.) parameters. The bedload and suspended load are calculated separately, bed load using a choice of classical relationships and suspended load using transport equations for depth-averaged suspended sediment concentration. The bed evolution is determined by solving the Exner equation. The sediment transport processes also include the effect of bottom slope, rigid beds (non-erodible) and a bed roughness predictor. To include hydrodynamics the SISYPHE model is dynamically coupled with the TELEMAC Hydrodynamic Model and wave conditions can be imposed in the model from formatted wave climate model output file.

As directed the impact of capital dredging was evaluated from the combined capital and maintenance dredge simulations presented in the EIS Figures 8.4.42 to 8.4.57.

4.1.2 Sediment Transport Simulations

In the EIS in Section 8.4.2.6 use was made of the bed shear stresses to identify locations where erosion / resuspension are likely to take place for different sediment sizes. The magnitude of shear stresses presented for various spring-neap and river flow conditions indicate that the potential erosive areas for fine sands are associated with the Corrib outflow velocities with very little potential outside of this area in respect to tidal flow velocities.

The SISYPHE model was ran to examine the sediment transport and evolution of the sea floor in the vicinity of the proposed development. This model used the same refined mesh as the hydrodynamics for both existing and proposed models.

The SISYPHE simulations indicated that under spring – neap tides and without river inflows the hydrodynamics were unable to mobilise sands from the sea bed in the vicinity of the proposed Harbour development and the existing navigation channel. For simulations with river flows median and winter flood flows, significant scouring of the Claddagh river channel and Lough Atalia inlet channel takes place when modelling coarse silts and fine sands. In reality these sections of river bed behave as rigid (non-erodible) beds as they already have been eroded free of these sediment fractions sizes.

Depending on the Corrib flow magnitude the scouring of the navigation channel for both existing and proposed cases extend seaward of the Corrib Entrance (at Nimmo's Pier) for silt and fine sediment fractions. At the lower summer flows of say 30cumec the Corrib sediment when present will temporarily settle inside the Corrib Entrance but will be flushed seaward once river flow increases.

4.1.3 Dredging History of Channel

The dredging History of the existing navigation channel is c. 63,000m^3 in 1978, 70,000m^3 in 1990 and 65,000m^3 in 2001 and has not been dredged since 2001. It is expected that the existing Navigational Channel will require maintenance dredging in 2016, which represents a gap of 15years. The above volumes equate to 100,170 tonnes, 111,300tonnes and 103,350 tonnes respectively based on a porosity of 40% and a grain density of 2650 kg/m^3 (equates to between 8,300 and 9,300 metric tonnes per annum). Based on the 2012 and 2014 HSL Bathymetry survey the deposition volume over the two year period between surveys is 18,200 m^3 (9,100m^3 per annum) and this includes the severe wave climate tidal flooding of January 2014. The main deposition area is just to the south of the Corrib entrance off Nimmo's Pier. This would agree with the winter flow conditions in the Corrib described in Figures 4.1.14 to 4.1.17 for sand (i.e. where it would drop the sand if present). At the end of January 2012 and 2014 the date of the two channel surveys, the River Corrib would have been in winter flow conditions and suggests that the sediment deposition observed from the difference in surveys is most likely sand as opposed to river silt.

Based on the low sediment yield characteristics of the Corrib it is considered that the majority of the deposition (possibly up to 80%) is from littoral deposition under wave action being swept in around Mutton Island and settling in the deeper channel and the remainder from the Corrib.

These figures indicate that the dredging requirement for the existing case is quite low requiring dredging on average every 12years at approximately 9,000tonnes per annum.

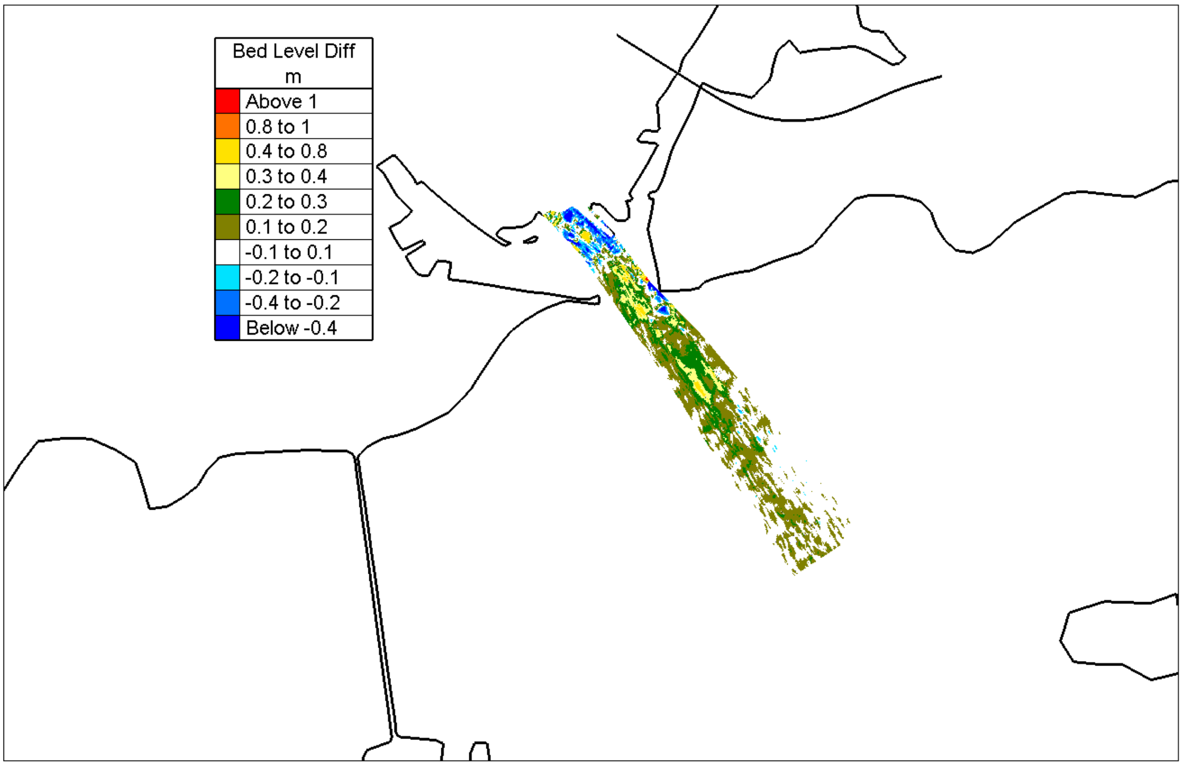

Figure 4.1.1 Difference plot of existing navigation channel HSL Survey - January 2014 and January 2012 showing principal deposition over 2 year period occurring primarily at and near the Corrib entrance.

4.1.4 River Corrib Sediment Deposition

In order to assess the contribution of the River Corrib sediment load on the Local morphology SISYPHE analysis was carried out using a rigid bed option so as to isolate the Corrib sediment input over ambient erosion and deposition features. Simulations were carried out modelling median river flow of 82cumec and 1% winter flow of 272cumec for a silt with d_{50} = 20microns and a fine sand/coarse silt with a d_{50} of 60microns. These were modelled as non-cohesive sediments. The Corrib inflow suspended sediment concentration was set at 10 mg/l (0.01kg/m^3). Based on Corrib sediment load assessment in Section 4.2 the average concentration is likely to be 3 to 4 times lower at 2 to 4 mg/l.

The simulations were run for 15day spring-neap-spring simulation with the evolution determined each time step and the bathymetry updated in the hydrodynamic model. The evolution results for a 20micron silt load from the Corrib under median (82cumec) flow conditions are presented in Figure 4.1.2 and 4.1.3 for the existing and proposed harbour cases and as depositional rates (mm per day) in Figures 4.1.4 and 4.1.5 respectively. The corresponding fine sand/coarse silt simulation results are presented in Figures 4.1.6 to 4.1.9.

As expected under median river flows for both existing and proposed cases the fine sand settles out near the Corrib entrance once velocities reduce, whereas for the smaller silt fraction (20 microns) this settles out more gradually over a larger footprint area. For both cases local elevated deposition is found adjacent to the New Pier to the east of the Docks gates. For the proposed case elevated local deposition is found at the proposed Marina entrance.

The sediment transport results for the larger Corrib winter flows are presented in Figures 4.1.10 to 4.1.17. These show similar pattern to the previous silt simulation results except that the deposition in the navigation channels occurs further seaward for both existing and proposed cases.

The Corrib flow magnitude dictates the extent that sediment is transported along the navigation channel. In low flow periods sediment is dropped inside the Corrib entrance and under median flows at the Corrib entrance and under winter flood flows seaward of the entrance. This depositional pattern is also evident from a comparison of the bathymetric surveys of the existing navigational channel between 2012 and 2014, refer to Figure 4.1.1.

The River Corrib simulation shows for the silt fraction under median (average) flows and suspended sediment concentration of 10mg/l that the Claddagh channel is self cleansing as far as the deeper water in the Corrib entrance adjacent to the Dock Gates. The depositional pattern shows settlement of silt within the length of the Channel and further south towards Mutton Island and also some settlement coming around into the new commercial Port (refer to Figures 4.1.2 to 4.1.5). Under typical winter flood conditions the simulations show that the proposed channel is self cleansing for virtually its entire length (4.1.10 to 4.1.13). The simulation shows the depositional pattern to be well spread out to the south, east, and west of the Harbour development and Mutton Island. The figures presented in the EIS 8.4.16 to 8.4.39 support the above findings in terms of the critical self cleansing velocities achieved in the proposed channel and the less efficient existing channel.

The simulation indicates that the silt fraction is well dispersed under winter flows and that a potential sediment bar towards the end of the navigation channel will not form under both existing and proposed cases.

A fine sand simulation modelling again a suspended sediment concentration in the Corrib of 10mg/l under median and winter flows shows that fine sand will settle out under median flow conditions (Figure 4.1.6 to 4.1.9). Under typical winter flows the sand is cleansed as far as the Marina Entrance where downstream of this (south) deposition is shown (Refer to Figure 4.1.14 to 4.1.17).

Based on the catchment characteristics of the Corrib and its sediment yield discussed in the Section 4.2, it is unlikely that persistent sediment concentrations of 10mg/l or higher will occur under median or Corrib flood flow conditions (with concentrations of 2 to 4mg/l being recorded) and that the sediment fraction being mobilised is a fine silt as opposed to sand and less likely to settle out in the immediate receiving waters of Galway Bay. Under these conditions the majority of the Corrib sediment will be dispersed as suspended sediment and will not settle.

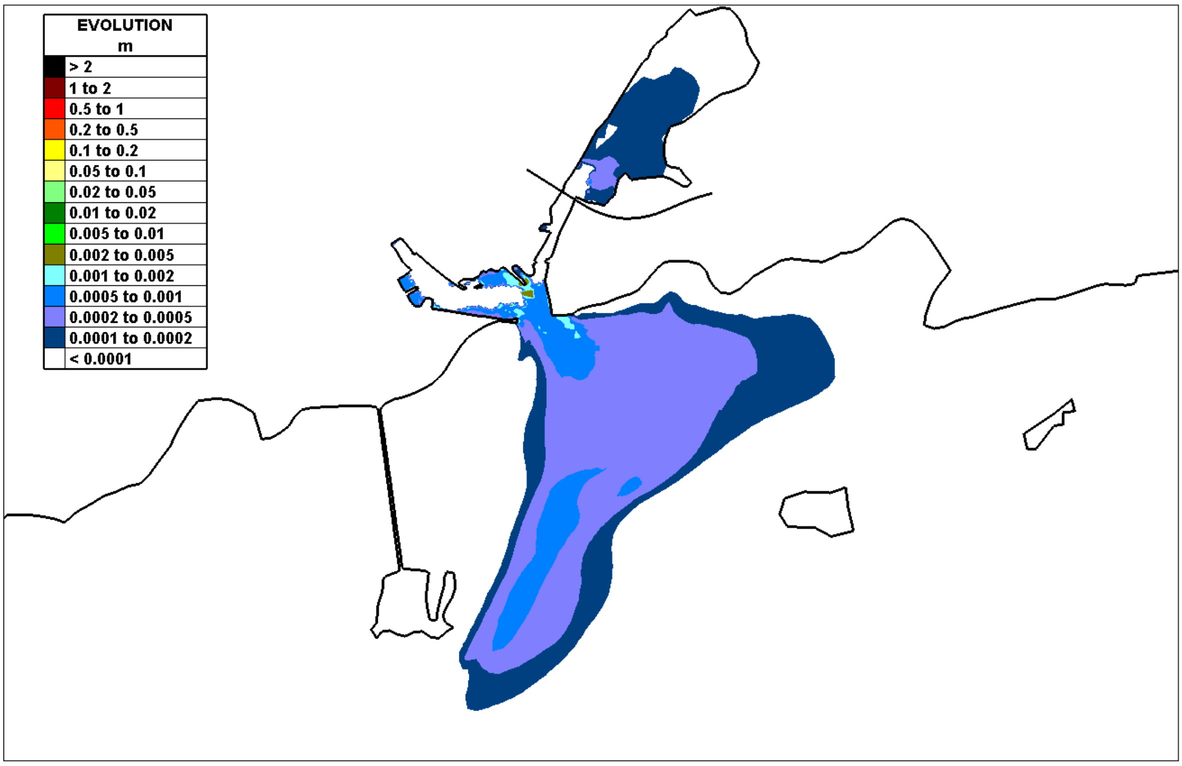

Figure 4.1.2 Deposition of a Corrib silt under median flows at the end of 15 days - Existing Case (the white area within the Claddagh Basin and Lough Atalia channel is self-cleansing.

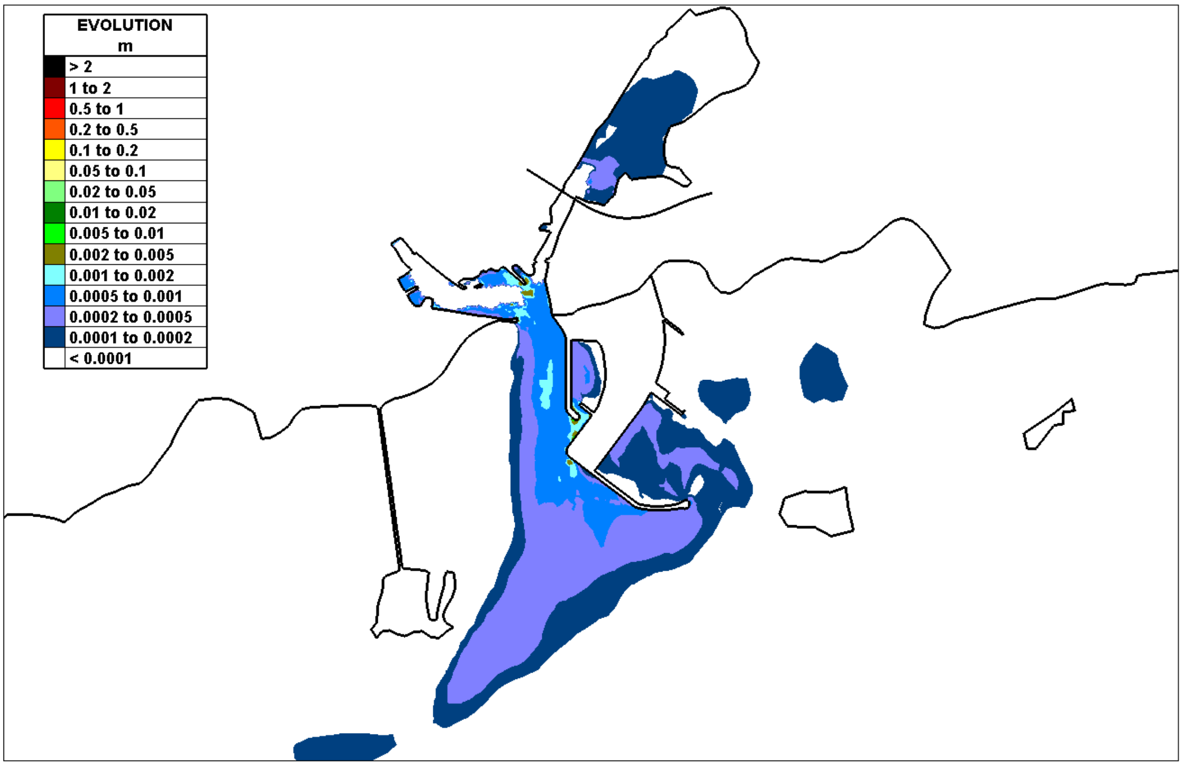

Figure 4.1.3 Deposition of a Corrib silt under median flows at the end of 15 days - Proposed Case (the white area within the Claddagh Basin and Lough Atalia channel is self-cleansing).

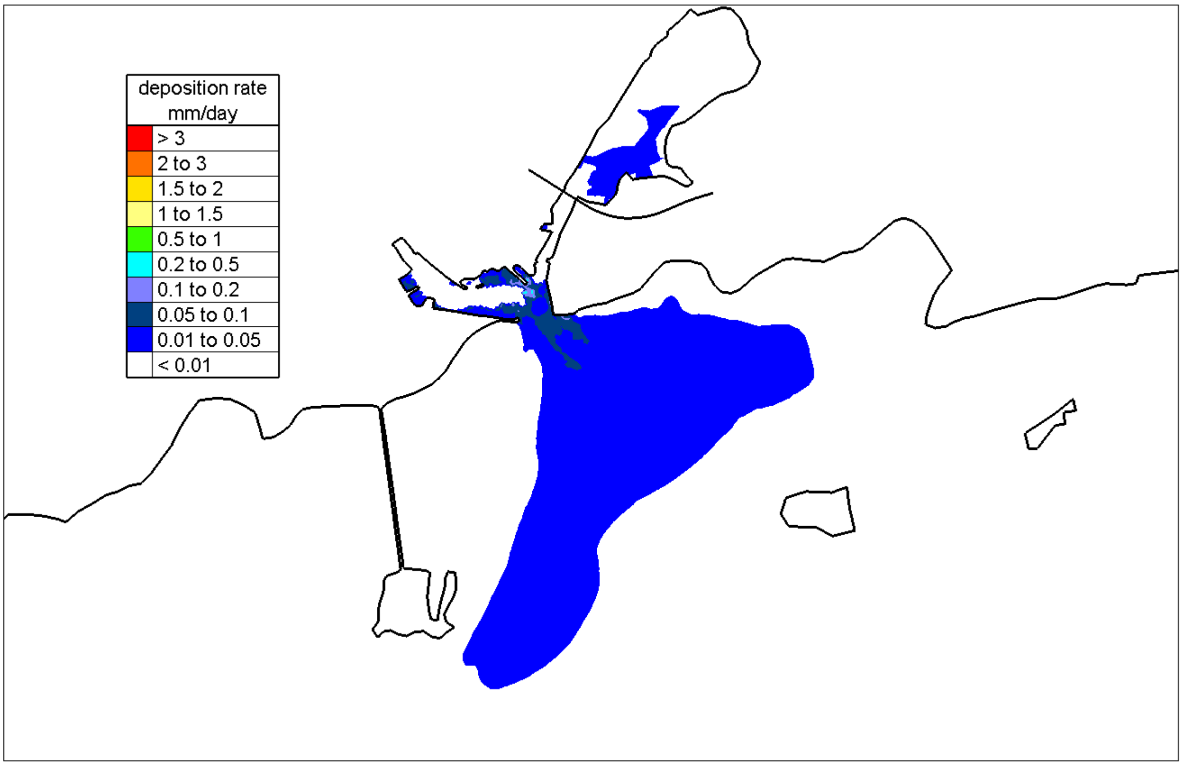

Figure 4.1.4 Computed Depositional Rates of a River Corrib fine silt under median flows for Existing Case

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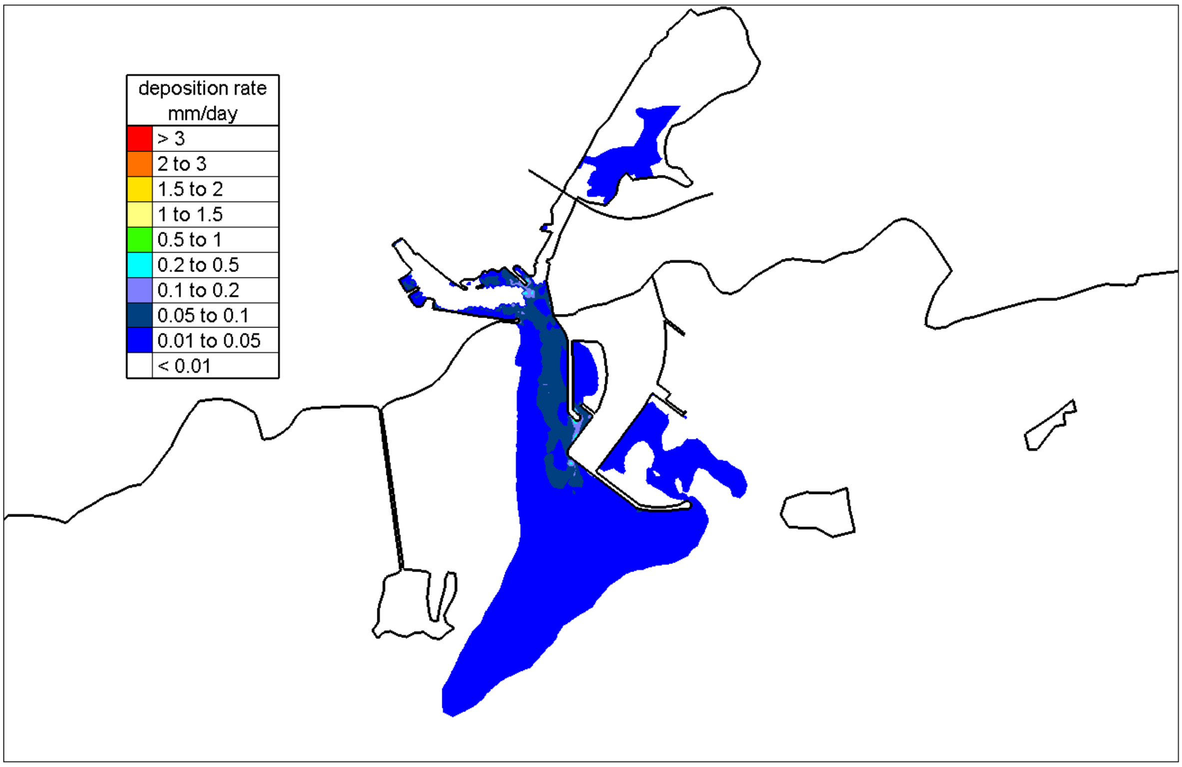

Figure 4.1.5 Computed Depositional Rates of River Corrib fine silt under median flows for Proposed Case.

Figure 4.1.6 Deposition of Corrib fine sand under median flows at the end of 15 days - Existing Case

Figure 4.1.7 Deposition of a Corrib fine sand under median flows at the end of 15 days - Proposed Case

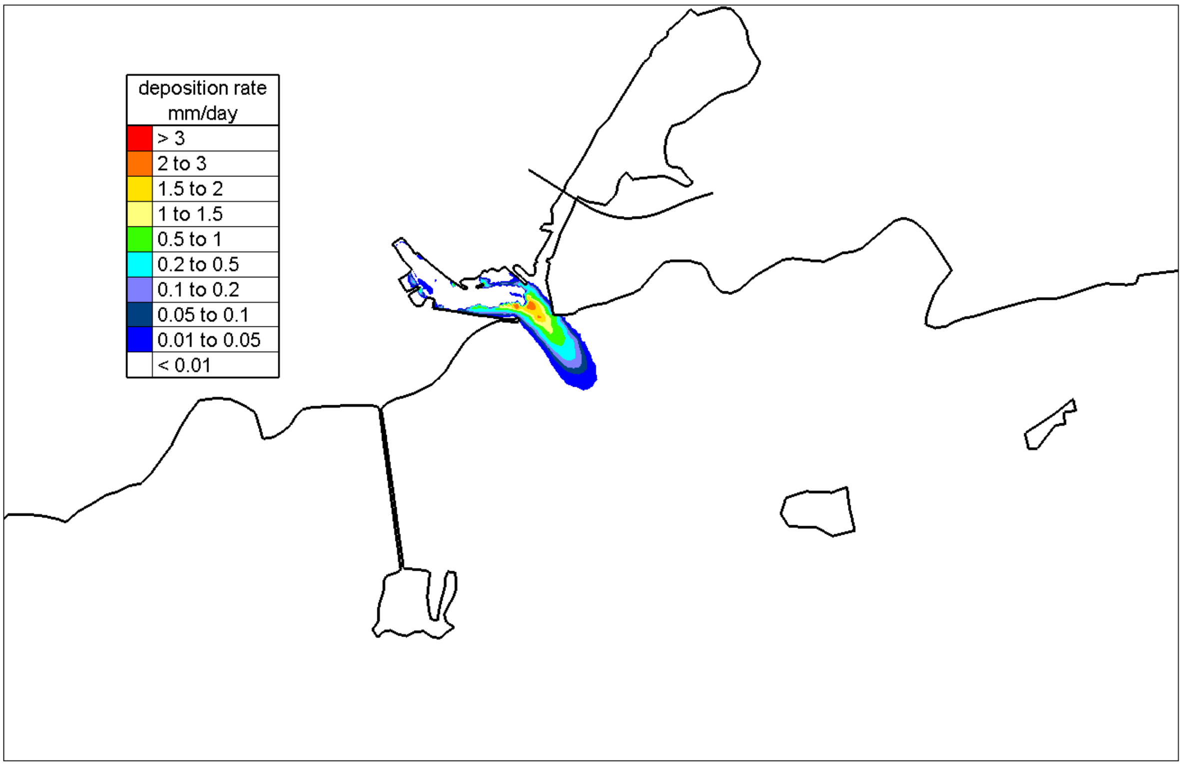

Figure 4.1.8 Computed Depositional Rates of a River Corrib fine sand under median flows - Existing Case

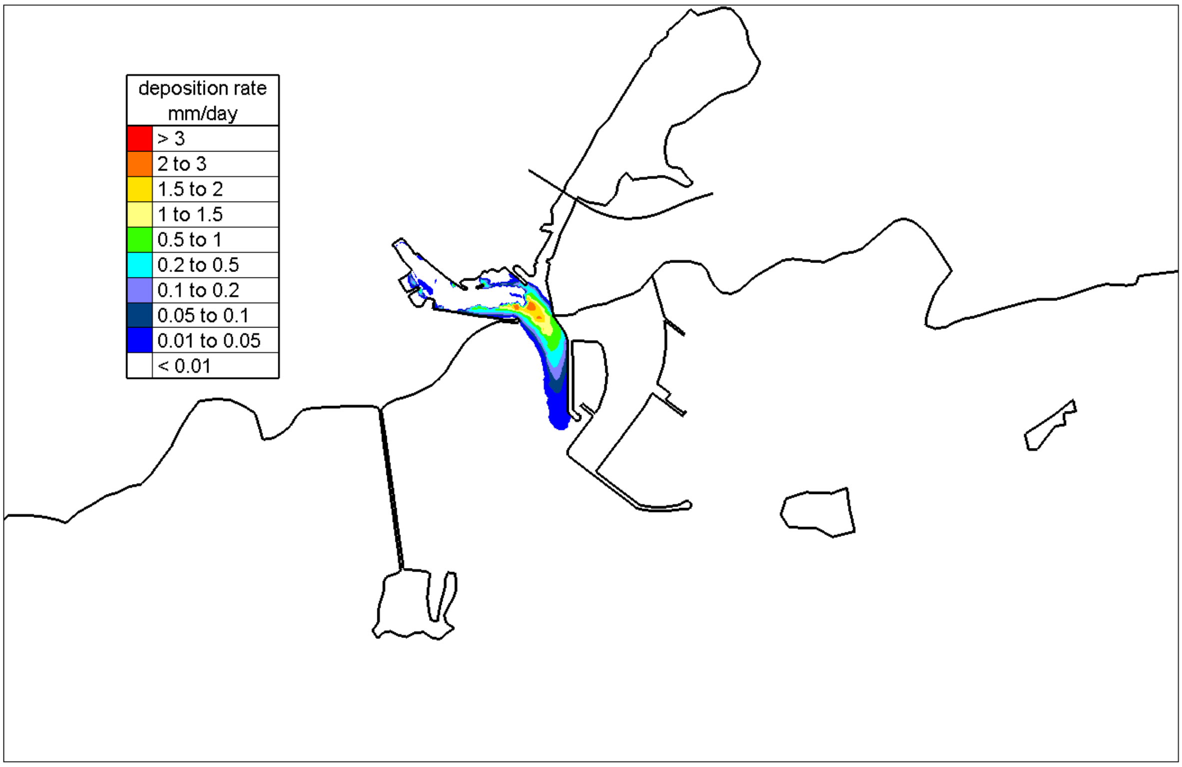

Figure 4.1.9 Computed depositional rates of a River Corrib fine sand under median flows - Proposed Case

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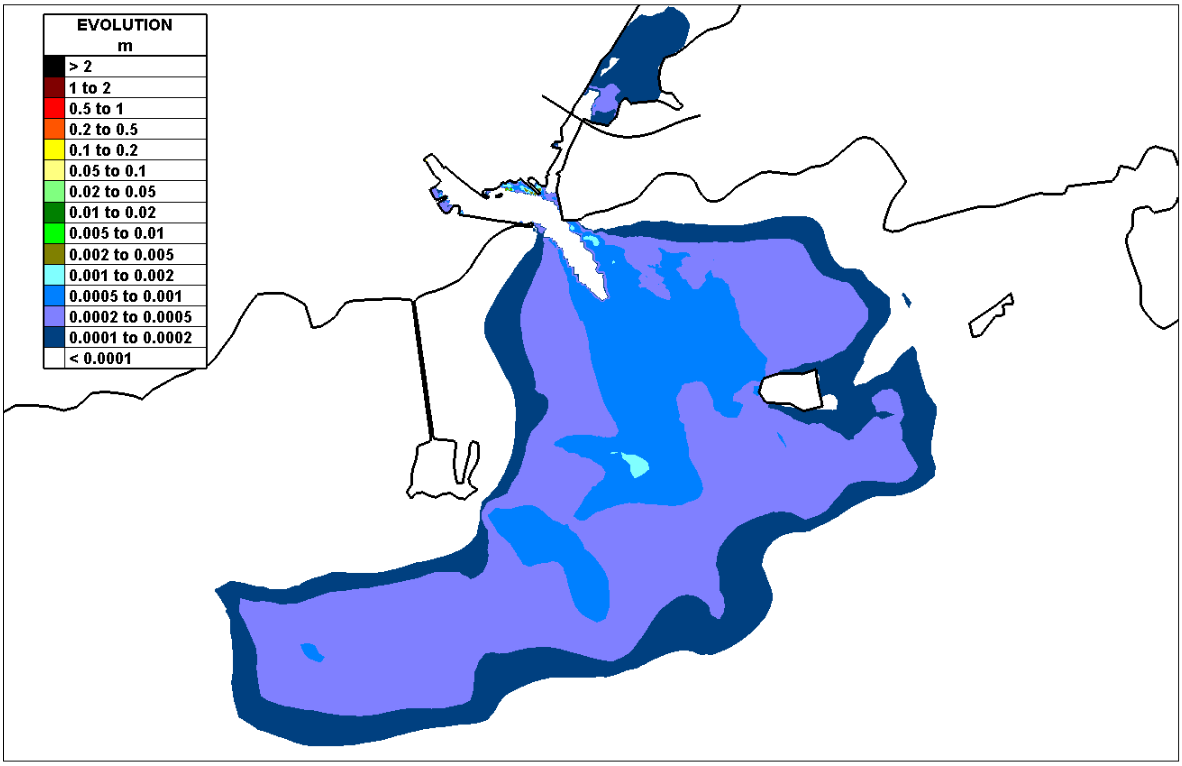

Figure 4.1.10 Deposition of a Corrib fine silt under winter flows (272cumec) at the end of 15 days Simulation - Existing Case

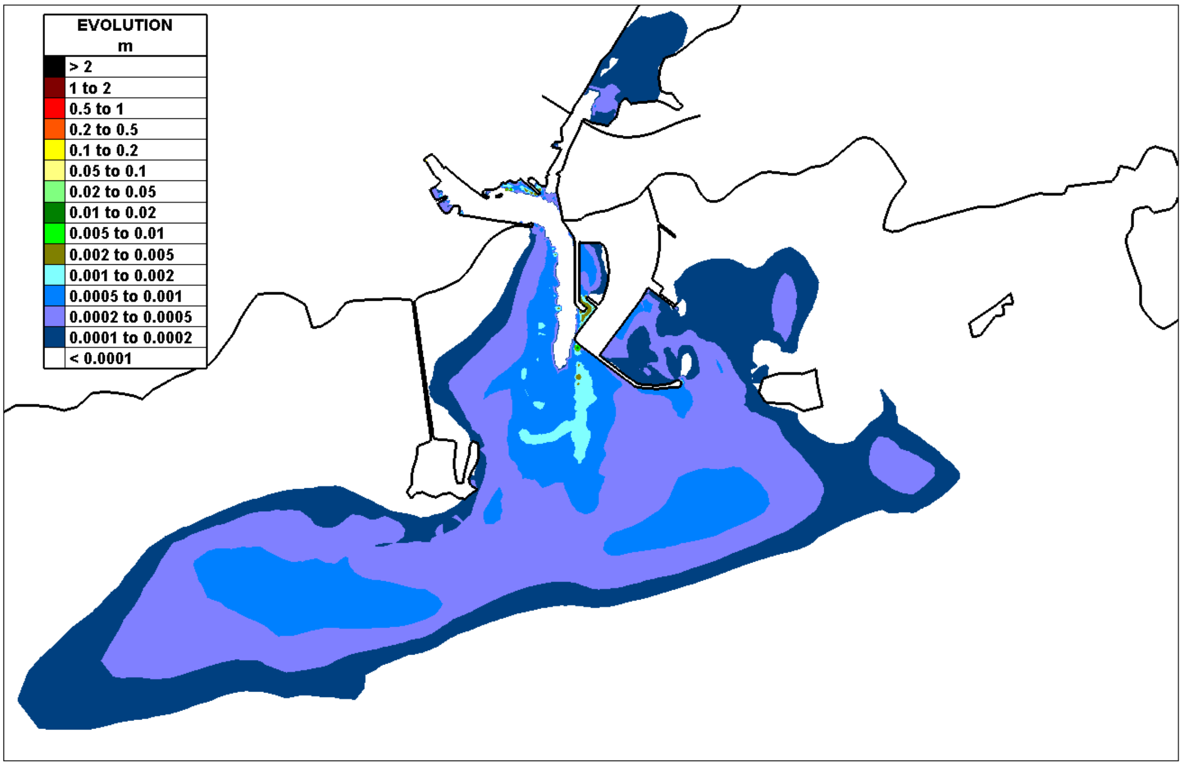

Figure 4.1.11 Deposition of a Corrib fine silt under winter flows (272cumec) at the end of 15 days Simulation - Proposed Case

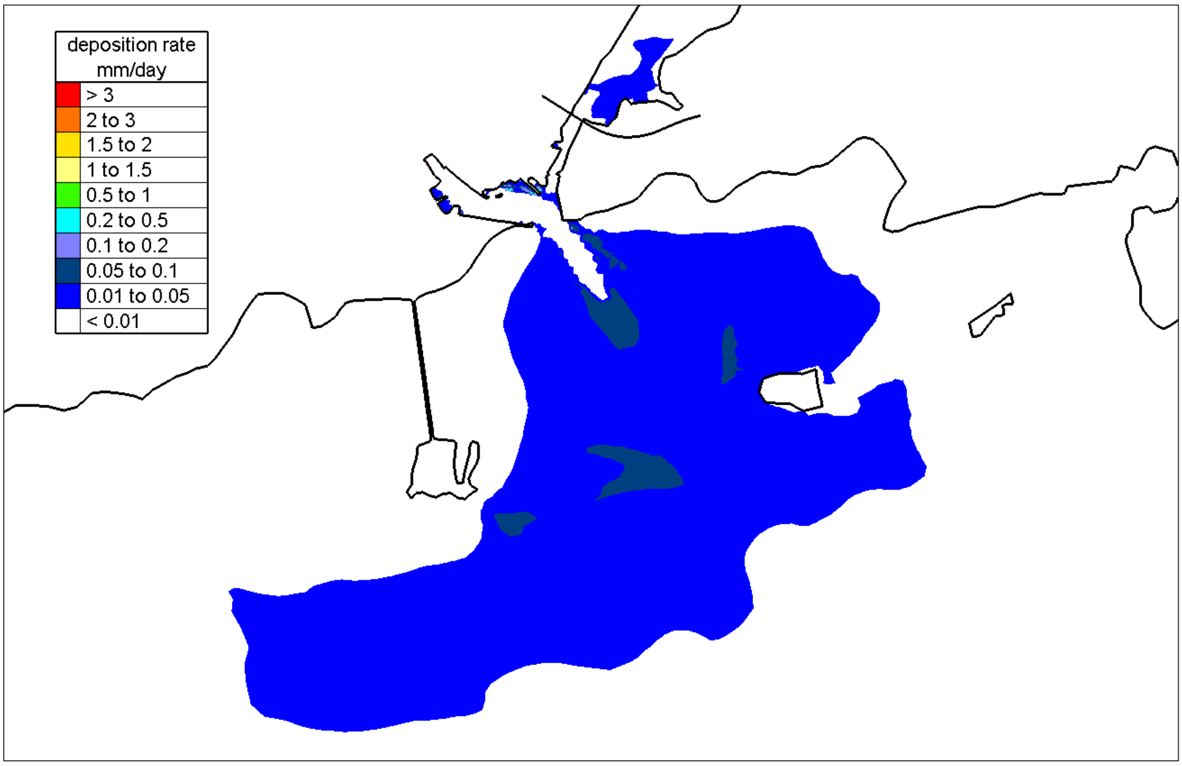

Figure 4.1.12 Computed depositional rates of a River Corrib fine silt under Winter flood flows (1-%ile 272cumec) - Existing Case.

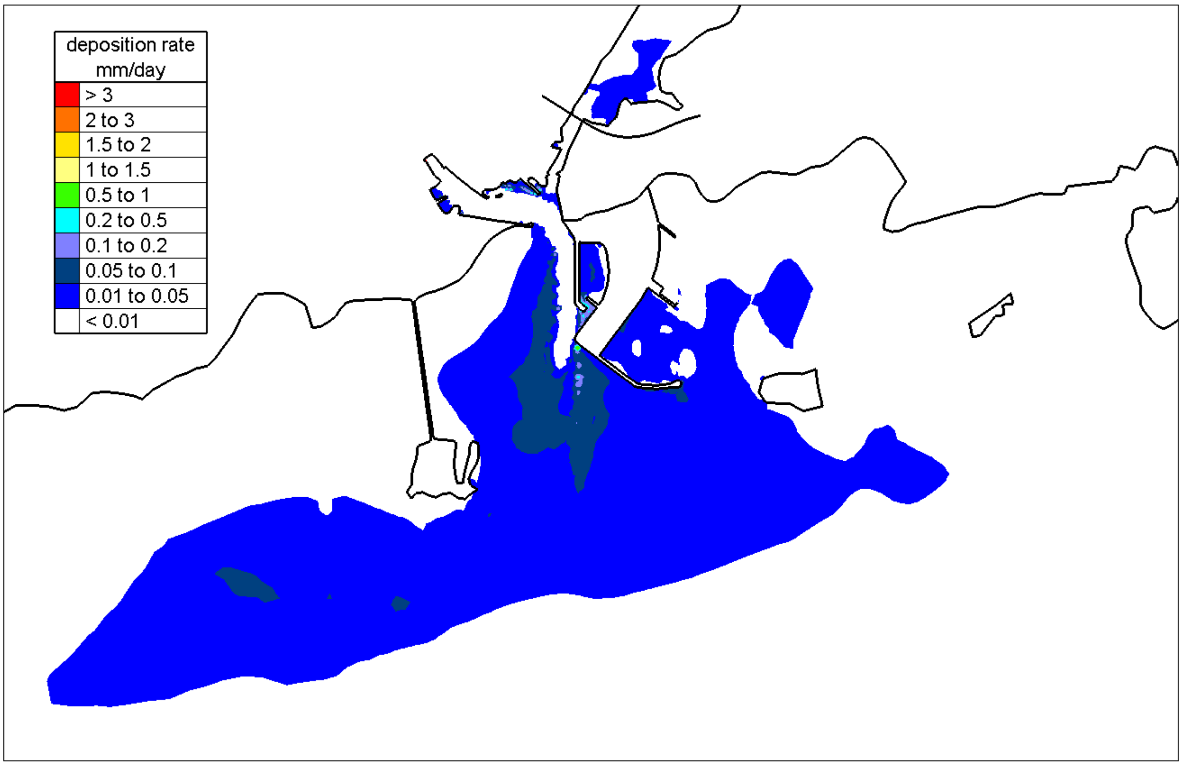

Figure 4.1.13 Computed depositional rates of a River Corrib fine silt under Winter flood flows (1 %ile 272cumec) - Proposed Case.

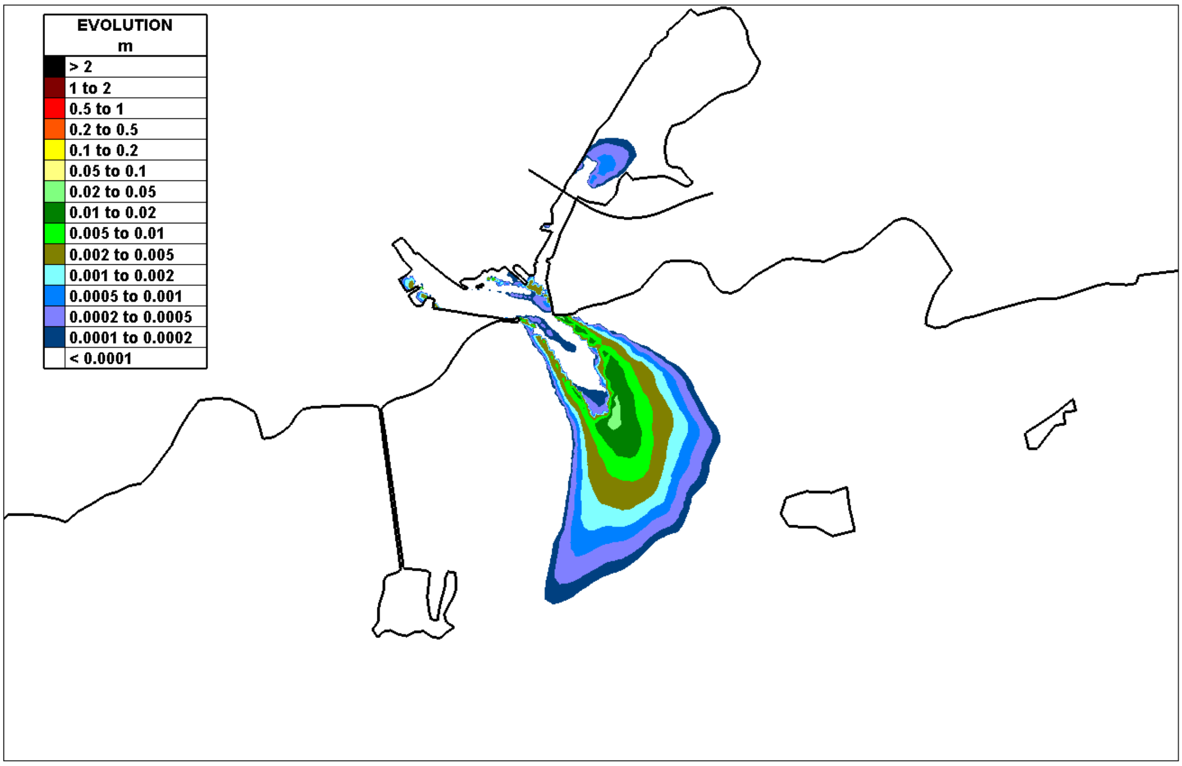

Figure 4.1.14 Deposition of a Corrib fine sand under winter flows (272cumec) at the end of 15 days Simulation - Existing Case

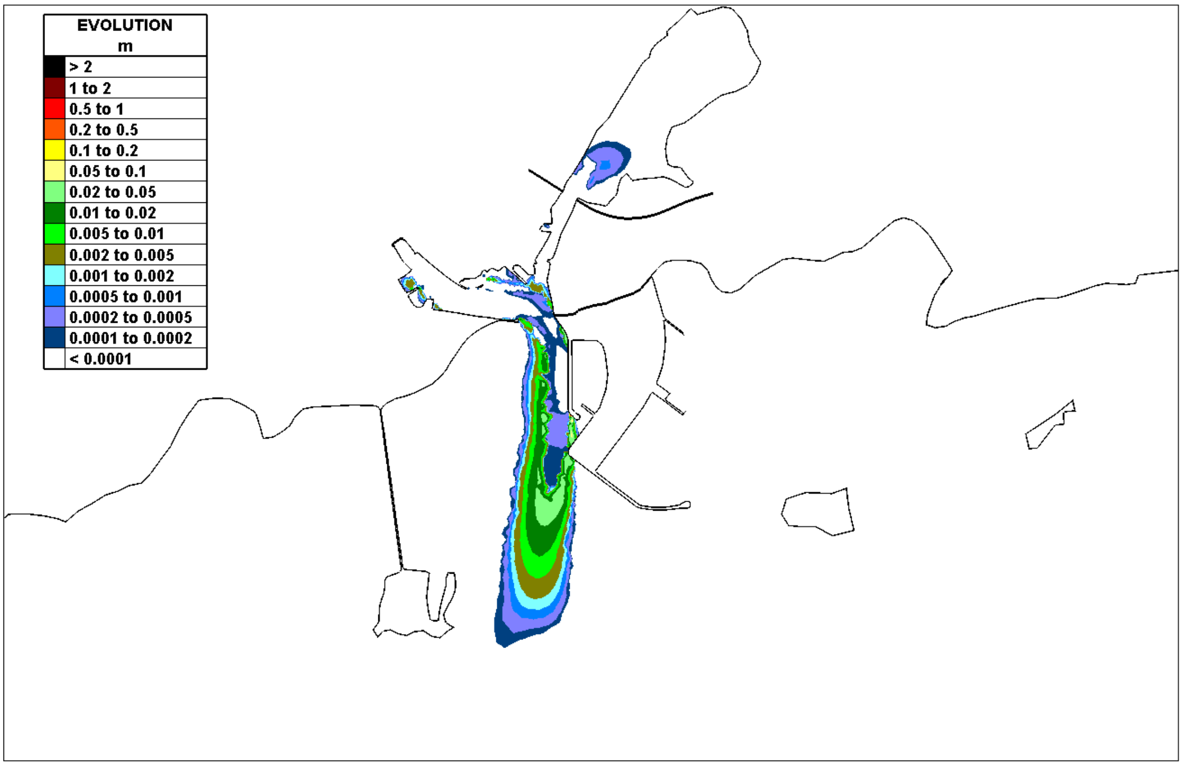

Figure 4.1.15 Deposition of a Corrib fine sand under winter flows (272cumec) at the end of 15 days Simulation - Proposed Case

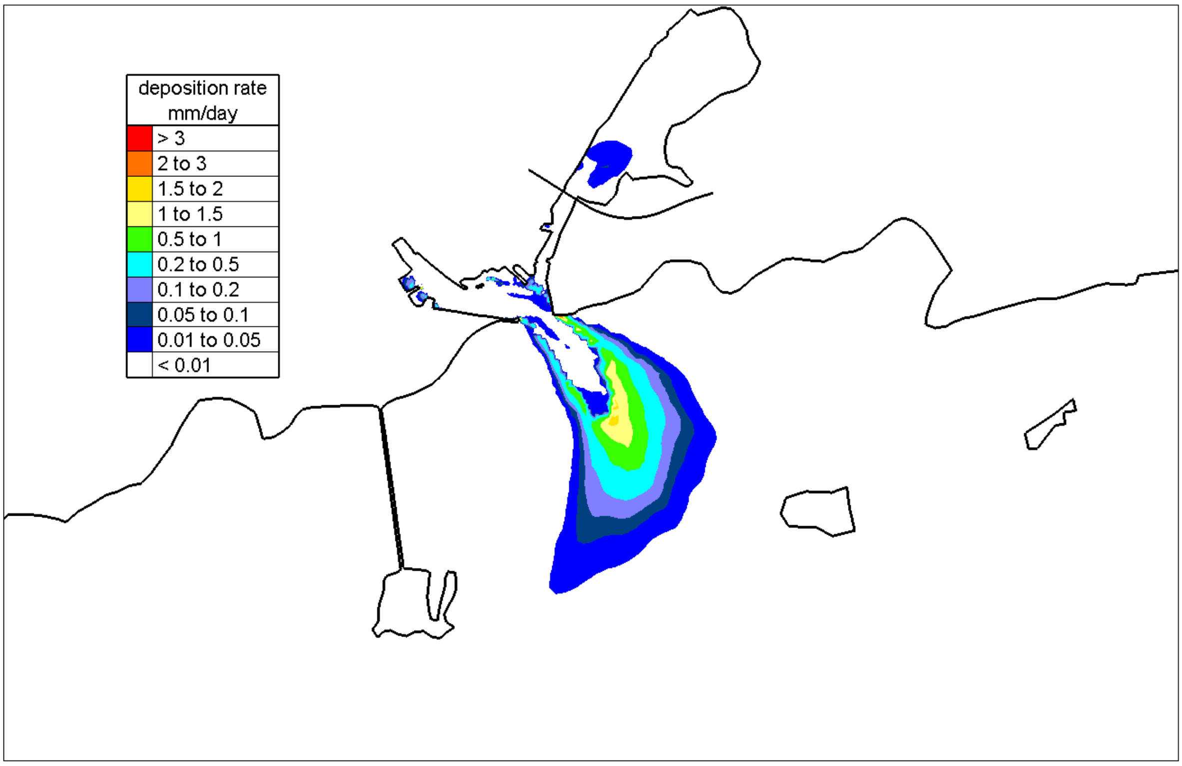

Figure 4.1.16 Computed depositional rates of a River Corrib fine sand under Winter flood flows (1-%ile 272cumec) - Existing Case.

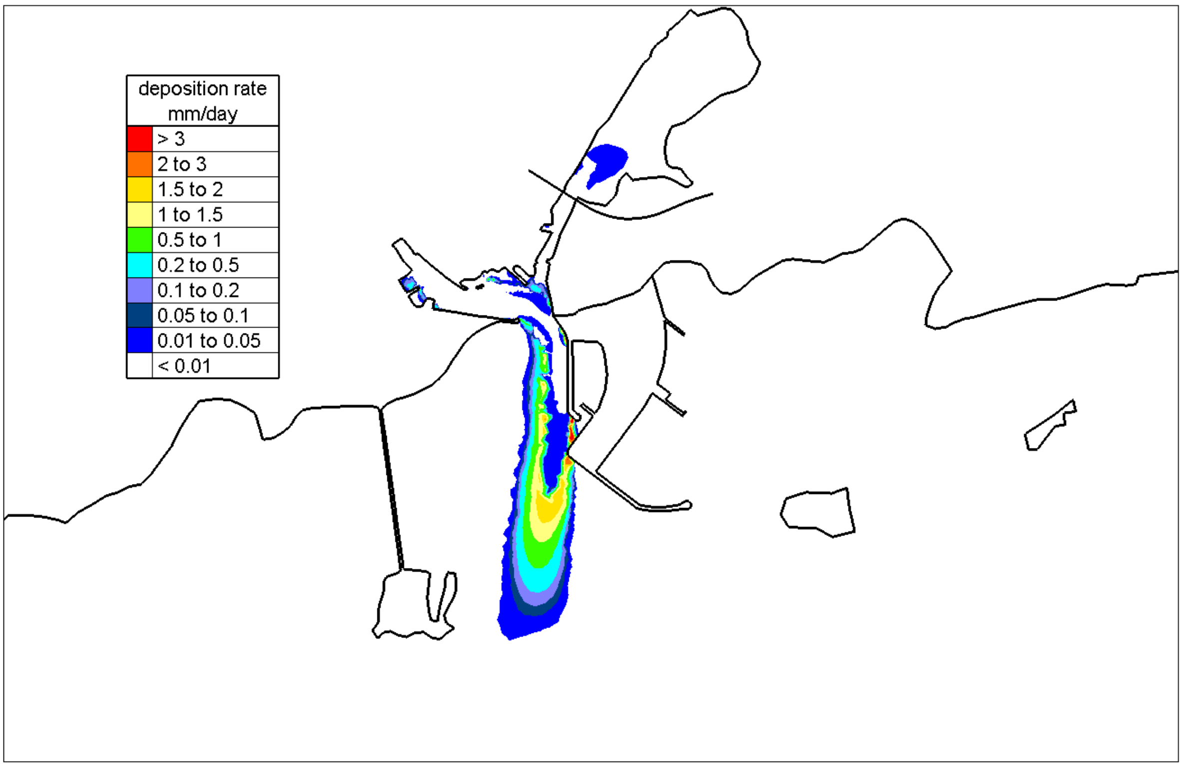

Figure 4.1.17 Computed depositional rates of a River Corrib fine sand under Winter flood flows (1-%ile 272cumec) - Proposed Case

4.1.5 Storm Wave Morphology in the vicinity of the Development

SISYPHE simulations were carried out examining the potential effect of storm wave conditions on the morphology of Inner Galway Bay. In order to provide meaningful information on wave dominated morphology an assumption had to be made in the modelling that the sediment was a sand having a typically d_{50} of 0.12mm. Simulations were run for a continuous two-day design storm wave event and the evolution determined between the initial and final bed levels. The storm winds specified are from the south and southwest using 30m/s wind speeds and combined with an Atlantic swell using the same strength winds offshore. The hydrodynamics accompanying the wave storm simulation are spring tides and median river flows. A zero sediment flux (inflow condition) was applied at the Corrib inflow boundary.

The evolution results for a south storm event are presented in Figures 4.1.18 and 4.1.19 and for a southwest storm event in Figures 4.1.20 and 4.1.21 under existing and proposed cases respectively.

The simulation results show considerable erosion along the exposed shoreline area to the west of the Mutton Island causeway with deposition of this eroded material occurring locally offshore under both south and southwesterly storms. Erosion is also predicted immediately to the west and south of Mutton Island. The simulation indicates that some migration of this sediment around Mutton Island towards the northeast of the causeway is likely.

In the vicinity of the Harbour Area for both proposed and existing cases the simulation shows that little erosional or depositional activity is taking place in the vicinity of the New Harbour development and the existing and proposed channels, particularly in comparison to the exposed shoreline to the west of Mutton Island and also to the east of the development in the vicinity of Hare and Rabbit islands.

The plots for the existing case show some erosion and deposition predicted along the shoreline area to the east of the Corrib entrance. This is substantially reduced under the proposed harbour case which affords a degree of shelter to this shoreline from the Wave climate and thus the erosional wave forces. This includes protection to the vulnerable shoreline cliff section immediately to the west of Ballyloughaun Beach (refer to Plate 4.1).

Significant erosion of Hare and Rabbit Island shoreline areas are predicted in both cases (no noticeable difference between proposed and existing cases) with deposition indicated in the lee of these islands.

Importantly for the new proposed approach channel to the Commercial Port the sediment transport storm wave simulations do not indicate any significant erosional or depositional features along the channel with only minor deposition occurring near the breakwater entrance to the port indicating a reasonably stable environment for the dredge channel. For the proposed and existing cases some local deposition under wave action is shown in the navigation channels to the docks near the Corrib entrance. The rate of deposition shown is not significant.

These simulations were unable to capture the longer term littoral drift mechanism but do indicate that erosional forces on exposed shoreline deposit the material just offshore of the zone of erosion where further storms (from south to west) can progressively move sediment eastward around Mutton Island. The dredging history and channel bed surveys indicate that sediment building up in the channel is primarily fine sand given the location of the deposit within the channel and consequently its source has to be from littoral drift as opposed to siltation from the Corrib. The surveys also indicate that the depositional rate is relatively low at c. 9,000 tonnes per annum and that the main drift occurs between -1 and -4m OD Malin.

Drift along the bed in the deeper waters cannot be ruled out but is likely to be considerably less given the tidal flows, wave characteristics and depth of water. It is important to note that the design of Mutton Island outfall had intended to site the diffuser manifold slightly further offshore (southwards) but bed conditions showed a deep silt which constrained the design to locating closer to the island.

Plate 4-1 Typical view of eroded Boulder Clay shoreline banks to the southeast of Ballyloughaun Beach adjacent to the Harbour Development. These erodible shorelines are likely to be the principal Source of Silts, sands gravel and cobbles released during Storms that forms the seabed sediments in the Vicinity

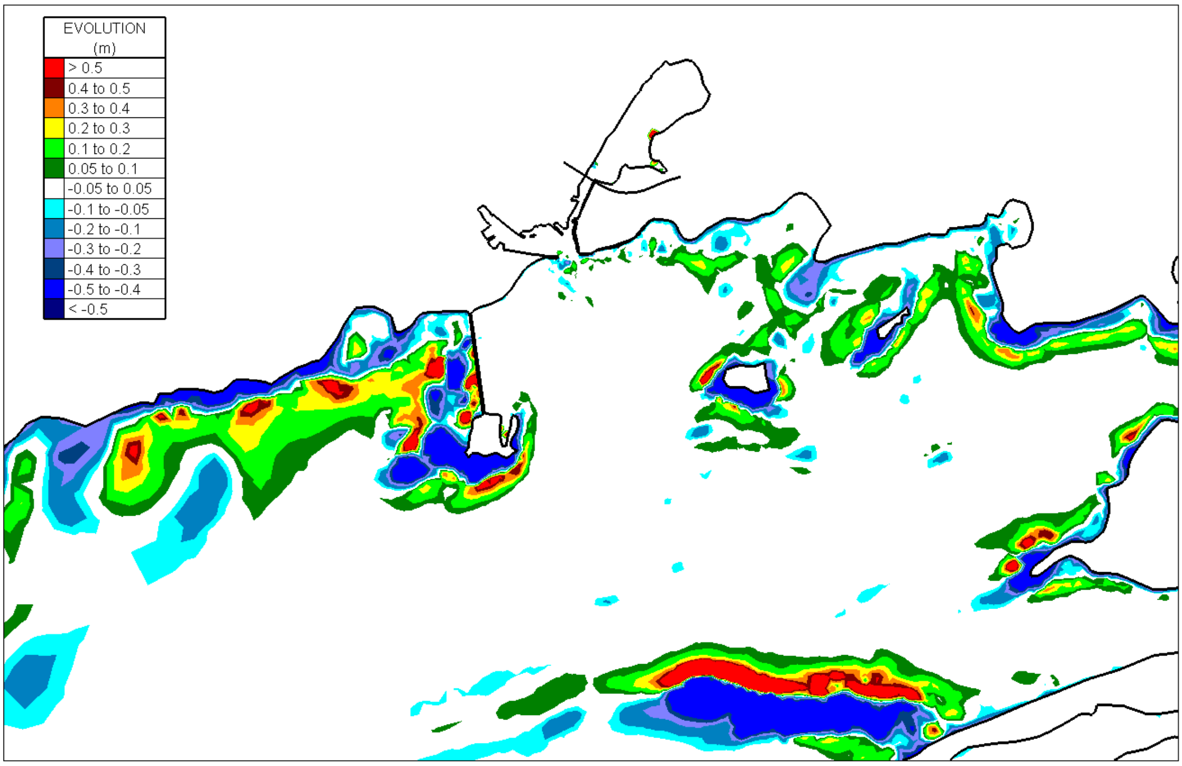

Figure 4.1.18South Storm Waves Simulation modelling a fine sand - Existing Case

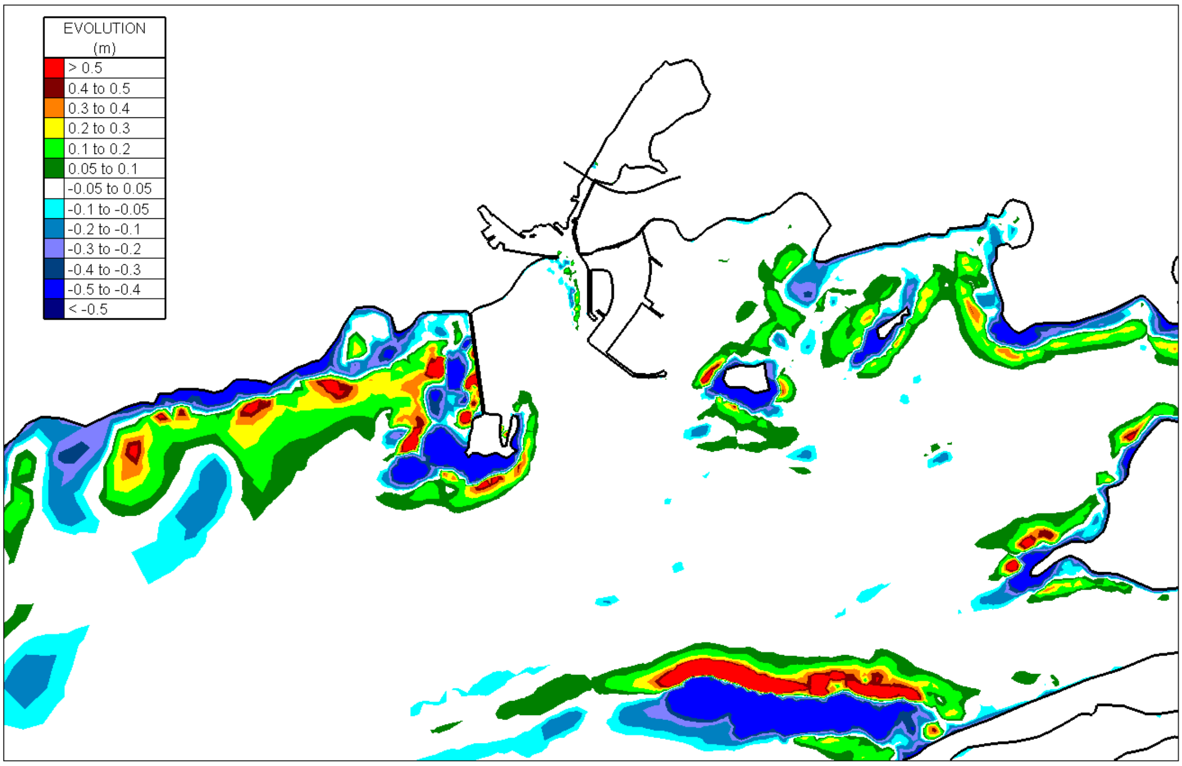

Figure 4.1.19 South Storm Waves Simulation modelling a fine sand - Proposed Case

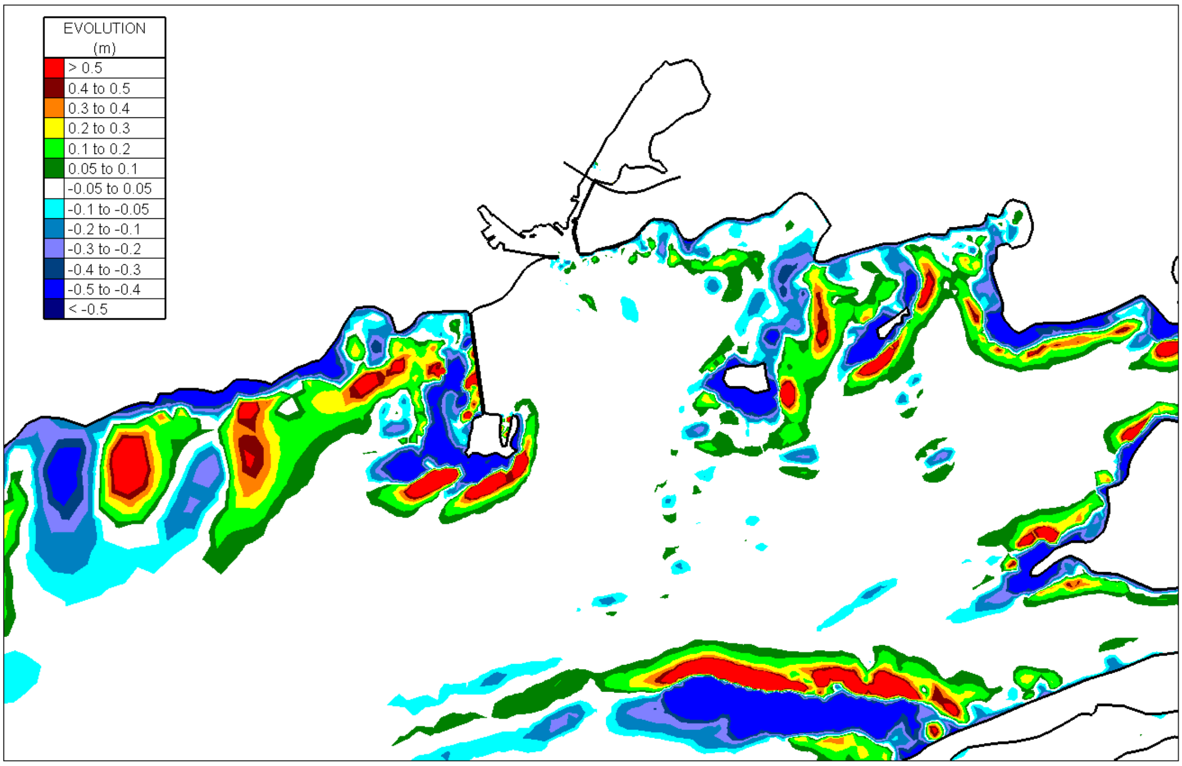

Figure 4.1.20 Southwest Storm Waves Simulation modelling a fine sand - Existing Case

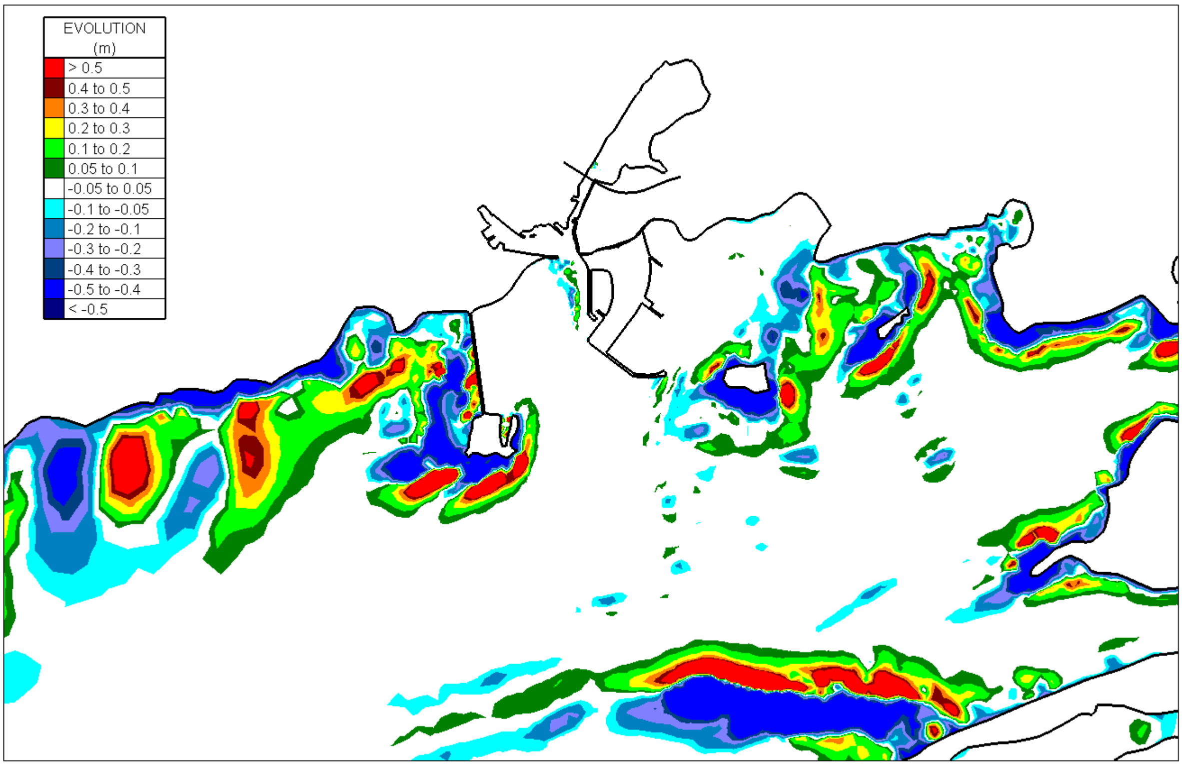

Figure 4.1.21 Southwest Storm Waves Simulation modelling a fine sand - Existing Case

4.1.6 Capital Dredge Depositional Features

In the EIS 11 dredging locations (refer to Figures 8.4.41 and 8.4.50 of the EIS) over the dredge area were simulated for a 4day continuous release of dredge sediment refer to EIS (Figures 8.4.42 to 8.4.49 and 8.4.51 to 8.4.57). Combining the results of these 11 dredge locations and their respective plume characteristics over the tidal cycle a mean dredge suspended sediment concentration was evaluated and is presented in Figure 4.1.22. This figure shows concentration bands (depth and tidal mean averaged extracted from Telemac3D suspended solids simulations) of < 1mg/l, 1 to 2mg/l and >2mg/l. It is important to note that figure 4.1.22 represents the unmitigated case in which dredging occurs throughout the tidal cycle. The proposed mitigation for the new navigation channel to the docks to minimise sediment entering Lough Atalia is dredging work only taking place on the ebbing tide and thereby avoiding direct inflow from the dredge works on the incoming flooding tide.

The simulations presented in the EIS Figures 8.4.42 to 8.4.49 show that the coarse silt/ fine sand fraction deposits rapidly and that the plume is local to the dredge works with elevated sediment concentrations occurring close to the dredge works area and reducing rapidly with distance from the dredging. The finer silt simulations show good dispersal of sediment.

To convert suspended sediment concentration to depositional rates, assuming an ability to settle based on the critical shear velocity, the settling velocity is used to produce a rate of sediment in kg per m^2. For example an average suspended sediment concentration of 1mg/l over a 12month period will potentially deposit on the sea floor 3.152kg per m^2 of silt using a settlement rate of 0.0001m/s for fine silt. It should be noted that the dredge program will not result in a continuous dredge concentration lasting for 12months and such durations will be considerable less based on the dredging program (refer to dredging sequence summarised below).

Converting this mass loading of 3.152kg per m^2 to sediment depth gives 1.98mm (2mm) of sediment depth per m^2 (based on using sediment grain density of 2,650kg/m^3 and an average porosity of 40%). The shear stress analysis presented in the EIS under Figures 8.4.16 to 8.4.39 indicate that deposition of the finer silt will take place within the receiving waters and plume area shown in Figure 4.1.22 below. Only when the Corrib is in flood will erosion of the deposited material within the channel occur resuspending the sediment and dispersing it widely within the Bay at low concentrations.

The suspended sediment concentration contour plot in Figure 4.1.22 can be interpreted in terms of deposition rate as follows (based on a grossly conservative 12month continuous dredging period throughout the dredge works area:

blue < 2mm siltation depth,
green 2 to 4mm siltation depth,
yellow > 4mm siltation depth

Summary of Dredging sequence
The proposed dredge sequence is as follows:

A) New channel to old port months 10 to 11, Oct/Nov year 1, suction/ pumped to lagoons 1 and 2 mitigated by dredging only on turning or ebbing tide see EIS (script 8.4.2.8.4. and 4.4.2.9.5)

B) Soft dredge over turning circle etc, months 20 to 23 Aug / Nov Year 2, suction/ pumped to lagoons mitigated by marina wall (element 6)

C) Dredge of stiffer materials at B, months 32 to 34 Aug / Oct Year 3, backhoe / barge to initial quay mitigated by lagoon 6 (element 8)

D) i) Dredge marina access and berths, month 56 Aug year 5, suction / pumped to lagoon 7, mitigated as per dredge work A)
ii) Dredge fishing pier, month 56 aug year 5, “ mitigated by quays ,breakwater and land formation (elements 10,11, and 12)

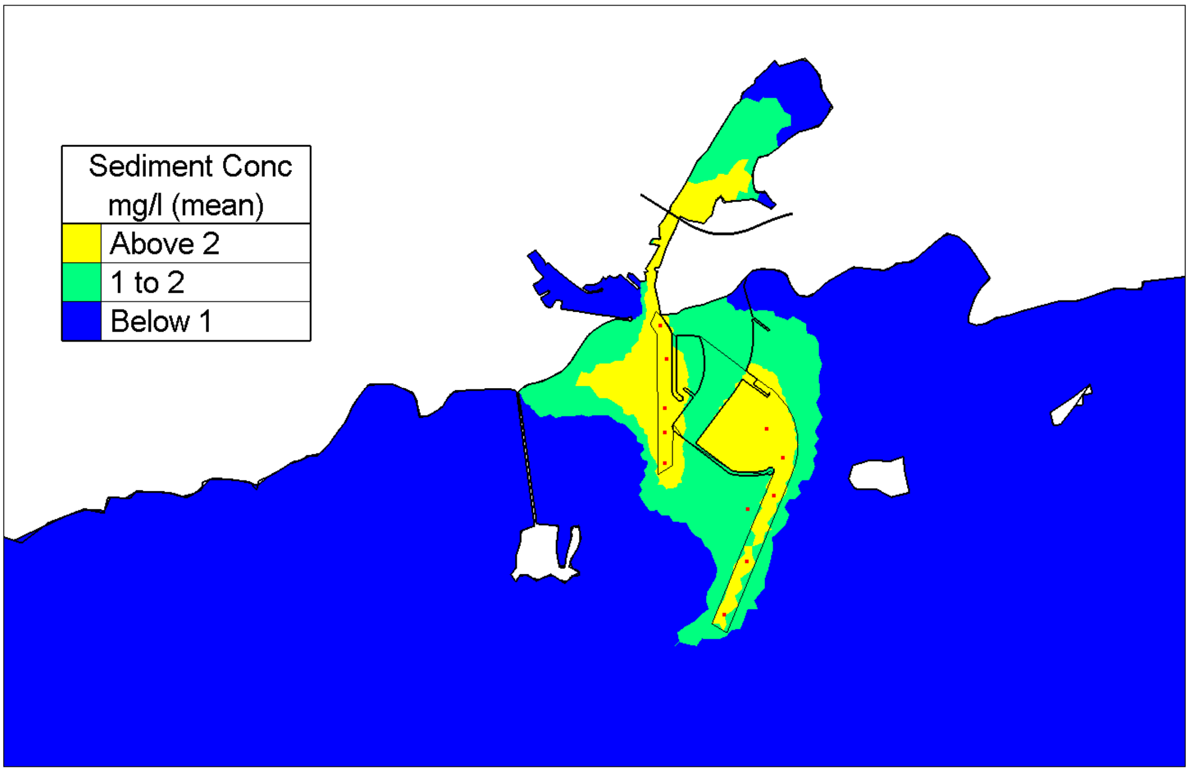

Figure 4.1.22 Capital Dredge Sediment concentrations extrapolation from sediment transport results from EIS Figures 8.4.42 to 8.4.49 and 8.4.51 to 8.4.57 representing the unmitigated case

The above concentrations and deposition rates assume that the dredge sediment is completely a silt, when in fact approximately 50% of the dredge material is a fine sand that was shown in the EIS modelling to settle out locally within the dredge works area and thus the deposition rate presented in Figure 4.1.22 below for the blue, green and yellow areas is likely to be half the above figures. Due to the dredging of the new channel to the old Port being restricted to ebbing flows only, the deposition will be significantly lower in Lough Atalia.

The area of impact shown in Figure 4.1.22 is relatively local to the Development and the impact magnitude in terms of suspended solids concentrations and depositional rates is small. The proposed mitigation measures and the sequencing and duration of dredge operations outlined in the EIS will minimise impact to the water column and to the sea floor from deposition.

4.1.7 Conclusions

The Maintenance dredging requirement of the existing navigation channel is reasonably low requiring maintenance every 12years at approximately 9000tonnes per annum. The source of the dredge is primarily a fine sand from littoral drift as opposed to the Corrib silts. The Corrib silts if unable to settle out upstream of the Galway Barrage will not settle out easily within the navigational channel or the immediate harbour area. The littoral drift heading eastward is not very significant and currently the existing channel traps this drift with the main sediment infill occurring at -1 to -4 m OD Malin.

Under the proposed case the new navigation channel to the docks will trap this littoral sediment similar to the existing channel but the deposit after winter river flows is likely to occur further southwards in the channel near the Marina entrance.

One cannot rule out deeper littoral drift being captured by the new channel to the commercial Port however it is expected that such drift similar to the docks navigation channel will not be significant. The Commercial Port Area itself is sheltered from the littoral material and settlement rates will be low and will be from suspended silts. Conservatively it is expected that the Maintenance requirement for the Harbour Development should be of a similar period (12years) and less than twice the existing dredge requirement.

The depositional impact of the Capital dredge activities from presence of silt plumes is a minor impact and depositional rates outside of the dredge works area will be low.

Galway Harbour Company

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Appendices to NIS Addendum / Errata

Appendix No. 3.3

Appendix No. 2 – Potential for Transport of Sand for River Corrib

4.2 POTENTIAL FOR TRANSPORT OF SAND FROM RIVER CORRIB

Query:

Furthermore and related to the above estimates are required for the total annual transport of fine sand from the River Corrib (section 8.4.2.7) to assist in the understanding the near harbour morphology.

Response:

4.2.1 Introduction

The sediment load from the Corrib River is small due to the very large lake system located upstream of Galway City which provides considerable retention time to settle out all but the fine sediment fractions. Previous dredging of the canals and moorings upstream of the Salmon Weir barrage encountered a fine silt.

4.2.2 Hydrology

The Corrib River is a short outflow channel from Lough Corrib which is gated at the Galway Barrage and under the management of the OPW Arterial Drainage Section. The OPW are responsible for maintaining minimum and maximum summer and winter lake levels for navigation requirements and flood relief.

The Corrib Catchment is some 3111km^2 in area to its sea outfall. A large portion of this catchment is karst limestone which produces a relatively damped response to rainfall events. The Lake Area of Lough Corrib is 176km^2 in area making it Irelands second largest Lake second to Lough Neagh in Northern Ireland. Immediately upstream of Lough Corrib is Lough Mask which has an area of some 83 km^2. These lakes are reasonably deep with Lough Corrib on average 12m deep (lake Volume of c. 2.11km^3) and Lough Mask 15m deep (lake Volume of c. 1.3km^3). These lakes are reasonably deep and provide a long retention time within the Lake volume for settlement of sediments, with only fines discharging from the Lake.

The mean annual rainfall over the Corrib Catchment is 1331mm and the evapotranspiration is 452mm resulting in 879mm effective rainfall representing an average Catchment flow rate of 63cumec. A flow duration curve for the River Corrib at Wolftone Bridge gauging station located in the estuary is presented below. This presents a mild sloped curve indicating gradual change of flow from flood to low flow with the range varying from 9 to 272cumec and a median flow of 82cumec.

At the median Flow of 82cumec the hydraulic retention time in Lough Corrib is of the order of 298days which is substantial for settlement of all but very fine silts. At winter flood flows of say 500cumec entering the lake the hydraulic retention time is of the order of 49days (which is still substantial). Silt deposited near the Lake outlet or along the river channel can be stirred up during flood conditions but EPA sampling would indicate that even under winter flows suspended sediment is relatively small.

Figure 4.2.1 Corrib Catchment Map showing Lough Corrib and Lough Mask

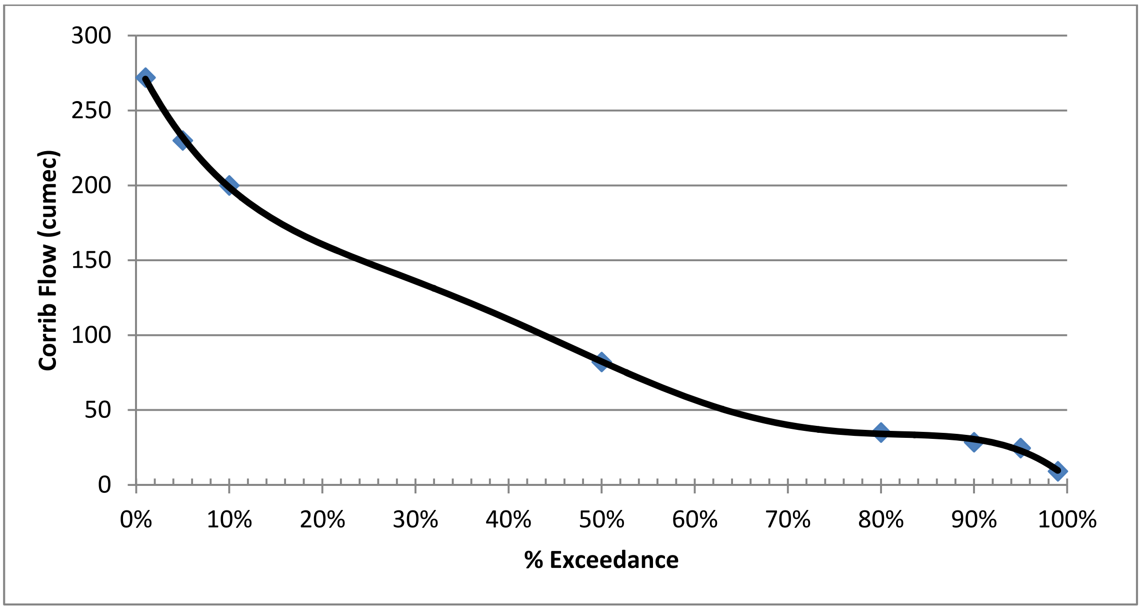


Figure 4.2.2 Flow Duration Curve for River Corrib at Galway City

The Corrib channel upstream of the Salmon weir Barrage is backwatered by the gate control and consequently flow velocities are generally very low and even during flood conditions the velocities are not significant. The downstream channel from the Barrage to the Claddagh Basin is a short, steep, rock cut channel with little potential for providing any significant contribution to the sediment load to the Bay.

4.2.3 Monitoring Data

A review of EPA Suspended solids monitoring from 2010 to Dec 2013 reveals a consistent trend of very low suspended solids concentrations throughout the year and generally at 4 mg/l or below and consistent throughout the year and between sample locations. Some elevated spikes of 10 and 62mg/l occur but these are very occasional and are often not consistent with results for the other sample locations taken on the same date.

Testing

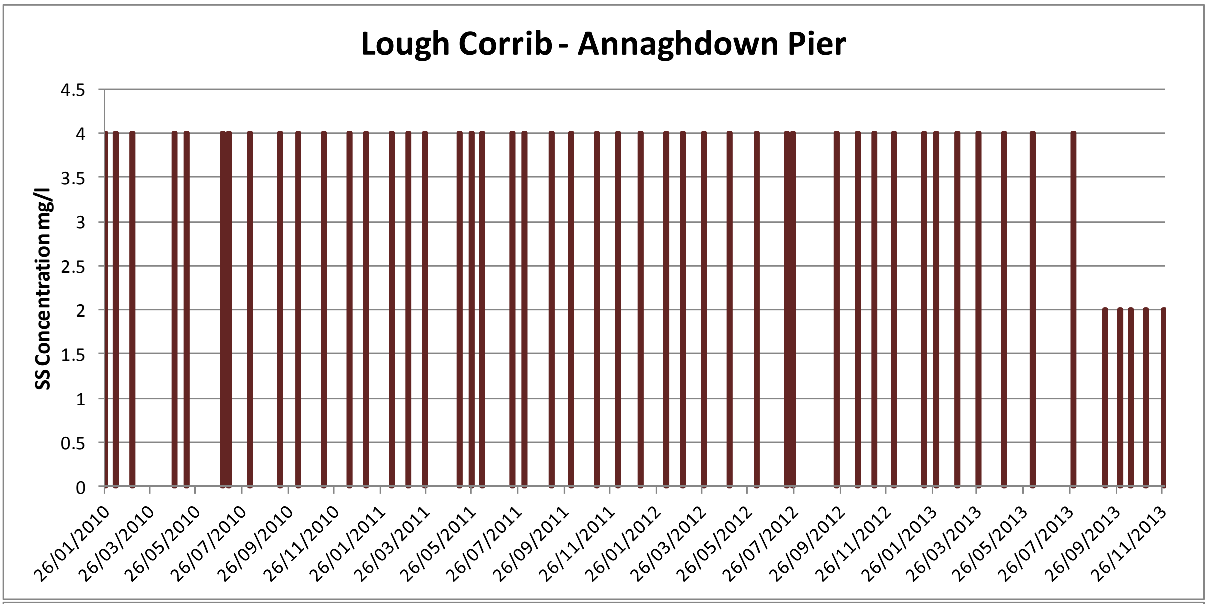
In reply to this further information a sediment trap was deployed by Aquafact on the river bed upstream of the Salmon Weirs for the month of September 2014. On retrieval no sediment was present within the trap. September was a very month with almost historical low flows.

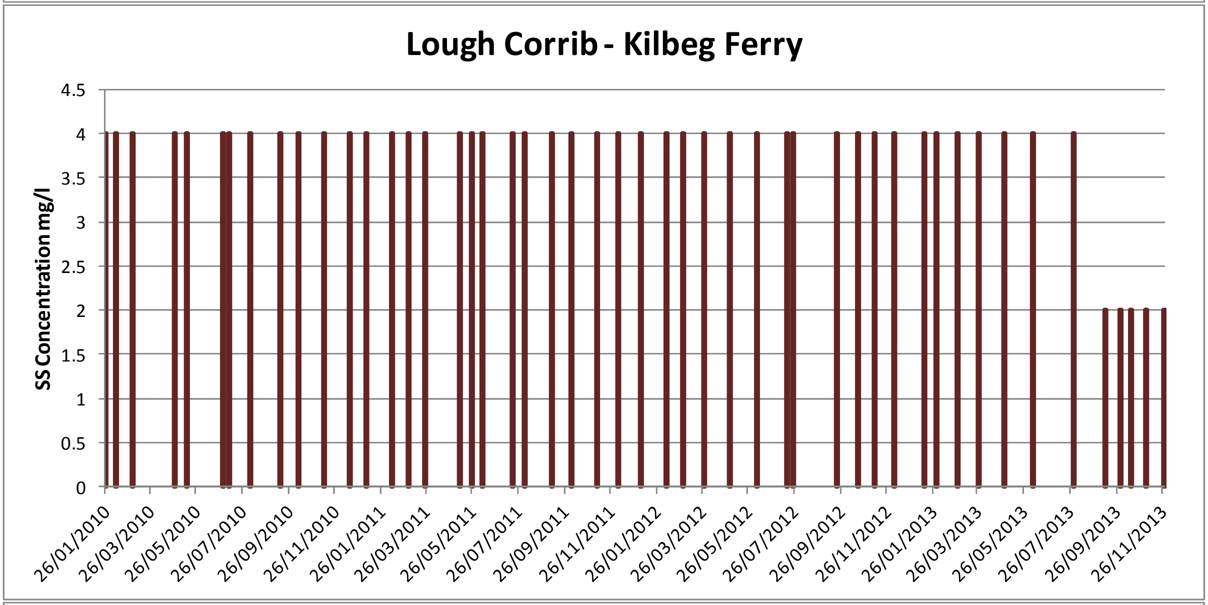
4.2.4 Sediment Load from the Corrib

The EPA data consistently reports suspended solids concentration of 4mg/l. It is suspected that the 4 mg/l figure recorded in the EPA data is the Limit of Quantitation for the testing. Improved testing towards the end of 2013 suggest typical suspended solid concentrations of 2mg/l. Therefore the annual sediment load from the River Corrib is likely to be between 5000 and 10,000 tonnes of sediment (82cumec at suspended solids concentration of 2 to 4mg/l). The EPA monitoring data does not indicate a high frequency of spikes associated with winter flood conditions.

Given the substantial settlement time available in Lough Corrib, the river silt that eventually discharges to the harbour waters will be a fine silt of which a large portion is unlikely to settle out in the immediate receiving waters of the Bay. As a best estimate at least 50% of the 5000 to 10,000T per Annum will not settle out in the harbour waters (i.e. Corrib entrance to inside of Mutton and Hare Islands).

It is considered that the primary source of the sediment settling in the existing navigation channels is generated by Wave action on the soft Boulder Clay shoreline areas to the east and by littoral drift originating from the west.





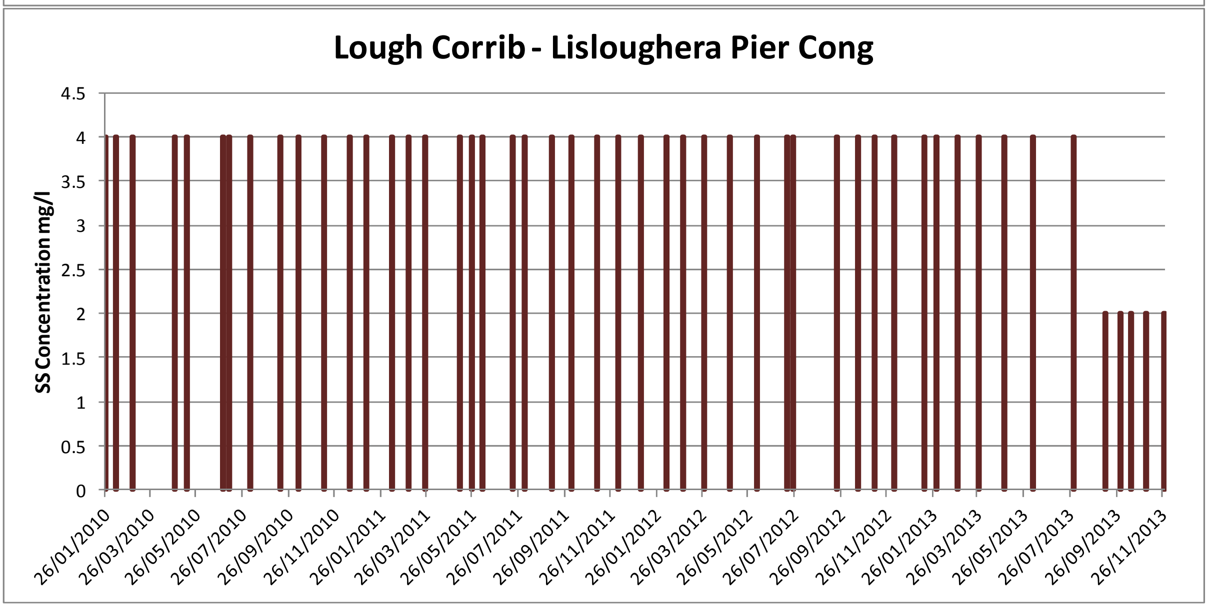
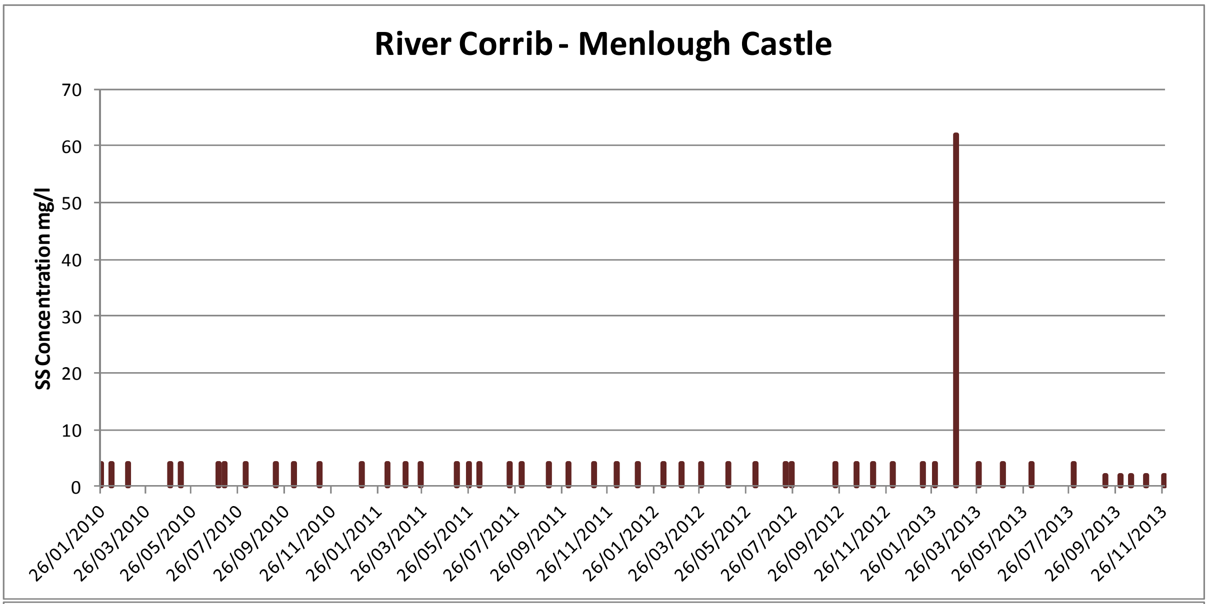
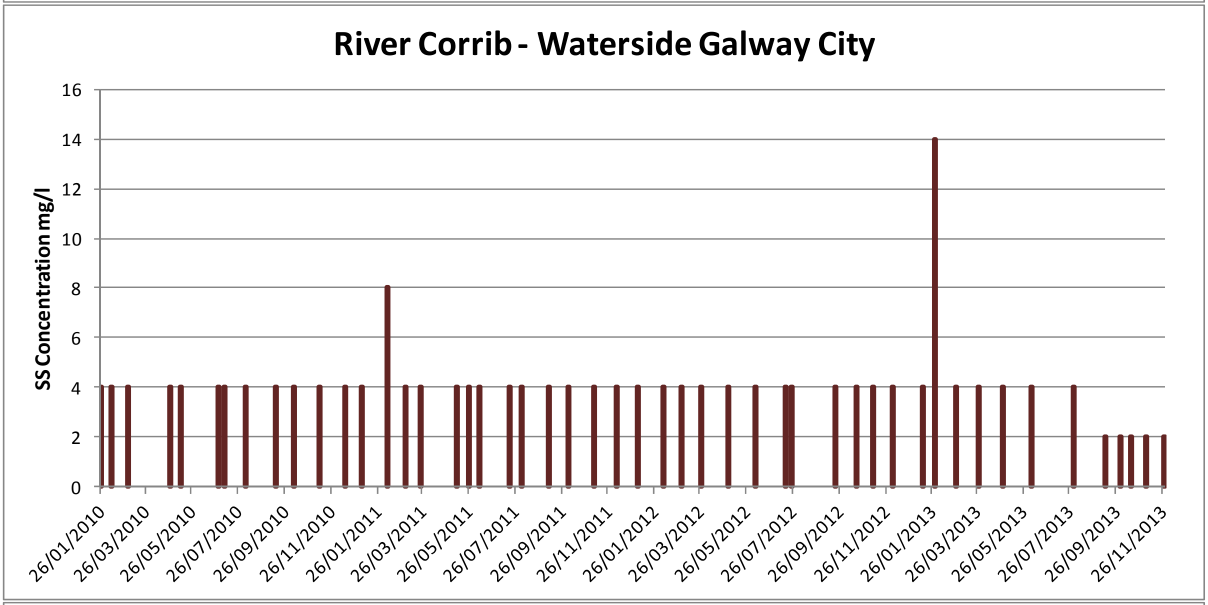


Figure 4.2.3 EPA Lough Corrib Suspended Sampling Results 2010-2013 (note In most cases the samples are below the Limit of Quantitation ranging from 4-8 mg/l)





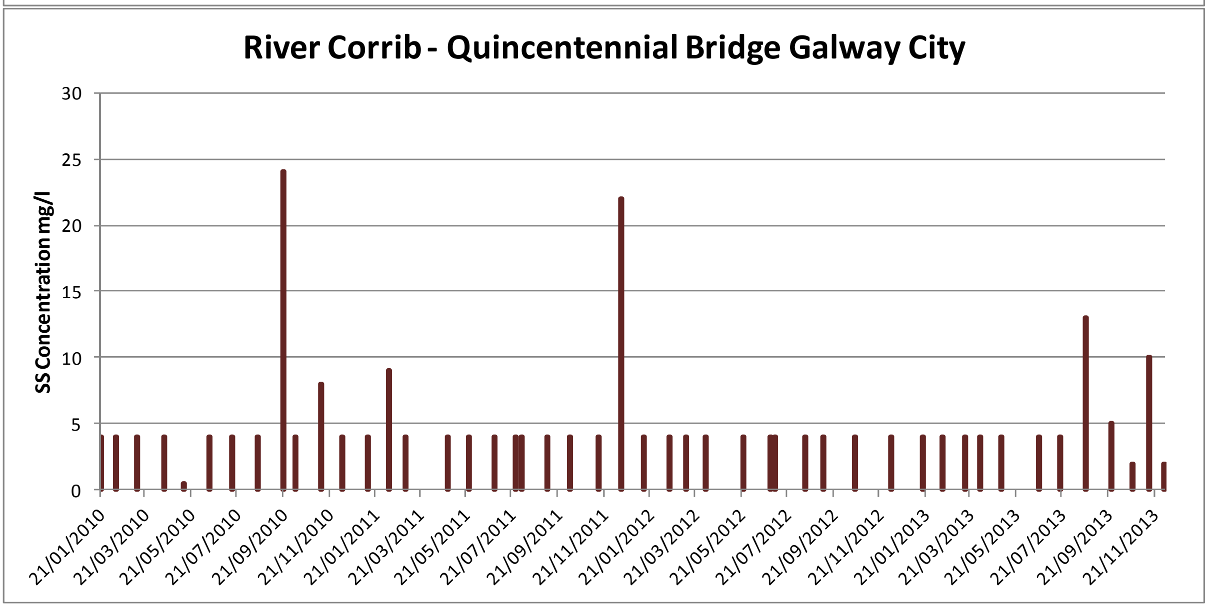


Figure 4.2.4 EPA River Corrib Suspended Sampling Results 2010-2013 (note In most cases the samples are below the Limit of Quantitation ranging from 4-8 mg/l)

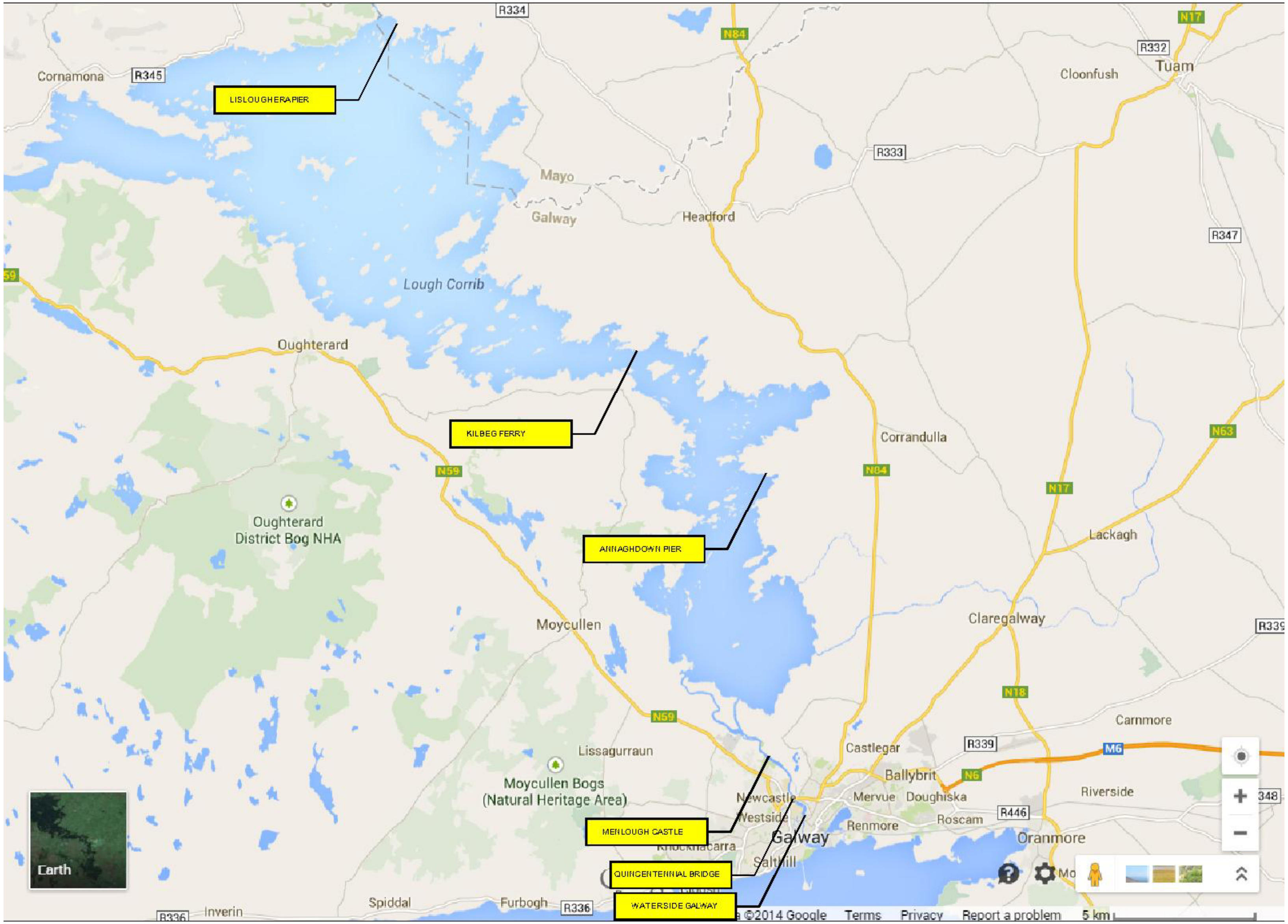


Figure 4.2.5 Location of EPA Sample Points

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Appendices to NIS Addendum / Errata

Appendix No. 3.3

Appendix No. 3 – Modelling of Wind Waves

4.3 WIND WAVES:

4.3.1 Modelling of Wind Waves

Query:

The wind waves appear to be quite small in the harbor area according to the model results presented in 8.4.6, mainly due to the protective impact from the Mutton-Island causeway. The near field wave climate in this area is modeled using the ARTEMIS numerical model. For waves coming from SSW and S, wave heights up to 1.6m can be attained, Figure 8.4.135. It seems that the near field wave climate is calculated without including impact of current, unlike the spectral wave model TOMAWAC applied further away. If this is the case, the waves can actually be even higher than predicted in the EIS at a large outflow from Corrib River combined with the tidal flow due to current refraction. Please provide further justification for the large change in the flow pattern in this area being of no importance for the wave climate.

Response:

In the EIS the Wave climate modelling of the proposed Harbour area was carried out using ARTEMIS Wave Agitation model which solves_Berkhoff's equation or Mild Slope Equation through finite element formulation. The Mild Slope Equation has been extended to integrate dissipation processes. With a consistent set of boundary conditions, ARTEMIS is able to model the following processes:

- Bottom refraction
- Diffraction by obstacles
- Radiation or free outflow conditions
- Depth induced wave breaking
- Bottom friction
- Full or partial reflections against walls, breakwaters, dikes, ...

Similar to other such Industry standard Boussinesq type Wave models ARTEMIS cannot include the effects of refraction by currents or include the effect of localised wind growth.

It is acknowledged that a wave field travelling against opposing currents will have a tendency to steepen due to a Doppler shift resulting in a shorter intrinsic wave period (shorter wave length) and increased wave height (Hedges et al. 1985, and Lia et al. 1989). Rsearch has shown that in a strong opposing current the wave steepness and wave height increase significantly. These changes can take place rapidly where the waves are blocked by the current and are often accompanied with current induced whitecapping and reflections.

Consequently wave heights are likely to be higher than predicted by the ARTEMIS Model where opposing currents are significant which in the case of Galway Harbour is specifically along the new approach channel to Galway Docks for the proposed case and along the existing old channel to the Docks for the existing Case (without development).

4.3.2 Methodology

In order to quantify the effect of refraction effects by currents on wave heights the SWAN model is used to examine wind waves with and without an Atlantic swell . The SWAN model is a spectral model that is solved in an iterative manner using an implicit finite difference solution scheme. The current version of the SWAN model allows regular and irregular meshes to be input. The SWAN model (1993 to 2014) is developed by Delft University of Technology, the Netherlands.

SWAN accounts for the following physics:

- Wave propagation in time and space, shoaling, refraction due to current and depth, frequency shifting due to currents and non-stationary depth.
- Wave generation by wind.
- Three- and four-wave interactions.
- Whitecapping, bottom friction and depth-induced breaking.
- Dissipation due to aquatic vegetation, turbulent flow and viscous fluid mud.
- Wave-induced set-up.
- Propagation from laboratory up to global scales.
- Transmission through and reflection (specular and diffuse) against obstacles.
- Diffraction.

The SWAN model was choosen over the Tomawac Spectral Wave model used in the EIS as it handles better diffraction and in particular local wind wave generation in the absence of an existing wave field.

The drawbacks with the SWAN model are that its implicit numerical scheme makes its solution diffusive and it does not handle well the process of full or partial reflection off structures / breakwaters. However it is considered a sufficiently adept and robust wave model to simulate the local wave climate and the effect on the wave field of changes in the current velocity pattern surrounding the Galway Harbour Development.

In respect to the Galway Harbour Study strong outward opposing currents are generated by the flood flows in the River Corrib under both the existing undeveloped case and for the proposed case. In terms of flooding and flood risk the critical period is towards or slightly after highwater. The current velocity from the hydrodynamic model for spring tide, tidal surge conditions and 100year design flood flows under existing and proposed Harbour cases was input to the SWAN model (refer to Figure 4.3.1 and 4.3.2 showing the velocities for the Proposed and Existing cases after highwater Spring tides.

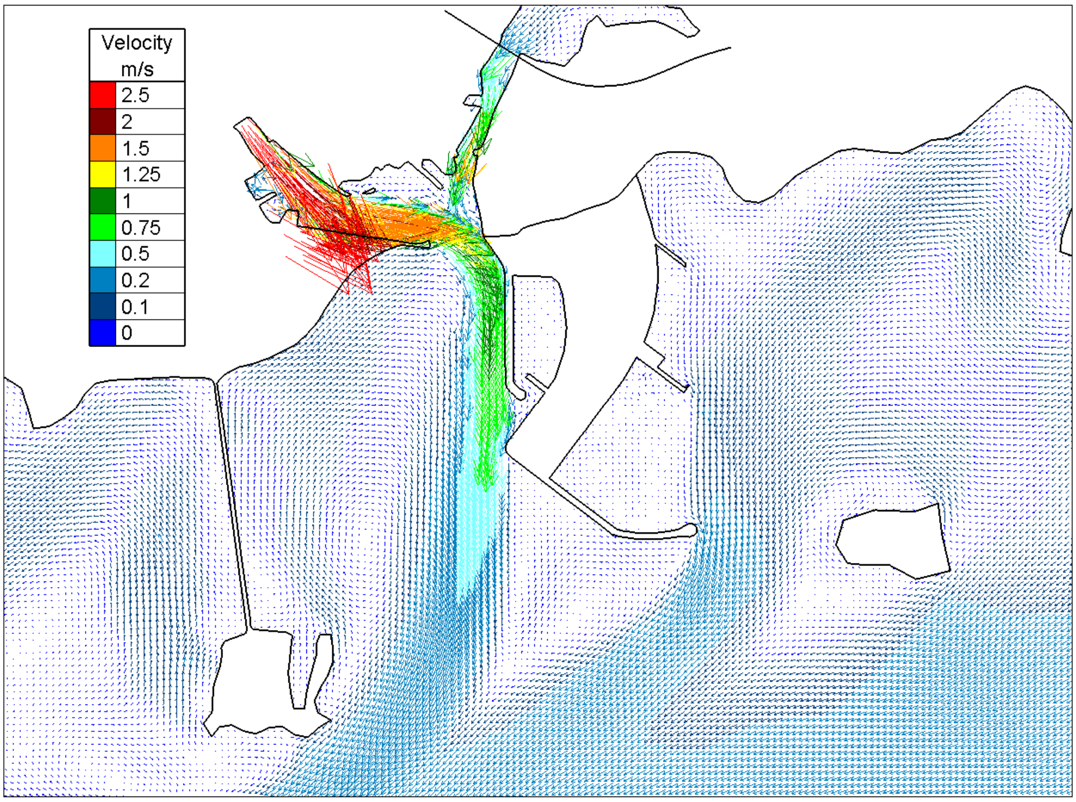


Figure 4.3.1 Snapshot of opposing flow and tidal velocities for Corrib 100year flood flow and spring tides with the Harbour Development

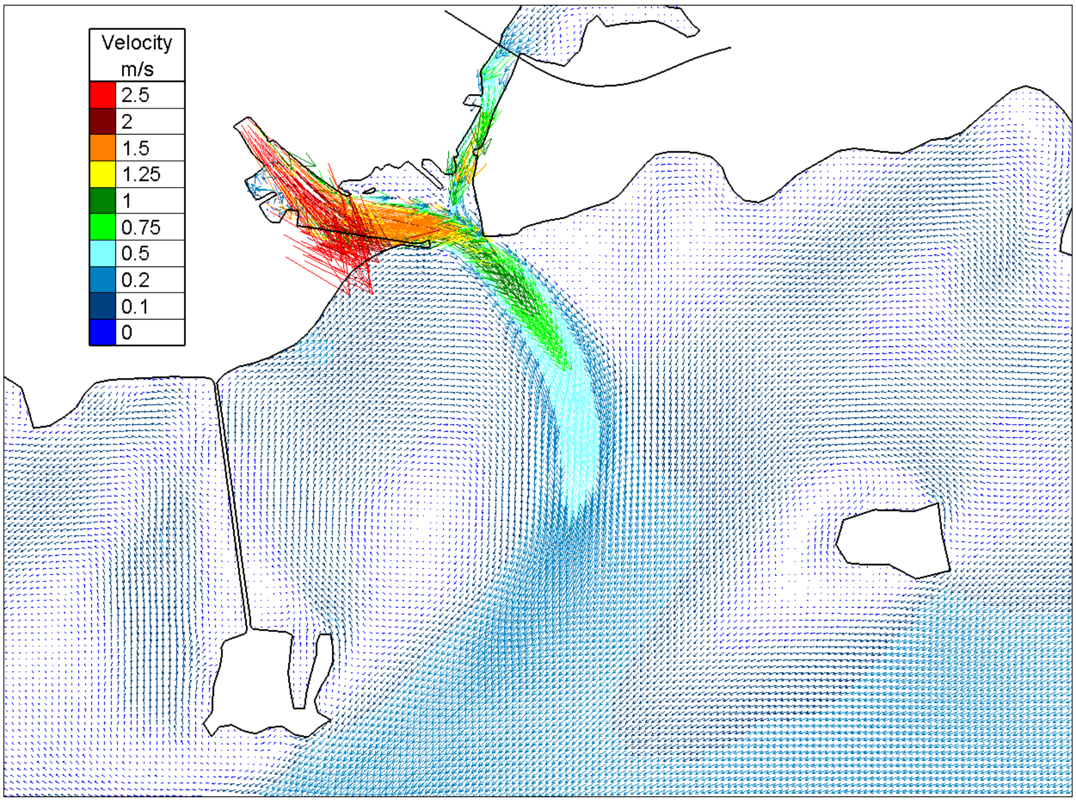
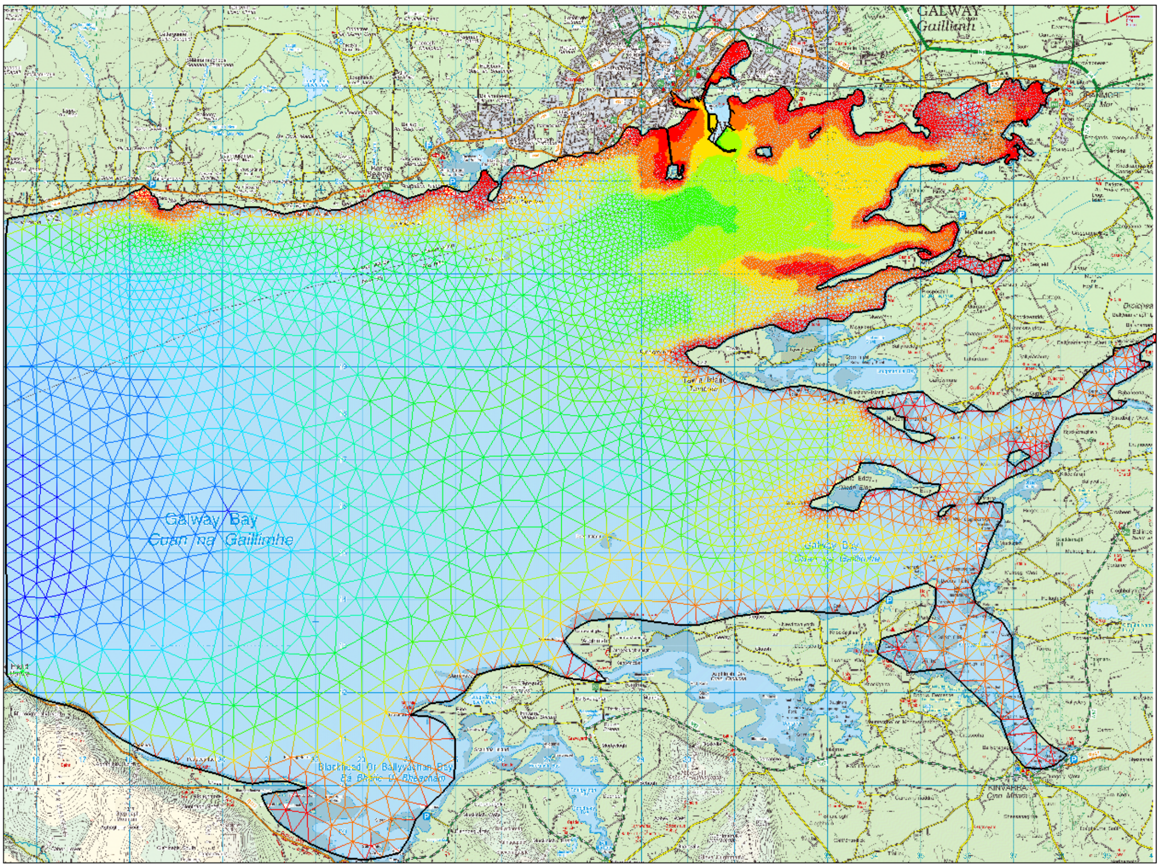


Figure 4.3.2 Snapshot of opposing flow and tidal velocities for Corrib 100year flood flow and spring tides without the Harbour Development (existing Case)

The irregular finite element mesh of bathymetry and boundary geometry used in the Telemac3d and 2d hydrodynamic models was input to the Swan model so as to maintain the same node locations and allow for direct input of the current velocity and water depths file from the Telemac simulations. This refined mesh provides high resolution detail in the dredge channels, the harbour area and the Claddagh Basin Area for modelling the wave field, refer to Figure 4.3.3.



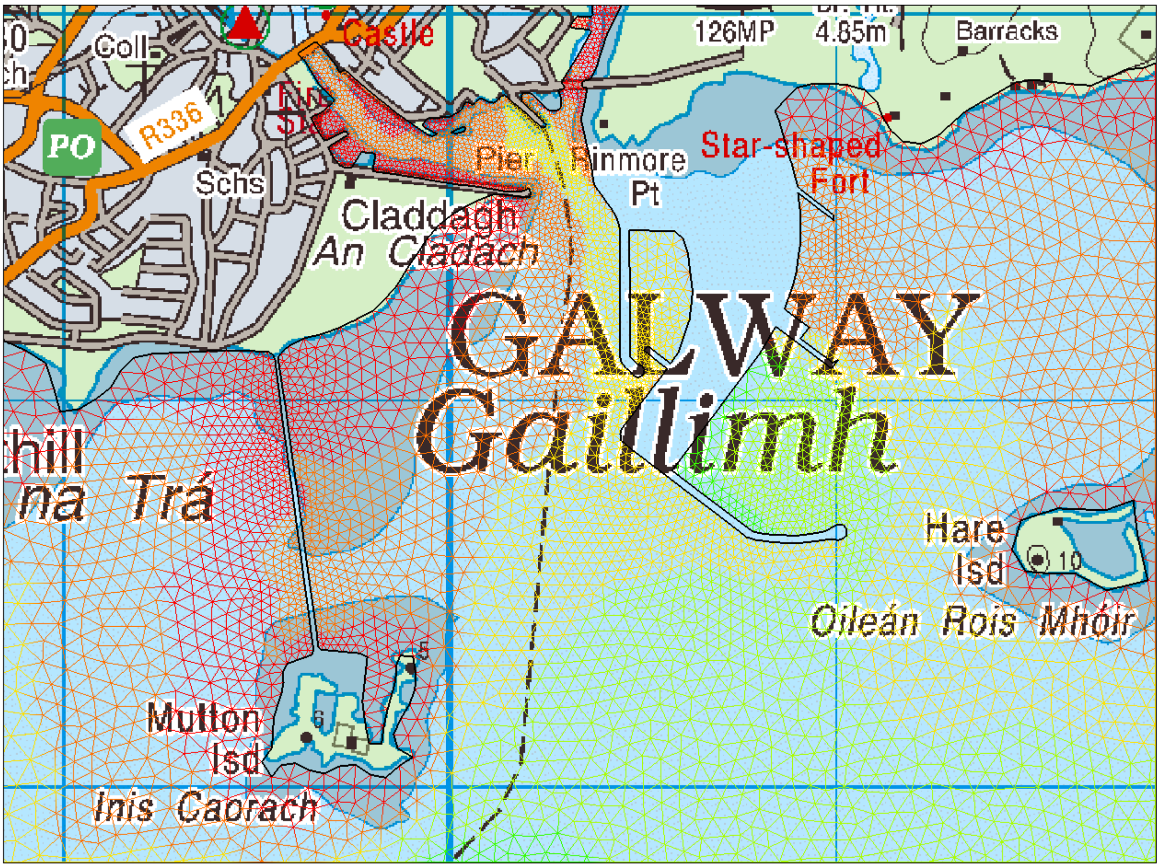


Figure 4.3.3 Swan Wave Model Domain and refined mesh in vicinity of Harbour Development (similar to hydrodynamic model mesh)

4.3.3 Effect of Tidal Currents on Wave Field

The swan model was run to demonstrate the effect that the predicted tidal currents close to highwater had on wave heights for the SSW and South Local wind direction combined with an Atlantic storm swell. Proposed and existing simulations were run both with and without tidal currents included. The predicted Significant Wave Heights are presented in Figures 4.3.4 to 4.3.6 for the Proposed Case under SSW winds, Figures 4.3.7 to 4.3.9 under South Winds. For the existing Case the predicted Significant Wave Heights are presented in Figures 4.3.10 to 4.3.12 for the for SSW winds and 4.3.13 to 4.3.15 for southerly winds.

4.3.4 Discussion

The simulations show that localised increases in wave height occur due to the presence of an opposing current for both the existing and proposed cases. For the existing case under SSW and Southerly wind waves (3.13 to 3.15) the effect is a local increase of 0.1 to 0.2m in significant wave height along the Navigation channel to Corrib entrance and 0.1m in the wider area . On a southeasterly storm wind (3.16 to 3.18) the predicted change in wave height is 0.15m at the Corrib Entrance and 0.2 to 0.3 in the approach channel for the Existing Case. On A SSW there is little predicted effect by the currents on the wave heights with increase within the range of 0.05 to 0.2m. (4.3.10 to 4.3.12)

Under the proposed case a similar pattern to the existing case of wave height increase due to currents is predicted for the wider area of the Bay having an increase in wave heights of the order of 0.1m. A significant local increase in wave heights are predicted along the proposed navigation channel to the Docks adjacent to the Marina having maximum increases of 0.5 to 0.6m due to refraction by high River Corrib currents. However along Nimmo's Pier and for a small section of Southpark shoreline to the West of the pier moderate increases of 0.05 to 0.1m are predicted. Such increase are also predicted at the entrance to the Corrib east of Nimmo's Pier.

In conclusion the effect of currents on wave climate along the vulnerable shoreline of Corrib entrance to the Claddagh basin, Nimmo's Pier and the Southpark coastline and other vulnerable area is shown through the above analysis not to be a significant factor with predicted increases in wave height of 0.1m and lower for the proposed case. The comparison of 4.3.6 with 4.3.12 and 4.3.9 with 4.3.15 show the same increase in heights for tidal velocity upstream of the Corrib entrance, proposed and existing. No increases arise along the South Park shore in this regard.

4.3.18 shows the greater waves upstream of the Corrib entrance in the existing case are caused by S.E. storm winds from which it will now be sheltered.

The impact of current on wind waves is best seen on the new Plots 4.3.6 S.S.W. and 4.3.9 S. This is in parallel to the marina breakwater and the height of same has been checked as adequate.

The impact on the Western side of the head of Nimmos Pier was previously reported in EIS 8.4.141. The further combined studies included in this R.F.I. show it at Plot 4.4.42. This shows the impact at that location to be no worse with the impact of current included.

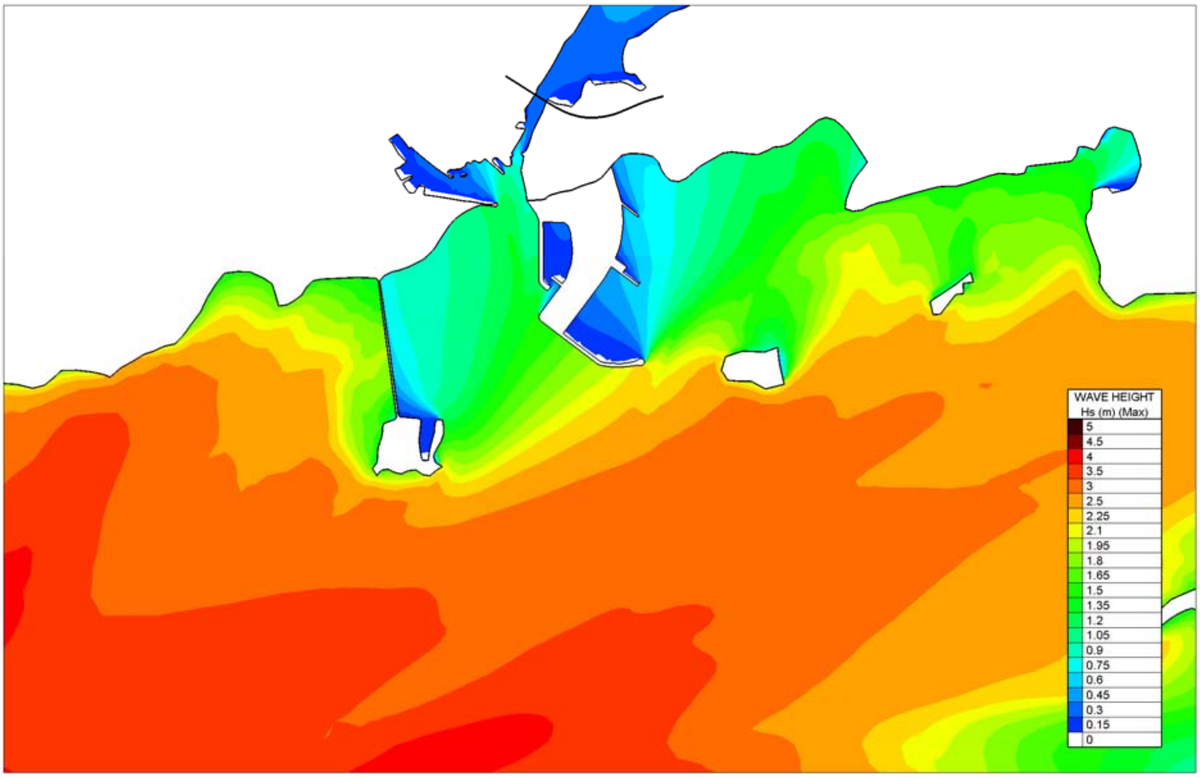


Figure 4.3.4 Predicted Wave Climate for SSW storm Wind without including tidal velocities - Proposed

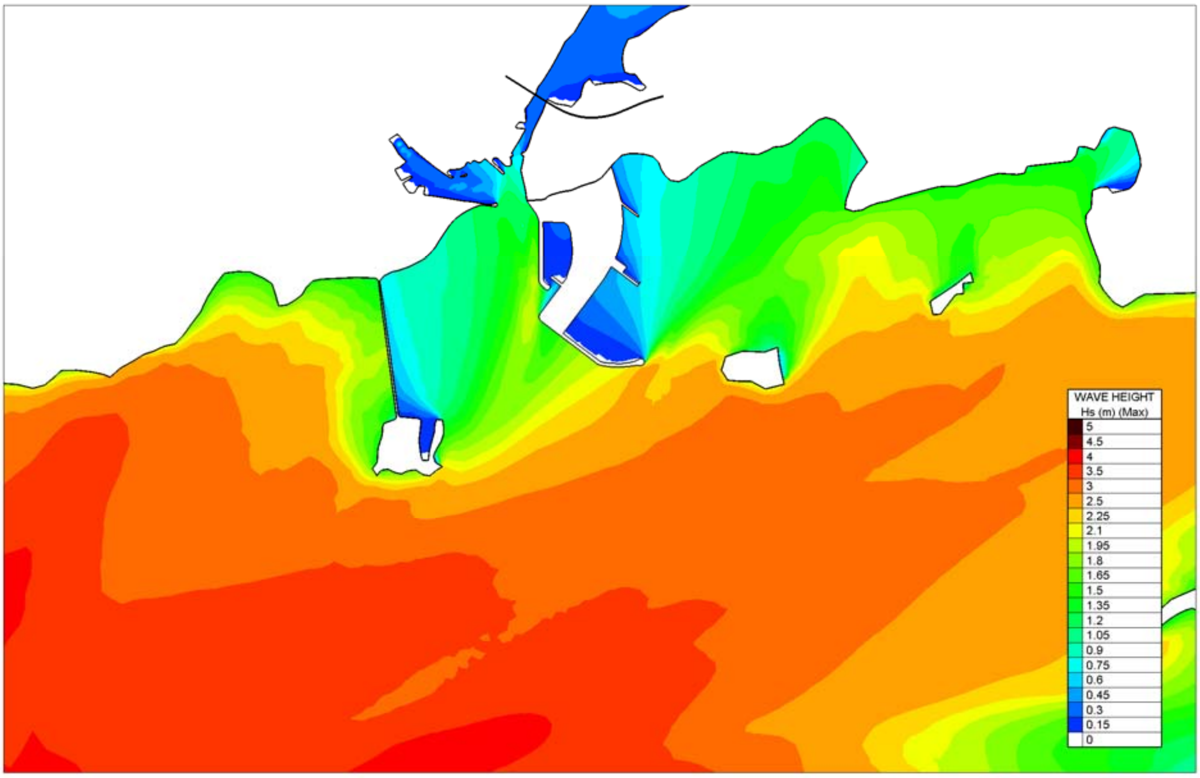


Figure 4.3.5 Predicted Wave Climate for SSW storm Wind with tidal velocities included - Proposed

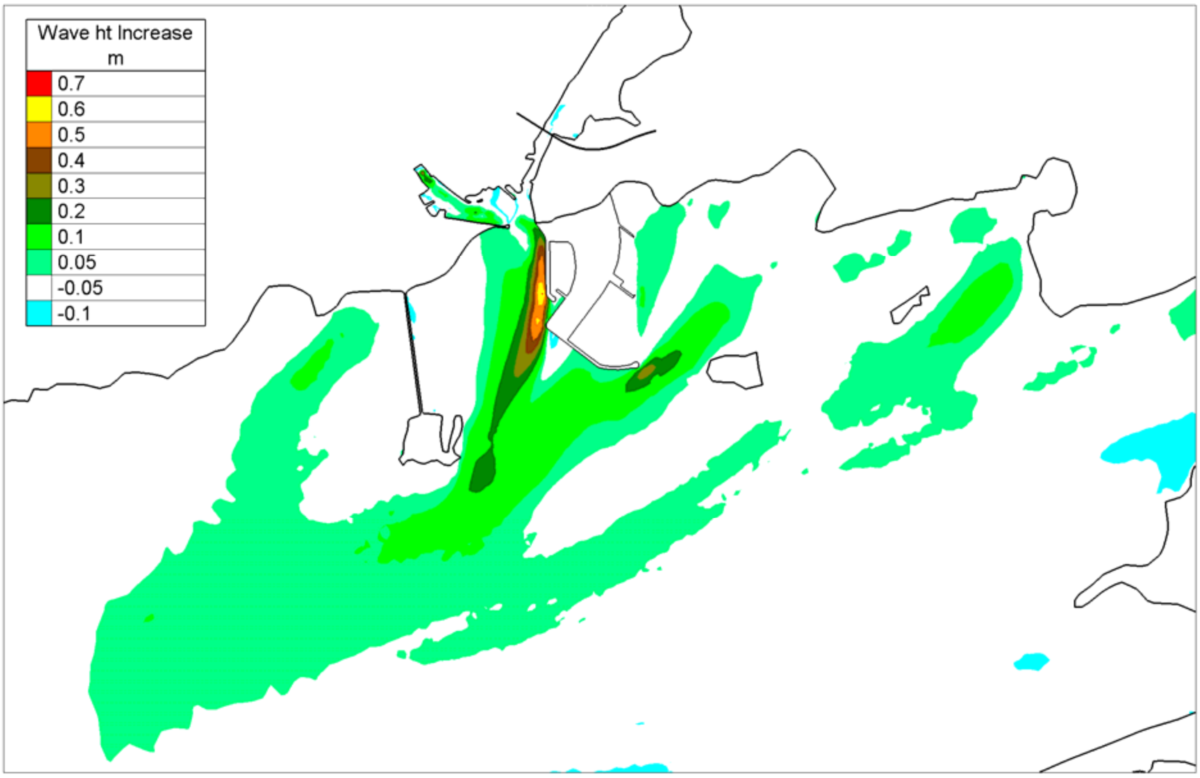


Figure 4.3.6 Difference Plot showing the effect of Tidal velocities on Wave height for SSW Storm wind conditions - Proposed

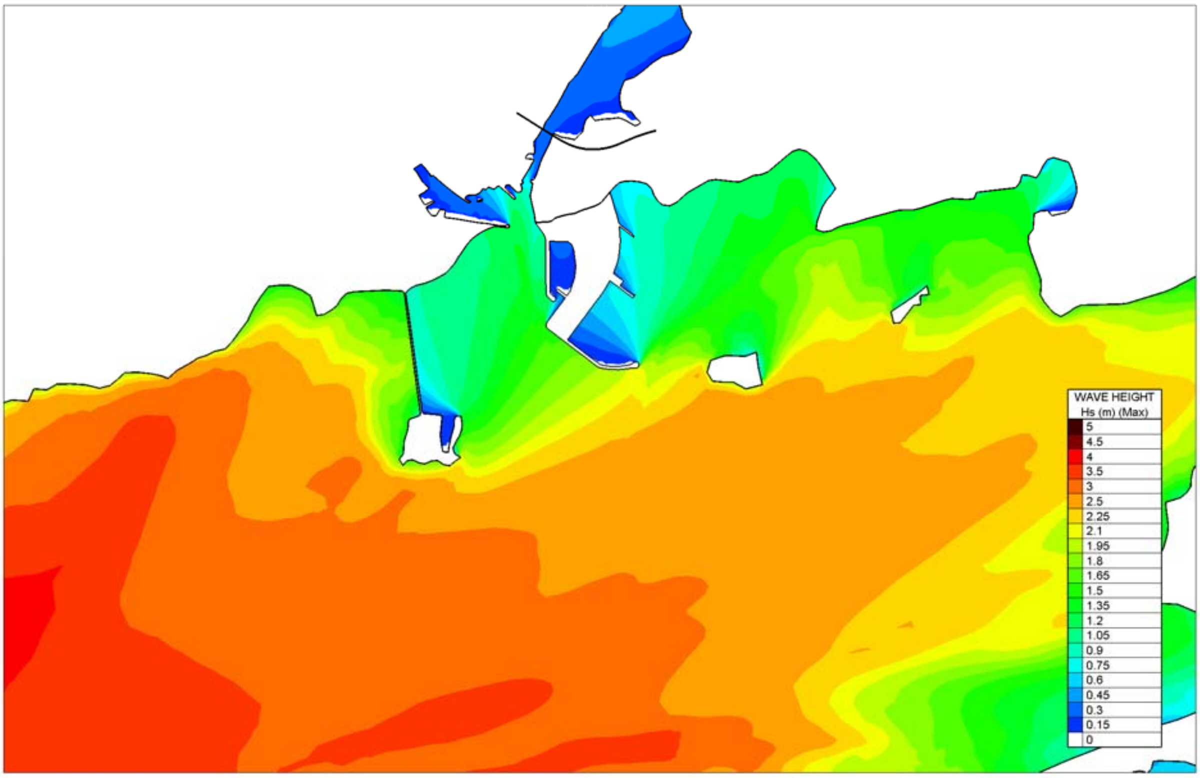


Figure 4.3.7 Predicted Wave Climate for South storm winds without including tidal velocities - Proposed

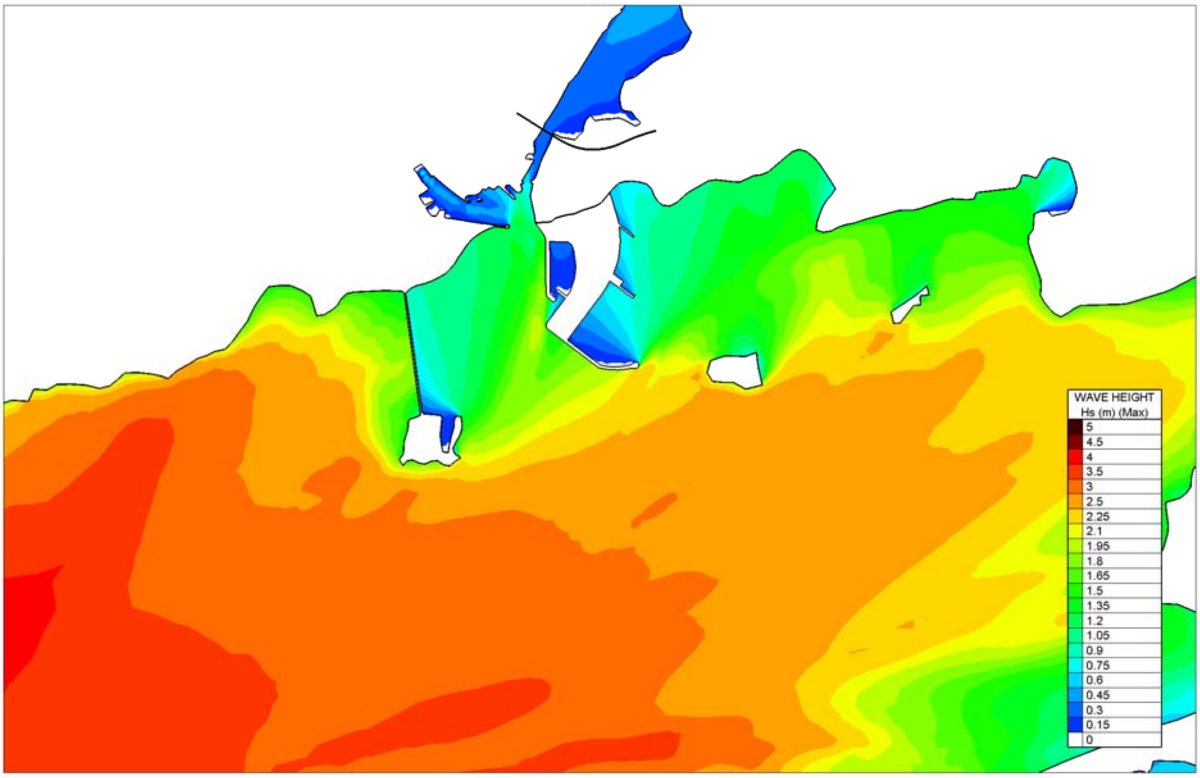


Figure 4.3.8 Predicted Wave Climate for South storm winds with tidal velocities included - Proposed

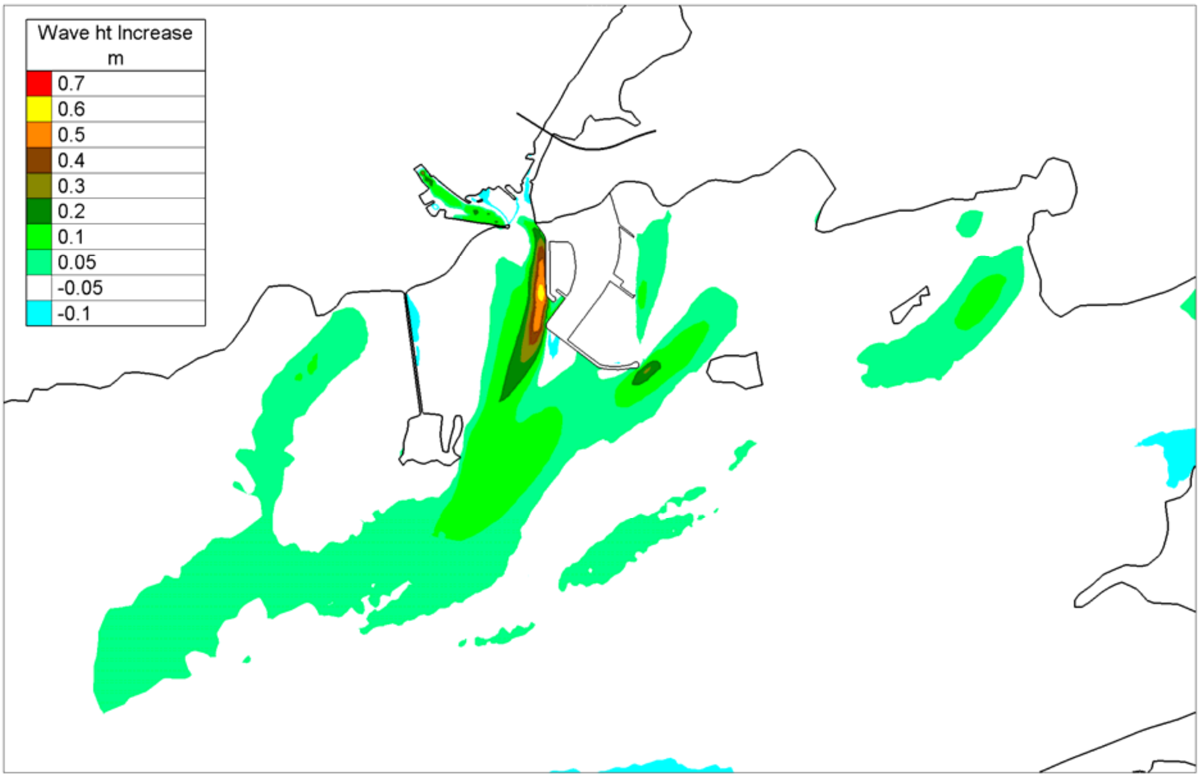


Figure 4.3.9 Difference Plot showing the effect of Tidal velocities on Wave height for South Storm wind conditions - Proposed

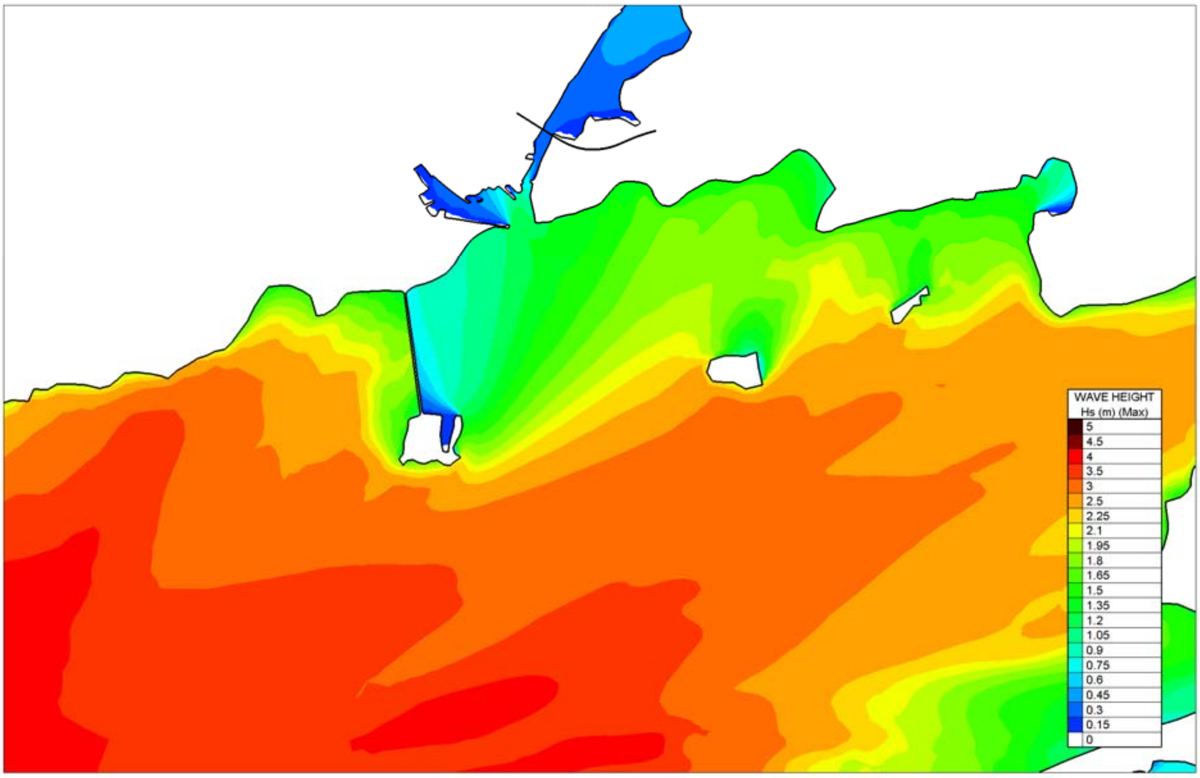


Figure 4.3.10 Predicted Wave Climate for SSW storm Wind without including tidal velocities – Existing

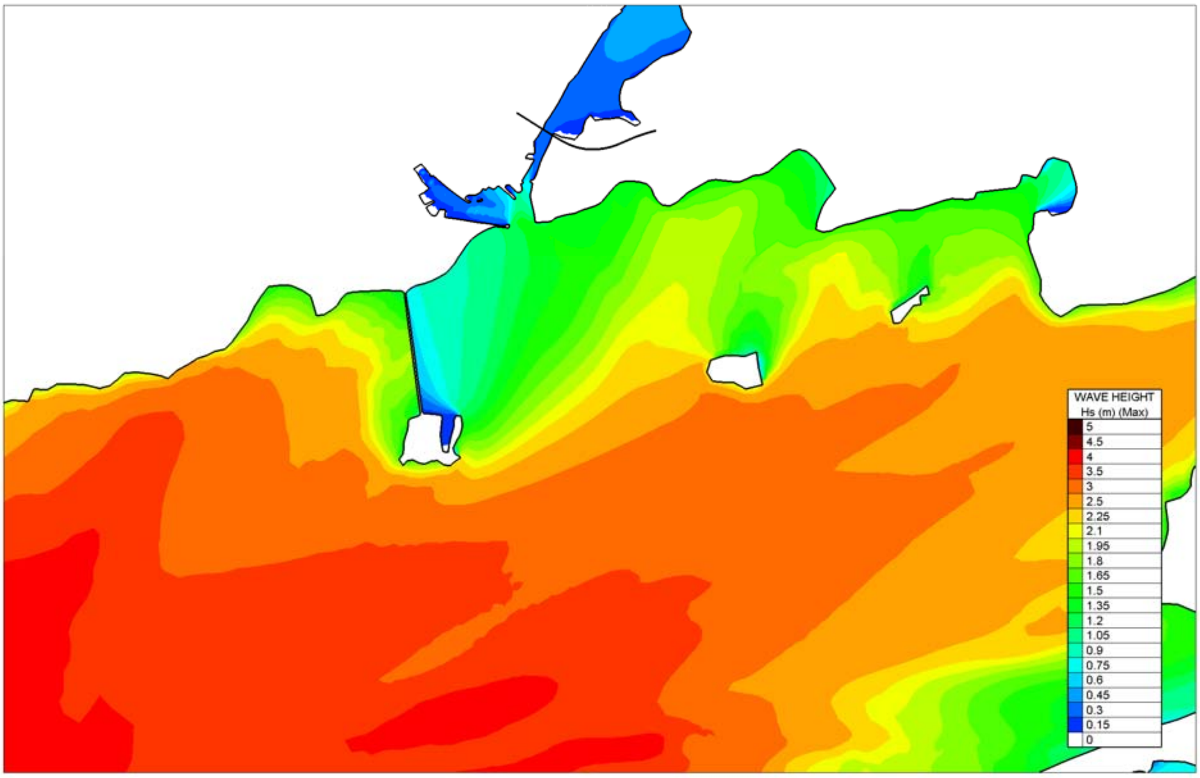


Figure 4.3.11 Predicted Wave Climate for SSW storm Wind with tidal velocities included - Existing

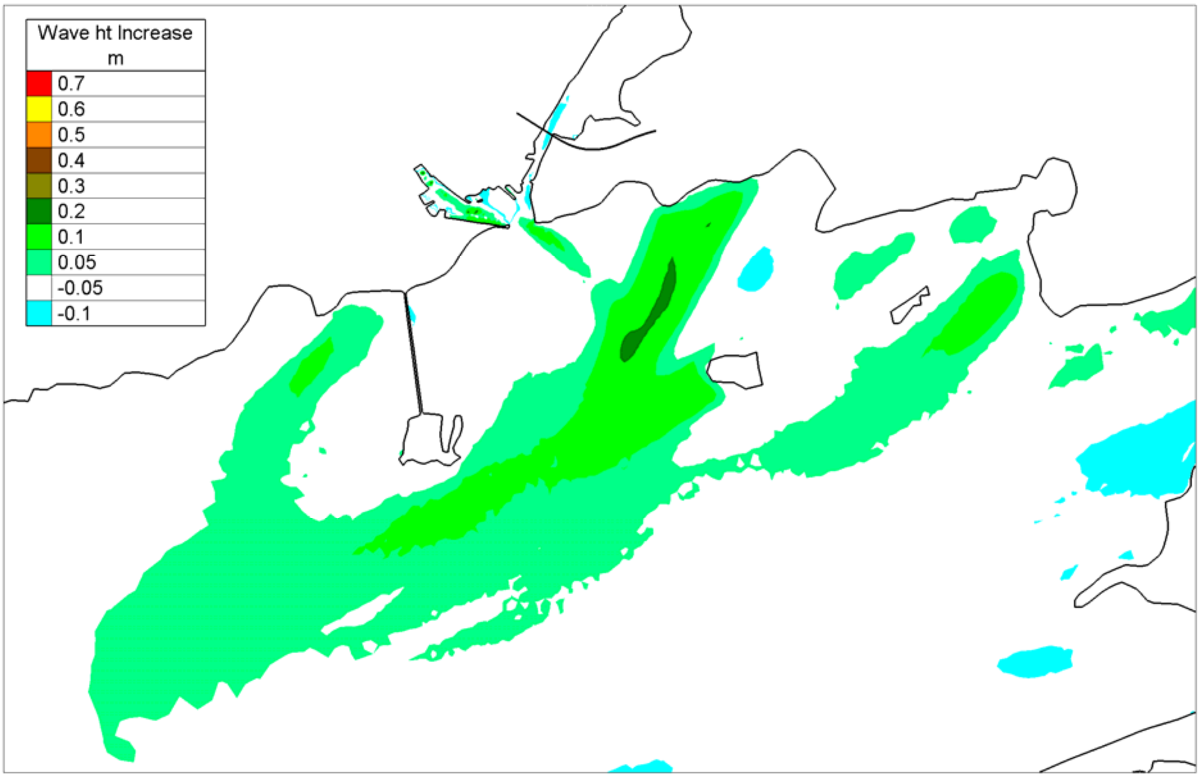


Figure 4.3.12 Difference Plot showing the effect of Tidal velocities on Wave height for SSW Storm wind conditions - Existing

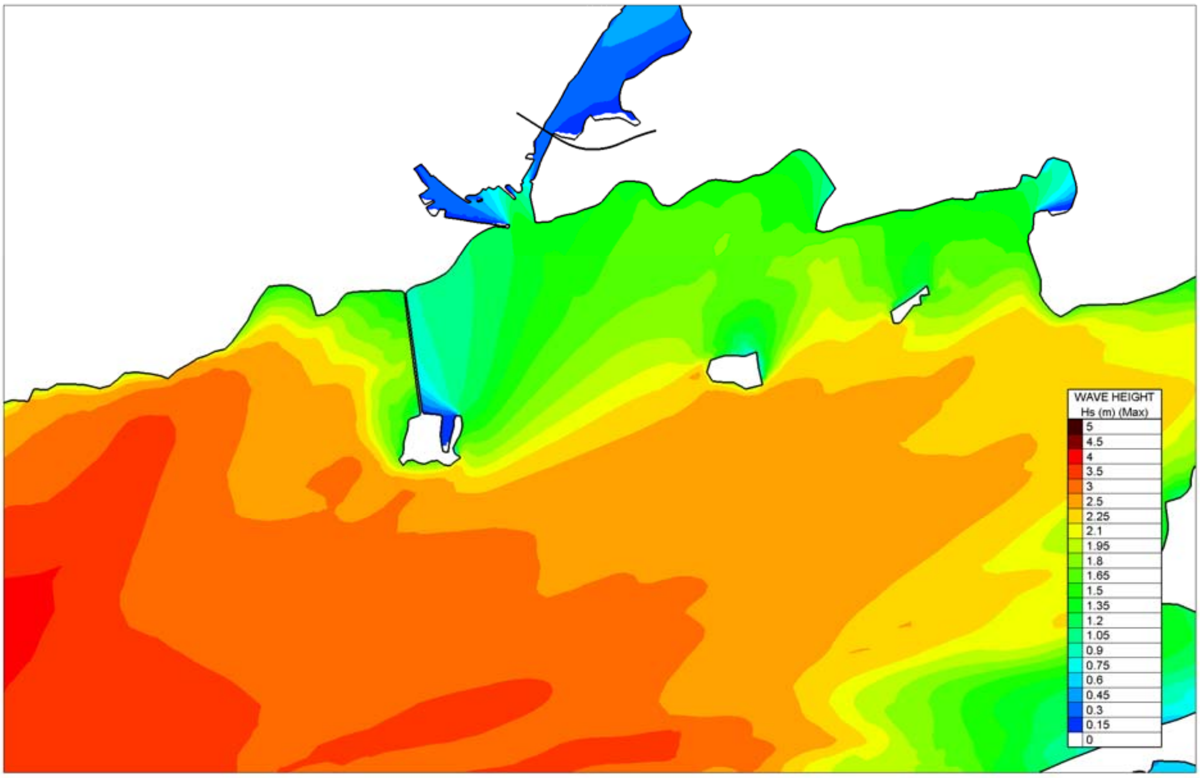


Figure 4.3.13 Predicted Wave Climate for South storm winds without including tidal velocities - Existing

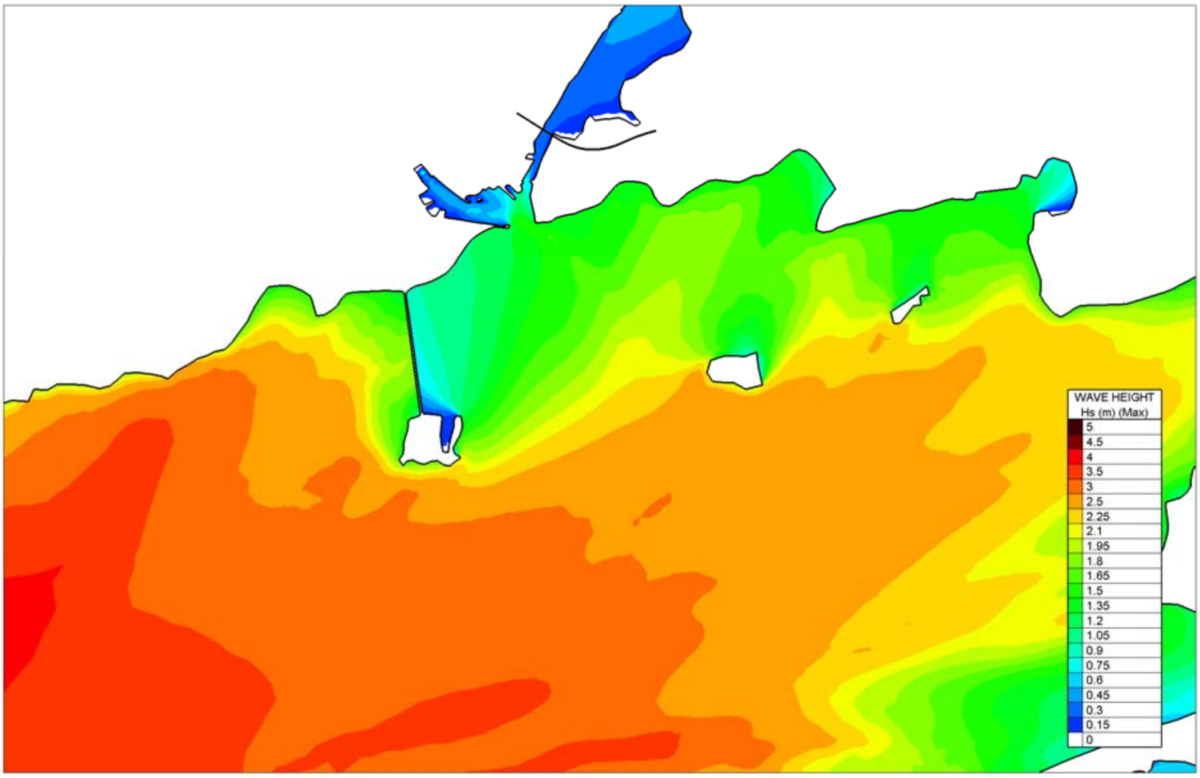


Figure 4.3.14 Predicted Wave Climate for South storm winds with tidal velocities included - Existing

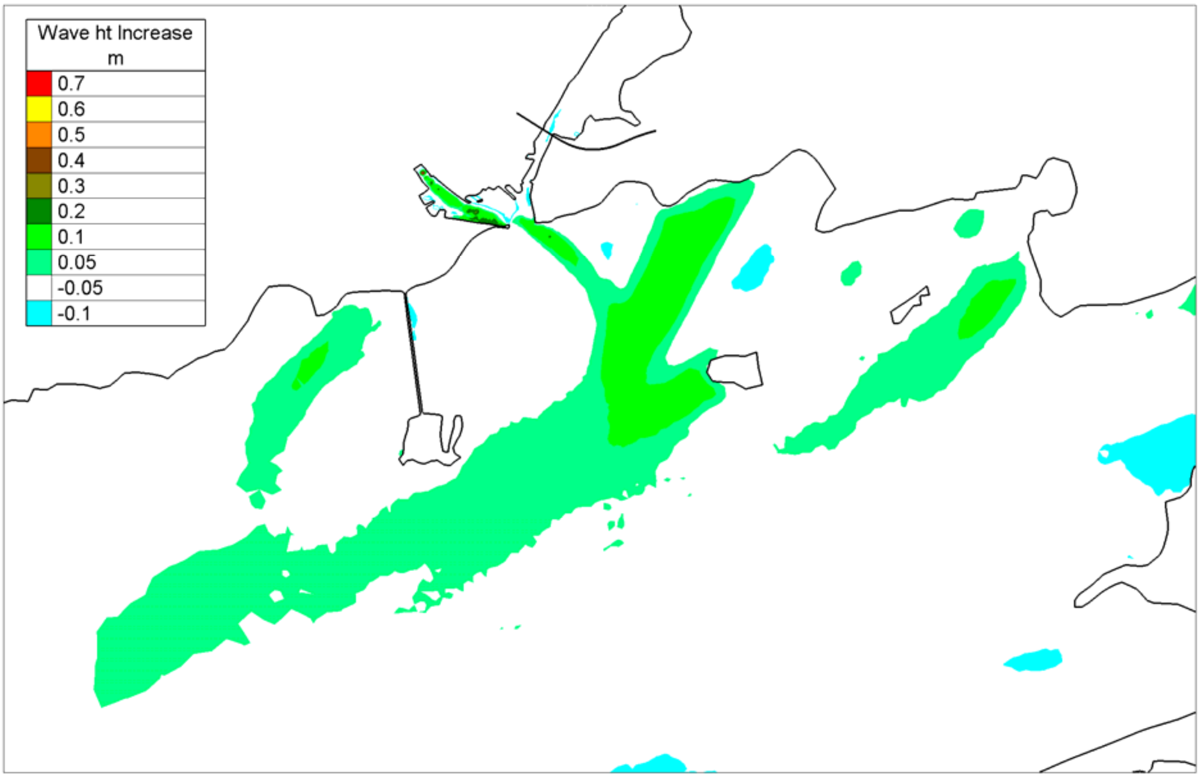


Figure 4.3.15 Difference Plot showing the effect of Tidal velocities on Wave height for South Storm wind conditions - Existing

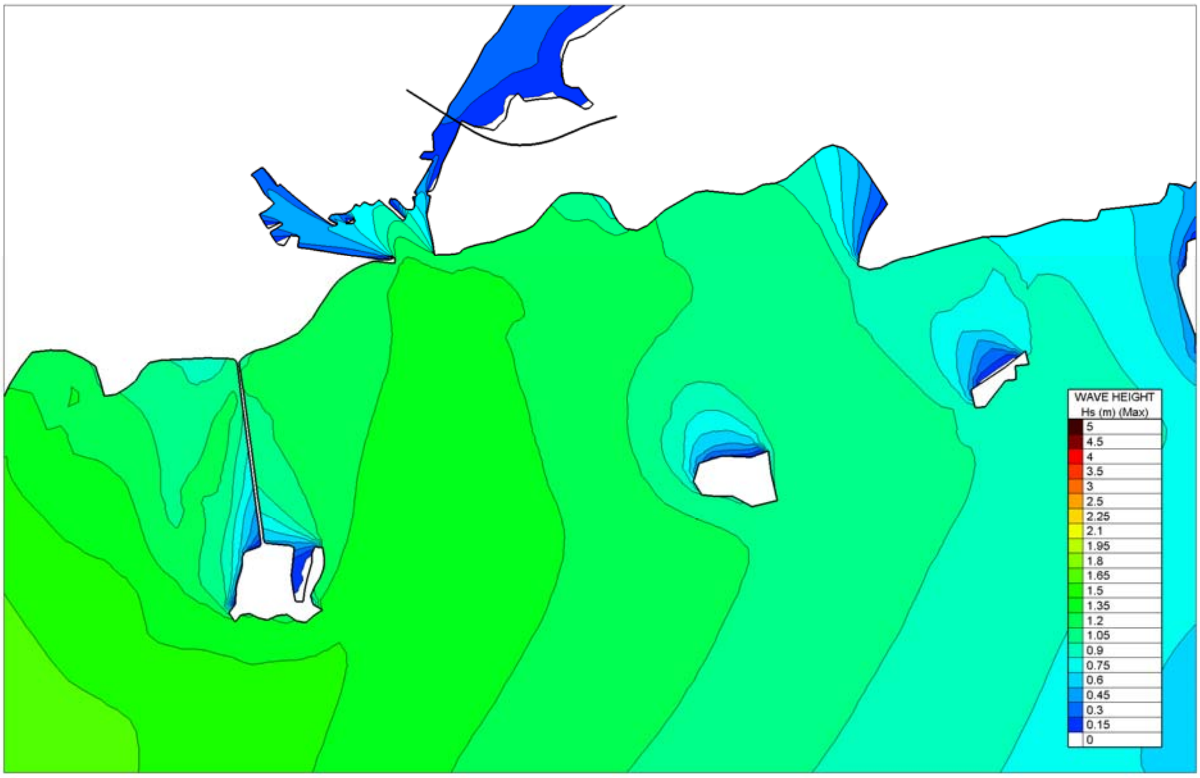


Figure 4.3.16 Predicted Wave Climate for local SE storm wind waves without tidal velocities included - Existing

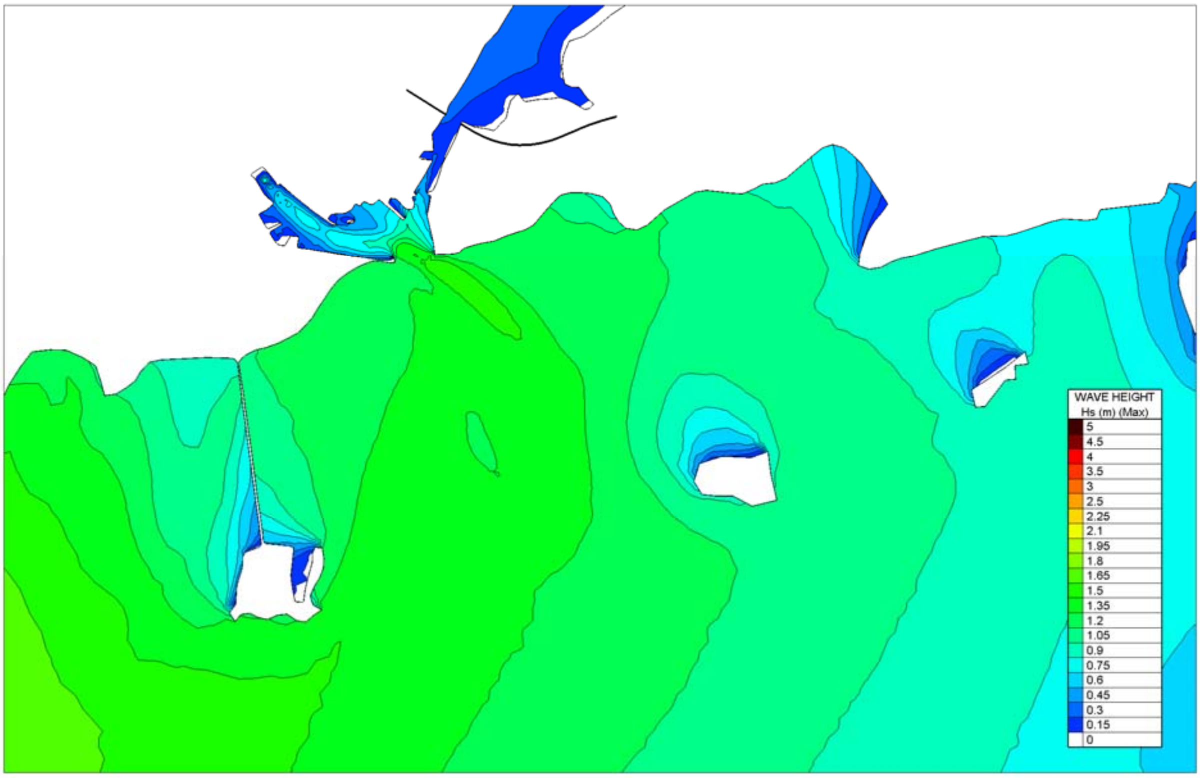


Figure 4.3.17 Predicted Wave Climate for local SE storm wind waves with tidal velocities included - Existing

Figure 4.3.18 Difference Plot showing the effect of Tidal velocities on Wave height for SE Storm Wind Waves - Existing

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Appendices to NIS Addendum / Errata

Appendix No. 3.3

Appendix No. 4 – Wind Waves and Current Effects

4.4 RELATIONSHIP BETWEEN WIND WAVES AND CURRENT EFFECTS

Query:

Please clarify whether within the area that experiences high wind waves, willÿ the wave heights be exacerbated if the current-effects are included?

Response:

4.4.1 Introduction

To incorporate the effect of Tidal Currents for the proposed and existing cases a full range of Wave climate simulations were carried out modelling both Atlantic Swell and Local wind Waves using the SWAN Spectral Model described in Section 3. These simulation were carried out with the tidal currents from the hydrodynamic model included for the proposed and existing cases.

4.4.2 Wave Climate Simulations

The following Wave Simulations Runs were carried out for proposed and existing Cases:

- West Storm Wind Waves and Atlantic Storm Swell (Figure 4.4.1, 4.4.2 & 4.4.25)
- WSW Storm Wind Waves and Atlantic Storm Swell (Figure 4.4.3, 4.4.4 & 4.4.26)
- SW Storm Wind Waves and Atlantic Storm Swell (Figure 4.4.5, 4.4.6 & 4.4.27)
- SSW Storm Wind Waves and Atlantic Storm Swell (Figure 4.4.7, 4.4.8 & 4.4.28)
- South Storm Wind Waves and Atlantic Storm Swell (Figure 4.4.9, 4.4.10 & 4.4.29)

- WSW Local generated Storm Wind Waves (Figure 4.4.11, 4.4.12 & 4.4.30)
- SW Local generated Storm Wind Waves (Figure 4.4.13, 4.4.114 & 4.4.31)
- SSW Local generated Storm Wind Waves (Figure 4.4.15, 4.4.16 & 4.4.32)
- South Local generated Storm Wind Waves (Figure 4.4.17, 4.4.18 & 4.4.33)
- SSE Local generated Storm Wind Waves (Figure 4.4.19, 4.4.20 & 4.4.34)
- SE Local generated Storm Wind Waves (Figure 4.4.21, 4.4.22 & 4.4.35)
- ESE Local generated Storm Wind Waves (Figure 4.4.23 4.4.24 & 4.4.36)

In these simulations the storm winds and local storm winds were taken as 30m/s.

The significant wave heights are presented in Figure 4.4.1 to 4.4.24 and wave height difference plot between proposed and existing cases are presented in Figures 4.4.25 to 4.4.36.

The results from the above simulations are compiled to produce a Plot of Maximum Wave Heights within the Bay for all on-shore directions (local wind waves and Atlantic storm swell) which is requested by An Bord Pleanála under Item 9 of the Further Information Request, refer to Figures 4.4.37 to 4.4.40.

4.4.3 Discussion

A full series of the SWAN Spectral Wave model simulation runs were carried out to complement the ARTEMIS Simulation results reported in the EIS. The SWAN modelling included for refraction by currents and generally showed compatible results with the Artemis Model. Along the Southpark shoreline it showed wave heights only slightly higher than the Artemis Model (0.1 to 0.3m) which may be as a result of the ARTEMIS model being unable to include local wind generation within its domain (i.e. between the incident wave boundary and the shoreline). These SWAN results in combination with the ARTEMIS wave results can be used to assess the potential impact of the development on the surrounding wave climate.

In terms of Impact by the proposed development on the wave climate both sets of model results (Artemis and Swan) generally agree.

For both Atlantic and local wind generated waves from the West to South sector an increased wave climate occurs to the west of the Harbour development with increased wave heights predicted in the vicinity of Nimmo's Pier and the easterly section of Southpark shoreline with increases ranging between 0.05 and 0.2m, see 4.4.42.

4.4.42 shows a reduction in maximum wave heights at the Corrib entrance predicted by both the Artemis and Swan models in the proposed case.

4.4.41 shows a reaction in maximum wave heights in the Corrib / Claddagh Basin and on the South park shore other than the small area near to the head of Nimmos Pier.

A reduction in wave climate is predicted to the East of the Development between Ballyloughaun to the north and Hare Island to the south and the Harbour development.

For the South to East Wind fetch directions the proposed development has generally a sheltering effect and particularly on its western side which shelters against an ESE and SE wave directions which for the existing case can propagate up the Claddagh Basin.

In terms of maximum wave heights along the shoreline area of Southpark and the Corrib entrance the Swan Model indicates an overall reduction in the maximum wave heights as a result of the development (due to the sheltering of southeasterly wind waves).

The Renmore shoreline from east of Ballyloughaun Beach to the proposed Harbour is afforded significant shelter from Waves as a result of the development.

The only area of significant wave height change due to the refraction by currents is in the proposed navigation channel near the Marina entrance with predicted increases in wave heights of 0.5 to 0.6m as a result of strong flood Corrib Flow velocities). This is not critical as the Marina Breakwater is suitably sized in terms of Crest level.

The effect from tidal velocities elsewhere in the Bay on wave heights is not significant with predicted maximum increases of 0.1 to 0.2 m/s when opposing the wave direction (i.e. ebbing Flow).

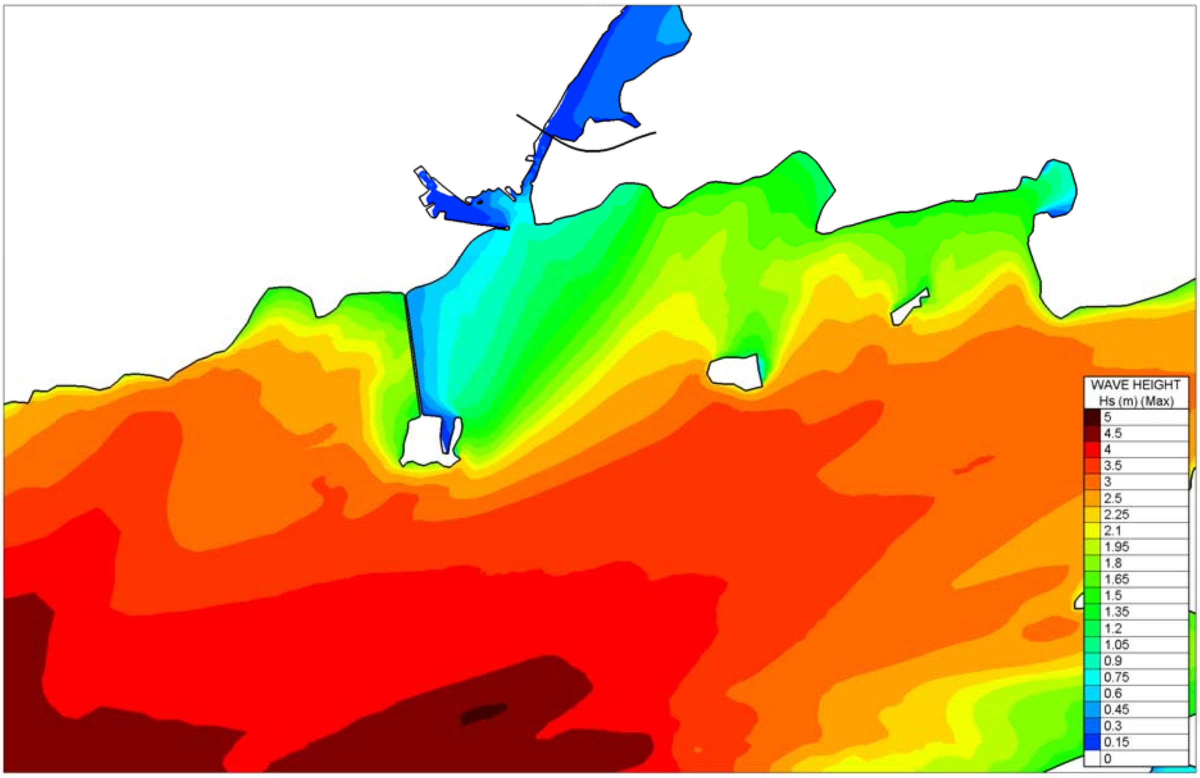

Figure 4.4.1 Computed Significant Wave heights for Atlantic Storm and West Storm Winds - Existing

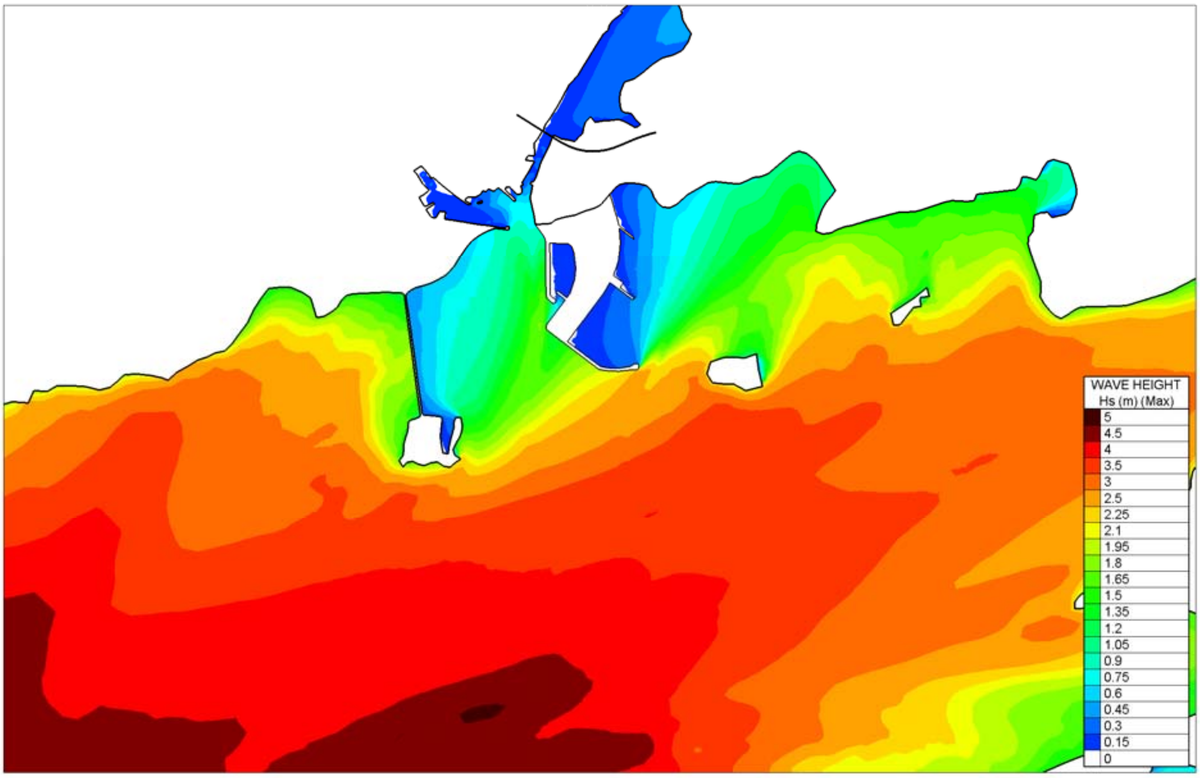

Figure 4.4.2 Computed Significant Wave heights for Atlantic Storm and West Storm Winds - Proposed

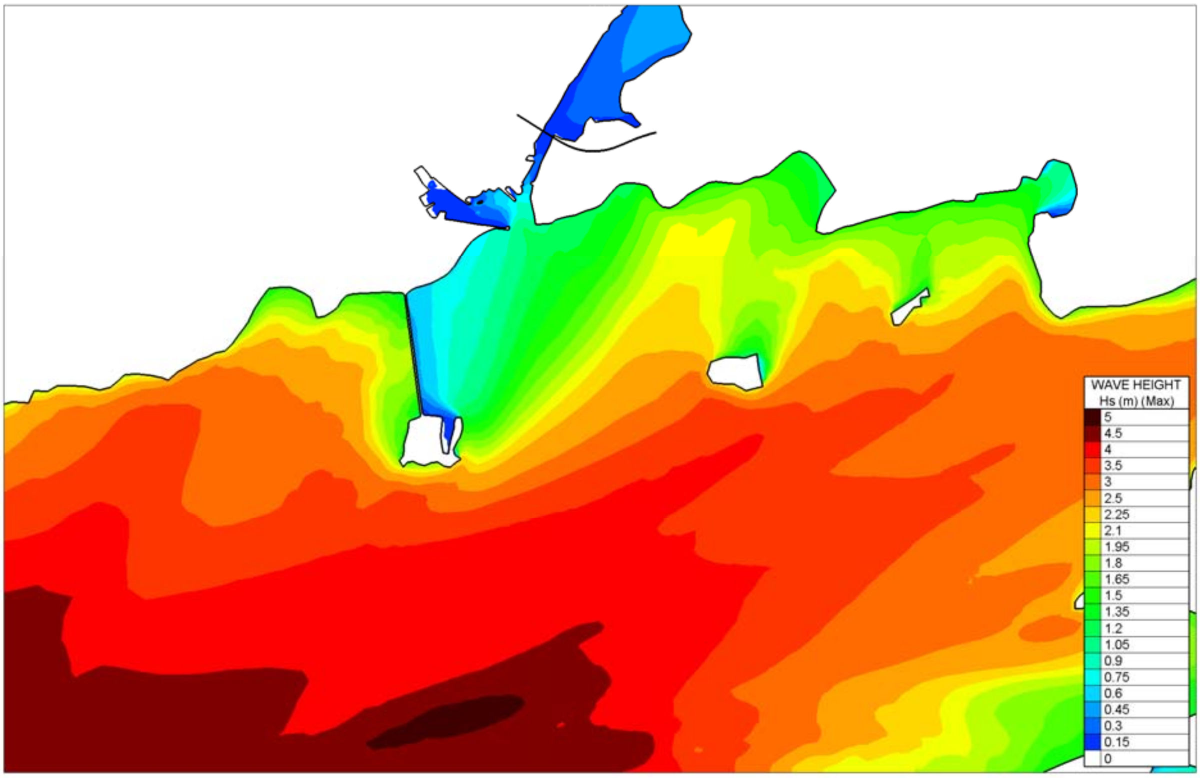

Figure 4.4.3 Computed Significant Wave heights for Atlantic Storm and WSW

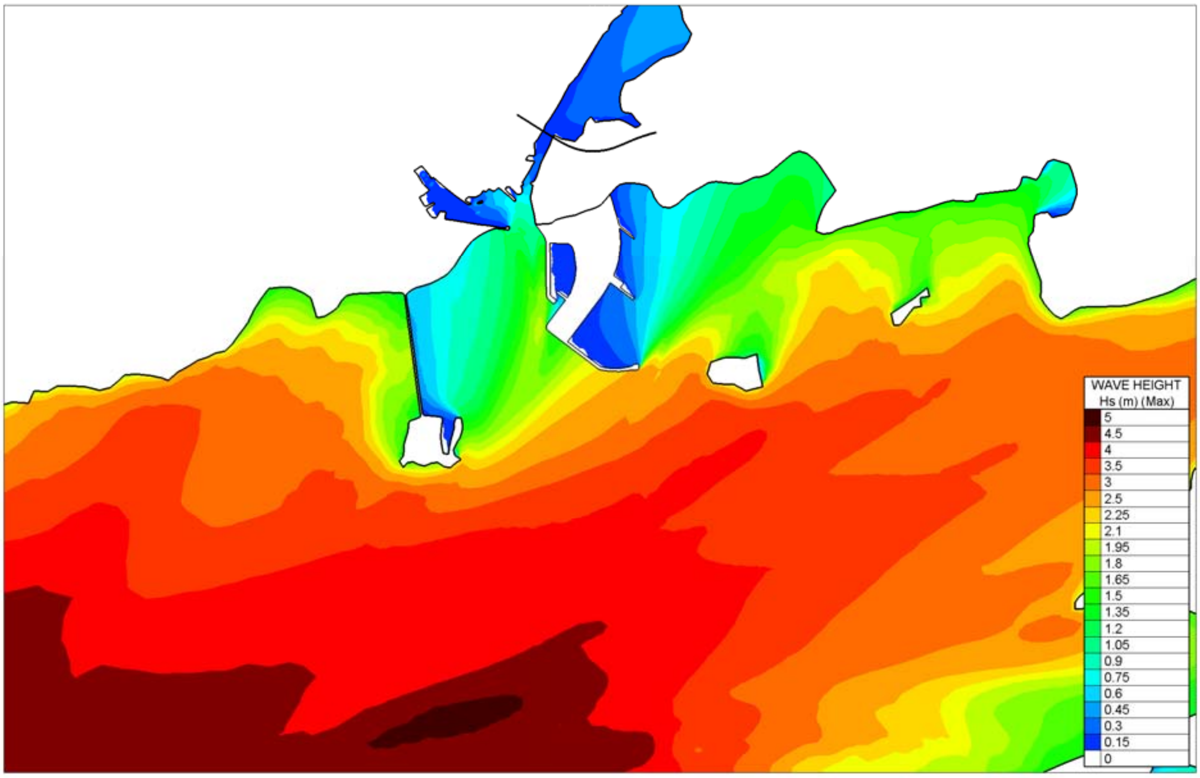

Figure 4.4.4 Computed Significant Wave heights for Atlantic Storm and WSW

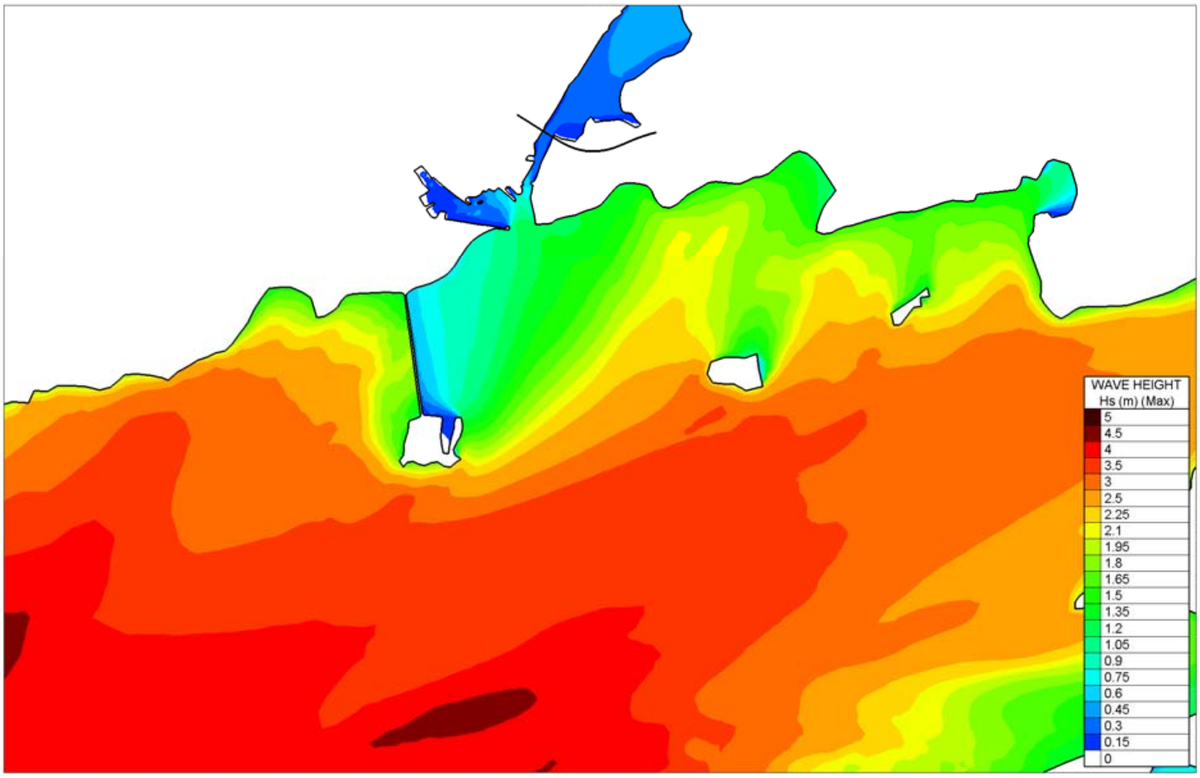

Figure 4.4.5 Computed Significant Wave heights for Atlantic Storm and SW

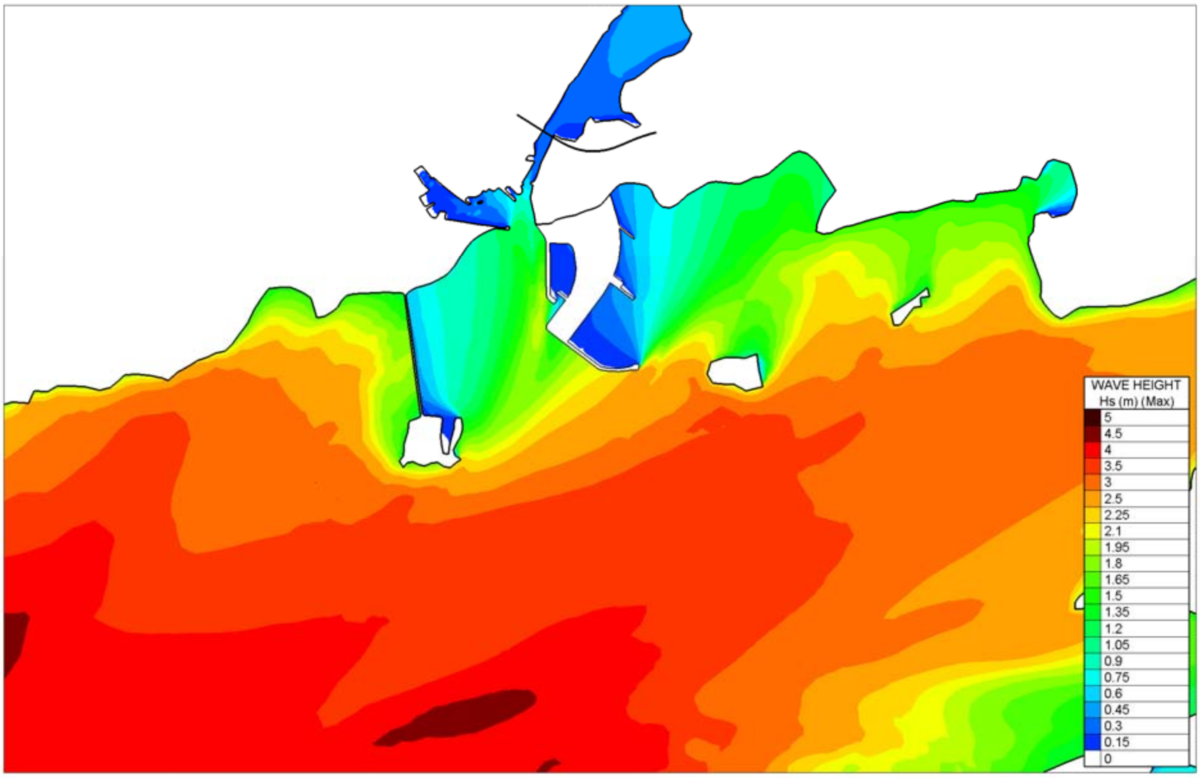

Figure 4.4.6 Computed Significant Wave heights for Atlantic Storm and SW

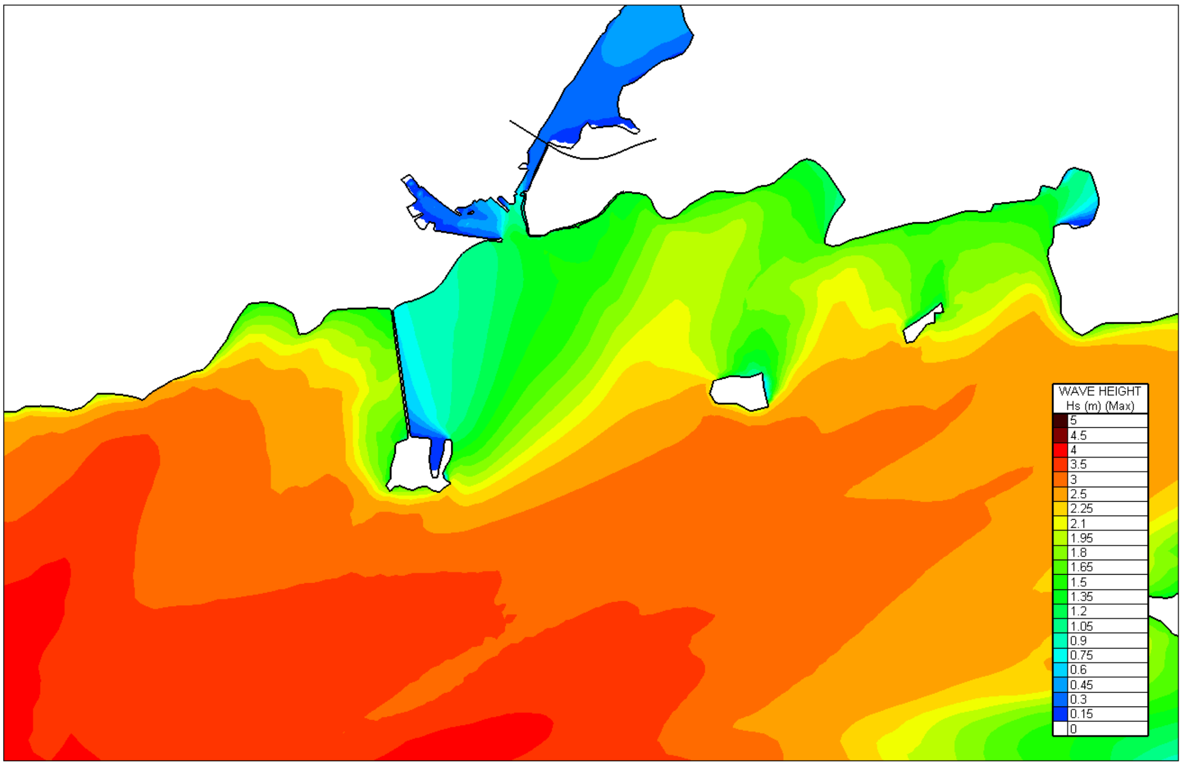

Figure 4.4.7 Computed Significant Wave heights for Atlantic Storm and SSW Storm Winds - Existing

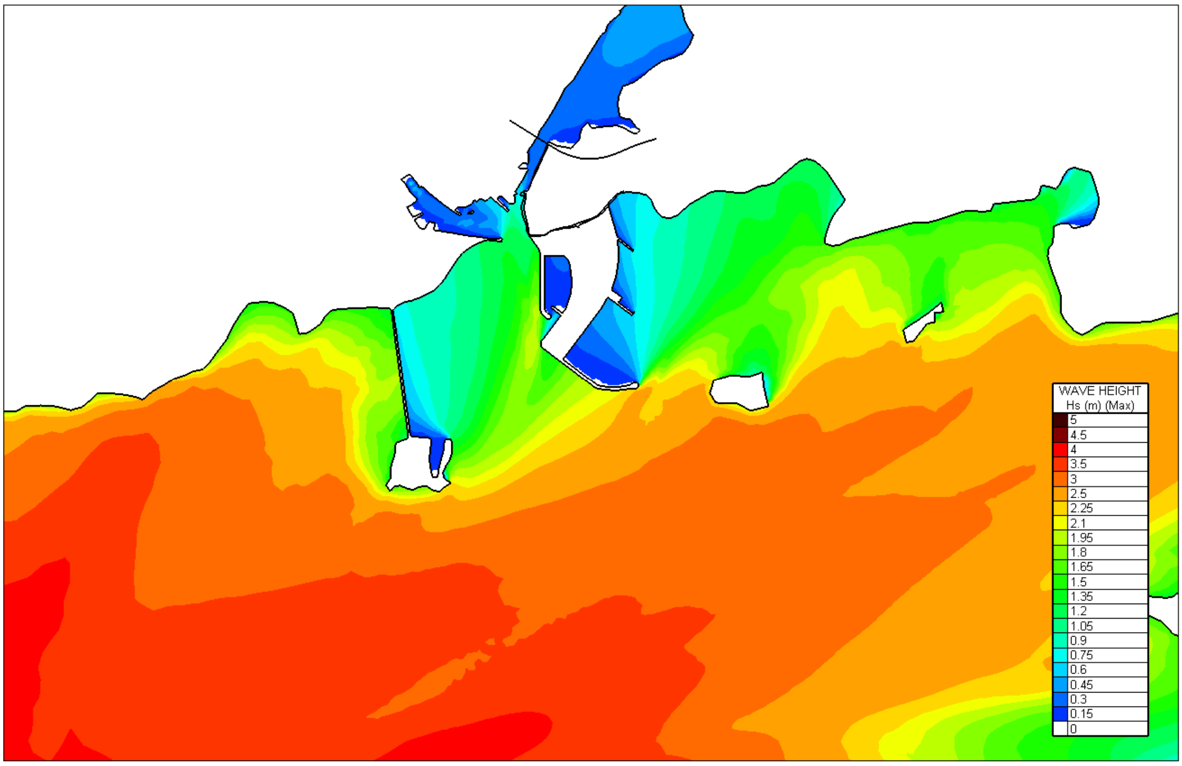

Figure 4.4.8 Computed Significant Wave heights for Atlantic Storm and SSW Storm Winds - Proposed

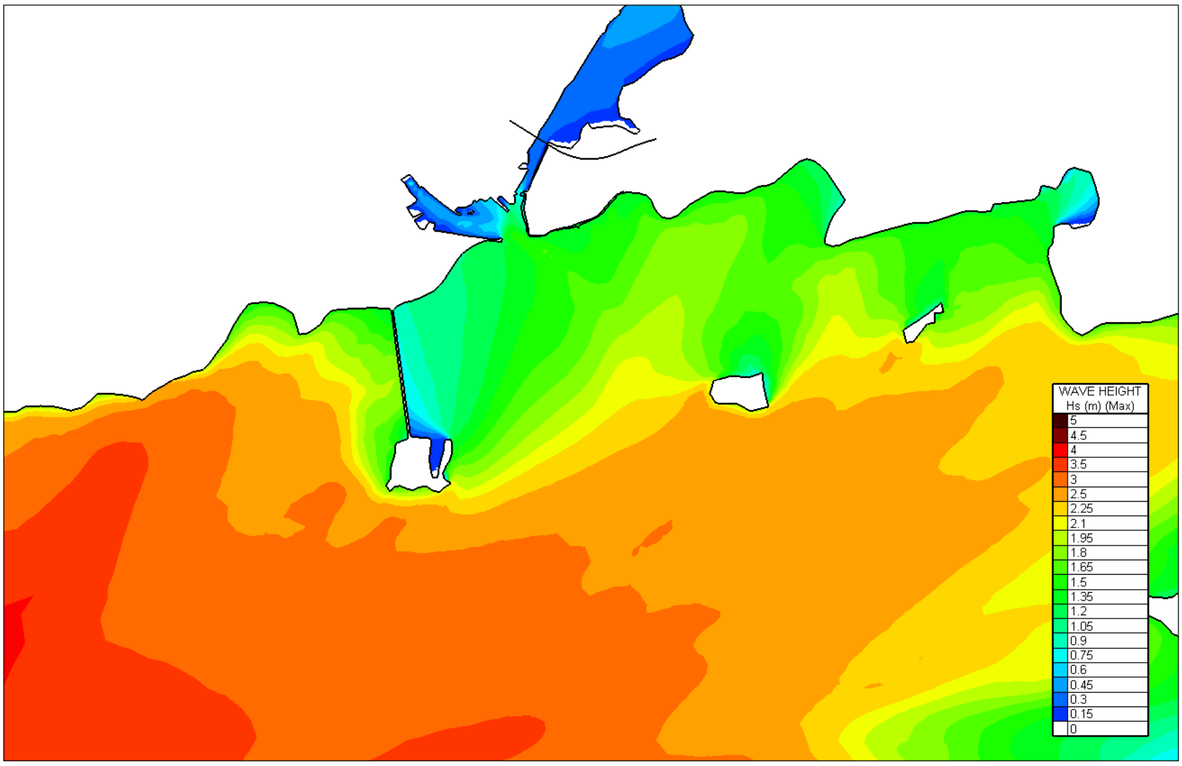

Figure 4.4.9 Computed Significant Wave heights for Atlantic Storm and South Storm Winds - Existing

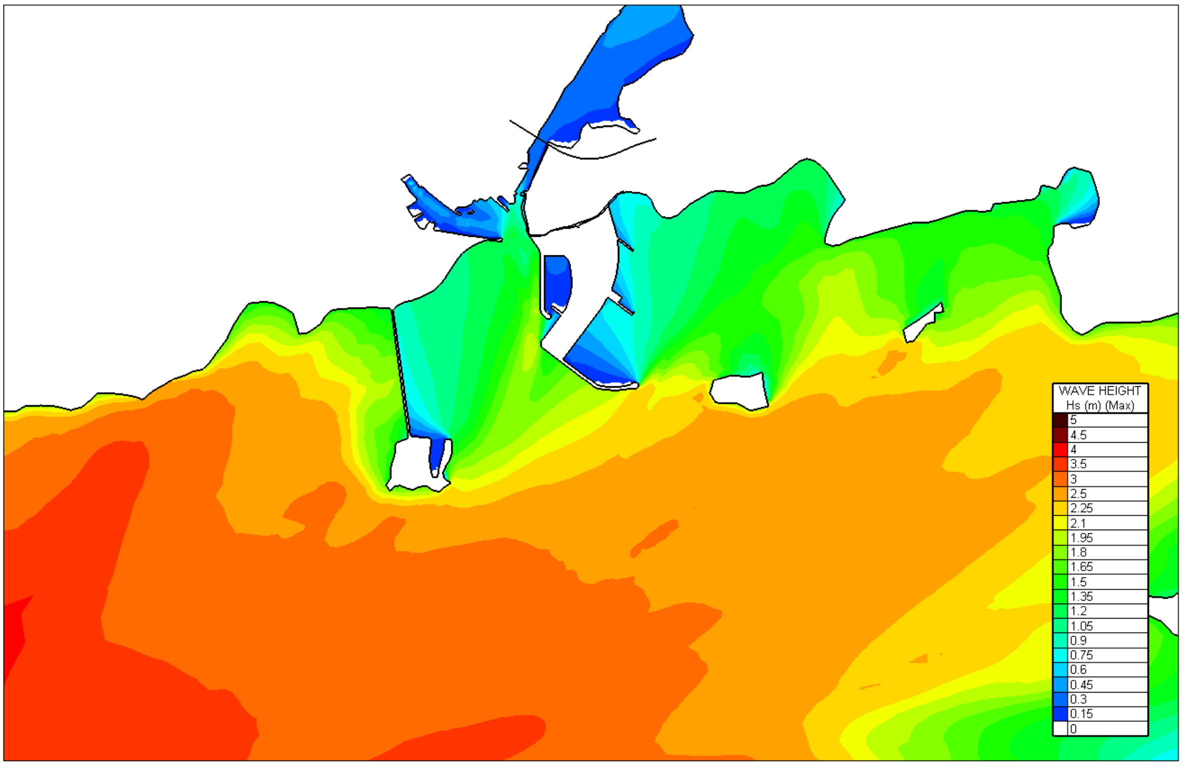

Figure 4.4.10 Computed Significant Wave heights for Atlantic Storm and South Storm Winds - Proposed

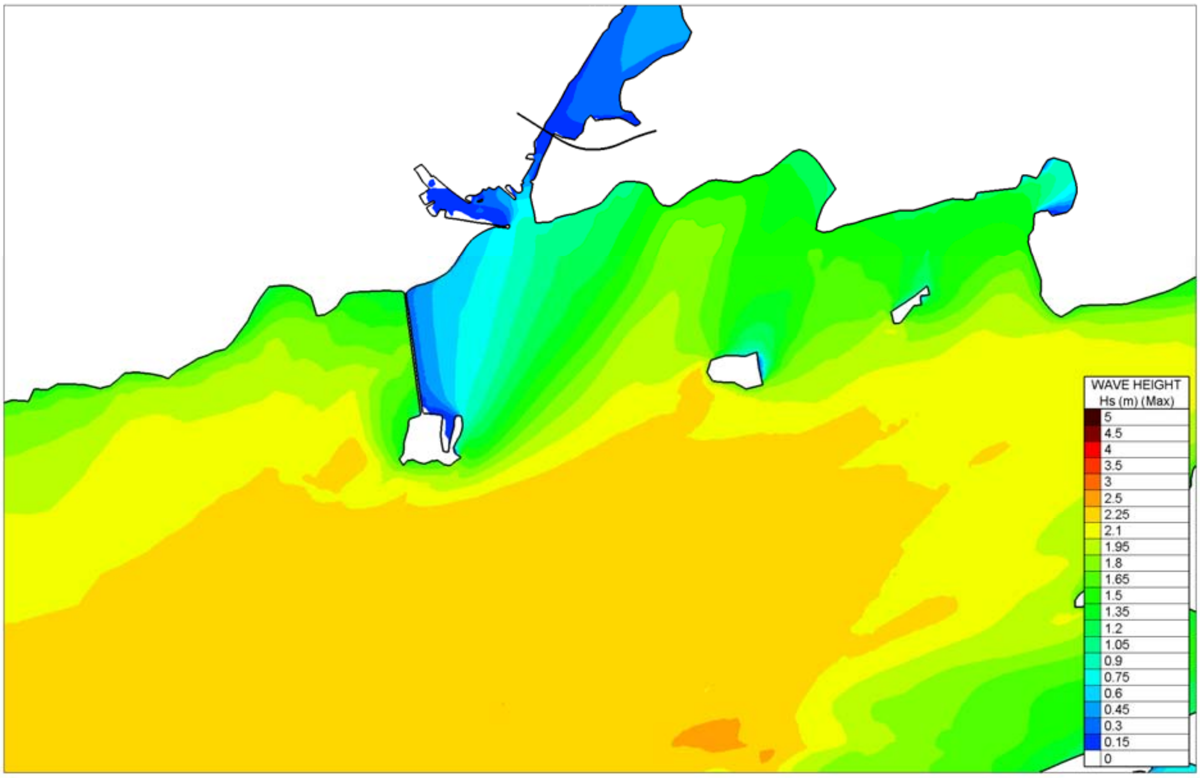

Figure 4.4.11 Computed Significant Wave heights for Local WSW Storm Winds - Existing

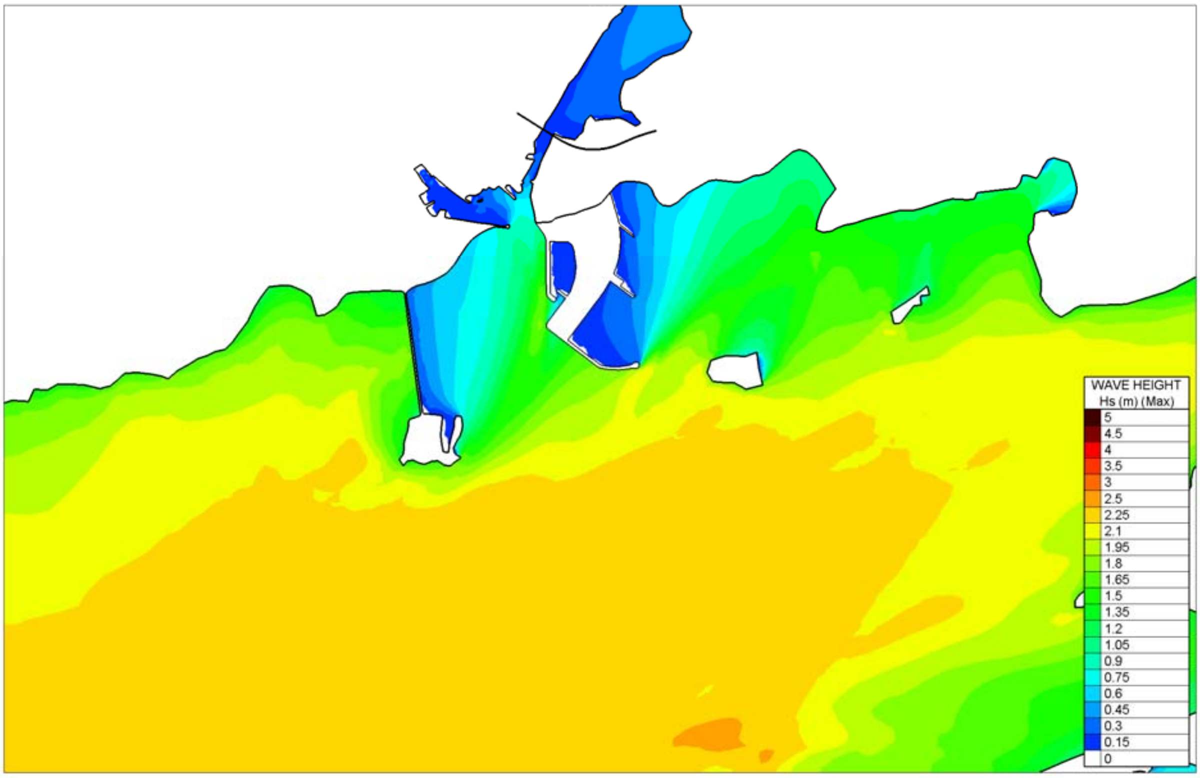

Figure 4.4.12 Computed Significant Wave heights for Local WSW Storm Winds - Proposed

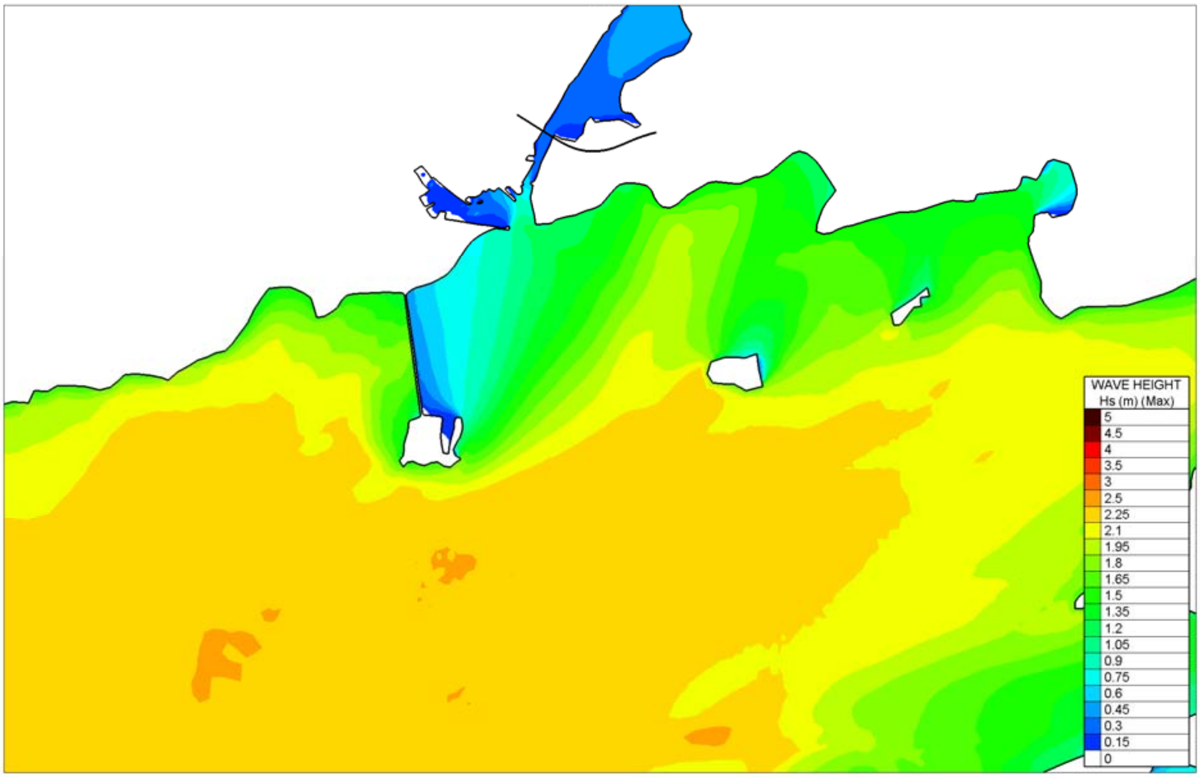

Figure 4.4.13 Computed Significant Wave heights for Local SW Storm Winds - Existing

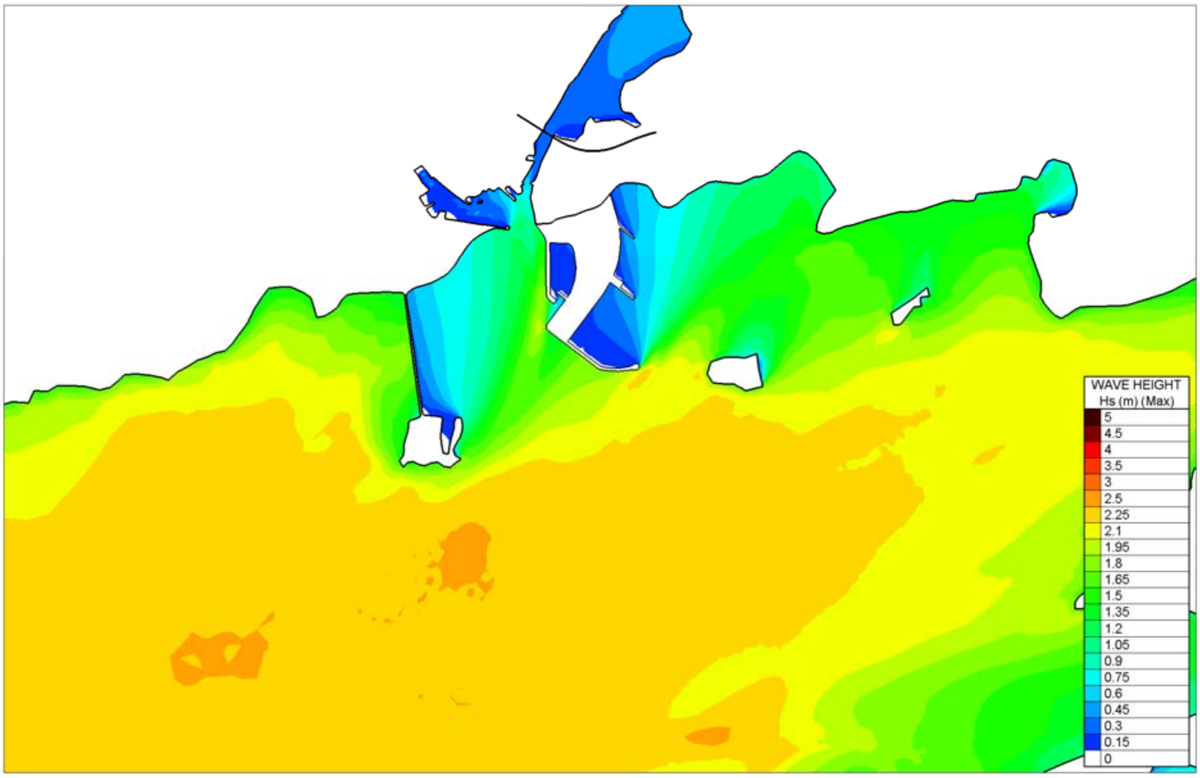

Figure 4.4.14 Computed Significant Wave heights for Local SW Storm Winds - Proposed

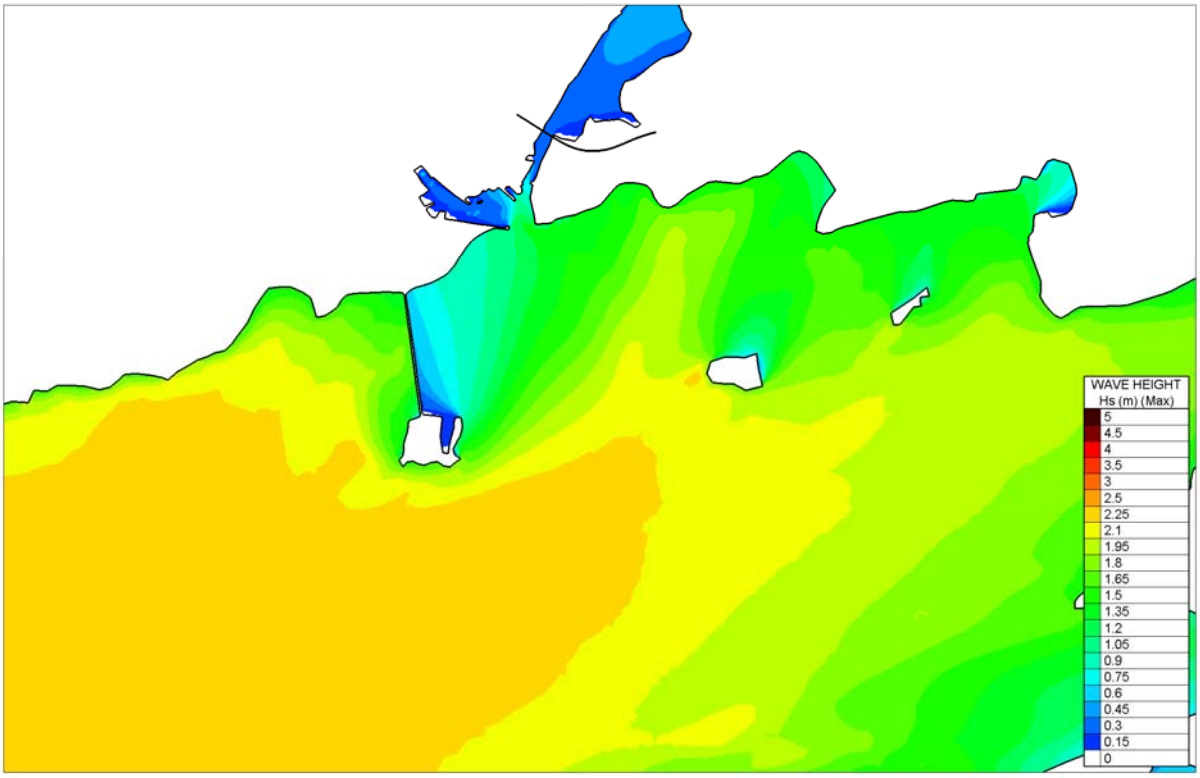

Figure 4.4.15 Computed Significant Wave heights for Local SSW Storm Winds - Existing

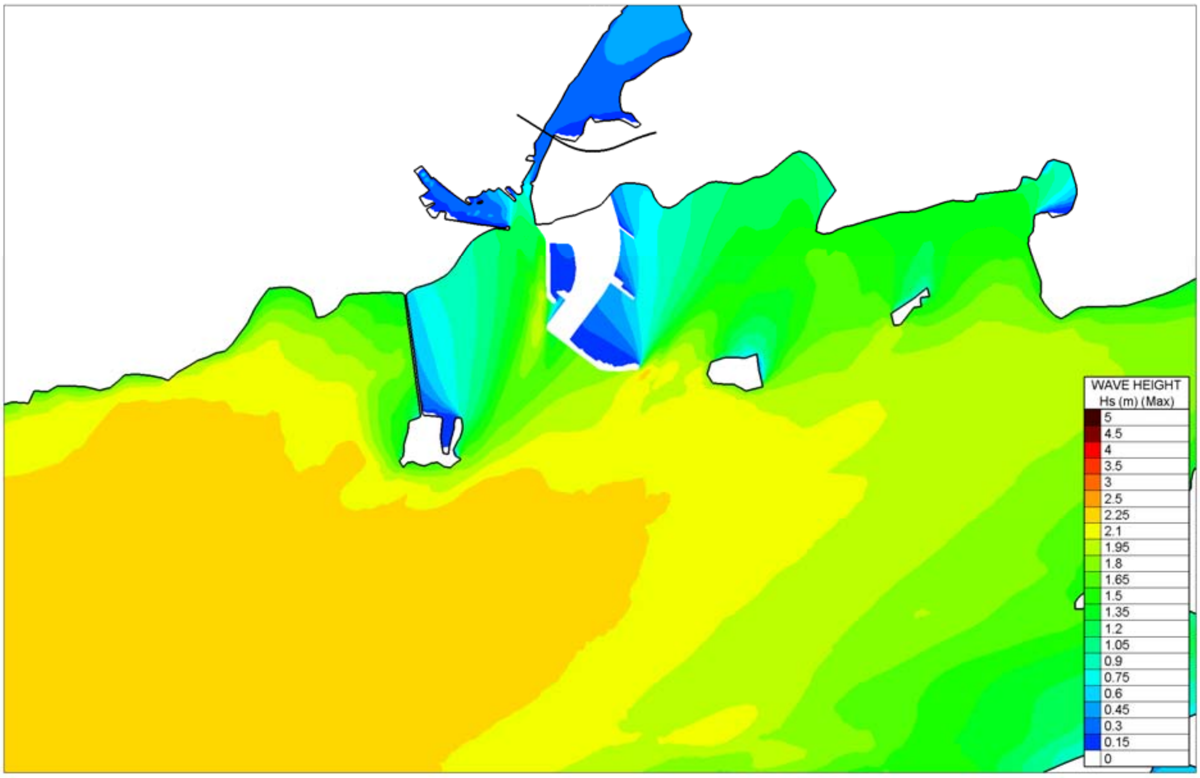

Figure 4.4.16 Computed Significant Wave heights for Local SSW Storm Winds - Proposed

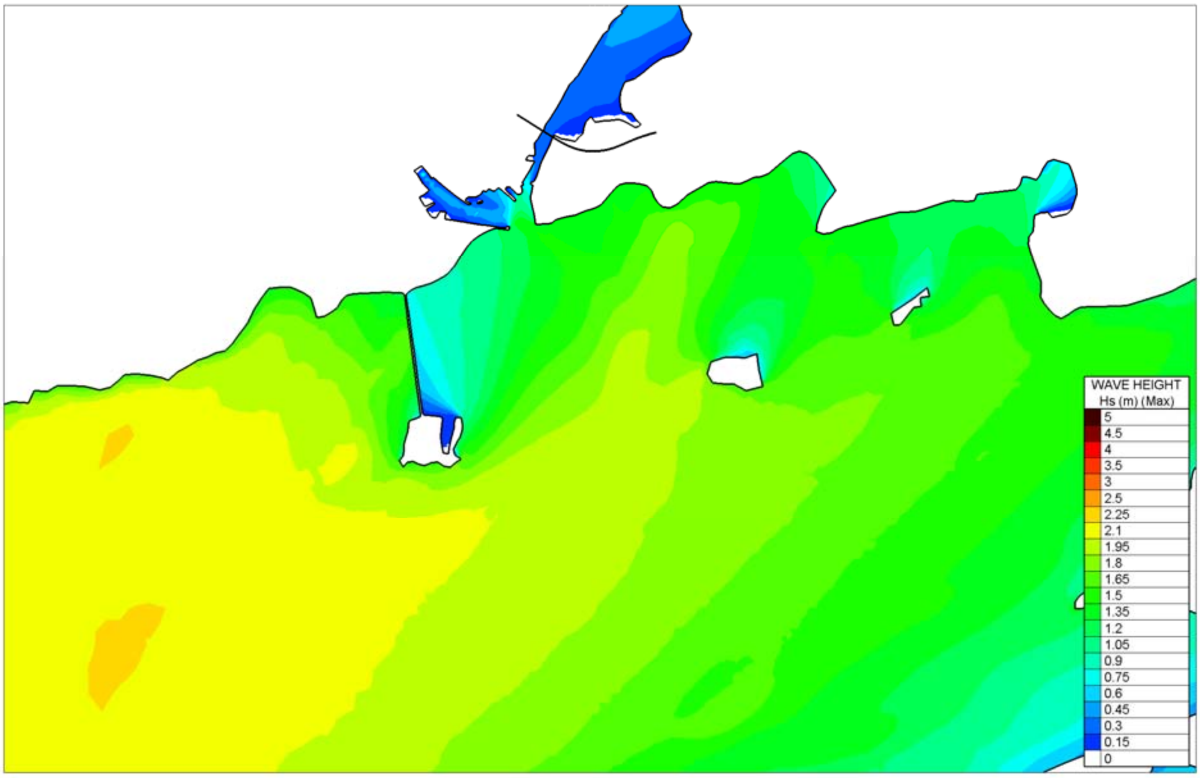

Figure 4.4.17 Computed Significant Wave heights for Local South Storm Winds - Existing

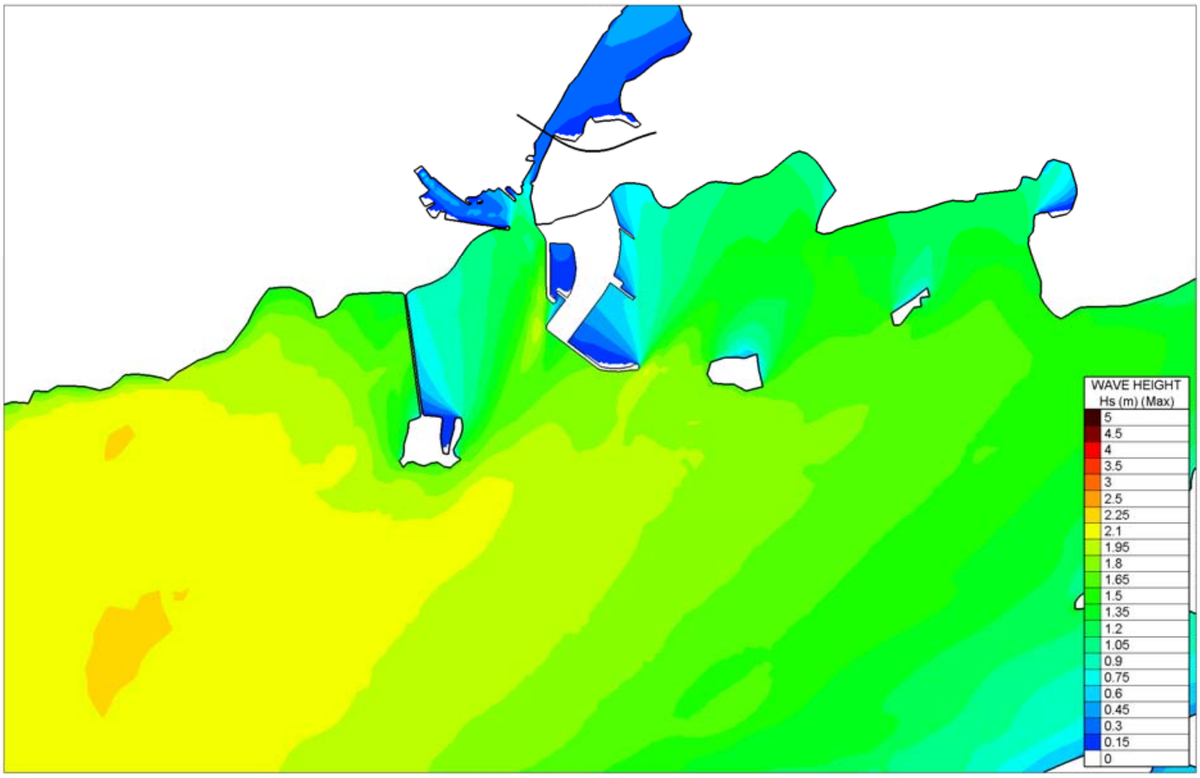

Figure 4.4.18 Computed Significant Wave heights for Local South Storm Winds - Proposed

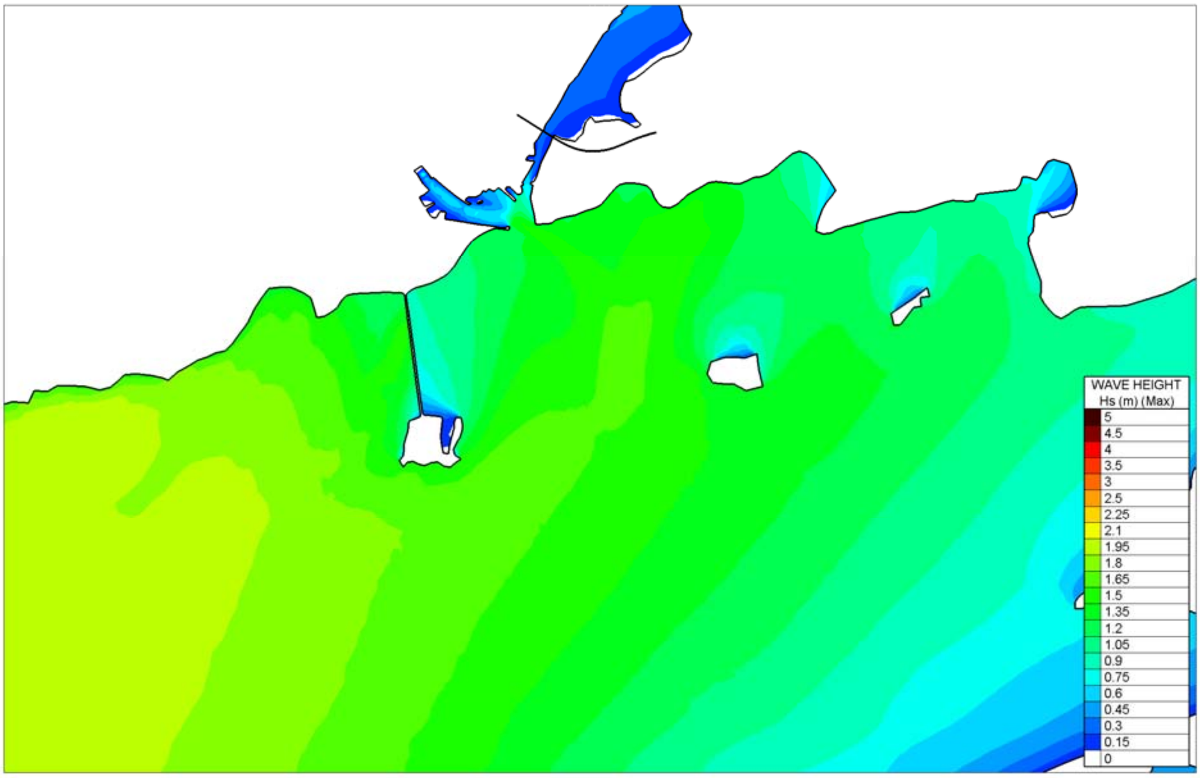

Figure 4.4.19 Computed Significant Wave heights for Local SSE Storm Winds - Existing

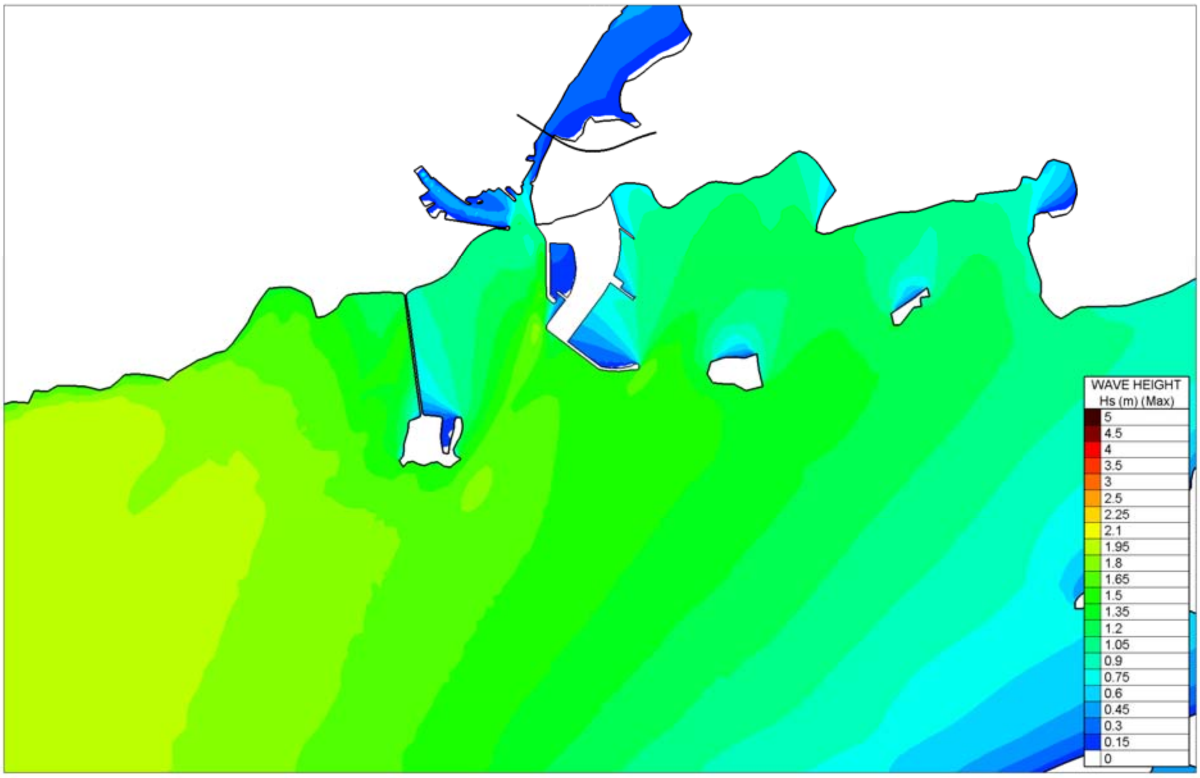

Figure 4.4.20 Computed Significant Wave heights for Local SSE Storm Winds - Proposed

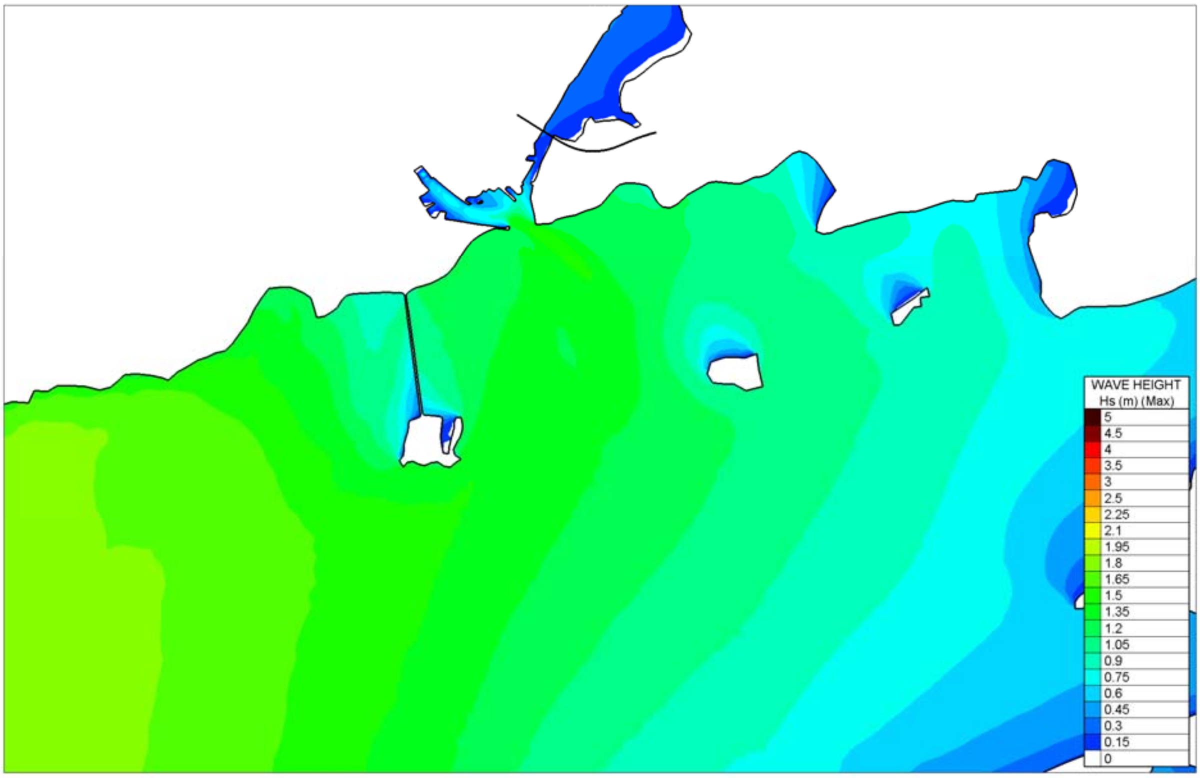

Figure 4.4.21 Computed Significant Wave heights for Local SE Storm Winds - Proposed

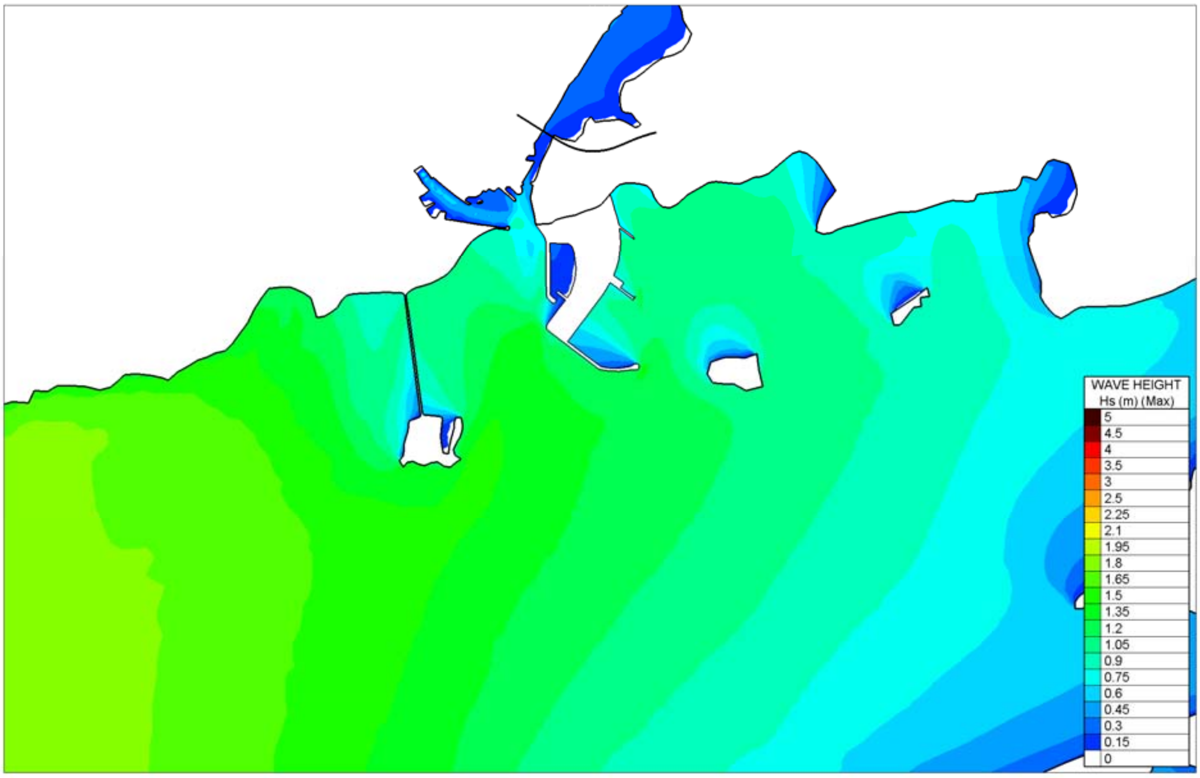

Figure 4.4.22 Computed Significant Wave heights for Local SE Storm Winds - Proposed

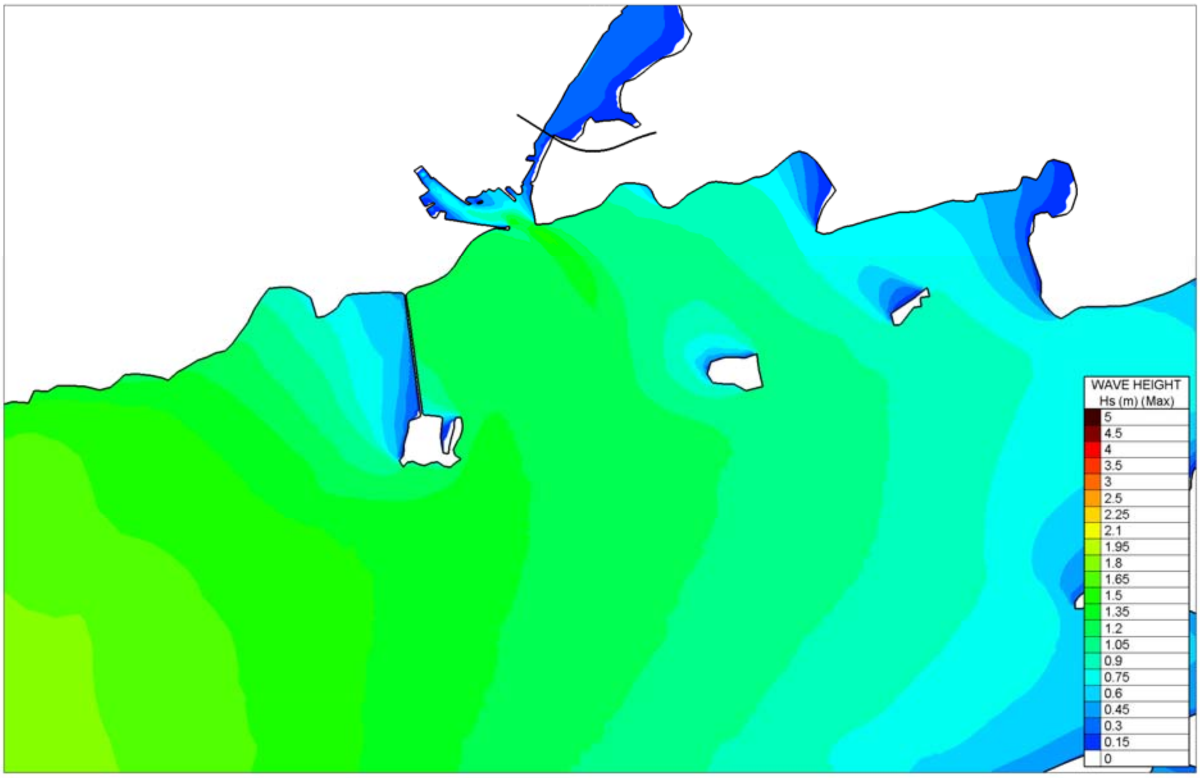

Figure 4.4.23 Computed Significant Wave heights for Local ESE Storm Winds - Existing

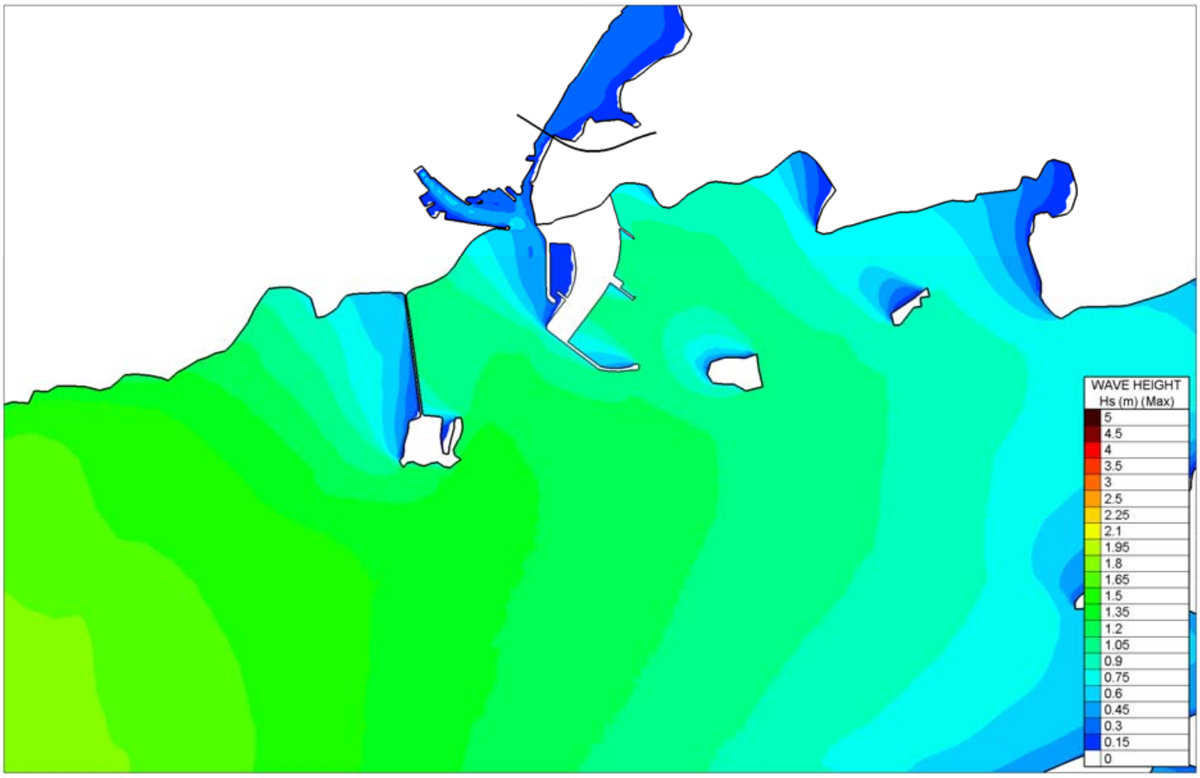

Figure 4.4.24 Computed Significant Wave heights for Local ESE Storm Winds - Proposed

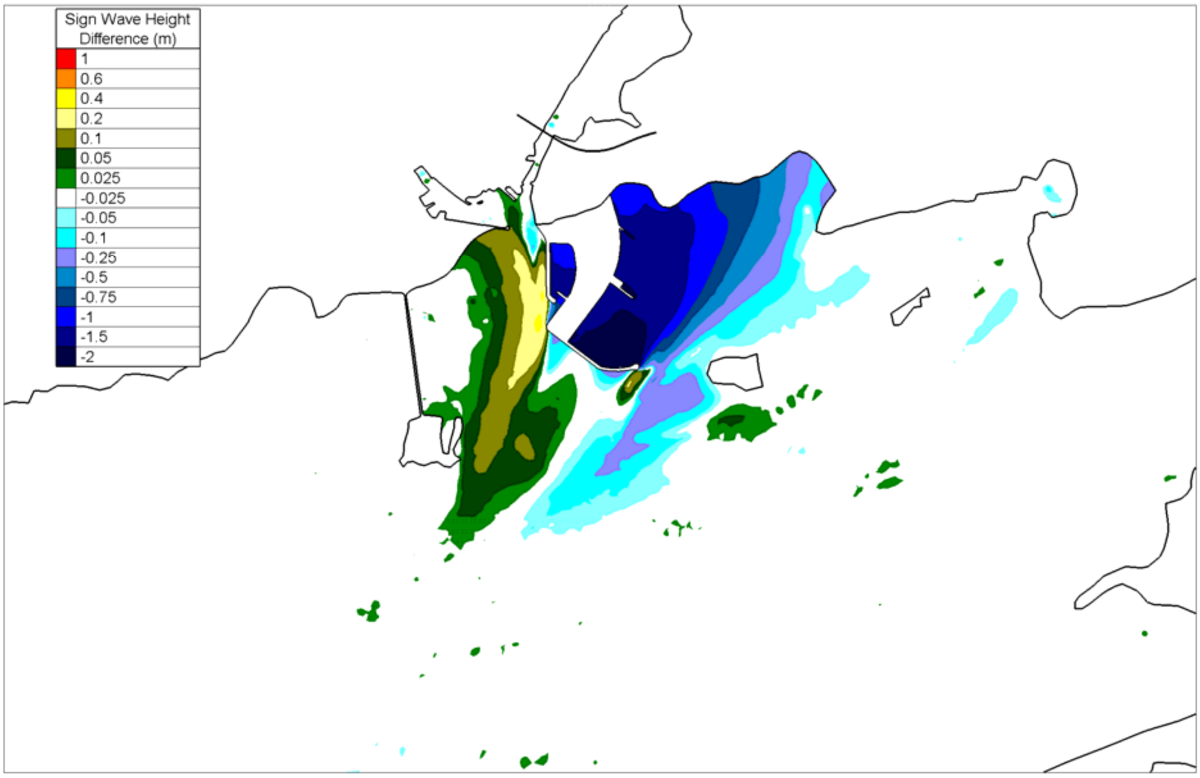

Figure 4.4.25 Difference Plot between Existing and Proposed Significant Wave heights for Atlantic Storm and West Storm Winds

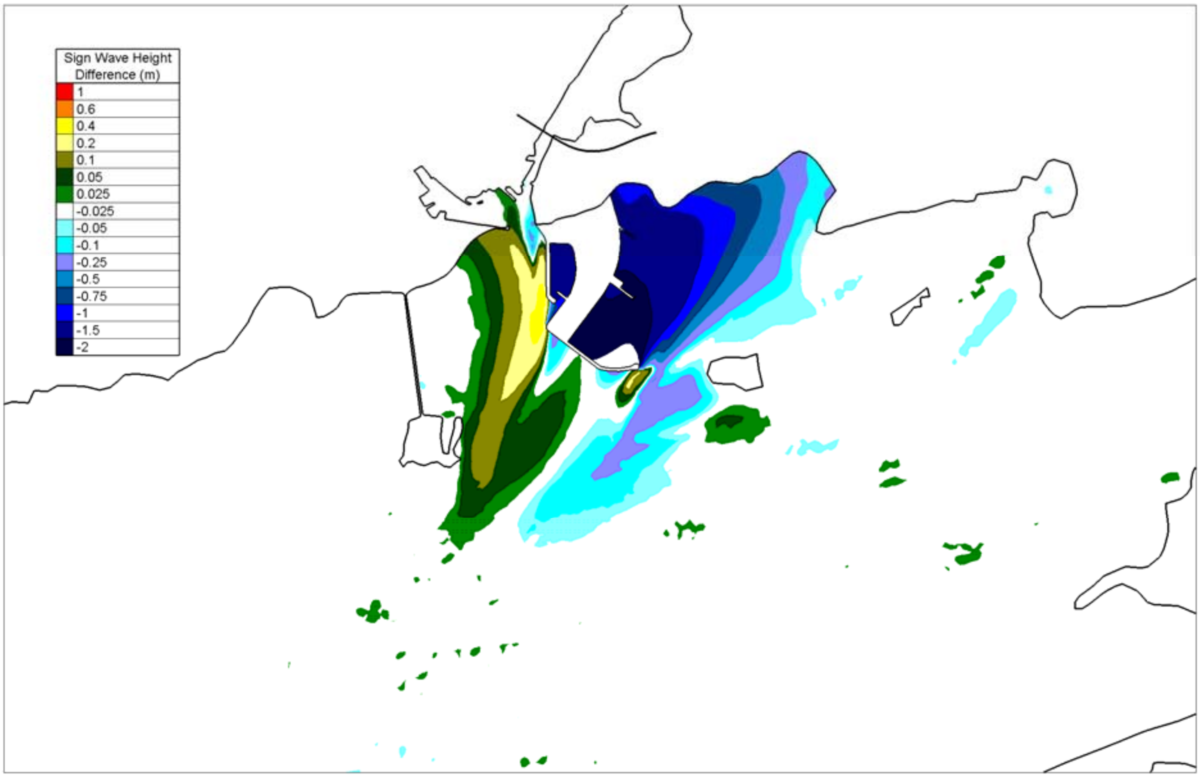

Figure 4.4.26 Difference Plot between Existing and Proposed Significant Wave heights for Atlantic Storm and WSW Storm Winds

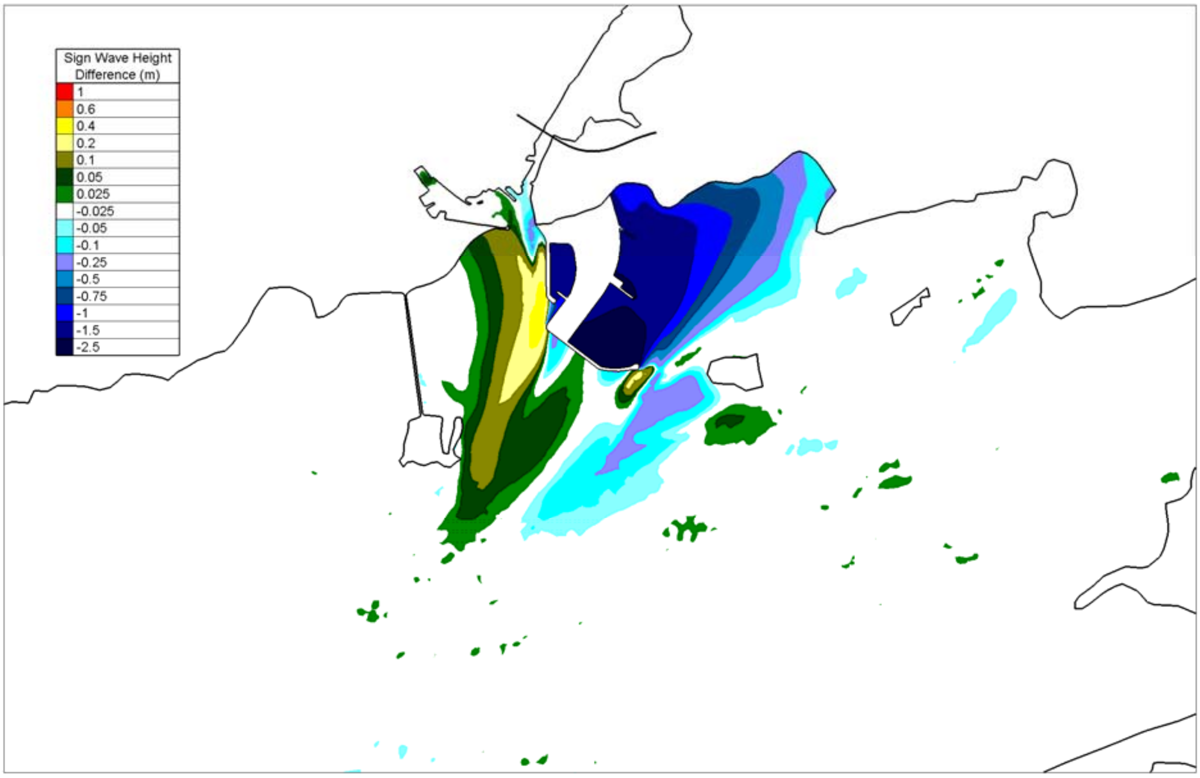

Figure 4.4.27 Difference Plot between Existing and Proposed Significant Wave heights for Atlantic Storm and SW Storm Winds

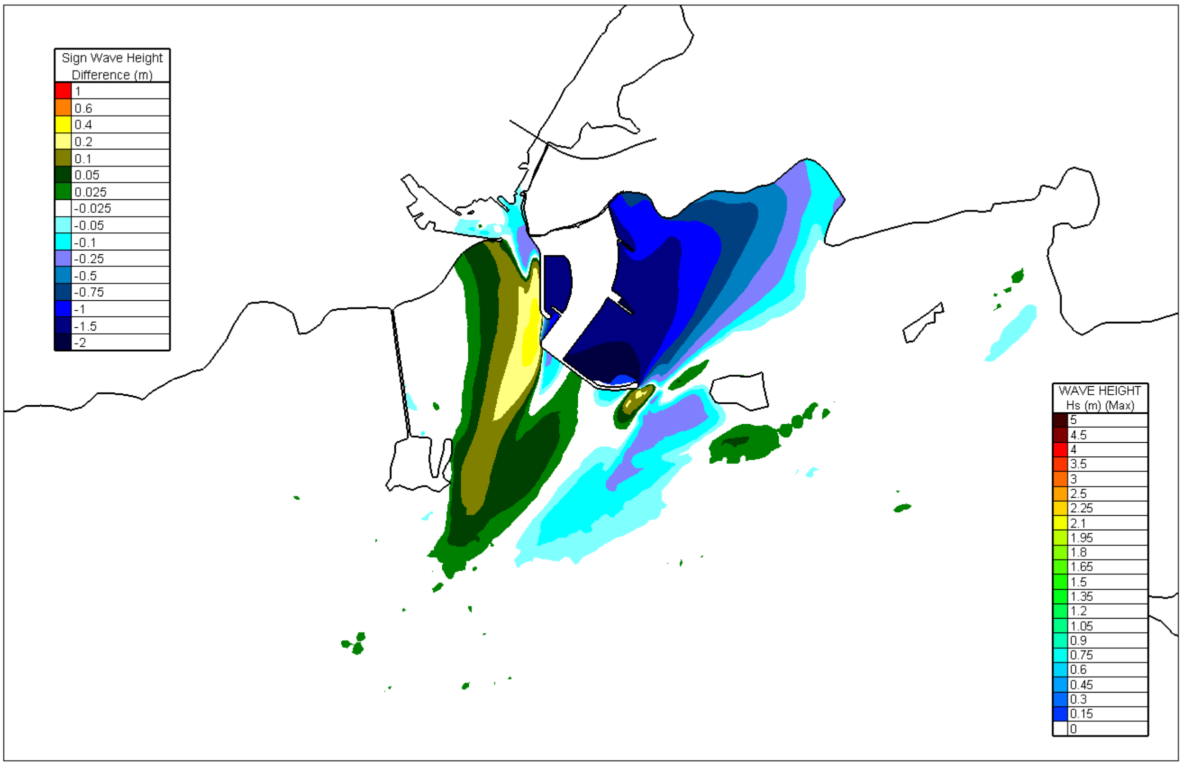

Figure 4.4.28 Difference Plot between Existing and Proposed Significant Wave heights for Atlantic Storm and SSW Storm Winds

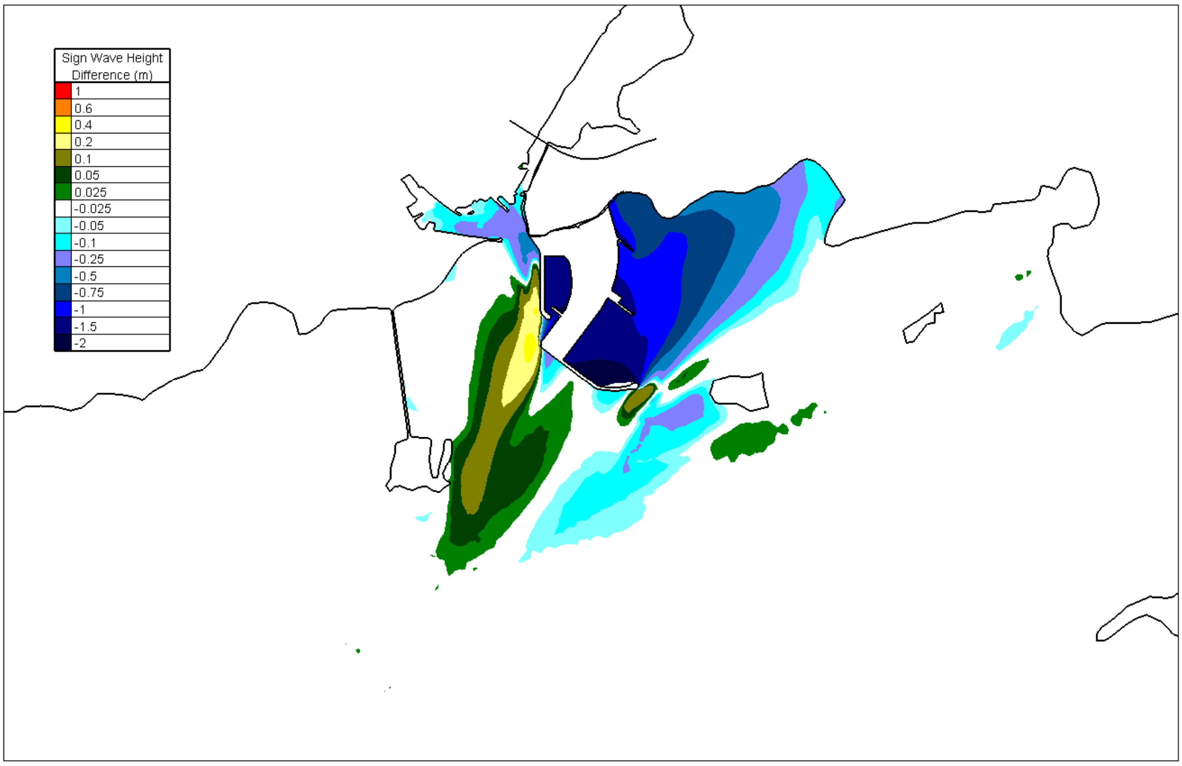

Figure 4.4.29 Difference Plot between Existing and Proposed Significant Wave heights for Atlantic Storm and South Storm Winds

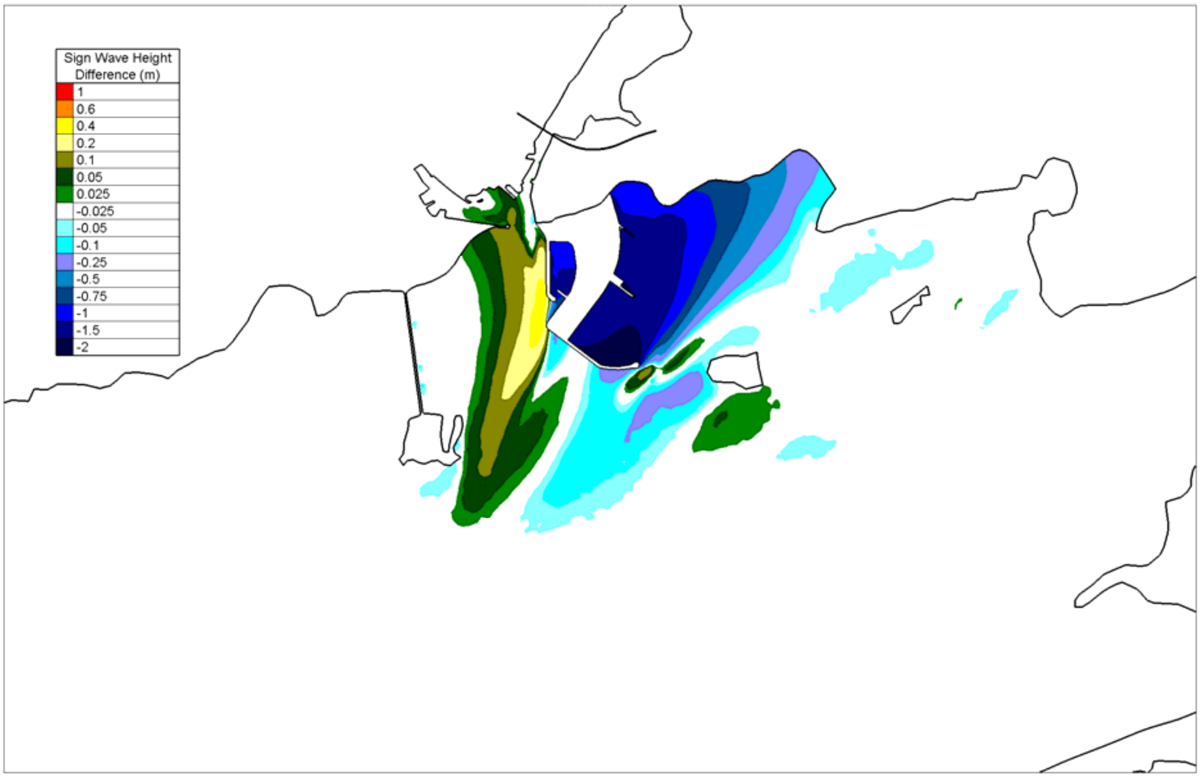

Figure 4.4.30 Difference Plot between Existing and Proposed Significant Wave heights for Local WSW Storm Winds

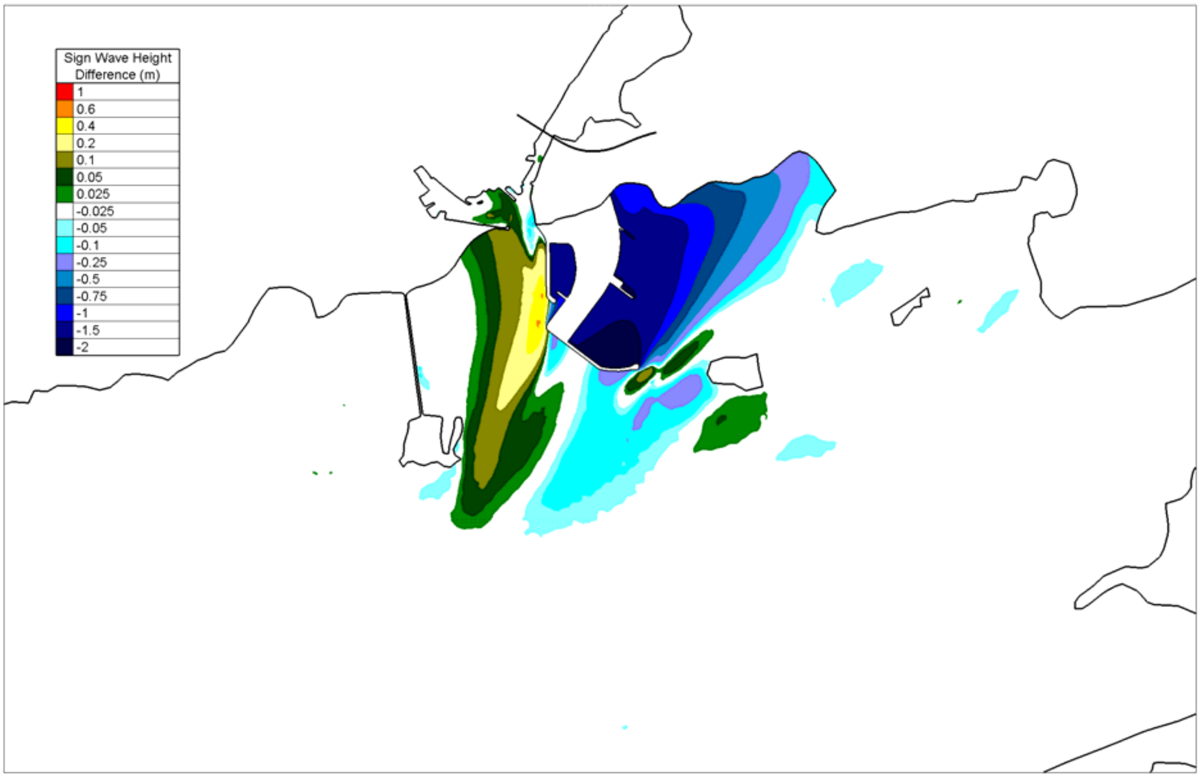

Figure 4.4.31 Difference Plot between Existing and Proposed Significant Wave heights for Local SW Storm Winds

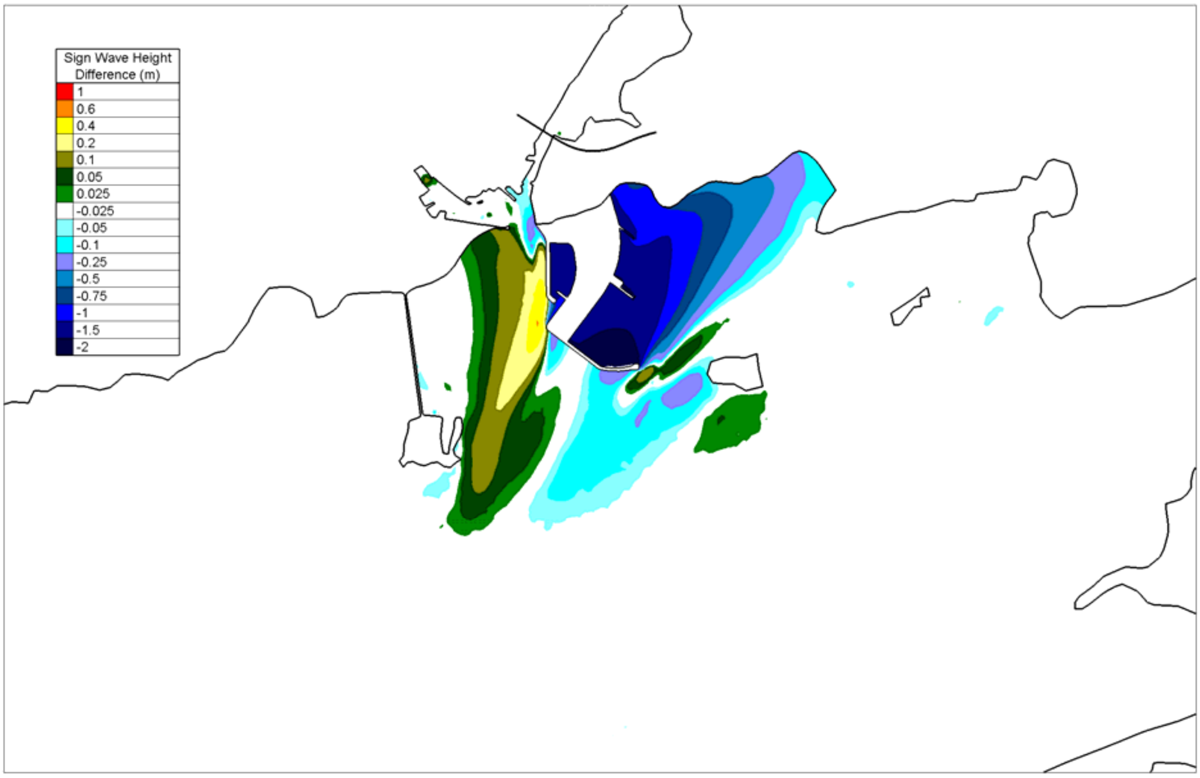

Figure 4.4.32 Difference Plot between Existing and Proposed Significant Wave heights for Local SSW Storm Winds

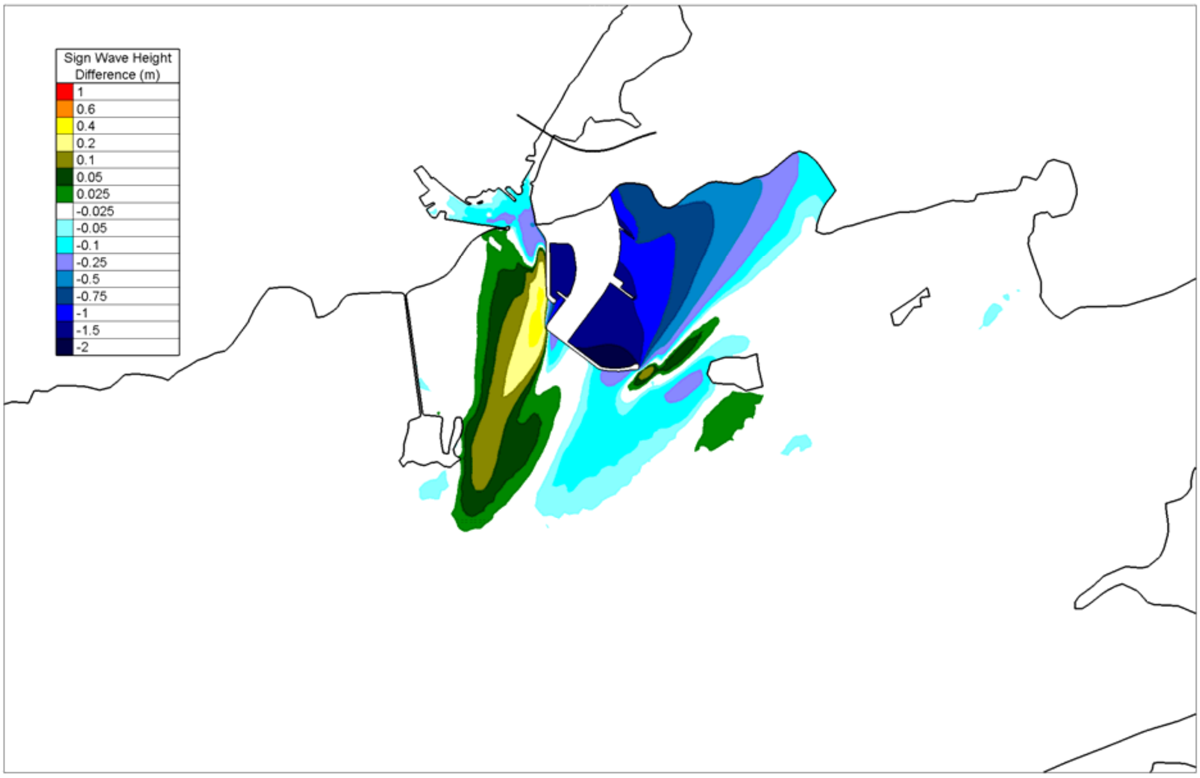

Figure 4.4.33 Difference Plot between Existing and Proposed Significant Wave heights for Local South Storm Winds

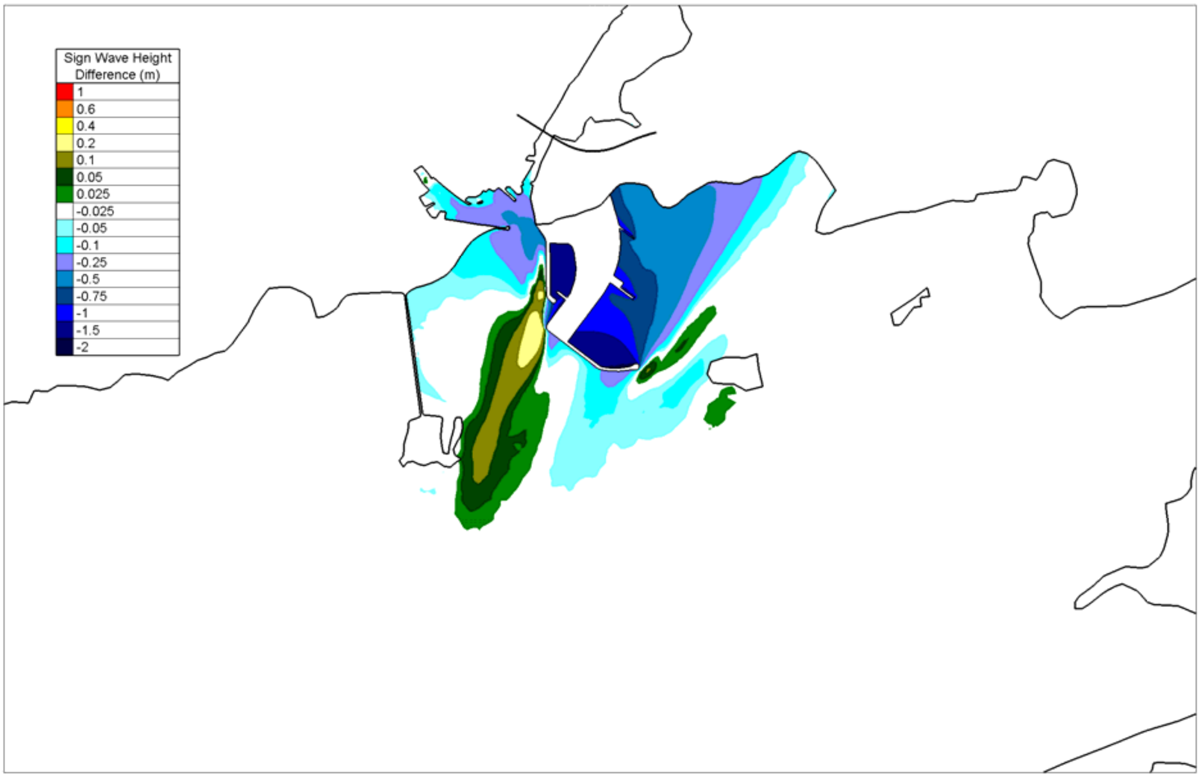

Figure 4.4.34 Difference Plot between Existing and Proposed Significant Wave heights for Local SSE Storm Winds

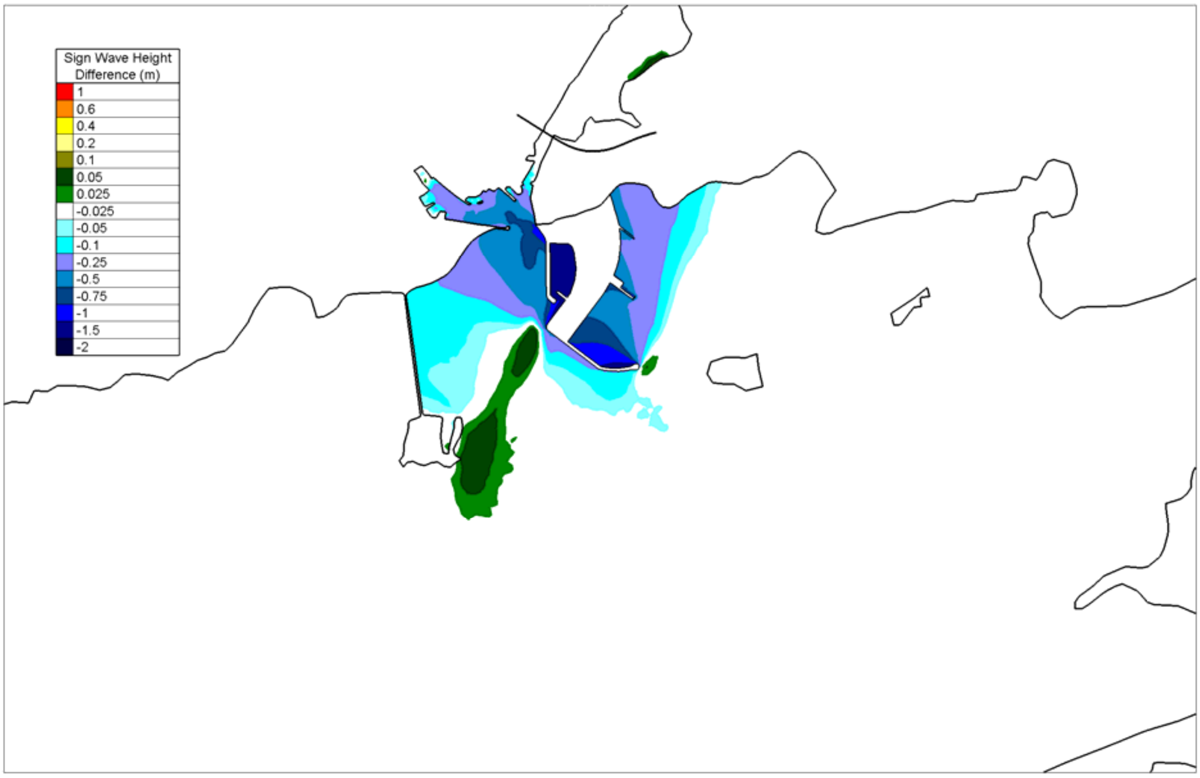

Figure 4.4.35 Difference Plot between Existing and Proposed Significant Wave heights for Local SSE Storm Winds

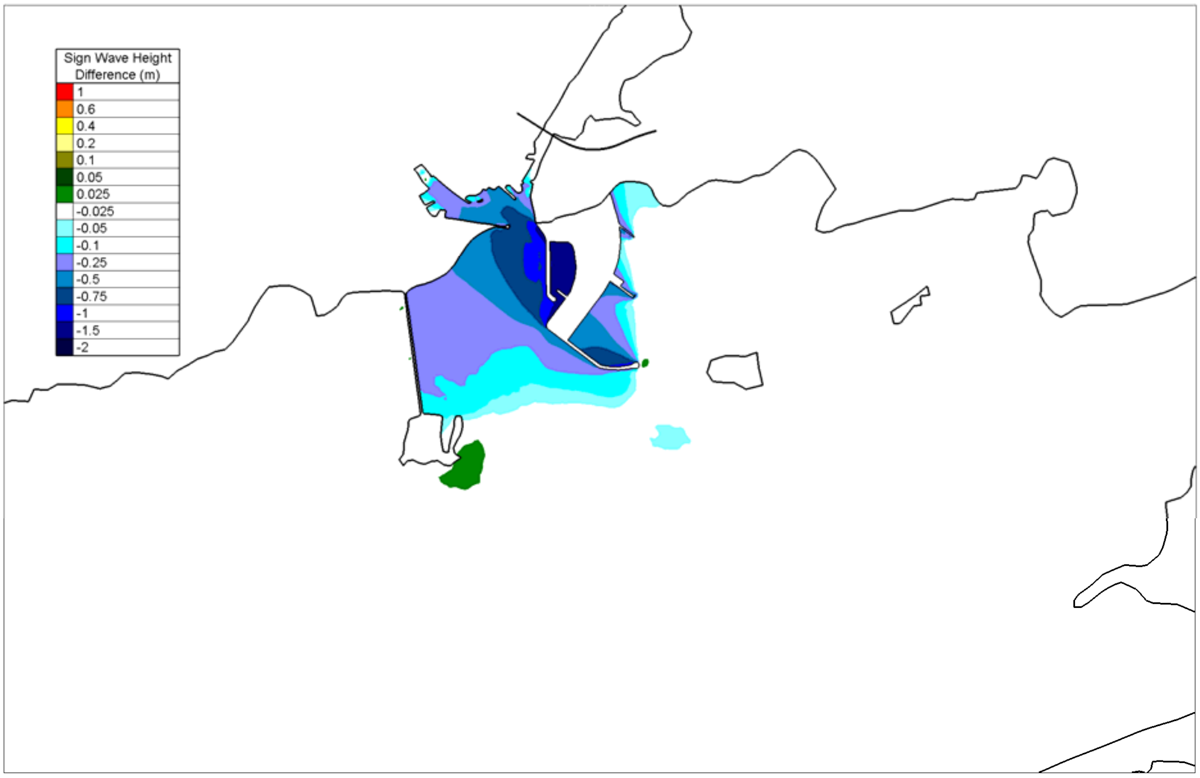

Figure 4.4.36 Difference Plot between Existing and Proposed Significant Wave heights for Local ESE Storm Winds

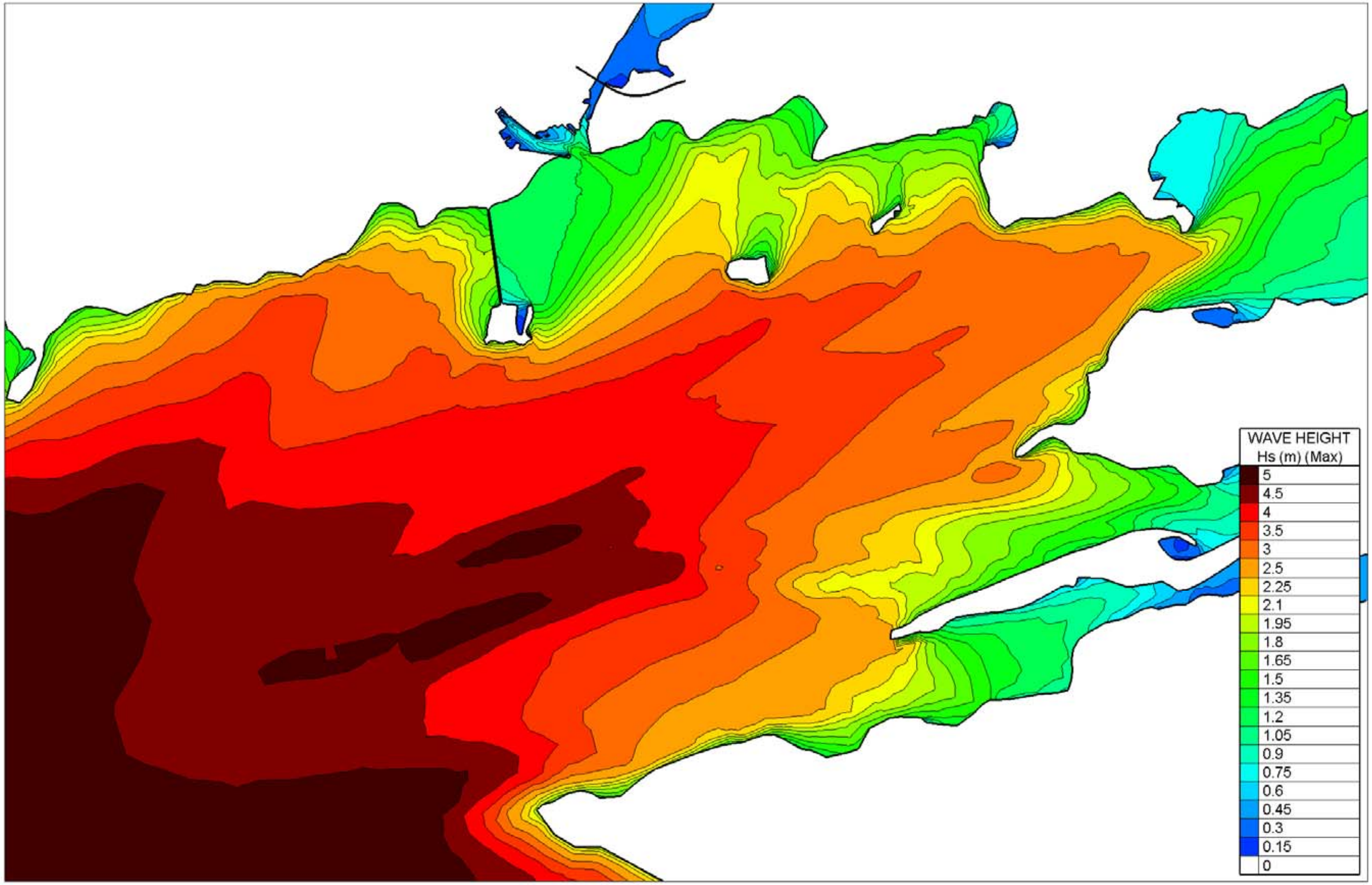

Figure 4.4.37 Computed Maximum Significant Wave Heights – Existing Case (all on shore directions W to ESE combined local and Atlantic storm swell wave climate runs)

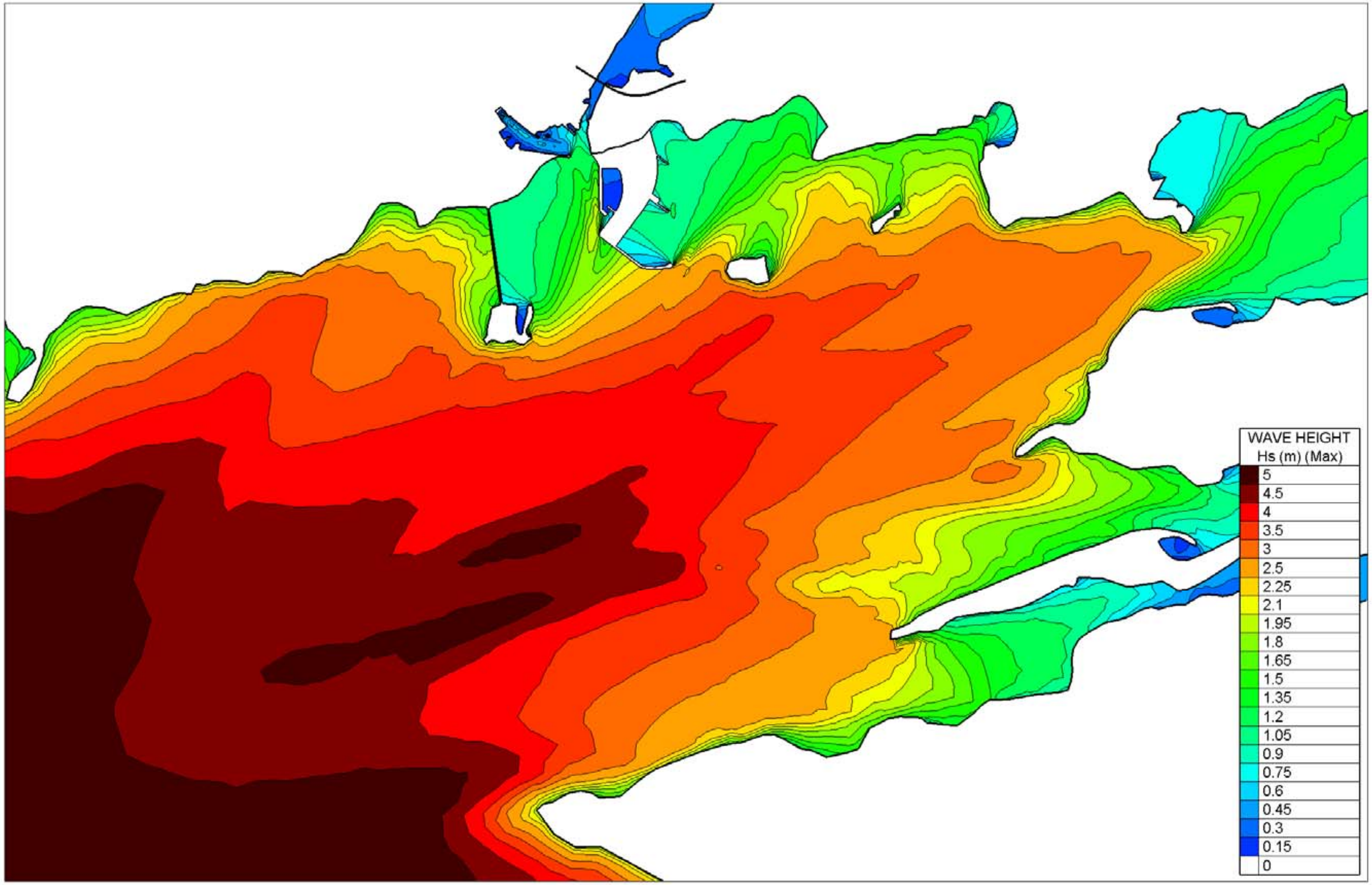

Figure 4.4.38 Computed Maximum Significant Wave Heights – Proposed Harbour Case (all on shore directions W to ESE combined local and Atlantic storm swell wave climate runs)

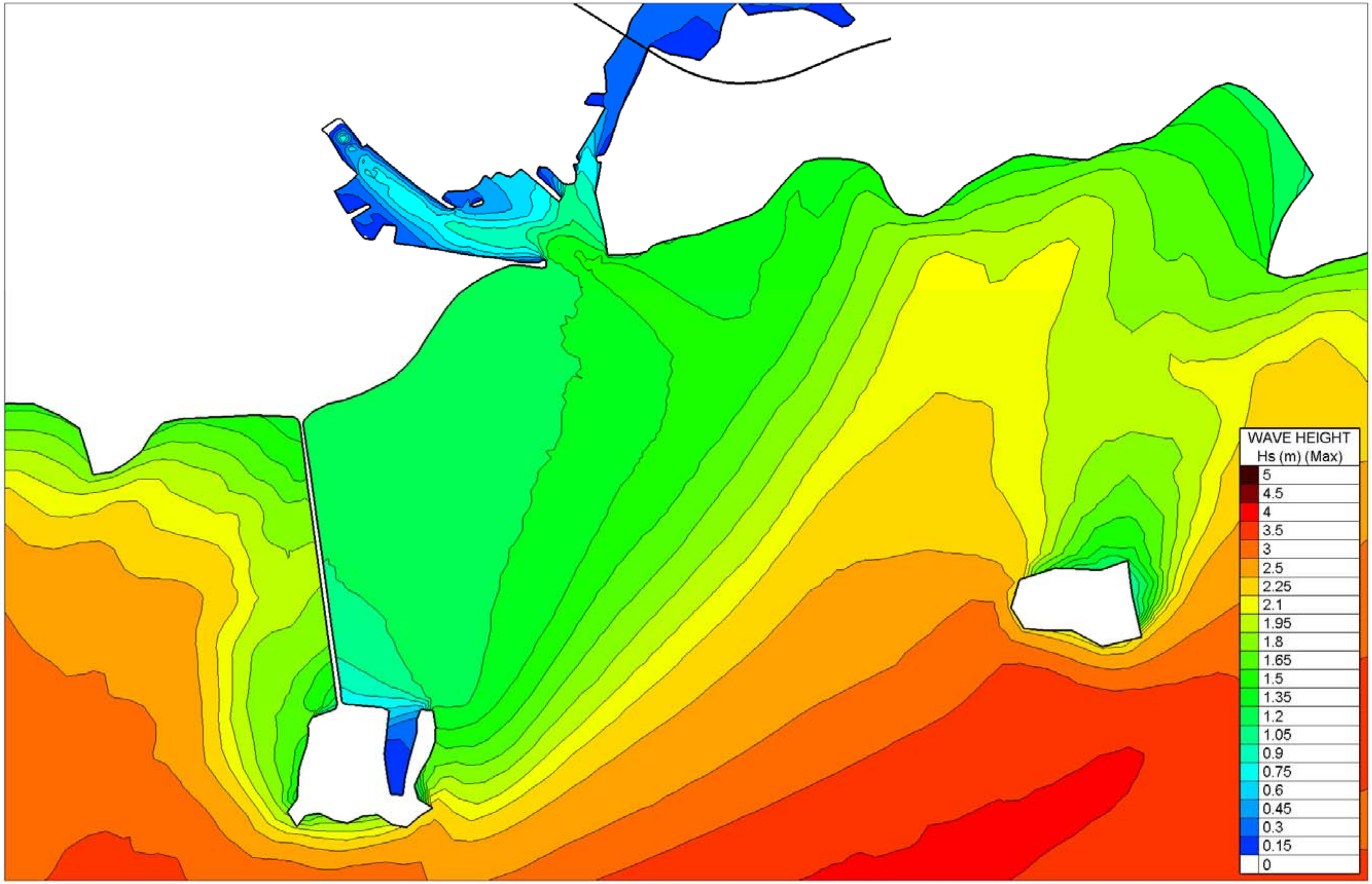

Figure 4.4.39 Computed Maximum Significant Wave Heights – Existing Case (all on shore directions W to ESE) – Harbour Area (Close up of Fig 4.4.37).

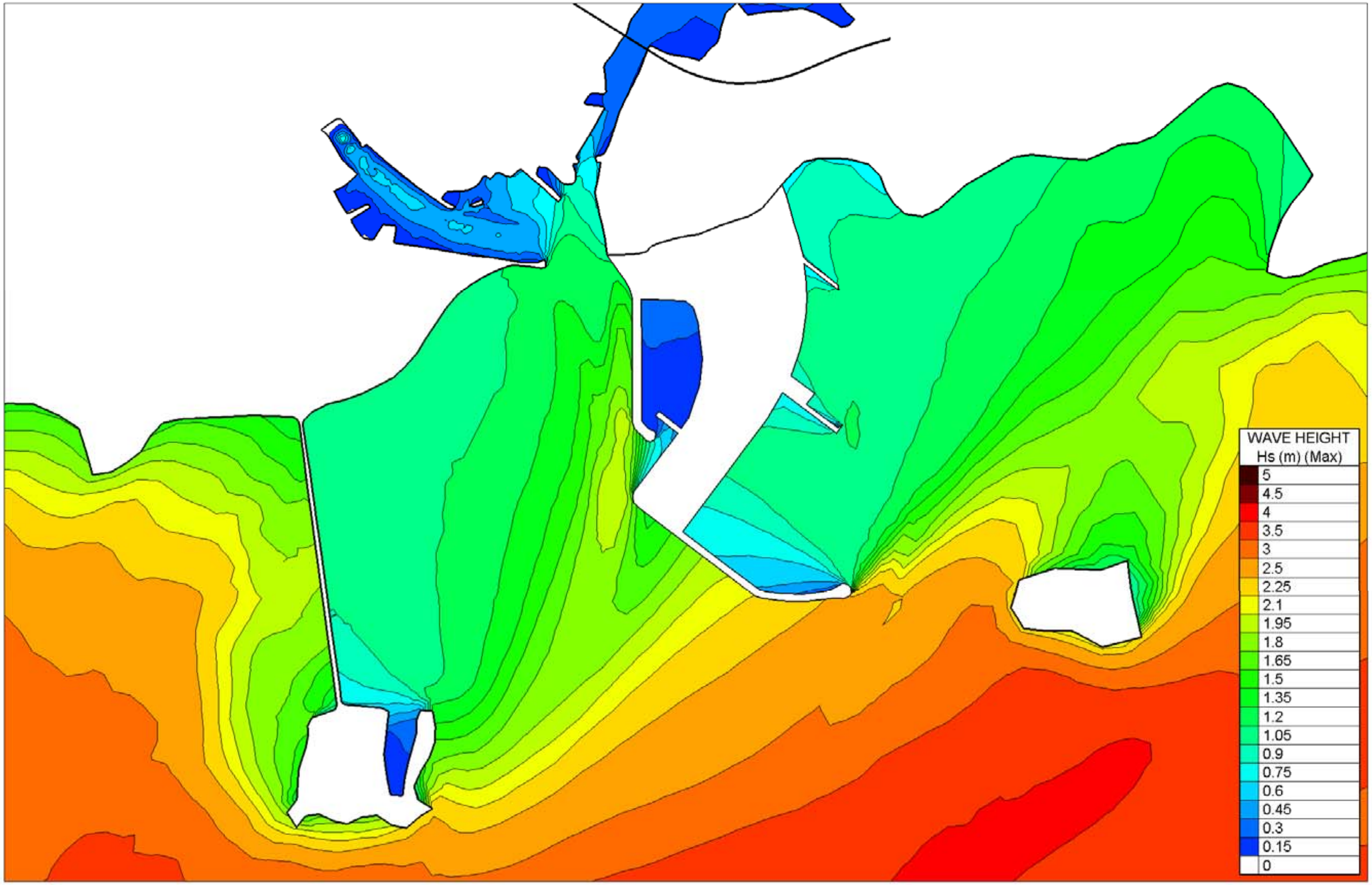

Figure 4.4.40 Computed Maximum Significant Wave Heights – Proposed Case (all on shore directions W to ESE) – Harbour Area (Close up of Fig 4.4.38).

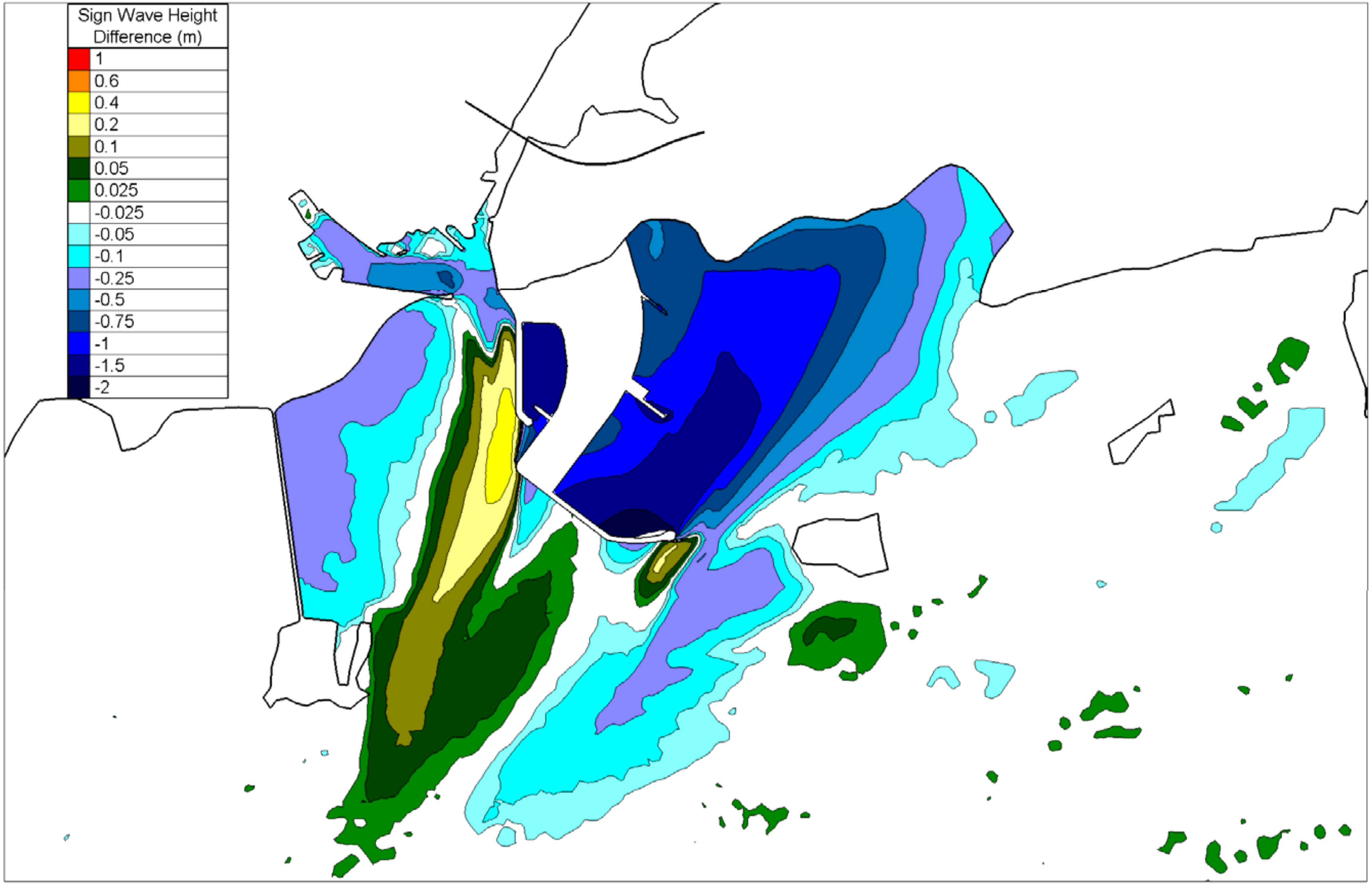

Figure 4.4.41 Difference plot of maximum predicted Wave heights existing and Proposed Wave climate for all onshore directions (West to ESE)

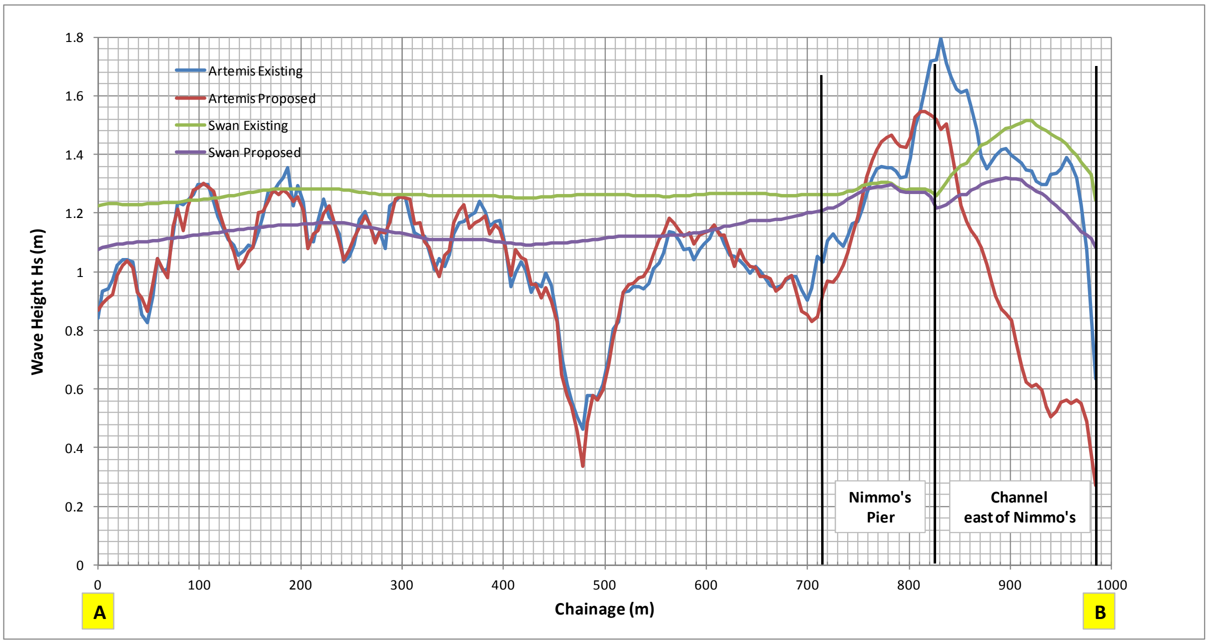

Figure 4.4.42 Computed maximum wave heights for all onshore directions West to ESE along Section A-B (refer to Figure 4.43) showing the SWAN and ARTEMIS Wave Climate model results for Southpark Shoreline and Corrib Entrance.

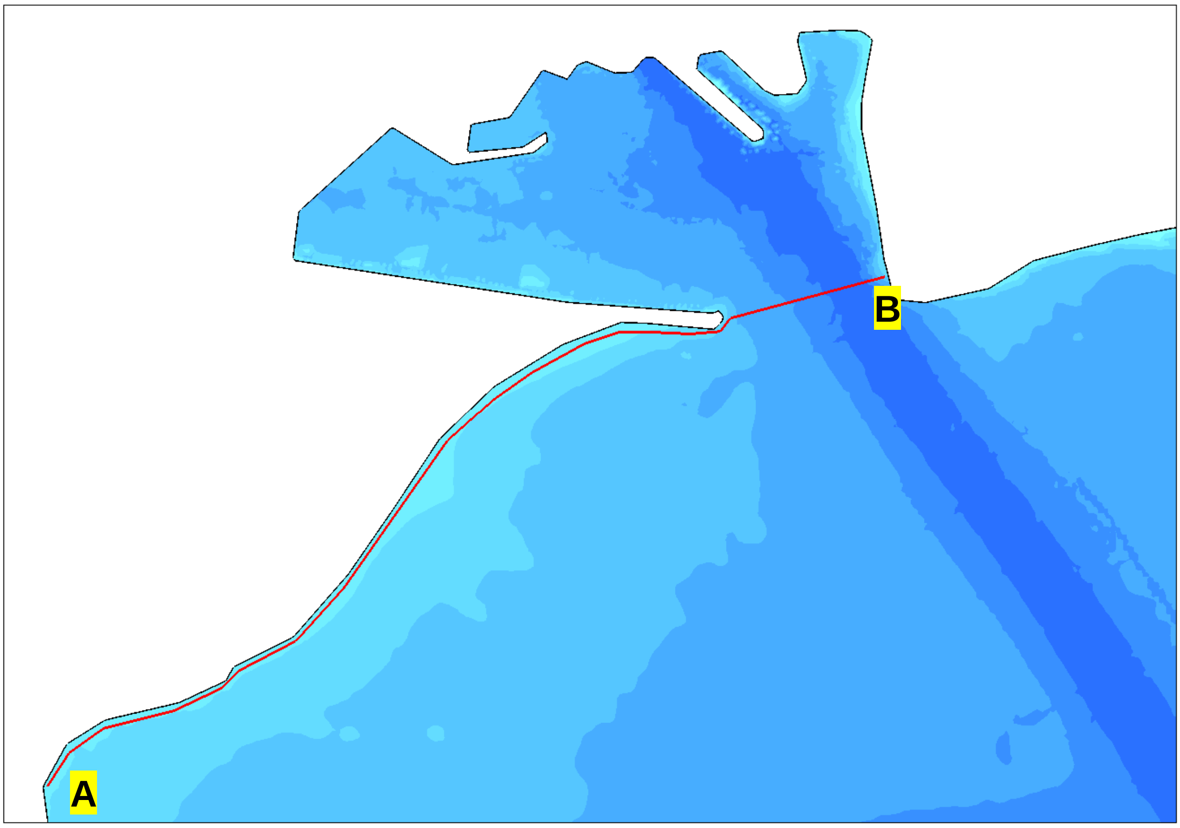

Figure 4.4.43 Shoreline Section A-B along Southpark, Nimmo's Pier and entrance to GalwayDocks / Claddagh Basin.

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Appendices to NIS Addendum / Errata

Appendix No. 5 – Wind Waves and Coastal Areas

4.5 COASTAL AREAS LIKELY TO BE AFFECTED BY WIND WAVES

Query:

Will the wind waves approach the breaking point and under such a scenario could the radiation stresses increase the wave level further inland, thus creating the risk of flooding in coastal areas and if so which coastal areas are particularly at risk?

Response:

4.5.1 Introduction

The only inland tidal / estuarine areas that potentially could be affected by the proposed development and generation of radiation stresses of breaking waves is between the Mutton Island Causeway and the Harbour Development which includes the Southpark Shoreline, the Claddagh Basin including the Docks and Lough Atalia areas. To the east of the development the vulnerable area to wave set up is at Ballyloughaun Beach. In respect to Ballyloughaun Beach the wave climate study shows generally a reduction in wave exposure for this beach and shoreline area and thus not adversely affected by the proposed development in respect to wave climate and wave set up due to breaking waves in the Surf Zone. To the west of Mutton Island there are no predicted changes to the tidal circulation and wave climate along the Grattan and Salthill promenade vulnerable shoreline areas and consequently they are not considered in respect to the influence of high radiation stresses on increased mean water level and the impact of the development on same.

Therefore the focus is on the potential effect of radiation stresses and such changes to water level in the sheltered waters within the Claddagh Basin and the near shore waters along the Southpark shoreline.

The Claddagh Basin has quay walls which allow the tide water to reach at least 3.3 to 3.5m O.D. before overtopping on to the roadways.

The Galway Docks area is gated but vulnerable to flooding and wave action and Lough Atalia is liable to inundate properties towards its northern end only from local wind generated waves on the Lough itself and not affected by downstream changes to Wave climate at the Harbour development.

The above listed areas are only at risk towards high water during a large storm surge event. The predicted maximum waves in this area immediately south of the Corrib entrance are of the order of 1.2 to 1.6m in height of varying wave period from 4 to 8seconds. The geometry of the foreshore area does not represent a shoaling beach and given the relatively low wave amplitude predicted there will not break until almost on land where a large portion of wave force will be absorbed on to land.

At much lower tidal stages there may be opportunity for some shoaling and breaking on the foreshore area giving rise to larger radiation stresses that could affect the upstream flow field and water levels, but such conditions apply to both the proposed development case and the existing case and at such tide levels are not critical to upstream flooding or flood risk in these vulnerable areas.

The Wave climate models allow for the calculation and output of the radiation force terms in the x and y direction (easting and northing direction) and the Telemac2d and 3D allow for the inclusion of such output in the hydraulic analysis. Radiation vectors in units of acceleration are presented in Figures 4.5.1 and 4.5.2 for a southerly storm wind waves approaching highwater with and without the proposed development. These plots show relatively low radiation force terms in the approaches to the Corrib entrance. A flood Simulation was run with the radiation force terms included and showed no discernible change in upstream flood level within the Claddagh Basin area. This was run for a 20m/s south Wind, a Storm Surge event producing a 3.5m OD highwater and Corrib 100year flood flow (refer to Figures 6.12 and 6.13 showing no discernible impact by the radiation stress terms on highwater elevation). Maximum water levels will therefore not increase as a consequence of additional wave breaking.

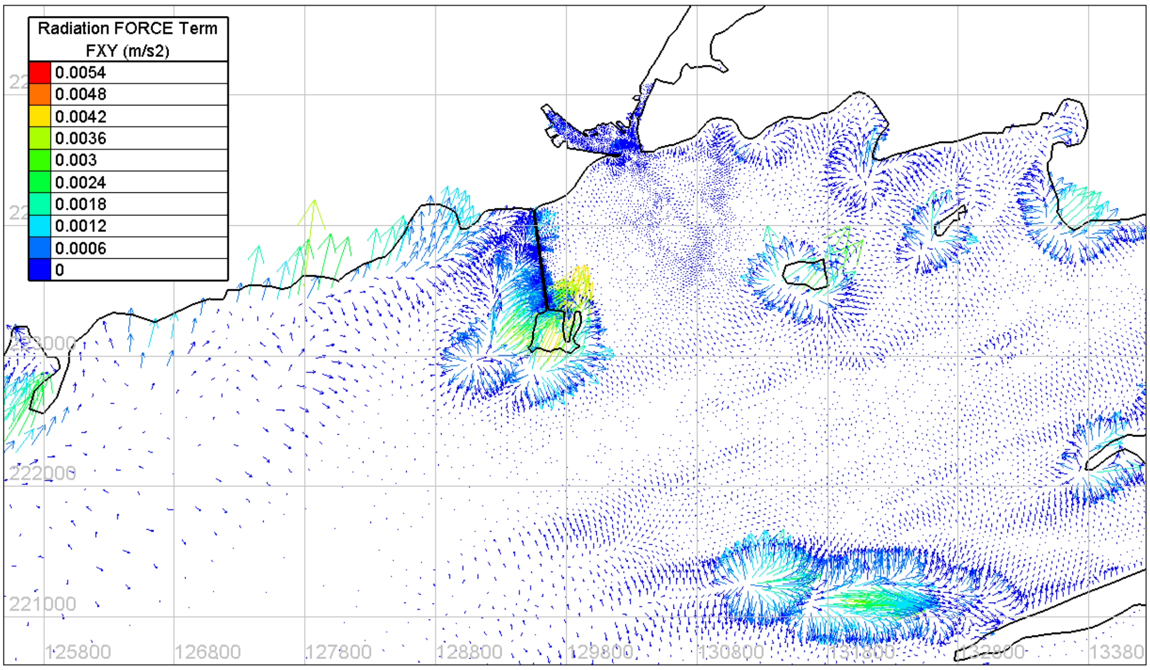

Figure 4.5.1 Radiation Force vector for existing Case

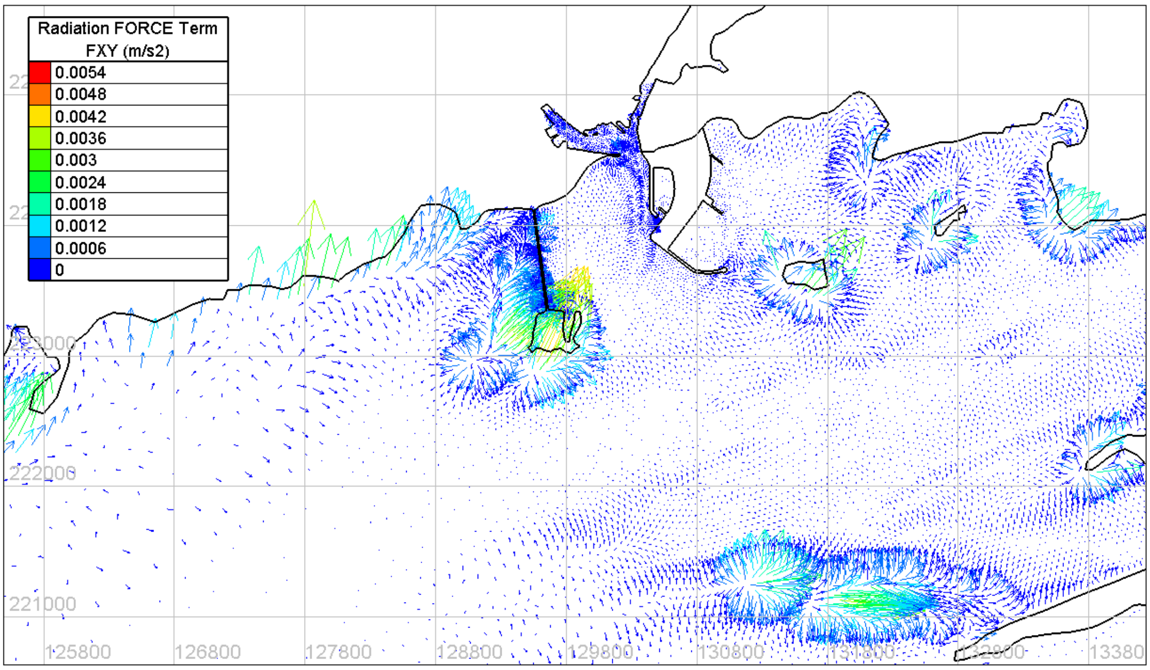

Figure 4.5.2 Radiation Force Vectors for Proposed Case

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Appendices to NIS Addendum / Errata

Appendix No. 3.3

Appendix No. 6 – Effects of Sea Bed Roughness

4.6 FLOW RESISTANCE:

Effects of Sea-Bed Roughness

Query:

As an input into the flow resistance modeling, details of the sea-bed roughness is required. Is the bed roughness kept constant in all runs, and how sensitive are the results regarding the choice of this value, say changing it by a factor of 10 and 100?

Response:

4.6.1 Background

In the Telemac hydrodynamic model the law of friction used to model bed roughness is the Manning Equation which is combined with the k-epsilon turbulence model. In the Telemac system other friction laws are available namely Haaland, Chezy, Stickler, Nikuradse, Colebrook-White and a frictionless option.

In the hydrodynamic modelling for the Galway Docks project the roughness coefficient was set at a constant Manning's n of 0.03 for the coastal area and a Manning's n of 0.035 within the slightly rougher Claddagh / Corrib Estuary and Lough Atalia inlet channels. A Manning's n of 0.035 for the Corrib channel agrees with typical values from literature and other studies for modelling river and estuarine reaches (Chow 1959, HEC etc.). Values of 0.02 to 0.04 are typical of the manning's bed roughness used in coastal modelling studies. It is common with coastal modelling studies to use a single composite Manning n value.

The shoreline sections of Galway Bay are quite variable in terms of roughness length with limestone rock outcrops, rock armoured groynes and breakwaters, stone and cobble shoreline areas and sandy and silty beds present. Such variability could merit the establishing of zones of different Manning's n values. The degree of variability is significant, subjective and difficult to measure and consequently a single value of n was applied to the coastal waters outside of the Corrib Entrance. The justification for a single value is that the hydrodynamics (velocities and depths) in the opensea are not very sensitive to the bed roughness given the generally large ratio between water depth and roughness length and the relatively low tidal velocities present in the bay. Outside of the shoreline area the study domain can be characterised as moderately deep coastal waters consisting of a silty sandy bed.

4.6.2 Roughness Sensitivity Testing

It is assumed that factors of 10 and 100 recommended for sensitivity testing of the roughness coefficient relate to the Nikuradse sand roughness length as opposed to the Manning's n, as such increases in Manning's n represent unrealistic roughness lengths particularly for the factor of 100 if applied directly. The relationship between Nikuradse roughness length and the Manning n can be approximated as follows:

$n = k_s^{1/6} / 25.4$ using the Chezy friction equation.

The roughness length k_s, using the Soulsby (1997) relationship can be related to the median grain diameter (d_{50}) as approximately $k_s = 2.5*d_{50}$ over flat homogenous beds.

	Sensitivity Factor		
Roughness coeff	1	10	100
n	0.020	0.030	0.043
ks (m)	0.018	0.18	1.8
d50 (m)	0.0072	0.072	0.72

Table 4.6.1 Soulsby Relationship between Manning n, Nikuradse sand Roughness and the median grain diameter size for the Sensitivity Test

For this R.F.I. comparison purposes additional hydrodynamic model runs were carried out for a 3.5m O.D. Tidal Surge highwater on a spring tidal range of 4.5m , 100year + Climate Change (CC) flood flow in the Corrib (549 Cumec) and calm wind conditions. Manning'n n of 0.02, 0.03 and 0.043 representing factors of 1, 10 and 100 for Nikuradse roughness scale (refer to Table 4.6.1 above) were specified in the model runs. The simulations were run over two complete tidal cycles and comparisons carried out. The previous runs had used the factor of 10.

For comparison purposes five observation reference locations were selected to demonstrate the sensitivity of computed tidal velocities and elevations to varying roughness factors. The reference locations are presented in Figure 4.6.1 and the times series plots for the five locations are presented in Figures 4.6.2 to 4.6.6 for water elevations and 4.6.7 to 4.6.11 for velocity magnitude and direction. These roughness sensitivity runs were carried out for the proposed development case.

4.6.3 Discussion

The impact of varying the roughness coefficient on tidal elevations at peak highwater levels is negligible in the open waters of Galway Bay (refer to sites 2 to 5 in Figures 4.6.3 to 4.6.6). Within the Claddagh Basin where the river is in full spate (100year Flood Flow including CC) the change in peak water level at highwater is relatively small at 0.13 m range over the three roughness values. As expected at low water periods a considerably larger difference in water level of 0.77m is predicted over the roughness range at the Claddagh basin site 1. This is due to the reduced depth of flow where the tidal influence has ebbed and the presence of high flow velocities giving rise to increase friction loss. It is important to point out where a difference occurs in water level within the Claddagh basin between the different roughness simulations, no discernible difference is predicted between the existing and proposed model runs for a given roughness, refer to Figure 4.6.12. In the open water the effect of the roughness coefficient (within the range tested) on the tidal curve is found to be negligible (at both high and low water).

At the 5 location sites the velocity and direction time series were generated for the three roughness values. As expected in the Claddagh reach the velocity magnitude varies significantly with roughness factor with the direction remaining almost unchanged due to the rectilinear nature of the flow. In the open sea some variation is present in respect to speed and direction and the most noticeable effect is on reducing the friction to lower value of 0.02 with the higher coefficient of 0.03 and 0.043 showing little difference at the higher roughness, refer to Figures 4.6.7 to 4.6.11.

Overall the effect of varying the roughness is not significant and less significant when used as a comparison tool between the proposed development flow field and the existing flow field.

In conclusion, the hydrodynamics within Inner Galway Bay are not overly sensitive (reasonably robust) to changes in roughness coefficient at the magnitudes tested. It is considered reasonable for the open coastal waters to vary the Manning's n from c. 0.02 to 0.04, above 0.04 the roughness becomes unrealistic even after accounting for storm wind wave effects through ripple formation on the bed roughness (refer to Section 7). The predicted water levels in the model including the estuarine flow area of the Claddagh Basin for highwater level are not very sensitive to the roughness coefficient as the depth of flow minimises the effect of friction. Velocity magnitude and direction are more sensitive to changes in Manning's n, particularly to reductions in the Manning n from 0.03 to 0.02, but the overall effect on the ambient flow field is not considered to be significant.

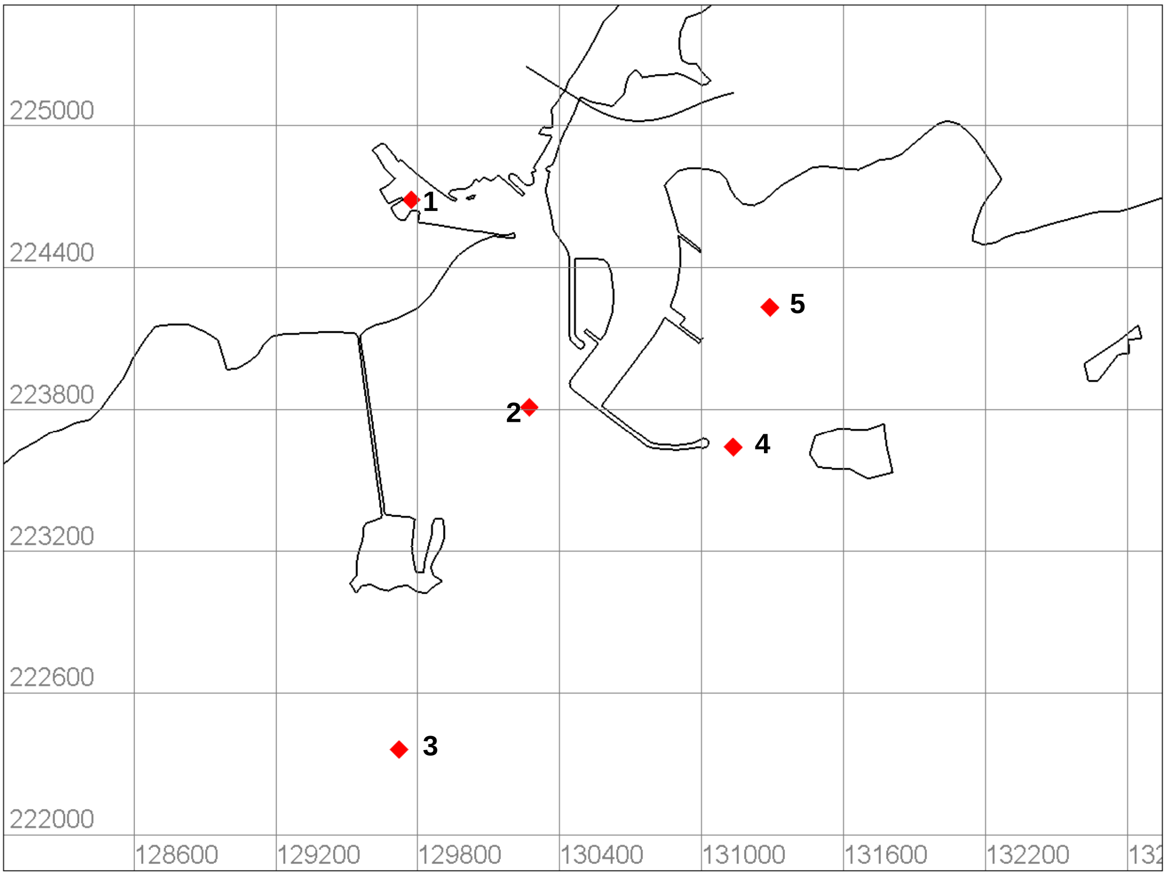


Figure 4.6.1 Location of reference points for roughness sensitivity

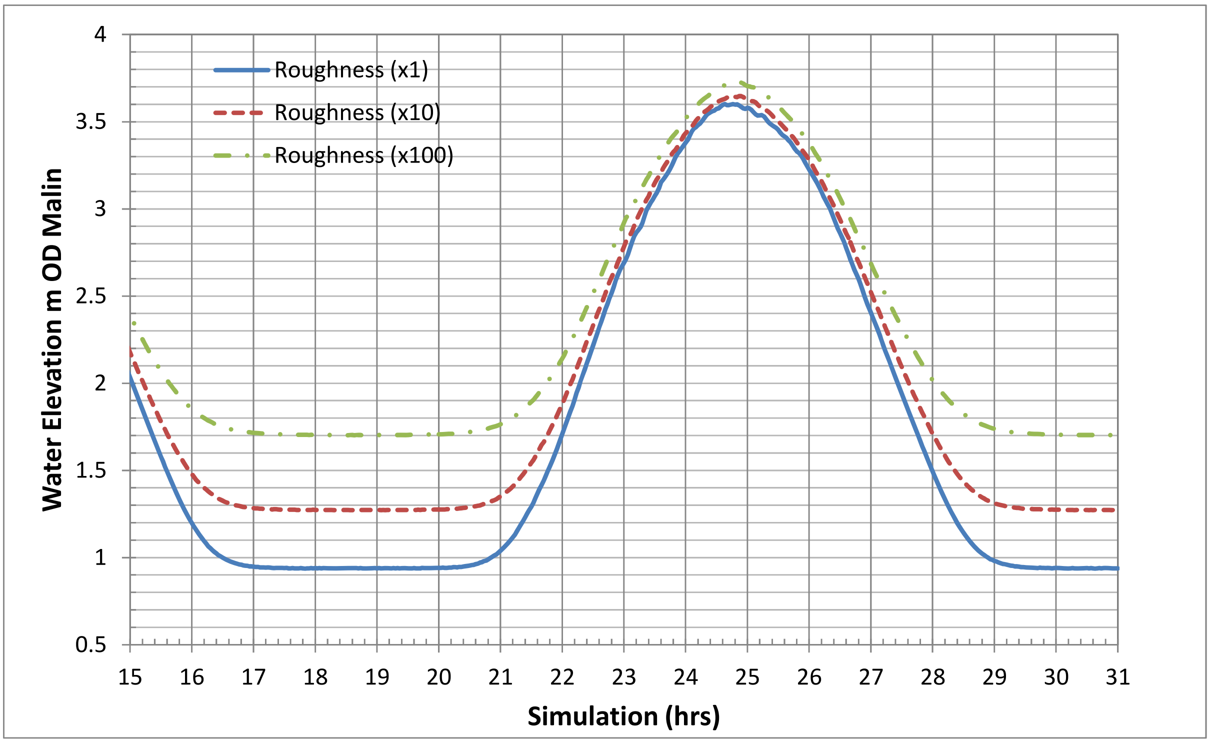


Figure 4.6.2 Sensitivity of elevation to Roughness factor at Site 1

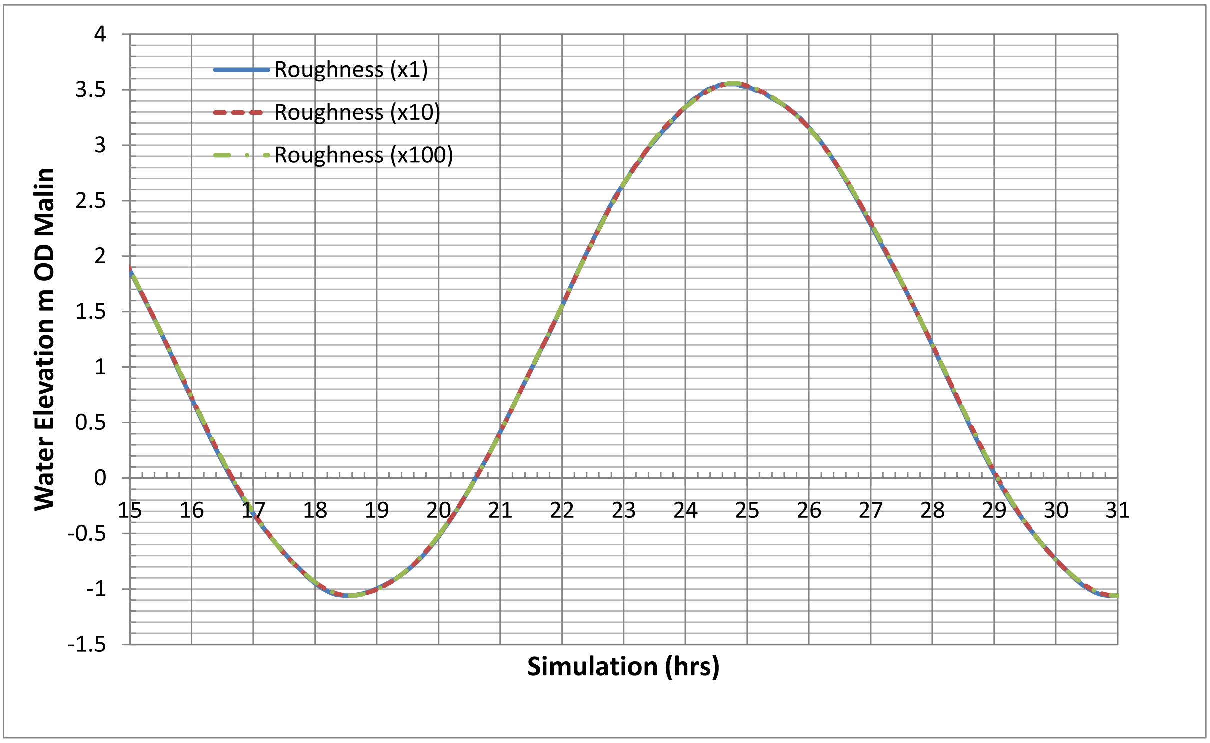


Figure 4.6.3 Sensitivity of elevation to Roughness factor at Site 2

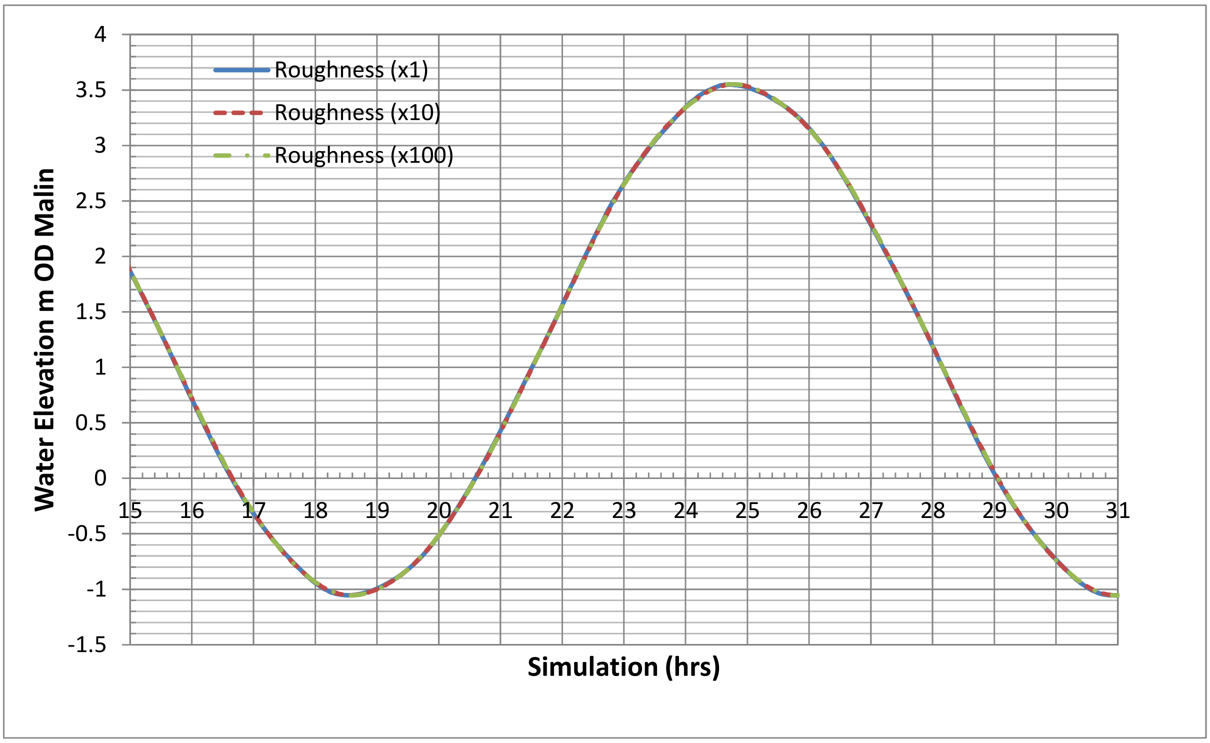


Figure 4.6.4 Sensitivity of elevation to Roughness factor at Site 3

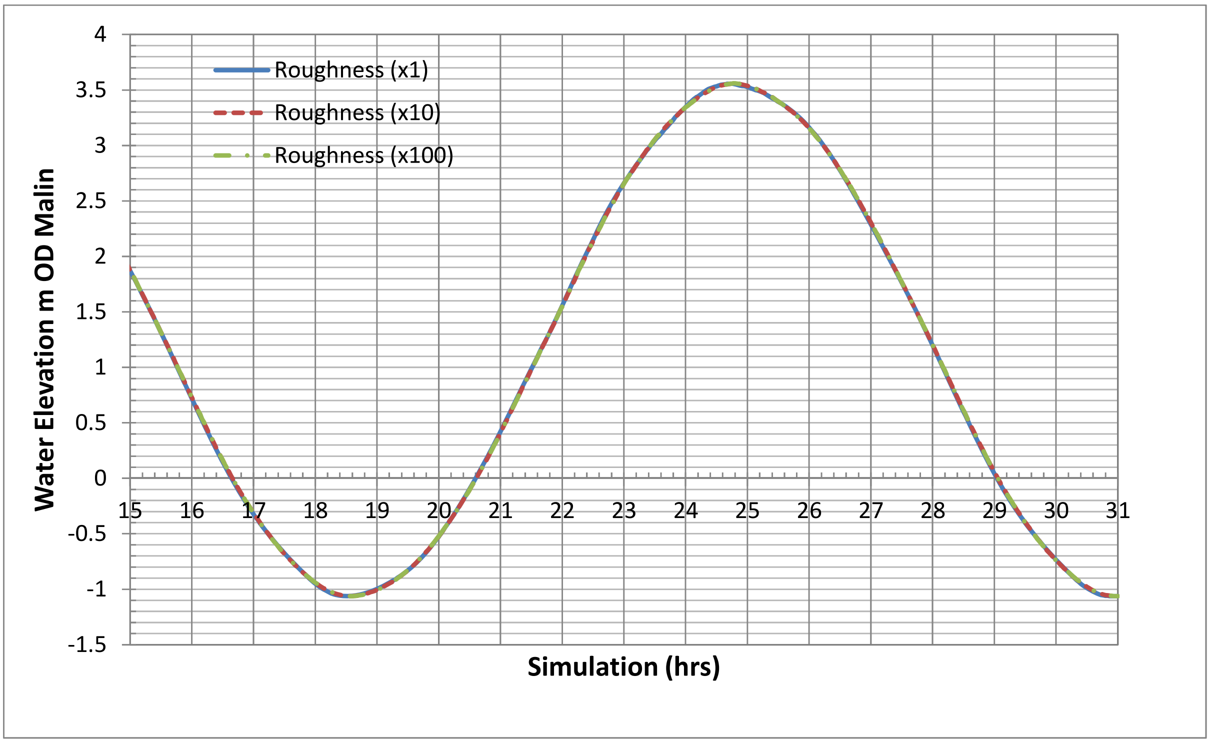


Figure 4.6.5 Sensitivity of elevation to Roughness factor at Site 4

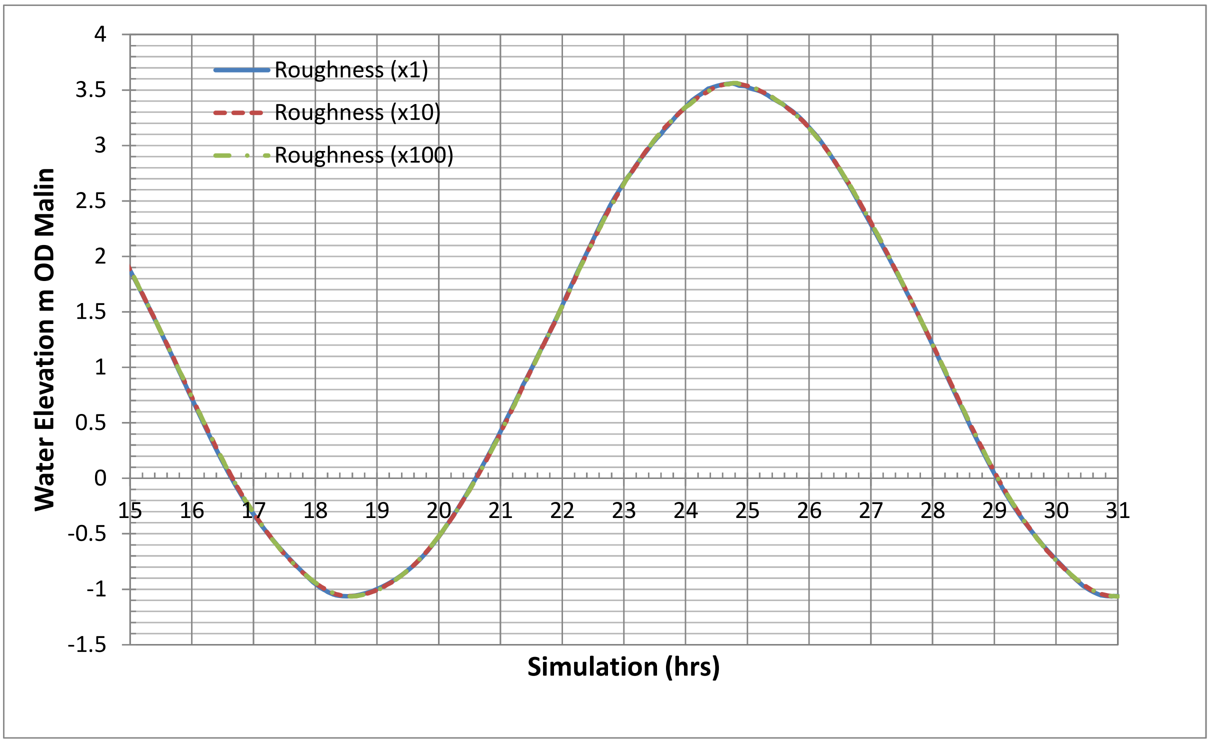


Figure 4.6.6 Sensitivity of elevation to Roughness factor at Site 5

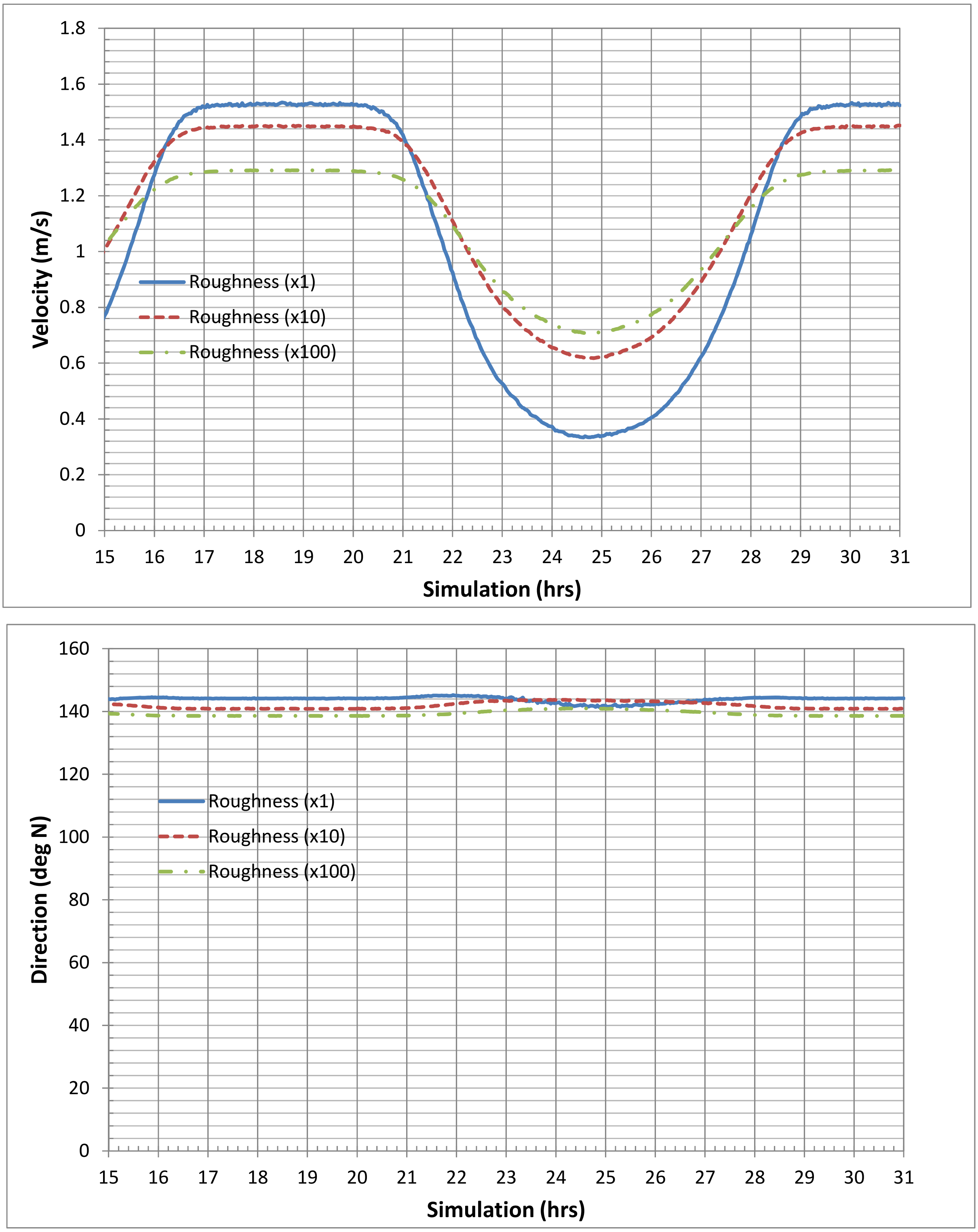


Figure 4.6.7 Sensitivity of Velocities to Roughness factor at Site 1

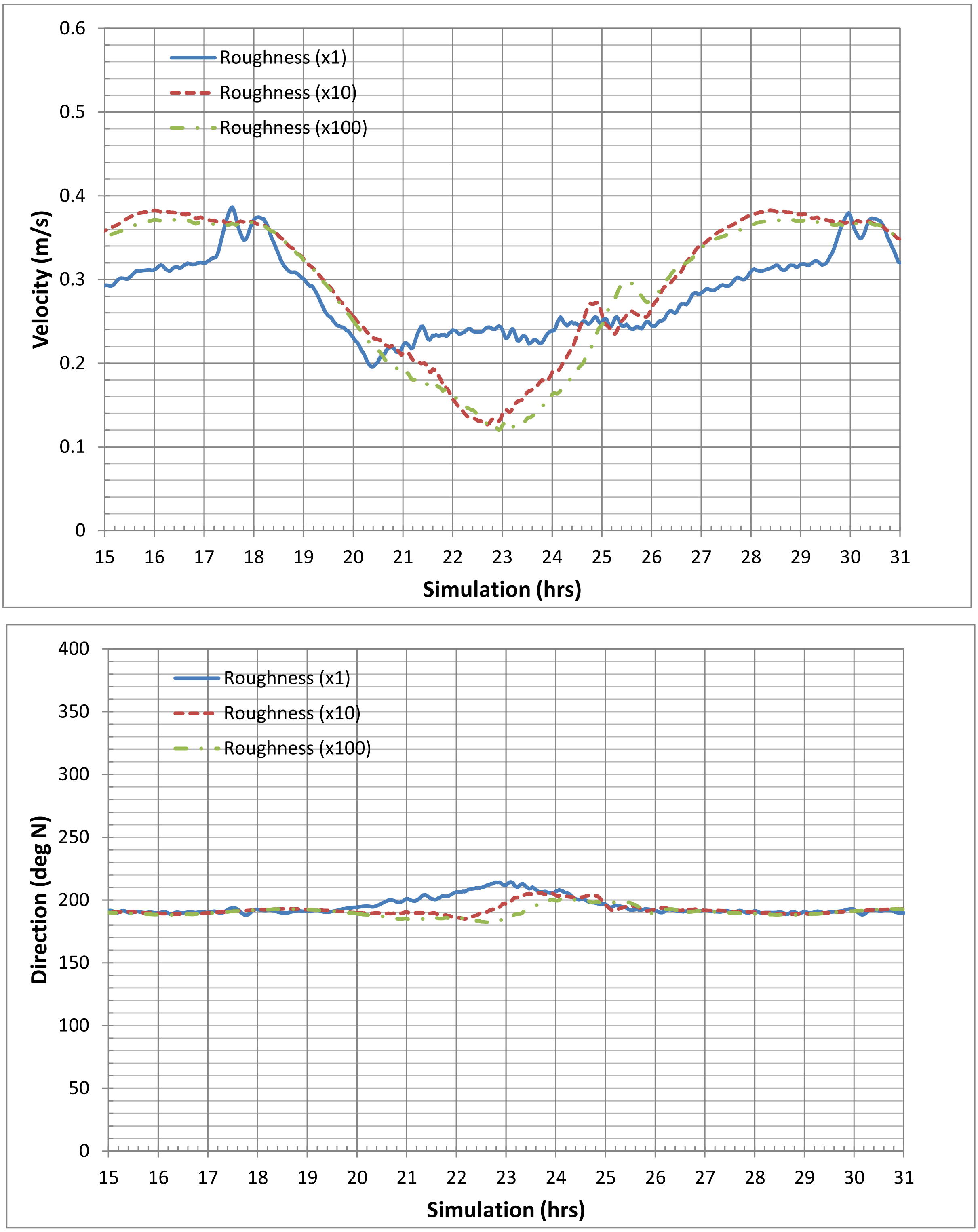


Figure 4.6.8 Sensitivity of Velocities to Roughness factor at Site 2

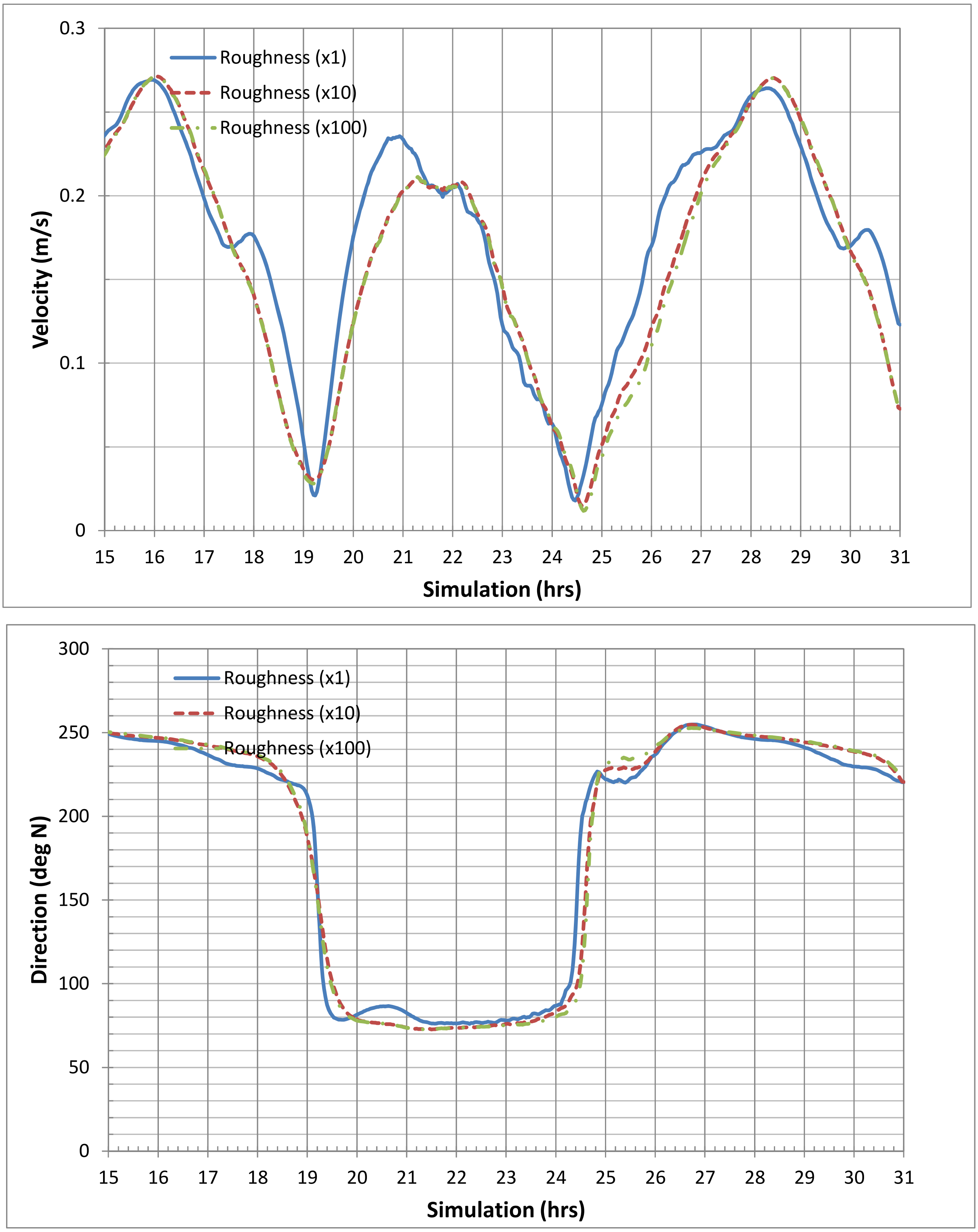
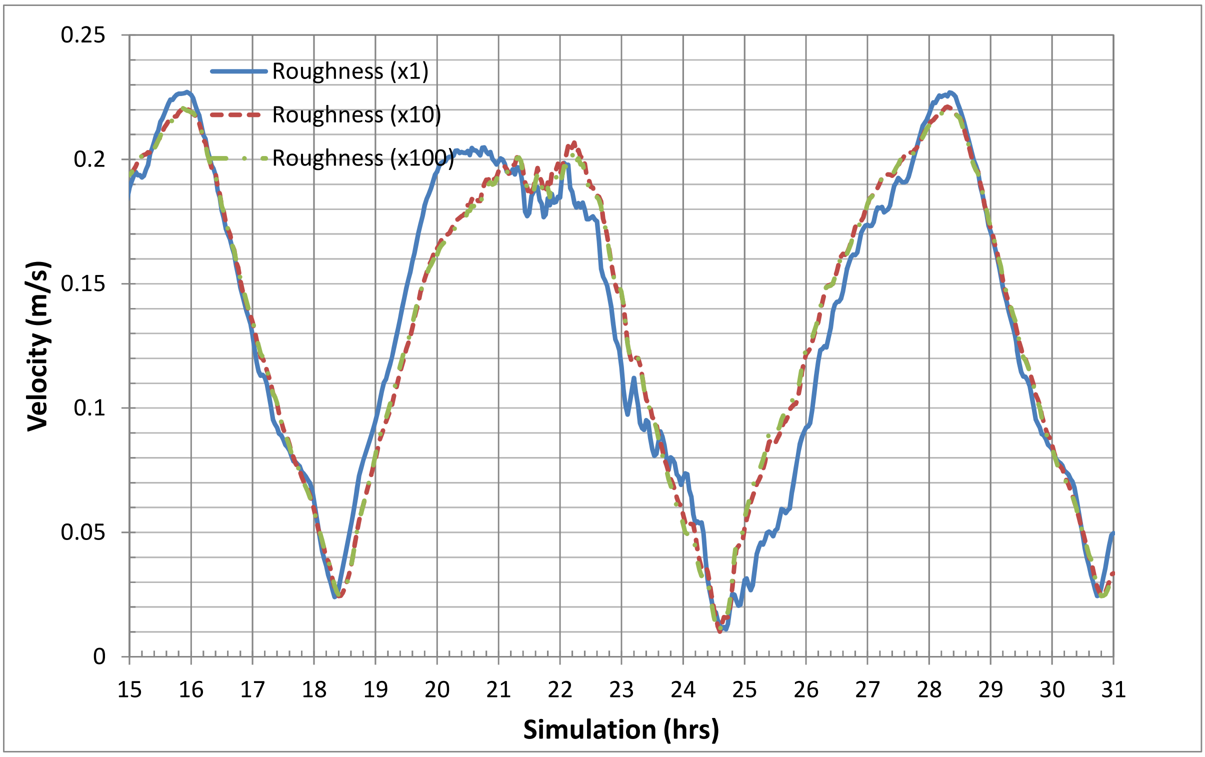


Figure 4.6.9 Sensitivity of Velocities to Roughness factor at Site 3



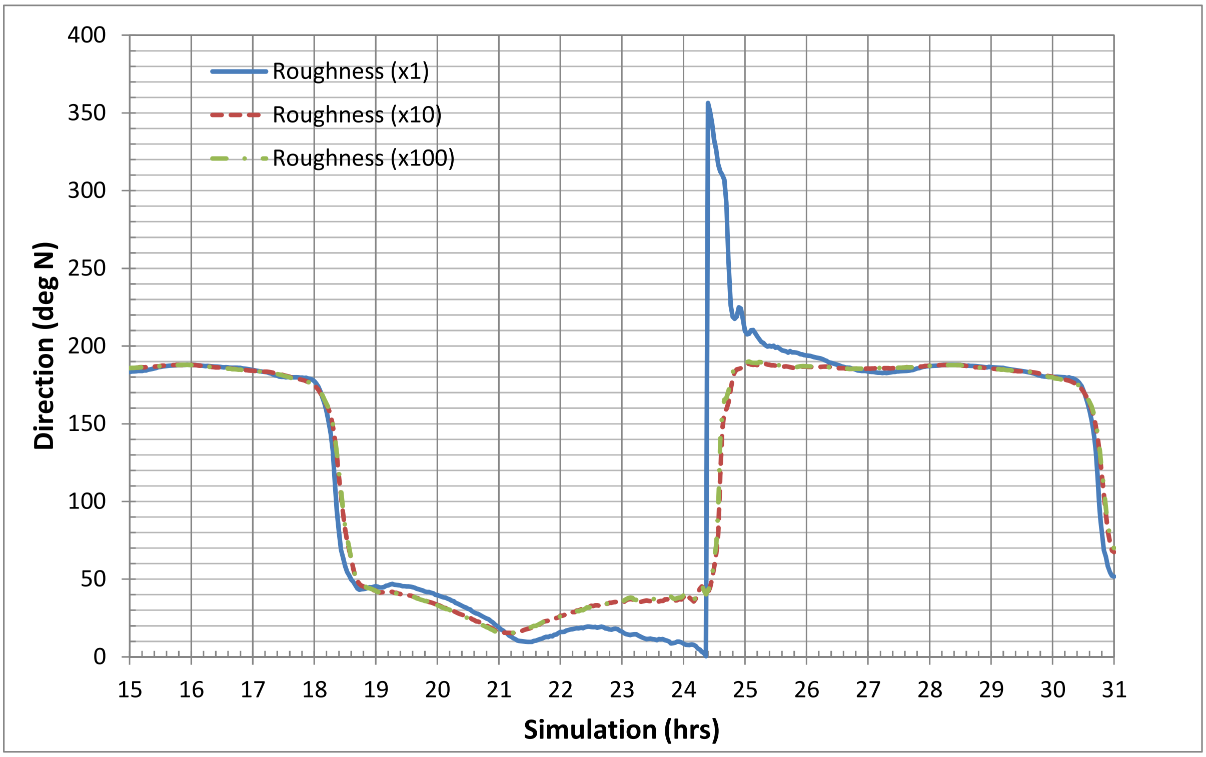
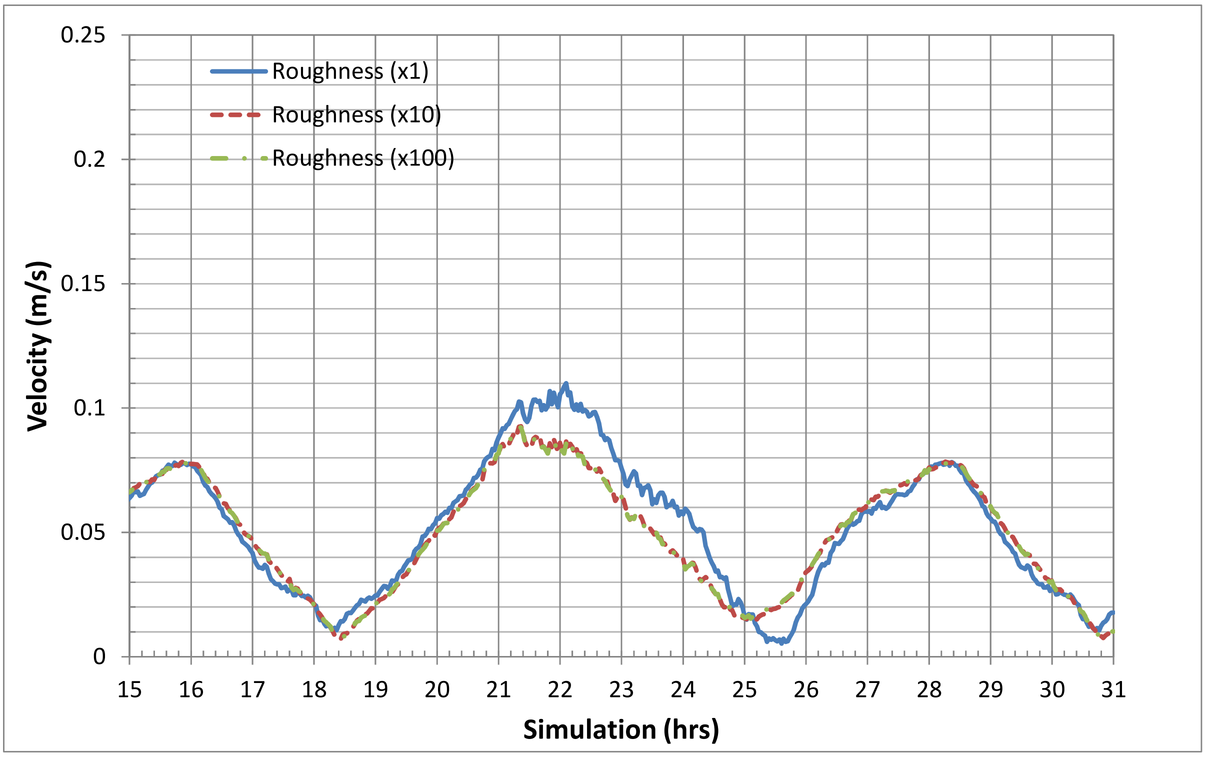


Figure 4.6.10 Sensitivity of Velocities to Roughness factor at Site 4



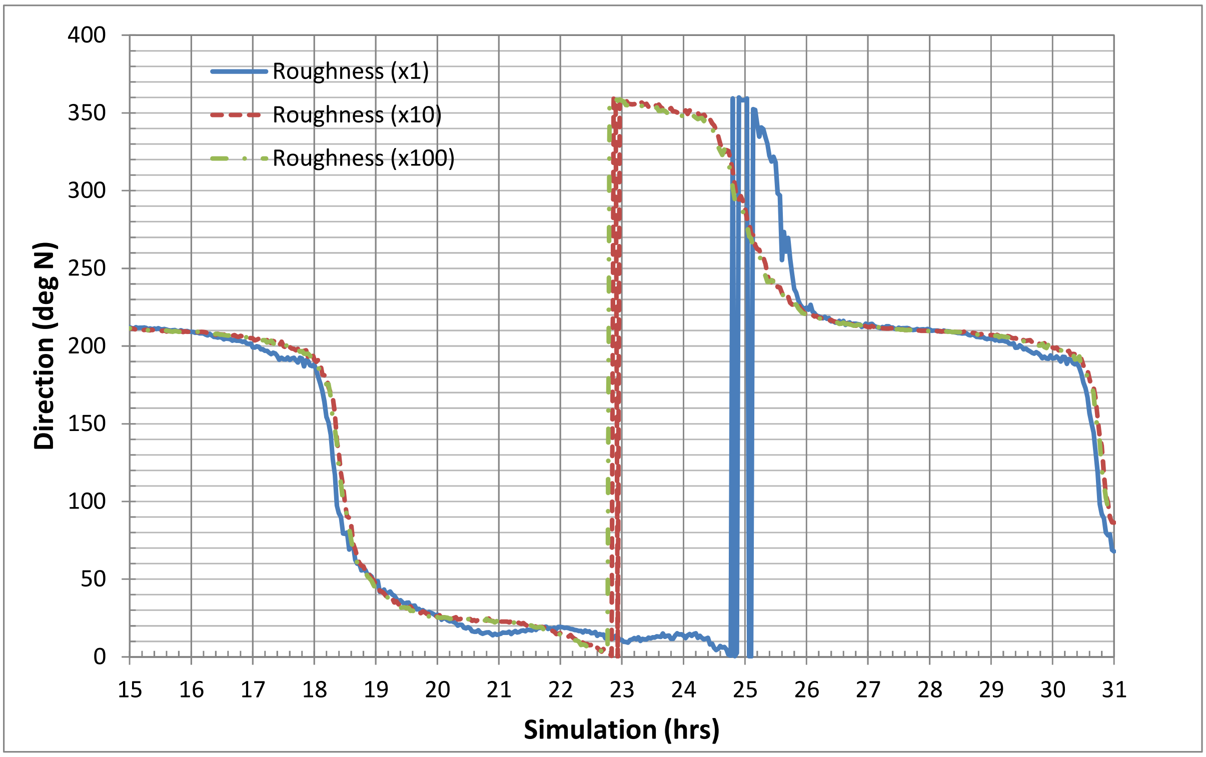


Figure 4.6.11 Sensitivity of Velocities to Roughness factor at Site 5

4.6.3.1 Design Flood Simulation for Cladagh basin including Wind shear and Wave radiation forces

A design flood simulation to examine the potential impact of the development on upstream elevations in the Cladagh Basin is presented in Figure 4.6.12 using the original modelled roughness coefficient of n = 0.03 in the open sea and n = 0.035 in the Claddagh Basin. The simulation was carried out for a 3.5m O.D. Tidal Surge wave, 100year + CC flood flow in the Corrib (549 Cumec), and with a southerly onshore wind force of 20m/s and the inclusion of the wind – wave radiation forces. In the hydrodynamic model the surface wind drag coefficient C_D specified in the surface stress term is $C_D = \rho_{air}/\rho_{sea} 0.0012615$ (for 5m/s<Wind<20m/s and measured 10m above surface).

The simulation showed a small increase in the storm surge from 3.5m highwater to 3.695m highwater in the Claddagh Basin (Site 1 of figure 4.6.1) due to the wind and river flow contribution. Importantly, the model results showed no discernible difference in computed water elevations between the existing and proposed cases for these conditions (refer to Figure 4.6.12 and 4.6.13).

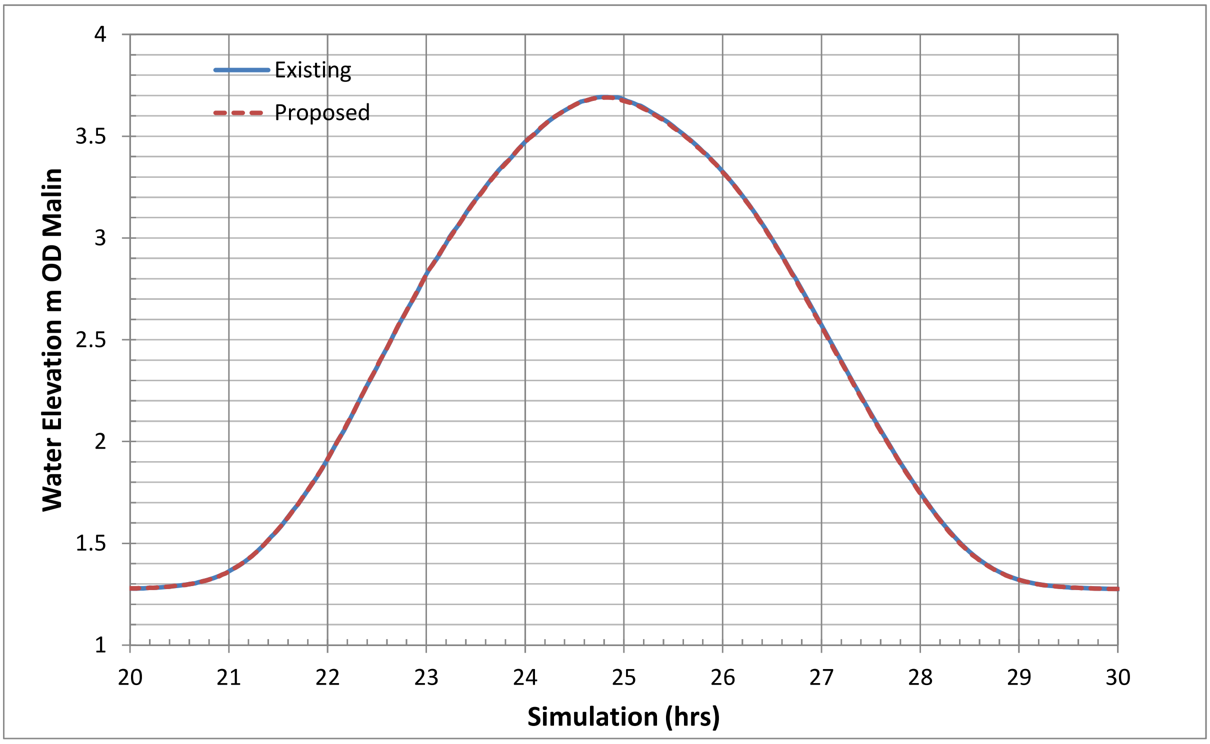


Figure 4.6.12 Comparison of Tide level at Site 1 Claddagh Basin for proposed and existing case under 3.5m tidal surge, 100year Corrib flood Flow and 20m/s southerly wind for proposed and existing scenarios (Existing and Proposed overlapping)

A difference plot of computed peak water level for the above hydrodynamic conditions was generated at 1cm resolution to demonstrate the negligible impact that the proposed development has on combined tidal and fluvial flooding in Galway Bay and in the Claddagh Basin area, refer to Figure 4.6.13.

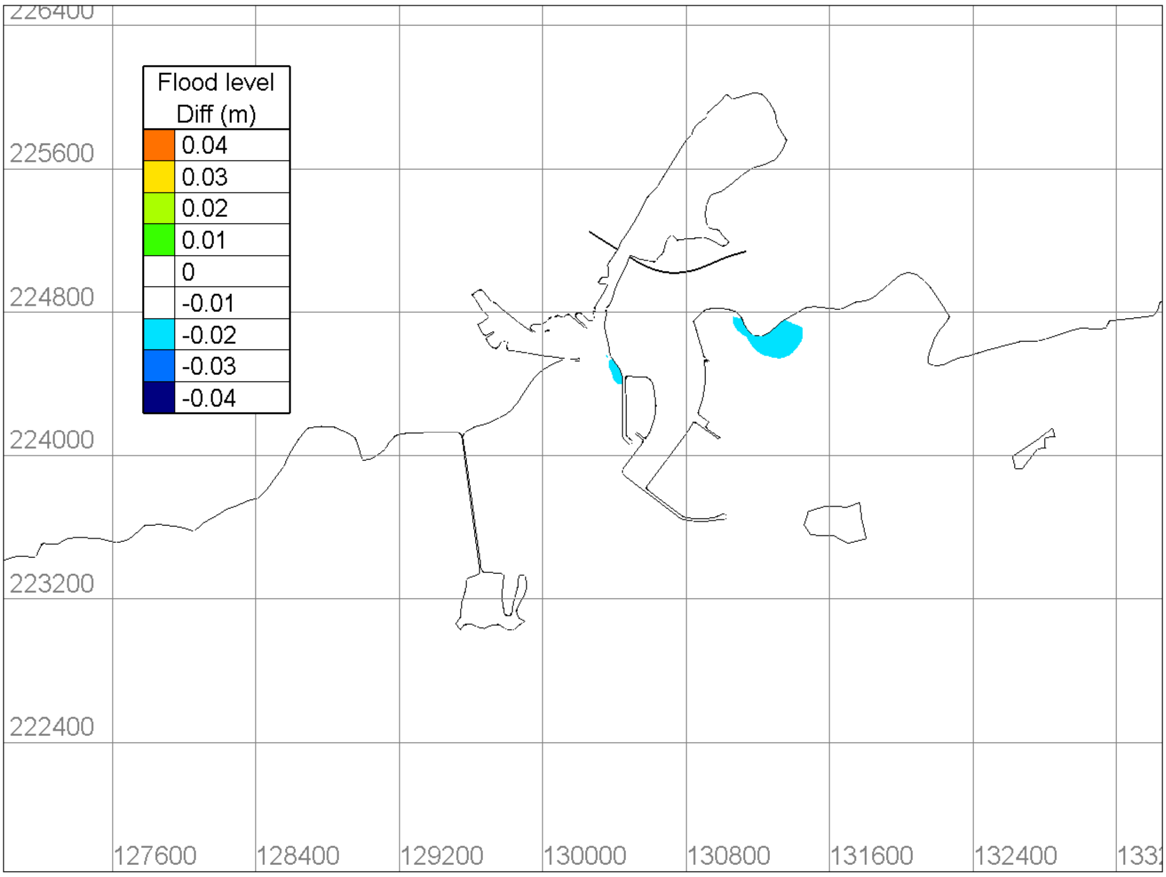


Figure 4.6.13 Difference Plot between predicted existing and Proposed peak flood levels

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Appendices to NIS Addendum / Errata

Appendix No. 3.3

Appendix No. 7 – Wind Waves and Friction

4.7 IMPACT OF WIND WAVES ON FRICTION

Query:

Has the impact of wind waves been incorporated into this friction, or is that effect negligible?

Response:

4.7.1 Introduction

The effect of wind waves have been incorporated as a source term (surface shear stress through a wind drag coefficient) and through inclusion of radiation stresses inputted to the hydrodynamic model. The effect of wind waves have not been incorporated into modifying the bed roughness coefficient either dynamically or as a manual adjustment to the friction factors. For the normal case of prevailing winds under spring / neap tides the wind wave effect on bed resistance will be relatively minor given the small wave heights relative to water depth that are predicted and thus producing relatively small orbital velocities and diameters to effect the bed conditions and the near bed flows.

4.7.2 Modification of Friction Factor By Waves

Outside of the surf zone wave induced ripples on the sea floor can form the size of which depend on the wave climate and hydrodynamics. These ripples increase the roughness length and thus increase the bed friction coefficient. The dimensions of these ripples can be predicted as a function of the Waves orbital velocity U_o and wave period T for a given sediment diameter and given wave climate conditions based on the procedure of Wiberg & Harris (1994). Under moderate wave conditions, as is the case in the Inner Galway Bay area in the vicinity of the proposed harbour area, the ripple dimensions (wave length λ and height η) will be proportional to the wave Orbital Diameter D_o : Wilberg and Harris, 1994 provide following method for evaluating the friction coefficient for wave induces sand ripples:

$\lambda = 0.62\, D_o$, $\eta = 0.17\lambda$

Where $D_o = 2U_o/\omega$ $\omega = 2\pi/T_p$ and $U_o = \frac{H_s\omega}{2\sinh(kh)}$ $\omega^2 = gk\tanh(kh)$

where k is the wave number, h is the water depth, H_s is the significant wave height, T_p is the Peak Period, ω is the intrinsic angular frequency and U_o is the wave orbital velocity and g the gravitational acceleration.

The effect of the ripples is to increase the bed roughness producing a Nikuradse roughness length expressed as follows (based on the Bijker's formula):

$k_s = \max(\eta, 3d_{50})$ where d_{50} is the sand grain roughness.

Using a water depth of 10m, a significant wave height H_s of 4m and a peak period T_p of 8seconds the ripple roughness k_s is 0.419m which represents a Manning roughness of n = 0.034 which is well within the sensitivity range demonstrated in Section 6.

Using a depth of 5m, a H_s of 2m, a T_p of 6seconds the ripple roughness k_s from the above equations is 0.228m representing a Manning's roughness n = 0.031 which is well within the sensitivity range demonstrated in Section 6 and is close to the Manning Value of 0.03 used in the simulations.

The above formulation is only applicable to oscillatory flow conditions and does not account for the effect of superimposed mean current. A correction factor σ to the wave orbital velocity following Tanaka and Dung can be applied to include the effect of the mean current.

4.7.3 Conclusion

In conclusion Wind Wave effects from large storm events will modify the bed roughness (defined by Manning n value) through rippling. This change in roughness is not significant in terms of the hydrodynamics within the inner Galway Bay as demonstrated in the Roughness sensitivity analysis presented in Section 6.

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Bijker E.W. 1968 “Mechanics of sediment transport by the combination of waves and current” In Design and Reliability of Coastal structures, 23rd int Conf. On Coastal Engineering 147-173.

Chow V (1959) “Opean Channel Hydraulics, McGraw-Hill New York

Soulsby R (1997) “Dynamics of marine sands” Thomas Thelford Edition

Tanaka H and Dang VT 1996. Geometry of sand ripples due to combined wave – currents flows J. Of Waterway, Port, Coastal and Ocean Engineering, ASCE,122 (6),pp 298-300.

US Army Corps of Engineers (2010) “HEC-RAS River Analysis System - Hydraulics Reference Manual”

Wiberg P.L. and Harris C.K., 1994. “Ripple geometry in wave dominated environments”, Journal of Geophysical research 99, pp 775-789.

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Appendices to NIS Addendum / Errata

Appendix No. 3.3

Appendix No. 8 – Outfall Dispersion Study

4.8 OUTFALL DISPERSION STUDIES:

Potential for Wind Driven Surface Currents to Transport Treated Waste Water Towards the Corrib Entrance

Query:

Dispersion studies due to tidal flow have been analyzed for the existing Mutton Island outfall and the proposed Galway East outfall, applying a depth integrated model (TELEMAC-2D). The Corrib entrance is not impacted by the proposed Harbour extension according to these simulations. However, due to prevailing wind from SSW, a wind driven surface current may transport waste water from the Mutton Island Outfall towards the Corrib entrance, and the concentrations may be impacted by the harbor extension. Since the location is quite windy, as indicated from the wind data from the Belmullet station, presented in figure 8.4.123, a number of (5-10) runs should be made using TELEMAC-3D to consider whether this will create any potential issues in the in terms of pollution.

Response:

4.8.1 Introduction

The TELEMAC-3D hydrodynamic and dispersion model developed for the EIS Study is used to simulate a surface plume from the Mutton Island outfall in order to address the above concerns of An Bord Pleanála in respect to the potential impact of the Harbour development on the effluent plume characteristics under adverse wind conditions resulting in greater impact to the inshore waters at the Corrib entrance (Head of Nimmo's Pier). These additional model runs also investigate the potential impact to the Bathing Beach at Ballyloughaun to the northeast of the development under similar adverse wind conditions.

It should be noted that the Mutton Island outfall discharges via a 10 port diffuser system, with horizontal jets distributed over 100m to maximise dilution of the buoyant plume in the nearfield before it reaches the surface. This Diffuser system was designed by Hydro Environmental Ltd in 2001 and achieves 95-%ile and median dilutions in excess of 30 and 60 respectively at 3DWF (Tobin 2006). At 1dwf it is likely that a median dilution in excess of 100 is achieved by the diffuser before reaching the surface. In the 3D model surface plume simulations this dilution is not factored in and it models the effluent as if released without dilution at the water surface. This could only be a very rare occurrence corresponding with still water at the turn of the tide. In the light of the above design dilutions, the application of a diffuser dilution factor is appropriate.

Hydrodynamic and dispersion simulations were carried out for varying wind speed and direction as recommended. The critical hydrodynamic conditions for the transport of the plume inshore towards the Corrib entrance and towards Ballyloughaun Beach are southerly winds combined with spring tides and low river flow conditions in the Corrib. The wind directions are the southwest to south sector.

The study was also expanded to consider the implication of adverse wind conditions on the proposed Galway East outfall being transported northwards towards the Harbour area, Corrib Entrance and Ballyloughaun Beach area. Galway East outfall is located a further 2.4km to the southeast of Mutton Island outfall.

4.8.2 Methodology

In order to provide a robust method to assess the implications of the development on various water quality parameters in the effluent a conservative tracer was simulated. The Mutton Island outfall discharge was set at the EPA Licensed Population Loading of 170,000 PE (represents a dry weather flow (dwf) of 0.3542cumec) and the Galway East outfall was set at the proposed future Population Loading of 550,000 PE (dwf = 1.1458cumec). Each outfall was modelled separately so as to account for their individual impacts.

The Mutton Island outfall was specified at grid point 129628, 222729 and the Galway East proposed outfall at 131892, 222010. Note the finite element scheme for parallel processing requirements translates the outfall locations to the nearest computational node point which are 129645, 222727 and 131909, 222033 for the Telemac3D model respectively.

In the 3-D hydrodynamic model the outfall discharge was input at the surface layer so as to commence the simulation with a surface plume as would be expected from a large freshwater discharge to the more dense tidal waters during dry weather flow conditions.

The Corrib Low flow was specified as the 95-percentile low flow of 26.2cumec.
Simulations were carried out for the following Hydrodynamic and meteorological conditions under existing and proposed development cases and represents a total of 14 model runs (7 each for proposed and existing scenarios):

Existing Mutton Island outfall - 170,000 PE

1. Spring tide and Corrib low flow and Calm Wind Conditions (8.1 – 8.6)
2. Spring Tide and Corrib Low Flow with 5 m/s from South West (8.7 – 8.12)
3. Spring Tide and Corrib Low Flow with 5 m/s from South-South West (8.13 – 8.18)
4. Spring Tide and Corrib Low Flow with 5 m/s from South (8.19 – 8.24)
5. Spring Tide and Corrib Low Flow with 15 m/s from South West (8.25 – 8.30)
6. Spring Tide and Corrib Low Flow with 15 m/s from South-South West (8.31 – 8.36)
7. Spring Tide and Corrib Low Flow with 15 m/s from South (8.37 – 8.42)

Faecal coliform simulations for the Mutton Island outfall were carried out for the following hydrodynamic conditions:

8. Spring tide and Corrib low flow and Calm Wind Conditions (8.43 – 8.45)
9. Spring Tide and Corrib Low Flow with 15 m/s from South-South West (8.46 – 8.48)

The Faecal Coliform simulations modelling 170,000 PE, a final effluent concentration of 300,000 cfu/100ml and a die-off rate set at a T_{90} of 24hours.

The Galway East outfall is a further 2.4km southeast of Mutton Island outfall and thus stronger adverse winds are required to transport the plume northwards towards Galway City. Consequently simulations modelling 15m/s winds from the SW, S and SE were carried out for the existing and proposed cases (representing 6 model runs, 3 per existing and proposed cases).

Proposed Galway East Outfall - 550,000 P.E.

10. Spring Tide and Corrib Low Flow with 15 m/s from South West (8.49 – 8.54)
11. Spring Tide and Corrib Low Flow with 15 m/s from South (8.55 – 8.60)
12. Spring Tide and Corrib Low Flow with 15 m/s from South East (8.61-8.66)

4.8.3 Water Quality Simulation Results

Simulations were modelled for a continuous outfall discharge over 112 hours (9 tidal cycles) to allow for a build up of pollutant and ensure a conservative assessment in terms of the impact of the development on the discharge plume during adverse winds.

The tracer concentration results are presented as a percentage of the discharge concentration. This approach allows for the interpretation within the flow field of the concentration of any given water quality parameter, assuming that it is does not die-off or decay (conservative solute). For example a 1% concentration contour relative to an outfall effluent BOD concentration of 25mg/l represents a concentration of 0.25mg/l BOD..

This approach is reasonable for assessment of the implication on BOD, ammonia, nitrates etc. Where die-off is important such as faecal coliforms the concentrations more remote from the outfall will be over estimated.

Plots of predicted instantaneous maximum tracer concentration and the tidal mean tracer concentration (i.e averaged over the full tidal cycle) in the surface layer are presented for each of the simulations showing existing and proposed harbour development cases. For each of the hydrodynamic scenarios a difference plot between development and existing case is produced showing the increase / decrease in tracer concentration expressed as a percentage of the outfall effluent concentration.

4.8.4 Mutton Island Outfall Simulations

4.8.4.1 Spring tide and Corrib low flow and Calm Wind Conditions

Figure 4.8.1 to 4.8.6 presents the concentration plume and difference plots for calm wind conditions.

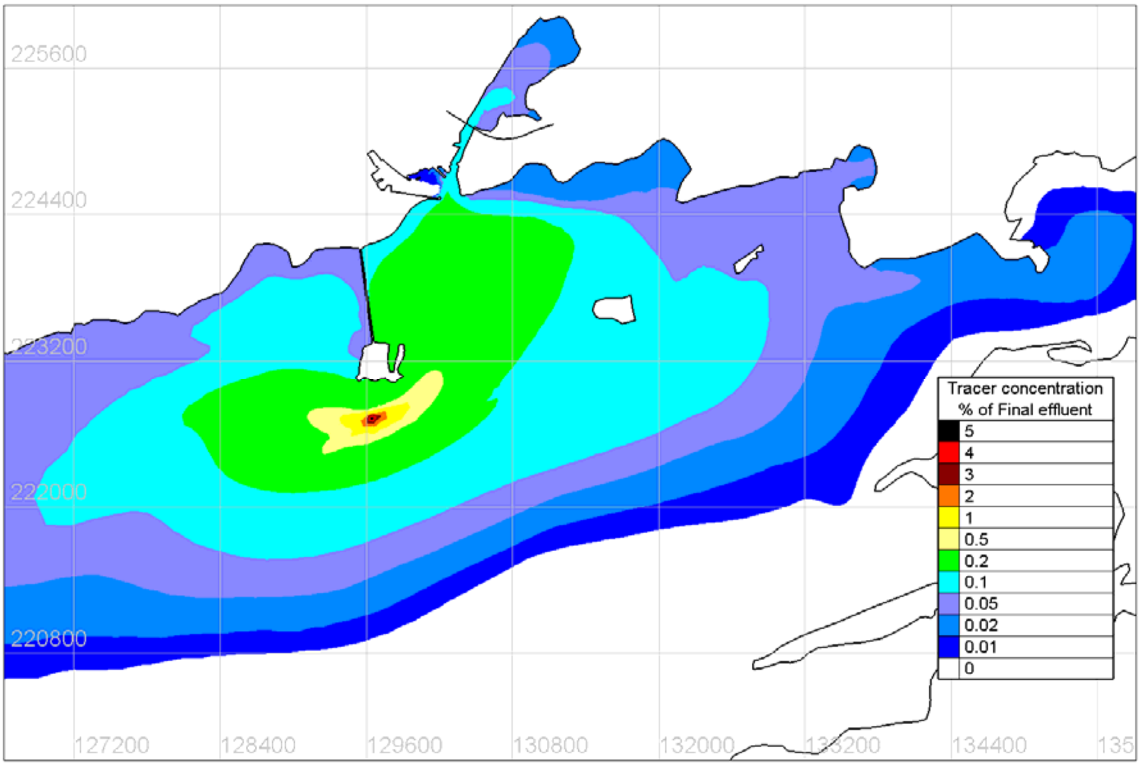

Figure 4.8.1 Maximum surface concentration of Tracer under calm wind conditions – Existing Case

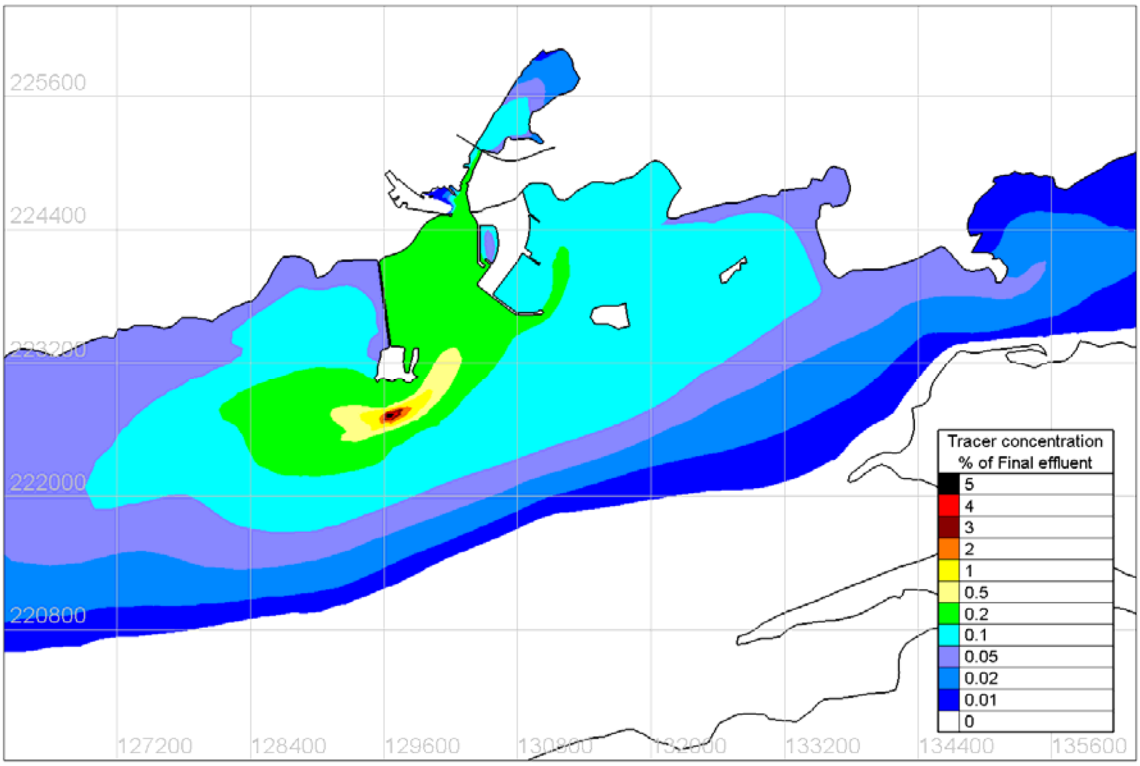

Figure 4.8.2 Maximum surface concentration of Tracer under calm wind conditions– Proposed Case

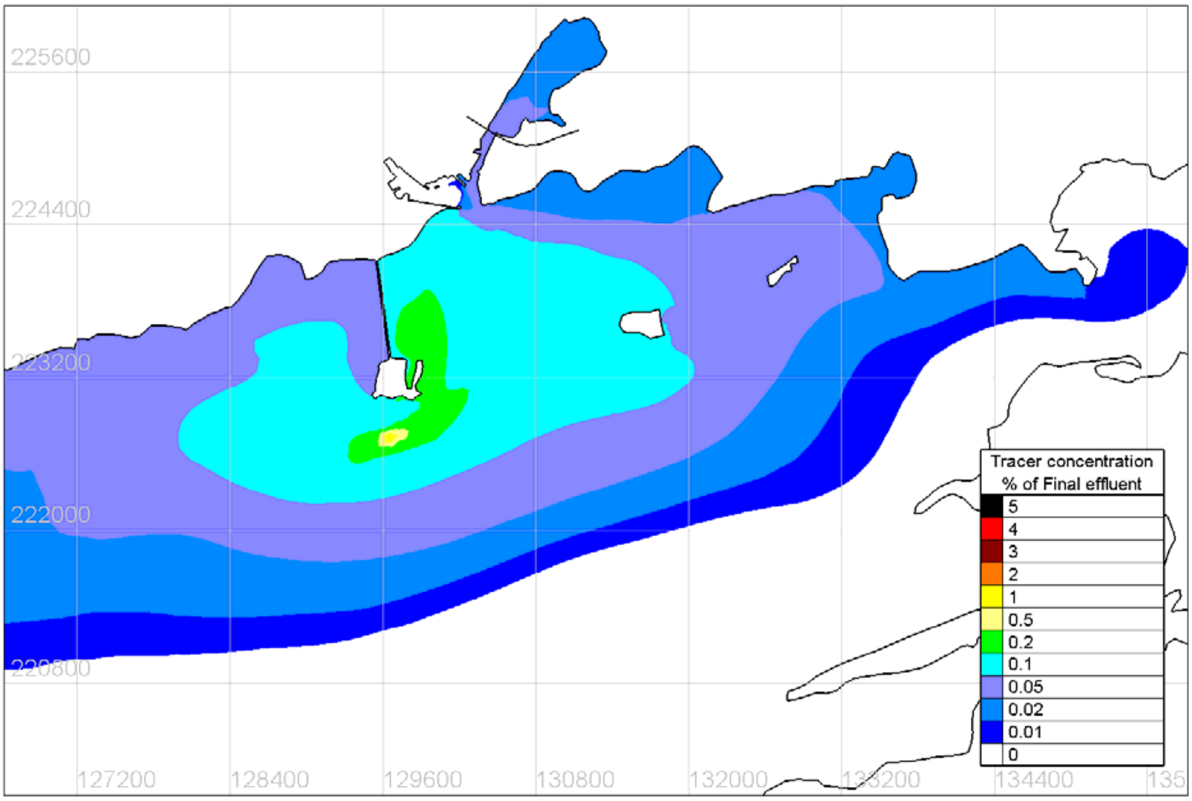

Figure 4.8.3 Tidal mean tracer concentration under calm wind conditions – Existing Case

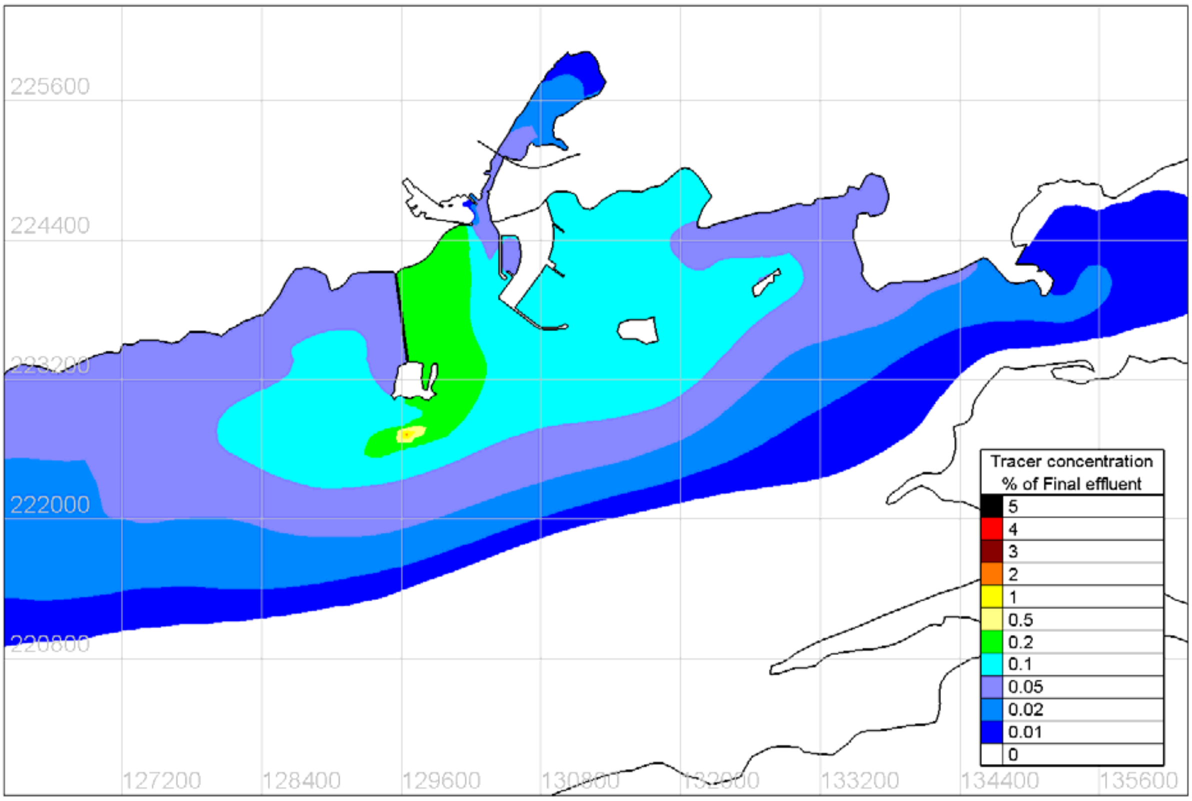

Figure 4.8.4 Tidal mean tracer concentration under calm wind conditions – Proposed Case

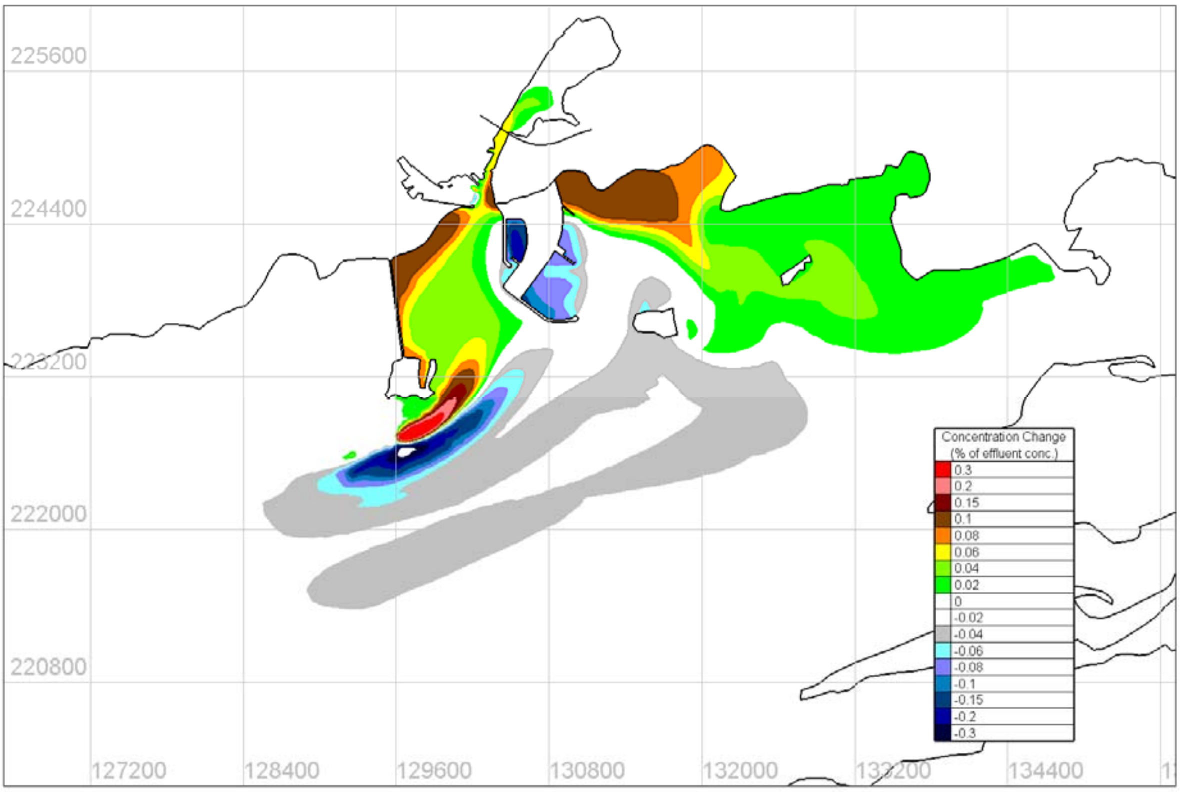

Figure 4.8.5 Predicted change in maximum surface tracer concentration – Calm Wind Conditions

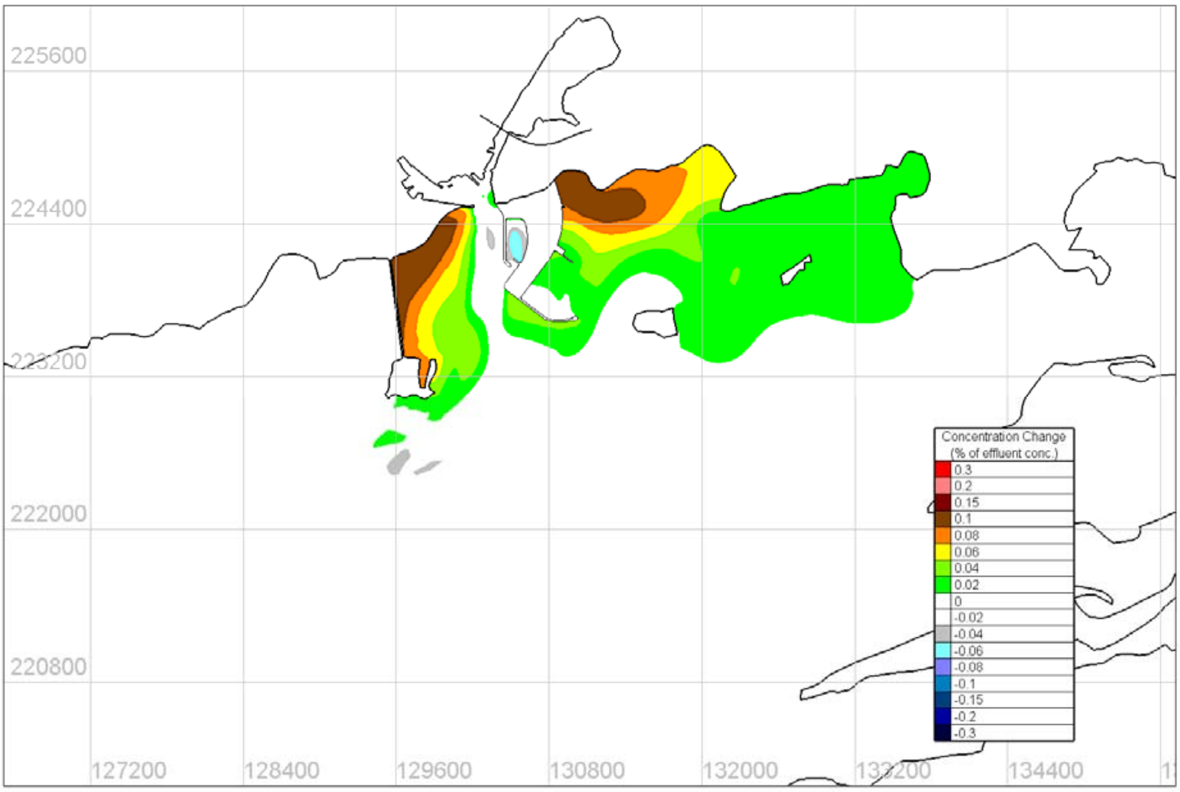

Figure 4.8.6 Predicted change in tidal mean tracer concentration – Calm Wind Conditions

4.8.4.2 Spring Tide and Corrib Low Flow with 5 m/s from SW

Figure 4.8.7 to 4.8.12 presents the concentration plume and difference plots for 5m/s wind from SW.

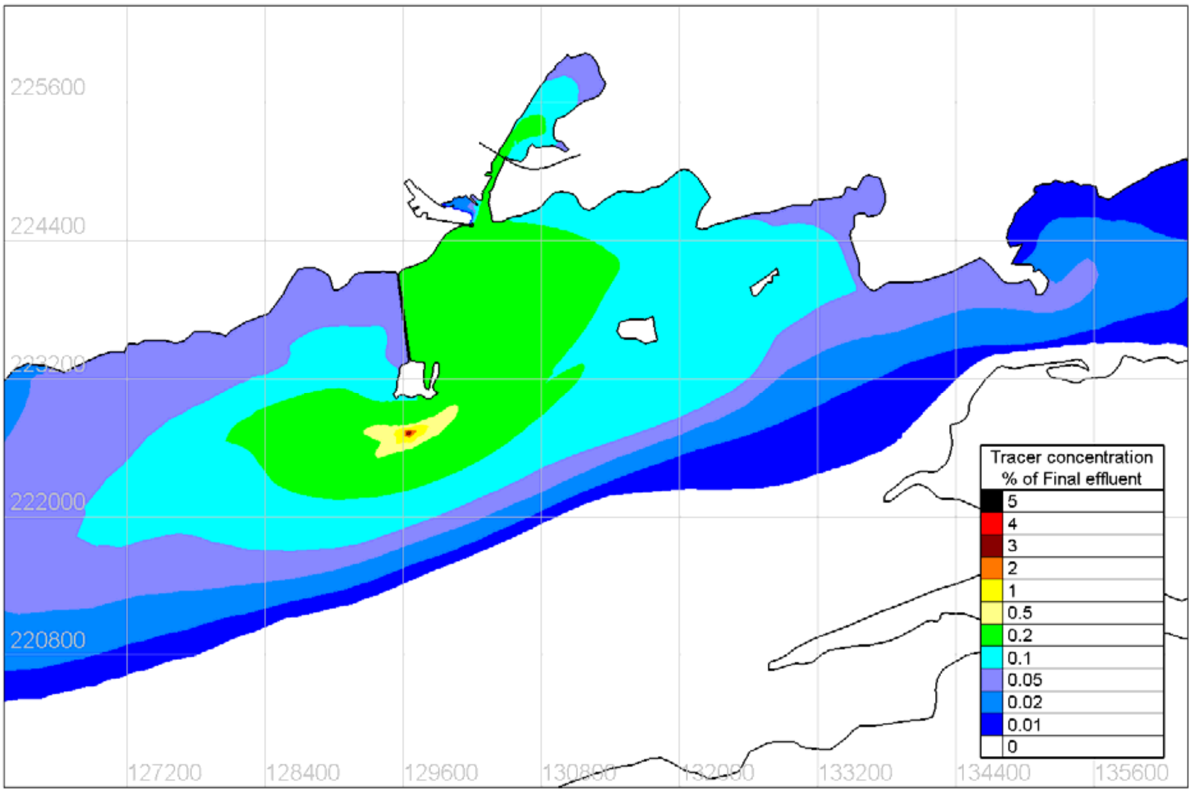

Figure 4.8.7 Maximum surface concentration of Tracer under under SW 5m/s wind conditions– Existing

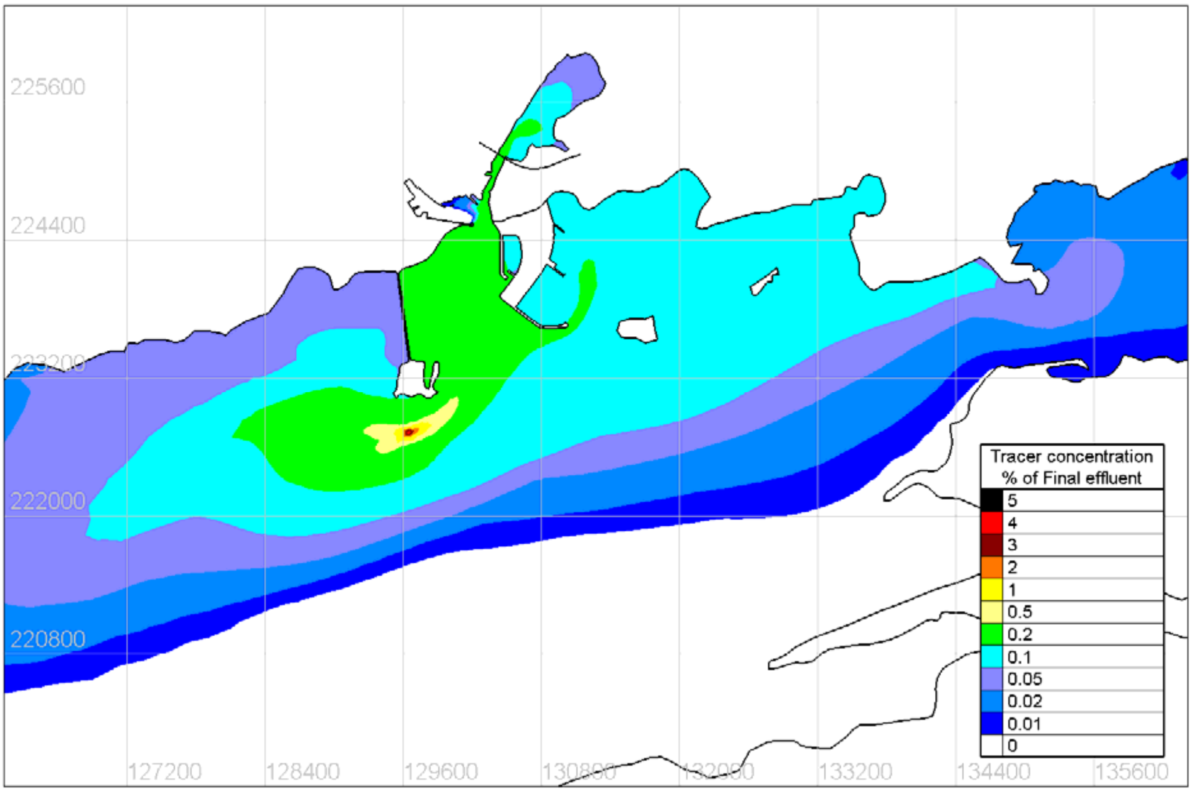

Figure 4.8.8 Maximum surface concentration of Tracer under under SW 5m/s wind conditions– Proposed

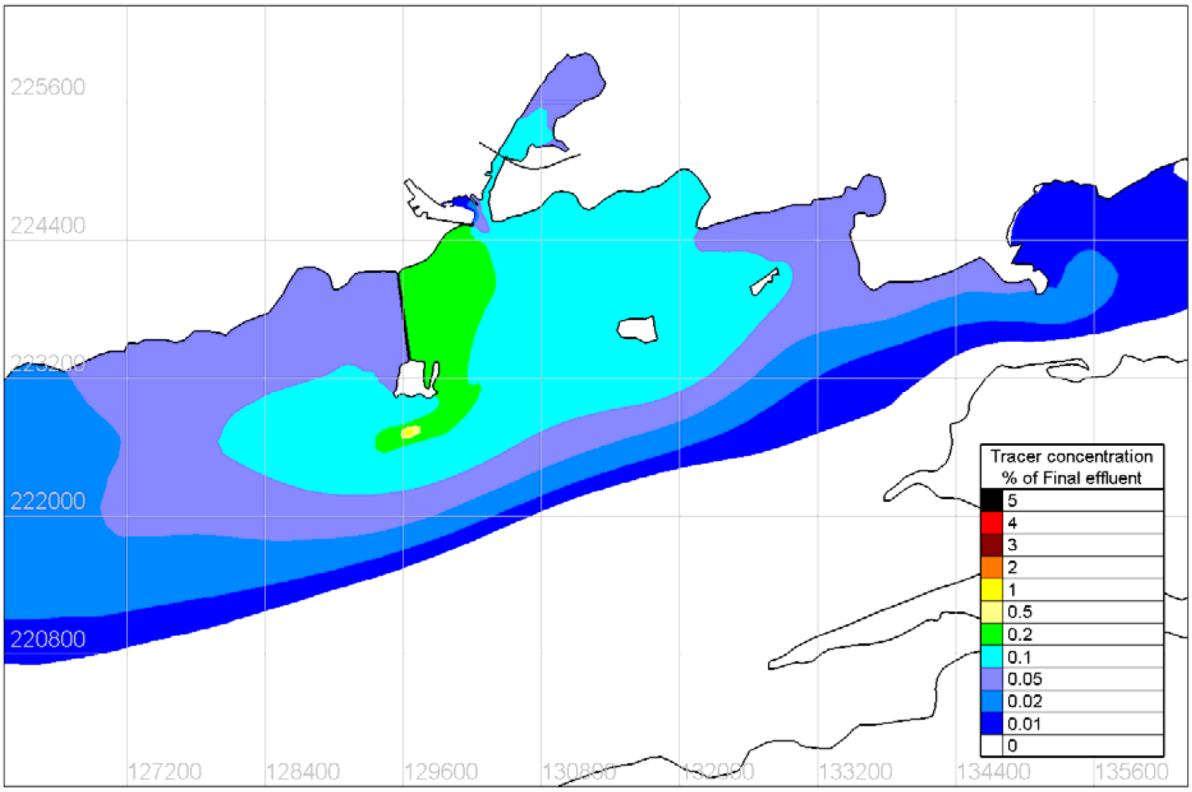

Figure 4.8.9 Tidal mean tracer concentration under SW 5m/s wind conditions – Existing Case

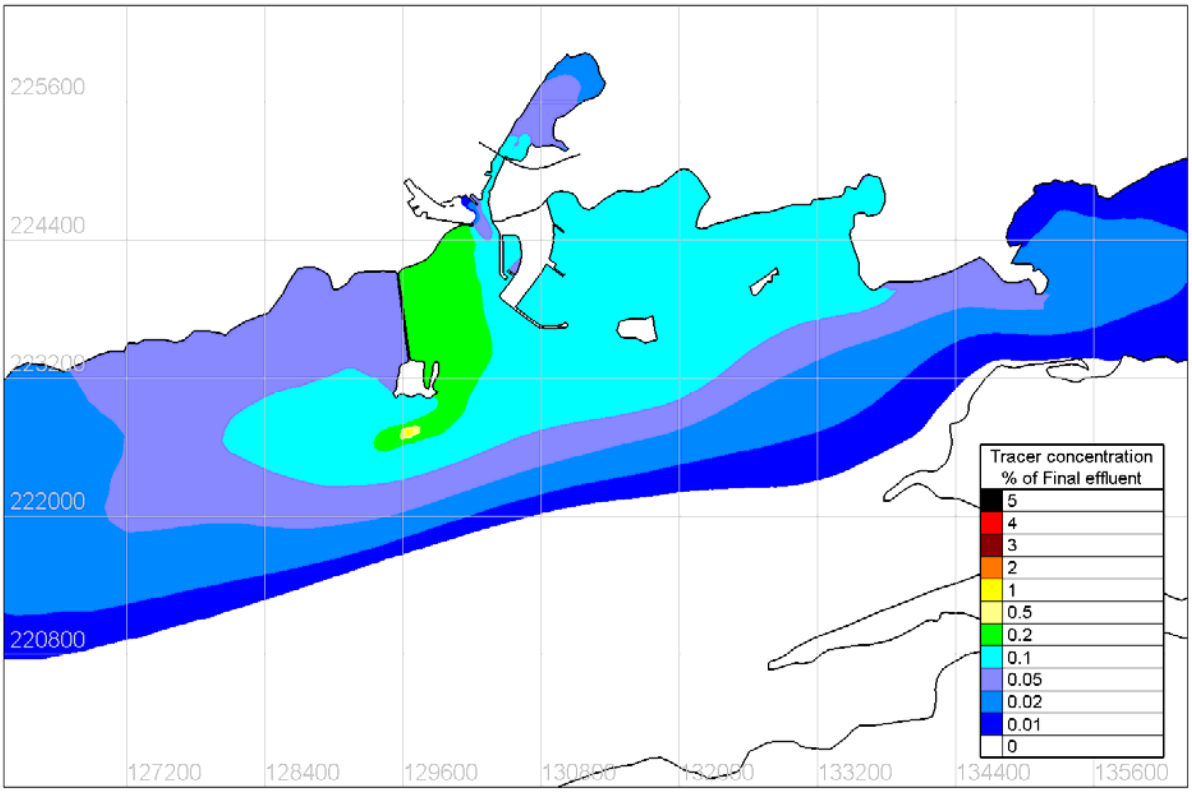

Figure 4.8.10 Tidal mean tracer concentration under SW 5m/s wind conditions – Proposed Case

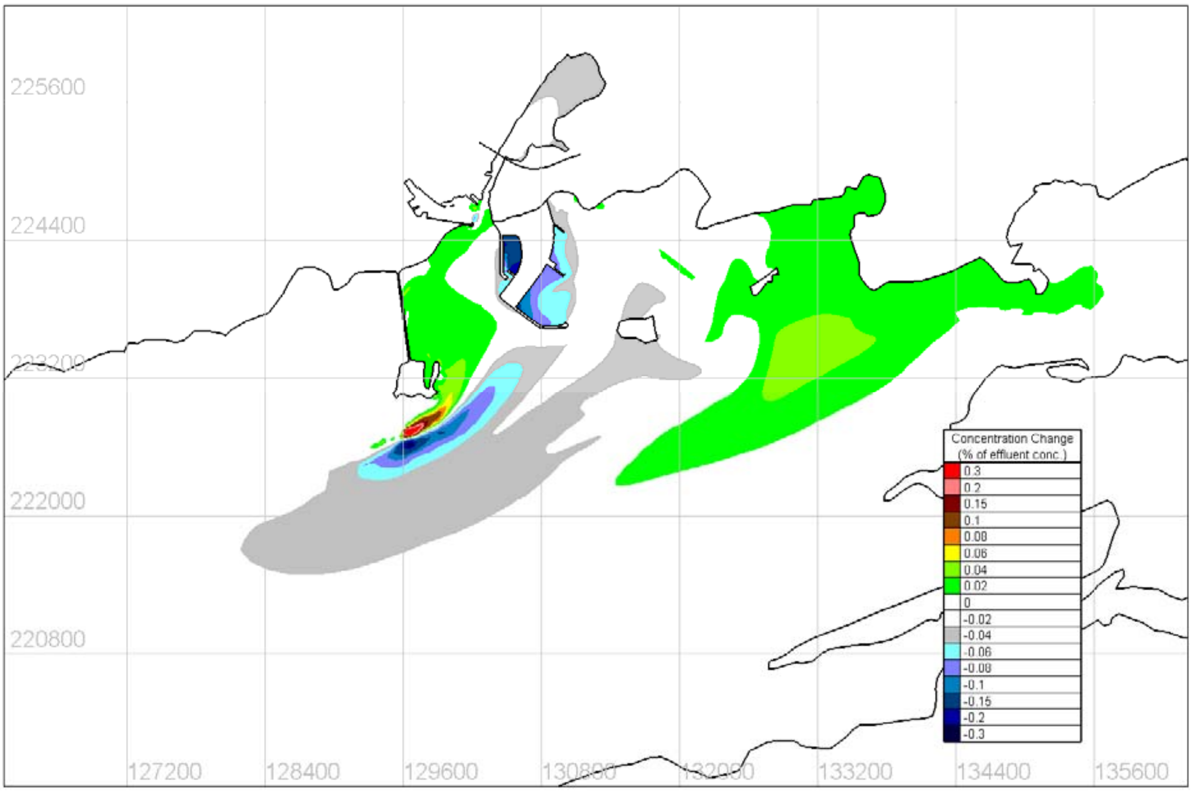

Figure 4.8.11 Predicted change in maximum surface tracer concentration – SW 5m/s Wind Conditions

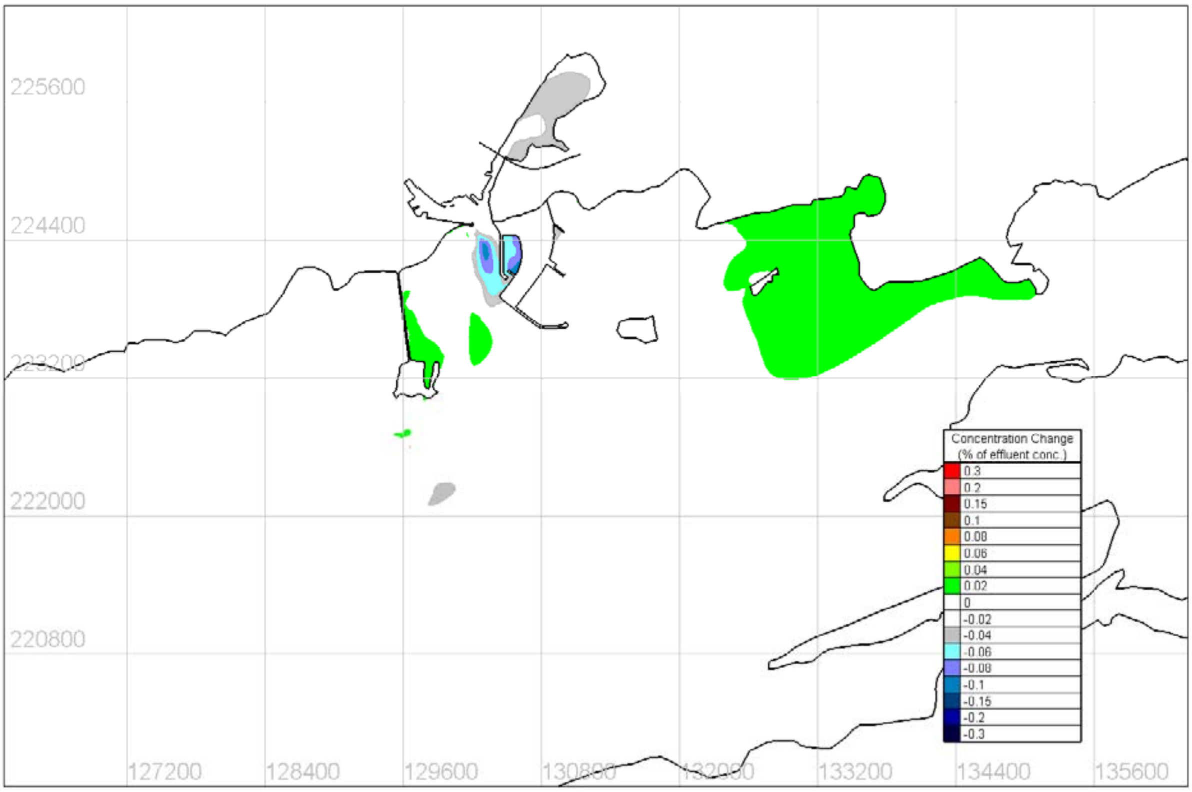

Figure 4.8.12 Predicted change in tidal mean tracer concentration – SW 5m/s Wind Condition

4.8.4.3 Spring Tide and Corrib Low Flow with 5 m/s from SSW

Figure 4.8.13 to 4.8.18 presents the concentration plume and difference plots for 5m/s wind from SSW.

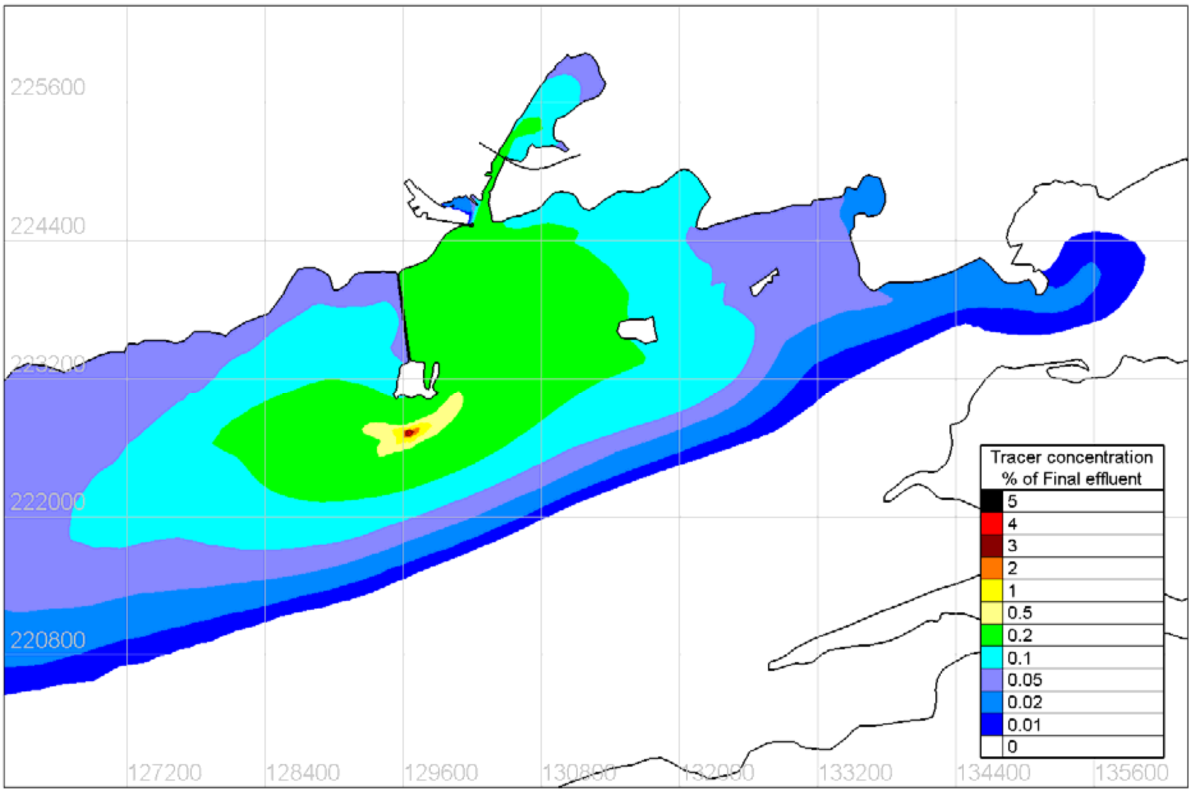

Figure 4.8.13 Maximum surface concentration of Tracer under SSW 5m/s wind conditions– Existing

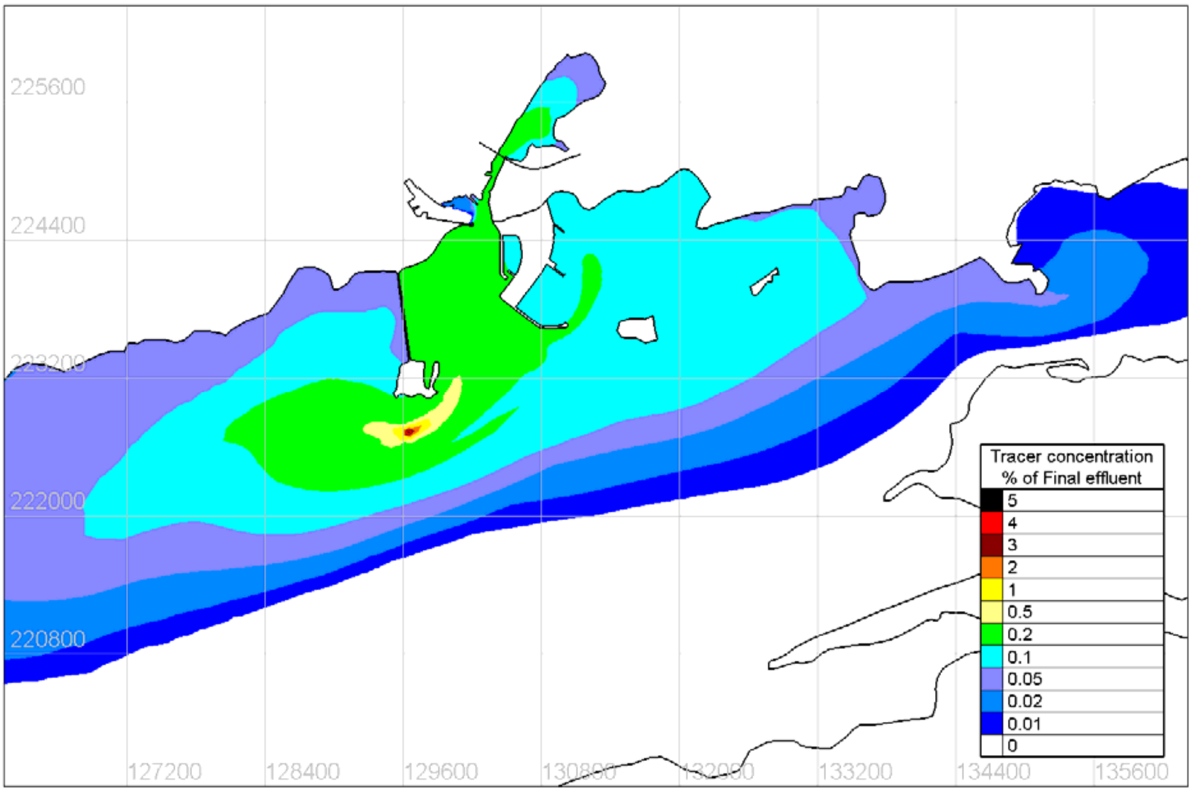

Figure 4.8.14 Maximum surface concentration of Tracer under SSW 5m/s wind conditions– Proposed

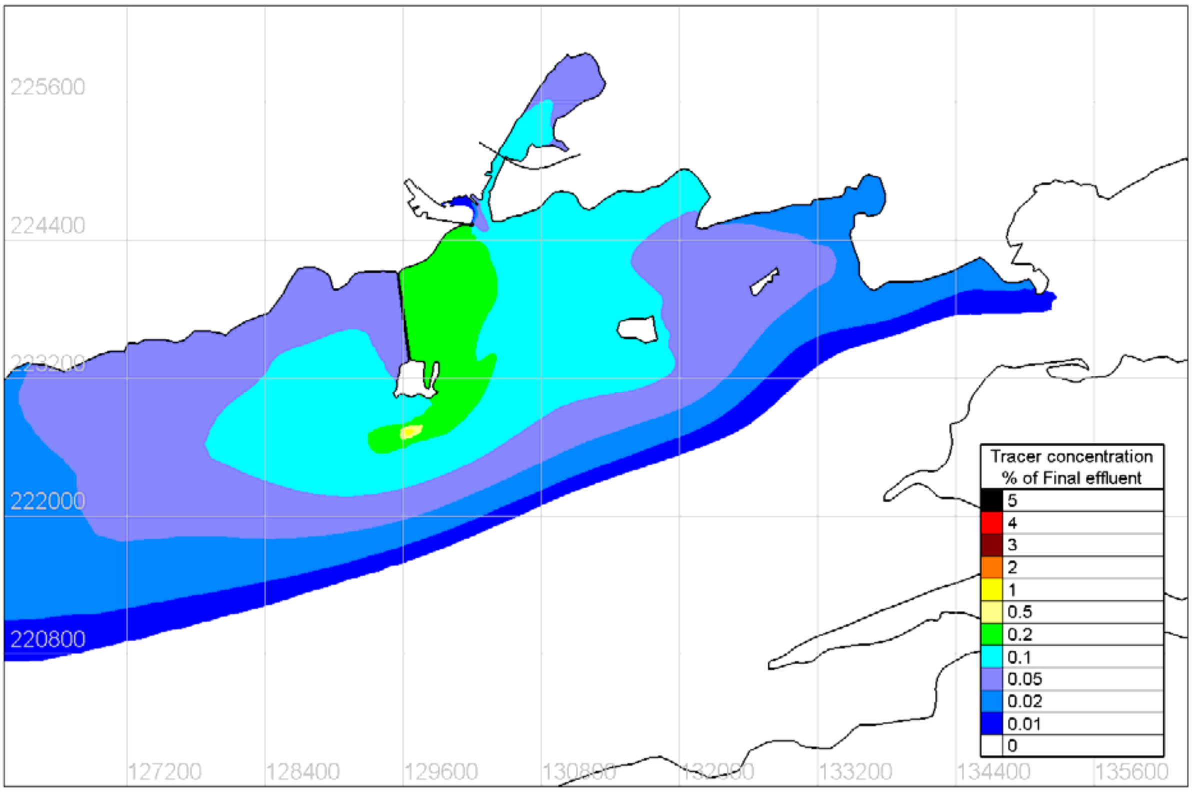

Figure 4.8.15 Tidal mean tracer concentration under SSW 5m/s wind conditions – Existing Case

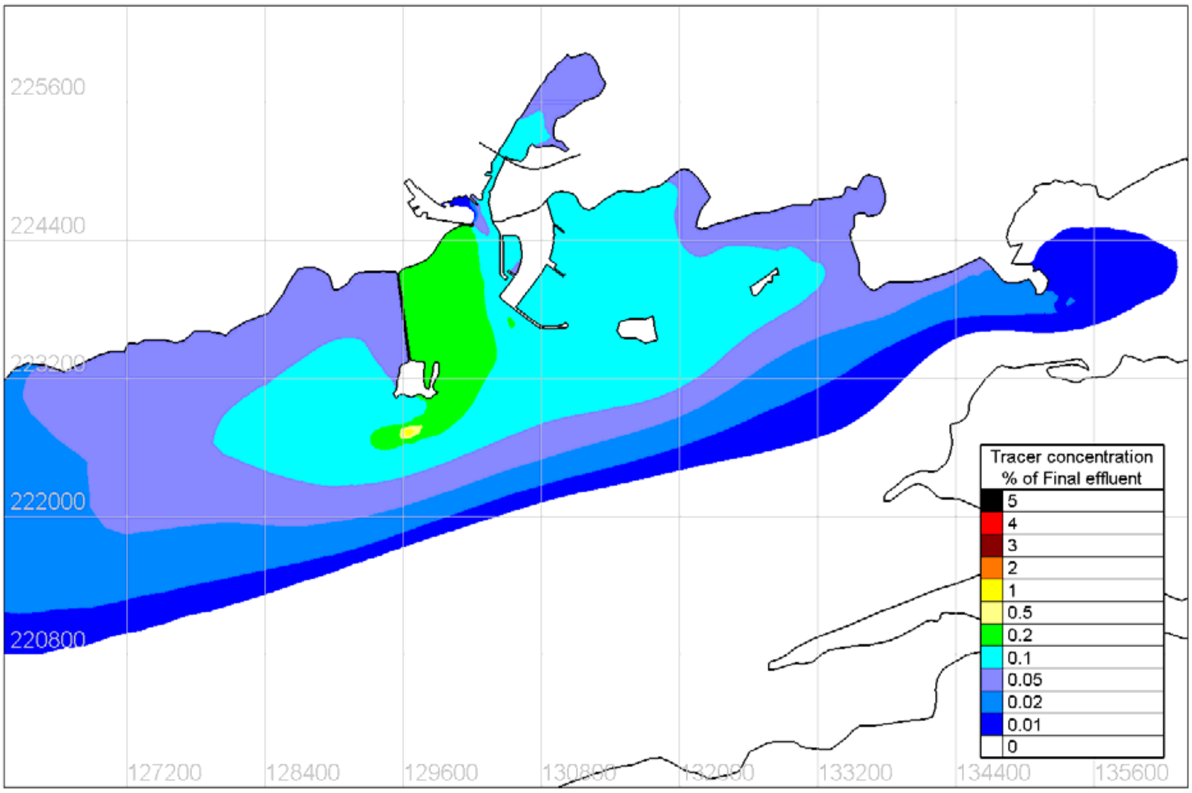

Figure 4.8.16 Tidal mean tracer concentration under SSW 5m/s wind conditions – Proposed Case

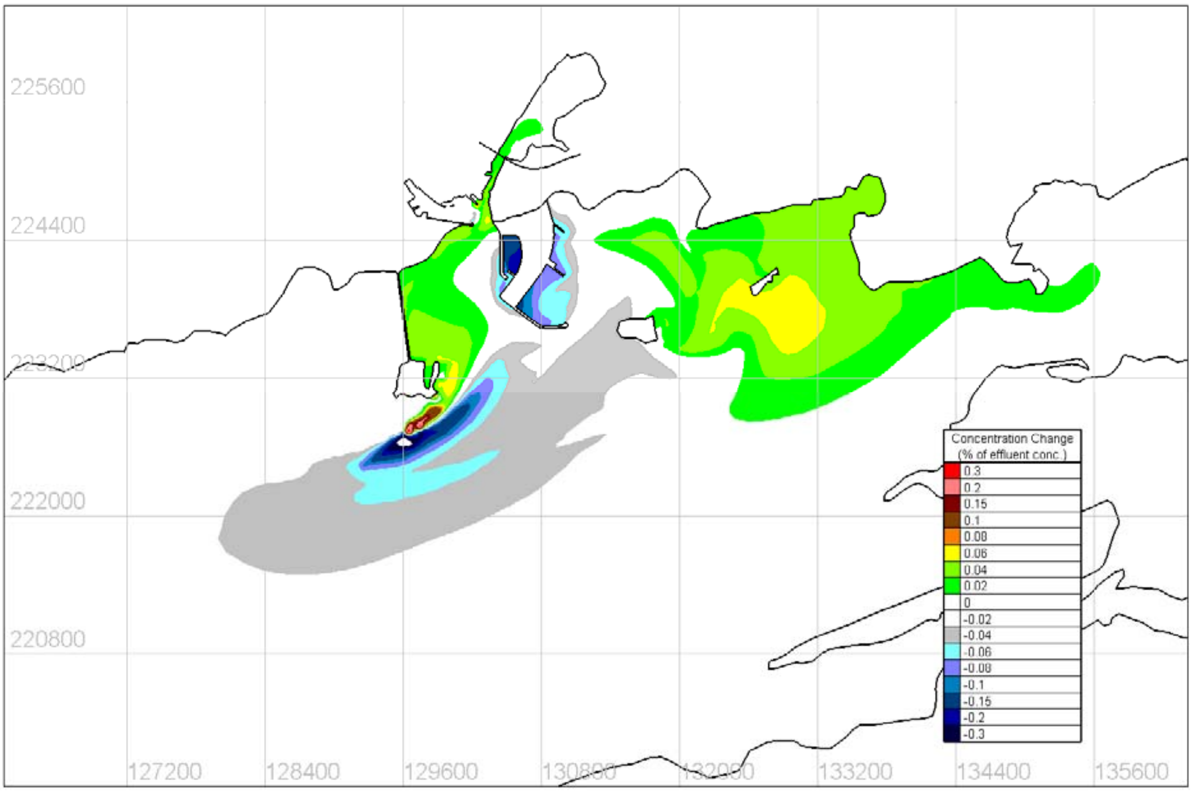

Figure 4.8.17 Predicted change in maximum surface tracer concentration – SSW 5m/s Wind Conditions

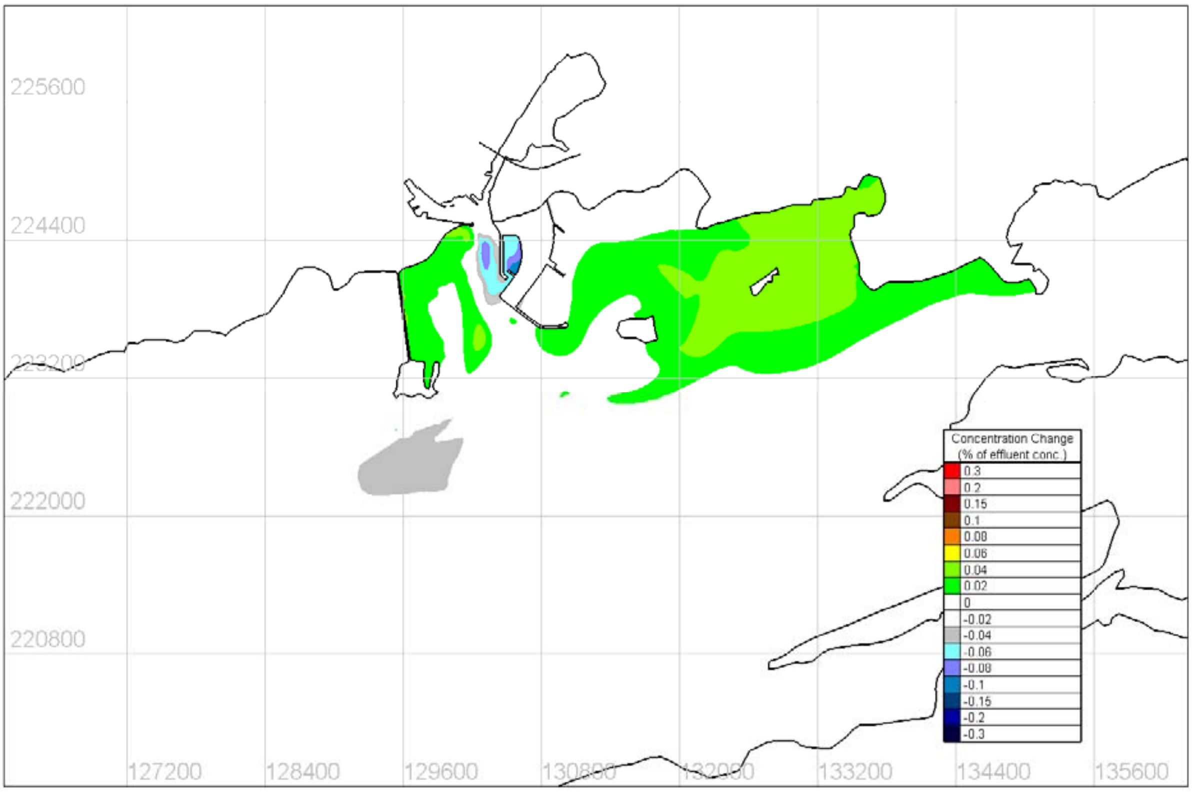

Figure 4.8.18 Predicted change in tidal mean tracer concentration – SSW 5m/s Wind Condition

4.8.4.4 Spring Tide and Corrib Low Flow with 5 m/s from South

Figure 4.8.19 to 4.8.24 presents the concentration plume and difference plots for 5m/s wind from South.

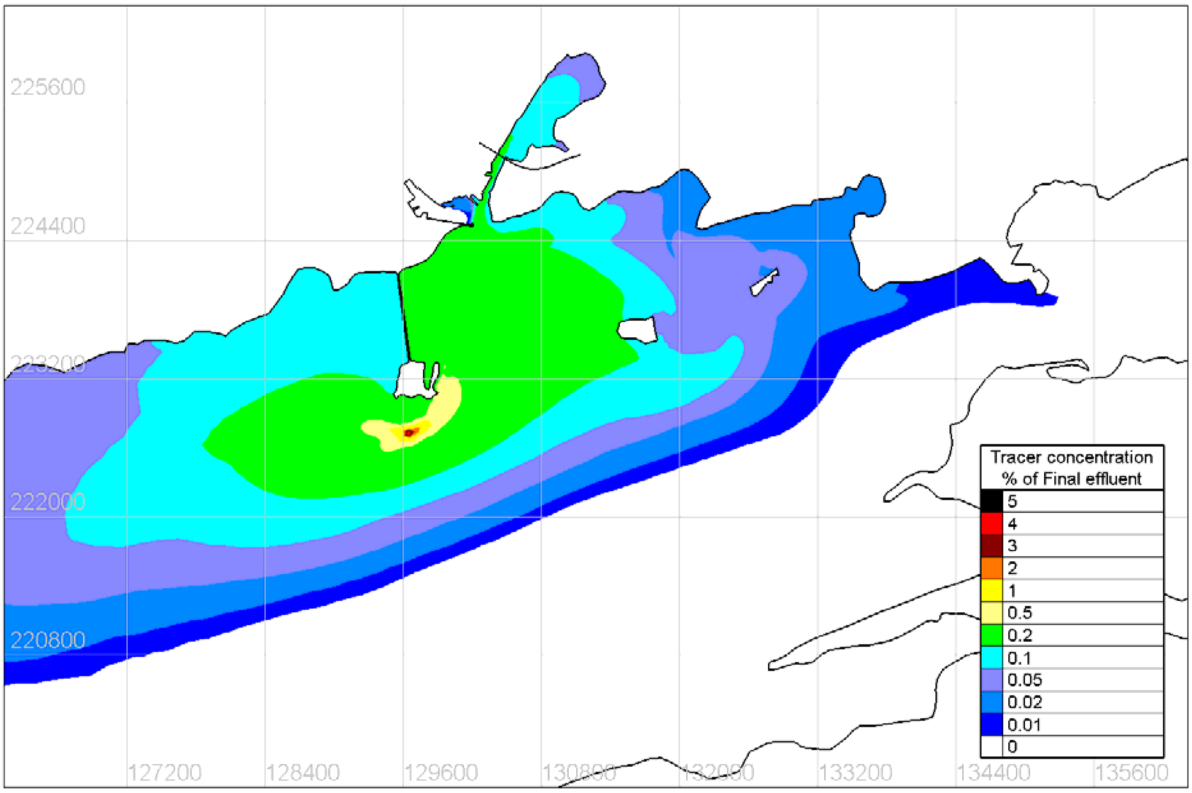

Figure 4.8.19 Maximum surface concentration of Tracer under South 5m/s wind conditions– Existing

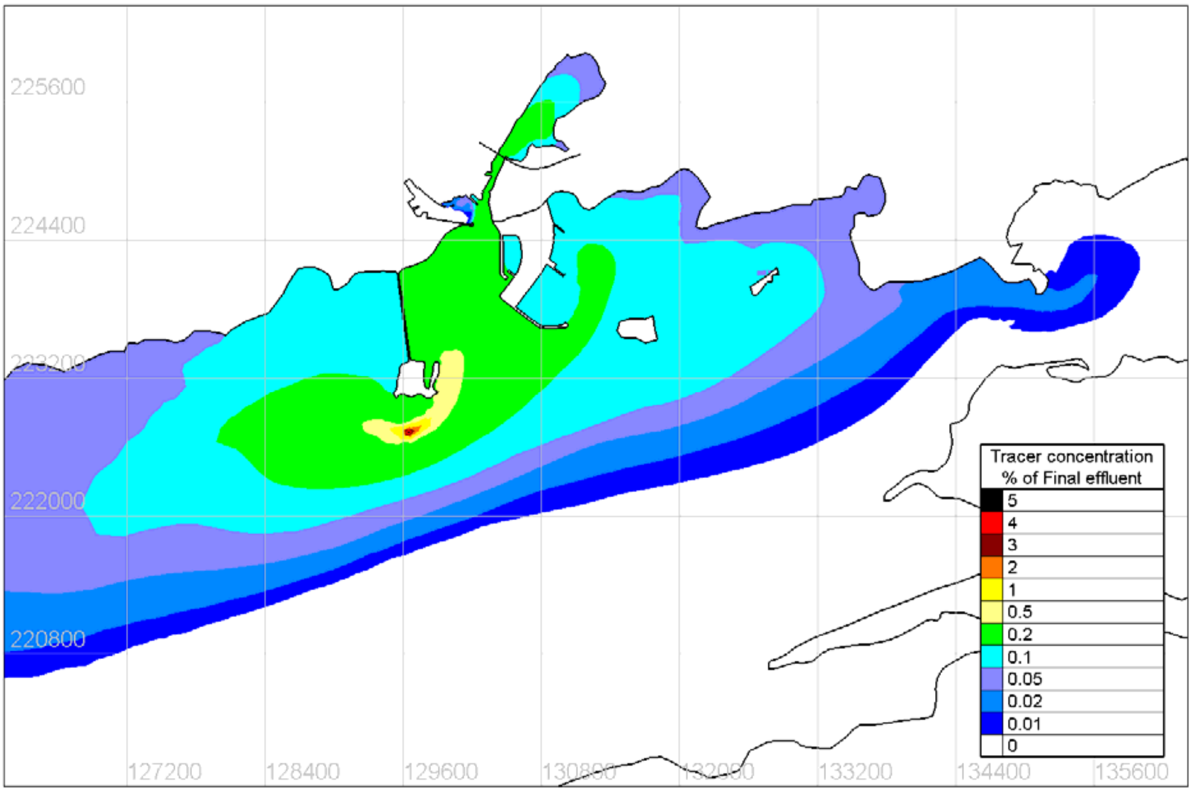

Figure 4.8.20 Maximum surface concentration of Tracer under South 5m/s wind conditions– Proposed

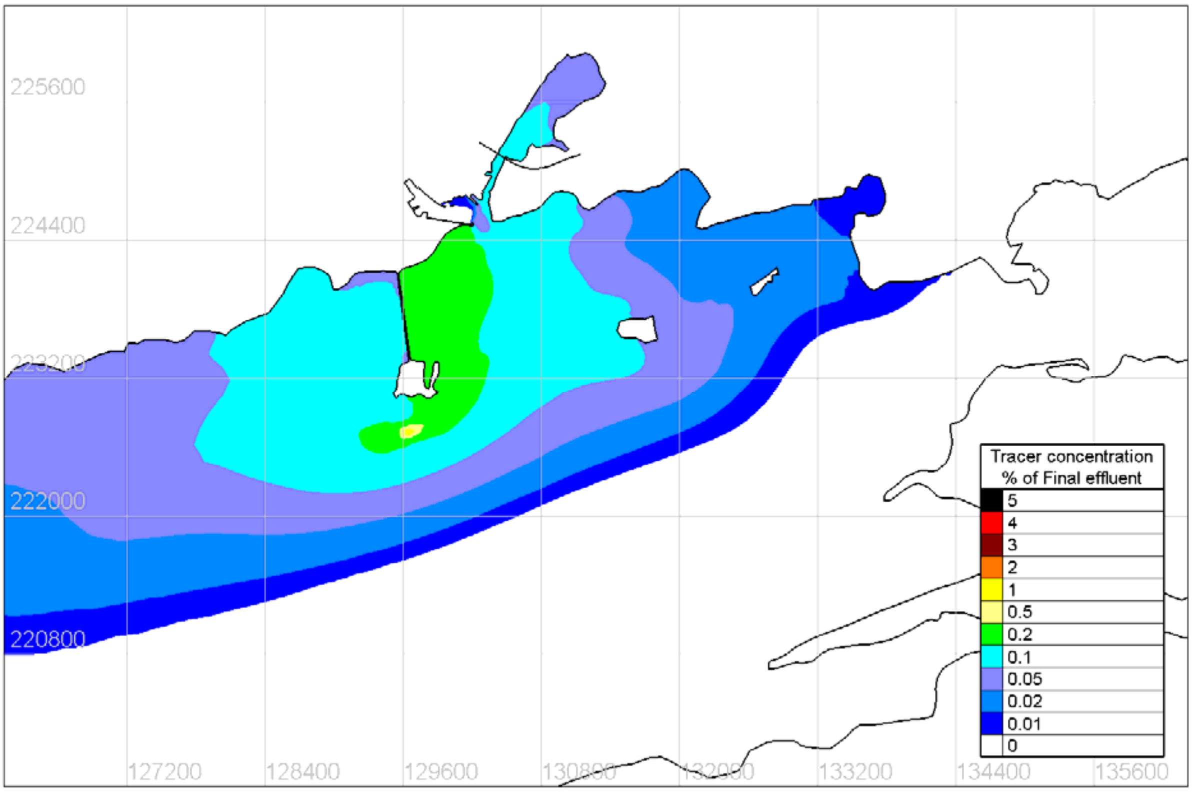

Figure 4.8.21 Tidal mean tracer concentration under South 5m/s wind conditions – Existing Case

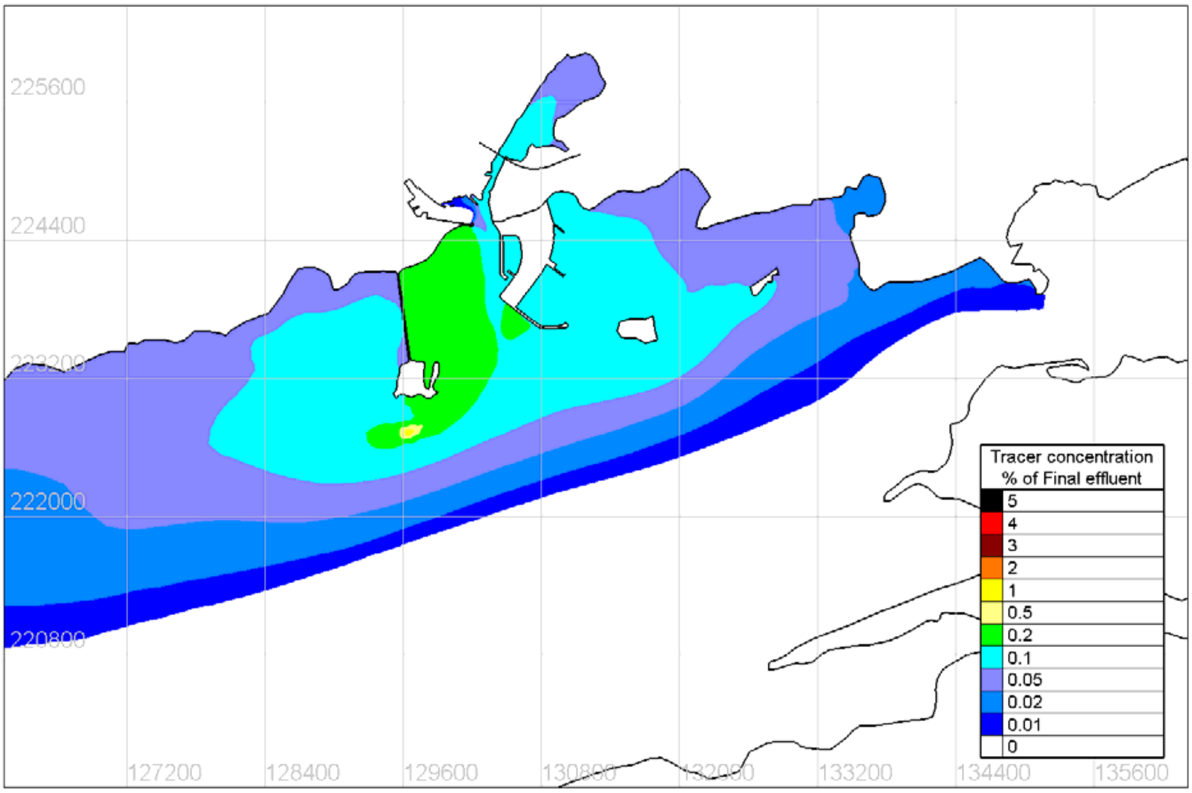

Figure 4.8.22 Tidal mean tracer concentration under South 5m/s wind conditions – Proposed Case

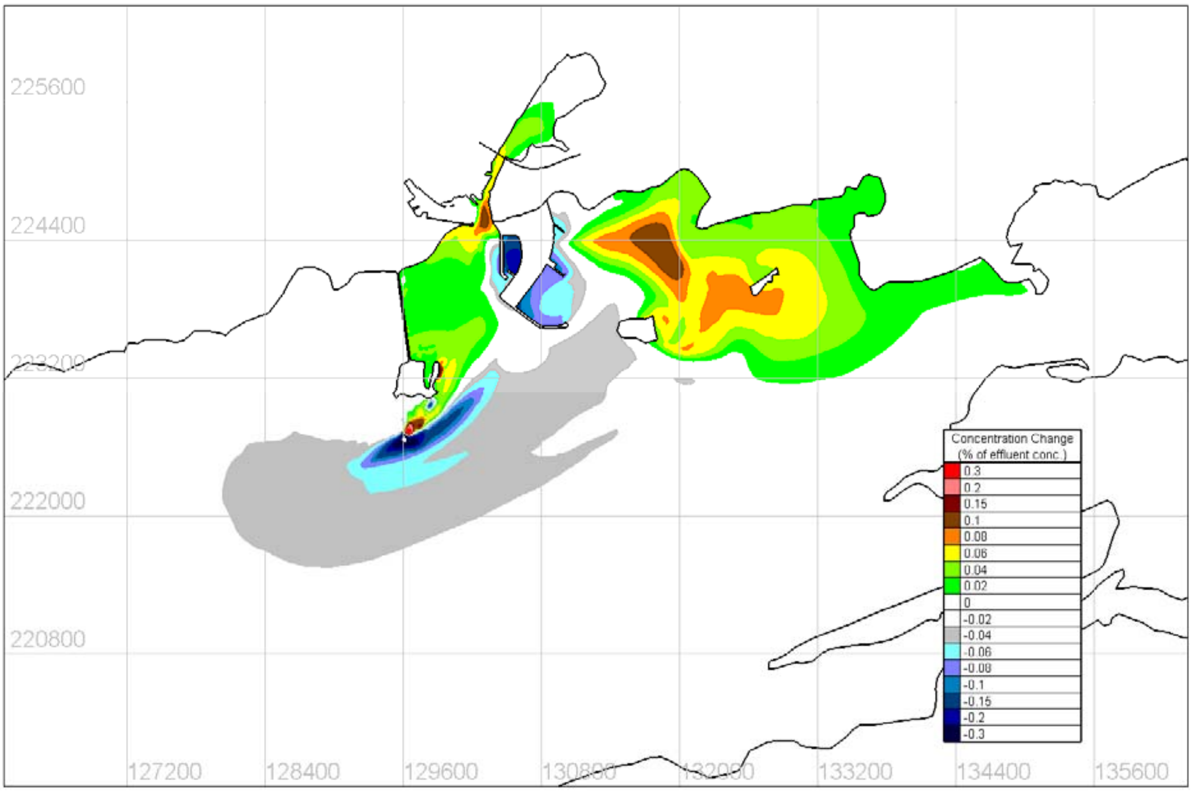

Figure 4.8.23 Predicted change in maximum surface tracer concentration – South 5m/s Wind Conditions

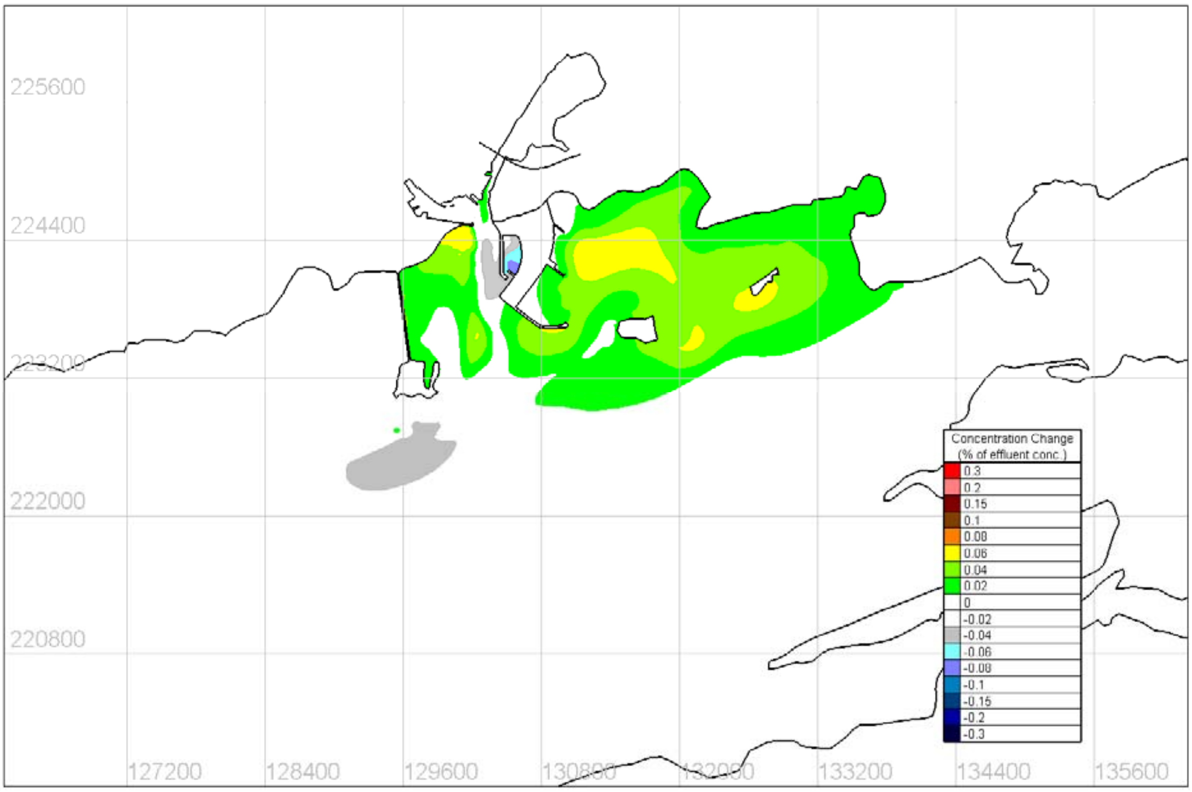

Figure 4.8.24 Predicted change in tidal mean tracer concentration – South 5m/s Wind Condition

4.8.4.5 Spring Tide and Corrib Low Flow with 15 m/s from SW

Figure 4.8.25 to 4.8.30 presents the concentration plume and difference plots for 15m/s wind from SW.

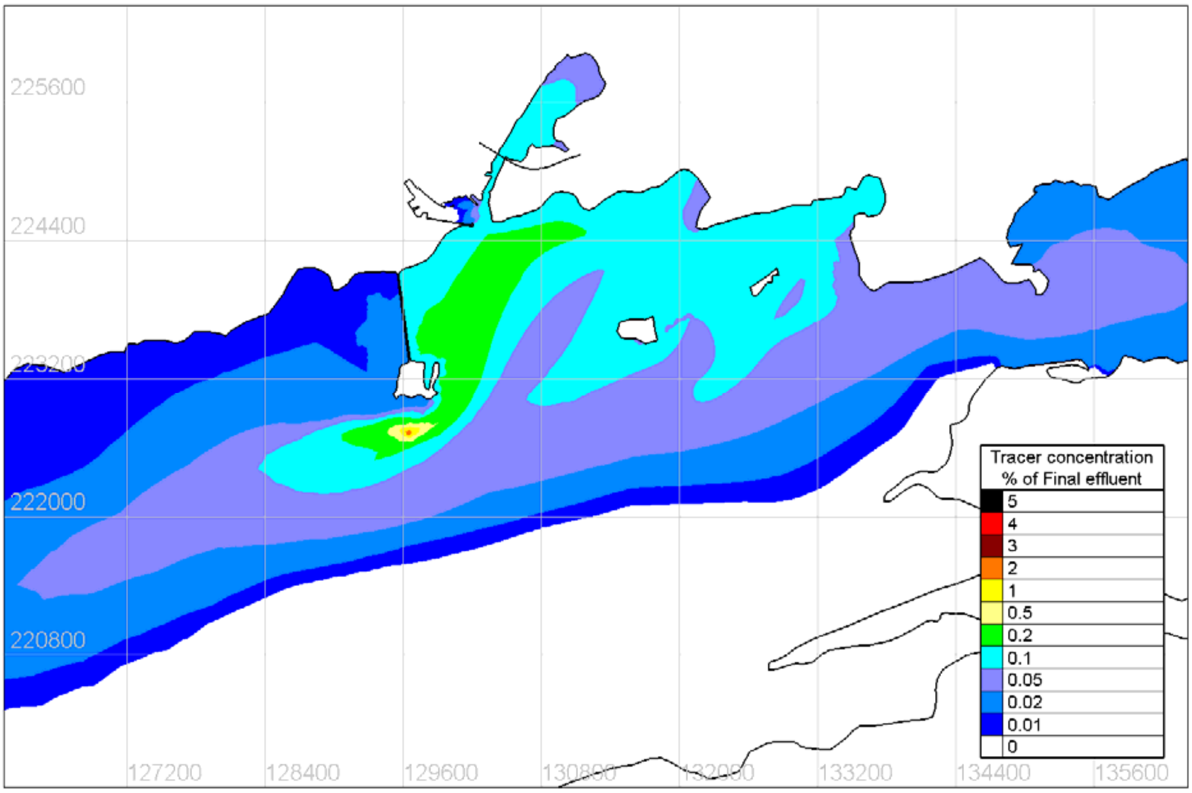

Figure 4.8.25 Maximum surface concentration of Tracer under SW 15m/s wind conditions– Existing

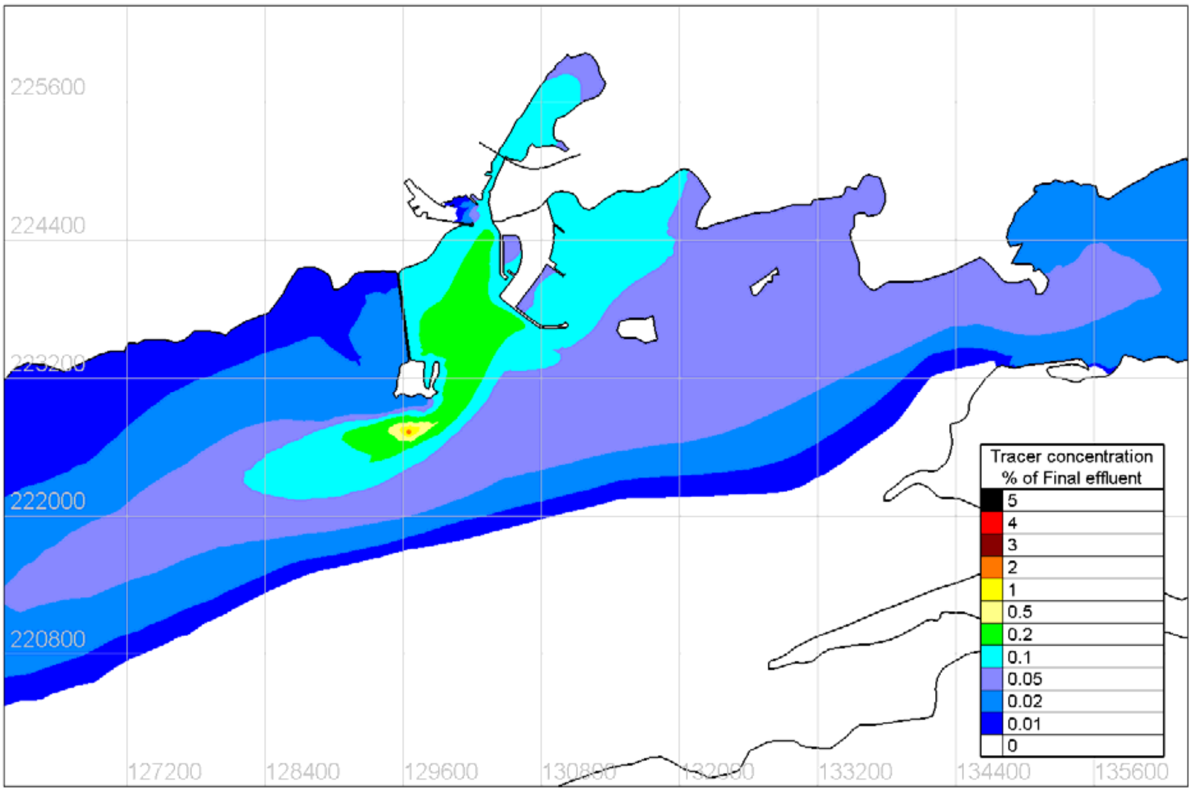

Figure 4.8.26 Maximum surface concentration of Tracer under SW 15m/s wind conditions– Proposed

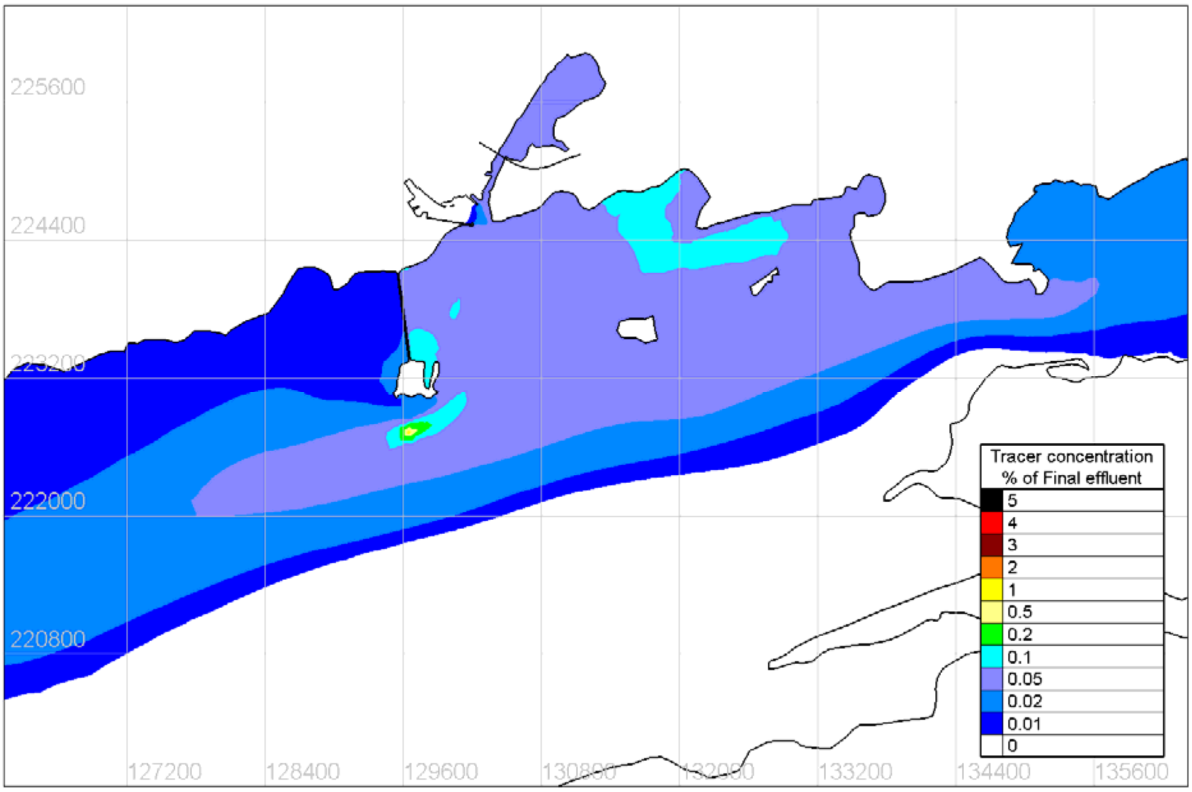

Figure 4.8.27 Tidal mean tracer concentration under SW 15m/s wind conditions – Existing Case

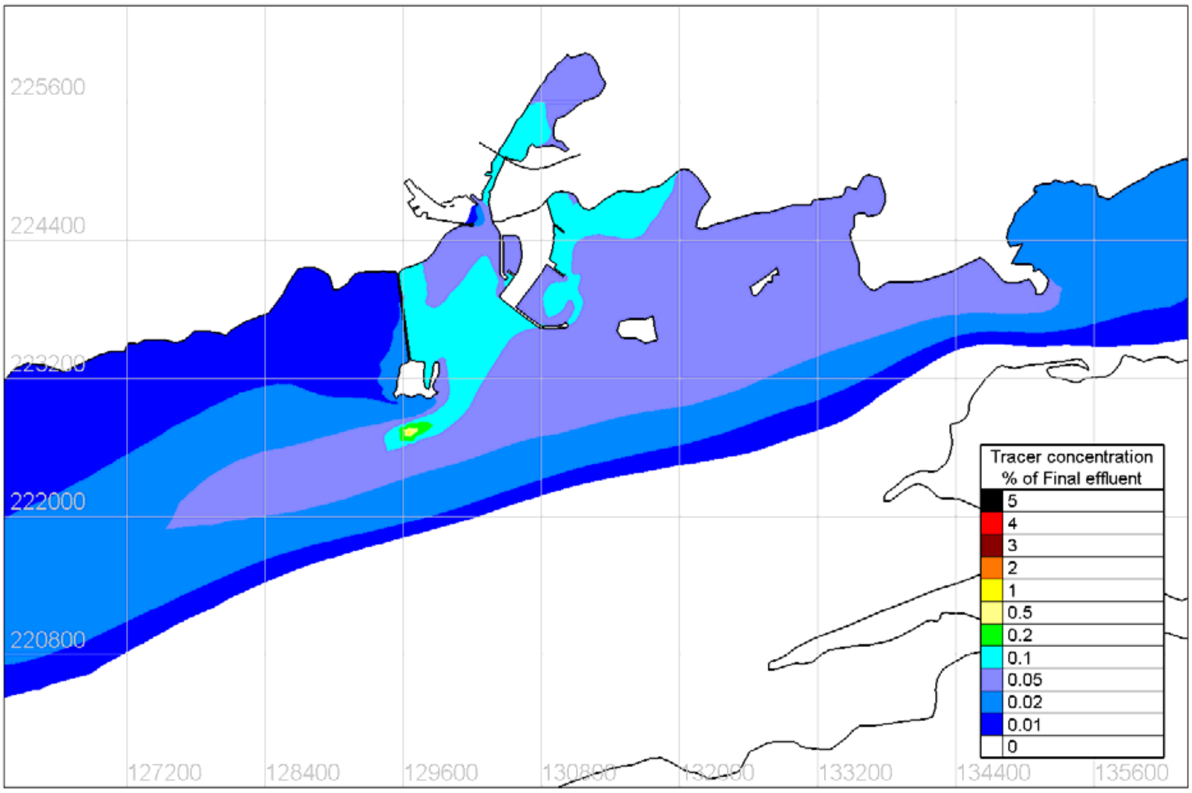

Figure 4.8.28 Tidal mean tracer concentration under SW 15m/s wind conditions – Proposed Case

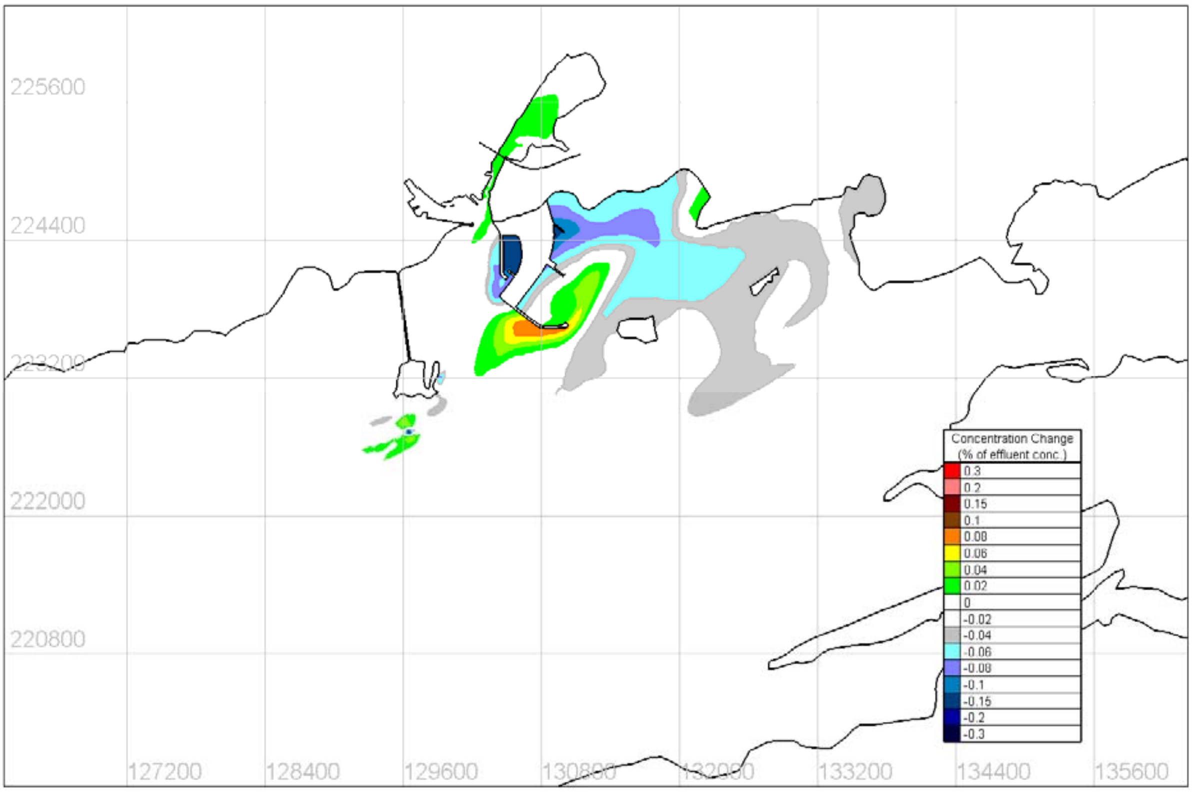

Figure 4.8.29 Predicted change in maximum surface tracer concentration – SW 15m/s Wind Conditions

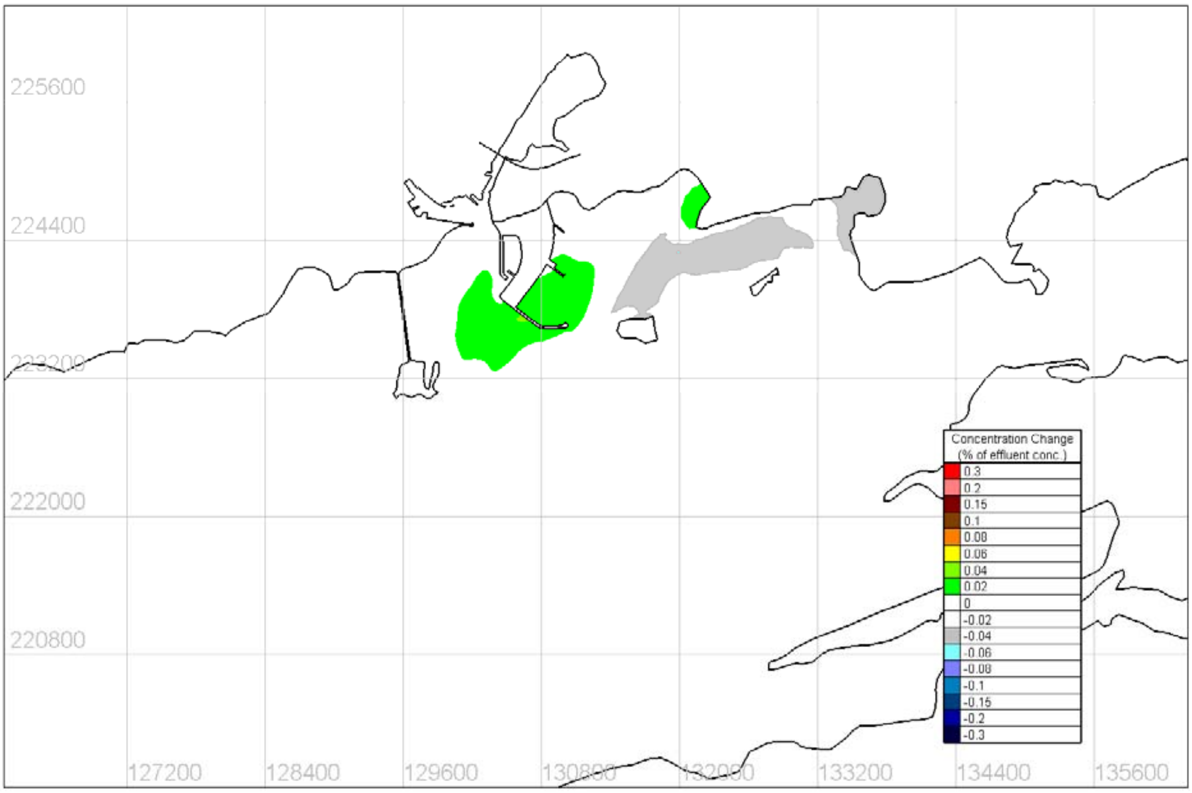

Figure 4.8.30 Predicted change in tidal mean tracer concentration – SW 15m/s Wind Condition

4.8.4.6 Spring Tide and Corrib Low Flow with 15 m/s from SSW

Figure 4.8.31 to 4.8.36 presents the concentration plume and difference plots for 15m/s wind from SSW.

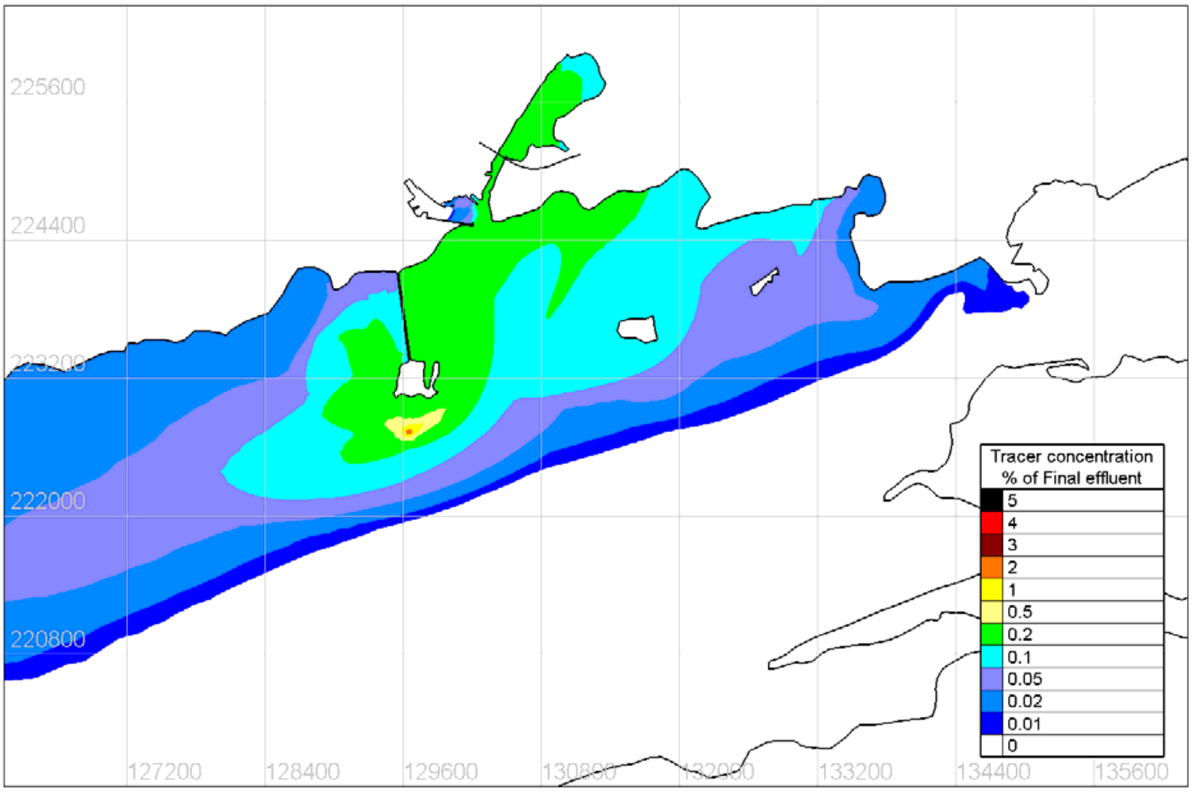

Figure 4.8.31 Maximum surface concentration of Tracer under SSW 15m/s wind conditions– Existing

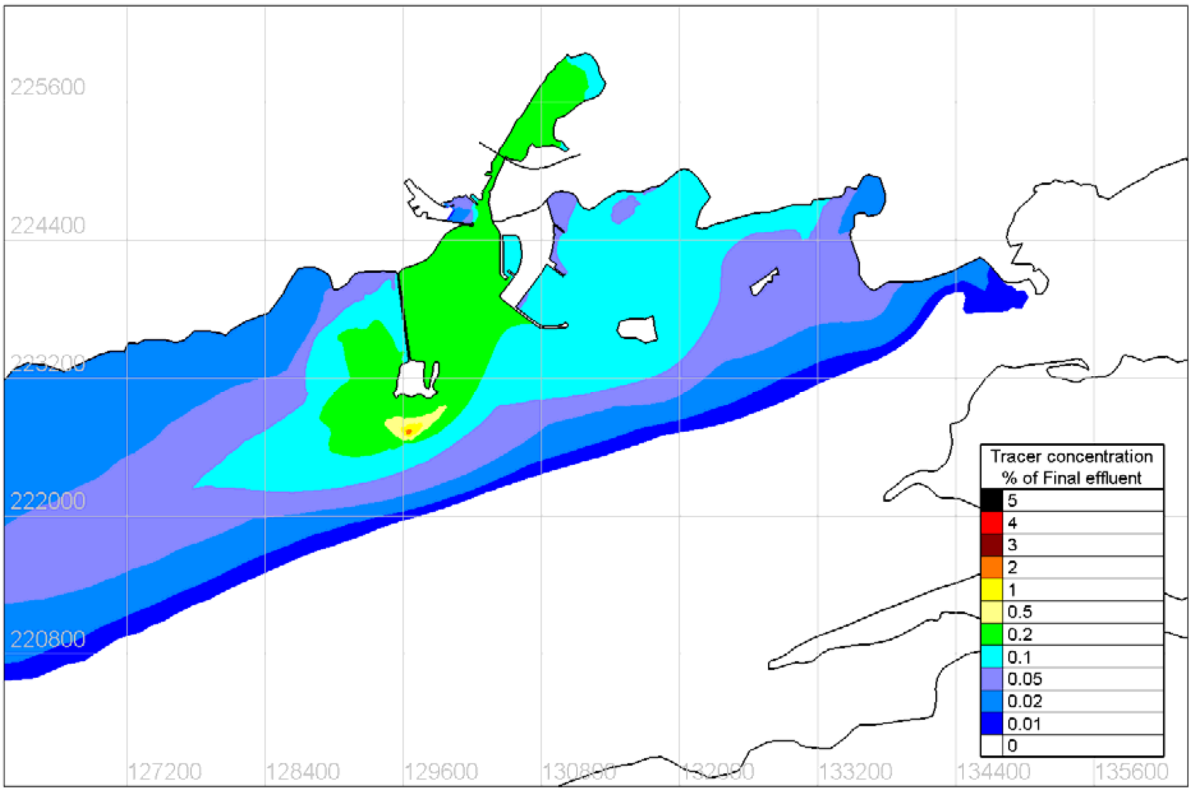

Figure 4.8.32 Maximum surface concentration of Tracer under SSW 15m/s wind conditions– Proposed

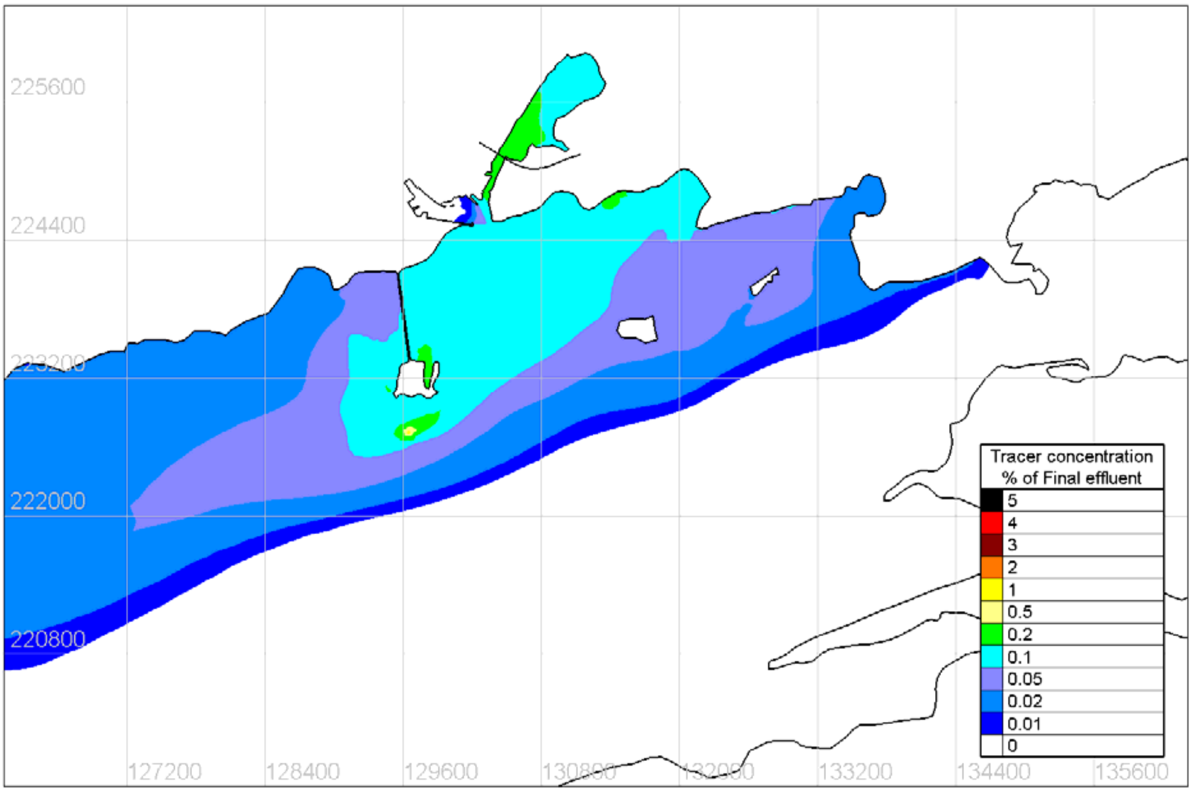

Figure 4.8.33 Tidal mean tracer concentration under SSW 15m/s wind conditions – Existing Case

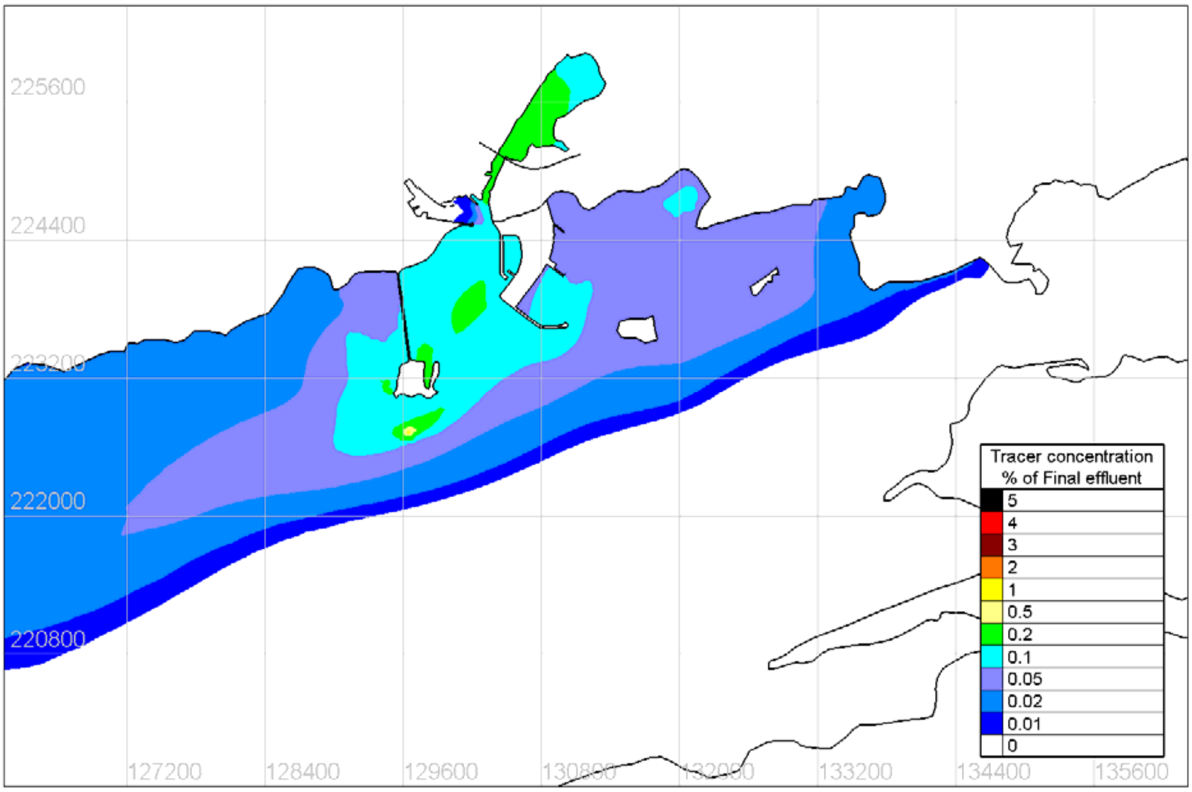

Figure 4.8.34 Tidal mean tracer concentration under SSW 15m/s wind conditions – Proposed Case

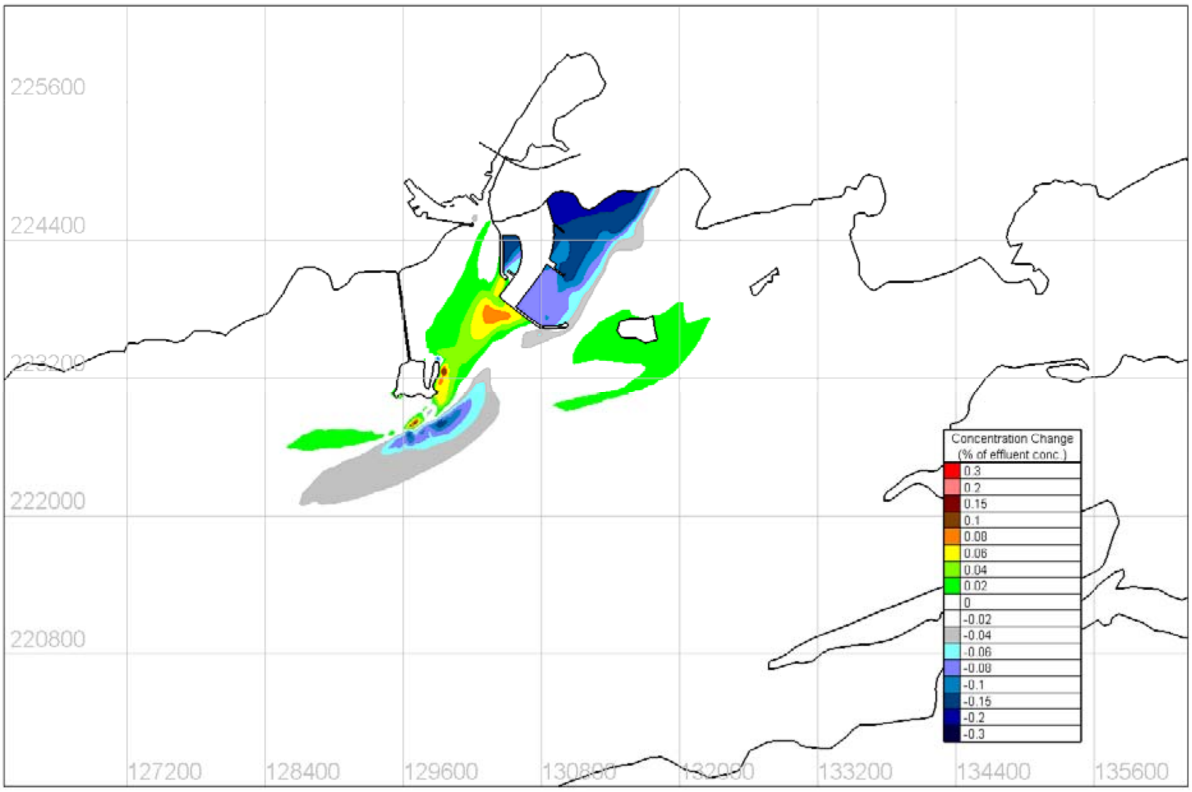

Figure 4.8.35 Predicted change in maximum surface tracer concentration – SSW 15m/s Wind Conditions

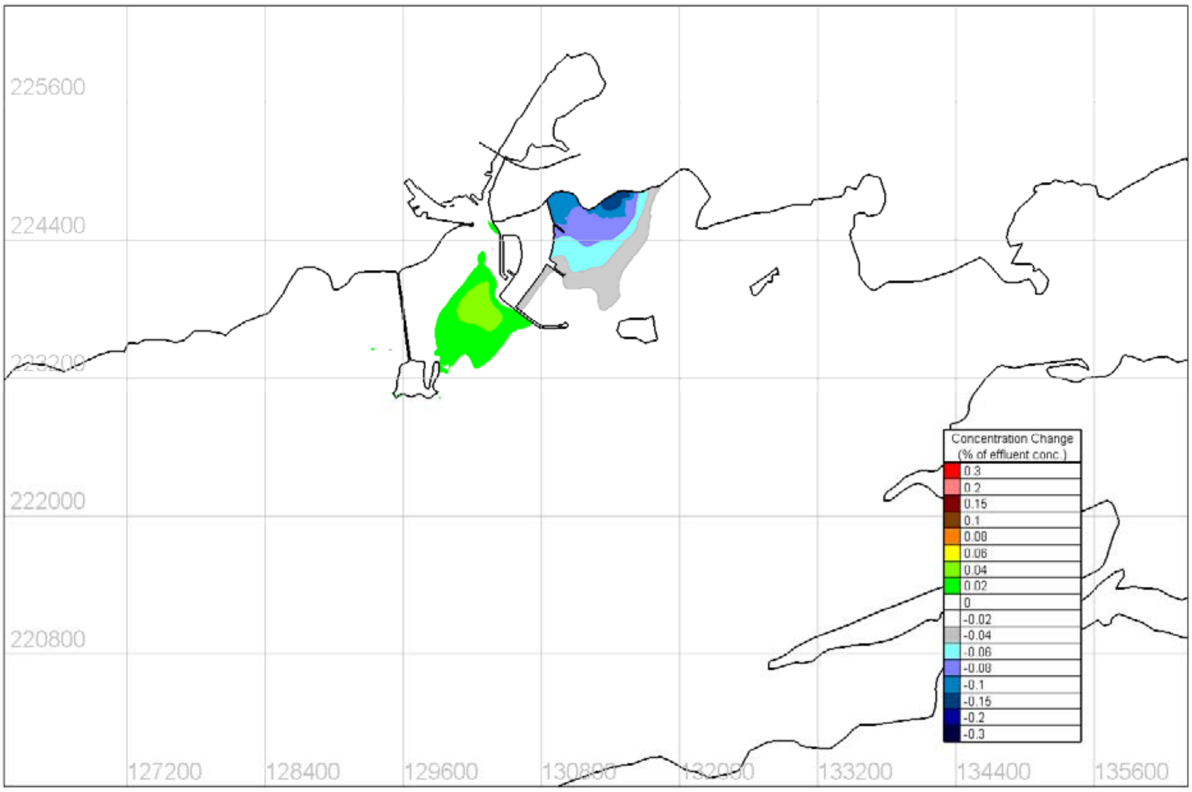

Figure 4.8.36 Predicted change in tidal mean tracer concentration – SSW 15m/s Wind Condition

4.8.4.7 Spring Tide and Corrib Low Flow with 5 m/s from South

Figure 4.8.37 to 4.8.42 presents the concentration plume and difference plots for 15m/s wind from South.

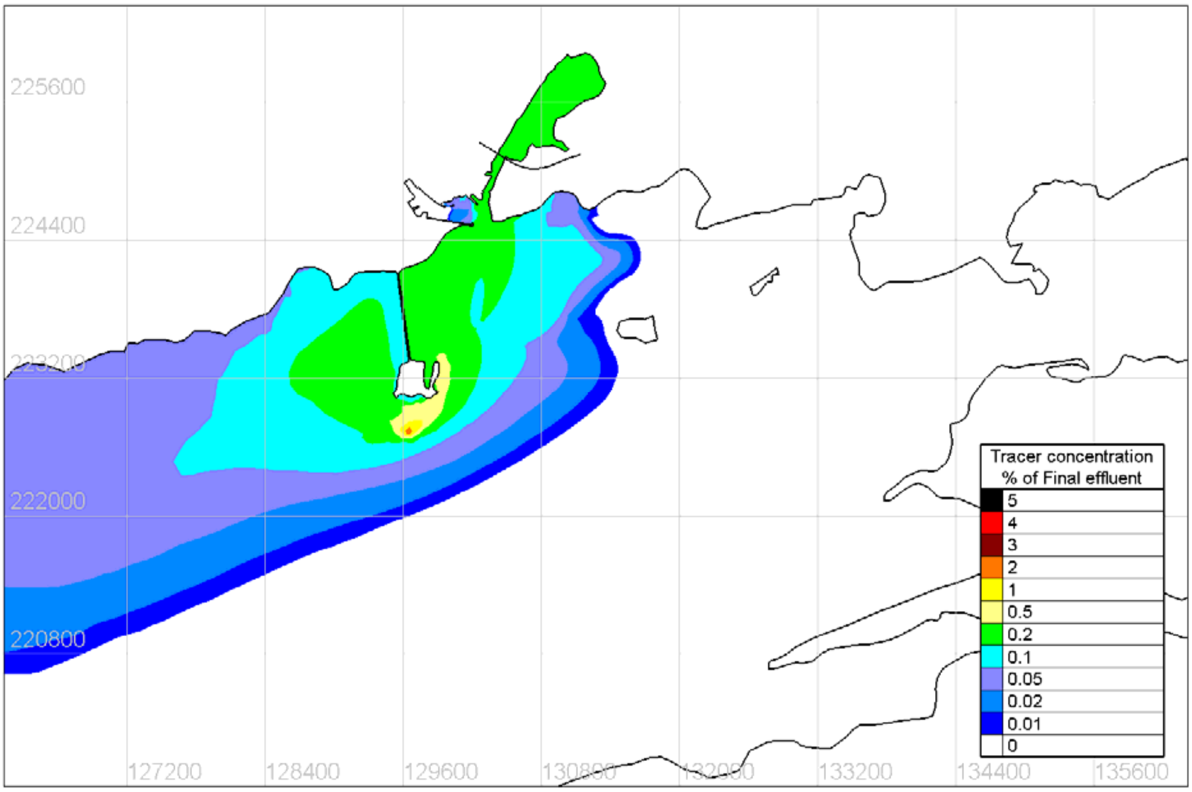

Figure 4.8.37 Maximum surface concentration of Tracer under S 15m/s wind conditions– Existing

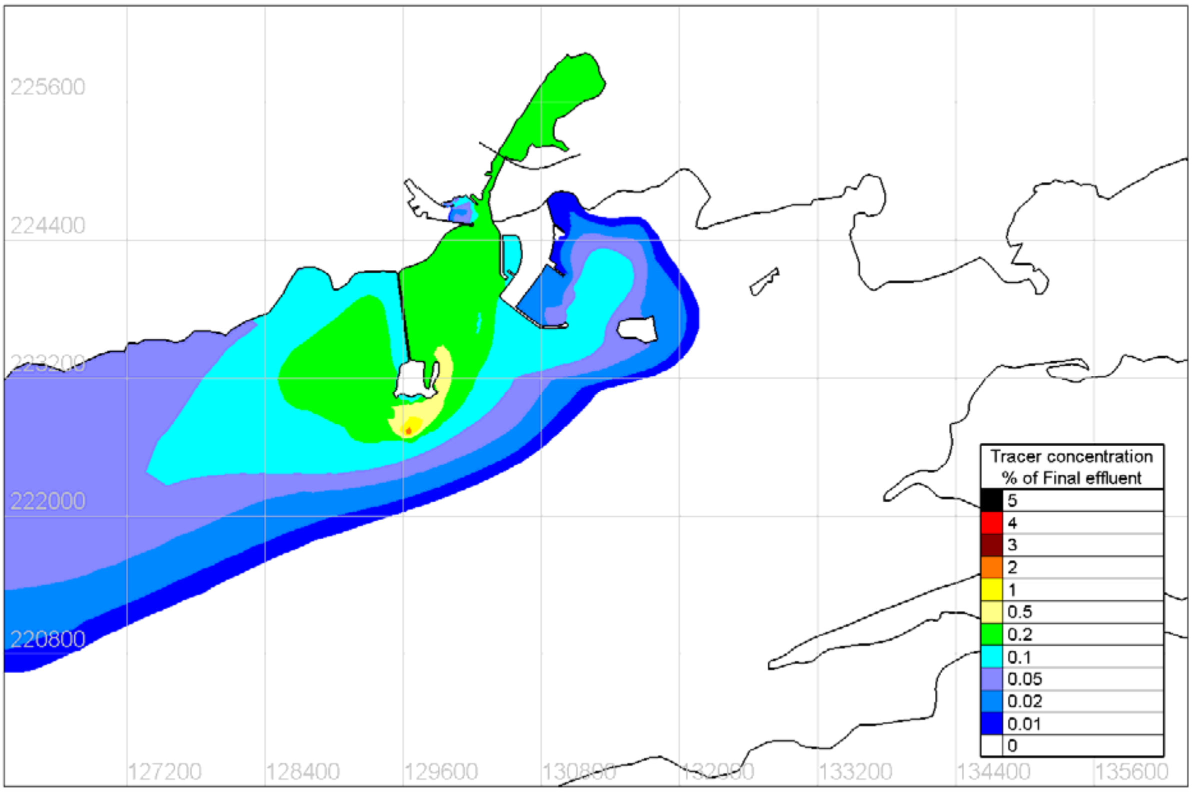

Figure 4.8.38 Maximum surface concentration of Tracer under S 15m/s wind conditions– Proposed

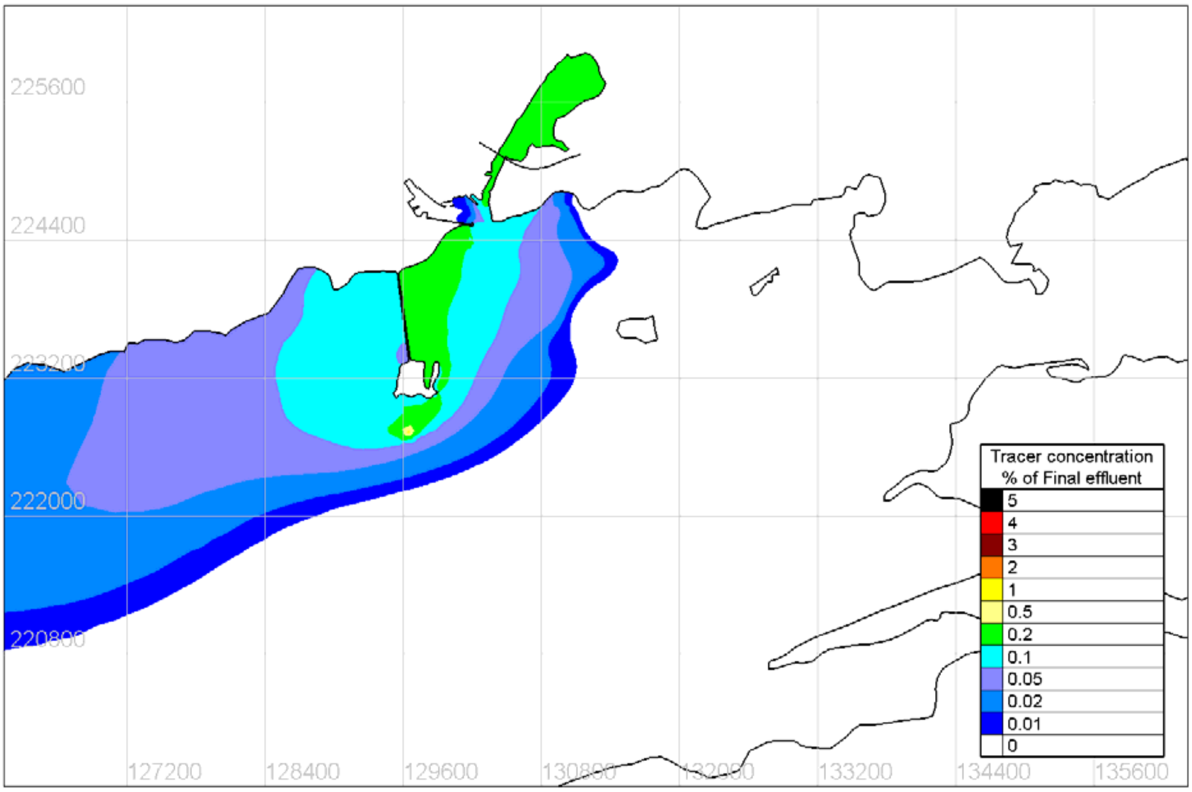

Figure 4.8.39 Tidal mean tracer concentration under S 15m/s wind conditions – Existing Case

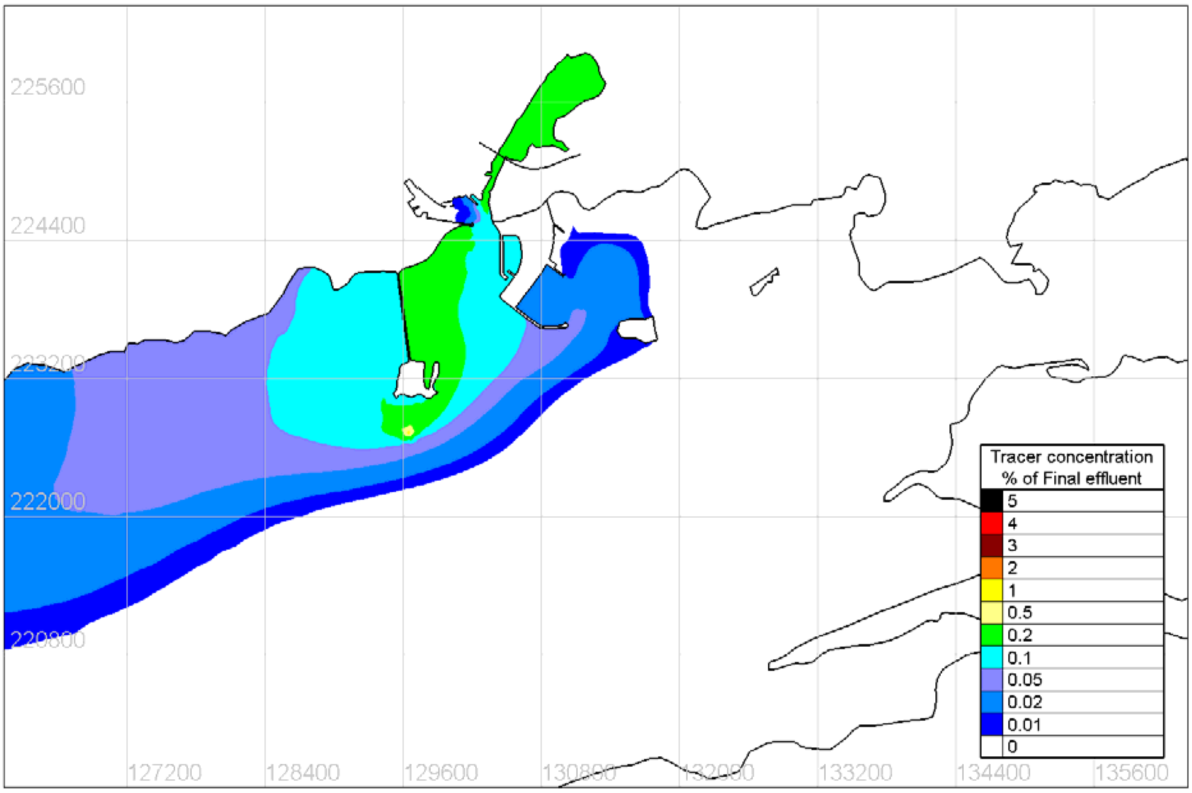

Figure 4.8.40 Tidal mean tracer concentration under S 15m/s wind conditions – Proposed Case

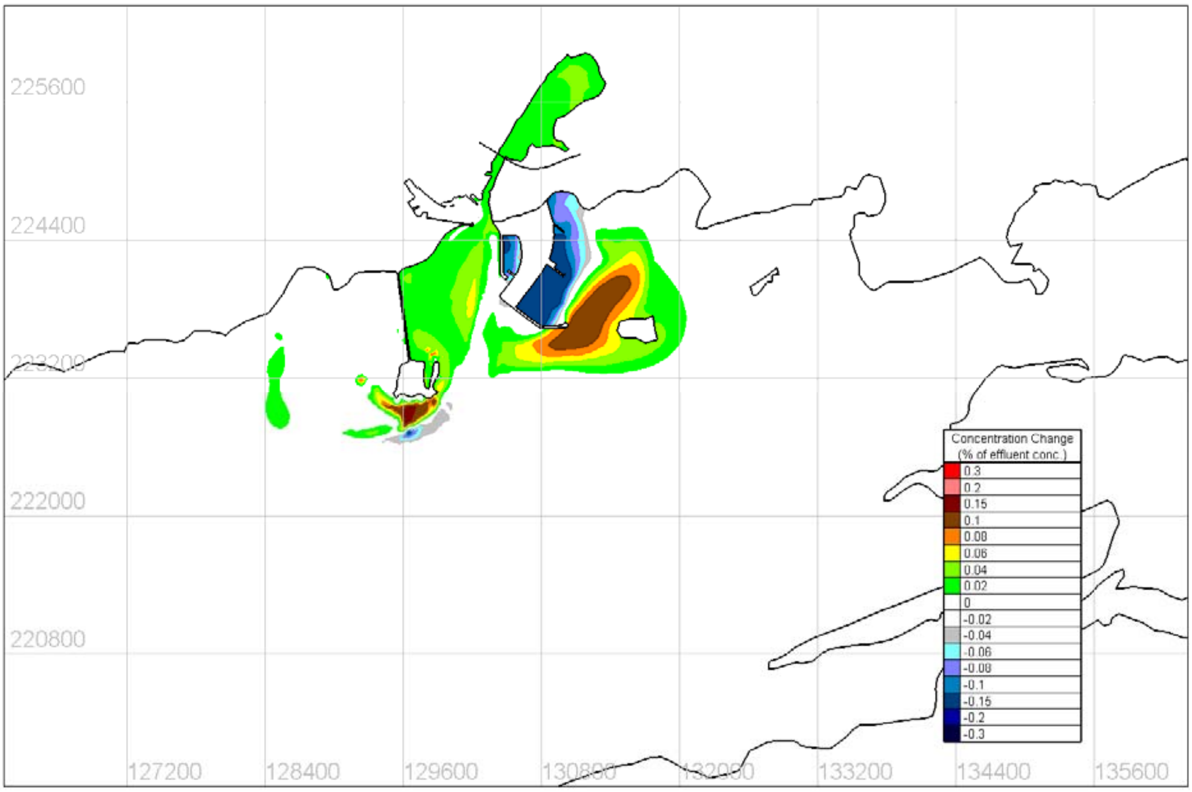

Figure 4.8.41 Predicted change in maximum surface tracer concentration – S 15m/s Wind Conditions

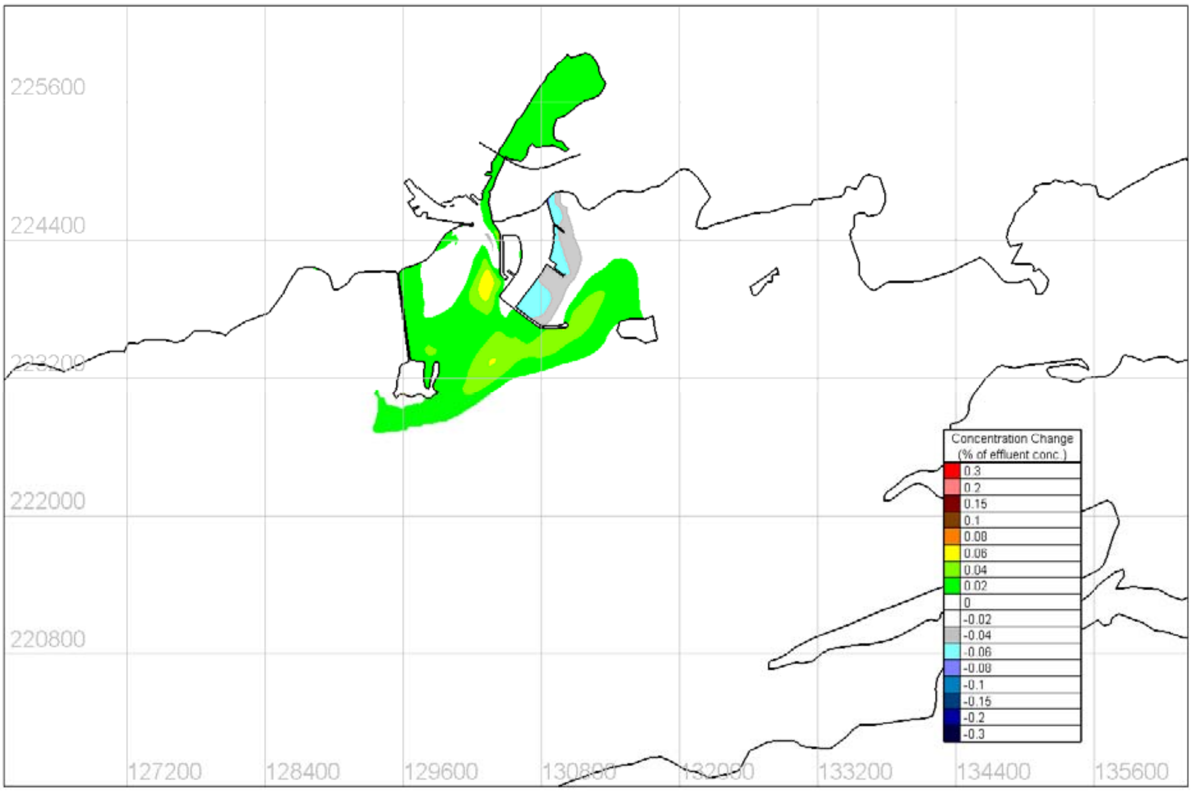

Figure 4.8.42 Predicted change in tidal mean tracer concentration – S 15m/s Wind Condition

4.8.5 Discussion Mutton Island Outfall

4.8.5.1 Conservative Tracer

Hydrodynamic Simulations of a conservative tracer were carried out for 7 different hydrodynamic / wind conditions for the Licensed Mutton Island Discharge. A comparison between the existing and proposed cases shows changes in the Plume pattern in the vicinity of Mutton Island and the Harbour development due directly to changes in the tidal circulation pattern caused by the harbour structure and navigational channels.

Under calmer wind conditions including the 5m/s wind simulations the model results show a slight increase in pollutant concentration of between 0.05% and 0.1% of the effluent concentration to the north of the outfall. The locations of increase are north of the outfall and east of Mutton Island, the Corrib entrance and Lough Atalia and along the Renmore Shoreline area to the East of the New Harbour. Areas of reduction in pollutant concentration are shown to the south of the outfall and in the immediate vicinity of the Harbour development, within the slacker water areas.

The largest predicted changes in concentration are immediately to the north of the outfall on the flooding tide where the plume trajectory under the proposed case takes a sharper more northerly route on the flooding tide. Corresponding reduction in concentrations are shown to the south of the outfall due to this northerly shift in the plume trajectory.

Under stronger wind conditions there are generally more similar plume paths and mixing at the outfall site and thus showing little change in pollutant concentrations. Under these stronger onshore wind conditions greater plume transport for both proposed and existing cases pushes the plume northwards into Lough Atalia and along Renmore Beach. However the relative change in pollutant concentration is small at generally less than 0.05 % between proposed and existing cases.

Immediately at the outfall site increases of up to 0.5% of effluent concentration for the proposed development case are predicted and generally less than 0.15% at the Corrib entrance and 0.1 to 0.15% to the east of the Harbour development. Within Lough Atalia the predicted maximum increase is less than 0.1% and the mean increase is typically less than 0.05%. Along the Renmore shoreline the maximum increase is less than 0.1%. Refer to Table 8.2 below as a guide for converting change in percentage values to mg/l (or cfu/100ml).

Pollutant	Mutton Island WWTP Final effluent concentration
Faecal Coliforms	**300,000 cfu/100ml**
BOD	**25 mg/l O_2**
Ammonia	**22.5mg/l as n**
Suspended Solids	**35mg/l**
Total Oxidised Nitrogen	**20mg/l**

Table 4.8.1 Final Effluent Quality for Mutton Island outfall

In terms of the above chemical parameters the predicted maximum percentage change resulting from the Harbour development is minor in terms of the respective concentrations and water quality standards and will not have a perceptible impact on the salmonid waters of the Corrib or on the water quality within Lough Atalia Lagoonal Water Body, prior to the application of a dilution factor at the diffused outfall.

Pollutant Chemical parameter	Effluent Concentration	Percentage Change			
		0.05%	0.1%	0.15%	0.5%
		Change in Concentration (mg/l)			
BOD	25 mg/l O_2	0.0125	0.025	0.0375	0.125
Ammonia	22.5mg/l as n	0.0113	0.0225	0.0338	0.1125
Suspended Solids	35mg/l	0.0175	0.035	0.0525	0.175
Total Oxidised Nitrogen	20mg/l	0.010	0.020	0.030	0.100

Table 4.8.2 Pollutant Concentration based on percentage change in effluent concentration

4.8.5.2 Faecal Coliforms

In respect to the bacteriological contaminants, such as faecal coliforms the conservative tracer simulations (i.e. do not include for die-off rates for faecal coliforms) show a potential impact to the Ballyloughaun beach area under the proposed development case. Typically the predicted maximum coliform numbers for the existing case under calm wind conditions are 300 cfu/100ml (i.e. 0.1% of 300,000 cfu/100ml final effluent) at Grattan Road Beach, 600 cfu / 100ml at Corrib entrance and 100cfu/ 100ml at Ballyloughaun Beach. The proposed case produces almost similar concentrations of 300 cfu at Grattan Rd Beach, 860 cfu/100ml at Corrib entrance (increase of 260 cfu/100ml) and 360 No/100ml at Ballyloughaun Beach (an increase of 260 cfu/100ml over the existing).

This predicted increase of 260 cfu/100ml faecal coliforms at Ballyloughaun Beach based on the conservative tracer simulation is significant in terms of Bathing Quality standards. Consideration of the simulation time series of faecal coliform concentration shows that the build-up at Ballyloughaun is over a number of days, which in reality is unlikely to occur given that T_{90} die-off rates are generally less than 12hours during summer periods and typically less than 24hours in winter periods.

To examine in more detail the potential impact from faecal coliforms specific dispersion model runs were carried out modelling a faecal coliform effluent concentration of 300,000 cfu/100ml with a low T90 die-off rate of 24hours (generally for bathing water studies higher die-off rates are used namely 90% die-off in 12hours as opposed to 24hours) and a dwf discharge rate of 0.3542 No./100ml.

Hydrodynamic simulation runs modelling calm wind conditions and an adverse 15m/s SSW wind were carried out for the existing and proposed cases. The simulation results in terms of predicted maximum concentrations and concentration change are presented in Figures 8.43 to 8.45 for the calm wind scenario and 8.46 to 8.48 for the SSW 15m/s wind.

These simulations with the T90 die-off rate of 24hours show significant reduction in coliform numbers over the conservative tracer simulation. The Simulation gives maximum predicted concentrations of 15, 130 and 1 cfu /100ml at Grattan Beach, Corrib entrance and Ballyloughaun Beach for the existing case under calm wind conditions and predicts maximum concentrations of 3, 451, and 43No./100ml under SSW 15m/s wind conditions. For the proposed case the simulation predicts maximum concentrations of 15, 227 and 10 cfu/100ml at Grattan Beach , at Corrib entrance and at Ballyloughaun Beach for Calm wind conditions and 3, 490and 36 cfu/100ml at the respective locations for SSW 15m/s wind condition.

If the Mutton Island outfall diffuser nearfield dilution is factored in, the above predicted concentrations would be significantly lower, pro rata for both the existing and proposed cases.

The magnitude of the predicted coliform concentrations at Grattan and Ballyloughaun beaches is small in terms of bathing waters standards (Blue Flag excellent quality class < 250 cfu/100ml at 95%ile) and therefore the small changes in water quality brought about by the proposed development will not impact on the water quality or bathing status of these waters or on the overall performance of the Mutton Island outfall.

4.8.5.2.1 Spring tide and Corrib low flow and Calm Wind Conditions – Faecal Coliforms

Figure 4.8.43 to 4.8.45 presents the maximum concentration plume and difference plots for calm wind conditions.

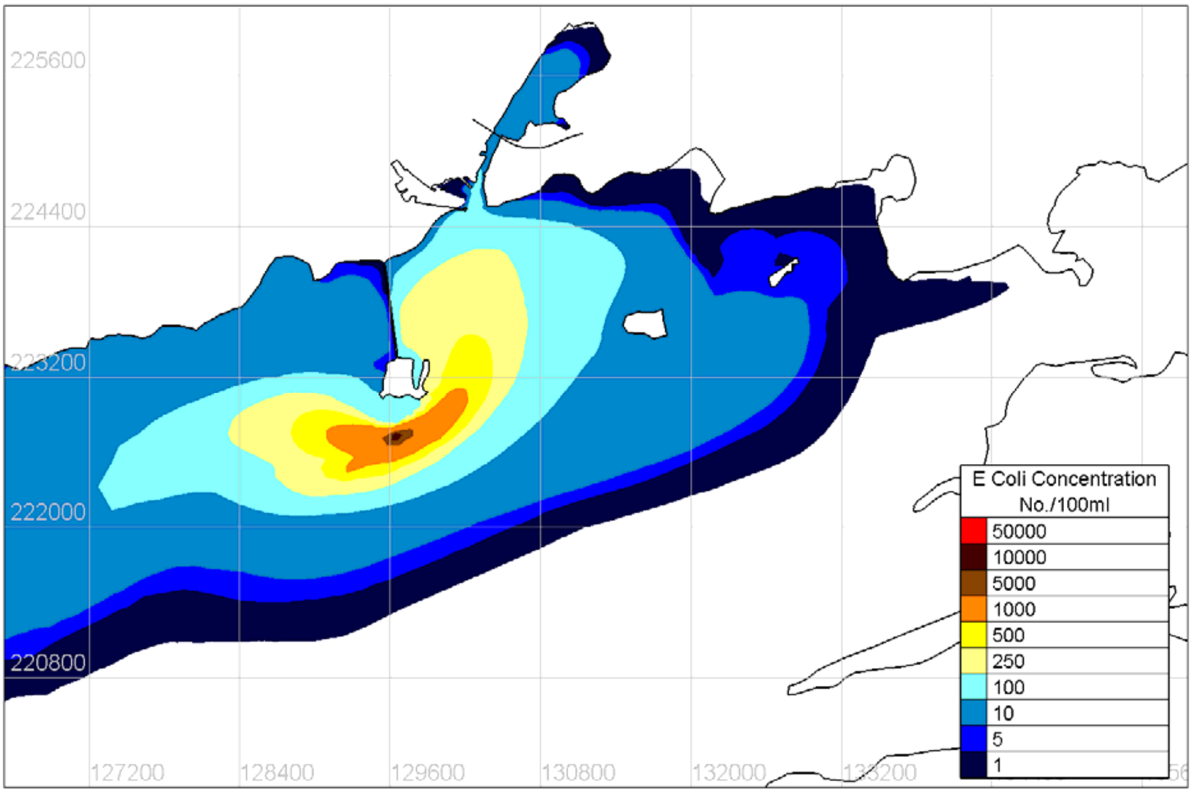

Figure 4.8.43Maximum faecal coliform surface concentration under Calm wind conditions– Existing

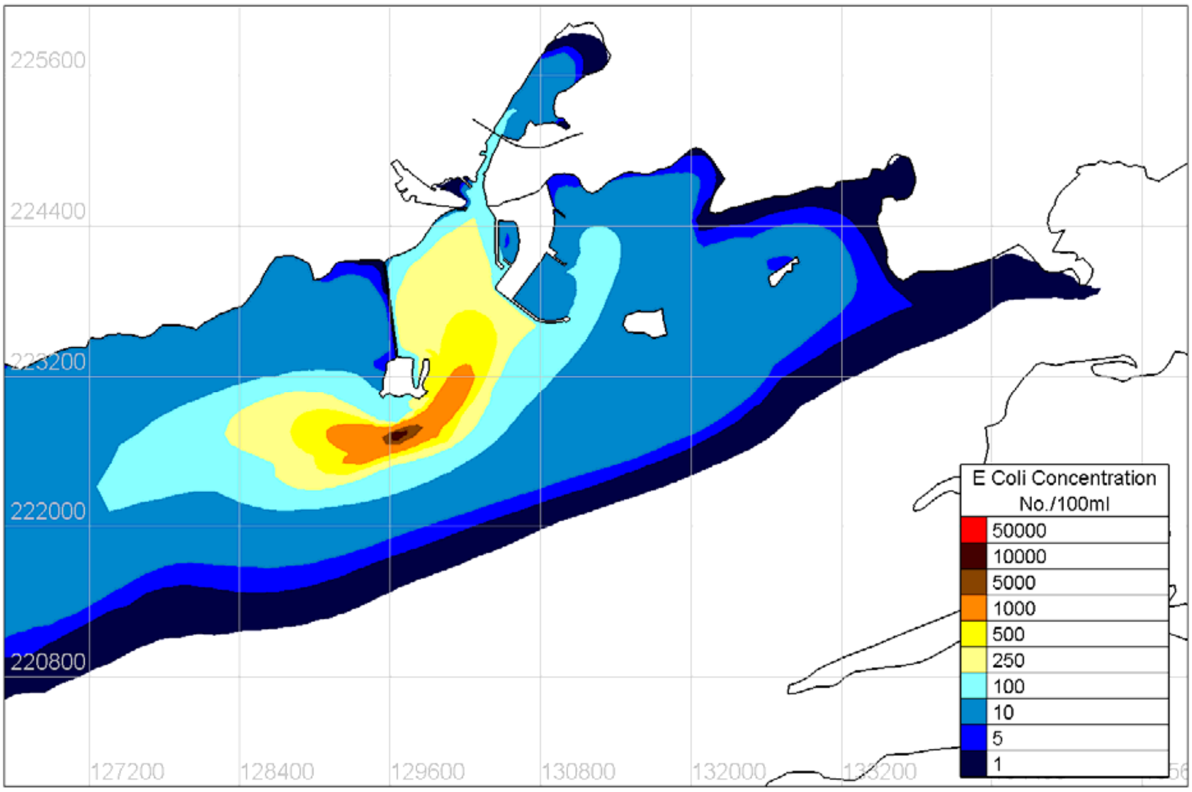

Figure 4.8.44 Maximum faecal coliform surface concentration under Calm wind conditions– Proposed

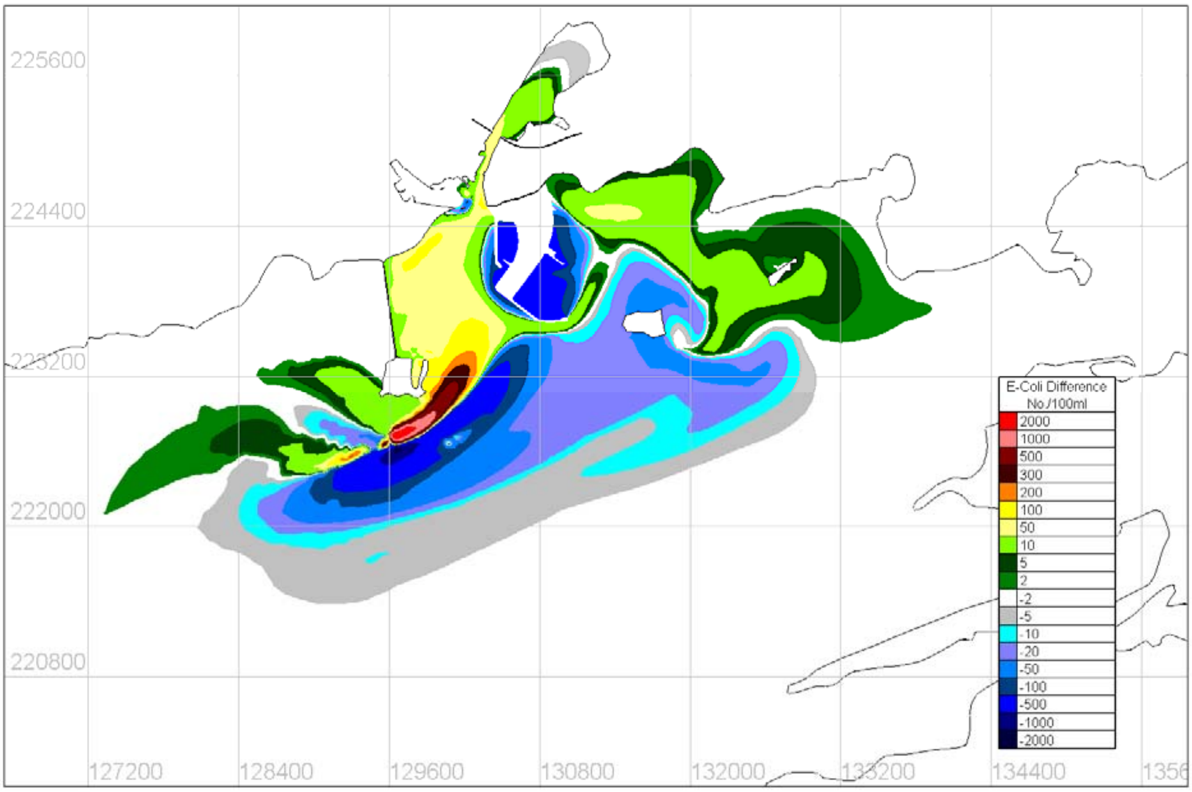

Figure 4.8.45 Predicted change in maximum faecal Coliform concentration – Calm Wind Conditions

4.8.5.2.2 Spring tide and Corrib low flow with SSW 15m/s Wind– Faecal Coliforms

Figure 4.8.46 to 4.8.48 presents the maximum concentration plume and difference plots for calm wind conditions.

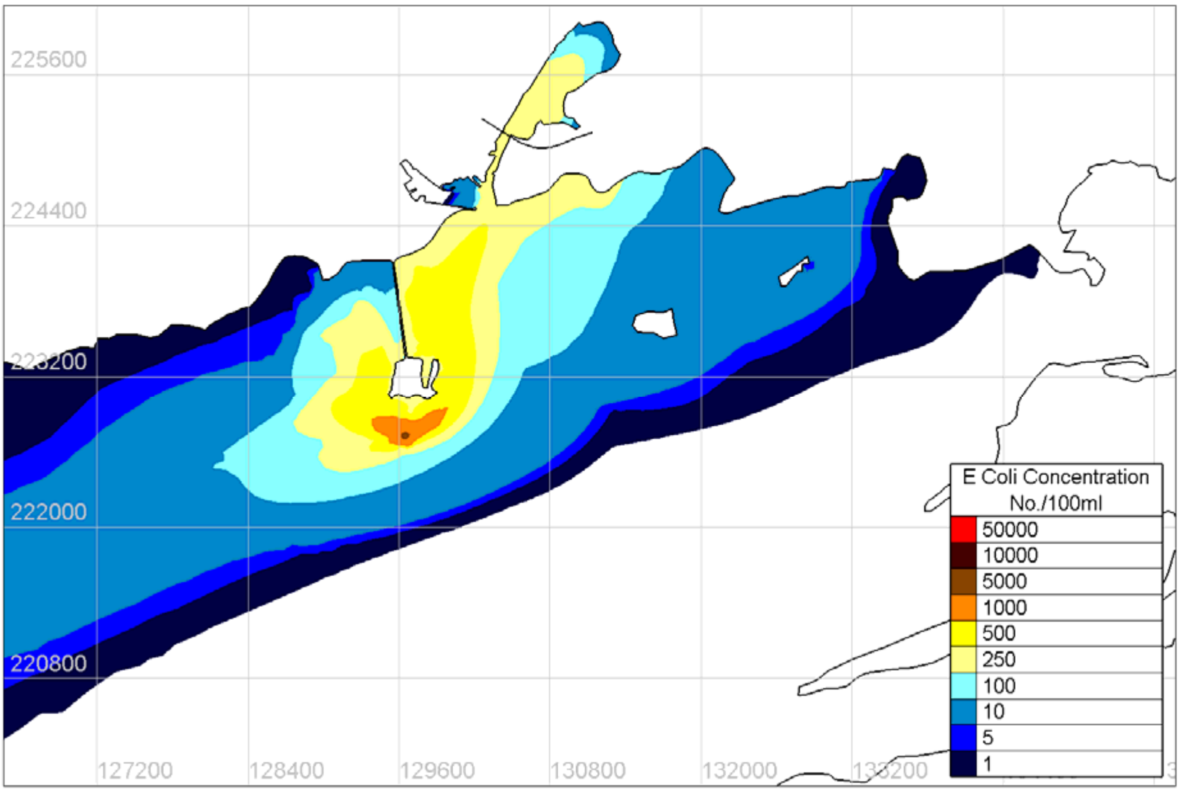

Figure 4.8.46 Maximum faecal coliform surface concentration of Tracer under SSW 15m/s wind conditions– Existing

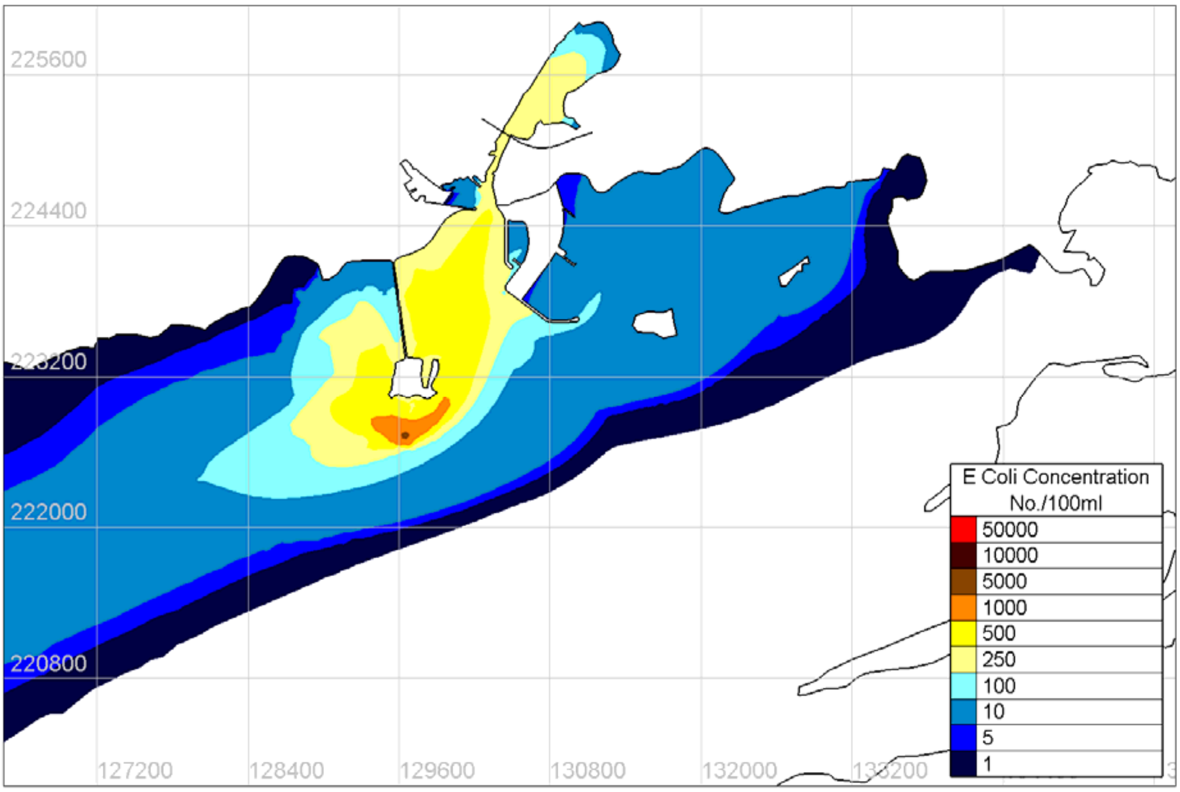

Figure 4.8.47 Maximum surface coliform concentration of Tracer under SSW 15m/s wind conditions– Proposed

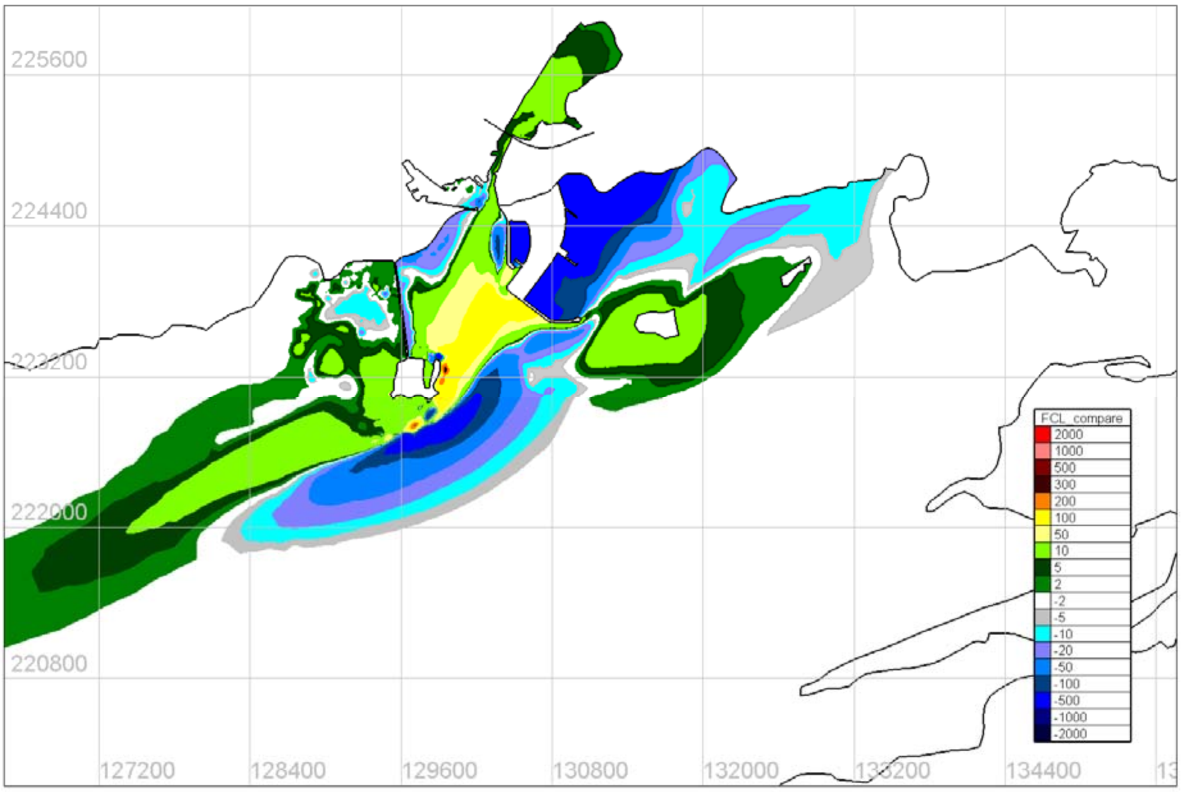

Figure 4.8.48 Predicted change in maximum surface tracer concentration – SSW Wind Conditions

4.8.6 Galway East Outfall Simulations

4.8.6.1 Spring tide and Corrib low flow and SW 15m/s Wind Condition

Figure 4.8.48 to 4.8.54 presents the concentration plume and difference plots for SW 15m/s wind conditions.

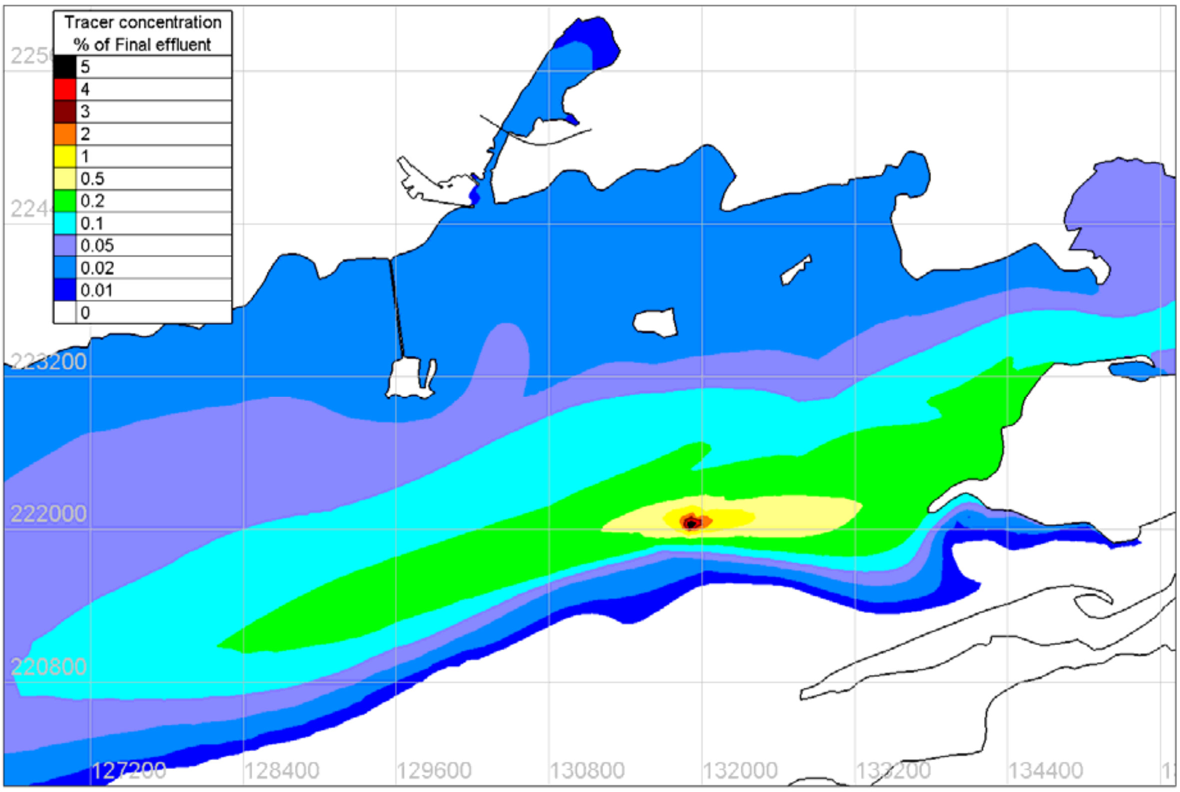

Figure 4.8.49 Maximum surface concentration of Tracer under SW 15m/s wind conditions– Existing

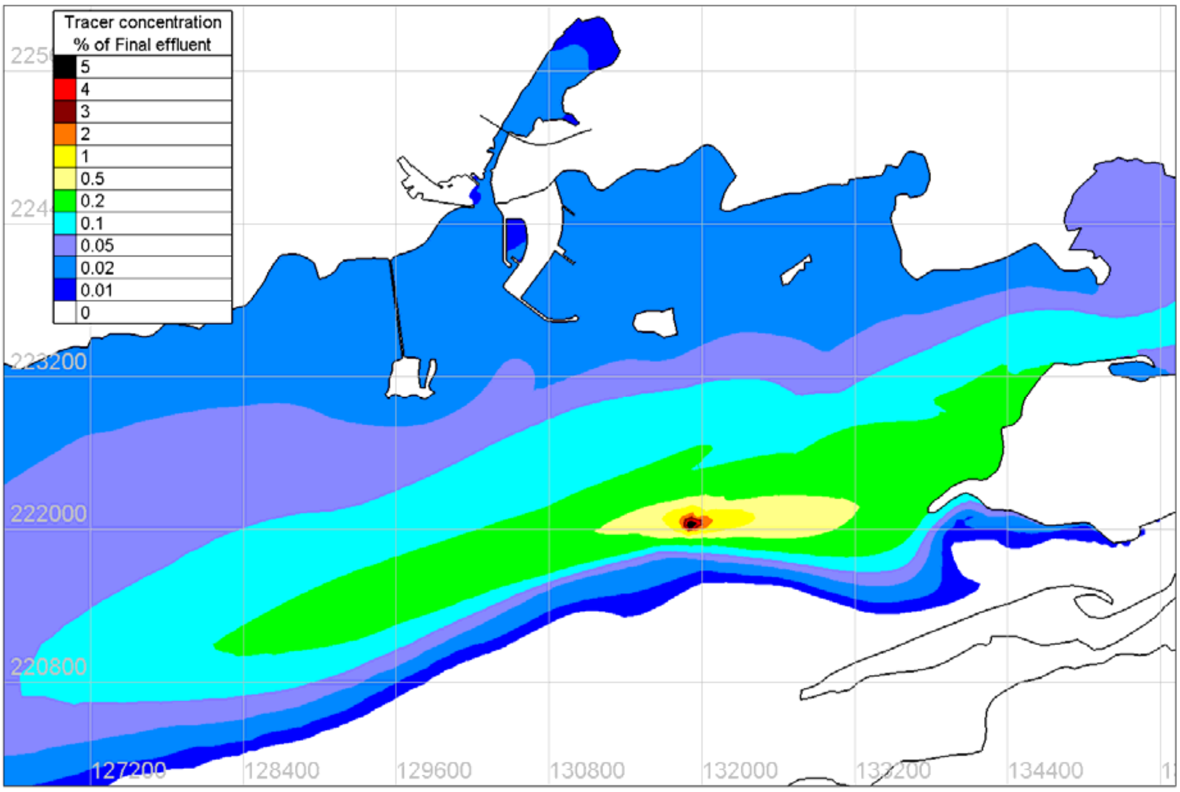

Figure 4.8.50 Maximum surface concentration of Tracer under SW 15m/s wind conditions– Proposed

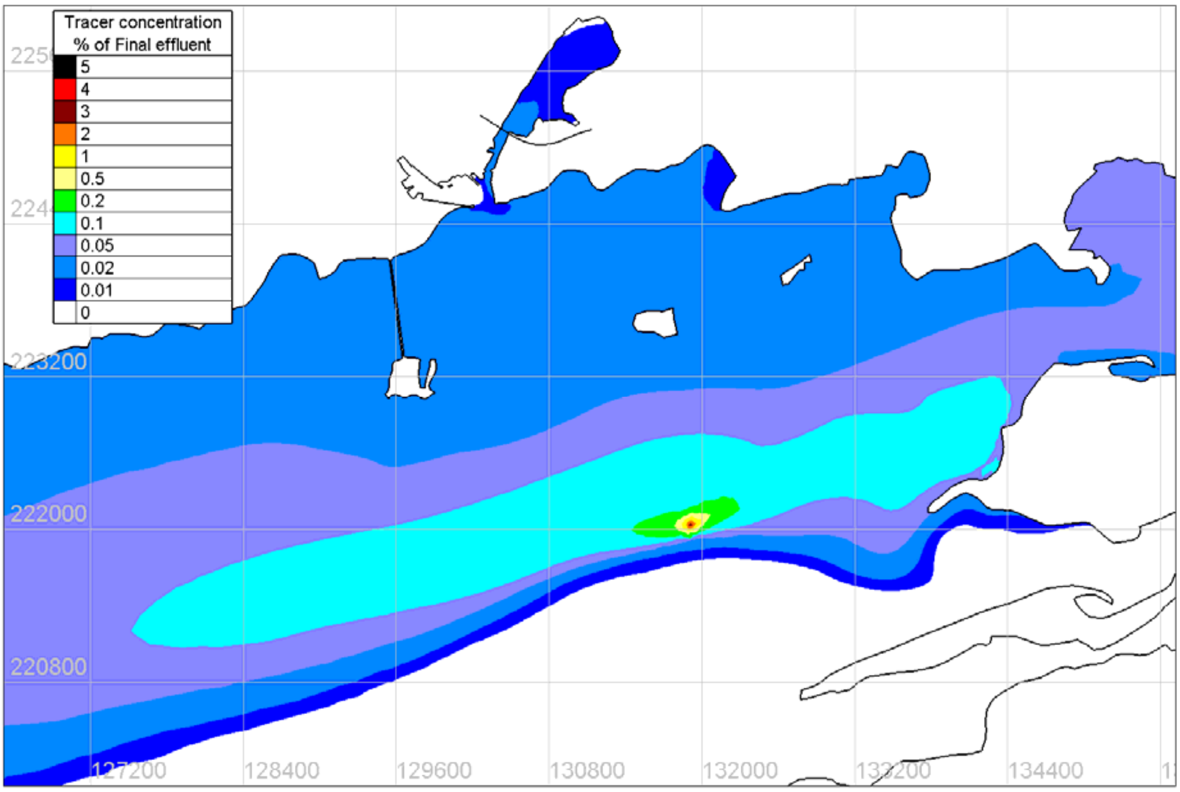

Figure 4.8.51 Tidal mean tracer concentration under SW 15m/s wind conditions – Existing Case

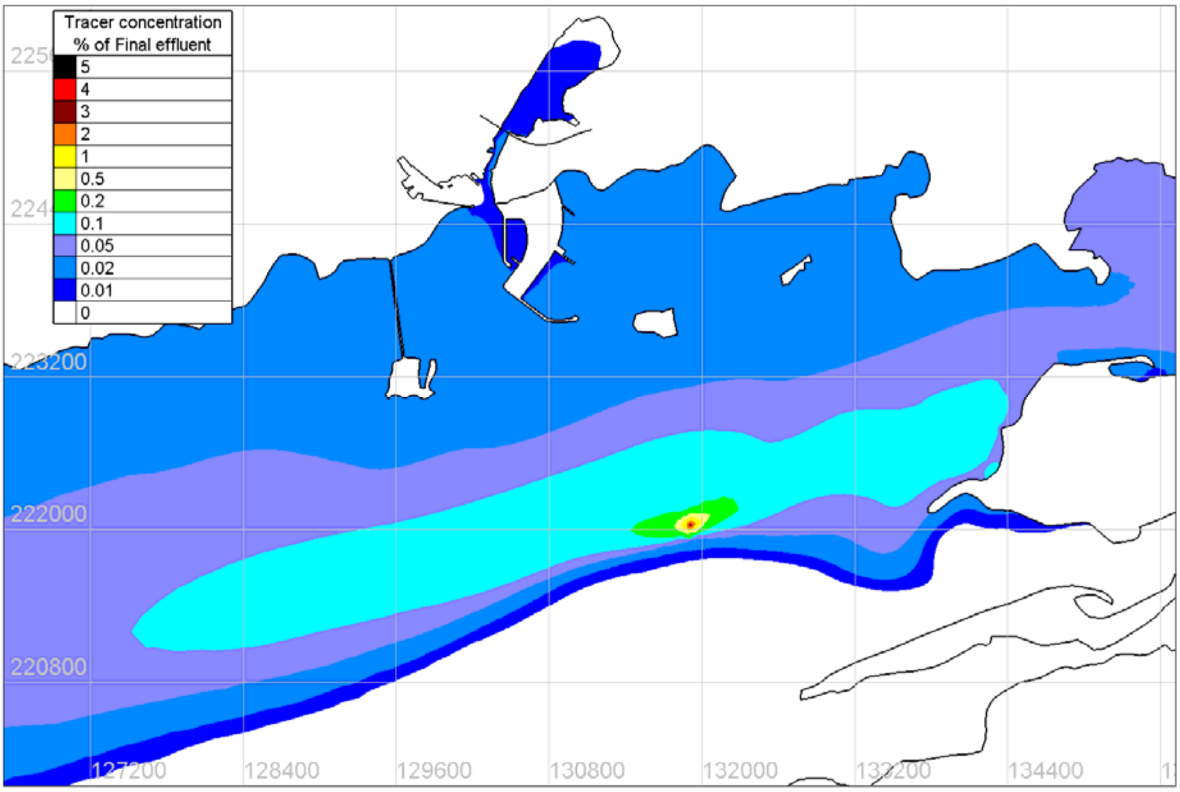

Figure 4.8.52 Tidal mean tracer concentration under SW 15m/s wind conditions – Proposed Case

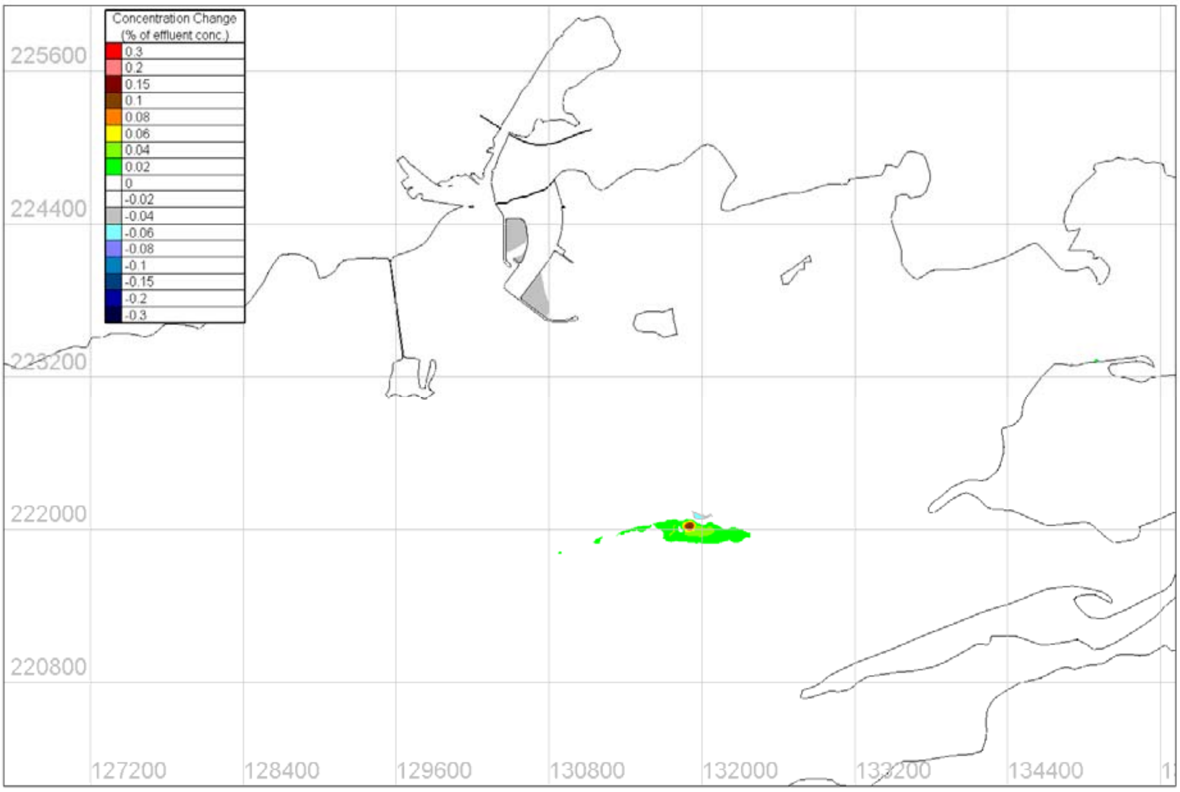

Figure 4.8.53 Predicted change in maximum surface tracer concentration – SW 15m/s Wind Conditions

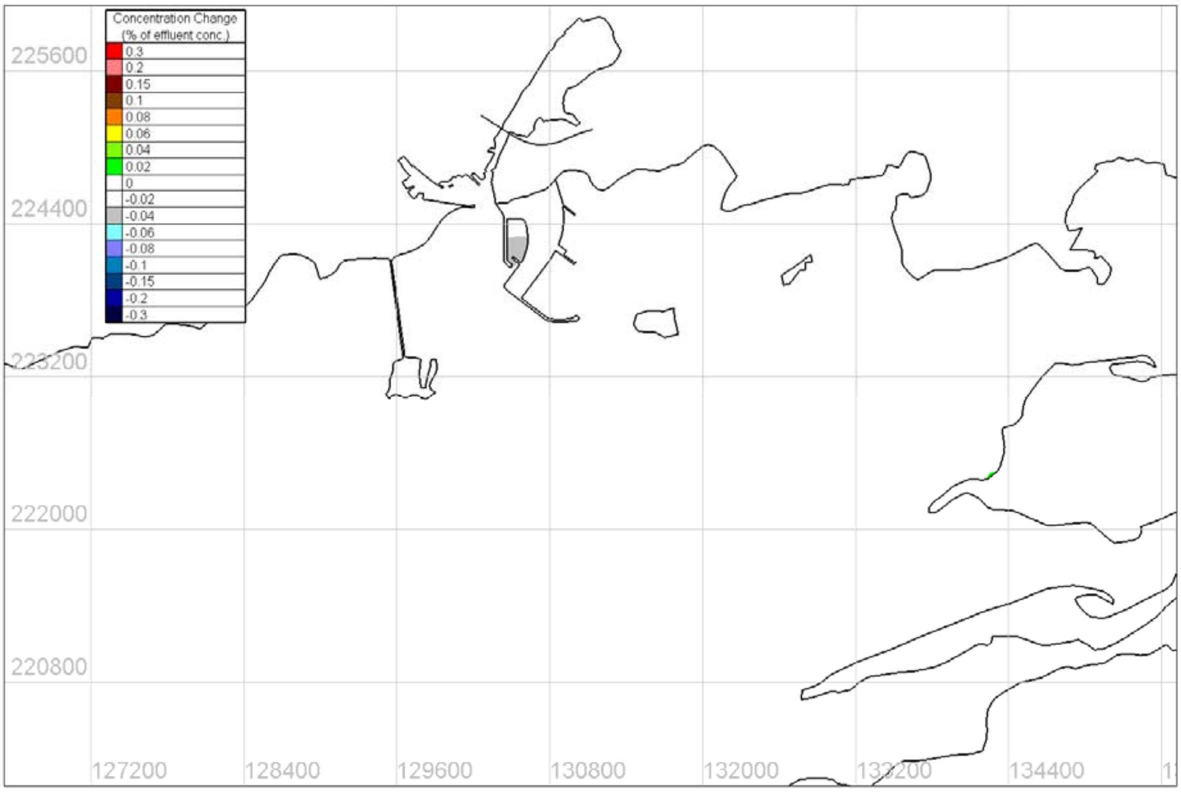

Figure 4.8.54 Predicted change in tidal mean tracer concentration – SW 15m/s Wind Condition

4.8.6.2 Spring tide and Corrib low flow and southerly 15m/s Wind Condition

Figure 4.8.55 to 4.8.60 presents the concentration plume and difference plots for South 15m/s wind conditions.

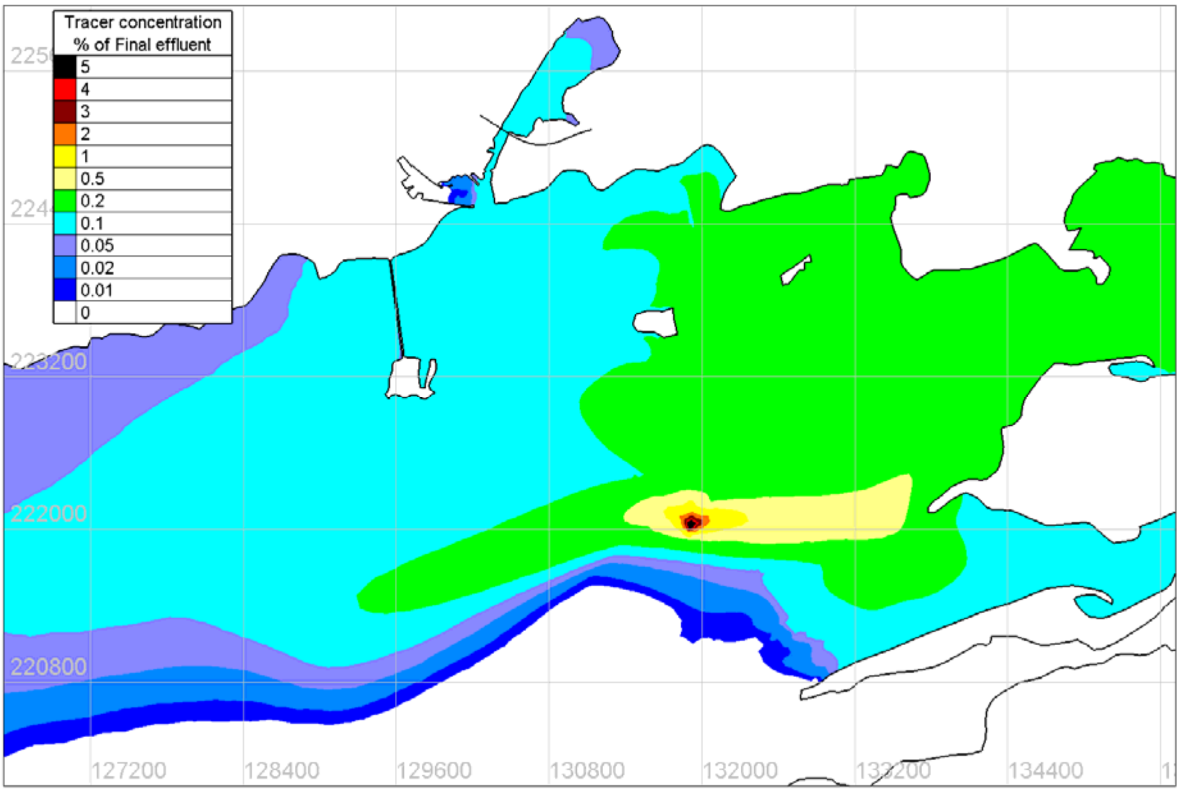

Figure 4.8.55 Maximum surface concentration of Tracer under S 15m/s wind conditions– Existing

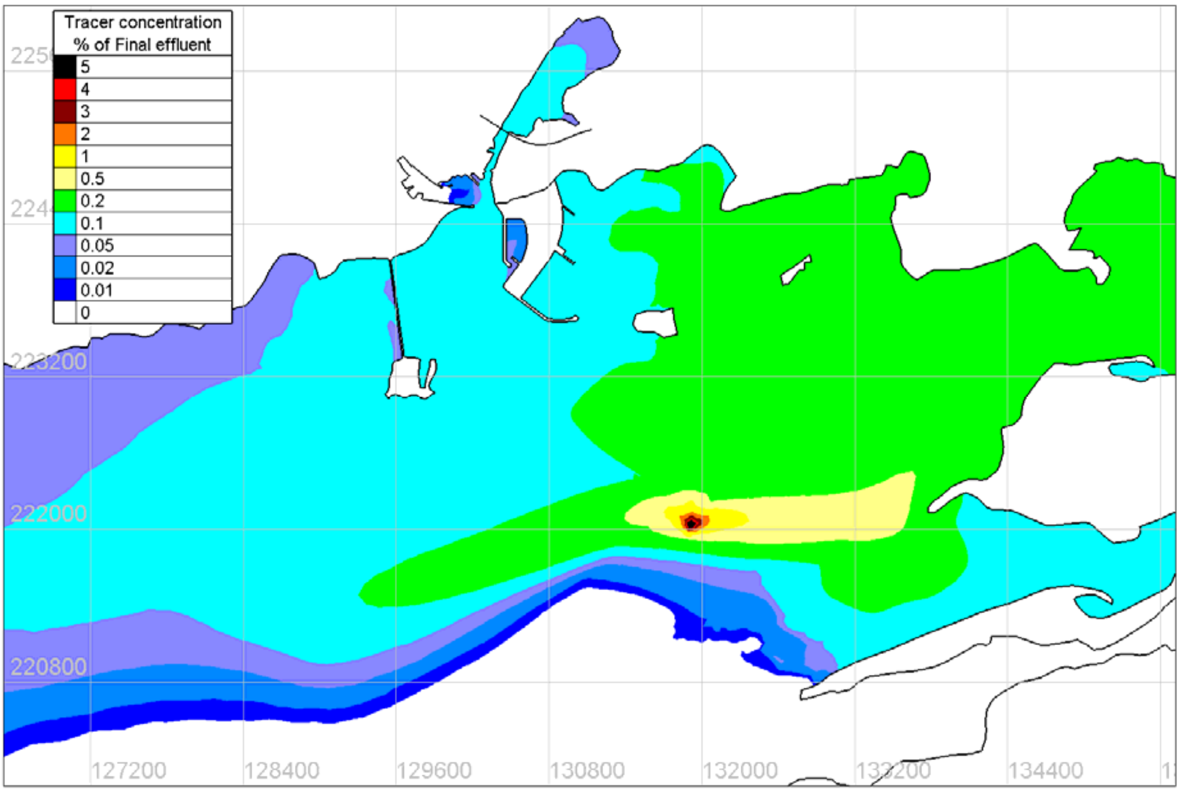

Figure 4.8.56 Maximum surface concentration of Tracer under S 15m/s wind conditions– Proposed

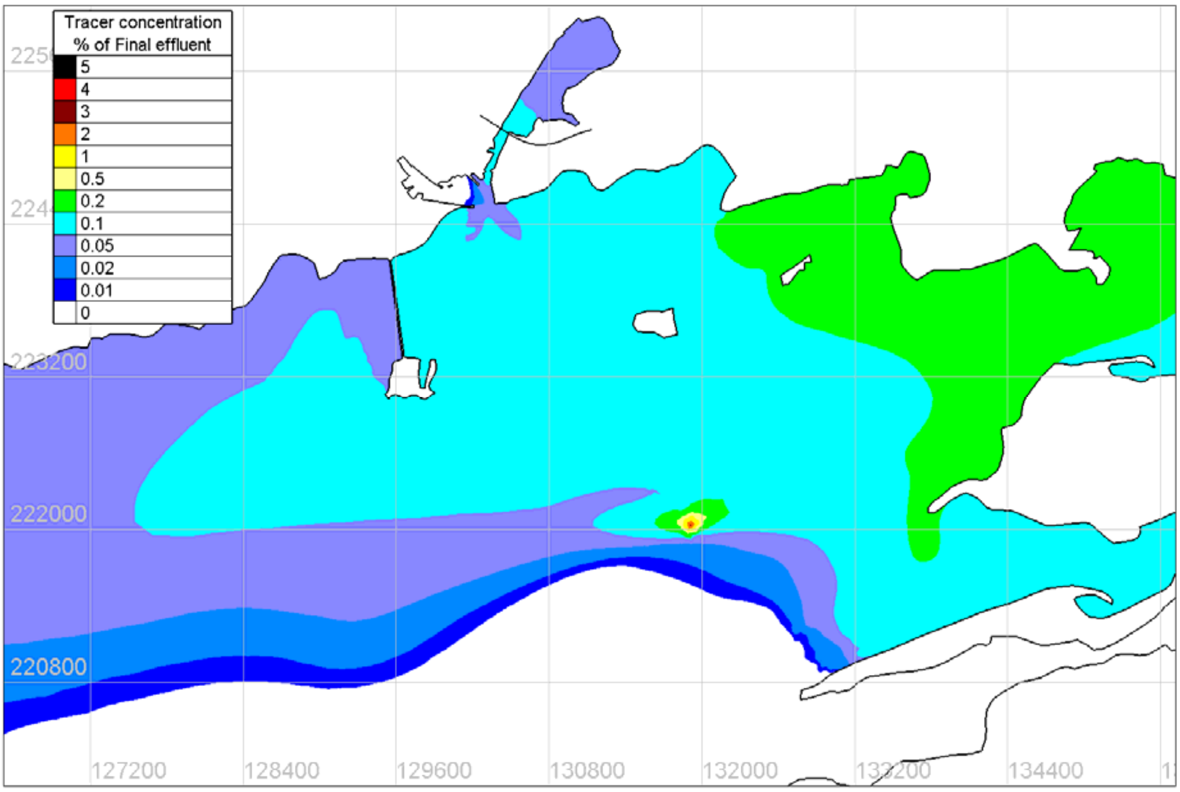

Figure 4.8.57 Tidal mean tracer concentration under S 15m/s wind conditions – Existing Case

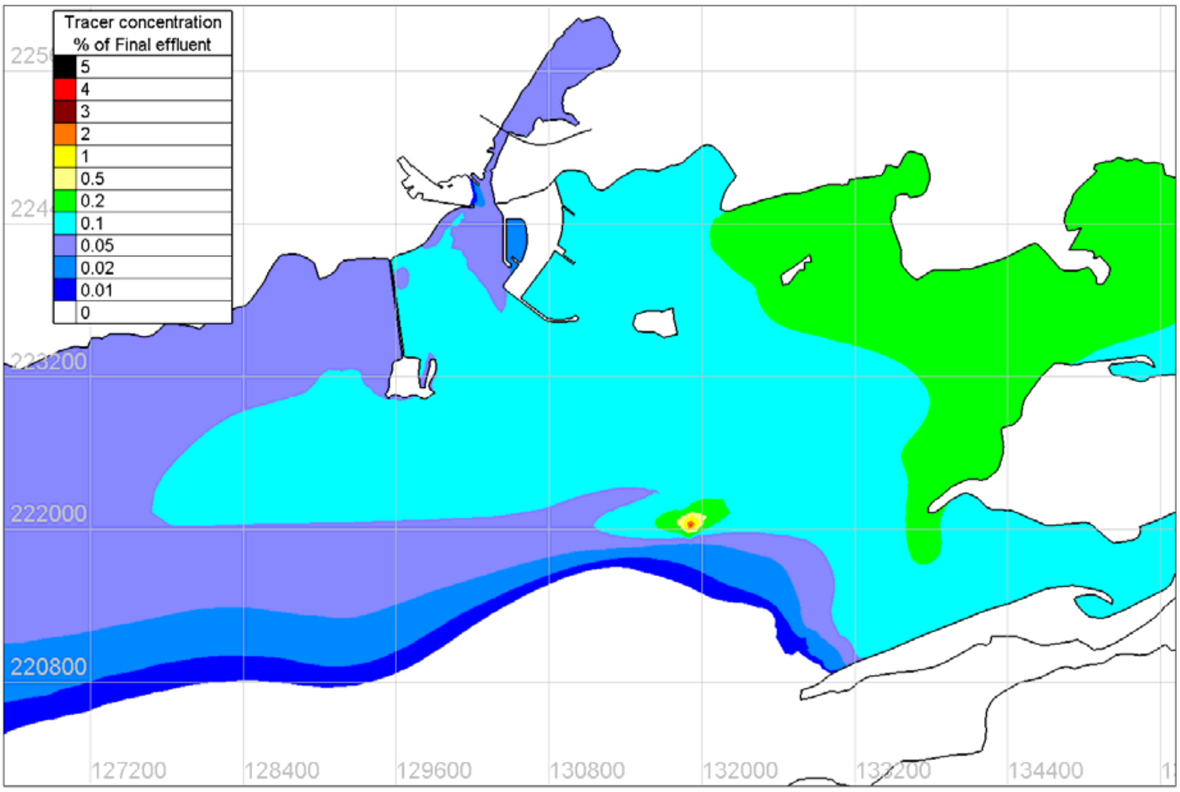

Figure 4.8.58 Tidal mean tracer concentration under S 15m/s wind conditions – Proposed Case

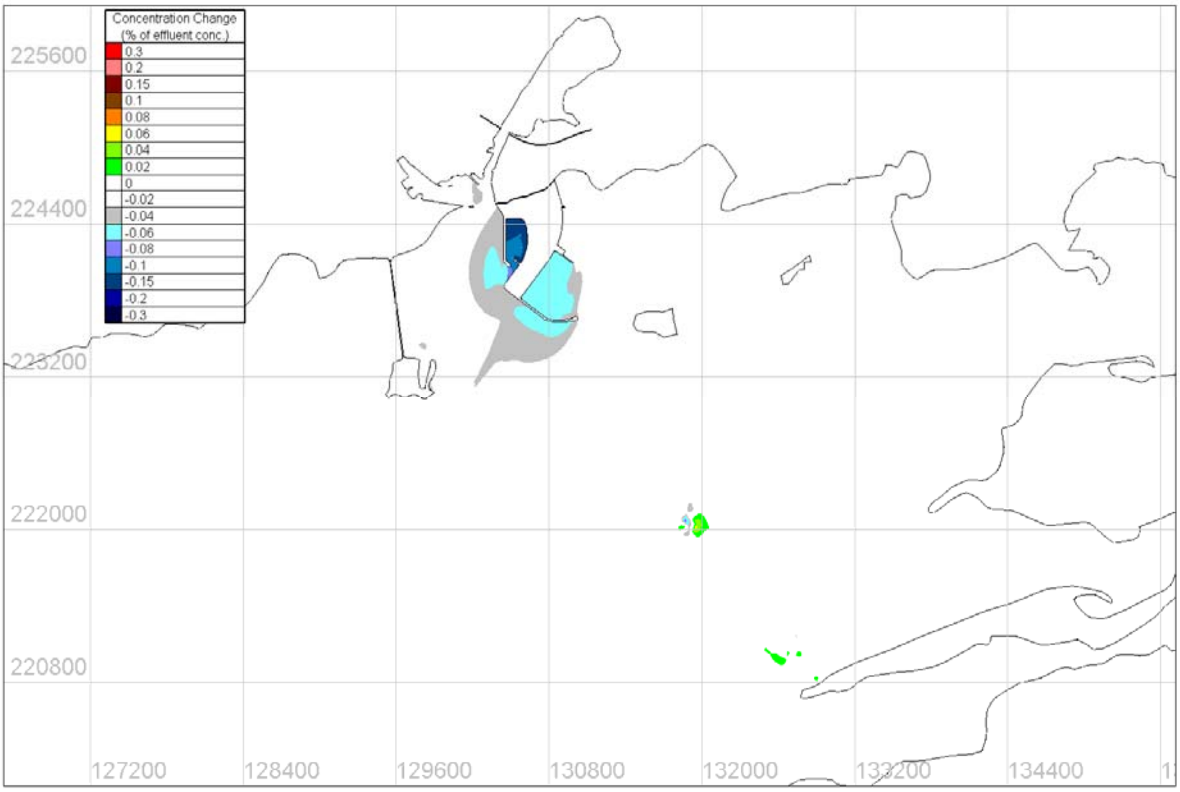

Figure 4.8.59 Predicted change in maximum surface tracer concentration – S 15m/s Wind Conditions

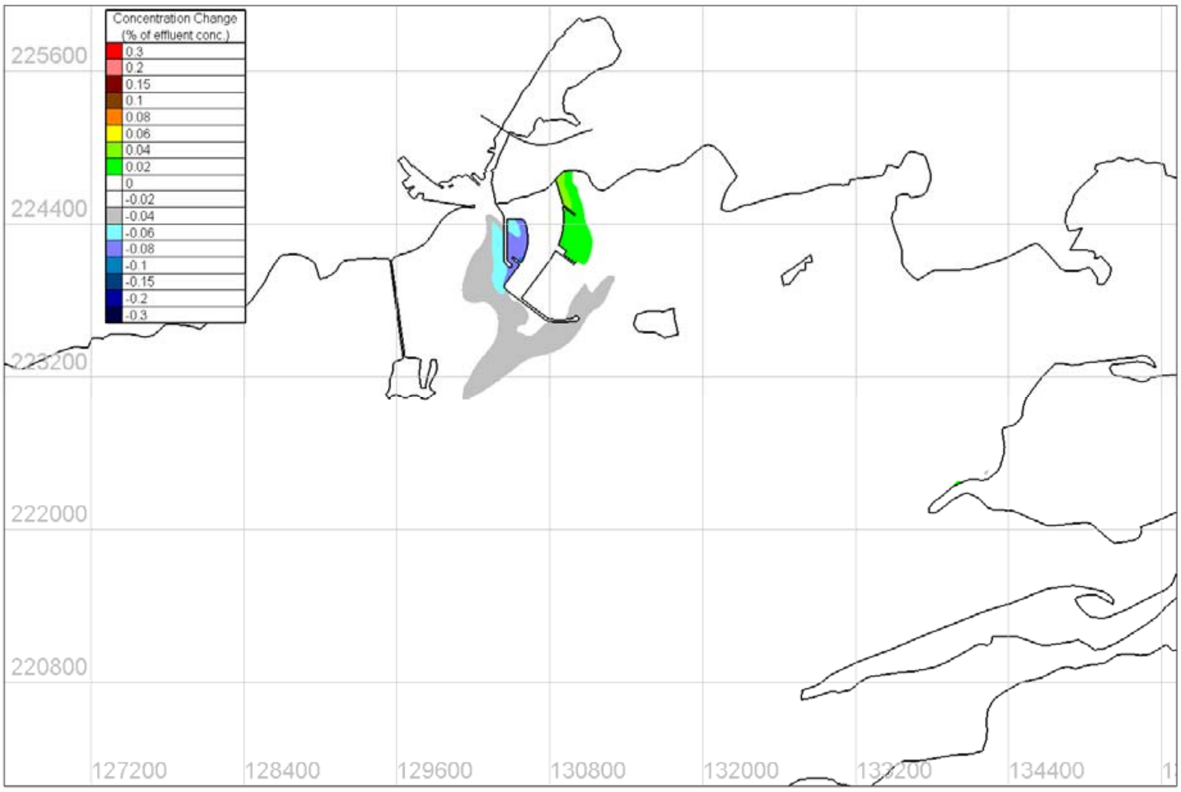

Figure 4.8.60 Predicted change in tidal mean tracer concentration – S 15m/s Wind Condition

4.8.6.3 Spring tide and Corrib low flow and SE 15m/s Wind Condition

Figure 4.8.61 to 4.8.66 presents the concentration plume and difference plots for for SW 15m/s wind conditions.

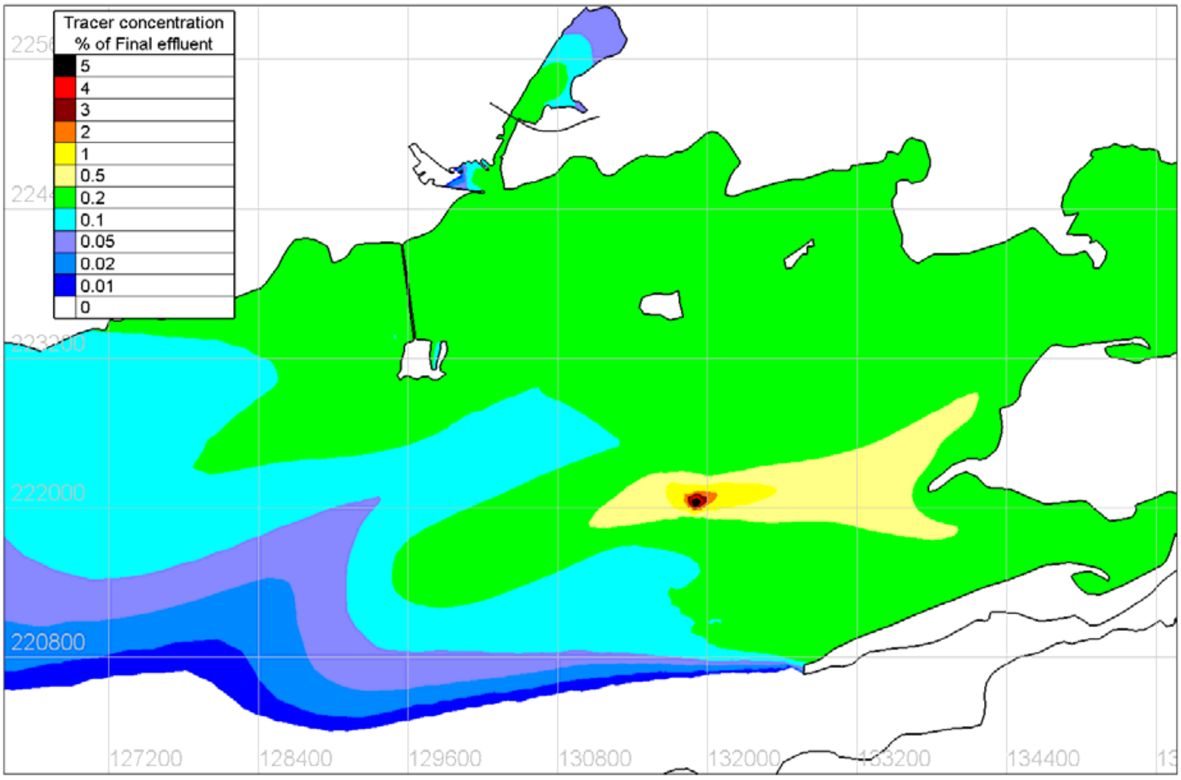

Figure 4.8.61 Maximum surface concentration of Tracer under SE 15m/s wind conditions– Existing

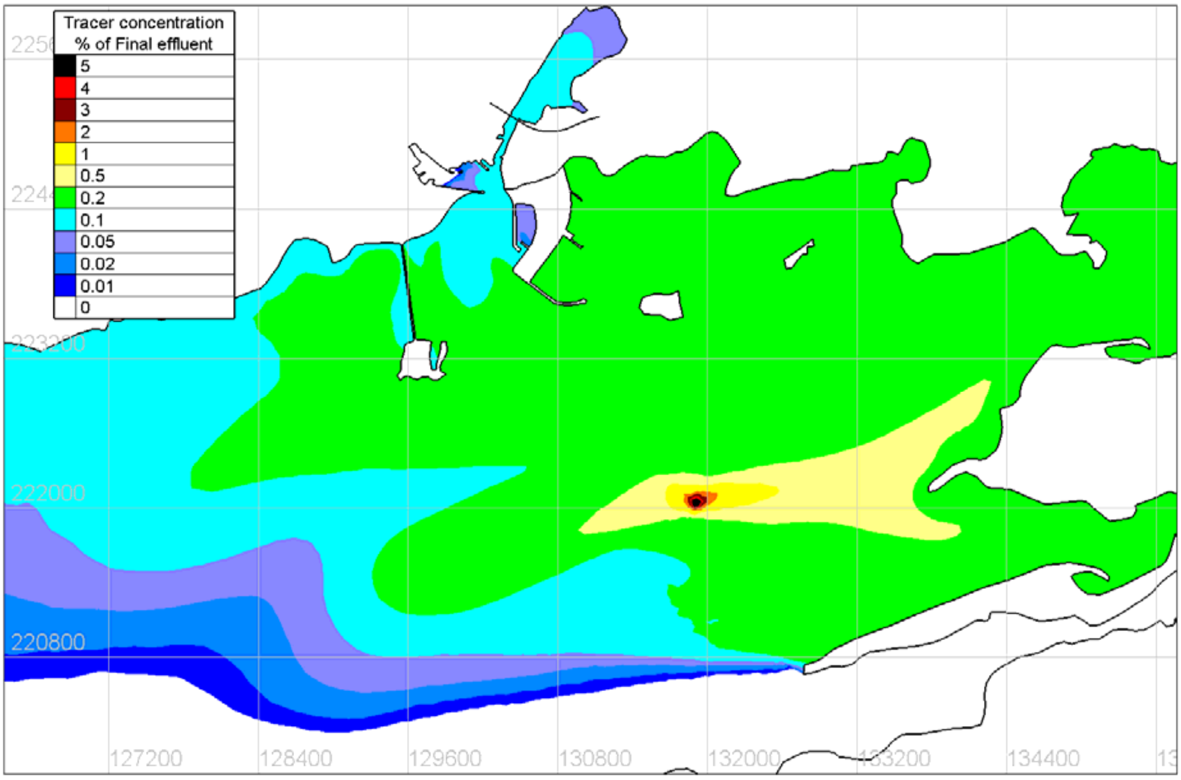

Figure 4.8.62 Maximum surface concentration of Tracer under SE 15m/s wind conditions– Proposed

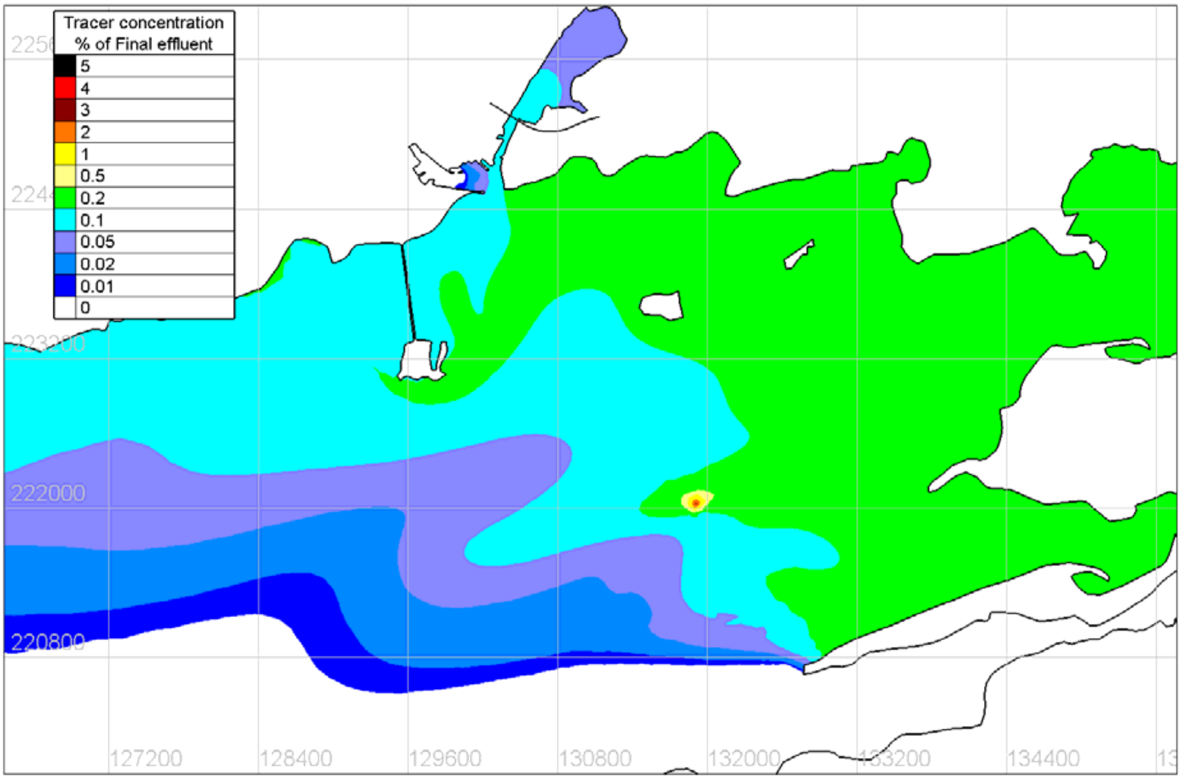

Figure 4.8.63 Tidal mean tracer concentration under SE 15m/s wind conditions – Existing Case

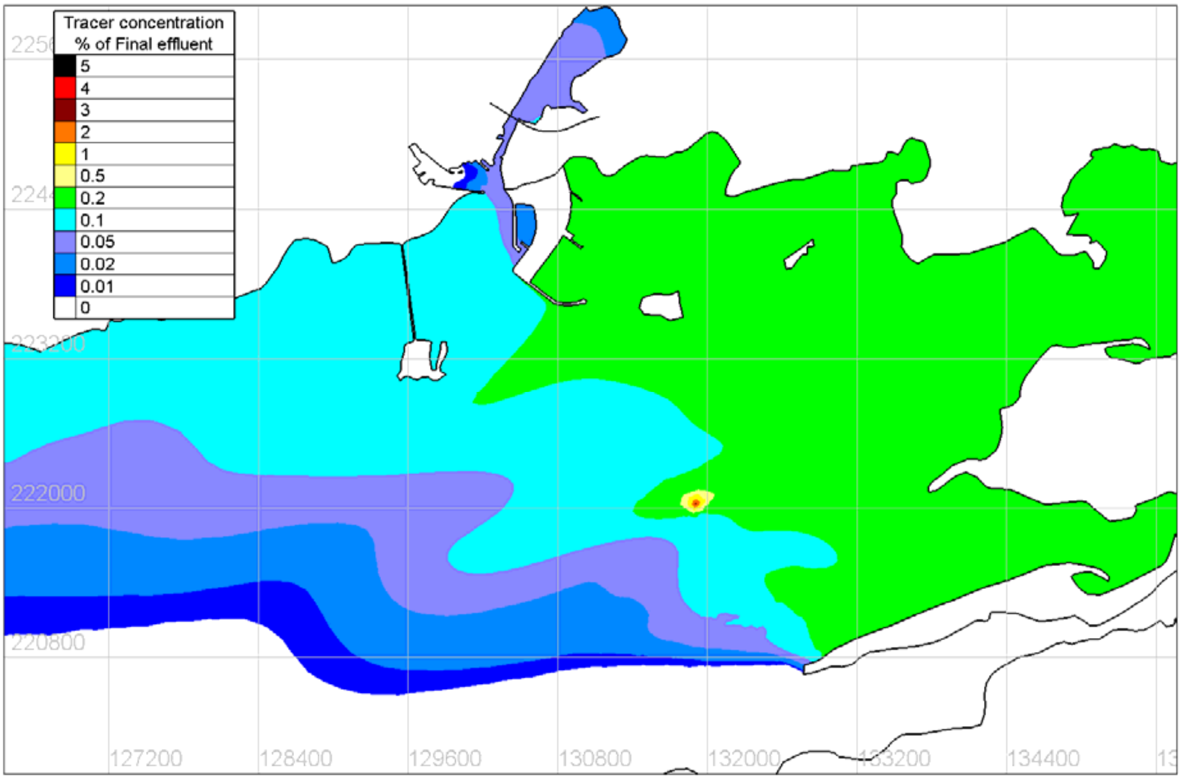

Figure 4.8.64 Tidal mean tracer concentration under SE 15m/s wind conditions – Proposed Case

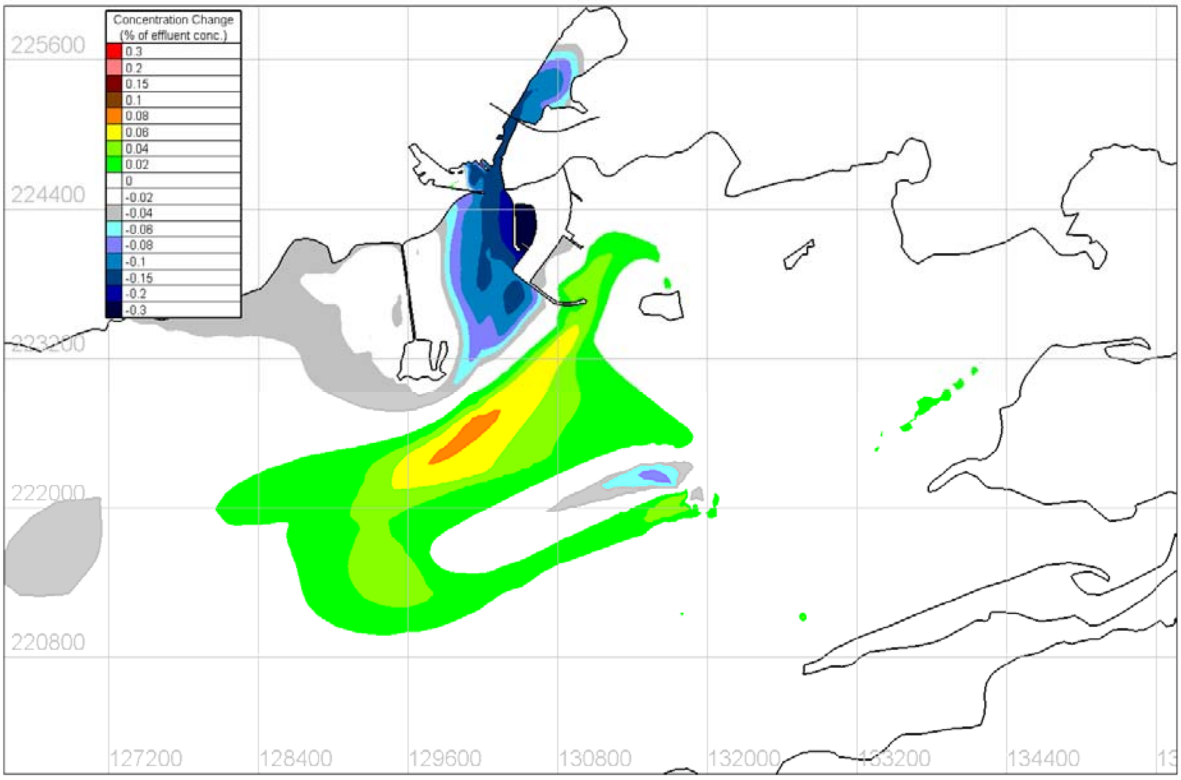

Figure 4.8.65 Predicted change in maximum surface tracer concentration – SE 15m/s Wind Conditions

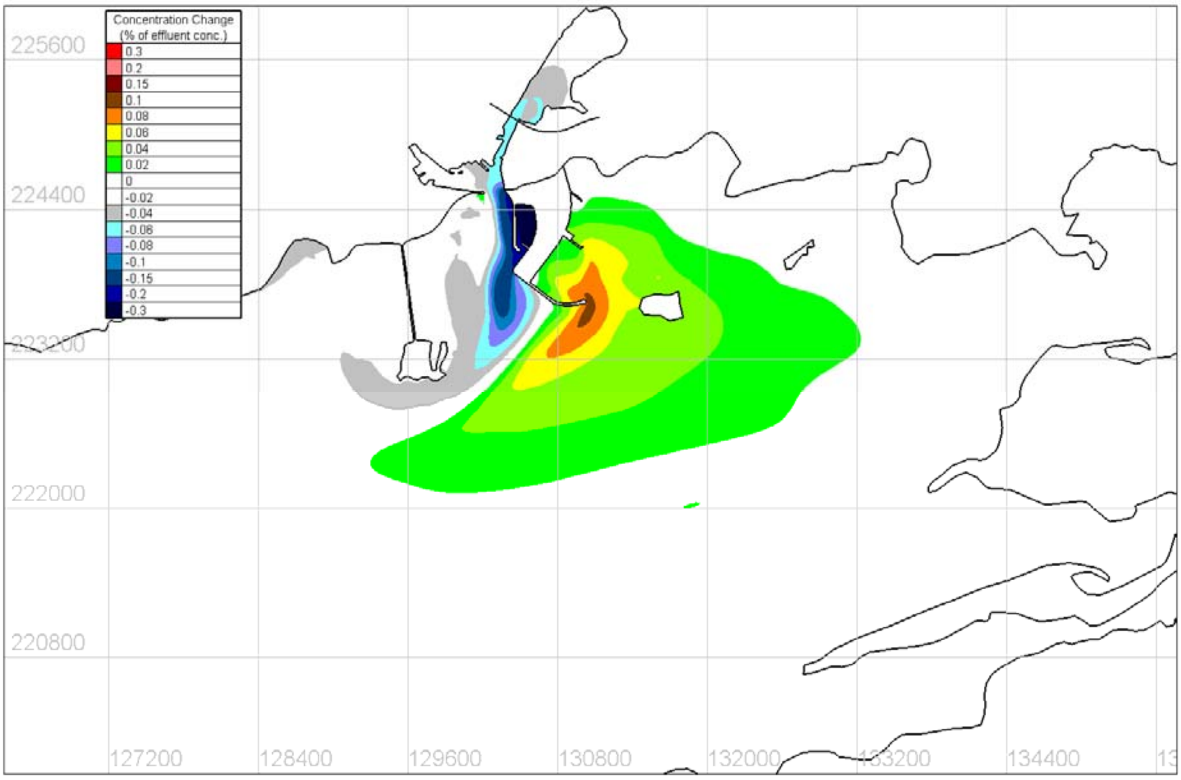

Figure 4.8.66 Predicted change in tidal mean tracer concentration – SE 15m/s Wind Condition

4.8.7 Discussion – Galway East Outfall

The previous 2D simulations presented in the EIS showed the Galway EAST trajectory to travel generally SW to NE from the outfall discharge with little ability to directly interact with the Mutton Island outfall discharge (located 2.4km to the northwest) and the northern shoreline area.

The 3-D Simulations presented in Figures 4.8.49 to 4.8.66 modelling adverse SW, S and SE wind conditions transport the Galway East Plume northwards towards the Harbour development area and the sensitive receptors of the Bathing Waters. The predicted plume concentration are a well mixed plume having concentration of 0.25 to 0.3% of the effluent concentration. The simulations also show that a number of tidal cycles are required to reach the northern shoreline area. Therefore faecal coliforms will be considerably lower (in excess of 10 fold lower) than the 0.25 to 0.3% as modelled without the diffuser dilution to be proposed.

The Impact of the Harbour Development on the Galway East plume concentrations is minor under south and southwest winds, with the greatest effect occurring for the southeast wind. The difference Plots in Figures 4.8.65 and 4.8.66 show a reduction (improvement) over the existing case to the west and north of the Harbour including the Corrib entrance and Lough Atalia and an increase of 0.04 to 0.08% to the east of the harbour in the vicinity of the Commercial Port and Hare Island. No Impact is predicted to the Ballyloughaun Beach or Grattan Road Beach.

Pollutant	Galway East Outfall WWTP Final effluent concentration
Faecal Coliforms	20,000 cfu/100ml
BOD	25 mg/l O_2
Ammonia	3mg/l as n
Suspended Solids	35mg/l
Total Oxidised Nitrogen	20mg/l

Table 4.8.3 Final Effluent Quality for Galway East Outfall

Pollutant Chemical parameter	Effluent Concentration	Percentage Change			
		0.05%	**0.1%**	**0.15%**	**0.5%**
Faecal Coliforms	**20,000 cfu/100ml**	**10**	**20**	**30**	**100**
BOD	**25 mg/l O_2**	**0.0125**	**0.025**	**0.0375**	**0.125**
Ammonia	**3mg/l as n**	**0.0015**	**0.0030**	**0.0045**	**0.0150**
Suspended Solids	**35mg/l**	**0.0175**	**0.035**	**0.0525**	**0.175**
Total Oxidised Nitrogen	**20mg/l**	**0.01**	**0.02**	**0.03**	**0.1**

Table 4.8.4 Pollutant Concentration based on percentage change in effluent concentration for Galway East Outfall Discharge

The simulation results clearly show that the potential impact by the Proposed Harbour Development on the Galway East Outfall plume concentrations is minor to negligible and will not affect the future performance of this outfall.

4.8.8 Conclusions

The 3-D hydrodynamic dispersion analysis confirms the conclusions reached in the EIS report that the Harbour Development will not significantly (noticeably) affect the performance of the Mutton Island outfall in respect to dilutions and mixing within the receiving waters of Inner Galway Bay. Changes in plume pattern are predicted as a result of the Development, however these changes will not impact the overall Water Quality Status of the receiving waters or impact on the status of sensitive locations such as the Corrib Salmonid Water, Bathing Waters at Grattan Beach, Ballyloughaun Beach and the Corrib entrance at Nimmo's Pier including the Claddagh basin, existing Docks and Lough Atalia.

The dispersion simulations confirm that the plume characteristics for the proposed Galway East outfall will not be impacted and that the combined effect with the Mutton Island outfall on the receiving waters along the Galway City Shoreline area including the Corrib entrance, Salthill beaches and Ballyloughaun Beach will be imperceptible even under adverse southerly wind conditions (SE to SW).

If the outfall diffuser nearfield dilution at both outfalls is factored in, then the above predicted concentrations would be significantly lower, pro rata for both the existing and proposed cases.

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Appendices to NIS Addendum / Errata

Appendix No. 3.3

Appendix No. 9 – Mapping of Maximum Wave Heights

4.9 MAPPING

Mapping of Maximus Wave Heights

Query:

In section 8.4.6.7 of the EIS reference is made to maximum wave heights within the Bay. The applicant is requested to present the maximum wave heights in the form of a map.

Response:

We present maps at Figures 4.9.1, 4.9.2 and 4.9.3 as follows:-

Figure 4.9.1 shows existing maximum wave heights within the Bay taking account of the additional swan modeling and the effects of wind, current and roughness as requested in this R.F.I.

Figure 4.9.2 shows the corresponding wave heights for the proposed case.

Figure 4.9.3 is a representation of Plot 4.5.41 which is the difference plot of the maximum predicted wave heights existing and proposed wave climate for all on-shore directions (West to East South-East).

This shows all of the landward locations which will have the benefit of reduced maximum wave because of the sheltering effect of the proposal as well as the seaward areas which will show greater maximum wave because of wave reflection, increased depth, realigned currents.

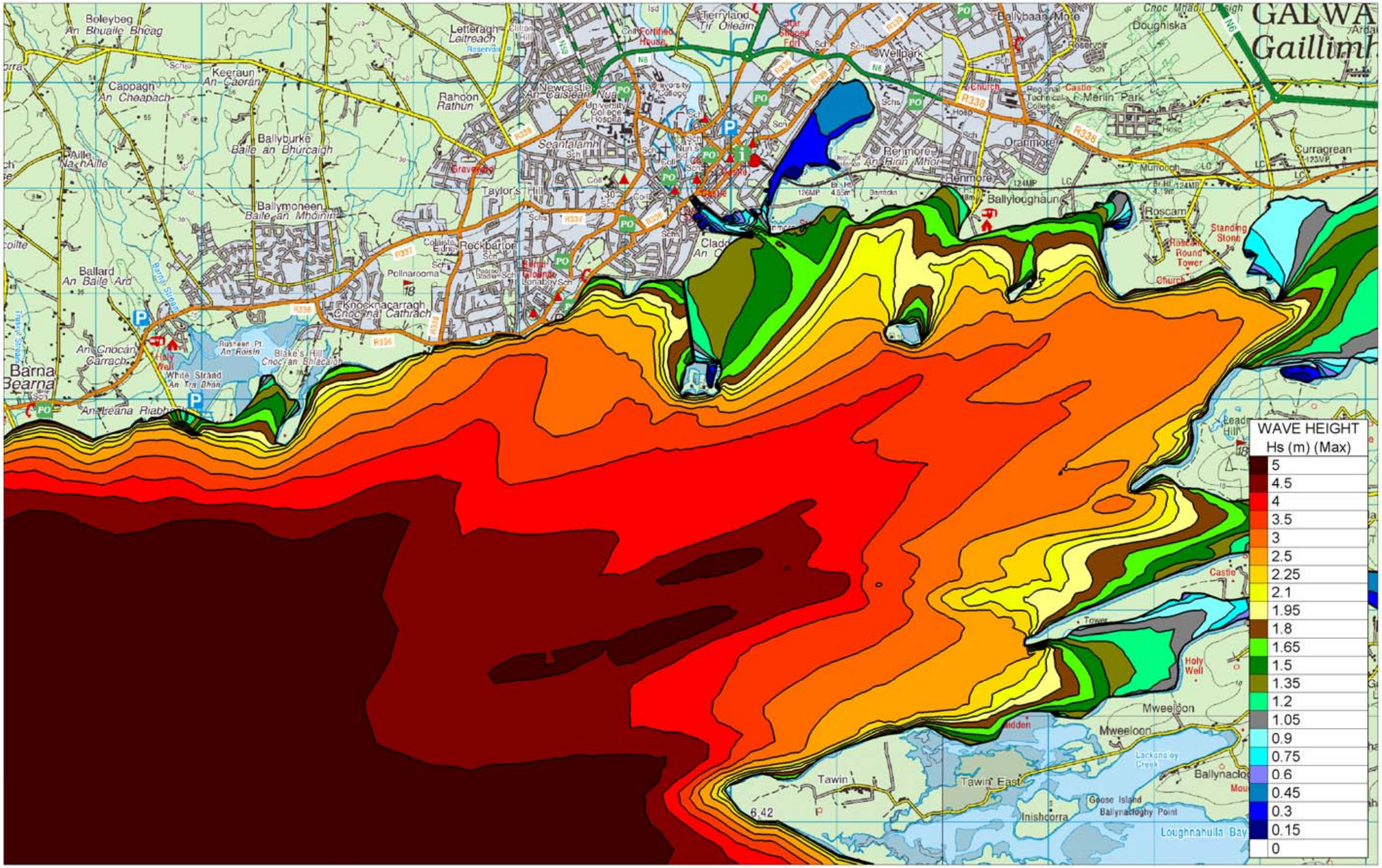
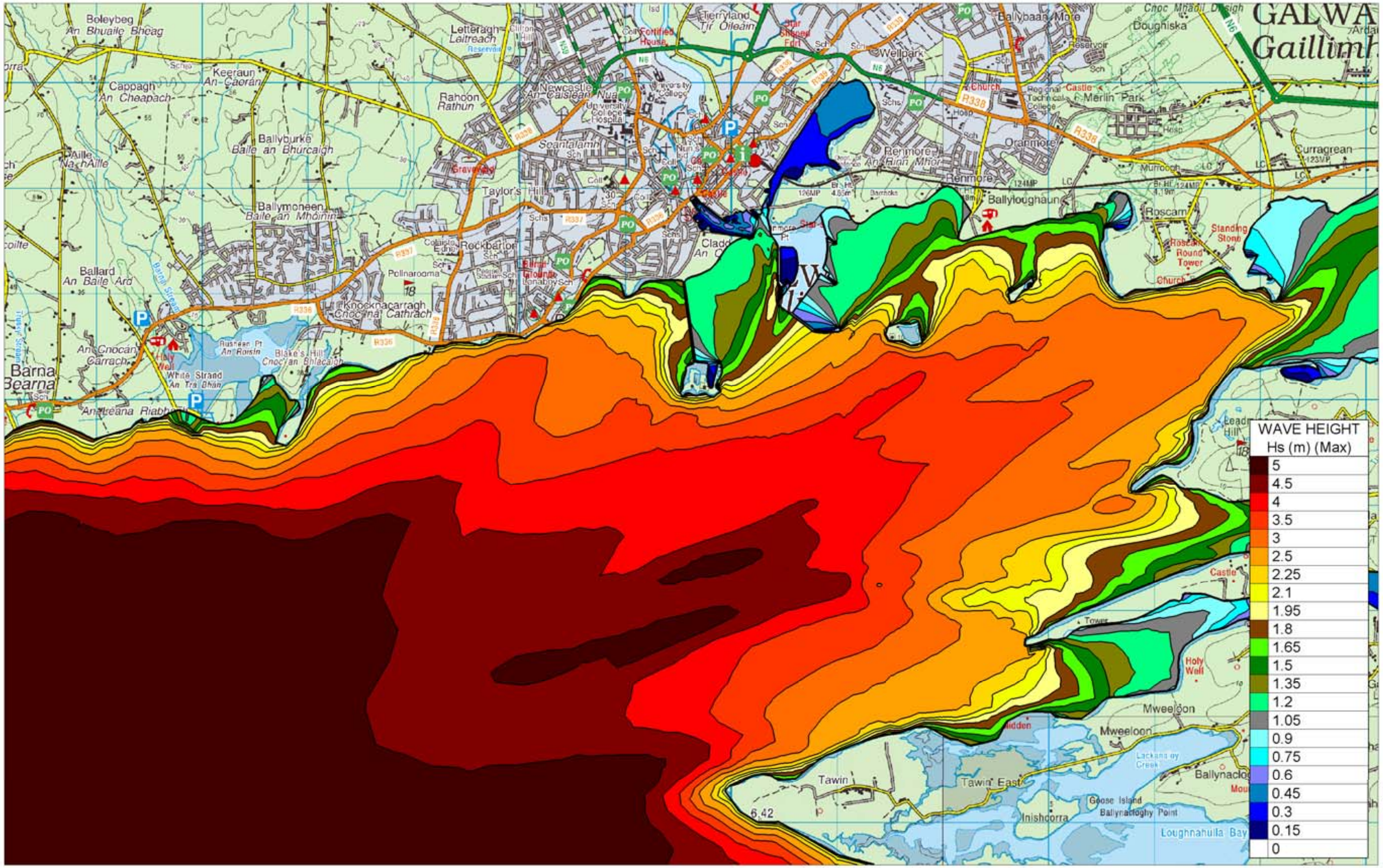


Figure 4.9.1 Shows maximum wave heights within the bay, existing case



4.9.2 Shows maximum wave heights within the Bay, Proposed Case

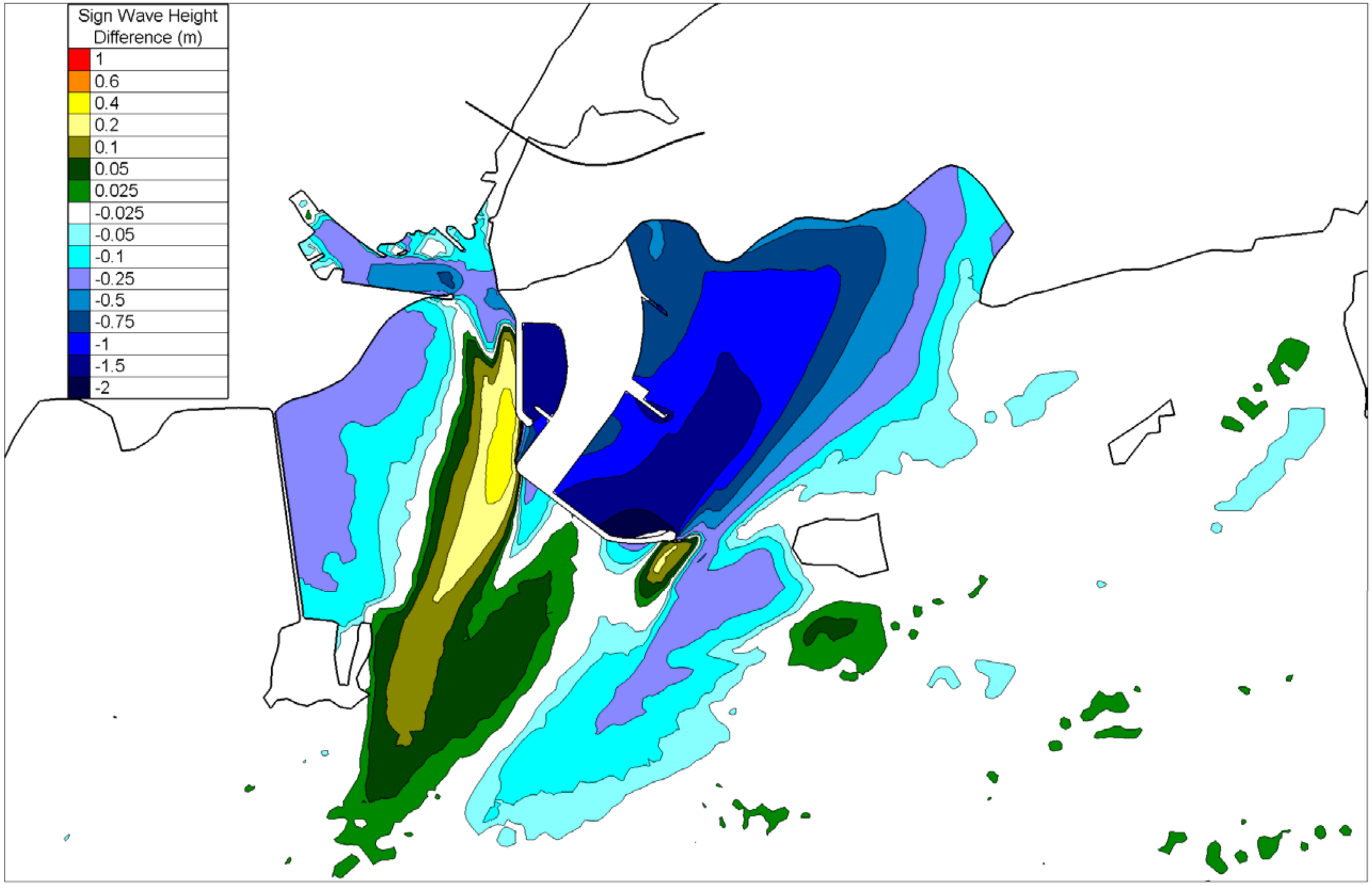


Figure 4.9.3 Difference plot of maximum predicted Wave heights existing and Proposed Wave climate for all onshore directions (West to ESE)

Also shown at Figure 4.5.4.

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Appendices to NIS Addendum / Errata

Appendix No. 3.3

Appendix No. 10 – Mapping of Areas of Potential Flood Risk

4.10 MAPPING OF AREAS OF POTENTIAL FLOOD RISK

Query:

Likewise section 8.4.7.3 of the EIS makes reference to the specific locations for potential flood risk. These are merely mentioned in the form of street names in the text. The applicant is requested to present this information in the form of a map.

Response:

We present a map at Figure 4.10.1 to address the above.

The map shows the 4.2m contour and 4.7m contour.

The 4.2m contour corresponds with the 200 year tide of 4.146 with additional freeboard allowance.

The 4.7m contour corresponds with the 200 year tide plus 500mm climate change, total 4.646m.O.D. Malin with additional freeboard allowance.

Highest astronomical tide is presently 2.84 m.O.D.

Recent storm events reached 3.6 (3.59 February 2014)

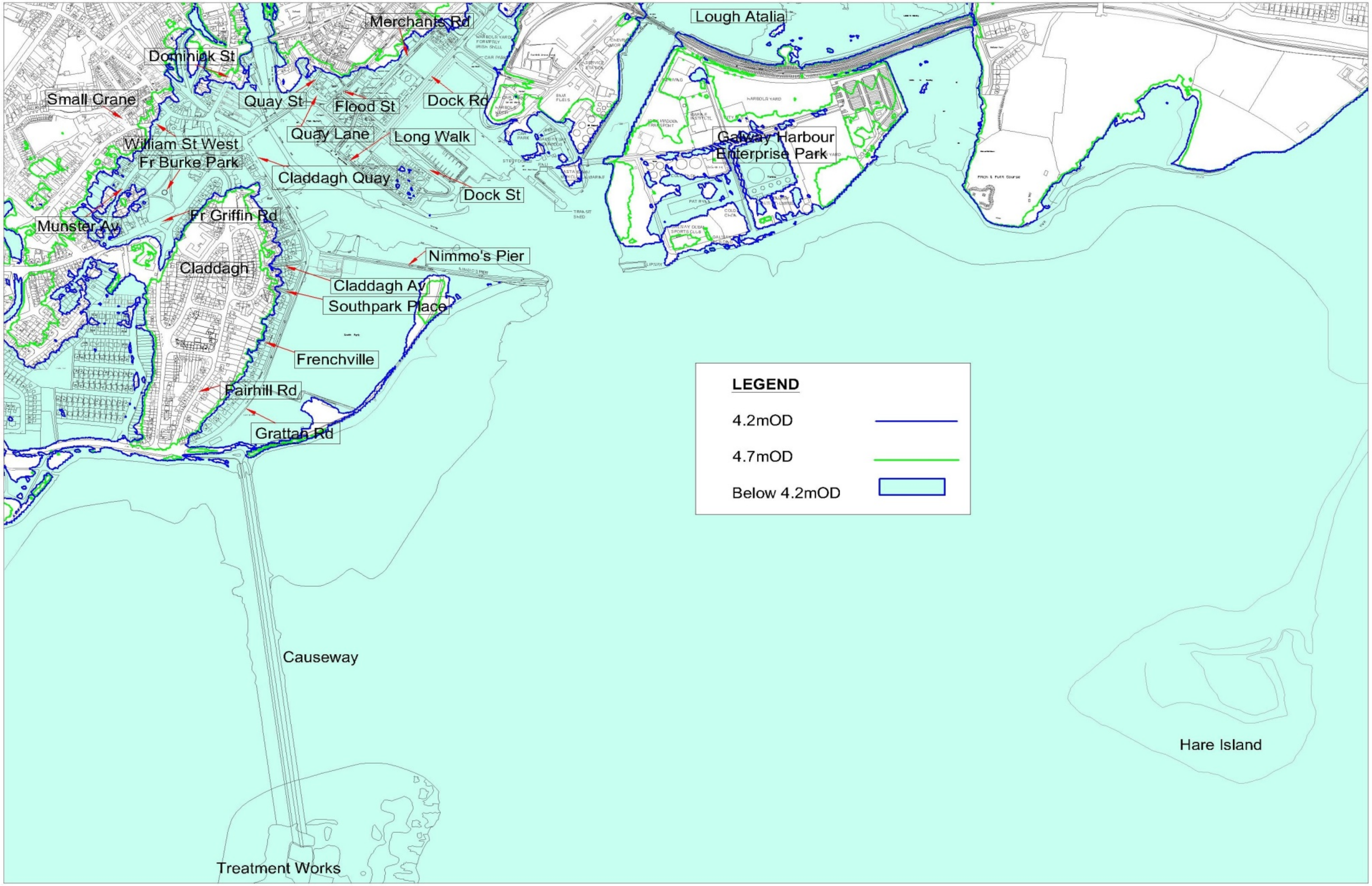

Figure 4.10.1 Map showing Locations of Potential Flood Risk, Showing Location Names