Galway Harbour Company

Galway Harbour Extension

Compensation - Reply to Further Information

An Bord Pleanála (Ref: 61.PA 0033)

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Galway Harbour Company

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Compensatory Measures Report

Appendices

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0. Introduction

We respond herein to the 10 points of clarification requested by the An Bord Pleanála letter of 07.10.2019, to the Compensatory Measures Report, as submitted in April 2019.

The 10 points are specifically addressed by Dr. Brendan O'Connor of Aquafact 1A, 4, 5, 6, 7, 8, 9 and 10 and by Dr. John Conaghan 1B, 2 and 3.

Although not specifically referred to in the ABP clarification request, it was considered relevant to explain the logic in the selection of the marine reference site location.

The area in the eastern part of Mweeloon Bay is where the highest concentration of oyster farming is located and this is also the area where *Didemnum* occurs. Its presence in this area was established during the overall survey of the marine habitat that was carried out for the Compensatory Management Report (CMR) and it was shown in the CMR as the area where *Didemnum* would be controlled (see attached Figure 14(1)). The eastern and northern parts of Mweeloon Bay were not covered as part of the baseline survey for the CMR and for this reason, they were not considered for either the *Didemnum* control work or as a monitoring site post-cessation of oyster farming.

The area where *Didemnum* will be controlled has been extended eastwards to the southeastern shoreline of that part of Mweeloon Bay (see Figure 14(1)).

For these reasons, this is the area that was selected as the location where these control activities and monitoring studies should be carried out (see Figure 20(1)). As there are no aquaculture activities within Mweeloon Lagoon, that area could not be used for neither a *Didemnum* control programme nor a fallowing experiment.

This area of Mweeloon Bay formed part of the entire study of Mweeloon Bay and Lagoon and parts of Lackanaloy Lagoon that was studied as part of the CMR and this data set will be used as an initial element of the baseline survey for the proposed *Didemnum* control and intertidal monitoring plan.

Furthermore, there is intensive agriculture carried on in the fields directly to the South of this marine reference site (see Reference Site 1 in Figure 20(1)). This is the additional area of the reference site to show comparison between Reference Area 1 where intensive aquaculture will continue and is adjacent to an area where intensive agriculture will continue and Reference Area 2 where aquaculture will cease and which is also adjacent to where intensive agriculture will continue.

Reference Area 3 is the location where aquaculture will cease but is adjacent to where agriculture will be organically managed.

Reference Areas 2 and 3 are within the intertidal management area as noted at paragraph 1, p.58 of the CMR as submitted April 2019.

The CVs of both of the ecologists who have been involved in the project for many years are presented in Appendix 1.

1. **There are specific concerns that the monitoring programme to be employed may not provide an effective method to measure the success of the compensatory measures. Detailed monitoring is required to test the success of the compensatory measures. It is considered that there are no clear specific objectives for the monitoring programme which set out measurable outcomes on which the success or otherwise of the proposed compensatory measures can be ascertained. The compensatory measures need to be compared against a set of established indicators and thresholds. Please provide an appropriate methodology to address this issue.**

Introduction
The approach to the response to this item is to set out the measures that have been devised to determine the success of the Compensatory Measures by reference to their specific elements, which are in turn subdivided into marine and terrestrial elements.

1A Marine Elements

The response to this Item identifies 3 individual and separate targets species/areas of the marine sections of the compensatory measures, namely:

1. The control of the non-native, invasive tunicate *Didemnum* that is fouling oyster farms in Mweeloon.
2. The fallowing of parts of Mweelloon Bay that are used for oyster cultivation and the cessation of tractor traffic to and from the farm to enable the benthos under and close to the trestles and along the access route to return to natural conditions.
3. The implementation of “organic” farming practices that besides having beneficial effect on terrestrial habitats, may also have beneficial effect on intertidal marine ecology.

Effective methods by which the success of the compensatory measures can be assessed have been identified and the response describes in detail what the monitoring plan entails. Clear and specific objectives for each aspect of the marine monitoring plan are identified and measurable out comes on which the success or otherwise of these measures will be ascertained. Both indicators and thresholds for each target have been established.

Objective 1 The control of the invasive, non-native tunicate species *Didemnum* in Mweeloon Bay. The target of this element of the CMR is to control the population of the non-native invasive tunicate *Didemnum* which is present on oyster trestles and bags at the site. Using the SACFOR scale (Superabundant, Abundant, Common, Frequent, Occasional, Rare) to describe % cover of the tunicate at the oyster farms at present, it is scored at Abundant.

Method
An annual control regime for the species is proposed as part of the compensatory measures. The control regime includes regularly turning the bags to increase “drying out” periods and the use of acetic acid that kills the tunicate. These methods are known to be an effective methods to control *Didemnum.*

Indicator
The Abundance and Distribution Range method (ADR) developed by Olenin *et al.* (2007) and used recently by Cottier-Cook *et al.* (2019) in a survey of *Didemnum* in Loch Creran, Scotland is the indicator that will be used to measure the relative effectiveness of the control regime at Mweeloon. Use of the ADR tool will readily and quickly show the effectiveness of the control regime.

In addition, a photographic survey will be carried out to visually document the population and distribution of *Didemnum* before the control practice commences and on an annual basis post-commencement.

It is proposed to carry out this *Didemnum* control regime throughout the entire reference site (*i.e.* Areas 1, 2, 3 and 4 shown on Figure 21)). This is to ensure that, if populations are left in close proximity to the fallow site, they cannot re-infest the fallow area.

Threshold
The threshold for *Didemnum* is that there will be a statistically significant reduction in its densities 5 years post-removal.

Management goal
The presence of the non-native tunicate *Didemnum* at the Mweeloon aquaculture site that lies within Galway Bay SAC is, in conservation terms, an unacceptable fact. Removing and controlling the tunicate at least from a part of the SAC is an important management goal of this objective.

Objective 2. The removal of oyster trestles and cessation of tractor movements from the reference area.

The second target of the marine aspect of the CMR is the permanent fallowing of sites in Mweeloon Bay that are currently used for culturing oysters including the elimination of tractor traffic to and from the fallow site. The greatest densities of trestles are in Areas 1 and 2 of Figure 21.

Method
The details of the monitoring methods for this objective are presented in Appendix 3.

Indicators
It is intended that the experimental design, methodologies and indicators used in the Forde *et al.* (2015) study will be used to track change over time at the Mweeloon site following the removal of the trestles and cessation of tractor traffic. Specifically, univariate and multivariate statistical analyses (PRIMER, PERMANOVA) will be used to assess changes in sediment characteristics, faunal diversity measures and IQI ES (see Appendix 3 for further detail).

The full suite of analysed data will provide a comprehensive and robust data set on which to base conclusions from the results of the statistical analyses. It will also allow comparisons in "*ante et post"* conditions at the fallow site, the active production site and the access route.

Thresholds
Details on threshold levels for biological data, organic carbon levels and mean size of sand particles are presented in Appendix 3.

Management goal
The objective of this target is to be able to demonstrate the effects of fallowing oyster production sites on intertidal benthic ecology. Given the number of sampling locations, the number of replicates and the temporal extent of the survey period (as presented in Appendix 3), it is considered that this sampling strategy is adequately specific to:

1. Establish a baseline of the intertidal habitat.
2. Determine the success of this aspect of the compensatory measure.

Success of this aspect of the compensatory measures is defined as the stabilisation of the benthic fauna at the fallow sites (Reference Sites 2 and 3) and on the former access routes in comparison to what is present at the trestle and access route to Reference Site 1.

Objective 3. The commencement of "organic" farming practices including reduced stocking densities, and non-use of fertilizers may bring about changes in intertidal ecology including the reduction in the spatial extent of green algae that are known to react positively to increased levels of organic enrichment. The presence/absence and percentage cover of green algae such as *Ulva*

(+ synonym *Enteromorpha*) will be documented as part of each annual survey to record changes in intertidal ecology due to these alterations in agricultural practices.

Method
The same methods as outlined in Appendix 3 will be applied to these surveys. A much longer time scale (decadal) is required to demonstrate this and well may be masked by a stronger signal such as a rise sea temperature or an increase in storm activity.

Indicators
The same suite of indicators as listed in Appendix 3 for the study on the fallowing of oyster culture sites will be used in the Target 3 study.

Threshold
As is noted above in the Method section, a much longer time scale (decadal) is required to demonstrate this an as the response may be masked by a stronger signal, it is not possible to set a threshold level for this target.

Management goal
One potential positive aspect of this section of the CMR is that it may demonstrate, over an extended time period, a reduction in green algae on the shore.

1B Point 1. Terrestrial elements

Management objectives in stony bank habitat areas

Objective 1.
The control/eradication of the non-native vascular plant species *Lactuca tatarica* on the stony bank area at Renmore.

Method
Lactuca tatarica is a non-native plant species which has a significant cover in the stony bank vegetation at Renmore. Plants will be pulled by hand, with careful attention paid to the removal of the well-develop rhizomes which occur. This removal will be carried out during the flowering period, *i.e.* July, when the species is easy to identify. It is envisaged that the removal of the species will be undertaken annually for five years or until such time as the species has been fully eliminated.

Indicator
The presence/cover of *Lactuca tatarica* will be monitored within four vegetation monitoring quadrats at Renmore. The general occurrence of the species outside of monitoring quadrat areas will also be surveyed and mapped using GPS.

Threshold
The threshold for this objective of the plan will be to initially reduce the cover of the species within the monitoring quadrats to less than 5%. The ultimate aim is to eradicate the species completely from the site.

Management goal
The overall CMR will be to either greatly reduce or eliminate the distribution of the species at Renmore.

Objective 2.

To promote improved structure and flowering/seed production of stony bank vegetation at Mweeloon.

Method
Historically, areas of stony bank vegetation at Mweeloon have been grazed by a range of livestock including horses and cattle. In the past this grazing has been sporadic and this has resulted in the overgrazing/undergrazing of the habitat. It is proposed to implement an appropriate light grazing regime within the site in order to promote the improved composition and phenology within the vegetation. During the initial implementation of the grazing regime, *i.e*. the first two years, there will be a degree of management fine-tuning in order to determine the appropriate grazing intensity/duration.

Indicators
A total of 20 vegetation monitoring quadrats will be established throughout areas of stony bank habitat at Mweeloon. Quadrats will be monitored twice each year (May and August). Within these quadrats the vegetation composition and cover will be recorded. Important parameters which will be noted includes plant species-richness, degree of flowering and height of vegetation.

Management goals
In this objective the main goals are as follows:

(1) Increase the species-richness within the quadrats.

(2) Increase the amount of flowering and seed production within the sward.

(3) Establish a varied sward height.

(4) To monitor the distribution and cover of the nationally rare and declining species *Glaucium flavum* (Yellow horned poppy) which grows on shingle at Mweeloon.

Results in areas with controlled grazing will be compared with results from quadrats located in control areas which will not be subject to controlled grazing.

Management objectives in salt-marsh habitat

Objective 1
To promote the recovery of salt-marsh vegetation at Mweeloon in an area degraded by cattle poaching and tractor movement in the recent past.

Method
At Mweeloon there is an area of salt-marsh - *c.* 0.5 hectares in extent - which has been severely damaged by cattle grazing/poaching and trafficking by a tractor in recent years. This damage is associated with the supplementary feeding of cattle during the winter/spring months. Livestock will be excluded from this area until satisfactory recovery of the vegetation has occurred.

Indicator
Five vegetation monitoring quadrats will be established in this salt-marsh area. Quadrats will be monitored twice each year (May and August). Within these quadrats the vegetation composition and cover will be recorded. The area of bare soil, due to livestock/tractor damage will also be recorded. Photographs will be taken in order to record vegetation recovery.

Threshold
The threshold for this objective is to reduce the cover of bare soil as much as possible and ideally to below 5% cover.

Objective 2
To promote improved structure and flowering/seed production of salt-marsh vegetation at Mweeloon.

Method

Historically, the salt-marsh vegetation at Mweeloon has been grazed by a range of livestock including horses and cattle. In the past this grazing has been irregular and this has resulted in the overgrazing/undergrazing of the habitat. It is proposed to implement an appropriate light grazing regime within the site in order to promote the improved composition and phenology within the vegetation. During the initial implementation of the grazing regime, i.e the first two years, there will be a degree of management fine-tuning in order to determine the appropriate grazing intensity/duration.

Indicators

A total of 60 monitoring quadrats will be established throughout areas of salt-marsh. Quadrats will be monitored twice each year (May and August). Within these quadrats the vegetation composition and cover will be recorded. Important parameters which will be noted includes plant species-richness, degree of flowering and height of vegetation.

Management goals

In this objective the main aims are as follows:

(1) Increase the species-richness within the quadrats

(2) Increase the amount of flowering and seed production within the sward.

(3) Establish a varied sward height

Results in areas with controlled grazing will be compared with results from quadrats located in control areas which will not be subject to controlled grazing.

2. The applicant is requested to demonstrate that the disturbance of the perennial stony bank vegetation [1220] at Renmore is only attributed to tidal disturbances, and that no disturbance can be attributed to trampling or shingle extraction. The Board consider that disturbances to the Stony Bank could be attributed to trampling due to anthropogenic interference with recreational walker and dog walkers etc.

Observations at the stony bank area in Renmore suggest that there is a low incidence of habitat disturbance due to recreational walking/dog walking. The area is relatively difficult to access and the numbers visiting the site are considered to be low. Surveys of pedestrians and dog walkers visiting the beach and stony bank area at Renmore were undertaken on 11.12.2019 and 14.12.2019. Observations show that between 15 and 19 people with 9 to 10 dogs visited the site each day, generally for a period of less than 1 hour (see Appendix 5). Observations also show that the vast majority of visitors walk on the sandy beach while only 29 to 37% of visitors access the stony bank area. While on the stony bank area the majority of visitors walk along an indistinct track which runs along the southern margins of the bank. This track is approximately 1 metre wide at most and the surface comprises a mixture of bare shingle and grassy vegetation. In total the area covered by this track accounts for less than 1% of the total stony bank area.

Disturbance of the shingle habitat due to sporadic storm events has a much more significant effect on the structure and vegetation composition of the shingle bank at Renmore. A striking example of shingle movement/redeposition caused by a storm event (Darwin) which occurred on 6th January 2014 is shown below.

View of the northern side of the shingle bar area at Renmore with large amounts of shingle thrown up after storm Darwin 6/1/2014.

In view of these observations it is suggested that occasional storm damage/disturbance events at Renmore have a much greater effect on the structure and floristic composition of the stony bank habitat/vegetation than the relatively low numbers of pedestrians and dog walkers which are generally confined to a small proportion of the stony bank area.

3. The applicant is requested to comment on the hypothesis that the expansion of the harbour under the current application will lead to increased shelter conditions which may in turn, improve the condition of the perennial vegetation of stony banks at Renmore.

Stony bank habitat is, by its nature, a dynamic habitat and significant changes in structure/vegetation composition can often occur over short periods of time due to the effect of sudden storm events. The stony bank area at Renmore comprises a mixture of shingle with a high cover of stones, dominated by sea radish, at the front of the shingle bar with more stabilized, vegetated shingle, dominated by grasses, further back. The stony shingle area at the front is subject to regular disturbance by storm events while the vegetated shingle area is not as influenced by storms due to its location further away from the high tide mark. These extreme storm events can add a further shingle / cobble layer over the vegetated area, as shown in the photograph in the previous section.

It has been shown that the construction of the new port area will reduce the incidence of disturbance by storm events (see Chapter 8 of the Galway Harbour Extension Environmental Impact Statement) (see Appendix 4, Extract from EIS by Tony Cawley Pages 8-135-155 "Wave Climate Prediction") which indicates that in storm events, the impact on wave heights from the following directions will change as follows:

Storm Direction		Wave Height Change		EIS Chapter 8 Page No.
West South West	(WSW)	0.3-0.7m to 0.1m	Reduced	8-148
South West	(SW)	1.0-1.5m to 0.1-0.3m	Reduced	8-149
South South West	(SSW)	1.1-1.5m to 0.0-0.1m	Reduced	8-150
South	(S)	1.1-1.4m to 0.1-0.6m	Reduced	8-151
South South East	(SSE)	0.4-0.7m to 0.3-0.9m	Increased	8-152
South East	(SE)	No change		8-153

The shelter provided by the harbour extension will result in a considerable reduction in the dynamic character of the stony bank at this location.

Over time this will probably lead to a gradual reduction in the amount of stony shingle habitat and an increase in the amount of more vegetated, grass-dominated shingle. It is important to note that this grassy shingle vegetation is still considered to be an example of natural stony bank vegetation. In the future the composition of shingle vegetation at Renmore will be closely monitored by the establishment and survey of 10 permanent quadrats over time. This will reveal any significant changes in vegetation composition and structure.

It must be pointed out however that some storm events do blow in from a south-south-easterly (SSE) direction and this resultant wave disturbance could lead to significant disturbance of the shingle habitat, even after construction of a new port area to the west of the stony bank area. This periodic disturbance of shingle is a feature of stony bank areas in the west of Ireland.

It is concluded that any future increase in sheltered conditions at Renmore will result in much less tidal disturbance which in turn will favour the development of a more grass-dominated shingle vegetation. Any changes in the condition of stony bank vegetation can only be verified by future monitoring.

4. The results of the intertidal survey at Renmore are presented in appendix 4 of the main report. It states that the surveys were undertaken between the 28th and 29th October 2015. The previous version of this Appendix issued in February 2016 states that the surveys were carried out in January 2016. Please clarify the survey dates.

The survey was carried out and the samples were collected on October 28th and 29th, 2015. The samples were sorted between 12th November through to 16th December 2015 and were identified between 12th November and 17th December, 2015. Statistical analysis was carried out in January. The report was then written and issued in February 2016.

5. **Please provide data of sediment chemistry to support the conclusion that the difference between groups A, B and C of infaunal macrobenthos identified in Renmore using cluster analysis techniques are due to high organic loads. Please discuss this in more detail, taking into consideration other natural and anthropogenic variables that may also explain these differences, and the evidence available to support any hypotheses on the distribution of infaunal benthic species and abundance in Renmore. Further data is required to support the conclusions reached.**

Organic carbon is a standard sediment chemistry analyte for assessing the quality of marine benthic sediments. This is because there is a high correlation between organic carbon loadings and the types groups of species that are present in the sediment, some species being tolerant of high levels (opportunistic species) and others being intolerant (sensitive species). A sample of sediment is weighed before and after 8 hours at 400°C and is expressed as a percentage of the difference between the two values (LoI stands for Loss on Ignition).

The results of the LoI test are presented below.

Station	% LoI
1	8.16
2	4.28
3	4.26
4	3.96
5	2.24
6	3.36
7	2.18
8	1.15
9	1.12
10	1.22

Only biological data were used for cluster analyses purposes. However, the highest and second highest values of organic carbon were recorded at Stations 1 (8.12%) and 2 (4.28%) and these are closest to the River Corrib. Stations 1 and 2 are the two stations that make up Cluster b in Figure 1 below.

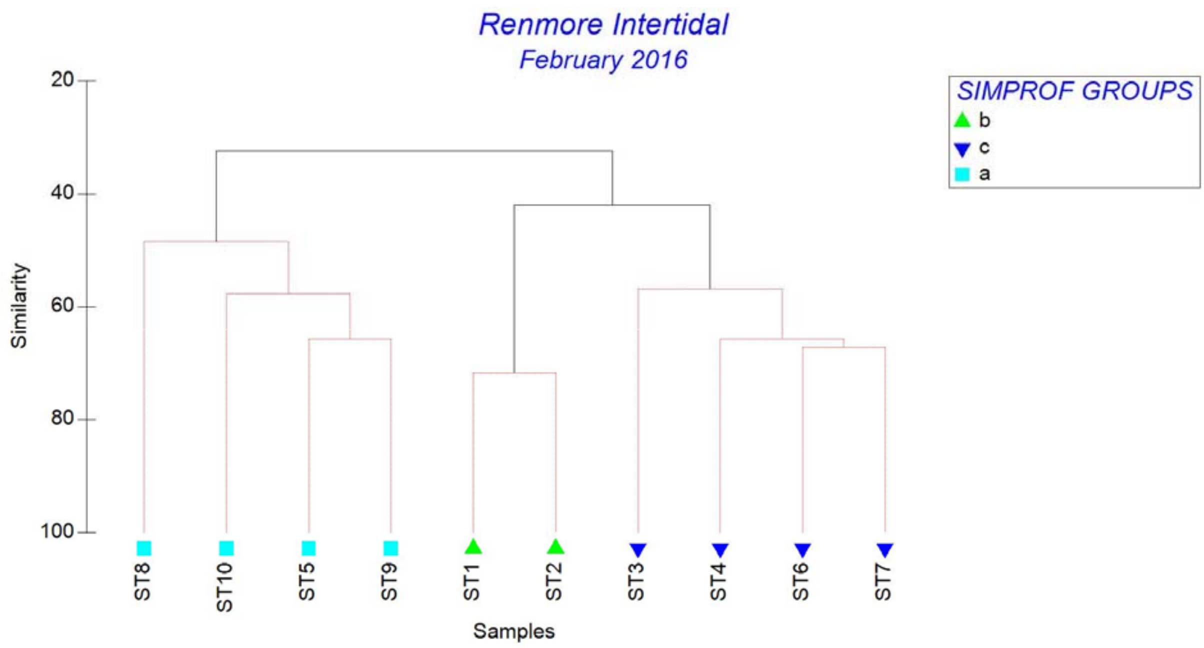

Figure.1. Cluster analysis of quantitative faunal data from ten intertidal stations at Renmore.

The lowest values (1.12% at Station 9, 1.15% at Station 8 and 1.22% at Station 10) were recorded furthest from the River Corrib and these stations along with Station 5 make up Cluster a in Figure 1.

Medium to high levels of organic carbon were recorded at Stations 3 (4.26%), 4 (3.96%), 6 (3.36%) and 7 (2.18%) and these are the stations that make up Cluster on Figure 1.

The mean organic carbon value for Stations 1 - 5 that are located closest to the River Corrib is 4.58% while the mean value for Stations 6 - 10 that are furthest away from the River Corrib is 1.8%.

The catchment of the River Corrib is 3,138 km^2 and land usage is mostly agriculture with some bog cutting and coniferous forestry. There are conurbations within the catchment, the largest of these include Oughterard, Cong, Headford and Tuam. Sewage treatment works in these is at best secondary treatment. Due to these characteristics, water quality in the River Corrib is compromised ever before it reaches Galway City.

With regard to Galway City, before the Mutton Island treatment plant was commissioned in the early years of this century, untreated sewage effluent was disposed of to the sea either via the river itself or via a disposal pipe south of Nimmo's Pier for many, many decades. This gave rise to sediments with low levels of oxygen, increased levels of sedimentary organic carbon and therefore reduced numbers of infaunal invertebrates.

With regard to natural variables noted above in Item 5 and as described in Items 2 and 3 above, the area at Renmore is presently exposed to wind directions from the South, the Southeast and the Southsoutheast. Under violent storm conditions (as occurred in Storms Darwin and Ophelia), this area experiences very violent wave climate conditions that cause significantly increased levels of suspended sediments in the water column and are strong enough to throw up large amounts of stones and cobbles (see photo in Item 2 above). This impacts the entire length and width of the shore line and cannot therefore be used to explain the macrobenthic infaunal communities recorded in the survey.

Concerning anthropogenic variables, the shore line at the site is used in Summer months for fishing mackerel. The shore itself is only rarely used for picking winkles and is not used as a potting site for shrimp or lobsters. It is not a demersal fishing site. Only shallow draft boats can cross the area at High Water if they are making a passage to or from Oranmore Bay. The beach at Ballyloughane is used by swimmers in the Summer but this area is outside the development site.

None of these natural variables are strong enough to regulate the distribution of the macrobenthic infaunal communities recorded in the survey.

The single most important anthropogenic variable that affects this area of Galway Bay is the introduction of organically enriched water either from the Corrib River or the waste water treatment plant at Mutton Island and when the organic carbon levels are examined in tandem with the macrofaunal infaunal date, it is apparent that it is this variable is giving rise to grouping of macrofaunal species at Renmore.

Conclusion
Sufficient data are available on organic carbon content of the sediments at Renmore to show that the western part of the study site which is closest to the Corrib River is the area where highest percentages of organic carbon were recorded and conversely, the eastern area of the study site had the lowest levels of organic carbon and that it is this variable that is controlling the distribution of the macrofaunal communities in the area.

6. Please provide full results of particle size analysis which were undertaken as part of the survey but are not presented in the report.

The methodology to generate the grain size data is presented in Appendix 3. Tables 1 and 2 below provide the results of grain size analyses while Figure 2 graphically represents those data shown in Table 1 based on the ratio of sand, mud and gravel in each sample.

Sedimentary particles are most commonly classified by grain size. Mud particles are less than 62.5µm while sand may be catgeorised as very fine sand (62.5µm - 125µm), very coarse sand (125µm - 250µm) and medium sand (0.25mm – 0.5mm). Gravel is subdivided, into categories of ascending size: granules (2mm - 4 mm), pebbles (4mm - 64mm), cobbles (64mm - 256 mm) and boulders (> 256 mm). Sediment types can be assigned to a sample depending on the relative proportion of partilcles in each grain size.

Tenary plots are used to show the distibution of mud, sand, and gravel particle within sediment samples. A plot of the grain size distributions of the samples (gravel, sand, mud) according to Folk's classification system (see Graph below).

Table 1. Results of granulometric analyses of ten sediment samples collected at Renmore.

Station	Fine Gravel (>4mm)	Very Fine Gravel (2-4mm)	Very Coarse Sand (1-2mm)	Coarse Sand (0.5-1mm)	Medium Sand (0.25-0.5mm)	Fine Sand (125-250mm)	Very Fine Sand (62.5-125mm)	Silt-Clay (<63mm)
1	23.5	23.5	24.6	11	6.1	4.4	4.1	2.8
2	13.8	15.3	22.3	15.4	12.2	12.4	5.8	2.8
3	7.9	15.1	25.5	15.6	7.6	12.3	12	4.1
4	3	15.4	36	20.4	6.9	11.8	5.4	1
5	0.3	0.3	0.3	1.1	1.6	17.8	61.2	17.5
6	38.6	21.3	10.3	4.5	5.9	12.5	5.6	1.4
7	21.5	23.3	16.2	8	9.3	13	7.5	1.3
8	0	0.1	0.1	0.8	3.7	74.1	21	0.3
9	0	0	0.1	0.8	2.6	62.1	34	0.5
10	3	15.4	36	20.4	6.9	11.8	5.4	1

Table 2. Statistical analyses of the data presented in Table 1 above.

		1	2	3	4	5	6	7	8	9	10
	TEXTURAL GROUP (FOLK 1954):	Sandy Gravel	Gravelly Sand	Gravelly Sand	Gravelly Sand	Slightly Gravelly Muddy Sand	Sandy Gravel	Sandy Gravel	Slightly Gravelly Sand	Sand	Slightly Gravelly Sand
FOLK AND WARD 1957 METHOD (µm)	MEAN (M_G):	1251.5	750.9	524.0	717.5	80.88	1227.7	942.6	126.3	119.3	114.5
	SORTING (σ_G):	3.642	3.864	4.299	3.192	2.041	4.430	4.387	1.389	1.425	1.551
	SKEWNESS (Sk_G):	-0.220	-0.289	-0.180	-0.451	-0.136	-0.587	-0.294	-0.541	-0.488	-0.136
	KURTOSIS (K_G):	1.187	0.844	0.819	1.085	4.224	0.674	0.773	1.611	0.611	0.846
FOLK AND WARD 1957 METHOD (description)	MEAN:	Very Coarse Sand	Coarse Sand	Coarse Sand	Coarse Sand	Very Fine Sand	Very Coarse Sand	Coarse Sand	Fine Sand	Very Fine Sand	Very Fine Sand
	SORTING:	Poorly Sorted	Poorly Sorted	Very Poorly Sorted	Poorly Sorted	Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted	Well Sorted	Moderately Well Sorted	Moderately Well Sorted
	SKEWNESS:	Fine Skewed	Fine Skewed	Fine Skewed	Very Fine Skewed	Fine Skewed	Very Fine Skewed	Fine Skewed	Very Fine Skewed	Very Fine Skewed	Fine Skewed
	KURTOSIS:	Leptokurtic	Platykurtic	Platykurtic	Mesokurtic	Extremely Leptokurtic	Platykurtic	Platykurtic	Very Leptokurtic	Very Platykurtic	Platykurtic
	% GRAVEL:	47.0%	29.1%	23.0%	18.4%	0.6%	59.8%	44.8%	0.1%	0.0%	0.5%
	% SAND:	50.2%	68.1%	72.9%	80.6%	82.0%	38.8%	53.9%	99.6%	99.5%	98.8%
	% MUD:	2.8%	2.8%	4.1%	1.0%	17.4%	1.4%	1.3%	0.3%	0.5%	0.7%

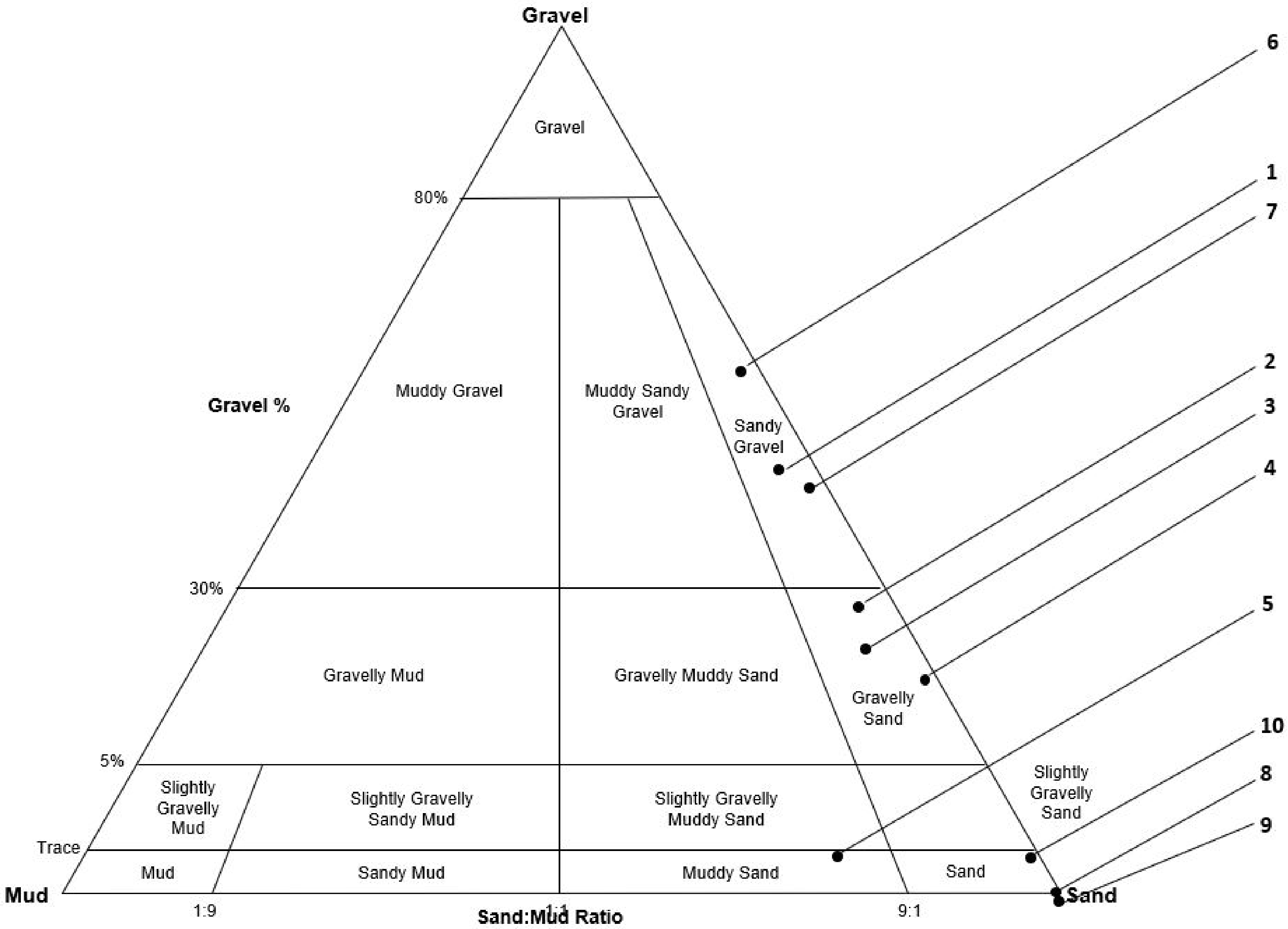

Figure 2. Gravel, sand and mud diagramme of ten sediment samples collected at Renmore (Folk and Ward, 1957).

7. **The report also claims that during the many decades in which untreated raw sewage discharged into the River Corrib and / or via a pipe to the south of Nimmo's Pier that this has given rise to sediment with low levels of oxygen, high levels of sedimentary hydrogen sulphide and therefore reduced numbers of infaunal invertebrates. However, the survey results indicate the opposite. Sites closer to the River Corrib have the highest number of infaunal invertebrates. Please comment further on this, especially in relation to any available data on hydrogen sulphide, and the influence of other variables that may determine distribution of infaunal macrobenthos, particularly particle size of sediment.**

As part of standard benthic surveys, the percentage of organic matter that is present in the sediment is the parameter that is measured and not hydrogen sulphide. This is because organic matter is "inert" and its value is not affected by the sampling process *i.e.* the grabbing or coring activity used to collect the sample and any subsequent processing event will not alter the value of organic matter. However, as hydrogen sulphide is a gas, the sampling process and subsequent treatment of the sample will cause the gas to dissipate from the sediment long before it can be analysed. For this reason, hydrogen sulphide is not routinely analysed as part of macrobenthic infaunal studies.

It is a fact that historically untreated sewage effluent was disposed of to either the River Corrib or to an intertidal location south of Nimmo's Pier, this disposal practice only stopped when the treatment plant at Mutton Island in the early part of the 2000s. Up to that, untreated sewage effluent impacted both water and sediment quality (and therefore the benthic macroinfaunal communities) in that part of Inner Galway Bay.

Concerning the interpretation of the faunal results, from Figure 2 below, it can be seen that Stations 1 and 2 are the ones closest to the plume of the Corrib. The occurrence of the pioneering polychaete genus *Capitella* and high numbers of tubificid oligochaetes in Cluster A (Stations 1 and 2 which are closest to the plume of the River Corrib) indicate a high level of organic carbon (as noted above in Item 5) and a decreased level of oxygen in the sediment.

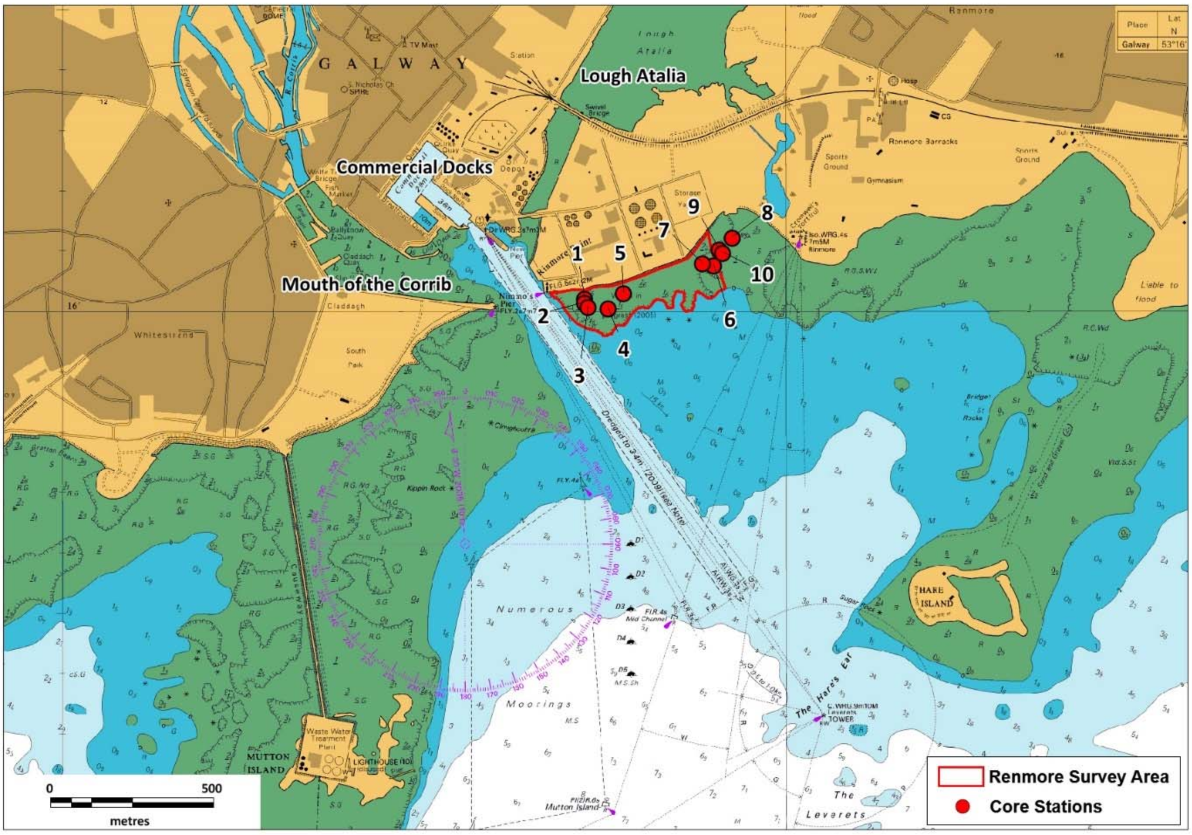

Figure 3. Location of 10 intertidal sampling stations at Renmore.

Also, examining Table 3 (see below), it is true to say that both numbers of species and numbers of individuals are higher at the stations closer to the Corrib but one must know what the tolerance of these species is to higher organic carbon levels and therefore low sediment oxygen conditions. Looking at the taxa in that area, they are opportunistic species that are tolerant of pollution. Also, like all opportunistic taxa, when they are present, they are typically present in high numbers.

	No. Taxa	No. Individuals	Richness	Evenness	Shannon-Weiner Diversity	Effective species number
Station	S	N	d	J'	H'(loge)	Exp (H')
ST1	20	1549	2.586665	0.263671	0.789888	2.20
ST2	15	963	2.03783	0.344377	0.932591	2.54
ST3	14	510	2.085201	0.455683	1.202574	3.33
ST4	26	366	4.235398	0.738705	2.406773	11.10
ST5	13	84	2.708304	0.754275	1.934676	6.92
ST6	24	309	4.011622	0.73269	2.328529	10.26
ST7	23	305	3.845944	0.78269	2.45412	11.64
ST8	8	45	1.838881	0.702141	1.460061	4.31
ST9	8	62	1.696092	0.655814	1.363727	3.91
ST10	8	45	1.838881	0.76063	1.581686	4.86

Table 3. Results of univariate statistical analyses. S: number of species, N: numbers of individuals, d: Margalef's species richness, J': Pielou's Evenness index and H'(log e): Shannon Weiner diversity, Effective species number: Exp (H').

Species richness is a measure of the total number of species present for a given number of individuals. Evenness is a measure of how evenly the individuals are distributed among different species. The Shannon-Wiener index incorporates both species richness and the evenness component of diversity (Shannon & Weaver, 1949). The diversity index is then converted to effective numbers of species to reflect 'true diversities' (Hill, 1973; Jost, 2006) that can then be compared across communities (MacArthur, 1965; Jost, 2006).

To these univariate statistics, the Effective Species Number (ENS) has been added. The ENS is equivalent to the number of equally abundant species that would be needed in each sample to give the same value of a diversity index, *i.e.* Shannon-Weiner Diversity index. The ENS behaves as one would intuitively expect when diversity is doubled or halved, while other standard indices of diversity do not (Jost, 2006). If the ENS of one community is twice that of another then it can be said that that community is twice as diverse as the other. Table 3 shows that Stations 1, 2 and 3 that are closest to the River Corrib, had the lowest ENS of all stations sampled meaning that they are the least diverse in the area.

Conclusion

The data on the percentages of organic matter in the sediments, the numbers and types infaunal taxa and their tolerance of sensitivity to organic enrichment are the main reasons for the relative distributions of macrofaunal communities at Renmore.

8. Please comment upon and explain the rationale for picking the location of sampling spots at Mweeloon as indicated on figure 3.2 of appendix 8 of the Main Compensatory Measures Report.

In the initial search for an area where the compensatory measures could be implemented, three sections of Tawin Island were examined at a high level for comparative purposes. These were Mweeloon Lagoon, the western section of Tawin Island and the southern section of Tawin Island. Because of the greater levels of exposure at the latter two areas, *i.e.* the western end of Tawin Island and the southern shore, they were deemed unsuitable locations. For that reason, the area of Mweeloon Lagoon was selected.

A total of 66 transects were surveyed at Mweeloon based on a spacing of 100m intervals. The rationale for choosing this distance was that it was considered sufficiently short to allow a high level of cover for both the open shore and the lagoonal area and thereby provide a robust baseline for future monitoring surveys. This density and tight spatial separation provides a high level detail of variability in types of shoreline and water bodies within the Compensation Measures area.

The rationale was that they fell within the area that had been selected for where the compensatory measures would be carried out to provide a clear understanding of this extended area.

Of the 66 transects surveyed, 15 are located within the proposed marine reference area, 40 lie within Mweeloon Lagoon and 11 are located in Lackanaloy Lagoon. The overall length of the intertidal area surveyed (including within the lagoonal and open sea habitats) was 6.5 km.

9. **Concern is expressed that in its current form, the sampling strategy is not specific enough for the establishment of a baseline environment on which the success of future compensatory measures can be assessed. Please provide further details of a sampling strategy which will provide comprehensive data on a baseline environment on which before and after scenarios can be established, and how these will be compared.**

A detailed sampling strategy that will provide comprehensive data on the baseline environment for all elements of the compensatory measures are outlined in the response to Item 1 and Appendices 3.1 and 3.2 and also under responses to Items 2 and 3. These data sets will also allow for *"ante et post"* comparisons to be carried out.

10. The Board have concerns that the monitoring programme for the intertidal habitats has some significant methodological errors, such as samples taken at different times of the year, with five replicas taken in Tawin Island (correct for statistical analysis), and only two samples provided at Renmore (not correct). The results of the two samples are compared for analytical purposes in the report. The Board recommend that any inferred results are based on more consistent and robust data set.

Monitoring programme for the intertidal habitats
Details of the sampling methodology has been outlined above in Point 1 and also in Appendix 3. The methodology proposed includes:

1. Annual programmes to control *Didemnum*
2. Temporal effects over a 5 year monitoring plan for the oyster fallow site study (including tracking by tractors) and
3. Over a longer time period for the effects of "organic" farming practices.

Seasonality and benthic sampling
It should be noted that with the exception of the annual reproductive cycle, unlike terrestrial flora and fauna and planktonic communities, intertidal and subtidal benthic fauna do not respond to seasons; the infauna taxa and densities typically reflect the long-term conditions (*e.g.* extant anthropogenic disturbance, violent storms, harmful algal blooms, threats and pressures) rather than as reactions to changing seasons. Consequently, it is scientifically acceptable to take benthic samples at different times of the year and compare the results.

Numbers of replicates
Compared to other areas of Galway Bay (including Renmore), the intertidal ecology of Tawin was poorly known and up to this survey, it had not previously been studied in any detail. (This poor level of knowledge of the area included the fact that it was not known to be a lagoon, which under the Habitats Directive is listed as a Priority Habitat). For this reason and in order to establish a robust base line for future studies, 5 subsamples were taken at Mweeloon. Furthermore, a high density of 66 transects was undertaken in Tawin based on a distance of 100m apart to ensure that the area was very well spatially surveyed.

As the area is the site of the proposed harbour development *i.e.* it will be permanently lost, 2 replicate faunal samples and 1 sample for granulometry and organic carbon at 10 sampling locations was considered adequate and therefore appropriate to describe the faunal and sedimentary conditions.

With regard to the final sentence of Item 10 above **"*The Board recommend that any inferred results are based on more consistent and robust data set*"** all future studies for *Didemnum,* tracking changes post-fallowing and studying long term trends in the presence and abundance of green algae will only occur at Mweeloon following the methodologies and time scales as presented in Appendix 3.

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Appendix No. 1

1. C.V. Dr. Brendan O'Connor
2. C.V. Dr. John Conaghan

Brendan O'Connor, Ph.D. – Curriculum Vitae

Nationality: Irish
Profession: Biologist / Ecologist
Specialisation: Marine Benthic Ecology & Terrestrial Biologist
Position in Firm: Managing Director
Year of Birth: 1951

Key Competence
MCIEEM
Environmental Impact Statements
Marine Benthic Ecology
Ecological Surveying
Coastal Zone Management
Taxonomy of Polychaeta, Oligochaeta, Priapulida, Pogonphorae, Sipunculidae, Echiurae and Echinodermata.

Brendan has been Managing Director of AQUAFACT International Services Ltd since 1986. He has 40 years of experience in the field of marine science and has published *ca* 80 scientific papers and numerous reports specialising in the biology and ecology of sea-floor communities. Brendan is a member of the Chartered Institute of Ecology and Environmental Management. Brendan is an internationally recognised polychaete taxonomist and has led numerous international workshops in polychaete taxonomy including workshops as part of the UK BEQUALM/NMBAQC. He has 33 publications on marine invertebrate taxa including descriptions of new species, revisions of families and additions to the European and Irish fauna.

As Managing Director of AQUAFACT Brendan has been responsible for all aspects of management including the design, execution and reporting of numerous subtidal benthic surveys all around the Irish coast. He has vast experience with all necessary surveying technology including various benthic samplers necessary such as van Veen, Hamon and Day grabs, Railler-du-Bathy dredges, box corers, gravity corers and epibenthic sleds. Brendan is very familiar with all sampling methodologies and guidelines which must be adhered to whilst sampling and has extensive experience in the processing of faunal and sediment samples.

Education and Professional Status
1973 B.Sc. (hons.) University College, Galway,
1981 Ph.D., University College, Galway

General Research Experience
1973 B.Sc. thesis: "A Preliminary Investigation of the planktonic Cnidaria and Ctenophora".
1981 Ph.D. Project, "A synecological survey of the benthos of Galway Bay with reference to class Polychaeta and Phylum Echinodermata and some lesser phyla".

Brendan's experience in harbour developments
Brendan has worked on several harbour related projects other than the proposed Galway Harbour Expansion. These include developments at Rossaveal, Westport, Sligo, Killybegs, Greencastle, Derry, Larne, Belfast, Newry, Dundalk, Drogheda, Clogher Head, Howth, Dublin, Dun Laoighre, Arklow, Wexford, Waterford, Cork, Fenit and Shannon ports.

Brendan's EIA Experience
Ongoing
Marine Ecology Chapter of Westwave EIS on behalf of ESBI
2014-2015
Marine Ecology Chapter of Compressed Air Energy Storage EIS on behalf of Gaelectric
Marine Ecology Chapter of Ringsend wastewater treatment plant

2010 - 2015

Environmental Impact Assessment for Galway Harbour Expansion Project.
2012
Marine Ecology Chapter of Ringsend Waste Water Treatment Plant EIS on behalf of CDM.

Brendan's Recent Intertidal Work Experience

- Brendan was involved in the intertidal surveying of the Shannon estuary on behalf of the Marine Institute and NPWS.
- Brendan carried out an intertidal and subtidal survey for an environmental survey for channel access, sea wall and storage yard for a deep water dock in Galway Enterprise Park. The intertidal involved the selection and analysis of four shore transects and included quadrat analysis, photographic documentation and identification of all flora and fauna.
- Brendan carried out intertidal sampling in Galway Bay as part of a study to determine the impact of a floating pontoon on the local environment. The shore at the location was of a rocky nature and the survey consisted of direct observations with photographic records at four predetermined stations (strandline, upper/mid/lower shore) along a transect during a low water spring tide. The shore profile was also recorded by means of an engineer's level and handheld DGPS.
- Intertidal and subtidal evaluations and Appropriate Assessments for a proposed Pier Development in the Galway Bay SAC. Client: Ard Precision Engineering

Brendan's Recent Natura Impact Statement Work Experience

- NIA and CMR for the proposed Galway Harbour Expansion project.
- Appropriate Assessment Screening Report for storm damage repairs to three piers in south Connemara, Galway (2014)
- NIS for the Stracashel River Crossing as part of Glenties Sewage Scheme (2014)
- Screening Report for a Waste Water Treatment Plant (WWTP) and associated outfall in Glenties, Co. Donegal (2014)
- NIS for a proposed hydroelectric scheme on the River Leenan, Co. Donegal (2013)
- Natura Impact Statement for the proposed Galway Harbour Extension (2013)
- Natura Impact Statement for playing fields on LIT Tipperary Campus, Thurles, Co. Tipperary (2012)
- Natura Impact Statement for a temporary footbridge over the river Corrib in Galway City (2012)
- Natura Impact Statement (NIS) for a proposed hydroelectric scheme on the River Leannan, Co. Donegal (2012)
- Appropriate Assessment for a hatchery on the River Scríb (2011)
- Natura Impact Statement for a proposed hydroelectric scheme on the River Leannan, Co. Donegal (2011)
- Natura Impact Statement for Galway Docks Expansion Project (2011)
- Natura Impact Statement for the Erection of a New Dwelling House, Domestic Garage and Puraflo treatment plant at Cabra, Glebe, Co. Donegal (2010)
- Natura Impact statement on the Status of a Causeway Connecting Taggart Island to the Mainland, Clew Bay, Co. Mayo (2010)
- Natura Impact Statement for the emplacement of coastal protection at Bomore Point, Co. Sligo (2010)
- Natura Impact Statement screening process for proposed upgrading of an access road and shore protection works at Doonloughan Pier, Ballyconneely, Co. Galway (2010)
- Environmental Survey and Natura Impact Statement at Cúl an Chlaí Pier, Cuan Bhaile Conraoí, Co. Galway (2010)
- Natura Impact Statement for a Proposed Community Building at Cappagh Park, Barna, Galway (2009)
- Natura Impact Statement for 110kV Cable Crossing of River Corrib, Galway (2009)

- A Natura Impact Statement for a Pier Development at Raigh, Co. Mayo (2009)

Additional Information

- Extern examiner as Membré Invité de la commission d'Examen, Université deMarseille.
- Expert taxonomist at a polychaete workshop, Edinburgh, 1985.
- Leader of a 5 day workshop on polychaete identification in Helgoland, 1988.
- Appointed as Evaluator by the EU for MAST proposals in Marine Science, 1992.
- Chairman of the Irish MAST Committee which made a submission to Forbairt on the scope of the marine scientific section of the 5th framework.

Key Scientific Publications

1) Keegan, B., O'Connor, B ., McGrath , D . & Könnecker, G. 1976. The *Amphiura filiformis - Amphiura* chiajei community in Galway Bay (west coast of Ireland) - a preliminary account. Thalassia jugoslavia, 12:189-198.

2) O'Connor, B & McGrath, D.1980. The population dynamics of *Amphiura filiformis* (O.F.Müller) in Galway Bay, West Coast of Ireland. pp. 219 -233. In: Echinoderms: Past and present (Jangoux. J., ed.). A.A.Balkema, Rotterdam.

3) O'Connor, B. McGrath, D. and Keegan, B.F.K. 1986. Demographic equilibrium - the case of an *Amphiura filiformis* community on the west coast of Ireland. Hydrobiologia 142: 151-158.

4) O'Connor, B. and Tyndall, P. 1986. Some new and rare Echinodermata from Irish inshore waters. Ir.nat J. 22: 96 - 97.

5) O'Connor, B., Bowmer, C.T., McGrath, D. and Raine, R. 1987. Energy requirements through an *Amphiura filiformis* population in Galway Bay, West coast of Ireland: A preliminary investigation. Ophelia 2 : 351-357.

6) O'Connor, B. 1987.The Glyceridae (Polychaeta) of the Northeast Atlantic with descriptions of two new species. J. Nat .Hist. 21: 167-189.

7) O'Connor, B. 1991. The use of mathematical models in predicting the distribution of macrofaunal communities. Proceedings of a Workshop on "Modelling the Benthos", Yerseke, Holland, March 1991.

8) Keegan, B., Rhoads, D., Germano, J., Solan, M., Kennedy, R., O'Connor, I., O'Connor, B., McGrath, D., Dinneen, P., Acevedo, S., Young, S., Grehan, A. and Costelloe, J. Sediment Profile Imagery as a benthic monitoring tool: Introduction to a 'longterm' case history evaluation (Galway Bay West Coast of Ireland). Pps 43 – 63. Eds. Aller, Woodin and Aller. Belle Baruch.

Dr. John Conaghan B.Sc., Ph.D. MIEEM – Curriculum Vitae

Dr. John Conaghan is a botanist who has worked provided consultancy services since 1994. His main field of expertise is the botanical survey and management of Irish habitats and vegetation. In 1995 he was awarded a Ph.D. in Botany from the National University of Ireland (Galway) for his research into the distribution and ecology of the rare cottongrass species *Eriophorum gracile* and *Eriophorum latifolium* in Ireland.

Since that time has carried out numerous botanical and habitat surveys/assessments in a wide range of Irish habitats including sand-dune, salt-marsh, blanket bog, calcareous fen and calcareous grassland. This work has been conducted for a wide range of clients including the National Parks and Wildlife Service, Coillte, the National Roads Authority, the Electricity Supply Board and the Heritage Council. Examples of botanical/ecological surveys undertaken include:
The assessment of limestone pavement and coastal habitats and vegetation in connection with the Kilronan Pier construction, Inis Mor, Co. Galway.

Description and assessment of coastal habitats and vegetation in connection with the Ard Thoir, pier development, Connemara, Co. Galway.

Survey and assessment of sand-dune habitats at Sligo Airport.

Vegetation survey and management proposals for a sand-dune/salt-marsh system at Barleycove, Co. Cork.

Baseline survey of coastal habitats and vegetation at the Derrynane estate, Co. Kerry.

Survey of machair and associated coastal habitats, e.g. sand-dune, dry heath, salt-marsh and fen, in the north-west of Ireland.

Survey of rare plant species distribution and conservation in Counties Galway, Limerick and Clare.

Appendix No. 2

Map 14(1) Fig. 14(1) *Didemnum* Management Control Area

Map 20(1) Fig. 20(1) Additional Intertidal Reference Area

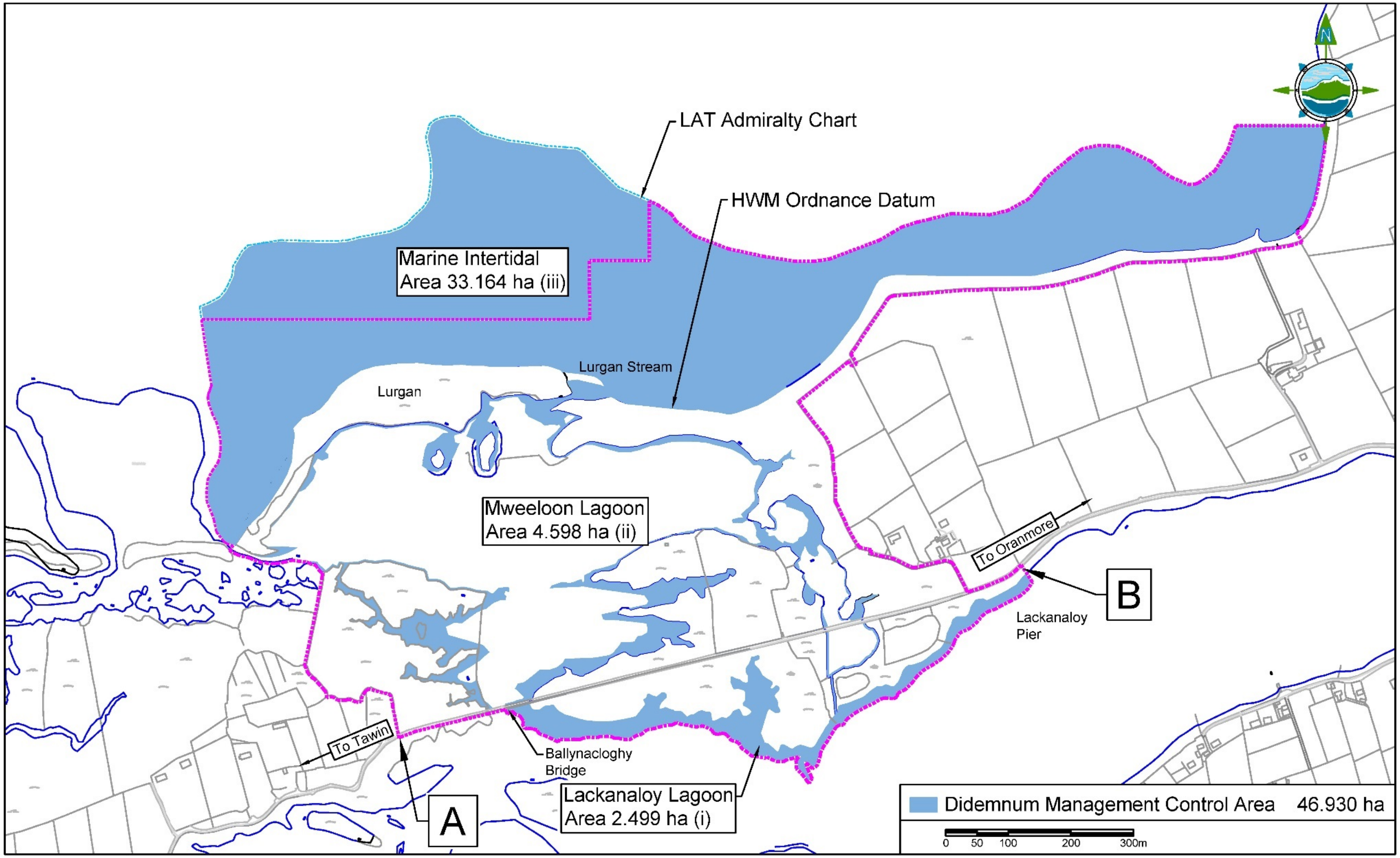


Fig. 14(1) *Didemnum* Management Control Area

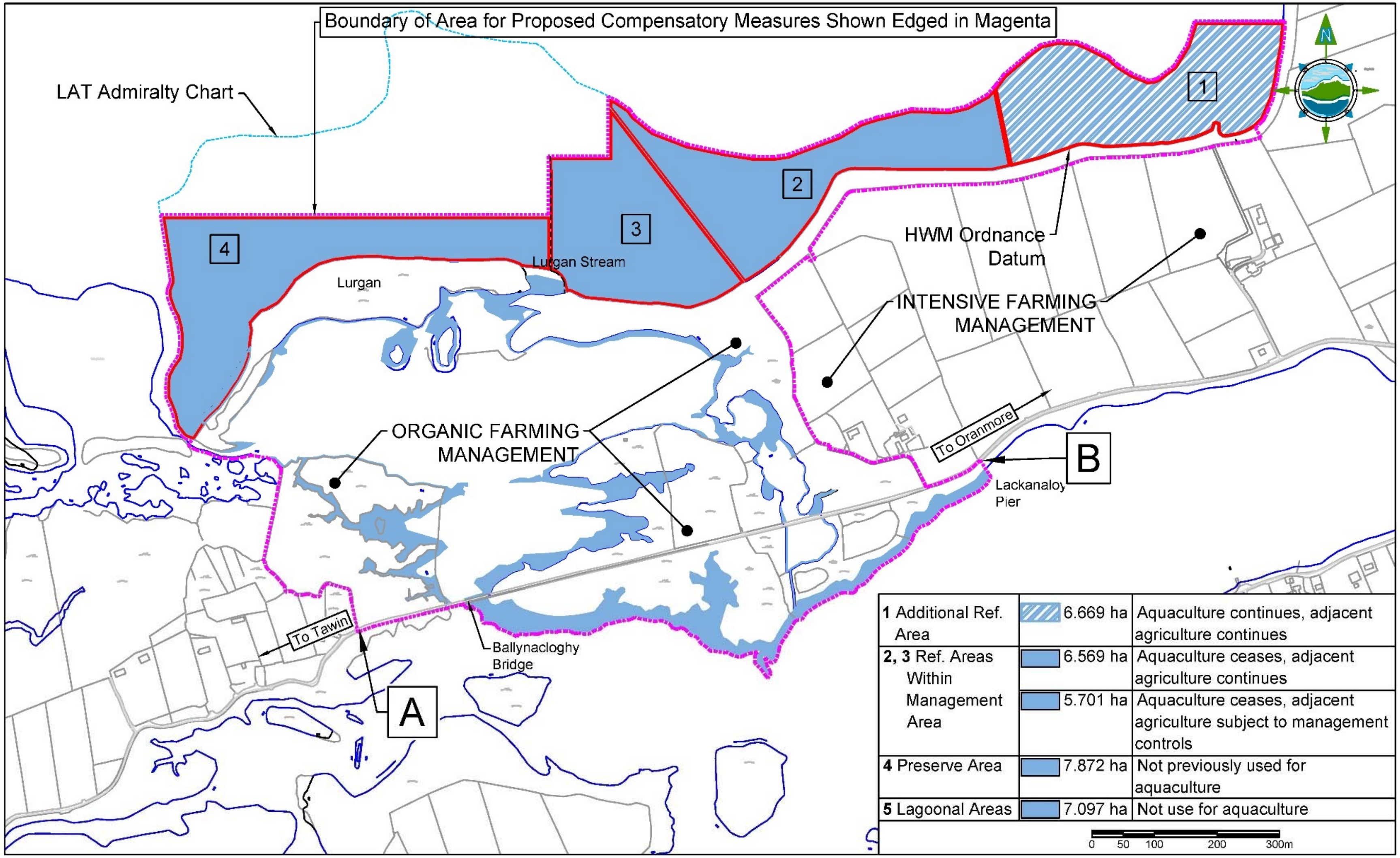


Fig. 20(1) Additional Intertidal Reference Area

Appendix No. 3

3.1 Intertidal Sampling Methodology

3.2 The Monitoring of salt marsh and stony bank vegetation at Mweeloon and Renmore

Appendix 3.1

Intertidal Sampling Methodology

The effects of mollusc aquaculture on marine ecology has received some focus of research not only in Ireland (Forde *et al.*, 2015 *inter alia*) but also further afield (see for reviews see McKindsey *et al.,* 2011; Gallardi, 2014). Forde *et al.* (2015) investigated the impact of oyster trestle cultivation activities on intertidal soft sediment habitats and infaunal communities at six sites located within four designated Natura 2000 sites distributed around the north-west, west and south coasts of Ireland. Specifically, the study investigated changes in sediment characteristics and associated infaunal communities 1) underneath trestles and 2) along access routes.

Results showed that sediment characteristics and the associated infaunal community structure and diversity indicators across the sites was highly variable, with increases in species abundance and diversity attributed to faecal/pseudofaecal material produced by the oysters acting as a source of additional food for the infaunal taxa. The variability across sites prevented the detection of the general effects of cultivation activity on sediment characteristic and faunal community structure. To overcome variability, the Water Framework Directive (WFD) Ecological Quality Ratio (EQR) Infaunal Quality Index (IQI) indicator was used to assess impacts on the Ecological Status (ES) of the infaunal communities.

This study showed that traffic along access routes had a significant negative impact on ES. The negative impact on ES was attributed to tractor and trailer traffic and the consequent compaction of sediments. This study highlighted the IQI EQR indicator as a tool for the management of aquaculture activity and as a potential tool for assessing the conservation status of designated habitats in Natura 2000 sites.

Method
Within the Mweeloon marine reference site, four areas will be selected and these are as follows:

1. At the trestles of an active aquaculture site (Map 20(1), Reference Area 1) and adjacent to an area of intensive agriculture including the access route to and from it,
2. At an aquaculture site that will be fallowed and adjacent to an area of intensive agriculture (Map 20(1), Reference Area 2),
3. At an aquaculture site that will be fallowed and adjacent to an area of “organic” agriculture (Map 20(1), Reference Area 2) and
4. At a location on the tractor access route to the active aquaculture site (Reference Area 1).

Within each of these including the access routes, 10 stations will be selected. At each station two core samples will be taken, one core for faunal analysis and one core for sediment granulometry and organic carbon analysis. At each station, REDOX depth will be at the assessed visually using a transparent, plastic core. Summaries of the faunal and sediment analyses are presented below. Sampling will be carried out as listed below:

Before the trestles are removed;
1 week post removal;
1 month post removal;
6 months post removal;
1 year post removal and
Once a year for 5 years post removal.

The temporal changes at the fallowed sites will be compared to temporal changes at a nearby trestle oyster site where cultivation activity will be continue *i.e.* an active production site and at the access route. All sites to be investigated will be selected to ensure that they are comparable in terms of shore tidal height and sediment type.

Samples for quantitative faunal analysis will be sieved on a 1mm mesh sieve, preserved, sorted and identified to species level where possible.

The faunal samples will be processed in a systematic way to ensure that no samples are omitted. A daily inventory of what samples have been sorted/identified/counted will be maintained. The samples will be sorted as follows:

Conspicuous fauna will be placed in an illuminated shallow white tray and sorted first by eye to remove large specimens and then sorted using a stereo microscope at 6 to 10 times magnification.

Following the removal of larger specimens, the samples will be placed into Petri dishes, approximately one half teaspoon at a time and sorted using a binocular microscope at x25 magnification.

The fauna will be maintained in stabilised 70% industrial methylated spirit (IMS) following retrieval and identified to species level where practical using a binocular microscope, a compound microscope and all relevant taxonomic keys.

AQUAFACT has an extensive library of taxonomic publications (including BEQUALM/NMBAQC guides).

Species nomenclature will be classified in accordance with Howson & Picton (1997).

After identification and enumeration, specimens will be separated and stored to species where possible.

All containers will be clearly labelled on the outside stating site, date, sample code, replicate number and name of individual who analysed the sample.
A permanent internal label bearing the same information will also be included with all containers.

Specimens will be stored in stabilised Industrial Methylated Spirits (IMS) in containers with adequate seals and labelled accordingly.

Residual detritus will be kept in a separate container for each sample, labelled inside and outside.

Sample residue will be preserved in alcohol in containers with adequate seals and labelled accordingly.

All faunal abundance data will be recorded in an Excel spreadsheet.

The following description outlines the methodology for granulometric analyses.

Approximately 25g of dried sediment is weighed out and placed in a labelled 1L glass beaker to which 100 ml of a 6 percent hydrogen peroxide solution is then added. This is allowed to stand overnight in a fume hood.

The beaker is placed on a hot plate and heated gently. Small quantities of hydrogen peroxide are added to the beaker until there is no further reaction. This peroxide treatment removes any organic material from the sediment which can interfere with grain size determination.

The beaker is then emptied of sediment and rinsed into a. 63µm sieve. This is then washed with distilled water to remove any residual hydrogen peroxide. The sample retained on the sieve is then carefully washed back into the glass beaker up to a volume of approximately 250ml of distilled water.

10ml of sodium hexametaphosphate solution is added to the beaker and this solution is stirred for ten minutes and then allowed to stand overnight. This treatment helps to dissociate the clay particles from one another.

The beaker with the sediment and sodium hexametaphosphate solution is washed and rinsed into a 63µm sieve. The retained sample is carefully washed from the sieve into a labelled aluminium tray and placed in an oven for drying at 100ºC for 24 hours.

When dry this sediment is sieved through a series of graduated sieves ranging from 4 mm down to 63µm for 10 minutes using an automated column shaker. The fraction of sediment retained in each of the different sized sieves is weighed and recorded.

The silt/clay fraction is determined by subtracting all weighed fractions from the initial starting weight of sediment as the less than 63µm fraction was lost during the various washing stages.

The particle size (PSA) data will be processed using GRADISTAT (Blott and Pye, 2001) software to derive sediment type classification and sediment particle parameters including (ø) particle graphic mean values (Mz) and sediment distribution modality. All sediment samples will be classified using Folk and Ward (1957). Mz is a parameter used to describe the mean particle size of a distribution and is analogous to the graphic mean employed with the normal distribution in conventional statistics (Forde *et al*., 2012); consequently, the Mz parameter can be used with confidence where sediments exhibit unimodal distributions. If the particle size distribution of the sediments samples are unimodal (or approximately unimodal), Mz values will be used to track change in average particle size over time.

Regarding statistical analyses, univariate statistics will include:

1. Species richness which is a measure of the total number of species present for a given number of individuals.
2. Evenness which is a measure of how evenly the individuals are distributed among different species.
3. The Shannon-Wiener index which incorporates both species richness and the evenness component of diversity (Shannon & Weaver, 1949).
4. This diversity index is then converted to Effective Species Number (ENS) to reflect 'true diversities' (Hill, 1973; Jost, 2006) that can then be compared across communities (MacArthur, 1965; Jost, 2006). The ENS is equivalent to the number of equally abundant species that would be needed in each sample to give the same value of a diversity index, *i.e.* Shannon-Weiner Diversity index. The ENS behaves as one would intuitively expect when diversity is doubled or halved, while other standard indices of diversity do not (Jost, 2006). If the ENS of one community is twice that of another then it can be said that that community is twice as diverse as the other.
5. Multivariate statistical analyses will be used to investigate change in community structure.

Other indicators will include the level of reduction of organic carbon in the sediments and the increase in median particle size (Mz) at the fallow site in comparison to the actively farmed site.

Thresholds

Based on the results of Forde *et al.*, (2016), it is predicted that as there will be less organic matter in the sediment post-fallowing, numbers of individuals of suspension and deposit feeding taxa such as *Macomangulus* and *Polycirrus* (that were recorded in the reference area of Mweeloon as part of the intertidal survey for the CMP report) will decrease. The threshold for these taxa is that there will be a statistically significant reduction in their densities, 5 years post-removal.

Amphipoda are known to be sensitive to increased organic carbon loadings and densities in taxa such as *Bathyporeia* (that has also been recorded at the site) are predicted to increase post-fallowing. The threshold for densities of these taxa is that there will be a statistically significant increase in their densities, 5 years post-removal.

Nematoda and Oligochaeta are known to be tolerant to increases in organic loadings and a threshold for densities of these taxa is that there will be a statistically significant reduction in their densities, 5 years post-removal.

With regard to changes in numbers of individuals and numbers of species, it is predicted that post- removal of trestles, this should be reflected in the Effective Species Number (ENS). A threshold for the ENS is that there will be a statistically significant reduction in the ENS 5 years post-removal.

Threshold values for a decrease in levels of organic carbon and mean grain size is that there will be a statistically significant reduction in these values, 5 years post- removal.

Regarding the access route, it is predicted that numbers of species and numbers of individuals will increase over time. A threshold for densities of taxa is that there will be a statistically significant increase in both, 5 years post-removal.

Appendix 3.2

The monitoring of salt-marsh and stony bank vegetation at Mweeloon and Renmore

Salt-marsh and stony bank vegetation will be monitored using the survey techniques specifically developed by the National Parks and Wildlife Service for the monitoring of salt-marsh and stony bank vegetation, see McCorry and Ryle (2009) and Martin *et al.* (2017).

Central to this monitoring will be the establishment of a large number of monitoring points which can be revisited at regular intervals in order to document any changes in vegetation composition and structure which result from the different management practices employed. It is proposed that five quadrats will be established within each hectare of salt-marsh and stony bank habitat. This will give a total of 80 monitoring quadrats at Mweeloon (60 in salt-marsh habitat and 20 in stony bank habitat) and 10 quadrats in stony bank habitat at Renmore. Quadrats will be surveyed twice a year, at the beginning of the growing season, *i.e.* May and close to the end of the growing season, *i.e.* late July/early August.
Vegetation composition and structure will be surveyed within 2x2 metre quadrats.

In each quadrat the following parameters will be recorded:

(1) Size.

(2) Grid reference, as documented by GPS. This will aid in the relocation of quadrats during subsequent monitoring surveys.

(3) Percentage cover of vegetation, bare soil, water and rock.

(4) Percentage cover of vascular plant and bryophyte species present.

(5) Degree of flowering observed with respect to each vascular plant species.

(6) Percentage cover and height of the different vegetation layers, *i.e.* shrub, herb and bryophyte.

(7) Height of vegetation.

(8) Soil type and depth.

(9) Slope and aspect.

(10) Additional details, such as the composition of the surrounding vegetation, degree of grazing/habitat disturbance etc.

A photograph of each monitoring quadrat will be taken during each survey in order to document the appearance and condition of the habitat.

Stony bank monitoring
Important monitoring goals for stony bank vegetation/habitat include:

(1) Maintain a low cover of non-native or weedy species in the vegetation, *i.e.* <5% cover in monitoring quadrats. In the case of stony bank habitat the of monitoring the cover of weedy and non-native species, e.g. *Senecio jacobea, Lolium perenne, Cirsium arvense* and *Lactuca tatarica*, is of particular interest as the presence of these species indicate a degree of disturbance and enrichment of the habitat. The presence of the alien species *Lactuca tatarica* at Renmore has been previously noted and recent observations show that the species has a high cover in places.

(2) Ensure a low incidence of disturbance due to trampling and grazing of stony bank vegetation by livestock. This can be measured by noting parameters such as vegetation height, presence of bare soil etc. within monitoring quadrats.

(3) Promote improved flowering/seeding of stony bank vegetation. This will be achieved by implementing an appropriate, low-intensity grazing regime.

Salt-marsh monitoring
Salt-marsh monitoring points at Mweeloon will be positioned along transects which will sample the natural variation in the Atlantic salt-marsh vegetation which occurs ranging from upper marsh to lower marsh. Important monitoring goals for salt-marsh vegetation/habitat include:

(1) The maintenance of site specific structural variation in the sward.

(2) The presence of characteristic plant species of the various salt-marsh zones.

(3) Ensure that less than 5% cover of bare soil due to livestock poaching is achieved.

(4) Promote improved flowering/seed production of salt-marsh vegetation. This will be achieved by implementing an appropriate, low-intensity, grazing regime.

(5) Monitor for the presence of the invasive Cordgrasses (*Spartina* species). It should be noted however that these invasive grass species have not yet been recorded from the Inner Galway Bay area.

Appendix No. 4

Extract Tony Cawley – Chapter 8 Water – January 2014

Section 8.4.6 Wave Climate Prediction

8.4.6 Wave Climate Prediction

8.4.6.1 Introduction

A significant source of flood risk to the port and surrounding lands and urban shoreline areas is flooding by wave overtopping combined with highwater tides. In particular the protecting breakwaters proposed for the harbour extension are dependent on accurate prediction of design waves so as to set the height and location of the breakwater/quay wall. To this aim wave climate modelling of Galway Bay westward beyond the Aran Islands was carried out to predict the design waves at the Harbour and surrounding shoreline. To derive wave heights in the Proposed harbour area and at all other relevant locations of interest within the outer harbour area (*i.e.* between Mutton Island, Hare Island and the shore), two wave models have been used; a spectral wave model TOMAWAC used to transform deep water waves to nearshore waves and a harbour agitation model ARTEMIS suitable to studying wave disturbance within enclosed bays and harbour areas.

8.4.6.2 Methodology

Two wave models from the TELEMAC hydraulic computational suite of hydrodynamic software were used to assess and predict the wave climate at the new Harbour and along the adjacent shoreline. The first model used was TOMAWAC to model the propagation of deepwater waves into inner Galway Bay. A second more refined model ARTEMIS was used to model the proposed port area, its sea defences and to assess the effect of the new port extension on the local wave climate.

TOMAWAC is a third generation spectral wave model representing the generation of waves due to winds and offshore climates and propagation of these waves into shallow waters.

The following energy dissipation, transfer and propagation processes are modeled by TOMAWAC using an unstructured finite element mesh.

Dissipation processes

- white capping dissipation or wave breaking, due to an excessive wave steepness during wave generation and propagation;
- bottom friction-induced dissipation, mainly occurring in shallow water (bottom grain size distribution, ripples, percolation);
- dissipation through bathymetric breaking. As the waves come near the coast, they swell due to shoaling until they break when they become too steep; and
- dissipation through wave blocking due to strong opposing currents.

Energy transfer processes:

- non-linear resonant quadruplet interactions, which is the exchange process prevailing at great depths; and
- non-linear triad interactions, which become the prevailing process at small depths.

Wave propagation-related processes:

- wave propagation due to the wave group velocity and, in this case, to the velocity of the medium in which it propagates (sea currents);
- depth-induced refraction which, at small depths, modifies the directions of the wave-ray and then implies an energy transfer over the propagation directions;
- shoaling: wave height variation process as the water depth decreases, due to the reduced wavelength and variation of energy propagation velocity;
- current-induced refraction which also causes a deviation of the wave-ray and an energy transfer over the propagation directions; and

- interactions with unsteady currents, inducing frequency transfers (e.g. as regards tidal seas).

Model limitations
Due to model solution structure the following important physical processes are not addressed by the TOMAWAC wave Spectral model:

- diffraction by a coastal structure (breakwater, pier, etc.) or a shoal, resulting in an energy transfer towards the shadow areas beyond the obstacles blocking the wave propagation;
- reflection (partial or total) from a structure or a pronounced depth irregularity; and
- Unable to include Drying/mudflat areas

The limitations of the TOMAWAC Model in respect to diffraction and reflection were overcome by using the harbor agitation model ARTEMIS in the vicinity of the subject development area.

ARTEMIS solves the modified Elliptic Mild Slope Equation (EMSE) for wave propagation. It can be applied for the computation of agitation, resonance and seiching in harbours. It may also be used to calculate the wave field under combined refraction-diffraction and reflection effects in small bays.

ARTEMIS is used in various situations for harbour design and coastal hydraulics studies considering small domains for typical wave characteristics (a few kilometres) or larger ones for resonance computations (large periods). Wave deformation including refraction, diffraction, reflection and energy dissipation (wave breaking and bottom friction) processes is modelled. It is therefore applicable to estuarine and coastal engineering in the frame of the following typical studies:

- Wave agitation in harbours,
- Seiching in coastal channels,
- Shoaling in a small size coastal domain with or without important diffraction effects,
- Wave diffraction behind a dike,
- Wave reflection on sea bed features or obstacles (islands, harbour structures).

Random waves are considered in ARTEMIS as being a superimposition of several monochromatic waves of different periods, which are randomly out of phase with one another. The real wave energy is the sum of the energies of the constituent monochromatic waves.

8.4.6.3 Wind data

There is no absolute maximum wind speed at a given location, as it is always possible that a stronger wind may occur in the future. The most commonly used wind for wave climate studies is a 50-year return period wind. This represents the steady wind speed that is likely to be exceeded once in 50 years and so it has been used for this study.

Wind data were obtained from the Meteorological Office from the Belmullet monitoring station in Co. Mayo. This is the closest monitoring station to Galway Bay. The data consist of a series of maximum daily wind speeds and directions recorded over the stated period. The wind data for each year were segregated into 30° sectors and a 50-year wind speed was calculated for each direction category using the well-documented Gumbel (EV1) Distribution Method (Linacre, 1992). Table 8.4.15 lists the 50-year wind speeds calculated for each direction category.

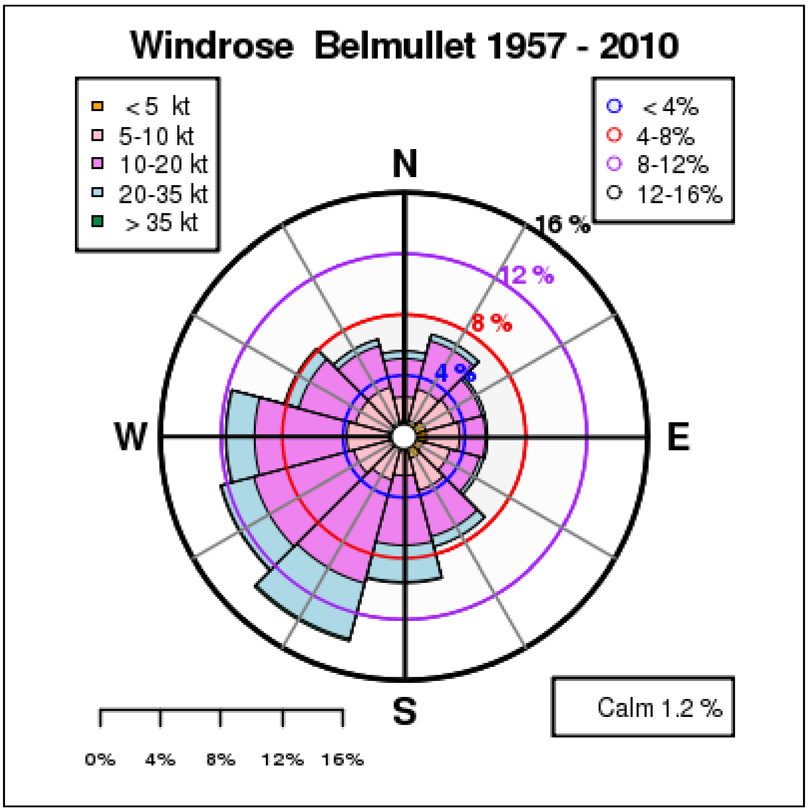
50-year wind speeds		
Wind Direction	Category	50-year Wind Speed [m/s]
350 – 10	N	17.42
20 – 40	N – NE	19.81
50 – 70	E – NE	16.46
80 – 100	E	18.21
110 – 130	E – SE	20.92
140 – 160	S – SE	21.54
170 – 190	S	19.67
200 – 220	S – SW	24.15
230 – 250	W – SW	29.01
260 – 280	W	30.59
290 – 310	W – NW	28.30
320 – 330	N – NW	20.92

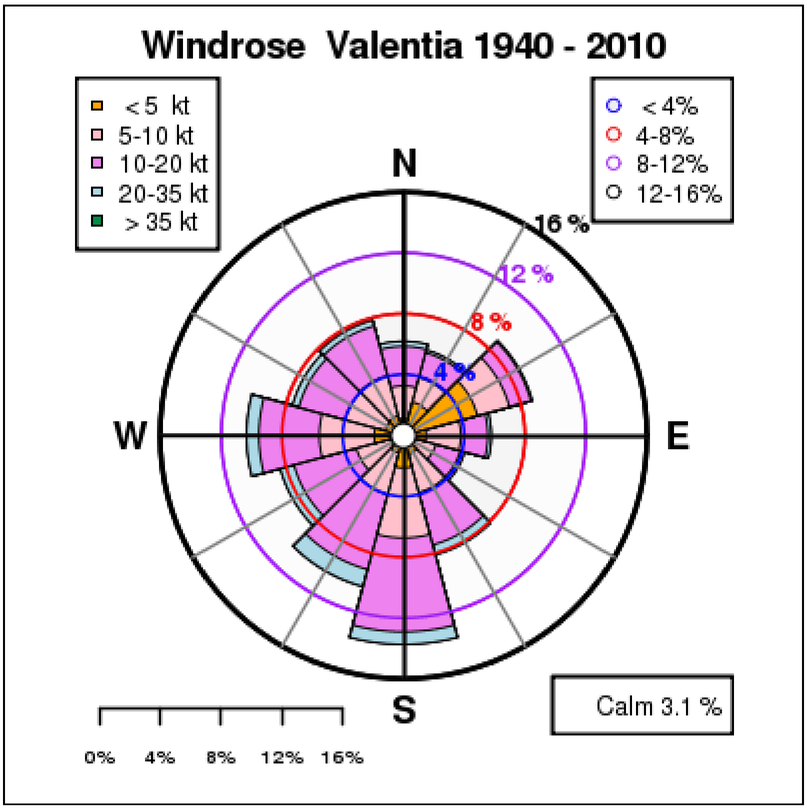
Table 8.4.15 50-year wind speeds calculated for selected wind direction categories

Met Eireann wind roses based on long-term observations for the coastal and estuarine stations of Belmullet, Valentia and Shannon Airport are presented below in Figure 8.4.123. It is clear from these wind roses that the principal directions are from the South to West sector with winds from the easterly sector considerably less frequent. In terms of distance the Shannon wind Met Station is closest to Galway but is considered to be more inland as it is located well up the Shannon Estuary and thus more sheltered than the Galway Bay area.

The Irish Met service provide a contour map of Ireland with 50year 1hour and 10min duration wind speeds, refer to figures 8.4.124 to 8.4.125. For the Inner Galway Bay area the 10 minute mean wind speed with return period of 50years is 30.5 to 31.0m/s (Met Eireann, 2005). The 1 hour mean wind speed with return period of 50years is 28m/s. In this study a wind speed of 30m/s is used in the local wave analysis.

The wind data in combination with the Shore Protection Manual (SPM) (1984) method were used to define the deepwater non-fetch limited significant wave heights and periods at the open sea boundaries west of the Aran Islands propagating onshore from the southwest and westerly sectors. These wind field data were also used to determine the magnitude of the local shallow water (fetch limited) wave climate using the Shore Protection Manual (SPM) method. This wind field information was also specified as the local wind shear generating force in the TOMAWAC Spectral model which allows the additional propagation and growth of the wave as it travels inshore.





Note 1kt (knot) = 0.514m/s

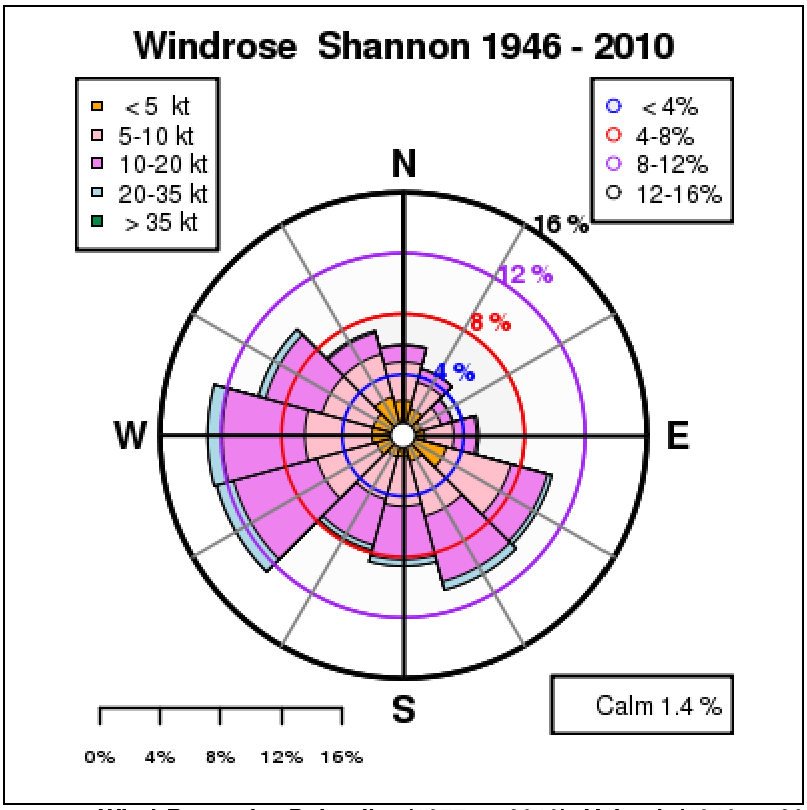


Figure 8.4.123 Long-term Wind Roses for Belmullet (1957 to 2010), Valentia(1940 to 2010) and Shannon Airport (1946 to 2010)

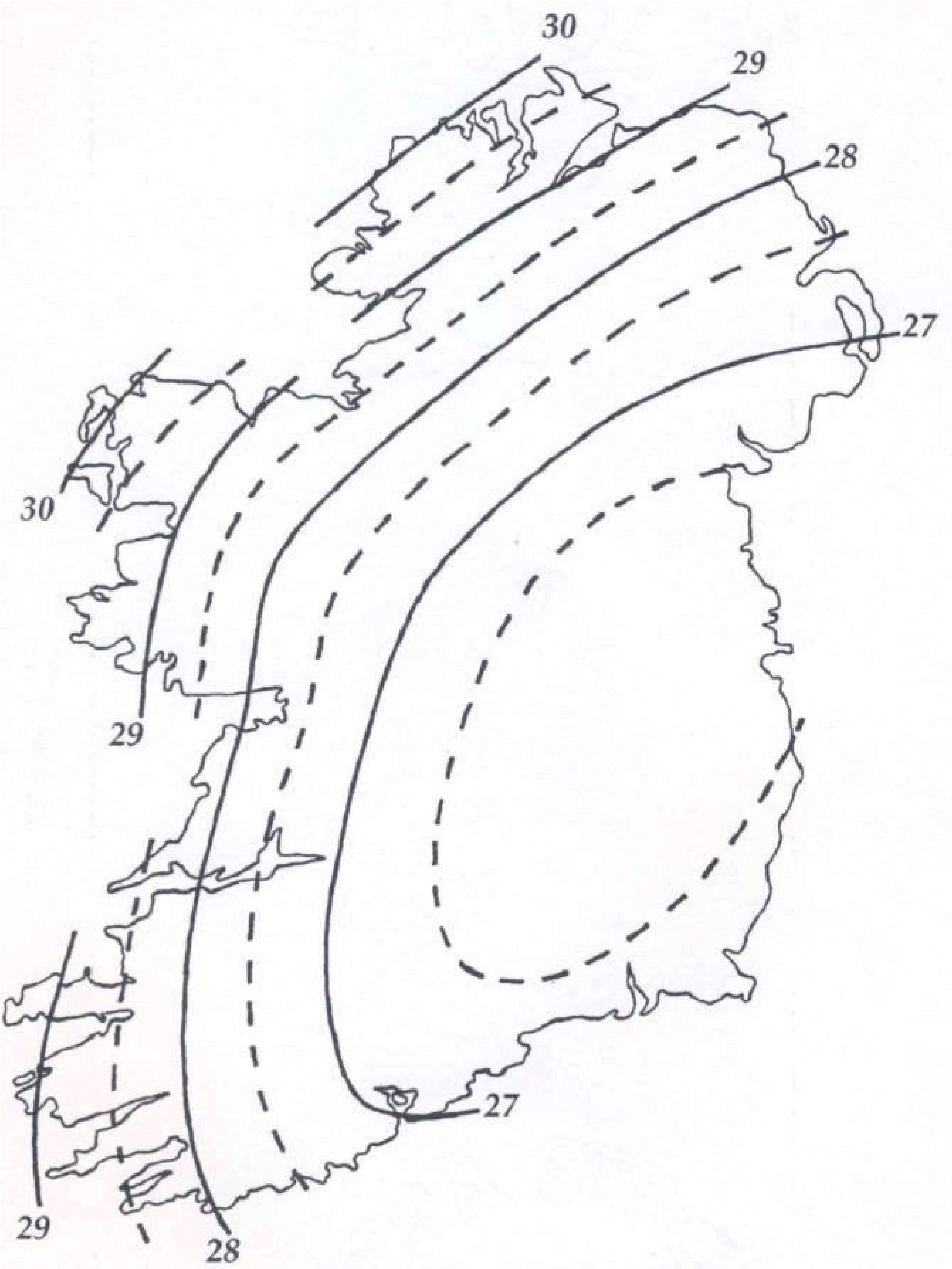


Figure 8.4.124 Met Eireann 1 hour mean wind speed of 50year return period

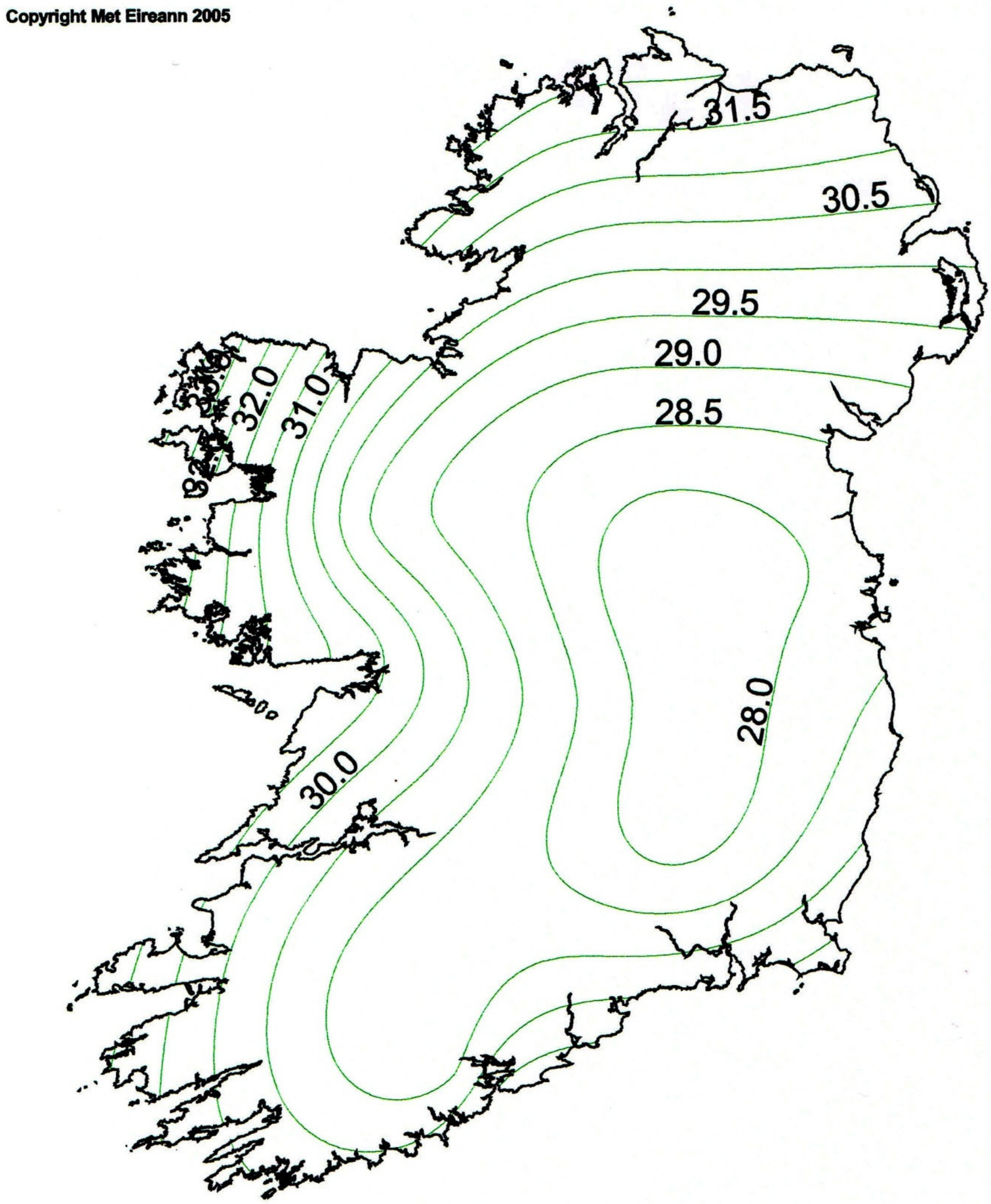


Figure 8.4.125 10minute mean wind speed of 50year return period (Met Eireann 2005)

8.4.6.4 TOMAWAC Model Simulations

8.4.6.4.1 Introduction

The boundary conditions along the seaward extent of the TOMAWAC Spectral model (west and south sea boundaries, refer to Figure 8.4.126) model were specified in terms of the significant height and period of the appropriate deepwater wave. These conditions were then used as the forcing function for the model and significant wave heights were predicted for each finite element nodal point within the domain. Deepwater wave propagations from the Southwest, West-southwest and West were examined (Table 8.4.16).

Deepwater wave conditions at model Open sea boundary			
Direction	**50-yr Wind Speed [m/s]**	**Deepwater Wave Height [m]**	**Period [sec]**
Southwest	26	15.	15.4
West-southwest	29	17.	16.4
West	29	17	16.4

Table 8.4.16 Deepwater wave conditions at model deepwater boundary

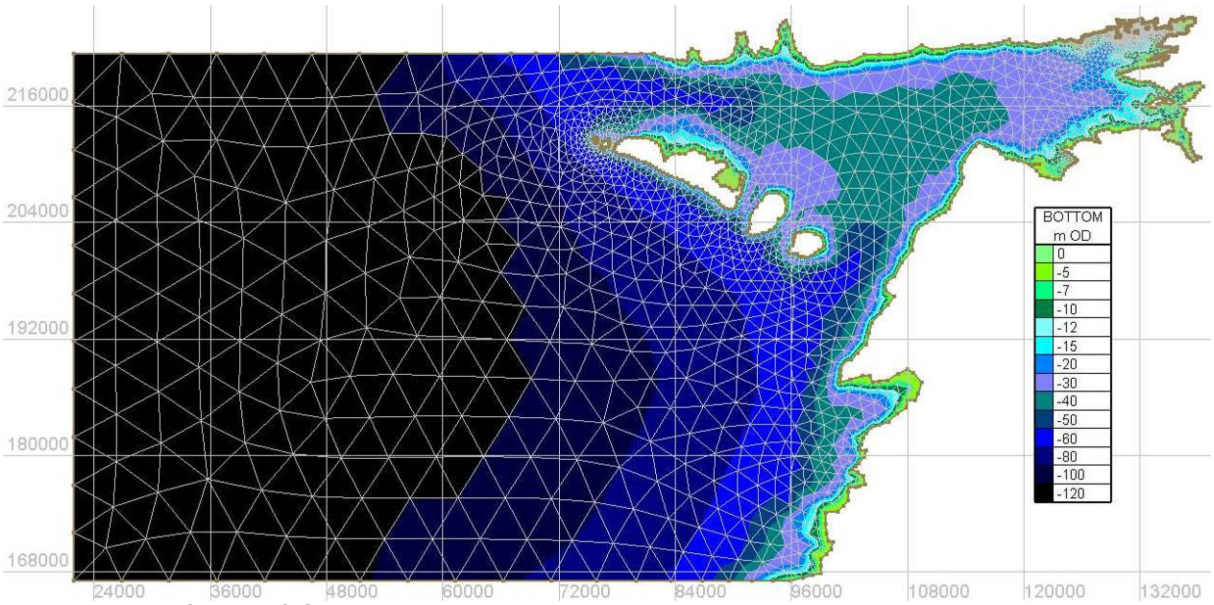


Figure 8.4.126 TOMAWAC Spectral Wave Model Domain

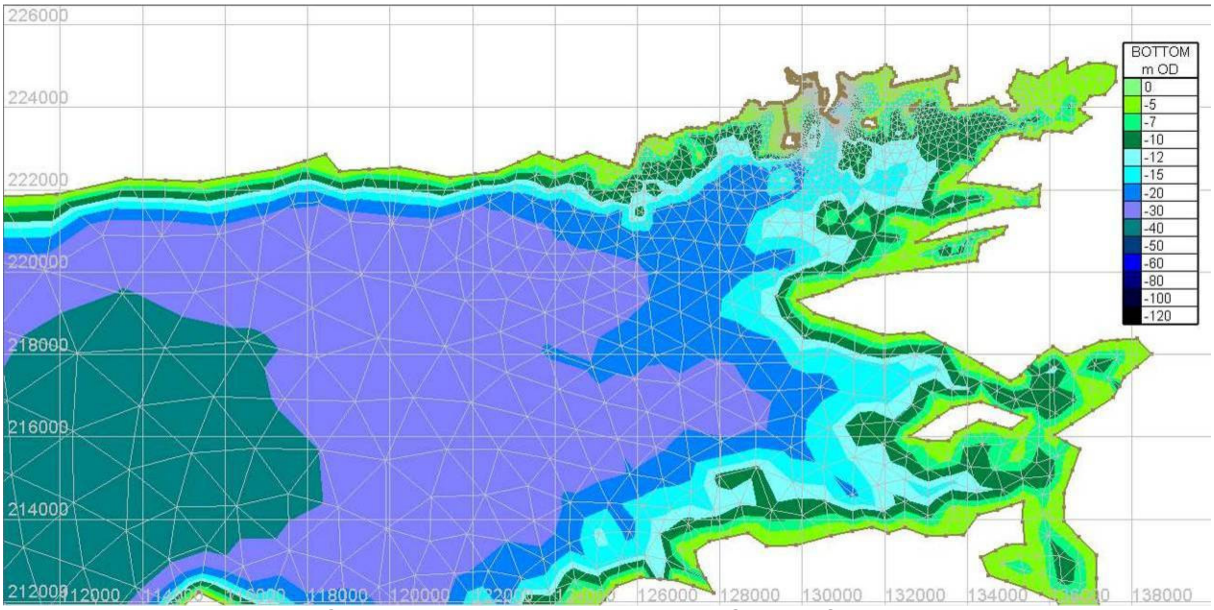


Figure 8.4.127 View of Inner Galway Bay as represented in the TOMAWAC Model

8.4.6.4.2 Wave Climate Results

A 50-year steady wind blowing from a south, southwest, west-southwest and west directions produces steady wind speeds of c. 26 to 31 m/s. The fetch length in these directions is considered to be unlimited with sea depths in excess of 100 m. These conditions result in significant wave heights varying from 15 to 18 m and wave periods from 15 to 17 seconds. In the analysis for the harbour extension, a significant wave height of 20 m with significant period of 17seconds and local wind speeds of 30 m/s was specified in the model for all offshore directions so as to ensure a degree of conservatism in predicting the 50-year wave climate.

Figures 8.4.128 to 8.4.131 show contoured plots of the significant wave heights predicted by the TOMAWAC spectral wave model as a result of the deepwater waves propagating inshore. The maximum value of the significant wave height that reaches inner Galway Bay just to the southwest of Mutton island (wave Input point for ARTEMIS wave agitation model) was found to be slightly less than 4 m (3.77 m on Southwest and 3.3 m for a west southwest wind and offshore condition). For westerly winds the significant wave height at this location is 2.9 m. The mean wave direction is typically 58 to 63 degrees for all of the critical off shore wave directions, (southwest, west-southwest and west). The mean and peak periods in the inner bay area are 8 to 8.5 and 10.2 to 10.3 seconds. Southerly and north-westerly offshore waves have very limited effect on the inner Galway Bay area. It is clear that the Aran Islands and the reducing sea depth east of the islands provide crucial protection to the inner Galway Bay area. This is primarily due to the position of the Aran Islands at the entrance to Galway Bay which act as a very effective breakwater for deepwater waves entering outer Galway Bay at particular angles.

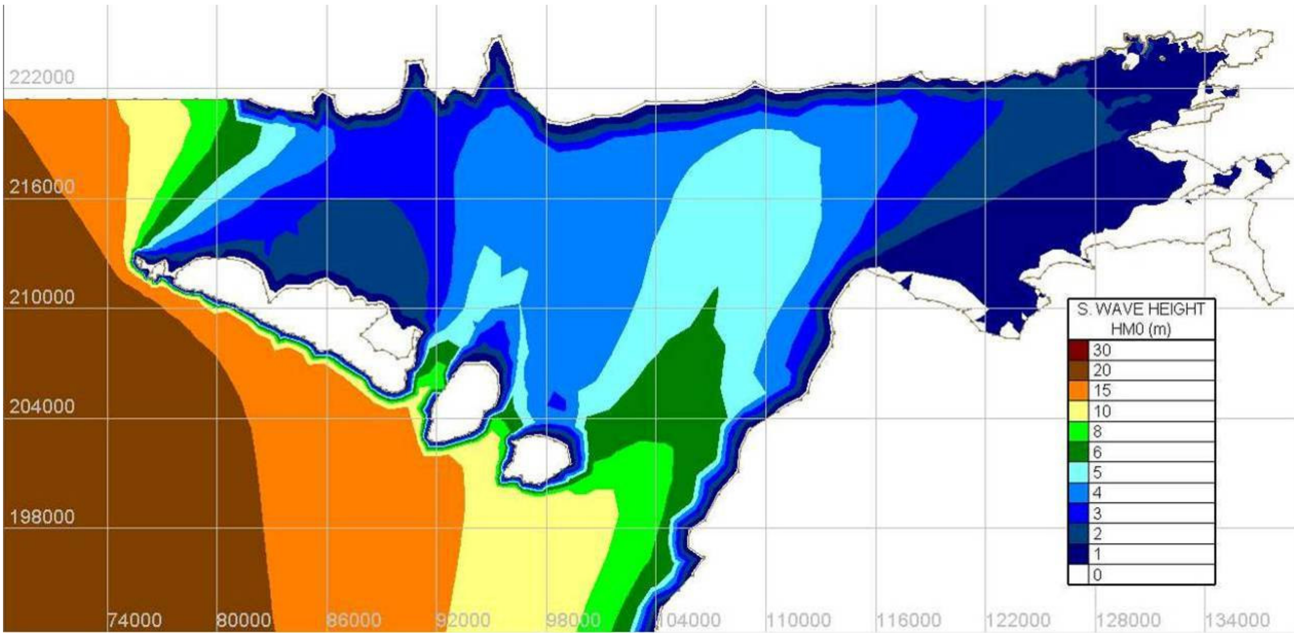


Figure 8.4.128 Wave climate under 50-year southerly wind conditions

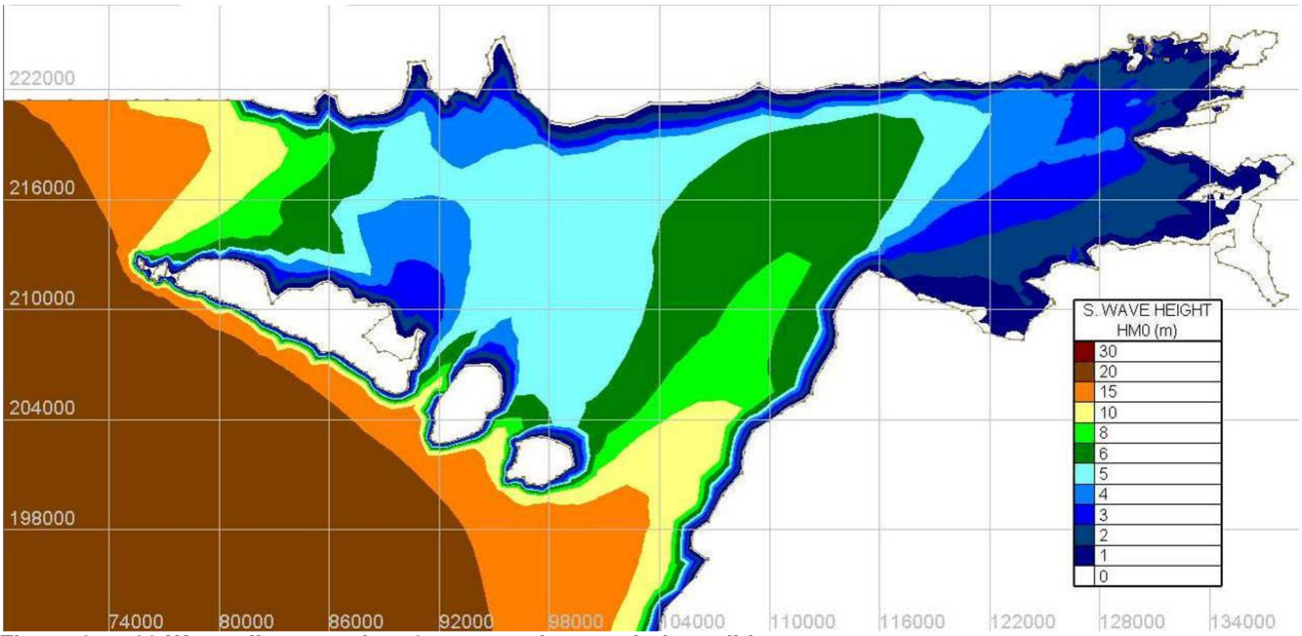


Figure 8.4.129 Wave climate under 50-year southwest wind conditions

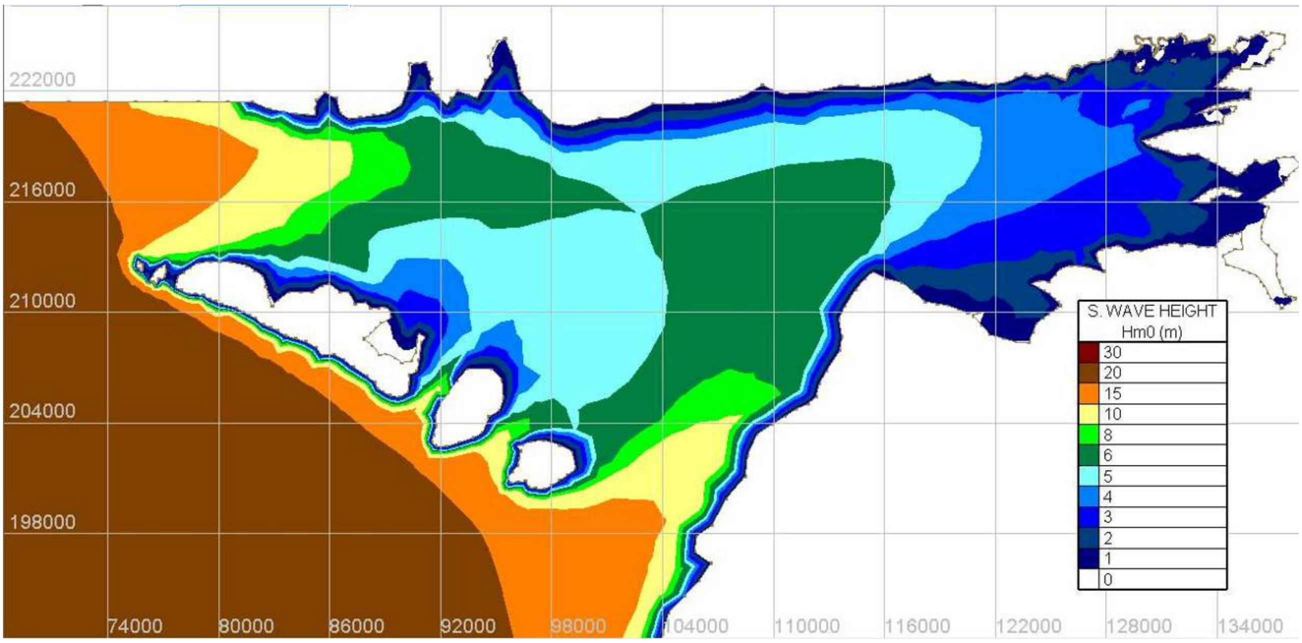


Figure 8.4.130 Wave climate under 50year west southwest wind conditions

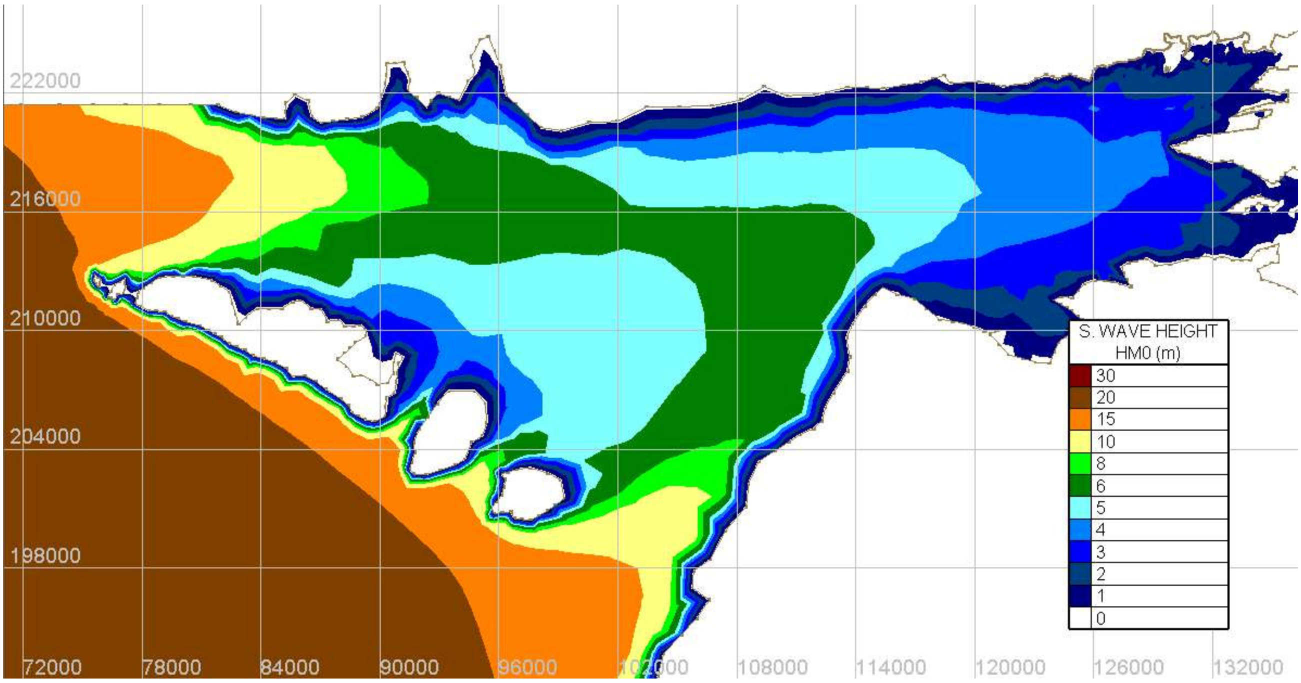


Figure 8.4.131 Wave climate under 50year Westerly wind conditions

8.4.6.5 ARTEMIS Model Simulations

8.4.6.5.1 Introduction

Because The ARTEMIS model software solves directly the modified Elliptic Mild Slope Equation (EMSE) for wave propagation, a very refined meshing of the order of metres is required particularly when modelling the short duration/high frequency waves (generated by winds over local shallow fetch lengths). A single model was developed with an element spacing of 3m to model the wave field for long period Atlantic storms and the shorter period local fetch storms both for existing and proposed harbour cases. The ARTEMIS Model was run in random wave mode both in respect to the period about the significant period and direction about the principal direction.

Simulations were carried out for the various sectors from West to East to assess the potential impact of the proposed harbour development on wave climate and quantify the design conditions for the proposed harbour protective breakwaters and quay walls.

The reflection coefficient used in the ARTEMIS model for the harbour extension quay wall and vertical sheet piled breakwaters was set at 0.8 to 0.9 with the incident /reflective wave direction determined through trial and error by running simulations and outputting incident wave direction. The reflection coefficient for the shoreline area along South Park was specified at 0.25 to 0.5, 0.15 for the Mutton Island Causeway (designed to absorb wave energy) and 0.25 along the Renmore shoreline and Hare and Mutton Islands respectively.

8.4.6.5.2 Design Tide Inputs

The design wave inputs to the Artemis model are presented in Table 8.4.17 as follows:

Design Wave Inputs to ARTEMIS Models		
Direction	Significant Wave Height Hs [m]	Ts [sec]
East (Local Fetch, 3.3km)	1.21	3.8
East-South-East (Local Fetch, 3.9km)	1.25.	3.9
South-East (Local Fetch, 4.1km)	1.34.	4.0
South-South-East (Local Fetch, 4.9km)	1.41	4.2
South (Local Fetch, 7.4km)	1.52	4.4
South South West (Local Fetch, 8.1km)	1.68	4.75
South-West (Atlantic Storms Deepwater Wave)	3.77	10.3
West South West (Atlantic Storms Deepwater Wave)	3.3	10.2

Table 8.4.17 Design wave inputs to ARTEMIS Models

8.4.6.6 Discussion of Results

The ARTEMIS Model was run for storm waves generated by local fetch from the East, East South East, South East, South South East, South and South South West sectors respectively. Longer period Atlantic waves propagating from the southwest to the West were also examined. All of the above runs were specifically aimed at assessing the protection afforded by the proposed breakwaters in respect to conditions within the mooring areas of the Commercial Harbour and Fisherman’s pier and within the proposed marina area and any other operational areas. The southerly sector was also considered the critical direction for storm waves acting on the proposed Harbour and the vulnerable South Park shoreline area (inside the Mutton Island Causeway) and the mouth of the Corrib Estuary and the existing docks entrance adjacent to Nimmo's Pier.

The simulations show the breakwaters protecting well the harbour and marina areas against the dominant wave directions from the south to the west. The southwesterly deepwater wave simulation represents the design condition for the Commercial Harbour Breakwater (southern Breakwater) with wave heights along the breakwater increasing south-eastward along the breakwater from 1.5 m towards the northwest corner to just less than 4 m at the outer most exposed tip adjacent to Hare Island (refer to Figure 8.4.132 and 8.1.33).

The breakwater protection is not designed to protect the commercial harbour against storm waves propagating locally from the east and southeast with model results predicting 0.7 to 0.8 m waves within part of the commercial harbour for the southeast design storm conditions with the local waves propagating northwestward through the opening between the breakwater and Hare Island. The model predicts waves slightly in excess of 1 m at the south face of the Fisherman's pier for the east-south-east direction. Refer to Figure 8.4.137 to 8.4.139 for southeast to East design wave simulation plots. Hare Island is shown to provide some protection against south-easterly to easterly storms.

A simulation was also carried out assuming the causeway to be completely submerged by 200-year Tide with Sea level Rise (4.635 m O.D. Malin) >1 m water depth and a southwesterly (SW and WSW) deepwater design wave of 3.77 m significant wave height applied. The simulation shows that the Mutton Island Causeway would under these submerged conditions break the storm waves and dissipate energy and thus provide protection to the westerly face of the development even under submerged conditions (refer to Figure 8.4.142).

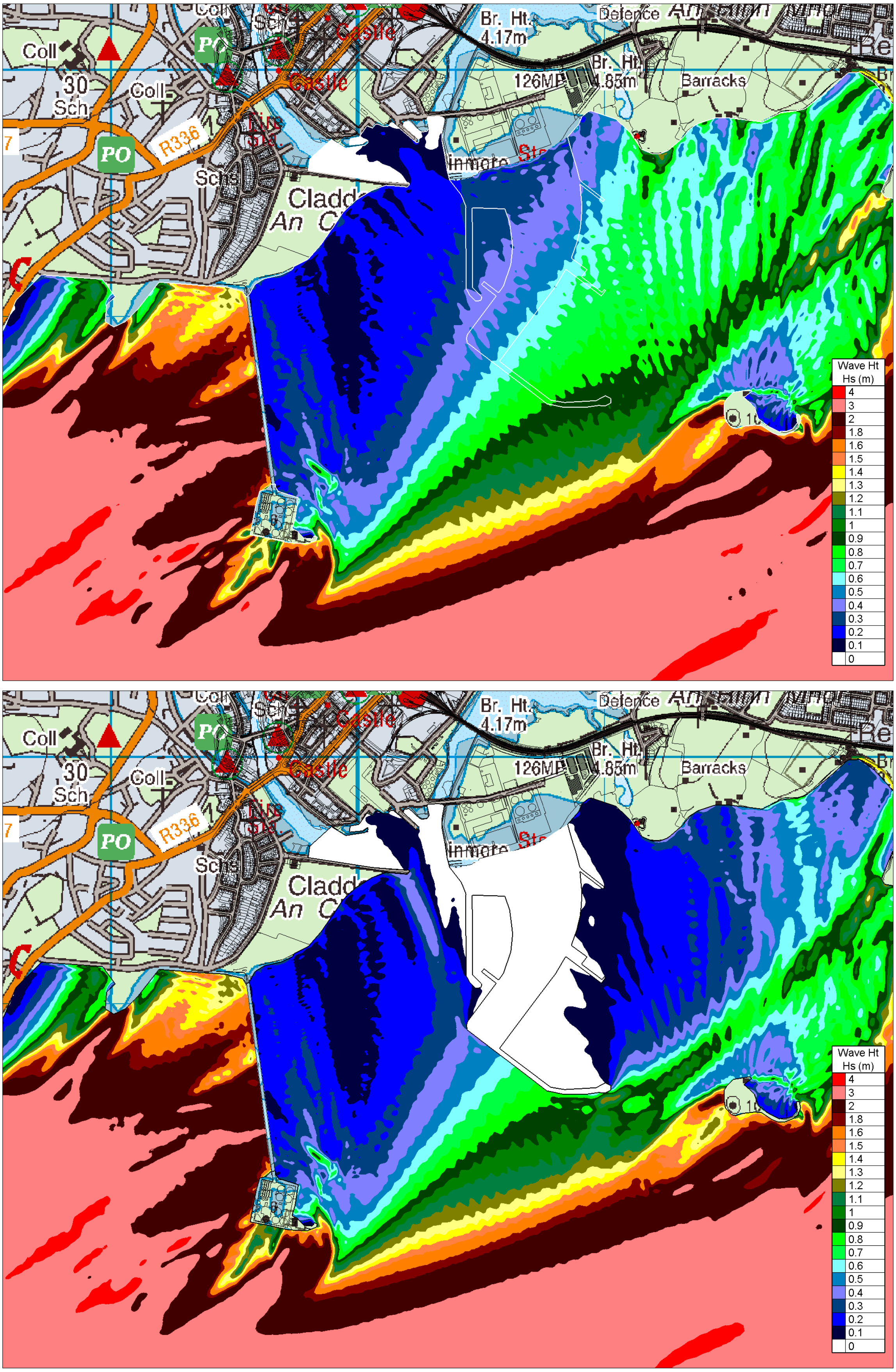


Figure 8.4.132 ARTEMIS Significant Wave Heights for Atlantic Storm from the West-South-West for Existing and Proposed Case

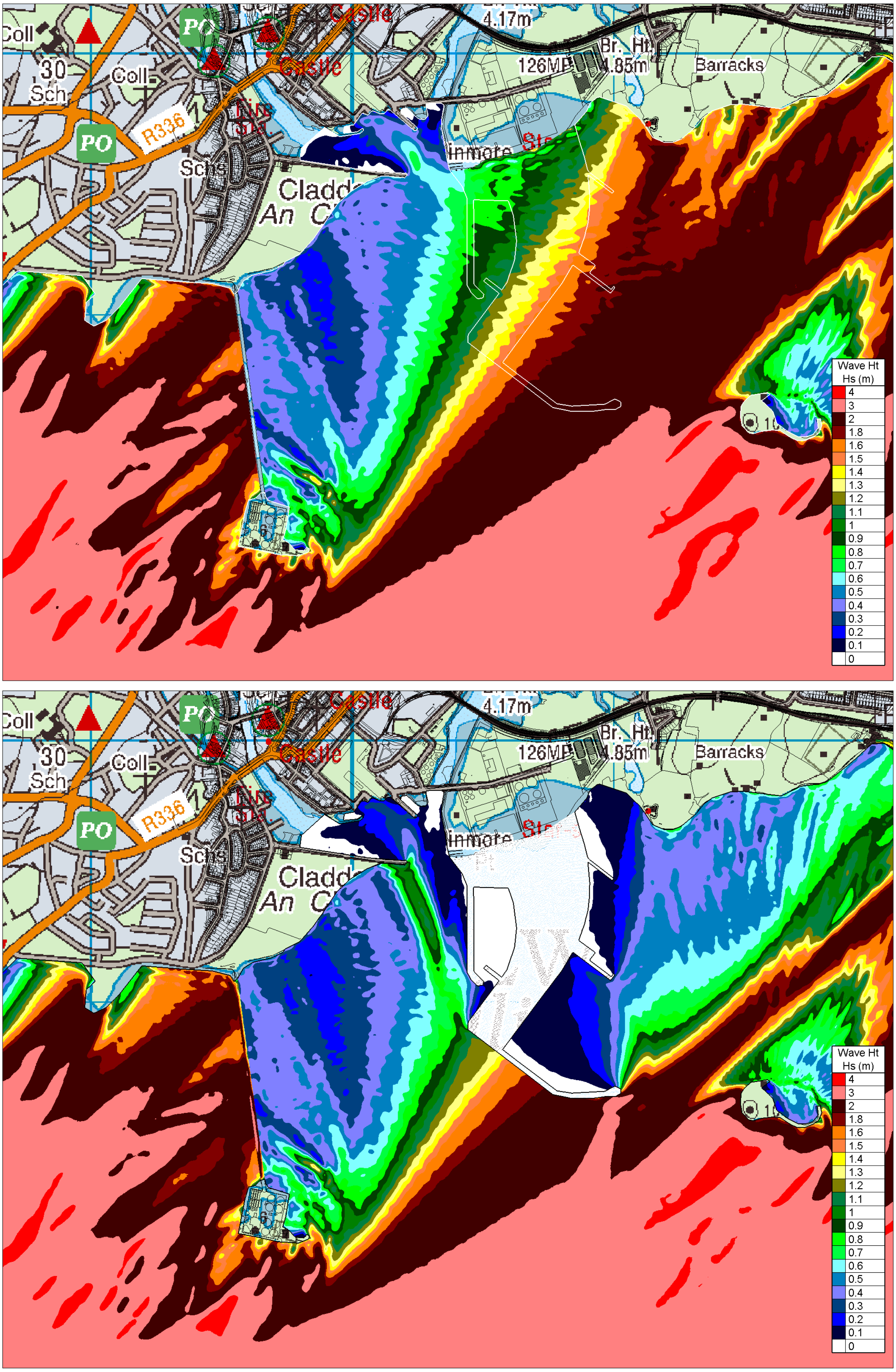


Figure 8.4.133 ARTEMIS Significant Wave Heights for Atlantic Storm from the South-West for Existing and Proposed Case

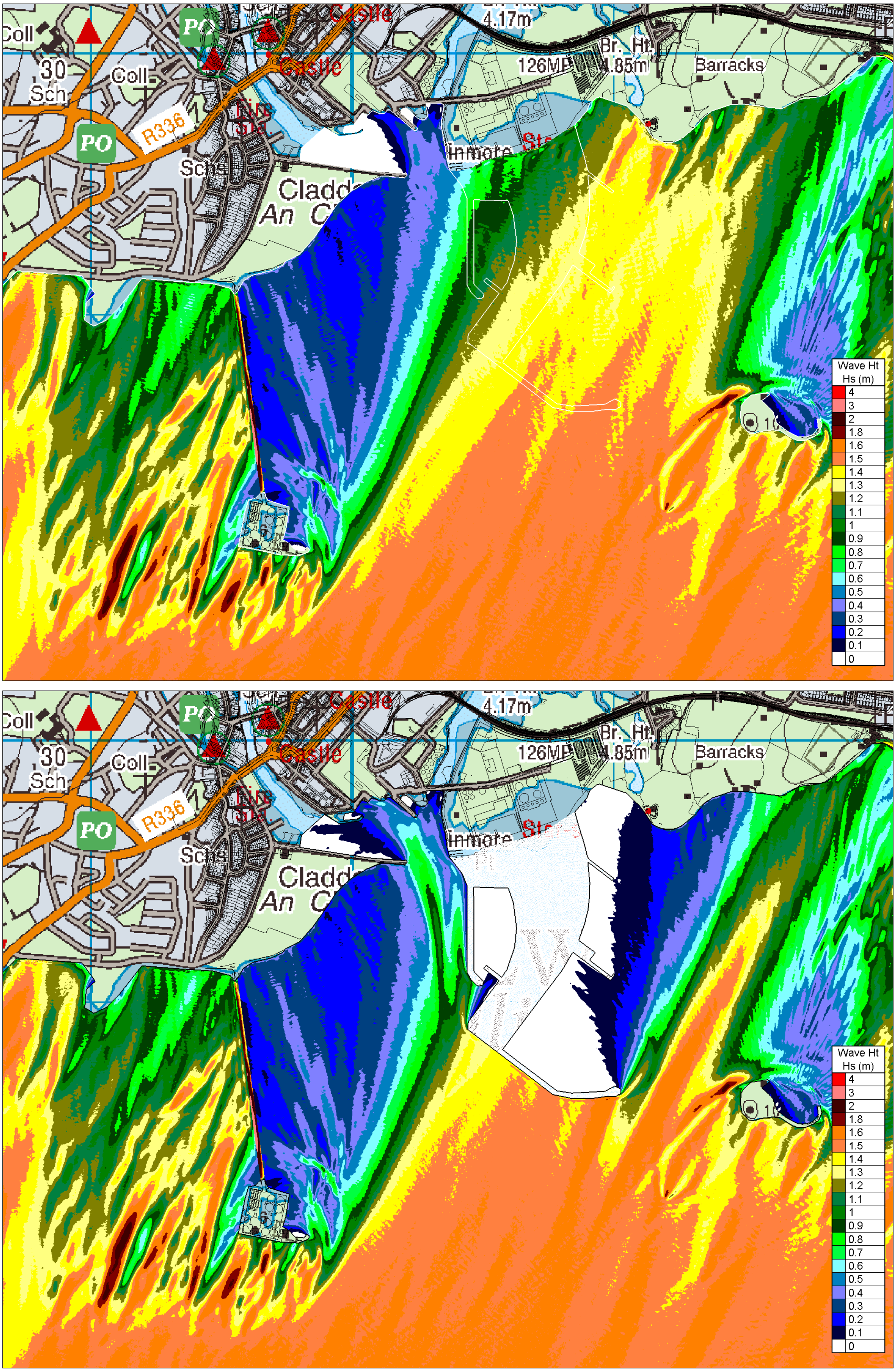


Figure 8.4.134 ARTEMIS Significant Wave Heights for local Design Storm Waves from the South-South-West for Existing and Proposed Case

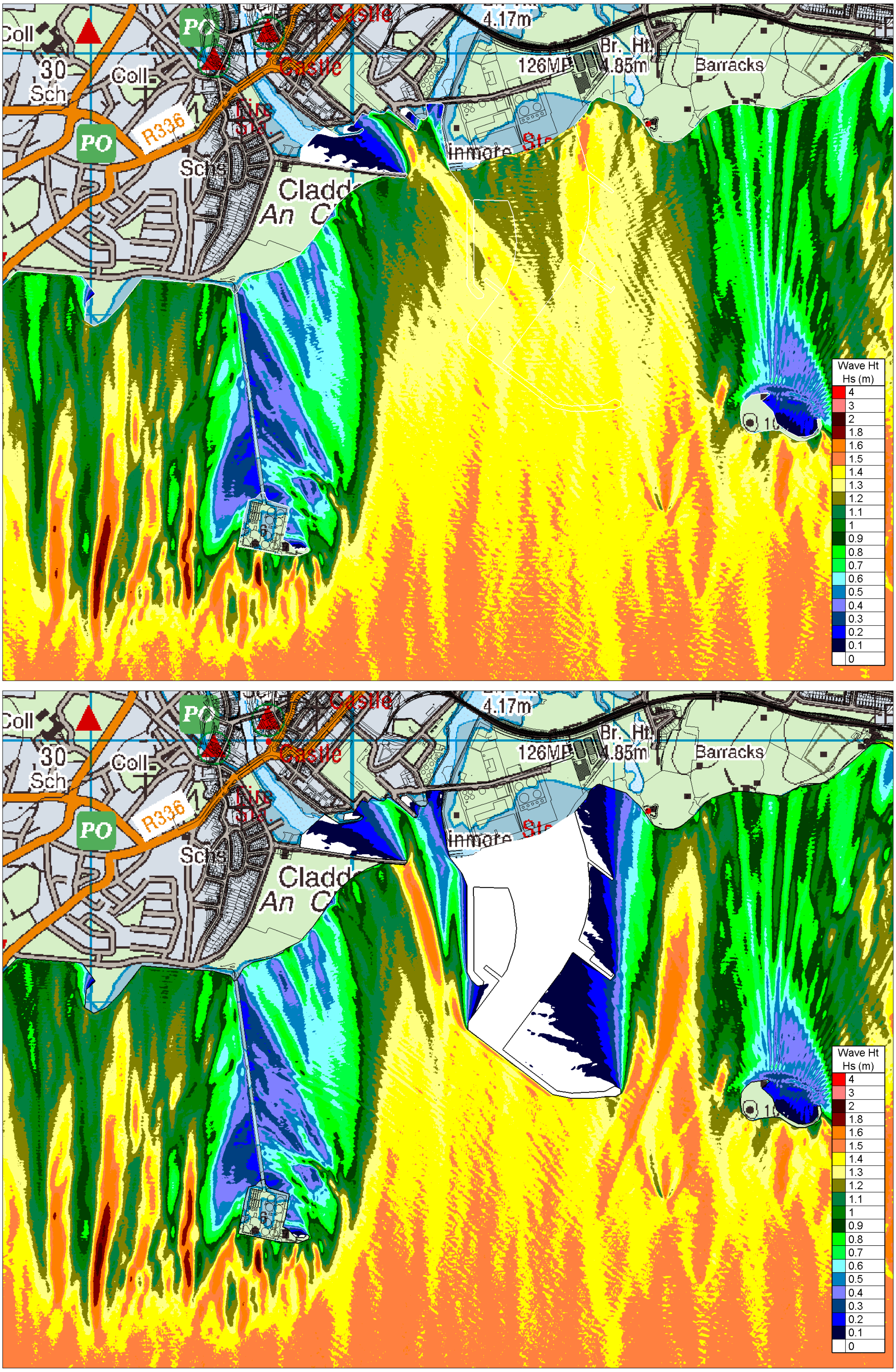


Figure 8.4.135 ARTEMIS Significant Wave Heights for local Design Storm Waves from the South for Existing and Proposed Case

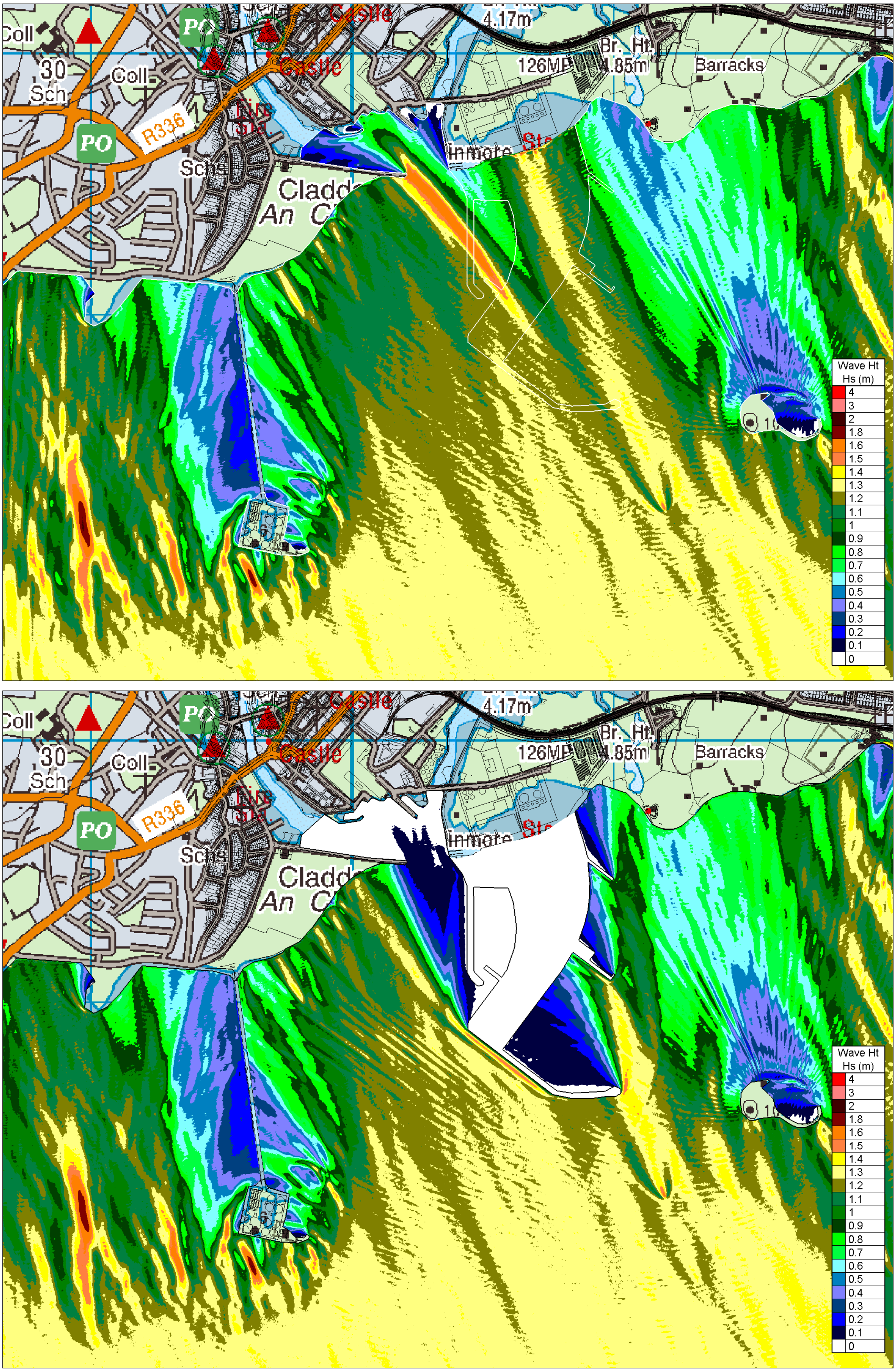


Figure 8.4.136 ARTEMIS Significant Wave Heights for local Design Storm Waves from the South-South-East for Existing and Proposed Case

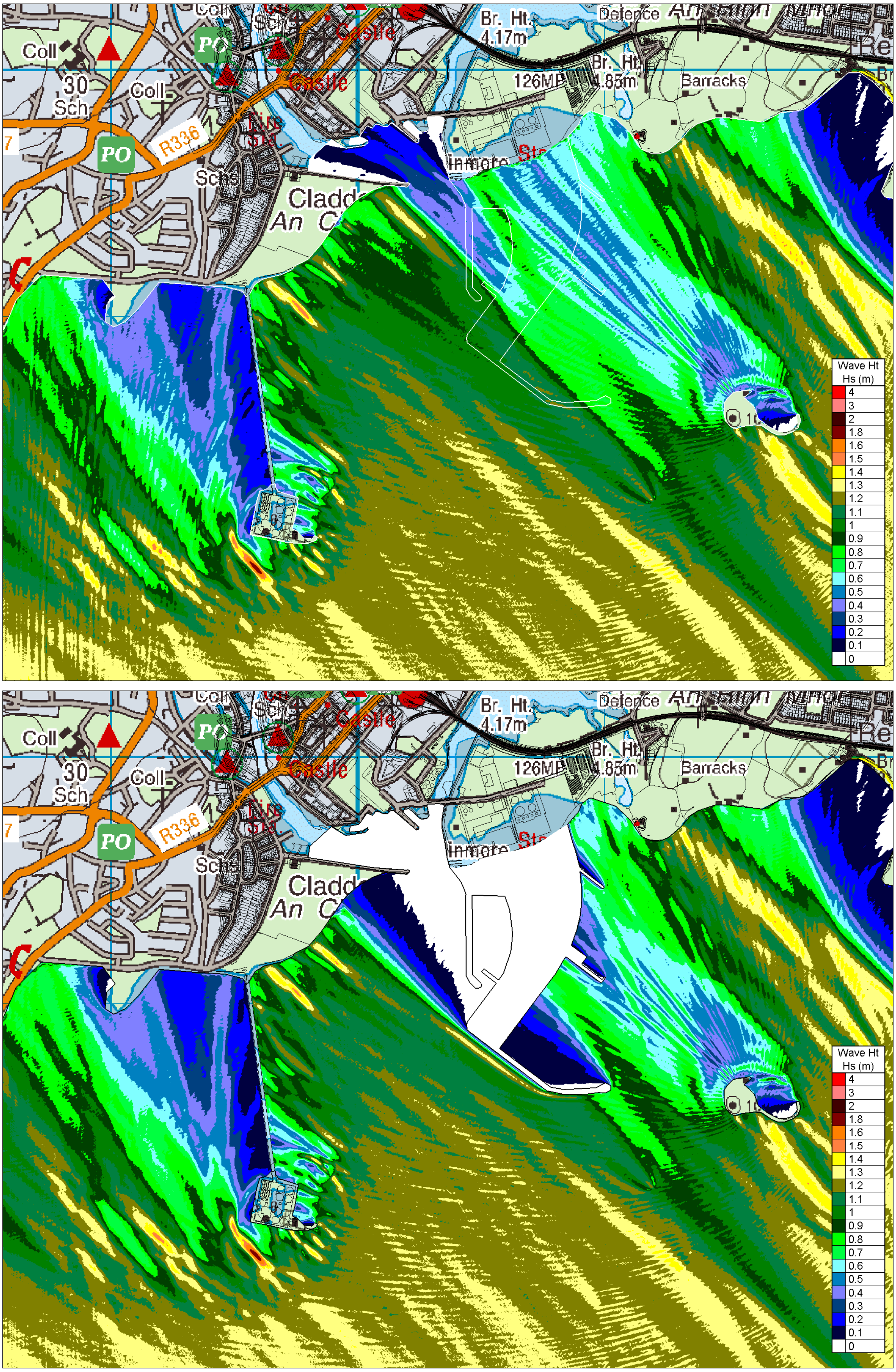


Figure 8.4.137 ARTEMIS Significant Wave Heights for local Design Storm Waves from the South-East for Existing and Proposed Case

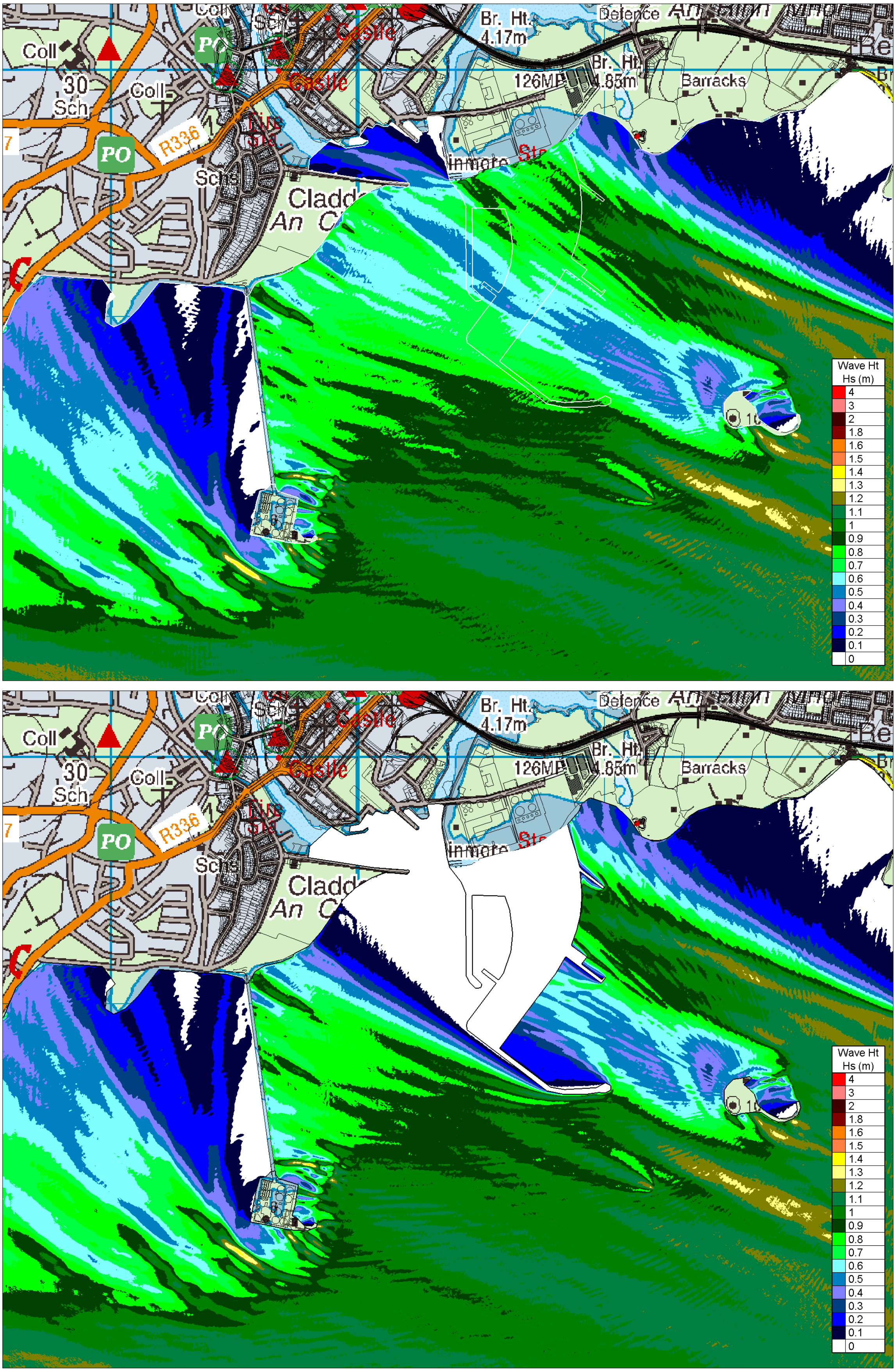


Figure 8.4.138 ARTEMIS Significant Wave Heights for local Design Storm Waves from the East-South-East for Existing and Proposed Case

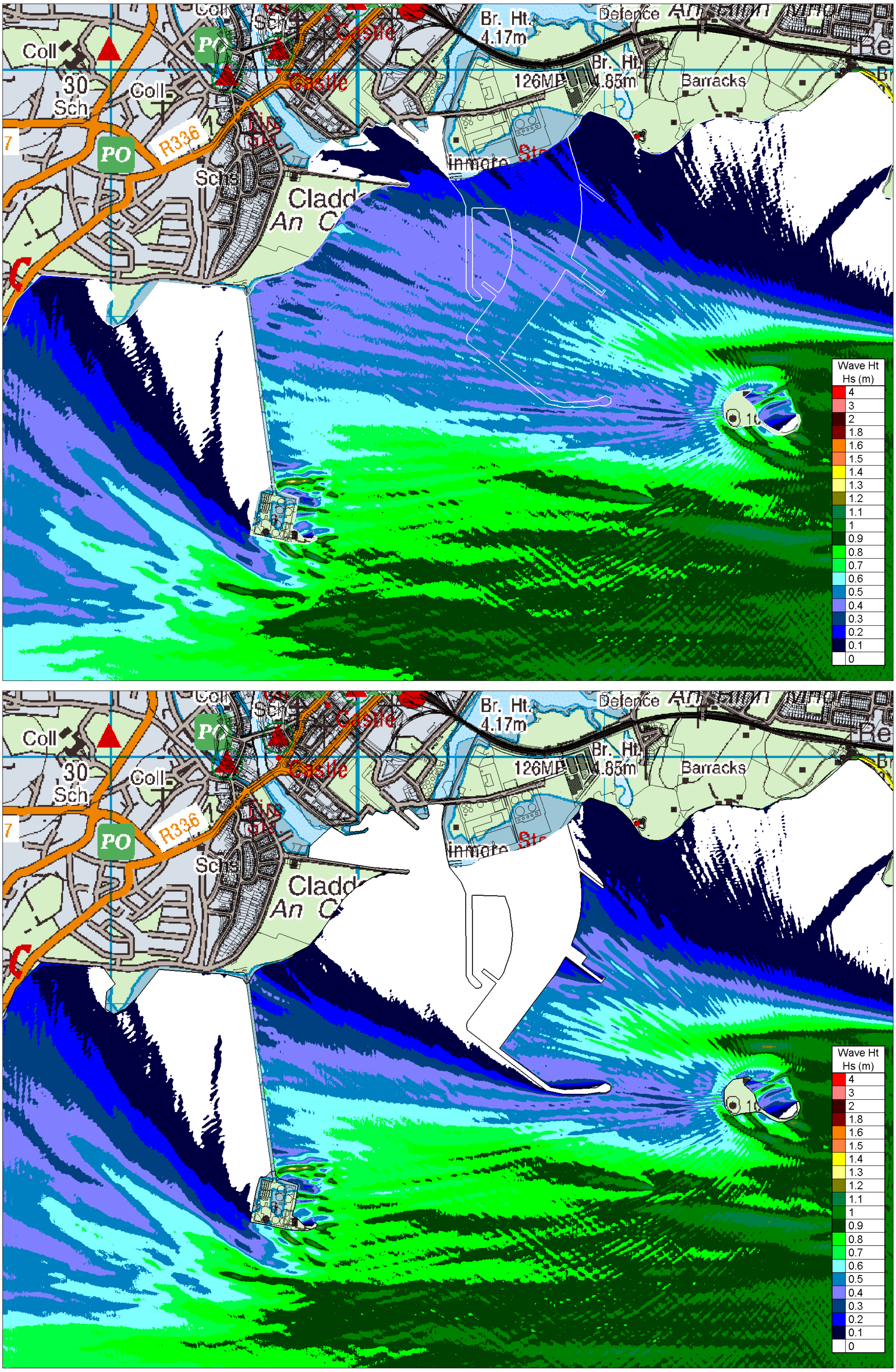


Figure 8.4.139 **ARTEMIS Significant Wave Heights for local Design Storm Waves from the East for Existing and Proposed Case**

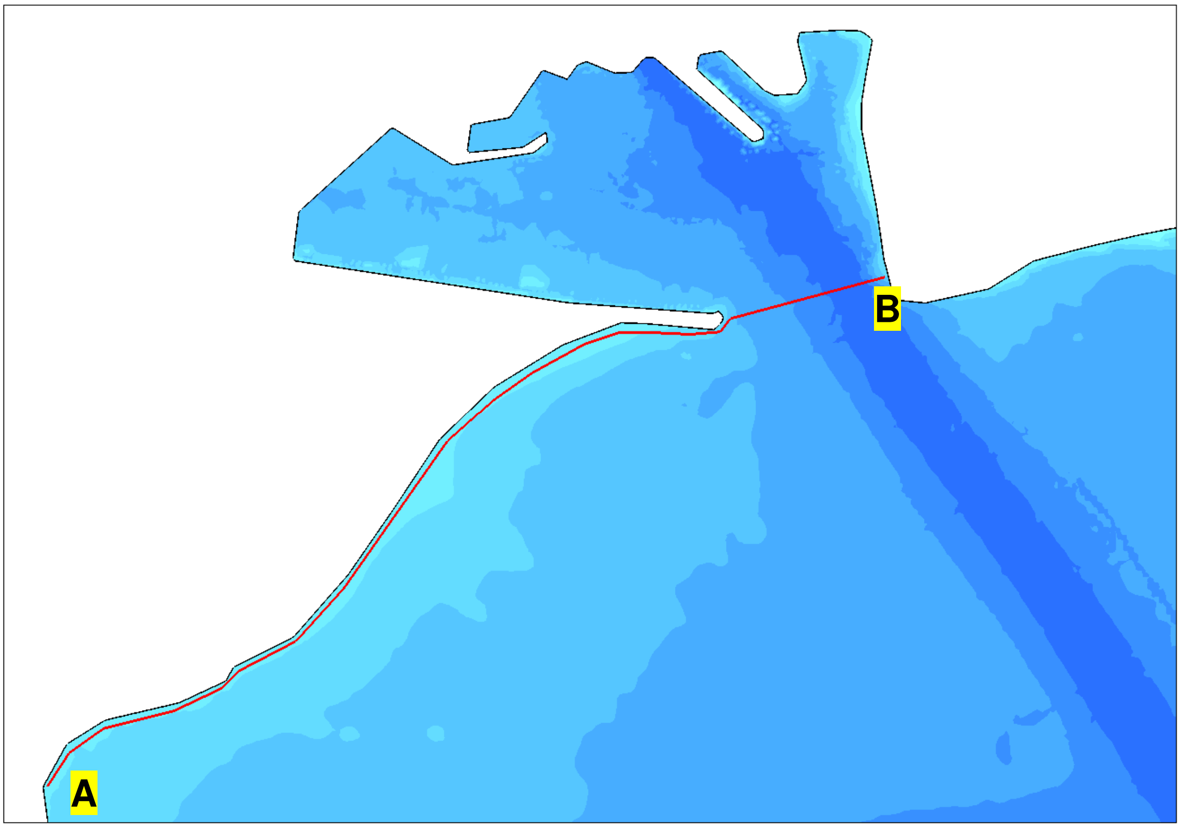


Figure 8.4.140 Shoreline Section A-B along Southpark, Nimmo's Pier and entrance to GalwayDocks / Claddagh Basin.

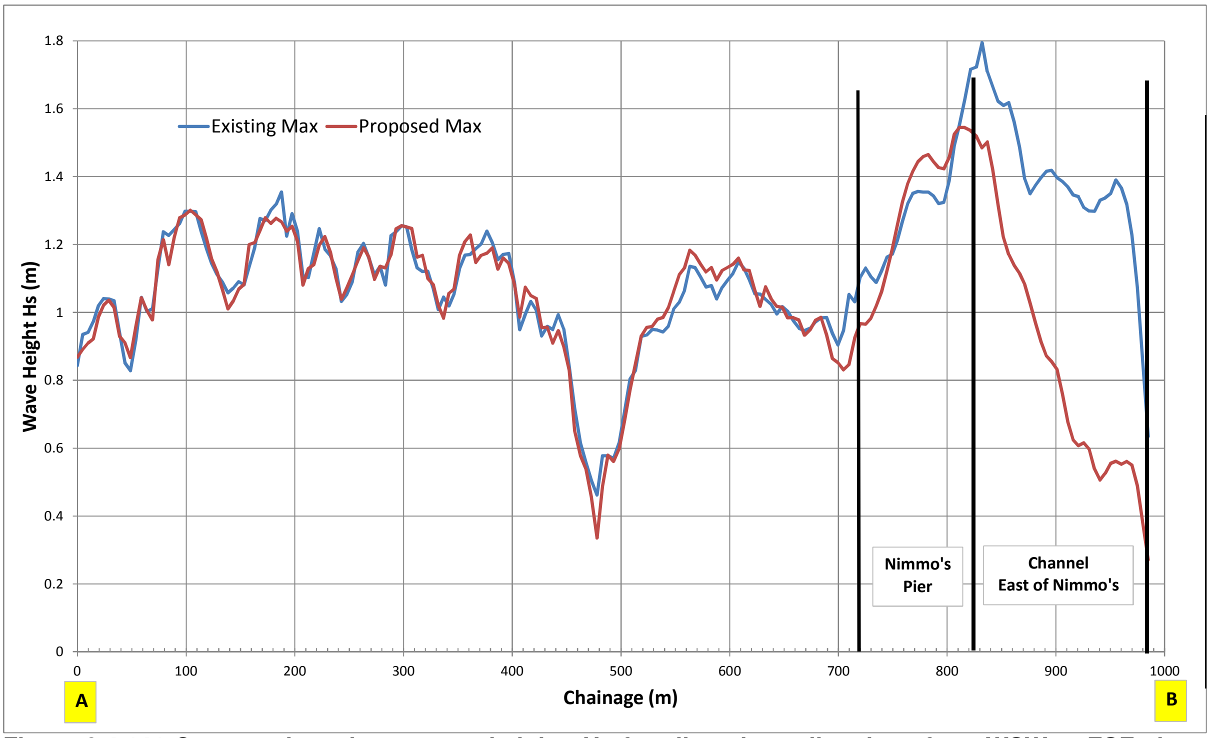


Figure 8.4.141 Computed maximum wave heights Hs for all onshore directions from WSW to ESE along Section A-B for Existing and Proposed Cases.

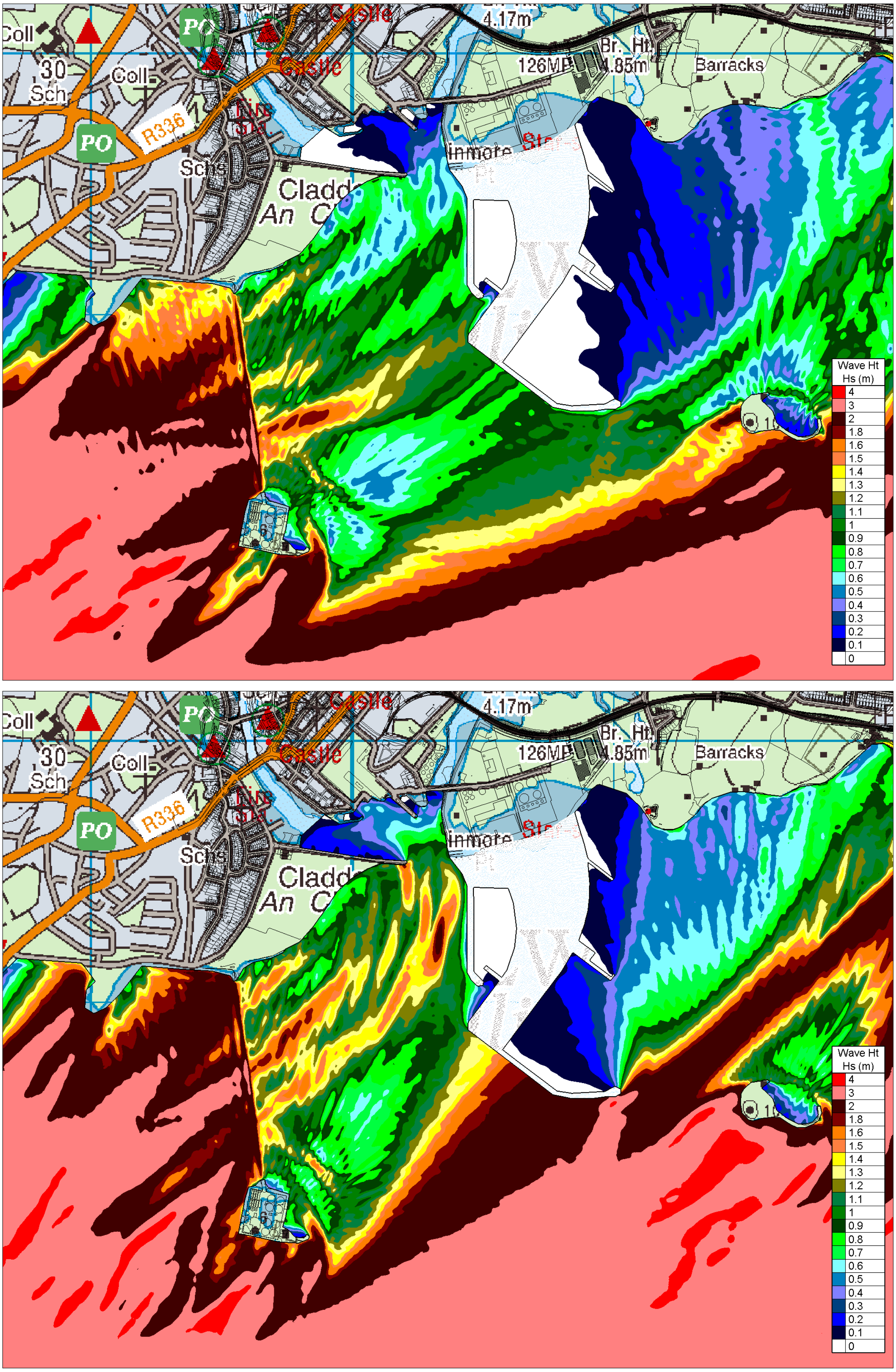


Figure 8.4.142 West-South-West Design Wave at extreme highwater of 4.635 m O.D. Malin to examine the ability of Mutton Island Causeway to protect the Harbour and Marina area from West-South-West and south-west deepwater design waves

8.4.6.7 Impact of development on surrounding wave climate

Wave climate simulations were carried out with and without the proposed harbour development to evaluate the potential impact that the development will have on the local wave climate of the shoreline areas to the west and east of the development.

The model simulations show a significant sheltering effect from the head of Nimmo's Pier to the Renmore Shoreline area including Claddagh Basin, Spanish Arch/Long Walk under southerly to easterly storms, refer to Figure 8.4.135 to 8.4.139.

For the southwesterly (SSW to WSW) sector the harbour development will result in increased wave heights in the vicinity of Nimmo's pier with the wave field being diffracted westward by the proposed Harbour and breakwater structures, refer to figure 8.4.132 to 8.4.134. Further west along the Southpark shoreline there is little or no predicted change in wave climate.

In terms of maximum wave heights (refer to Figures 8.4.140 to 141) along Southpark shoreline and Docks Area (i.e. Shoreline from the Causeway to the docks/Claddagh Basin entrance channel) the critical wave directions are southerly SSW to SSE. Under such conditions the proposed development reduces the maximum predicted wave height at the entrance channel to the Docks/Claddagh Basin area by between 0.3 and 0.5m, from 1.4 to 1.8 under the existing case to 0.8 to 1.5m under the proposed case. At the Nimmo's pier section here is a slight increase of less than 0.15m in maximum wave height as a result of the proposed harbour development.

Further westward along the Southpark Shoreline section the impact on the wave heights is minor, refer to figures 8.4.132 to 8.4.139. The analysis shows only slight increases and decreases of less than 0.05m in the maximum predicted wave heights along the Southpark shoreline, refer to Figure 8.4.141.

The simulations show no impact to the Wave climate to the west of the Causeway (i.e. Grattan Road shoreline area) which is more exposed and vulnerable area in respect to wave overtopping during southwesterly storms.

The wave modelling shows the Claddagh Basin to north of Nimmo's pier to be generally sheltered from wave climate except under East-South-East wave storm which is shown to propagate into the basin producing wave heights of 0.2m under the existing case. The proposed Harbour development is shown to completely shelter the Claddagh Basin against this direction.

8.4.6.8 Conclusions

The breakwater protection varies in height depending on the location and exposure to wave climate with southerly breakwater having a crest elevation of 9.1 to 10.1 m O.D. which provides 4.465 to 5.465 m above the design tide level (4.635 m O.D.) for wave climate and wave run-up effects. This level of protection will minimise the risk of overtopping of the breakwater structure by extreme waves. The westerly breakwater located in the more sheltered waters has a top elevation 6.65 to 6.95 m O.D. which based on wave climate analysis will protect this area from overtopping by the waves predicted for these locations.

A simulation was also carried out assuming the Mutton Island causeway to be completely submerged by 200-year Tide with Sea level Rise (4.635 m O.D. Malin), covered by over 1m of water depth and a westerly deepwater design wave of 3.77 m significant wave height applied. The simulation shows that the Mutton Island Causeway would under these submerged conditions break the storm waves and dissipate much of its energy and thus provide protection to the westerly face of the proposed development even under submerged conditions.

The wave climate simulations show that the proposed harbour development impacts the local wave climate environment through a combination sheltering via dissipation and reflection off its breakwaters and diffraction and refraction of the wave field around the development and over the dredged channels. The development generally shelters the eastern section of the adjacent Renmore shoreline against storms from the south to southwesterly sector. It protects the Galway Docks entrance and much of the Southpark shoreline against storms from the south to the east.

The simulations show under south and south westerly storms increased wave activity along the south face of Nimmo's Pier and the entrance to Galway Docks and the Corrib channel. These are not the most significant waves which presently occur at this location and theses waves are directed across the Corrib channel as opposed running up along it.

The wave simulations show that this increased wave activity at Nimmo's pier entrance does not appreciably impact wave heights within the inner Claddagh Basin area and such impacts are less than those which presently arise from the southeast direction which will now be blocked by the proposed development.

Appendix No. 5

Visitor Numbers / Observations at Renmore, December 2019

And

Further Photos of Effect of storm Darwin 06.01.2014
on Renmore Stony Bank

Visitor numbers / observations at Renmore, November 2019

Observations between 9:00 and 16:00

11/12/2019

No. of people accessing from harbour	15
No. of dogs	6
No. of people on sandy beach	15
No. of people on stony bank	6
No. of people accessing from Renmore	4
No. of dogs	3
No. of people on sandy beach	4
No. of people on stony bank	1
Total No. of people accessing area	19
Total No. of dogs accessing area	9
Total No. of people on sandy beach	19
Total No. of people on stony bank	7
% of people who access stony bank area	37%

14/12/2019

No. of people accessing from harbour	6
No. of dogs	4
No. of people on sandy beach	6
No. of people on stony bank	0
No. of people accessing from Renmore	9
No. of dogs	6
No. of people on sandy beach	8
No. of people on stony bank	4
Total No. of people accessing area	15
Total No. of dogs accessing area	10
Total No. of people on sandy beach	14
Total No. of people on stony bank	4
% of people who access stony bank area	29%