



WET STORAGE

WET STORAGE IN IRELAND: A RESEARCH SYNTHESIS



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Executive Summary

As the world shifts toward more sustainable energy solutions, Offshore Renewable Energy (ORE) is increasingly recognised as a key contributor to Ireland’s energy transition. Ireland’s Atlantic seaboard offers one of Europe’s most promising opportunities for offshore wind energy, with a vast maritime area coupled with ideal wind conditions owing to its strategic location on the edge of the North Atlantic Ocean. Floating Offshore Wind (FLOW) generation has the potential to provide up to 30GW of energy by 2050, surpassing current domestic electricity demand six-fold. A critical factor in realising this potential is wet storage, the temporary nearshore storage of FLOW structures during the construction and installation phase. This is expected to be particularly important in Ireland due to its harsh wave climate, which limits the available weather windows for installation. This study addresses the key uncertainties surrounding wet storage, focusing on identifying suitable sites and tackling the associated technical challenges. Following a comprehensive literature review on wet storage, the research is conducted in two phases: the first phase examines suitable conditions and potential locations for wet storage, while the second phase explores the technical aspects of designing optimal layouts and mooring configurations. Advanced Geographic Information System (GIS) methods are used to analyse the potential sites, incorporating a range of geospatial criteria to account for constraints, restrictions and opportunities in the site suitability assessment. High-level numerical modelling tools and physical wave tank testing methods are employed to evaluate various designs, configurations, and layouts for wet storage. GIS results highlight significant potential for wet storage in the Shannon Estuary and Bantry Bay on Ireland’s southwest coast, with additional limited possibilities in Belfast Lough. The numerical and physical modelling reveal optimised mooring layouts, and the associated forces acting upon them, for various wet storage scenarios. The use of shared anchors in some array configurations is technically feasible at both the Shannon Estuary and Bantry Bay. However, further investigation is needed into anchor uplift forces and array resonance effects to develop robust design guidelines. The research provides key insights into this critical enabler for FLOW deployment in the years ahead, thus laying the groundwork for wet storage as Ireland prepares to harness the vast offshore wind energy potential in its deep Atlantic waters.

Acronyms

AA	Appropriate Assessment
AHTS	Anchor Handling Tug Supply
AHV	Anchor Handling Vessel
AONB	Area of Outstanding Natural Beauty
CAD	Computer Aided Design
CAPEX	Capital Expenditure
CFD	Computational Fluid Dynamics
CIL	Commissioners of Irish Lights
CLC	Corine Land Cover
CLV	Cable Laying Vessel
CoG	Centre of Gravity
CoM	Centre of Mass
CS	Case Study
DAFM	Department of Agriculture, Food and Marine
DEA	Drag Embedded Anchor
DECC	Department of Energy, Climate and Communications
DHI	Danish Hydrographic Institute
DMAP	Designated Maritime Area Plan
DOB	Deep Ocean Basin
DoF	Degree of Freedom
DTM	Digital Terrain Model
EIA	Environmental Impact Assessment
ESB	Electricity Supply Board
EU	European Union
FIU	Fully Integrated Unit
FLOW	Floating Offshore Wind
FOWT	Floating Offshore Wind Turbine
FSS	Floating Support Structure
GIS	Geographic Information Systems

IMO	International Maritime Office
IRCG	Irish Coast Guard
ISWCS	Inner Seas off the West Coast of Scotland
KPI	Key Performance Indicator
LAT	Lowest Astronomical Tide
LC	Load Cell
LCA	Landscape Character Assessment
LCOE	Levelized Cost of Energy
MARA	Maritime Area Regulatory Authority
MAC	Maritime Area Consent
MCDA	Multi-Criteria Decision Analysis
MPA	Marine Protected Areas
MRIA	Marine Renewables Industry Association
MUL	Maritime Usage Licence
NI	Northern Ireland
NOTF	National Ocean Test Facility
O&M	Operation and Maintenance
ORE	Offshore Renewable Energy
ORESS	Offshore Renewable Energy Support Scheme
PDA	Pile Driven Anchor
PJA	Port Jurisdiction Area
POC	Port of Cork
PSD	Power Spectral Density
QTF	Quadratic Transfer Functions
QTM	Qualysis Track Manager
RAO	Response Amplitude Operator
RD	Rotor Diameter
RMS	Root Mean Square
ROI	Republic of Ireland
ROMS	Regional Ocean Modelling System
SAC	Special Area of Conservation

SCA	Seascape Character Assessment
SC-DMAP	South Coast Designated Maritime Area Plan
SD	Standard Deviation
SEAI	Sustainable Energy Authority of Ireland
SFPC	Shannon Foynes Port Company
SOLAS	Safety of Life at Sea
SPA	Special Protected Area
SD	Standard Deviation
TLP	Tension Leg Platform
TSS	Traffic Separation Scheme
UCC	University College Cork
UKHO	United Kingdom Hydrographic Office
WEI	Wind Energy Ireland
WTG	Wind Turbine Generator

Notation

A	Horizontal distance
f_p	Frequency Peak
GW	Gigawatts
Ha	Hectares
H_{m0}	Spectral Significant Wave Height
hr	Hour
H_s	Significant Wave Height
H_{max}	Maximum Wave Height
Hz	Hertz
Km	Kilometres
kts	Knots
kV	Kilovolts
m	Metres
MN	Meganewtons
m/s	Metres per Second
m ²	Square Metres
MW	Megawatts
MWh	Megawatt Hours
NM	Nautical Miles
θ	Angle
t	Tonnes
T_p	Wave Period
s	Seconds
U_w	Wind Speed
γ	Gamma
€/kW	Euro per Kilowatt
€m	Million Euro

1 Introduction

The offshore wind industry has experienced significant growth in recent decades, with Europe generally leading the way in harnessing the power of this abundant resource. Fixed-bottom offshore wind farms have dominated the sector during this period, where turbines have been installed in shallower depths (<80m). As availability of such sites becomes increasingly scarce, attention has shifted to the vast potential of deeper waters. This has led to the emergence of Floating Offshore Wind (FLOW) technology, which offers a promising solution to harnessing wind energy in deeper waters (>80m).

The US Energy Information Administration predict a worldwide increase in global energy use of 50% by 2050 when compared to 2020, due to economic and population growth [1]. To minimise the harmful effects of hydrocarbon use and reduce environmental impact, several countries have set targets for 2030 and 2050. Specifically, the European Union have committed to cutting greenhouse gas emissions by at least 55% by 2030 when compared to 1990 as well as reaching net-zero carbon emissions by 2050 [2]. The EU recognise that a scaling up of renewable energy generation is essential to meet these targets and have aimed for at least 42.5% of energy to come from renewable sources.

In terms of renewable electricity generation in the EU, wind has the largest share at 37.5% [3]. As of 2022, Europe has 255GW of wind capacity installed, which generated 487TWh of electricity, constituting 17% of the total electricity demand that year [4]. Of the installed capacity, 225GW is onshore and 30GW is offshore. An average of 31GW per year until 2030 must be installed if the EU is to reach its renewable energy targets. Within Europe, Germany, Sweden and Finland had the most wind energy installations. In terms of offshore capacity, the UK and Germany are by far the most prominent, with 14GW and 8GW installed respectively.

Large scale offshore wind deployment is expected to play a crucial role in meeting the European Commission's Green Deal target of 40% from renewable sources by 2030 [5]. Notwithstanding other sensitivities associated with developing and operating in a maritime area, the physical separation between offshore wind turbines and land-based receptors will generally mitigate against, or minimise, negative impacts and interactions that can be associated with onshore wind, including noise, flicker and visual impacts. As mentioned, fixed bottom turbines are only feasible in water depths less than 80m, which is a significant barrier to the uptake of offshore wind in many countries. FLOW technology can be used at depths beyond this 80m threshold to tap into the vast offshore wind resources available in deeper waters. However, FLOW technology is currently still somewhat in its infancy, with only a handful of demonstration projects operational worldwide. To date, only five FLOW arrays have been developed globally, all of which are relatively small scale (<100MW). The world's first was the 30MW Hywind Scotland deployment commissioned in 2017. WindFloat Atlantic is a 25MW project in Portugal that has been operational since 2020. A second UK project, the 48MW Kincardine Offshore Wind Farm, was commissioned in 2021, while in 2022, the 88MW Hywind Tampen farm began exporting power

before it was fully completed in 2023. The French 24MW Provence Grande Large project was also commissioned in 2023. Table 1 shows the details of the five FLOW farms that are currently operational worldwide.

Table 1. FLOW farms currently operational worldwide.

Name	Location	Technology	Commissioned	Capacity
Hywind Scotland	UK	Spar	2017	30MW
WindFloat Atlantic	Portugal	Semi-Sub	2020	25MW
Kincardine	UK	Semi-Sub	2021	50MW
Hywind Tampen	Norway	Spar	2022	88MW
Provence Grand Large	France	TLP	2023	24MW

Due to the longer installation timelines of offshore wind projects, Wind Europe expects 74% of new installations between 2023 and 2027 to be onshore [4]. Nevertheless, the market for offshore wind is expected to increase rapidly in the coming years. Figure 1 depicts the projected growth of both onshore and offshore wind according to the EU renewable energy targets [4]. Offshore wind cost forecasting conducted from the US department of energy estimated that lifetime power plant cost to overall energy production ratio could decrease from \$207 per MWh in 2021 to \$64 per MWh in 2035 for FLOW, mainly attributed to growth in installed capacity as well as infrastructure development [6].

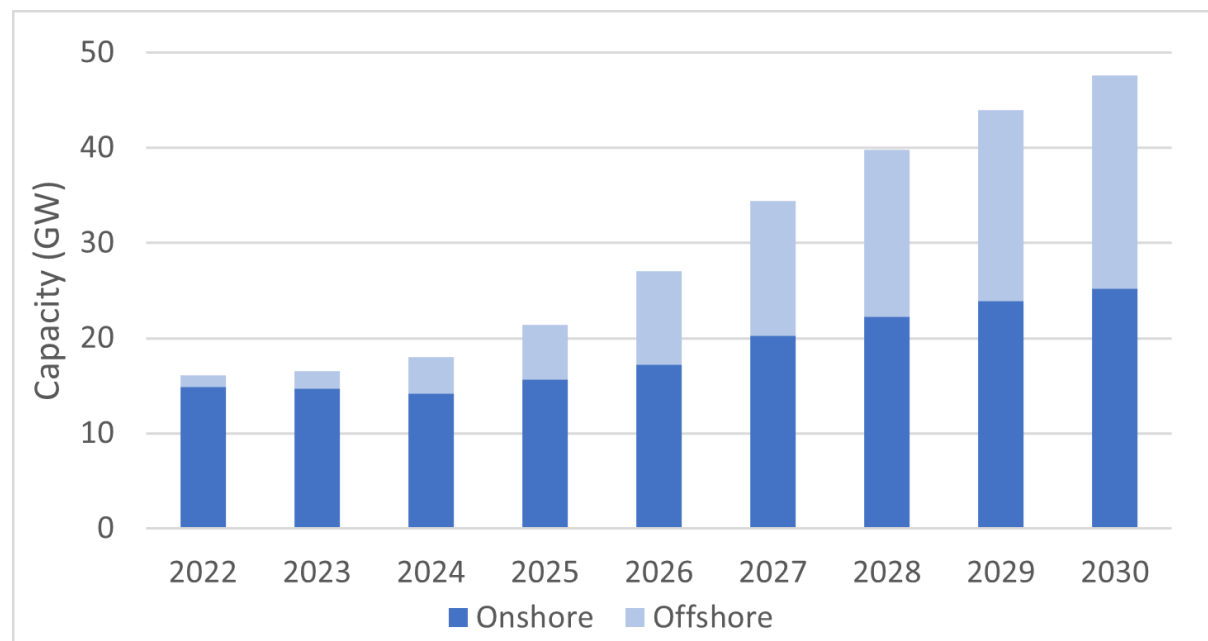


Figure 1. Projected growth in capacity of onshore and offshore wind to meet 2030 EU targets [4].

As of 2022 Ireland currently has 25MW of offshore capacity and over 5GW of onshore capacity [7], comprising ~38% of its total electricity generation [8]. This is the second highest share in Europe, with Denmark generating ~54% of their electricity from wind [4]. However, in comparison to the UK, who have become an industry leader, Ireland only has one offshore wind farm in operation, Arklow Bank

Wind Park Phase 1. Issues in legislation and consent are highlighted as the main causing factors for this. The Government of Ireland have an ambition of 37GW of offshore wind to be installed by 2050 [9], with SEAI estimating that 27GW of this would come from FLOW in a scenario analysis [10]. However, considering the current lack of offshore wind in Ireland, immediate action is required to realise these targets within this timeline. With a potential resource capacity of up to 579GW in deeper waters (albeit without major consideration of constraints) [11], Ireland could become a key player in the EU market. In support of that, the Irish Government have adopted a policy of plan-led development in the maritime area and initiated the adoption of multi-sectoral management plans for maritime areas known as Designated Maritime Area Plans (DMAPs), the first of which was adopted in October 2024.

Port infrastructure (to enable substructure manufacturing and assembly, turbine parts, station keeping, equipment storage, integration, etc.) has been identified as one of the main barriers to FLOW farm development in Ireland [5]. If Ireland fails to assign sufficient resources to solve this problem, we will be forced to rely on UK or other EU ports to deliver projects which will delay delivery and increase costs. Not only would this put the projects themselves in jeopardy, but it would also result in the loss of significant future investment in Irish supply chains. Furthermore, to keep up with the projected pace of deployment, Ireland will need multiple ports that can serve this market. A key component of this port infrastructure, for FLOW development will be wet storage. The harsh wave climate off Ireland's west coast results in narrow weather windows. This will necessitate Floating Offshore Wind Turbines (FOWTs) to be temporarily stored nearshore until deployment becomes possible during appropriate weather conditions, particularly for larger scale projects. It is anticipated that this temporary nearshore wet storage will be required both for floating substructures prior to wind turbine generator (WTG) mating at the quayside and for fully assembled FOWTs (post integration) prior to tow-out during the available weather window.

This report provides a comprehensive exploration of wet storage, structured to provide a thorough understanding of the subject. Section 2 presents a detailed literature review, offering insights from existing research on wet storage. Section 3 outlines the foundational assumptions guiding the study. The analysis of site suitability for wet storage is detailed in Section 4, followed by an examination of layout and mooring configurations in Section 5. Conclusions are drawn in Section 6.

2 Literature Review

This review aims to provide the reader with a background of FLOW worldwide and in Ireland, before detailing port infrastructure and wet storage requirements specifically. Current knowledge on the assembly of FOWTs and proposed strategies for the significant upscaling of the associated manufacturing and assembly are reviewed, with an emphasis on installation port infrastructure and wet storage. In terms of scope, the review focuses mainly on assembly and installation strategies for FLOW. Due to the emerging nature of FLOW technology and the low number of commercial projects to date, there are limited information sources available. Information was gathered using journal articles and reports from renewable energy developers and researchers as well as relevant data from government bodies. Areas outside the scope include considerations during offshore installation, operation and maintenance of FLOW farms and optimisation of transport vessels. Limitations are stated as they arise in the review.

2.1 Current technologies

2.1.1 Outline of FLOW platform types

Floating substructures that have been successfully implemented offshore in demonstrative FLOW projects or in the oil and gas industry can be categorised as either semi-submersible, barge, spar and tension leg platforms, as depicted in Figure 2 [12].

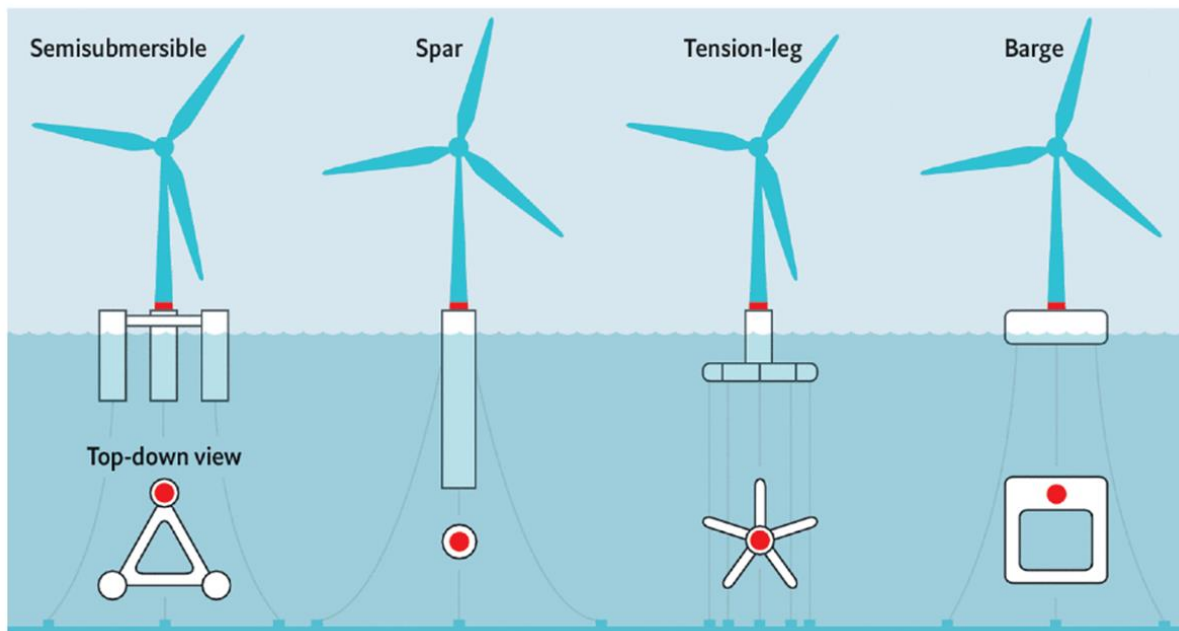


Figure 2. The main FLOW platform types [12].

They can be described as follows [13] [14] [15]:

- **Semi-submersible:** Characterised by three or four columns connected by pontoons or trusses, with the semi-submersible platform achieving stability through its wide footprint. The wind turbine is typically mounted on one of the columns or at the hull's centre, supported by lateral bracings. With a shallower draft than spar designs, it allows for convenient quayside assembly in water depths generally over 40 metres. While it has the largest seabed footprint of any substructure, its stability can be further enhanced through ballasting.
- **Spar:** The spar platform employs a slender, vertically floating cylindrical hull that derives its stability from a low centre of gravity. Heavy ballast in its lower section keeps the centre of mass well below the centre of buoyancy, providing excellent resistance to heeling forces. Its deep draft and small waterplane area result in low wave-induced motions. It is suitable for depths generally over 100 metres. However, this deep draft complicates manufacturing, installation, and quayside assembly, requiring ports with very deep water.
- **Tension Leg Platform (TLP):** A TLP relies exclusively on a taut mooring system for stability, using highly tensioned, vertical tendons tethered to the seabed. While common in the oil and gas industry, it has yet to be widely adopted for floating wind. This design offers the lowest motion characteristics of all platform types but is not self-stable. It is suitable for depths over 100 metres and requires robust anchors capable of withstanding significant vertical loads. The complex installation process often precludes port-based turbine integration, potentially necessitating full assembly on-site, and involves a costly, high-load mooring system.
- **Barge:** The barge is a simple, single-hull structure with a large waterplane area, where its length and width greatly exceed its height. It is suitable for water depths over 40 metres. However, this large surface area at the waterline makes it susceptible to higher wave-induced motions than other designs, which can lead to significant turbine tower movement, particularly in extreme weather conditions.

Both semi-submersible and barge substructures can be described as buoyancy stabilised platforms (particularly barge as the semi-submersible also uses ballast and mooring), meaning that they gain stability through a large second moment of water plane area. For barge-type floaters, the large second moment of the waterplane area is due to the significant hull waterplane area around the hull centreline. For the semisubmersible, it is a combination of the spacing and size of the water plane area that determines the height (and position) of the meta-centre.

2.1.2 Platform material

With respect to the platform material, concrete, steel or a combination of the two have been considered. The decision on whether to use concrete or steel substructures is highly case specific [13]. In terms of cost, steel is generally expected to be more expensive, and prices are highly volatile compared to concrete. A comparative study has been conducted of steel vs. concrete use in substructures, concluding

that the cost breakdown is highly dependent on the nature of the substructure as well as the project itself given that transit costs make up a significant proportion of the overall costs if manufacturing is to be done in another location, such as Asia [16]. Excluding transportation costs, concrete semi-submersibles were predicted to be 11% more expensive than steel alternatives, assuming manufacturing was conducted in Asia. It is noted steel manufacturing in Europe would be 25-30% more expensive than in Asia. Steel substructures are already widely established in the offshore wind industry. Alternatively, concrete as a material is cheaper and requires less complicated equipment, meaning that a local supply chain could be utilised [17].

2.1.3 Relevance of features/properties to the installation process

In terms of the assembly and installation process, semi-submersible and barge platforms allow for onshore and quayside construction and assembly, which requires significant area but low drafts, typically less than 15m. This is not feasible with spar or some TLP platforms, depending on the design. Aside from supply chain considerations, which will be case dependent, steel substructure components can be prefabricated and stored in laydown areas for long periods of time quayside before assembly. Depending on the assembly and installation strategy, this could be an advantage. Furthermore, concrete substructures require a greater draft, which may be a limiting factor, depending on port facilities.

Considering these points in the context of the Irish industry where substructure components may be imported from abroad, and where there are water depth limitations in many ports, steel semi-submersible substructures may be more suitable and are therefore focused on in the remainder of this review. However, it is noted that priorities may vary from project to project. Projected dimensions for semi-submersible substructures supporting a 15MW turbine are given in Table 2 [5]. The University of Maine have also designed a reference 15MW platform although a de-ballasted port operating draft is not given. Given that the overall height is 10m over that proposed [5], it is likely the port draft would also be higher.

Table 2. Projected dimensions for semi-submersible (FSS) supporting a 15MW turbine [5].

Parameter	Value for Steel	Value for Concrete	UMaine (steel)
Substructure Width (m)	100	100	102.13 x 90.13
Substructure Height (m)	25	25	35
Substructure Port Draft (m)	9	15	~
Substructure Operating Draft (m)	13	22	20
Substructure Mass (t)	4500	13000	3914

2.2 Mooring and anchoring considerations

BVG Associates [13] present the 4 main types of mooring system for semi-submersible structures, as illustrated in Figure 3 [18].

- **Plain Chain Catenary:** This design uses free hanging chain lines to connect the FLOW substructure to the anchors. The mooring line forms a catenary curve, which is a natural curve that a flexible chain or cable assumes under its own weight when supported at its ends. It typically consists of heavy chains that provide the necessary tension to keep the structure in place. The weight of the chain helps to absorb the forces exerted by waves, wind, and currents, providing station keeping compliance for the floating structure. A length of chain on the ground results in the anchor loads being mainly horizontal. Floating platform to anchor radius is 6-10 water depths.
- **Multi-catenary:** This is based on the plain catenary system, but with the inclusion of synthetic rope sections. The station keeping is due to weight of chain section as well as elasticity of the rope section. Clump weights and buoyancy modules can be added depending on mooring design requirements.
- **Buoyant semi-taut:** This mooring system combines chain sections at the top and bottom with a rope mid-section on each mooring line. The ground chain ensures that the loads on the anchors are predominantly horizontal, while buoyancy modules between the ground chain section and rope sections lift the rope sections above the seabed to prevent damage.
- **Taut:** This system uses only rope lines, made from synthetic fibre ropes such as polyester or nylon, which directly connect the anchor and floating wind substructure (see Figure 4). Greater loads, including vertical loads are placed on the anchor in this configuration. However, the footprint is significantly smaller, with a radius from floating wind turbine to anchor of approx. 2-3 water depths. The restoring force for the taut system is provided through elastic behaviour of lines (Figure 4).

For mooring systems which mainly impose a horizontal load at the seabed, drag embedment anchors are preferable. For taut systems, with significant vertical loading, anchor piles are often used [13]. Excursion values which describe the degree to which floating substructures can move from their initial station are often in the range of 30-35% of the water depth.

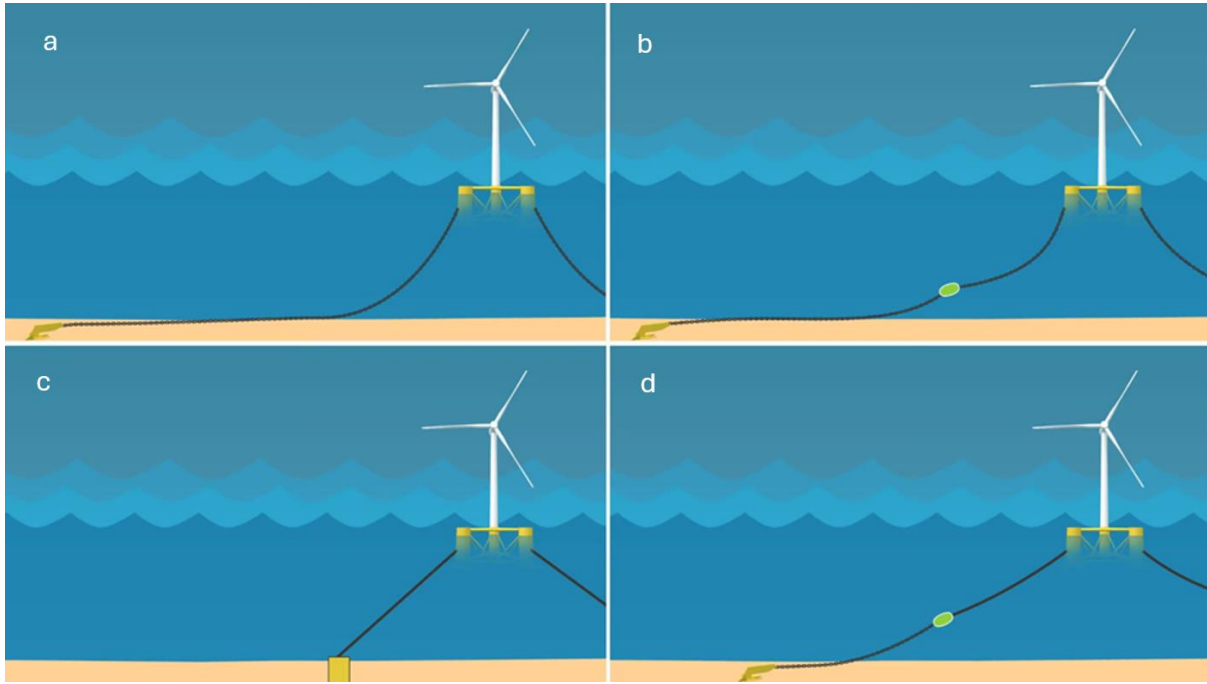


Figure 3. Typical (a) catenary, (b) multi-catenary, (c) taut, and (d) buoyant semi-taut system [18].

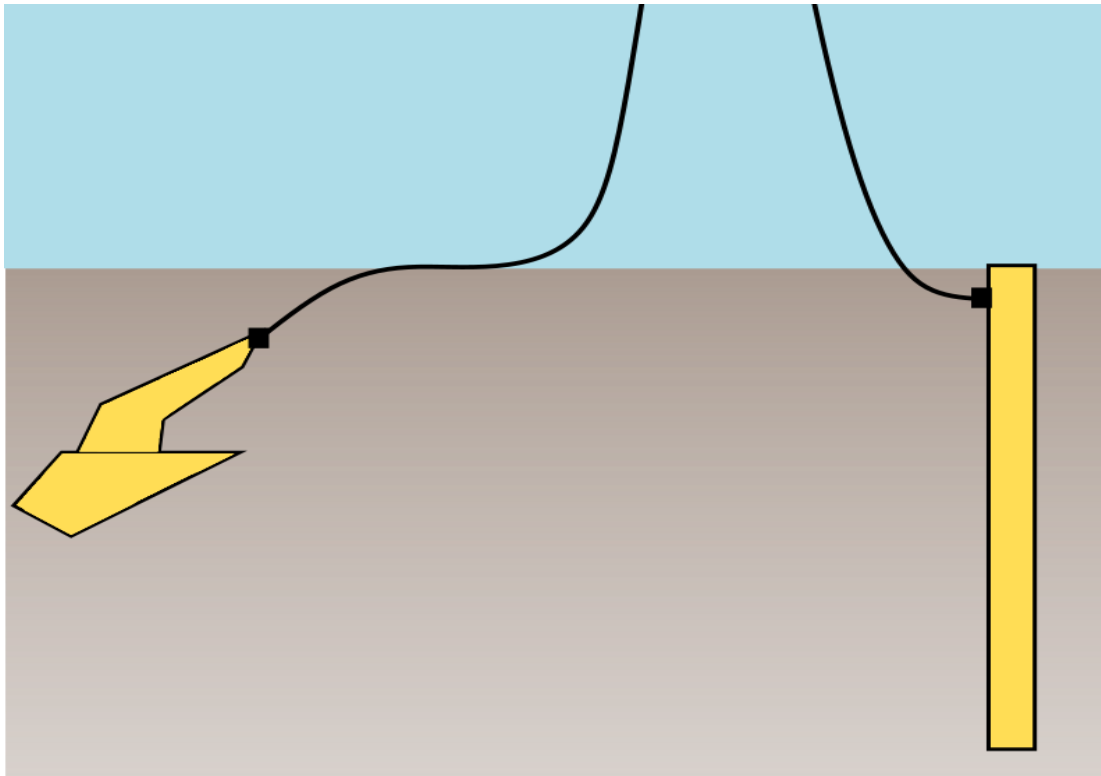


Figure 4. Side view of drag embedment anchor (left) and pile anchor (right).

2.2.1 Multiline anchoring potential

Since FLOW farms are generally deployed in arrays, there is significant potential for increased efficiency in mooring systems from attaching multiple mooring lines to a single anchor. This also

provides the possibility of reducing the seabed footprint of the system. Figure 5 shows various layouts for multiline anchoring systems [19].

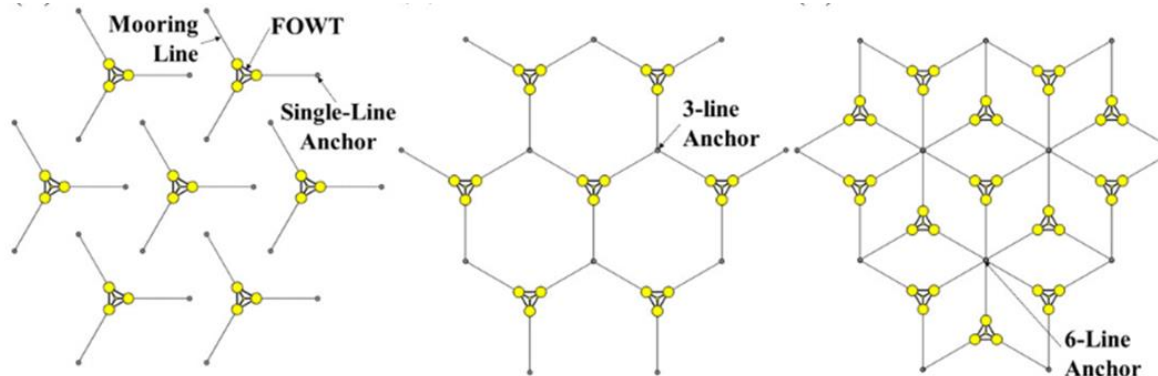


Figure 5. Examples of multiline anchoring arrangements [19].

One report [20] mentions some disadvantages to this approach, such as a reduction in system reliability and potential for cascading failures. However, adjusting mooring line and anchor sizing could significantly influence the reliability of the system. It is also stated that anchors with a vertical axis of symmetry such as pile driven anchors can be easily adapted to multiline arrangements, by simply increasing the number of pad eyes on the anchor. However, driven piles are said to come with a high cost due to their complex installation [21]. These requirements are in the context of an operational FLOW farm, therefore it is unclear whether driven piles would retain their high cost if used in temporary wet storage, given that the required sizes would be significantly smaller and water depths much lower than in a FLOW site.

The report investigating multiline anchoring concepts [20] showed a potential reduction in the number of anchors in a wind farm by a factor of three. In terms of loading however, this would require anchors to be able to resist multi-directional loading. It is noted that the feasibility and relative costs/benefits of these concepts depend heavily on interplay between water depth, mooring line geometry, spacing between turbines, etc. It is possible that reducing the number of anchors could result in increased mooring line lengths that may not be cost-effective.

2.3 Strategies and considerations for efficient installation

2.3.1 Proposed assembly and installation method

BVG Associates [13] provide a detailed description of a proposed FLOW assembly, storage, and installation process. Depending on the design of the semi-submersible substructure, they may need pre-assembly at a construction port. Semi-submersible barges can be used to move the structure into water for wet storage prior to assembly, where temporary moorings may be used. Other turbine components such as the rotor, nacelle and tower will be stored in a quayside facility, often referred to as a loadout quay. Projected sizes for blade length, hub height, total turbine height and nacelle weight are given by

[17] and are summarised in Table 3. Further component dimensions for a 15MW turbine are given by [5] and summarised in Table 4. Harbour tugs will bring the floating substructure from wet storage to the quayside. The final assembly/turbine integration will then occur at a ‘fit-out quay’ using a landside crane (Figure 6).



Figure 6. Example of turbine integration at the quay [22].

Table 3. Projected Turbine Component Sizes [17].

MW	Blade length (m)	Hub height (m)	Total height (m)	Nacelle weight (t)
8	84	116	202	443
10	94	126	222	579
12	103	135	241	675
14	111	145	260	868
16	118	154	278	1019

Table 4. Projected turbine component sizes for a 15MW turbine [5].

Parameter	Value
Rotor diameter (m)	240
Blade length (m)	115
Blade mass (t)	65
Blade root diameter (m)	6
Nacelle height (m)	10
Nacelle width (m)	10
Nacelle length (m)	20
Nacelle mass (t)	650
Tower height	120
Tower base diameter (m)	8
Tower mass (t)	1000

Following pre-commissioning and testing, the fully assembled FOWT will be wet-stored prior to tow-out, unless a weather window is immediately available. The substructure may also be ballasted prior to tow-out for stability purposes. Three anchor handling vessels (AHV's) may be required for the tow-out operation [20] [21]. It has been assumed that moorings could be pre-installed on site in advance of the offshore arrival of the assembled turbines for quick connection on site [20] [23].

2.3.2 Infrastructure issues

Due to the planned upscaling of FLOW, identifying port infrastructure that facilitates the assembly and installation of a large number of FOWTs for a given project is one of the main challenges facing the sector. However, considerable research has been undertaken to assess the port infrastructure requirements and evaluate the capacity of current ports. [20] emphasise the importance of major manufacturing facilities and port infrastructure for the assembly and storage of FLOW, stating that these activities will require a significant share of the overall project capital expenditure. In terms of reducing the overall project time (and cost), the location of the manufacturing and assembly facilities are highly impactful [24]. [17] state that ports are the 'pinch points' in terms of FLOW deployment. 36% of total capital expenditure costs are incurred during installation, operation and dismantling, yet this is expected to reduce as projects scale up [5].

2.3.3 Primary port functions

Multiple sources have been used to determine proposed port infrastructure requirements. [13] refer to 'Construction Port' requirements, stating that a port should have the following key facilities: a laydown area for turbine components, a pre-assembly area, a quay, cranes for assembly and jetties if crew transfer vehicles are required to support installation, as well as personnel facilities and workshops. [17] provide a more comprehensive review of port requirements, also stating that the port functions may need to be fulfilled by a combination of different ports working in conjunction with each other if required. The proposed port functions are:

- Geotechnical/weather survey supply base.
- Substructure construction area.
- Quayside facility for blade manufacture (if applicable).
- Loadout quay to store nacelle and tower prior to turbine integration.
- Loadout quay for mooring equipment (can be stored separately as they do not need a comparatively high lifting capacity).
- Laydown area for mooring components and dynamic array cables (could be in a separate facility since the mooring system will likely be installed separately prior to turbine installation).

- Wet storage.
- ‘Fit-out quay’ for turbine integration/installation.

It is noted that many of the UK based reports, such as [17], aim to maximise the proportion of the projects delivered by UK based supply chains and near-site manufacture of substructures and turbine components is mentioned. Therefore, details of these strategies may not be fully aligned with the priorities for projects in smaller regions such as Ireland. It remains unclear to what extent Ireland will source components locally or abroad as significant investments would be required to establish a local supply chain. A large project pipeline would be needed to justify these investments [25]. BVG Associates [13] suggest the following for a 450MW project:

- 15-20Ha for turbine component laydown.
- 10-12Ha of wet storage for floating substructures prior to assembly and fully assembled FLOW units post assembly.
- 500m length quay with the ability to bear 40-100t/m².
- 12-20m quayside depth for floating substructures and semi-submersible transport vehicles.
- Sufficient water access for delivery vessels (typically 160m long, with a 45m beam and 6m draft).

[17] provide estimated area requirements and weather restrictions for ports (Table 5.)

Table 5. Port weather restrictions [17].

Facility	Sig. Wave Height (m)	Wave Period (s)	Wind (m/s)	Current (m/s)
Loadout	< 1	< 8	< 10	< 0.5
Drydock	< 0.5	< 7	< 10	< 0.5
Floatoff HTV	< 0.5	< 7	< 10	< 0.5
Fit out crane	< 0.5	< 7	< 10	< 0.5
Wet Storage	3	10	30	1

[20] emphasise that the most important project requirements relate to specifics of the substructure and turbine component acquisition and assembly, suggesting that attaining appropriate laydown area, quayside draft, channel depth and width should be prioritised. It is also mentioned that knowledge of the duration of assembly of FLOW at the installation facility and other related logistics are essential to accurately define the required port area, although there is currently limited data available due to the low number of projects that have been completed to date. It is also stated that these requirements are based on available publications/data and the development of methodologies is in its infancy. Specifics of chain mooring or dynamic cable system manufacturing requirements are not greatly detailed in the literature.

Nevertheless, [20] suggest that these infrastructures have a lower impact on the efficiency and low-cost delivery of projects when compared to port infrastructure requirements.

2.3.4 Further strategic time, cost and efficiency considerations

In terms of the installation of FLOW projects, selecting methods that allow for the projects to be completed as efficiently as possible has been the focus of much of the recent research, as high LCOE estimates may serve as a barrier to the uptake of the technology. [20] highlight the importance of ensuring that port infrastructure remains sustainable, by having the ability to support other offshore services such as fixed bottom deployment, oil and gas servicing, import and export of goods, etc. Furthermore, to maximise the use of available ports, it may be possible to split certain activities across multiple ports (as already mentioned). Creating synergies in operations such as locating the laydown area for turbine components with direct access to a quayside will significantly reduce downstream costs.

The Welsh government worked with ORE Catapult to identify key strategic considerations for FLOW development [26], where some insights on expected assembly strategies were detailed. It was highlighted that substructure assembly would likely comprise the largest costs in a FLOW project. In terms of efficiency, the use of multiple assembly lines (two to three) simultaneously constructing eight to twelve structures was proposed. Both steel and concrete were considered as substructure materials here, with pre-fabrication intended to be carried out locally. A conceptual multi-port strategy was also used to illustrate different work breakdown strategies that could be employed (Figure 7). However, ports would have to be in reasonable proximity to each other to justify conducting sequential operations at separate locations.

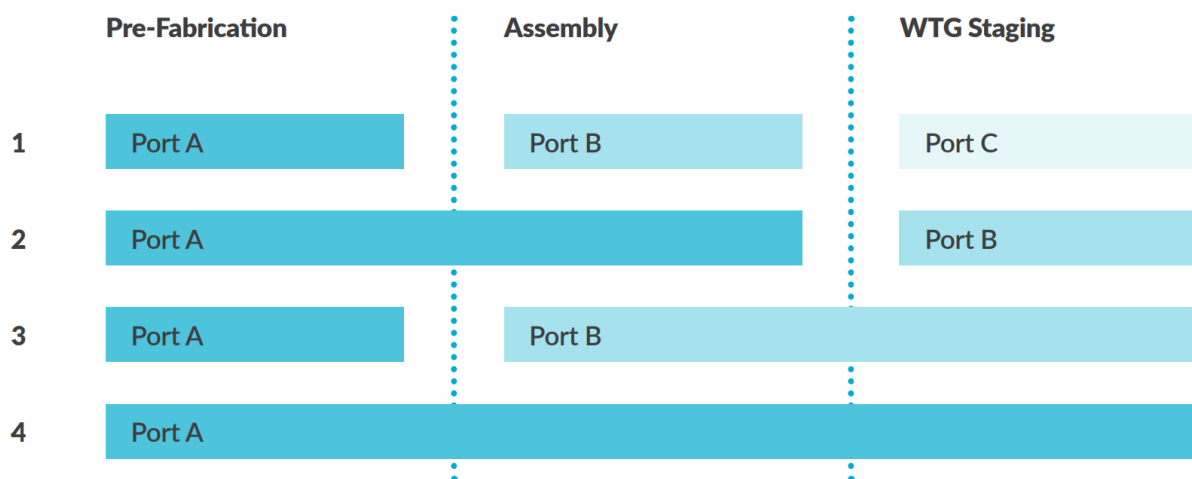


Figure 7. Proposed work breakdown options for a multi-port strategy [26].

2.3.5 Current state and pace of deployment

The nascent stage of the sector results in limited data availability regarding the times required for each stage of assembly and installation generally. [13] reference a current assembly and installation rate of

two FOWTs per week, which would enable a 1GW farm to be installed in a season and state that a minimum of one FOWT per week would be needed for a 450MW farm containing 30 turbines, inclusive of the inherent weather constraints. This assumed that installation is completed under transit speeds of 3-4kts. A significant wave height (Hs) of 1-1.5m and wind speeds of less than 14m/s are listed as reasonable weather conditions for transport. Semi-submersible substructures are the simplest to install given the amount of knowledge transferred from the oil and gas sector. A current total installation time of roughly 60 hours is given, which can be carried out at up to 1.5-2m Hs.

Several studies have described modelling tools for FLOW installation (aiming to increase installation efficiency) and identify the main KPIs associated. A case study of an offshore site west of Barra in Scotland highlighted the importance of the proximity of the marshalling port to the offshore site [27]. A fabrication port located 159NM from the site required 135 hours for the installation of a FLOW farm, with 78 hours of those for transit alone. Another port at 18NM required 74 hours for the installation, due to the reduction in transit time to 15 hours, assuming a towing speed of 3kts in both cases. Furthermore, weather forecasting beyond 78 hours is likely to comprise inaccuracies. While multiple fleets could be used to install multiple FOWTs at once, this may not be feasible and would significantly increase cost.

[24] conducted three case studies around the UK of a hypothetical 300MW farm consisting of 30x10MW FOWTs with semi-sub platforms, using real weather data, and assumptions of met-ocean conditions and transport routes. Simulations were repeated for a wide range of met-ocean conditions. In alignment with the previous demonstration projects such as WindFloat Atlantic, the Port of Ferrol in Spain was used as a manufacturing facility in the model, where the floating platform was fabricated and transported to the assembly port. This clearly affected estimated construction and installation times, with construction times ranging from 11.8 days in the Celtic Sea to 20 days in northeast Scotland (per FOWT), further highlighting the logistical differences between the demonstration projects to date and future large scale commercial projects. [28] state that the main installation challenge lies in finding the right weather window, and that safe havens should be chosen in advance in case harsh weather conditions emerge while towing.

With respect to the current port infrastructure in Ireland, [5] carried out a survey to identify ports that had suitable infrastructure based on a set of requirements shown in Table 6. It is noted that the requirements will likely evolve to suit what is achievable at the ports. There were no facilities deemed entirely suitable to accommodate substructure manufacture, assembly or turbine staging. However, development plans in several locations such as Moneypoint and Shannon Foynes have been put in place. A multi-port approach, where processes would be shared among multiple ports may be required to facilitate the completion of projects. However, this would not be optimal and, as previously mentioned, logistical issues such as port proximity would have to be considered.

Table 6. Geographical port restrictions [17].

Parameter	Unit	Min.	Pref.
Access Channel Width	m	150	200
Access Channel Draft	m LAT	9	15
Quay Water Depth	m LAT	9	15
Quay Berth Length (turbine staging)	m	300	600
Quay Berth Length (turbine staging and manufacture)	m	600	900
Quay Berth Width	m	40	80
Quayside Bearing Capacity	t/m ²	15	50
Laydown Area (substructure assembly)	Ha	12	18
Laydown Area (turbine staging)	Ha	6	12
Laydown Area (manufacturing + assembly of substructures and turbine staging)	Ha	34	50
Laydown Area Bearing Capacity	t/m ²	7.5	> 20
Wet Storage Area (10 substructures without topside turbine)	Ha	30	70
Wet Storage Area (10 substructures with topside turbine)	Ha	80	280
Wet Storage Draft	m LAT	13	23
Welfare / Office Space	m ²	200	700

2.4 Requirements

Areas for wet storage are likely to be required for both substructures prior to assembly and fully assembled FOWTs prior to installation. These will be of varying sizes with differing preferred site criteria. The criteria gathered from the literature are based only on the limited available data to date, but it is expected that the requirements will be project specific.

The SIMREI project aimed to use evidence-based research to identify port infrastructure requirements to support future industry activities [29]. Within that study, the installation and O&M stages for FLOW were modelled, from which potential wet storage requirements for assembled units were identified. Results showed that the availability of installation vessels had a larger impact on the installation rate in all scenarios compared to the availability of more wet storage areas. The unclear nature of the proposed requirements and the need for further work considering a wider range of variables like seabed topography and consenting was also highlighted.

[5] recommended a minimum wet storage area of 80Ha and 30Ha to store 10 semi-submersible substructures at a time with and without a topside turbine respectively. This is accompanied by a minimum draft for wet storage of 13m LAT. The figures assume the use of a 15MW turbine. [13] give

suggestions for a 450MW project of 10-12Ha of wet storage as well as a 12-20m quayside water depth. It is assumed that this figure is an overall requirement for wet storage prior to assembly and prior to tow-out. The difference between these figures highlights the unclear nature of specific wet storage requirements in current literature. Furthermore, with the increasing size of platforms, greater water depths of at least 20m could potentially be required. This may necessitate dredging of wet storage areas.

According to [5], the wet storage requirements for a specific project will depend mainly on the substructure chosen, number of units anticipated at a given time, placement of the substructures, water depth, and the proposed temporary mooring system (e.g. catenary or pile).

In terms of existing infrastructure, Shannon Foynes and Moneypoint are said to possess significant potential for wet storage, with water depths greater than 15 metres [5]. Areas have not been quantified, but are estimated to be sufficient. Ringaskiddy, Cork Dockyard, Galway and Killybegs are also proposed as suitable areas, although if concrete substructures were to be used, water depths could become an issue. The SIMREI study [29] also suggested that Bantry Bay and Shannon Estuary had relatively sheltered inlets and sufficient space for ~15 fully assembled FOWTs in wet storage, sufficient for an installation rate of 300-400MW per year. The study only considered wet storage requirements for assembled turbines and not stand-alone substructures (pre-assembly).

2.4.1 Temporary mooring in wet storage

Access to information regarding temporary moorings for wet storage of substructures or fully assembled turbines is limited and it is likely dependent on the site. However, it is assumed that many of the principles relevant to the offshore sites also apply to wet storage, with the exception that wind and wave loadings will be lower in wet storage and depths shallower. Assuming that one of the priorities in the planning of a wet storage facility is optimising the area usage, semi-taut or taut mooring systems with the adoption of anchor piles may have a significantly smaller footprint associated with them compared to catenary mooring. The SIMREI study [29] identified the vital need to clarify accessibility requirements for assembled turbines in wet storage. Whether units will be required to have onboard power and the clearances that will need to be in place for vessels and tugboats are all issues that have yet to be addressed and will likely affect the layout of the wet storage facility significantly. This is deemed less significant for the wet storage of substructures prior to assembly.

Discussion on multiline anchoring to date has been solely related to the offshore deployment site. However, depending on the specific project, it may be possible to use multiline anchoring in the wet storage of substructures or fully assembled turbines to maximise space utilisation, reduce costs and minimise the seabed footprint in the wet storage area. Some port development plans have depicted anticipated assembly and wet storage areas. However, it is unclear whether attention was given to the detail of specific mooring configurations. Humboldt Bay on the west coast of the US is an example of such a project (Figure 8). The Kincardine FLOW project, for which FOWTs were assembled on the

continent (Europe), utilised piled anchors for temporary wet storage. However, a commercial scale project would require wet storage for a significantly longer period of time, and it may need to withstand harsher wave loading conditions in Ireland's met-ocean climate. These piles may also have been in place prior to the operation itself.

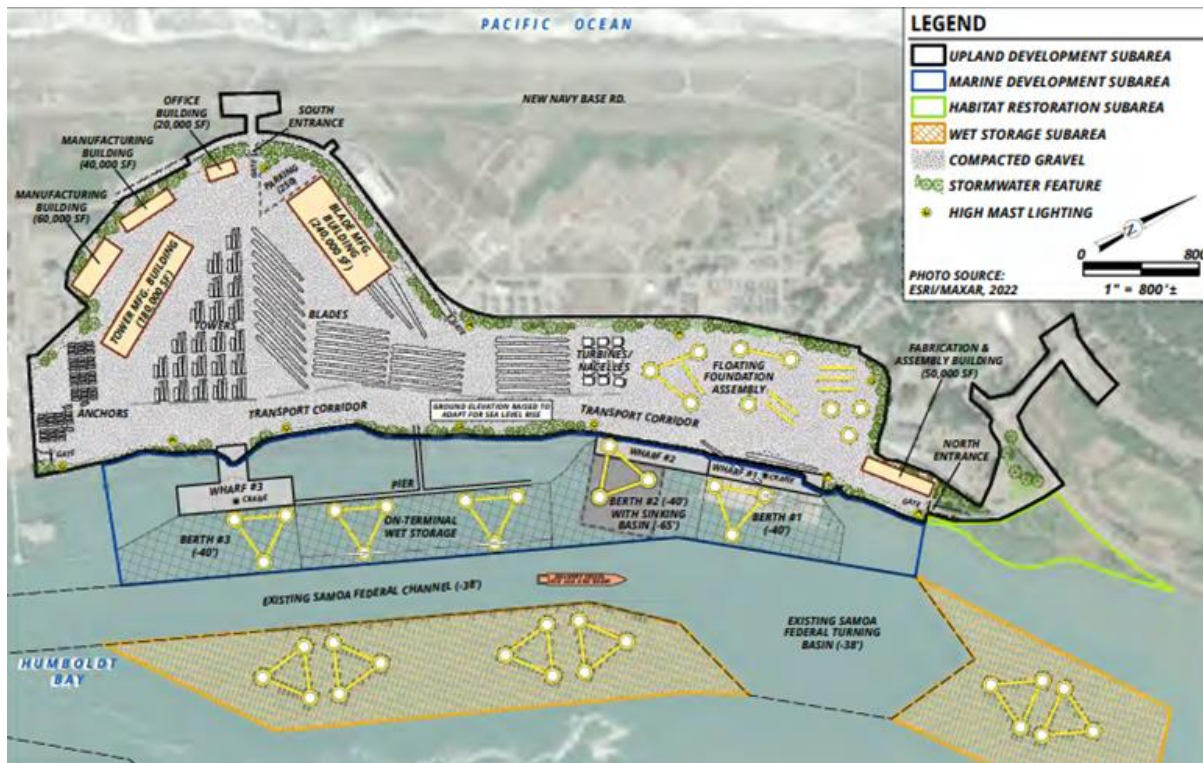


Figure 8. Example of potential layout of assembly and wet storage facility [30].

3 Study Assumptions

In any research project, the establishment of clear, logical assumptions is essential for guiding the study's design, methodology and interpretation of results. This section briefly outlines the key assumptions serving as the framework within which the study operates. Due to the non-existence of any large-scale commercial FLOW farm to date, the technical assumptions in Table 7 are based on expert industry knowledge of the direction in which this sector is moving. Details of assumptions made that are more specific to the individual assessments (site suitability analysis and layout and mooring study) are given in Section 4 and Section 5 respectively.

Table 7. Study assumptions.

Parameter	Value
<u>Technical</u>	
Foundation material	Concrete/steel
Foundation size	L: 85-125m
	W: 75-120m
	H: 35-50m
Turbine size	RD=270m
	Hub height=165m
	Max. tip height=300m
Foundation draft	
<i>Foundation only</i>	4-10m
<i>Foundation with integrated WTG</i>	5-12m
Quantity in wet storage	
<i>Foundation only</i>	Minimum 15-20
<i>Foundation with integrated WTG</i>	Minimum 5-10
<u>Area</u>	
<i>Foundation only</i>	Pending what mooring spread design and buffers is required
<i>Foundation with integrated WTG</i>	725-1,290 ha

All areas within the combined territorial waters of the Republic of Ireland and Northern Ireland were considered. This captured parts of the Irish Sea, the Inner Seas off the West Coast of Scotland (ISWCS), the Celtic Sea and the Atlantic Ocean. Significant ports within the study area include Shannon Foynes Port, Port of Cork (Bantry Bay and Cork Harbour), Port of Waterford, Rosslare Europort, Dublin Port, Belfast Harbour, Port of Larne, Foyle Port, Killybegs Harbour and Port of Galway (Figure 9).



Figure 9. The study area showing encompassed ports and sea areas.

4 Site Suitability Analysis

4.1 Data and methodology

4.1.1 MCDA – data

4.1.1.1 Wave climate

A 20-year hindcast of significant wave height data for the study area was required. Such data is freely available via the Copernicus Marine Service website [10]. The ‘*Atlantic -Iberian Biscay Irish - Ocean Wave Reanalysis*’ product covers the extents 19°W – 5°W; 56°N – 26°N [31], which encompasses the study area. This product was chosen due its hourly temporal resolution. The accuracy of this product has been proven in a validation against *in-situ* data for the region of interest in a previous study [32]. Further details of the product are shown in Table 8. Using this data, the 50-year return period significant wave height was calculated in Python using the *pyextremes* library [33], the output of which is shown in Figure 10.

Table 8. Details of wave data downloaded.

Parameter	Description
Name	Atlantic - Iberian Biscay Irish - Ocean Wave Reanalysis
Spatial Resolution	0.05° x 0.05°
Temporal Resolution	Hourly
Analysis Period	2000 – 2019 (20 years of data)
Underlying model	MFWAM (Meteo-France)
Variables selected	Spectral significant wave height (Hm0)

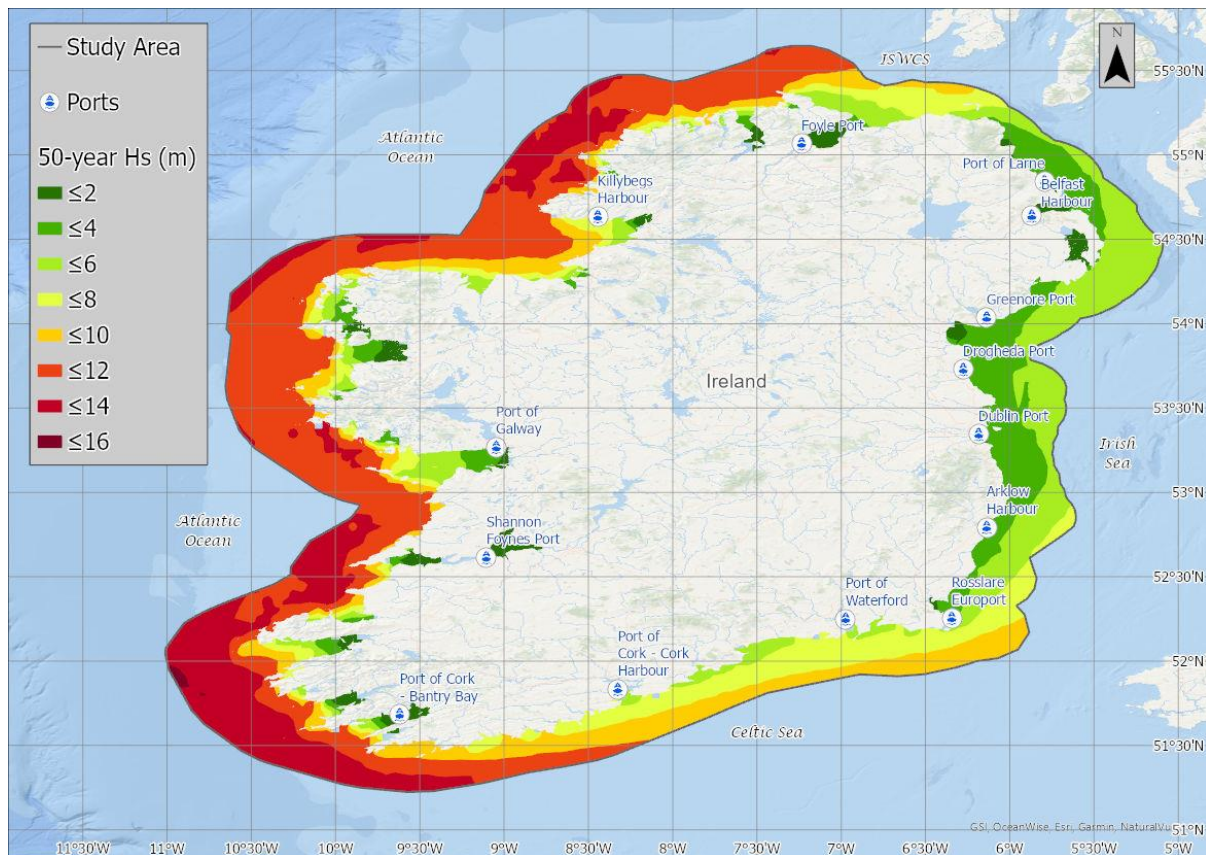


Figure 10. The 50-year return H_s (m) for the study area.

4.1.1.2 Wind climate

Hourly wind data is available from the Copernicus *ERA5* database [34]. As with the wave data, this is downloaded in the form of geographic and temporally subset netCDF files. Table 9 provides further details of the data downloaded. The 50-year return period wind speed was calculated in Python using the *pyextremes* library [33] (Figure 11).

Table 9. Details of wind data downloaded.

Parameter	Description
Name	ECMWF Reanalysis v5 (ERA5)
Spatial Resolution	0.25° x 0.25°
Temporal Resolution	Hourly
Analysis Period	2000 – 2019 (20 years of data)
Variables selected	10m u-component of neutral wind, 10m v-component of wind
Data used in calculations	Root mean square of the u and v components of the 10m wind speed

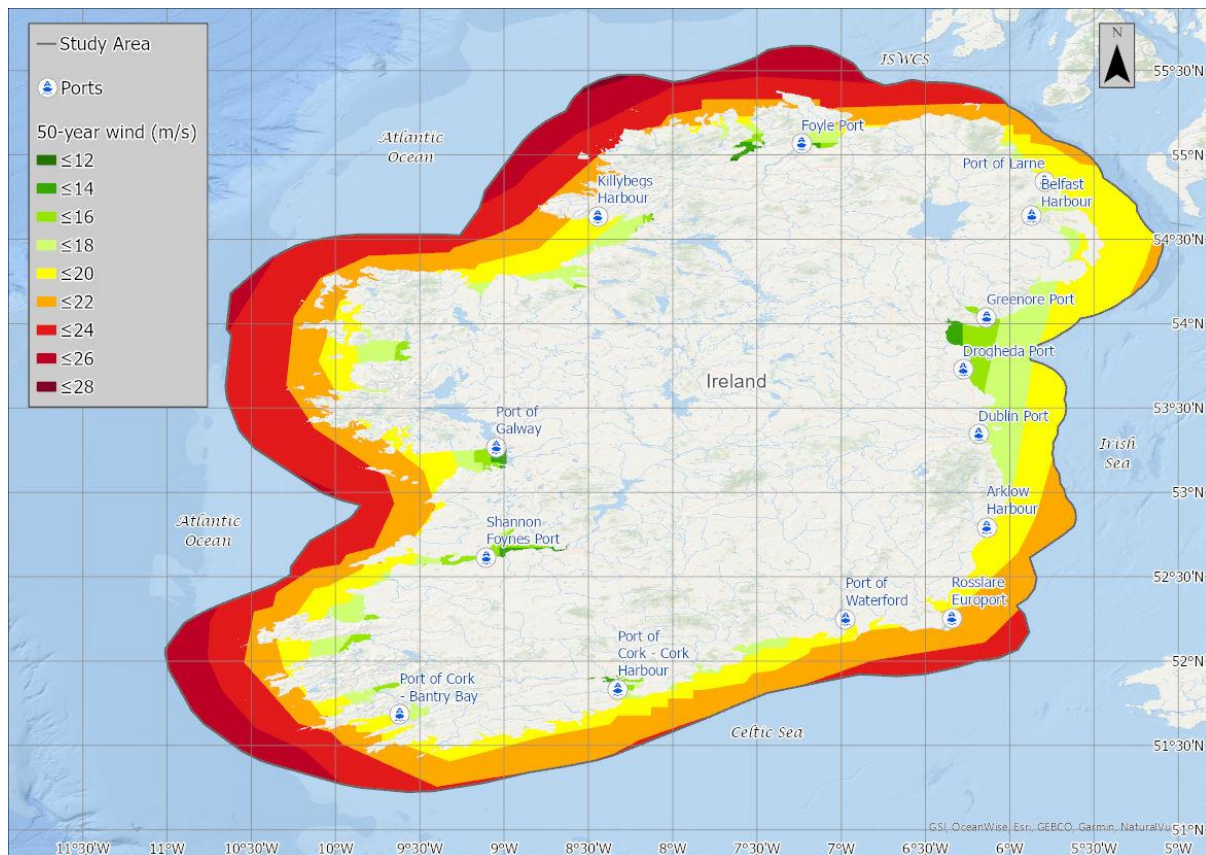


Figure 11. The 50-year return wind speed (m/s) for the study area.

4.1.1.3 Tidal/Ocean currents

The ocean current data used was obtained from the Marine Institute [35]. Their *ROMS hydrodynamic* model (Regional Ocean Modelling System) covers the study area. Details of the product are provided in Table 10 [35]. Once downloaded, the data was then processed in MATLAB to show the maximum peak current velocity (Figure 12).

Table 10. Details of tidal data downloaded.

Parameter	Description
Name	ROMS hydrodynamic model (Regional Ocean Modelling System)
Spatial Resolution	1.9 km * 1.9 km
Temporal Resolution	Hourly
Analysis Period	2020-01-01 00:00:00 to 2020-12-30 23:00:00 (1 year of data)
Underlying model/equation	Reynolds-averaged Navier–Stokes equations
Variables selected	‘uB’ (U-component barotropic velocity) and ‘vB’ (V-component barotropic velocity)

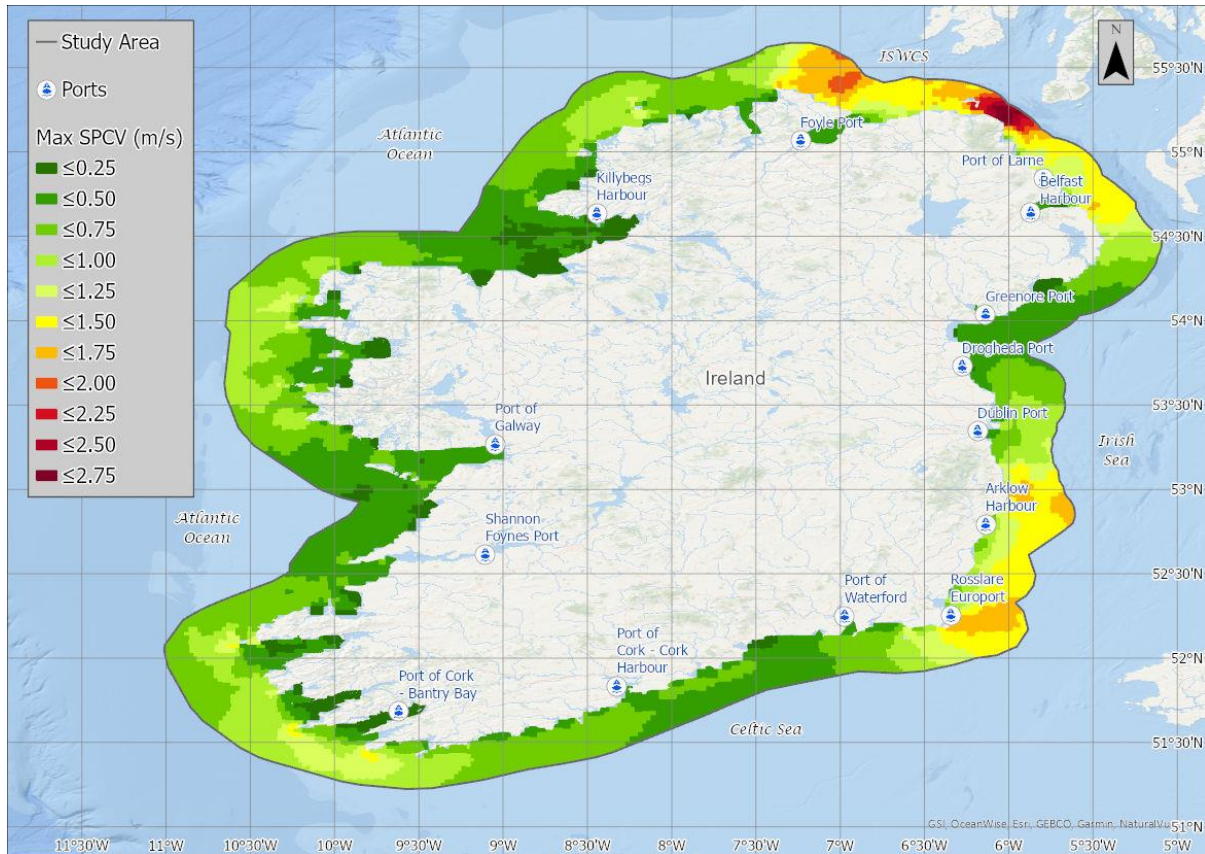


Figure 12. The max spring peak current velocity (m/s) for the study area.

4.1.1.4 High resolution modelling

The resolution of the wave and tidal hindcast products, from Copernicus and the Marine Institute respectively, were sufficient to represent the oceanographic climate for the vast majority of the study area. However, for the narrow enclosed inlets of the Shannon Estuary and Cork Harbour, a further step was needed. The wave and tidal climate data was input into a simulation using the DHI Mike-21 software. This simulation also required the bathymetric dataset and coastal/land boundaries, in order to get a higher resolution (approx. 100m) depiction of the wave and current conditions for these two enclosed areas. This is a procedure referred to as microscale modelling and was conducted in-house at MaREI. An example of extending the oceanographic models into the enclosed areas using the downscaling procedure in Mike-21 is shown in Figure 13 for the mouth of the Shannon Estuary.

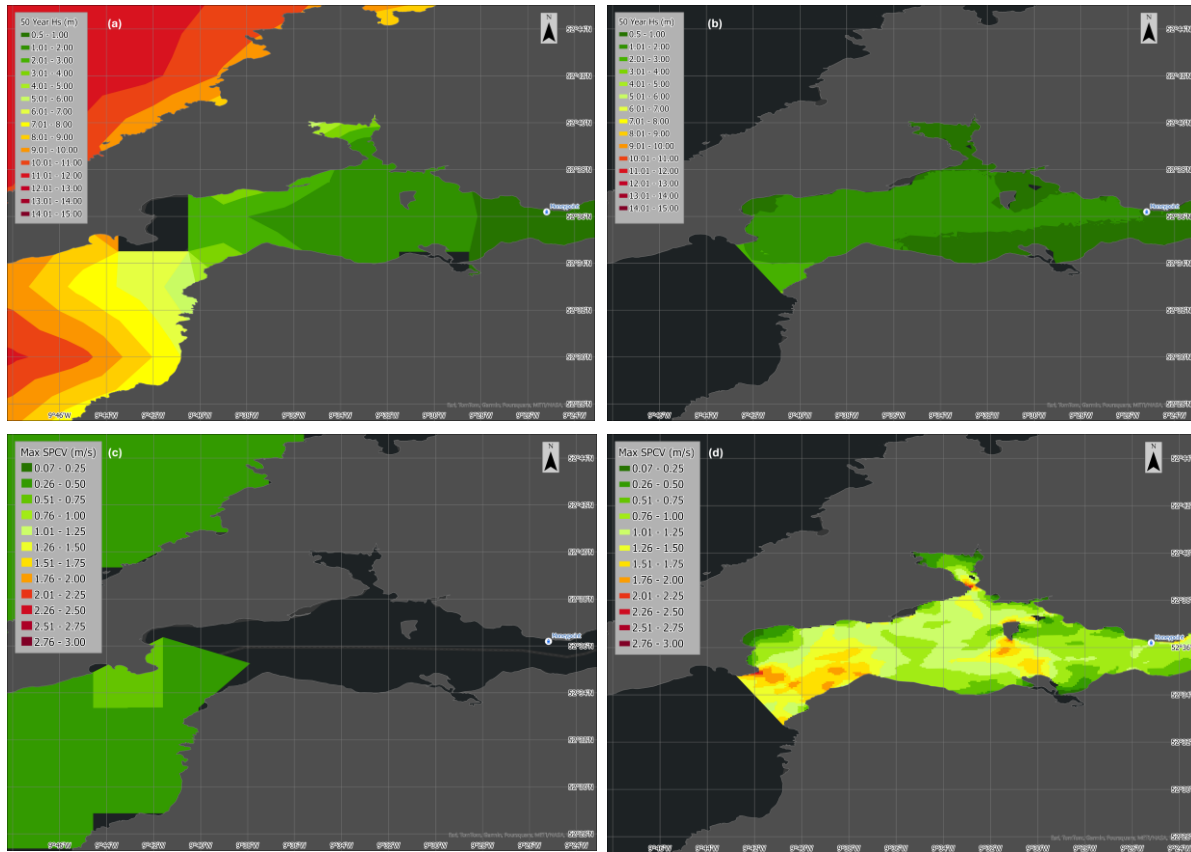


Figure 13. Results of the oceanographic modelling for wave heights (top) and current speeds (bottom) at a location close to the entrance of the Shannon Estuary for (a) the A-IBI-OWR wave model, (b) the Mike-21 extension of the wave model, (c) the ROMS current speed model and (d) the Mike-21 extension of the current speed model.

4.1.1.5 Bathymetry

Bathymetry data at a spatial resolution of approximately 10m was available for most of the study area from INFOMAR. This data covers the vast majority of Irish waters and has been generated from multibeam echosounder (MBES) technology aboard the Irish Marine Institute research vessels. It can be downloaded from the INFOMAR Marine Data Download Portal [36]. Where INFOMAR data was not available (e.g. Northern Ireland), the *harmonised EMODnet Digital Terrain Model (DTM)*, which covers the European sea regions (36°W – 43°E; 90°N – 15°N), was downloaded in raster format to fill the data gaps. The product has a spatial resolution of approximately 115m and has been generated from selected bathymetric survey data sets, composite DTMs and satellite-derived bathymetry products, whilst any data gaps are filled by integration of GEBCO Digital Bathymetry [37] [38]. The downloaded bathymetry data was then merged in ArcGIS Pro, ensuring that the higher resolution INFOMAR data was used where available with the lower resolution EMODnet data subsequently filling in any gaps (Figure 14).

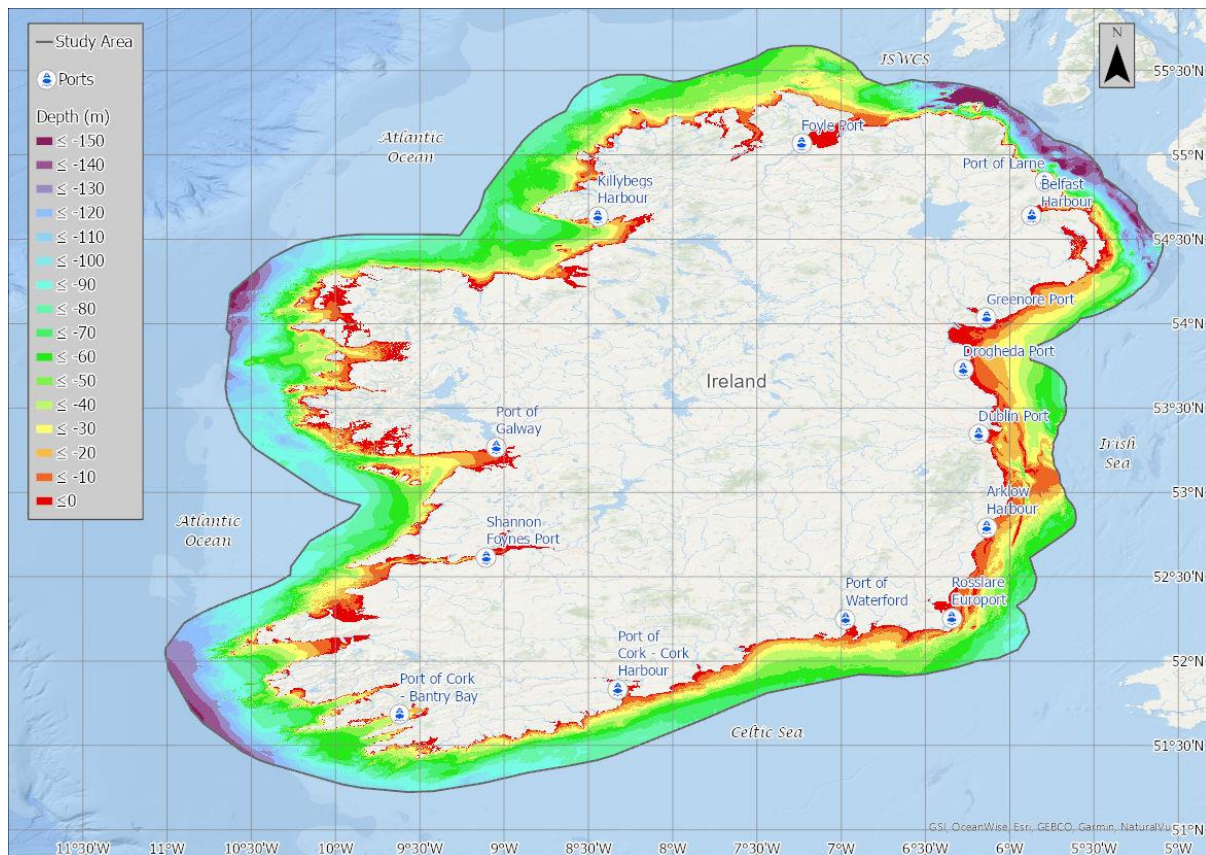


Figure 14. The water depth (m) for the study area.

4.1.1.6 Seabed characteristics

EMODnet also provide seabed substrate data products for the European sea regions comprising multiple datasets at various scales and confidence levels [39]. For the study area, much of this data is in fact produced by the aforementioned INFOMAR project and made available via the EMODnet Map Viewer [40]. Some parts of the study area, including NI waters and waters off the west coast of Connemara and southwest Mayo, have no seabed substrate data (Figure 15). With areas of no data excluded, the classification system used for mapping the seabed substrate data was the 5-point Folk grain size classification (Folk-5 Scale). This classification system divides the various seabed substrate types into the categories shown in Table 11, the geospatial output of which is represented in Figure 15.

Table 11. Details of Folk-5 seabed classification system.

Folk-5 Class	Description
Rock	Gravel $\geq 80\%$ (or Gravel $\geq 5\%$ and Sand $\geq 90\%$)
Coarse Sediment	Mud $95 - 10\%$; Sand $< 90\%$; Gravel $\geq 5\%$
Mixed Sediment	Mud $\geq 100 - 10\%$; Sand $< 90\%$; Gravel $< 5\%$
Mud to muddy Sand	Mud $\geq 100 - 10\%$; Sand $< 90\%$; Gravel $< 5\%$
Sand	Mud $< 10\%$; Sand $\geq 90\%$; Gravel $< 5\%$

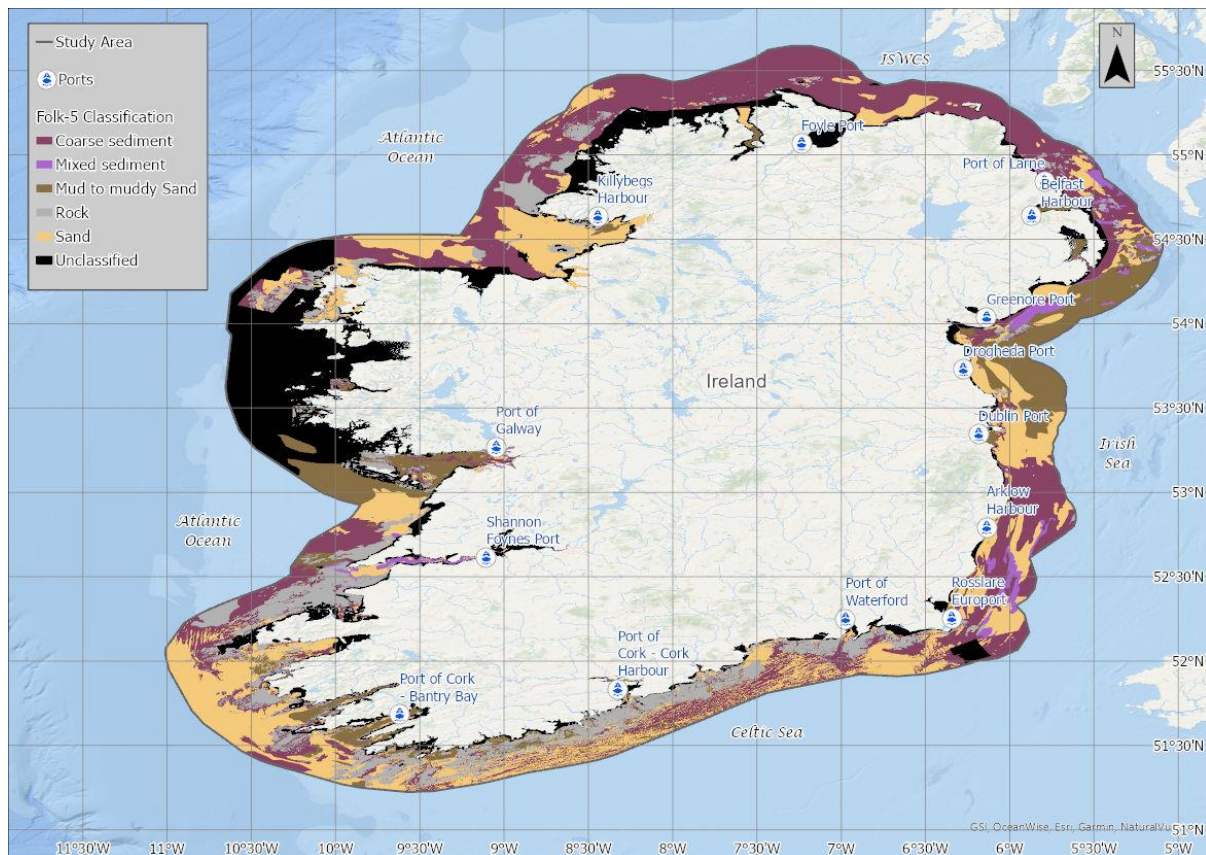


Figure 15. The Folk-5 seabed classification of the study area.

4.1.1.7 Charts

Each port area has a navigational channel which is essentially a safe route for vessels to navigate when entering and exiting the port. These channels are marked by the lateral system of buoyage which comprise navigational aids used to guide ships at sea and in harbour. In Ireland (north and south), responsibility for these aids to navigation lies with the Commissioners of Irish Lights under the Safety of Life at Sea (SOLAS) Convention [41]. The location and character of these navigational aids is marked on Admiralty charts, issued by the United Kingdom Hydrographic Office (UKHO) [42]. Using this chart data to obtain the position of the lateral buoys, the navigational channel was then digitised in ArcGIS Pro, as shown for Belfast Harbour as an example in Figure 16. The chart data also marks the geographical position and extent of designated anchorage areas, designated moorings, restricted areas (e.g. for military purposes or subsea cable/pipeline protection) and port jurisdiction areas (PJAs), all of which are relevant and were considered in the analysis.

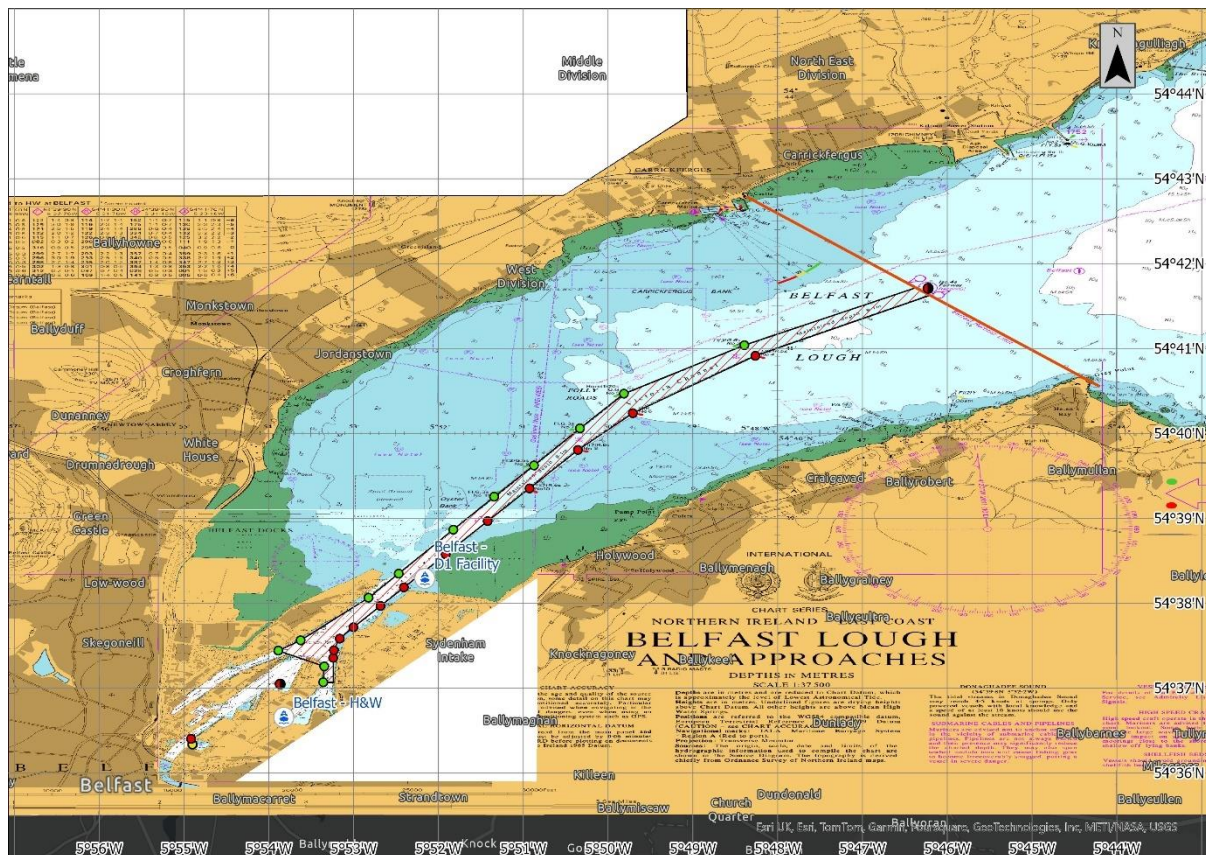


Figure 16. Belfast Harbour with lateral buoyage marking the navigational channel.

4.1.1.8 Traffic Separation Schemes (TSS)

Further out to sea, TSS act as corridors for large ships (similar to motorways for road vehicles). They are defined by the International Maritime Office (IMO) and are policed at a local level by the Coast Guard. Strict adherence to these is required by larger vessels, but freedom of movement is permitted between them (i.e. from one to the next). As open-access TSS data could not be found, it was created in ArcGIS Pro using Admiralty chart data and then clipped to the extent of the study area (Figure 17).

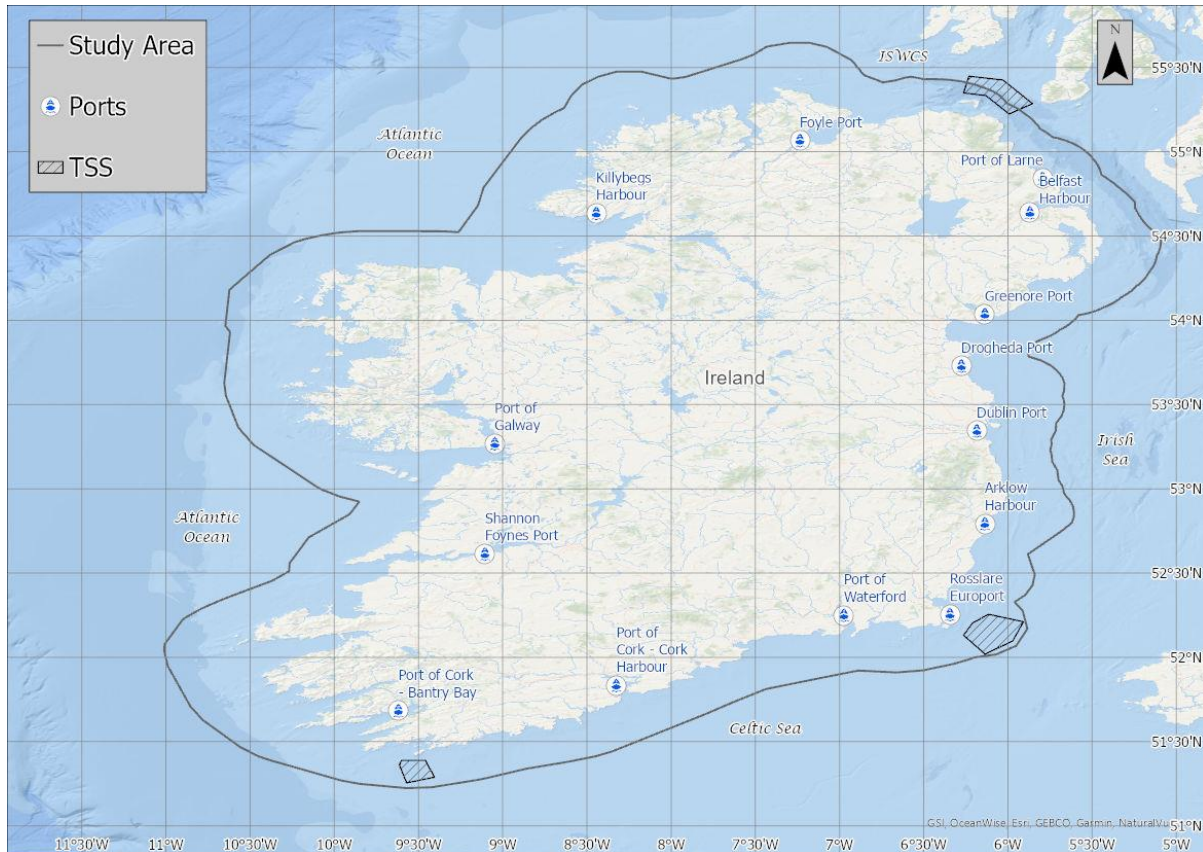


Figure 17. Traffic Separation Schemes (TSS) within the study area.

4.1.1.9 Prospective sites for ORE

In Ireland, the evolution of a plan-led development and consenting process for the Maritime area is ongoing, and this has significant consequences for the development of the ORE sector. There is currently only one operational ORE project – Arklow Bank 1 on the east coast. This project was developed in the early 2000s, subject of consents secured under the Foreshore Acts. As of 2025, Maritime Area Consents have been granted for six projects enabling developers to secure non-exclusive rights to occupy the maritime area and submit planning applications. Of these six projects, five are located off the east coast – Arklow Bank 2, Codling Wind Park, Dublin Array, the North Irish Sea Array and the Oriel Wind Farm. The sixth was to be sited off the west coast but has since been withdrawn – Sceirde Rocks off Connemara. The locations have not been subject of a relevant designation but are proceeding into planning as developer-led projects. Four of these projects were successful in securing a route to market via the ORESS 1 process [43]. The State’s first plan-led maritime development process, culminated in the adoption of the South Coast Designated Maritime Area Plan (SC-DMAP) in October 2024. This plan identifies and designates four sites for the development of offshore wind off the south coast, exclusively utilising fixed bottom wind energy technology. The geospatial data for each of these sites is available via Ireland’s Marine Institute [44] and the 4C Offshore Mapping Service [45]. Additional areas have been designated for testing ORE devices in Ireland, including Galway Bay ¼

Scale Test Site and the Atlantic Marine Energy Test Site in Mayo. Geospatial data for these sites is available via Ireland's Marine Renewable Energy Atlas [46].

4.1.1.10 Subsea cables and pipelines

Kingfisher Information Service - Offshore Renewable & Cable Awareness (KIS-ORCA) maintain an online database of cable routes for northwestern Europe [47]. From their downloads page, GIS data on this can be obtained. However, some smaller cable routes and routes of subsea pipelines (oil and gas) are not included in this dataset. These needed to be extracted from the aforementioned Admiralty chart data following the same procedure used for the creation of the TSS data, the output of which is shown in Figure 18. A 500m buffer was inserted around these cables and pipeline routes which was set as a hard constraint (exclusion zone) in the site selection analysis.

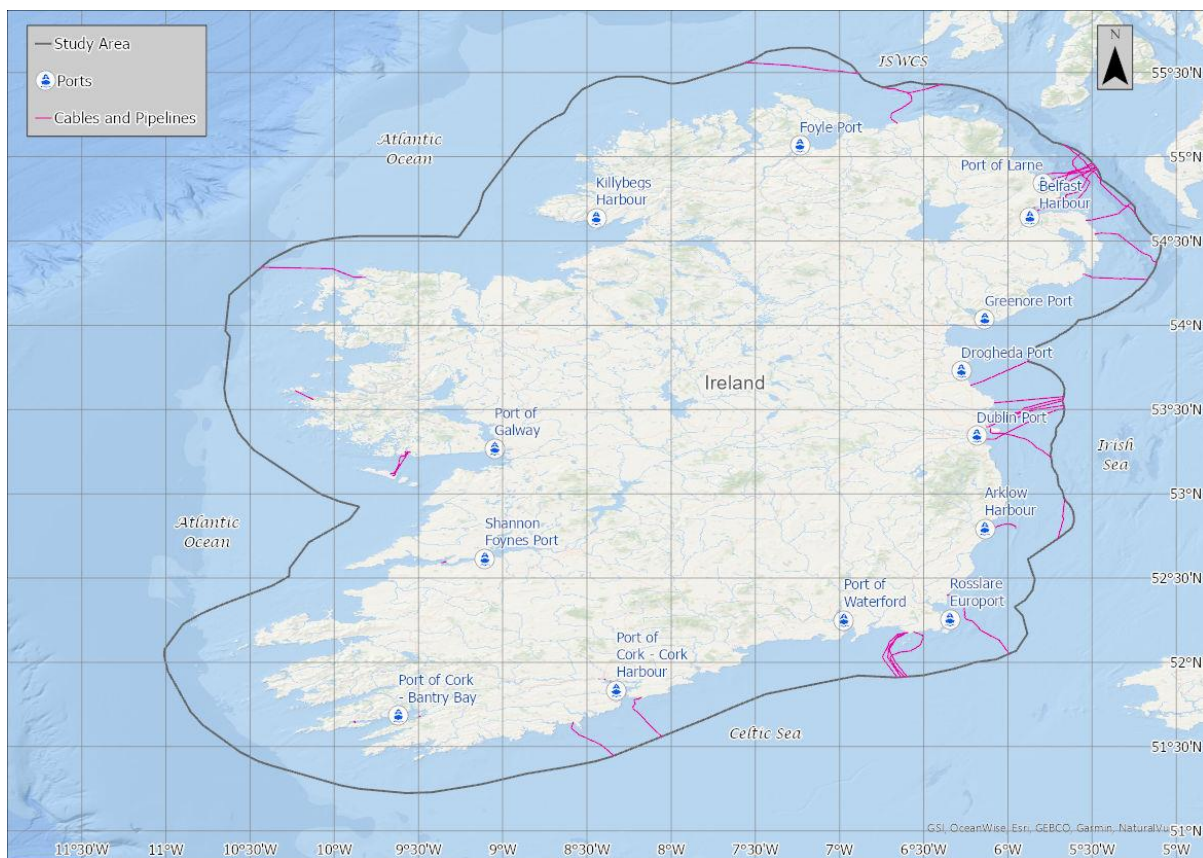


Figure 18. Cable and pipeline routes within the study area.

4.1.1.11 Aquaculture sites

Data for aquaculture sites designated for shellfish, finfish and seaweed harvesting was obtained in GIS shapefile format. The data for ROI was sourced from the Department of Agriculture Food and Marine (DAFM) through Ireland's Open Data Portal [48]. Data for NI is from the Department of Agriculture and Rural Development under the Fisheries Act (Northern Ireland) and was downloaded via the UK's Open Data Portal [49]. Figure 19 illustrates the aquaculture site locations.

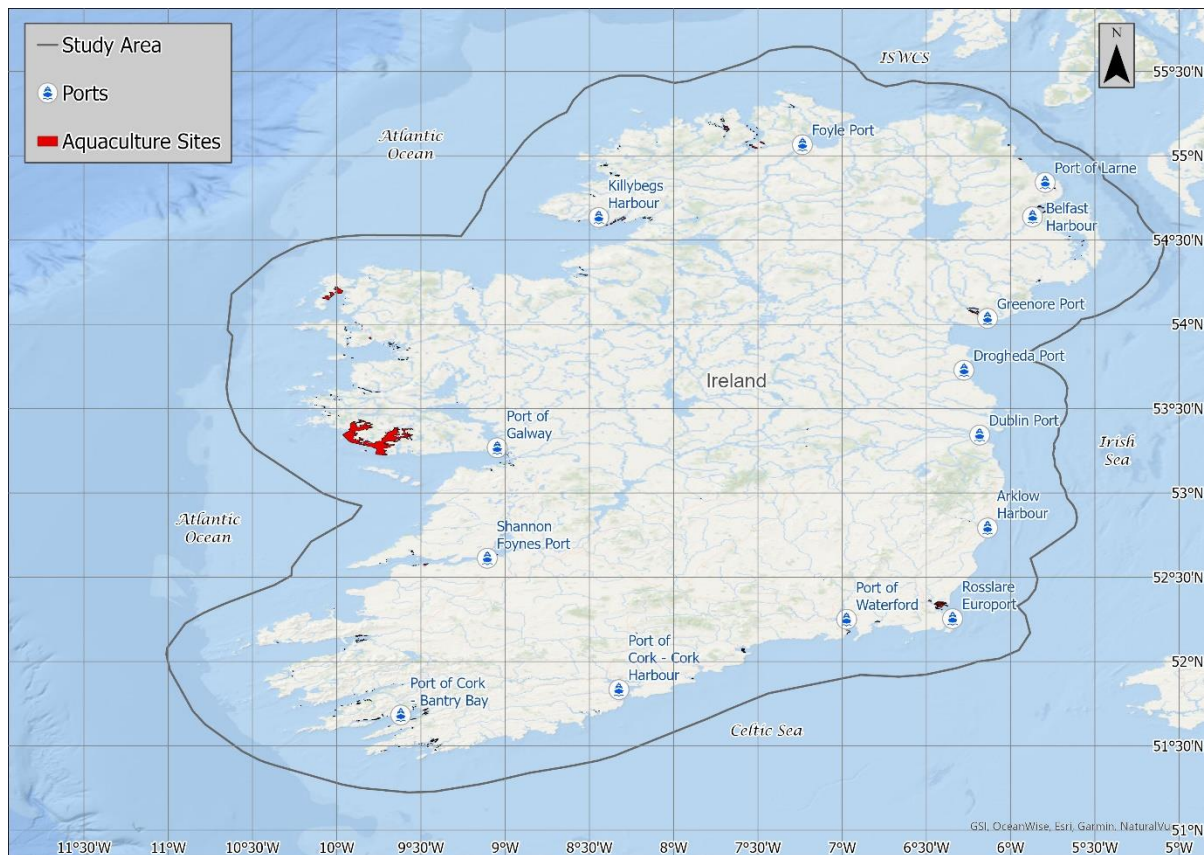


Figure 19. Aquaculture sites within the study area.

4.1.2 MCDA – model

With all of the data gathered and processed, the final step involved in the geospatial analysis was to filter out the areas of potential, based on their geospatial attributes. This is a procedure referred to as Multi-Criteria Decision Analysis (MCDA), or sieve-mapping in GIS terminology, where areas not meeting specifically defined criteria are removed from further consideration and all remaining areas go on to the next stage of analysis to meet additional decision nodes. This subsequently brings focus to individual sites/areas which meet all pre-defined suitability criteria and are thus deemed to have potential for wet storage designation subject to further planning and environmental considerations. The screening criteria considered apposite to the appropriate selection of wet storage sites, as agreed by the project partners, is summarised in Table 12. A simplified illustration of the associated methodology flow is shown in Figure 20. The MCDA model was run at different depth thresholds from the minimums in order to show where deeper waters were available within the areas of potential, as deeper waters are more desirable for layout and mooring optimisation (detailed in Section 5).

Table 12. Wet storage site suitability criteria.

Parameter	Value/attribute
50-year return significant wave height (H_s)	$\leq 2\text{m}$ (FIU), $\leq 8\text{m}$ (FSS)
50-year wind speed	$\leq 30\text{ m/s}$ (FIU), No limit (FSS)
Surface current (max spring peak velocity)	$\leq 2\text{ m/s}$
Water depth	$> 13\text{m LAT}$ (FIU), $> 5\text{m LAT}$ (FSS)
Seabed character (Folk-5)	$\neq$ 'Rock or other hard substrata'
Port jurisdiction area	Within (FIU), N/A (FSS)
Aquaculture sites	Not within
Traffic Separation Scheme (TSS)	Not within
Navigational channel	Not within
Designated MRE test sites	Not within
Offshore wind sites (ORESS 1)	Not within
DMAP deployment sites (A-D)	Not within
Designated mooring areas	Not within
Designated anchorage areas	Not within (Shannon), N/A (other ports)*
Restricted areas	Not within
Subsea cable and pipeline infrastructure	Not within 500m buffer

*As per meetings held with representatives of the relevant port authorities on a case-by-case basis regarding exclusion (on/off).

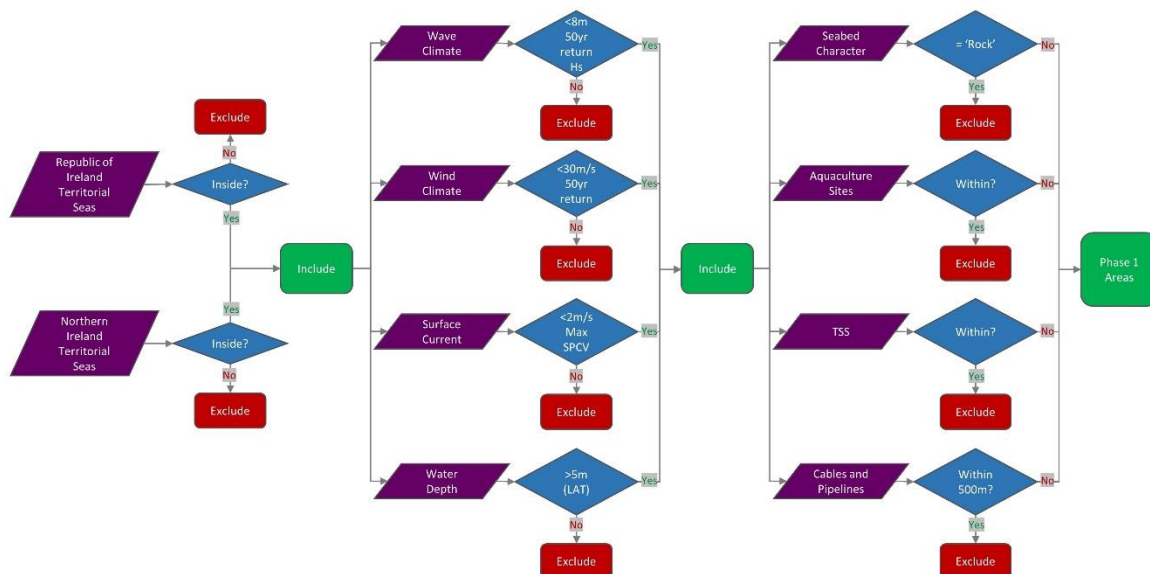


Figure 20. Generalised methodology flow for identifying areas in the study.

4.1.3 Planning and environmental considerations (ROI only)

It is noted above that in the Republic of Ireland (ROI), the transition to a plan-based system for the management and consenting of development in the maritime area is now in place. In parallel, additional environmental designations, specifically Marine Protected Areas (MPAs), are being identified. In

general terms, these will be geographically defined maritime areas that provide levels of protection to achieve conservation objectives. They are understood to be planned for identification in 2026.

The appropriate statutory tool to guide development in the maritime area, DMAPs, will be drafted and adopted in-line with the relevant provisions in the Maritime Area Planning Act, 2021 (as amended), on a prioritised geographical basis. One such plan that has been adopted to date is the aforementioned SC-DMAP, and this is exclusively a plan for fixed bottom, offshore wind energy projects.

DMAPs will typically be multi-sectoral. As per guidance provided by DECC within the SC-DMAP, they will be drafted in accordance with an ecosystem based approach. In the drafting of a DMAP, environmental constraints are identified and mapped, and data analysed from environmental, economic and social activities, to assess the interactions and impacts between the new offshore wind development and associated infrastructure and activities. This enables the impacts on the marine environment to be considered. As such, the preferred locations for development are identified and designated, with an appropriately detailed policy framework.

The range of factors and constraints that will inform the suitability of sites for development will differ for each maritime area, but the following commentary relates to the key considerations addressed in this study, notably the location and extent of areas protected to conserve habitats or species, identified landscape/seascape character areas and identified areas of inshore fishing activity.

4.1.3.1 European sites

Under the Birds Directive (2009/147/EC) and the Habitats Directive (92/43/EEC), EU Member States must identify and designate specific terrestrial and marine sites for protection and appropriate management. The ‘Natura 2000 network’ comprises Special Protected Areas (SPAs), protected habitats for bird species, and Special Areas of Conservation (SACs), protected habitats and other species of EU conservation concern. These are collectively referred to as ‘European Sites’.

While it is possible to develop a maritime project within, or proximate to, a European site, it requires careful consideration, thorough supporting assessments and demonstrable compliance with the aforementioned directives to ensure the integrity of those sites, habitats and the protected species are protected, and ideally enhanced. Under the Habitats Directive, ‘Appropriate Assessment’ is the means by which the potential impacts of any project on the conservation objectives of a site are assessed, and there is a general obligation on Consenting Authorities not to permit projects which would give rise to negative impacts, save in exceptional circumstances, per Article 6.4 of the directive. As such, the location and extent of such protected sites is not included as a ‘hard constraint’, i.e. an exclusion factor, but rather identified here so the presence of a site within, or proximate to, a potential development site, and the impacts that may arise, can be considered.

To that end, the data for Irish waters has been obtained from Ireland's Open Data Portal [50] and the data for NI waters has been obtained from the Joint Nature Conservation Committee (JNCC) [51].

4.1.3.2 Landscape Character Assessment (LCA) areas

Given the scale of a typical wet storage project (noted per Table 7) and its nature, namely a designated area of open sea containing structures up to 300m tall, at a location that is, by necessity, relatively close to shore; the potential impact of a project on landscape and seascape has been factored into the identification of potential sites. Given the generalised nature of the site identification process and the subjectivity of landscape assessment, this has been included as a consideration rather than a hard constraint, with a reliance on prevailing public policies as a measure of subjective landscape value and sensitivity. For objectivity then, the relative character or value of a landscape or seascape has been determined based on those classifications set out in statutory documents, such as development plans.

In respect of the onshore areas, each planning authority, in preparing its respective development plan, prepares a Landscape Character Assessment (LCA) – which identifies distinct geographical regions based on their unique landscape features, characteristics and qualities. The statutory assessment process considers factors such as topography, land use, vegetation, historical/cultural elements and visual qualities. The LCAs are incorporated into the development plan and are used to inform planning and development policies to ensure that landscape considerations are integrated into the planning process and decision making. These also form the basis for some spatial plans such as wind energy strategies, where landscape value informs the identification of areas deemed suited, or not suited, to wind energy developments.

The associated geographic data for the LCAs is held by the local authority concerned and may be available upon request or via Ireland's Open Data Portal [52] for the Republic of Ireland and Open Data NI [53] for Northern Ireland.

4.1.3.3 Seascape Character Assessment (SCA) areas

Similar to LCAs, Seascape Character Assessment (SCA) areas are designated regions characterised by their distinct coastal and marine features. SCAs focus on the physical, ecological, visual and cultural attributes of a specific area of the coastal environment. The information gathered from SCAs can inform coastal/marine planning and development policies, helping to ensure that the unique qualities of the seascape are protected in the face of development pressures and climate change.

The Regional Seascape Character Assessment for Ireland was prepared by the Marine Institute and identifies the Regional Seascape Character Areas for the entire ROI coast. SCA GIS data for ROI is held by the Marine Institute and is available via Ireland's Marine Atlas [54]. SCA GIS data for NI is held by the Department of Agriculture, Environment and Rural Affairs and is available via their website [55].

4.1.3.4 *Corine land cover*

The Corine Land Cover (CLC) Classification System is a European initiative aimed at providing a comprehensive and standardised assessment of land cover across Europe, including Ireland. Established by the European Environment Agency, it categorises land cover into various classes based on satellite imagery, facilitating the analysis of environmental changes, land use, and ecological monitoring. In Ireland, the CLC serves as a vital tool for policymakers, researchers, and environmentalists to understand land use patterns, track habitat changes, and support sustainable development initiatives. The classification helps in assessing environmental impact, managing natural resources, and planning for future land use by providing detailed, up-to-date information on the extent and type of land cover across the country. CLC GIS data for Ireland is available via Ireland's Open Data Portal [50].

4.1.3.5 *Inshore fisheries*

Data on inshore fisheries was obtained via Ireland's Marine Renewable Energy Atlas [46]. This source separates inshore fisheries data into dredge fishing, line fishing, nets fishing, bottom trawl fishing and midwater trawling. The datasets were created in support of the Natura 2000 risk assessment in 2013. Only the fishing activity of vessels <15 metres in length (i.e. the inshore fleet) is represented, which was more relevant to this study due to the nearshore focus. Fishing vessels of this size are not normally equipped with AIS transponders (contrary to the larger offshore pelagic fishing fleet). More information on the data can be found on the Irish Spatial Data Exchange website [56].

4.1.4 *Stakeholder engagement*

A comprehensive stakeholder engagement process was conducted to ensure that the study was grounded in practical, regulatory, and societal perspectives. The primary objective was to identify key opportunities, risks, and requirements that could impact the implementation of wet storage for FLOW.

Stakeholders were strategically selected from key sectors, including port authorities, regulatory authorities, representative groups, safety bodies, industry, insurance and local government. Engagement methods were tailored to facilitate effective dialogue. In-person or online engagements were offered to each stakeholder. In instances where neither of these methods was convenient, a telephone call or email exchange took place. The primary methods used were online and in-person meetings, which generally facilitated efficient and insightful discussions regarding future wet storage in Ireland.

Some of these engagements, particularly those with the port authorities relating to site-specific issues, informed the direction of the site suitability analysis for the respective area (in terms of perspectives regarding criteria such as anchorage areas – i.e. as a constraint or opportunity). Others were carried out primarily to inform the relevant stakeholder of the nature of the study, potential implications and results of the site suitability analysis. The complete list of stakeholders engaged with is summarised in Table 13. Points raised during feedback from these stakeholders is summarised below in Section 4.2.

Table 13. Wet storage project stakeholders.

Name	Area of interest	Method of engagement
Offshore Solutions Group	Ports	Online meeting
AirNav	Safety	Online meeting
IAA	Safety	Email exchange
DAFM	Fisheries	Phone call
WaveVenture	Ports	Online meeting
MMCC Port Marine	Ports	In-person meeting
Shannon Foynes Port Company	Ports	In-person meeting
Belfast Harbour Commissioners	Ports	Online meeting
Port of Cork	Ports	Online meeting
Port of Galway	Ports	In-person meeting
AON	Risk	Online meeting
WEI FLOW Committee	Industry	Online meeting
Marine Survey Office	Governance/Ports	
ORE Ports Facilitation Division	Ports/Industry	Online meeting
ESB	Industry	In-person/online meeting
Venterra Group	Research/Industry	In-person/online meeting
MARA	Governance	Online meeting
MRIA	Industry	Online meeting
CIL	Safety	Online meeting
IRCG	Safety/Environment	Online meeting
Marine Institute	Research	Email exchange
Clare County Council	Governance	In-person meeting*
Limerick City and County Council	Governance	In-person meeting*
Kerry County Council	Governance	In-person meeting*

*Met collectively in-person as part of a Strategic Integrated Framework Plan for the Shannon Estuary steering group meeting.

4.2 Results and discussion

As the criteria for running the fully integrated unit (FIU) scenario were more restrictive (in terms of depth and met-ocean conditions), an area deemed unsuitable for floating support structure (FSS) wet storage, is not going to be suitable for FIU wet storage. With this considered, if the conditions at a particular port area are not suitable for FIU wet storage, then it is questionable whether or not project deployment can take place from that port (since it is anticipated that both FIU and FSS wet storage will be required). Therefore, the following section details only the results of running the GIS model for the FIU scenario. Nevertheless, results of running the model for the stand-alone FSS scenario can be found in Appendix A, where additional areas of potential to those discussed below include Galway Bay and Killybegs Harbour.

4.2.1 Potential areas for wet storage

Three notable areas meet the criteria for potential sites capable of accommodating significant wet storage of FIUs. These are the Shannon Estuary in the mid-west, Bantry Bay in the southwest and Belfast Harbour in the northeast (Figure 21). Limited areas for FIU wet storage are available in Lough Foyle (north), while in Cork Harbour (south), potential is very limited. Details for each location are provided in the following sub-sections.

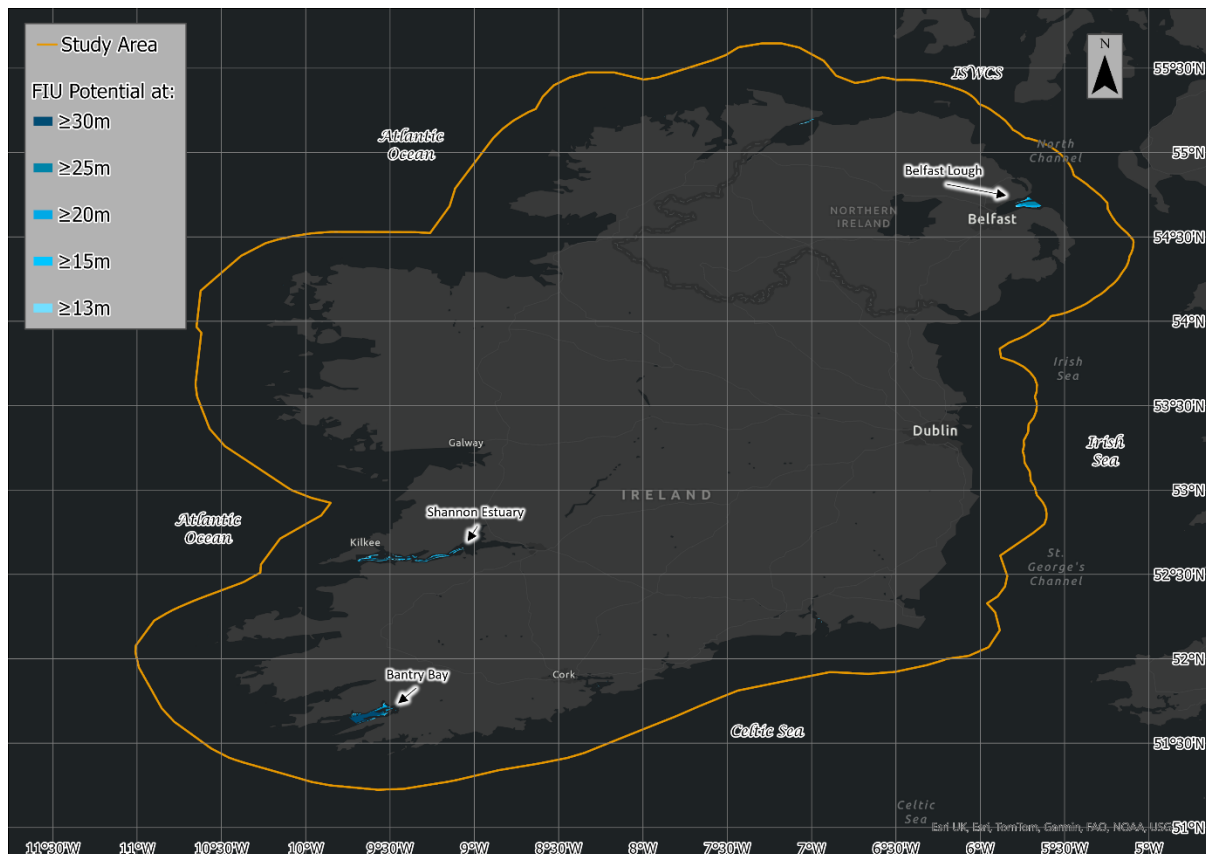


Figure 21. FIU wet storage suitability for the study area.

4.2.1.1 Shannon Estuary

The Shannon Estuary, under the authority of Shannon Foynes Port Company is the only PJA (Port Jurisdiction Area) in the midwest of Ireland. As the results of the geospatial modelling show (Figure 22), it is also a location which offers extensive suitability for FIU wet storage. The Shannon PJA extends from Limerick City west to a line running between Loop Head and Kerry Head. Within this PJA, the <2m 50 yr Hs threshold is met just inside Kildcredaun Point (Co. Clare), east of which there is vast potential for FIU wet storage. This includes areas surrounding Foynes Island (Figure 22a) and Moneypoint Power Station (Figure 22b), two locations expected to play a key role in the development of FLOW in the future. The effect of excluding Shannon's designated anchorage areas is significant and clearly evident south and southwest of Kilrush. Other notable exclusions are those areas associated with the existing and proposed cross-river cables just east of Moneypoint. Furthermore, the proximity of

Shannon Airport to the Shannon Estuary (Figure 22) will warrant thorough consultation with the relevant aviation authority to ensure compliance with the Shannon Airport Safeguarding Zone (see Section 4.2.4). The total theoretical area of availability for FIU wet storage in the Shannon Estuary is 3,529Ha, as shown in Table 14.

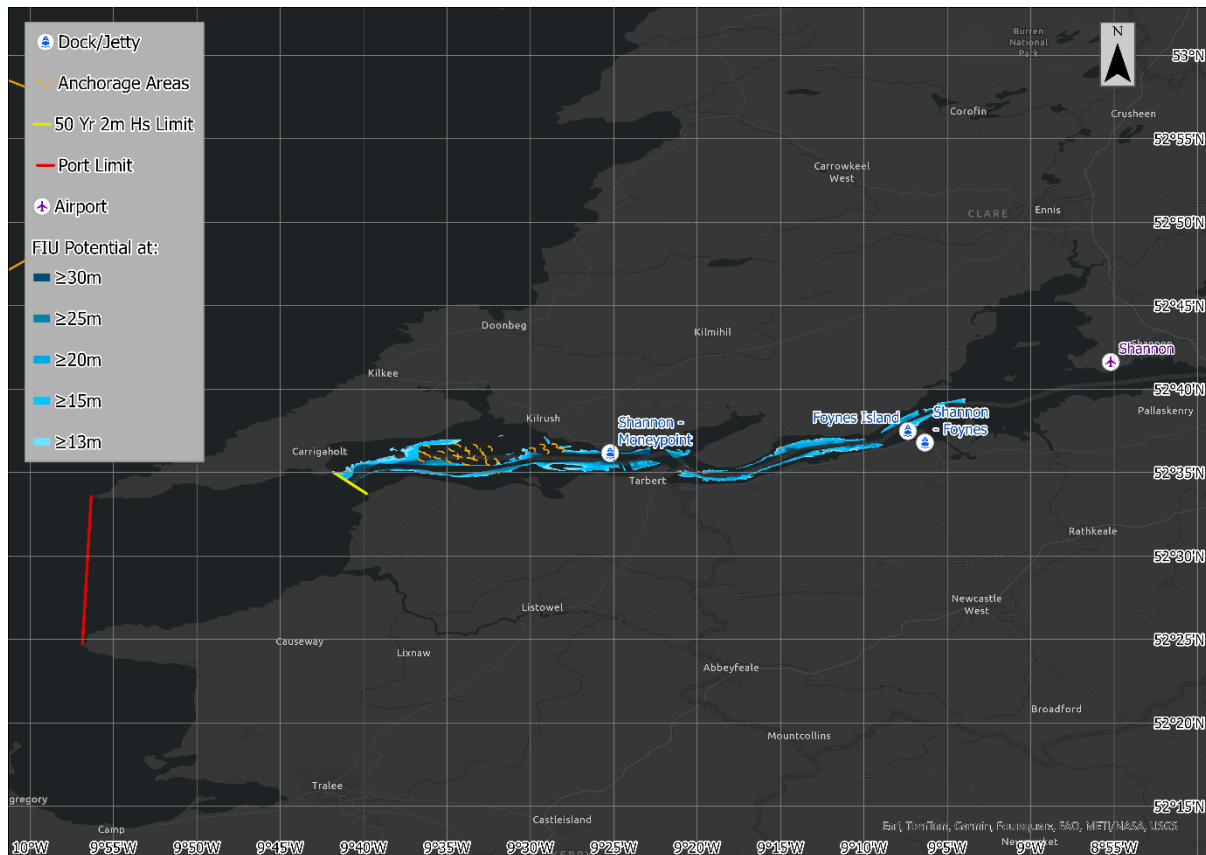


Figure 22. FIU wet storage suitability in the Shannon Estuary.

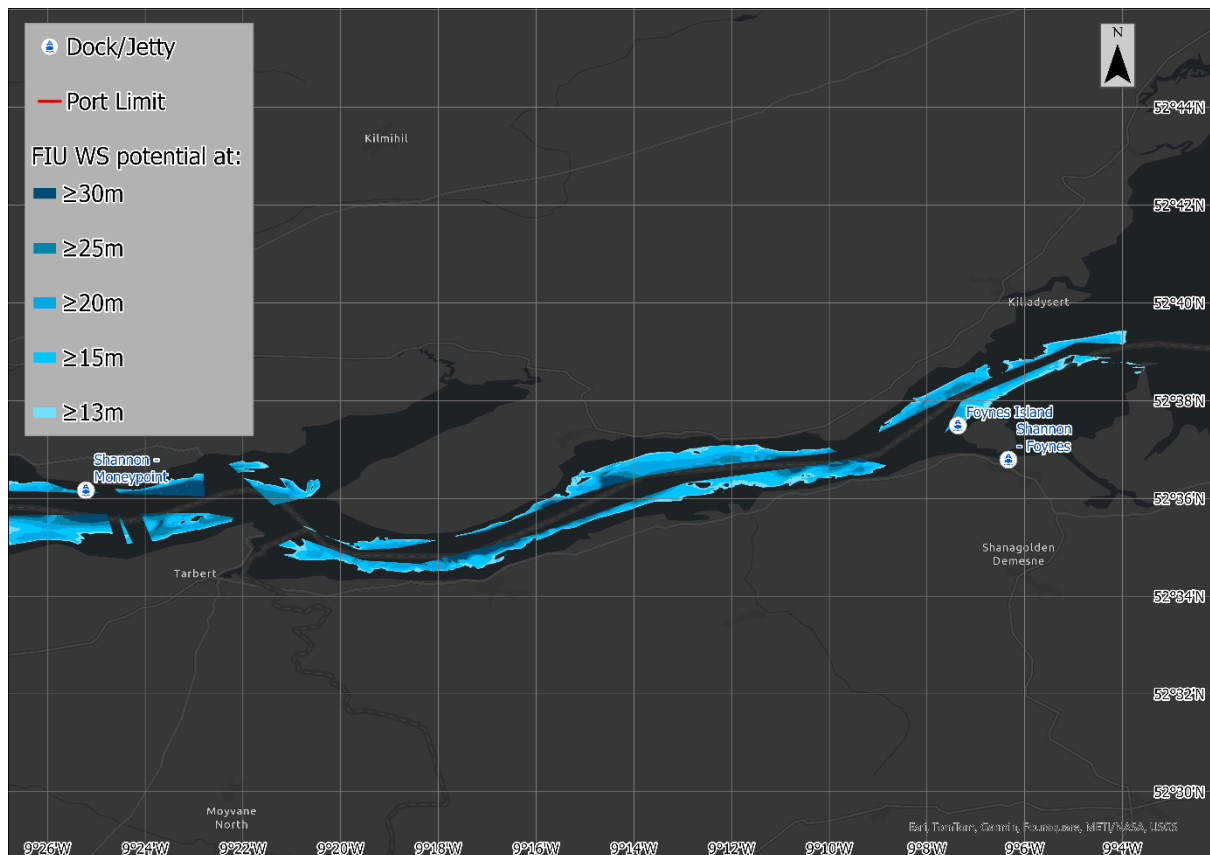


Figure 22a. FIU wet storage suitability in the upper Shannon Estuary.

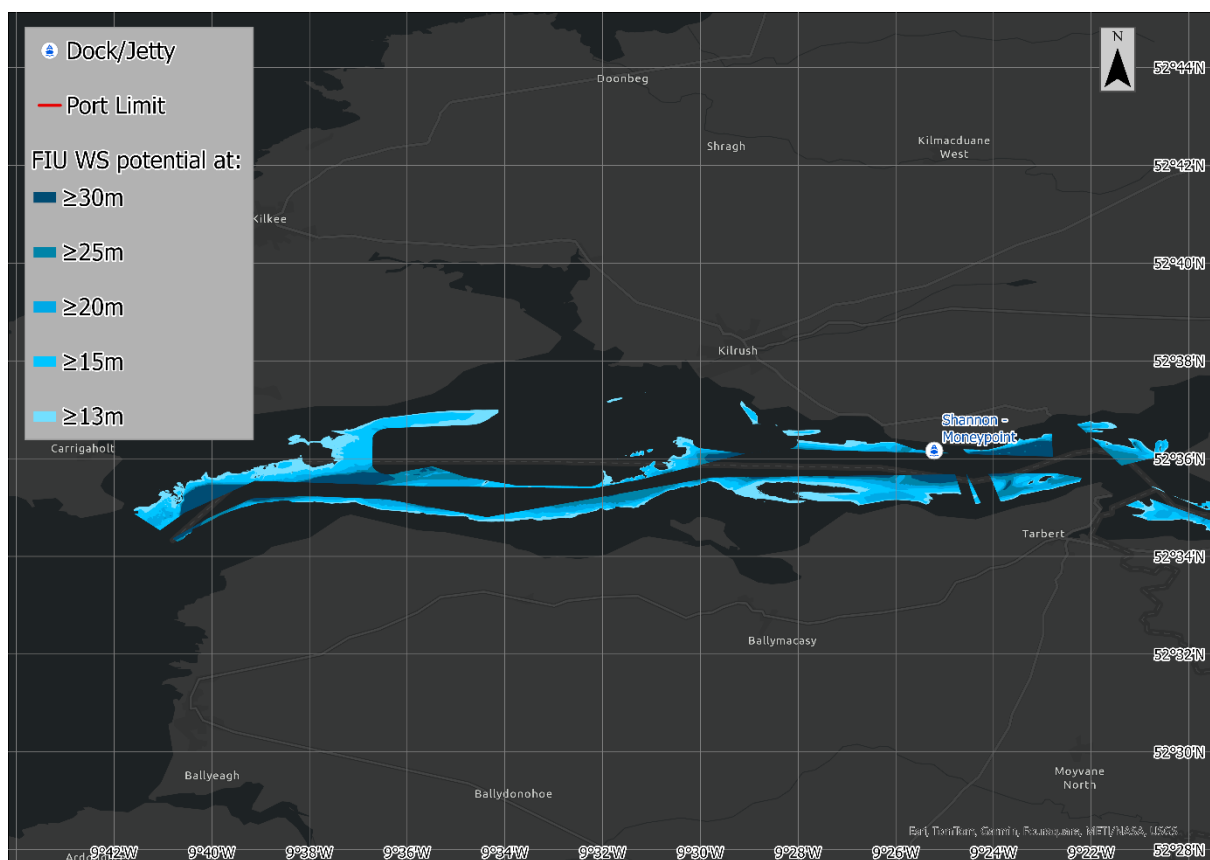


Figure 22b. FIU wet storage suitability in the lower Shannon Estuary.

Table 14. Wet storage particulars for the Shannon Estuary.

FIU wet storage: Shannon Estuary	
Wet storage potential	Extensive
Wet storage area theoretically available	3,529Ha
Designated anchorage areas	Excluded
Within 30km of Airport*	Partially
Within SAC (at potential area)	Yes
Within SPA (at potential area)	Yes
Access channel min. width (at 13m min. depth)	320m
Other constraints	N/A

*See Section 4.2.4 – Stakeholder considerations.

4.2.1.2 Bantry Bay

The only major PJA (Port Jurisdiction Area) in the southwest of Ireland is that of Bantry Bay, which falls under the authority of the Port of Cork. The Bantry Bay PJA extends from the town of Bantry west to a line running from Crow Head on the north side of the bay to Sheep's Head on the south side. It is apparent from the results of running the model at this location that there is vast potential for the wet storage of Fully Integrated Units (FIUs) in the more sheltered eastern segment of the bay (Figure 23). The results show that the 2m 50 yr Hs threshold is being met approximately halfway up the bay due south of Adrigole Harbour. There appears to be significant potential for FIU wet storage exceeding 30m water depth surrounding Leahill Jetty on the northside of the bay, a location of key interest to serve as a facility for the development of floating offshore wind. The effect of the navigational channel exclusion is apparent in the east of the bay near Whiddy Island Jetty. The effect of excluding areas of exposed bedrock ('rock or other hard substrata' as per the Folk-5 scale) is clear along the north coast of the Sheep's Head Peninsula and south of Adrigole Harbour. Designated anchorage areas were not excluded for Bantry Bay, with POC indicating that partial use of these designated areas for wet storage could be considered. The total theoretically available area for FIU wet storage in Bantry Bay is 5,540Ha (Table 15).

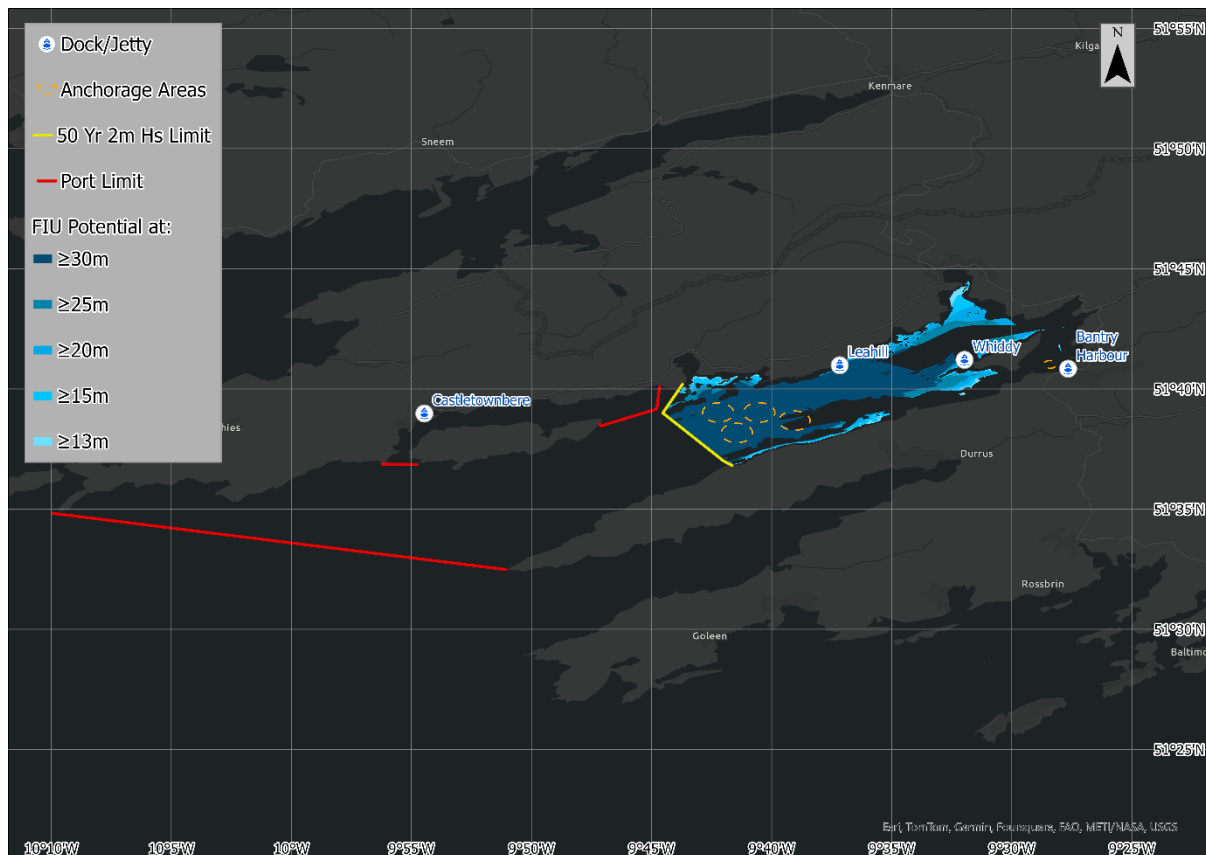


Figure 23. FIU wet storage suitability in Bantry Bay.

Table 15. Wet storage particulars for Bantry Bay.

FIU wet storage: Bantry Bay	
Wet storage potential	Extensive
Wet storage area theoretically available	5,540Ha
Designated anchorage areas	Included
Within 30km of Airport*	No
Within SAC (at potential area)	No
Within SPA (at potential area)	No
Access channel min. width (at 13m min. depth)	4.7km
Other constraints	Inshore fishing, visually sensitive area

*See Section 4.2.4 – Stakeholder considerations.

4.2.1.3 Belfast Lough

Belfast Harbour is the major PJA in the northeast of Ireland. It extends from the city of Belfast east to a line running from Carrickfergus Castle (Co. Antrim) south to Grey Point (Co. Down) and falls under the jurisdiction of the Belfast Harbour Commissioners, an authority which have considerable plans for port development in support of both the fixed and floating offshore wind sectors. The results for running the GIS model at Belfast are shown in Figure 24. Belfast Harbour's PJA is limited in comparison to many, so wet storage is being considered outside their designated PJA, a reasonable consideration given

the shelter that the lough provides, with the modelled 2m 50 Yr Hs limit not being reached until >5km east of the PJA's outer extent at the mouth of the lough. Furthermore, due to the immediate proximity of Belfast City Airport to the port, FIU wet storage further east in the lough outside this designated PJA may well be the only option at Belfast due to the potential interference with flight paths. Consultation with the relevant aviation authority would be required in any case as the entire lough falls within 30km of Belfast City Airport. The total area theoretically available for FIU wet storage inside the PJA is 334Ha (Table 16).

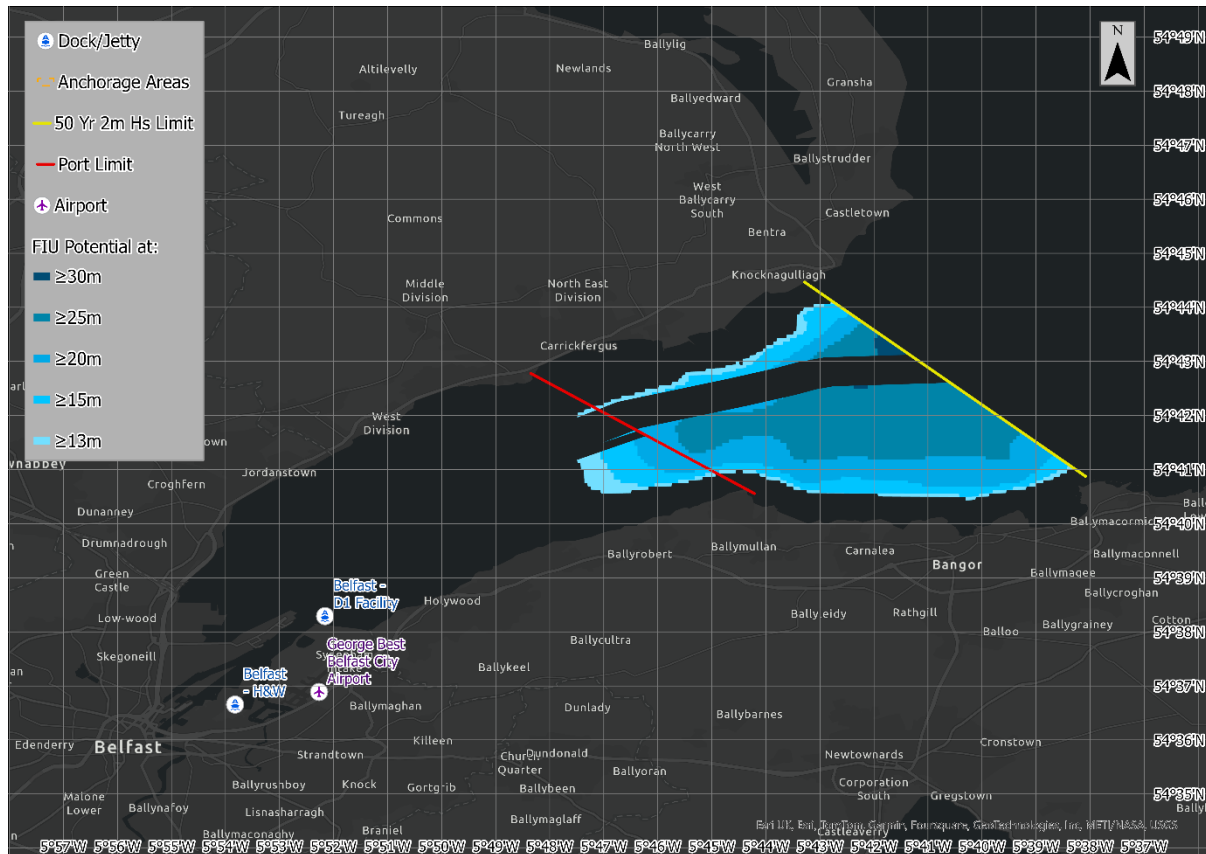


Figure 24. FIU wet storage suitability in Belfast Lough.

Table 16. Wet storage particulars for Belfast Lough.

FIU wet storage: Belfast Lough	
Wet storage potential	Limited inside PJA, significant outside PJA
Wet storage area theoretically available	334Ha (inside PJA), 2,697Ha (outside PJA)
Designated anchorage areas	N/A
Within 30km of Airport*	Yes
Within SAC (at potential area)	No
Within SPA (at potential area)	Partially
Access channel min. width (at 13m min. depth)	7.43km
Other constraints	Air draft a major concern, particularly inside PJA

*See Section 4.2.4 – Stakeholder considerations.

4.2.1.4 Lough Foyle

The Foyle Port PJA extends from the City of Derry northeast to a line running between Greencastle (Co. Donegal) and Magilligan Point (Co. Derry) at the mouth of the lough (Figure 25). The location offers suitable shelter, with the <2m 50 yr Hs threshold being just inside the PJA's outer limits. Depth is the primary constraint for FIU wet storage in Lough Foyle. However, a limited area of potential appears to be available just inside the port entrance close to the mouth of the lough, i.e. where there is both adequate shelter and depth outside of the navigational channel. The proximity of City of Derry Airport (<30km) would require thorough consultation with the relevant aviation authority prior to any designation for FIU wet storage here. The total area theoretically available for FIU wet storage in Foyle Port is 200Ha (Table 17).

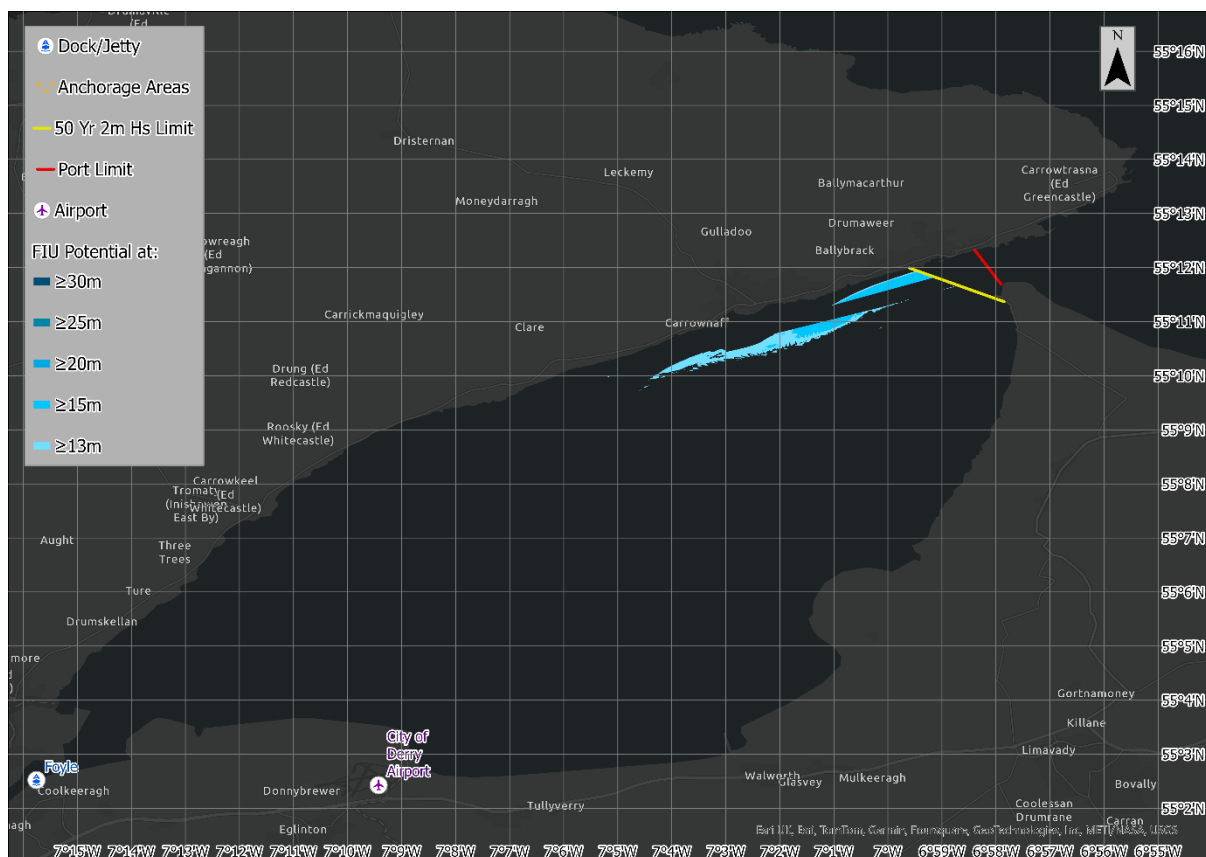


Figure 25. FIU wet storage suitability in Lough Foyle.

Table 17. Wet storage particulars for Lough Foyle.

FIU wet storage: Lough Foyle	
Wet storage potential	Limited
Wet storage area theoretically available	200Ha
Designated anchorage areas	N/A
Within 30km of Airport*	Yes
Within SAC (at potential area)	No
Within SPA (at potential area)	No
Access channel min. width (at 13m min. depth)	400m
Other constraints	Adjacent AONB (Binevenagh)

*See Section 4.2.4 – Stakeholder considerations.

4.2.1.5 *Cork Harbour*

The Cork Harbour PJA extends from Cork City out beyond Roches Point to a line running from Cork Head on the western approach to Power Head on the eastern approach (Figure 26). Adequate shelter for FIU wet storage is reached just inside Roches Point, but similar to Lough Foyle, the issue in Cork Harbour is associated with depth constraints. There are very few areas outside of the navigational channel where depths exceed 13m. Partial use of Anchorage A, northeast of Spike Island, is the most likely option, but even here depths struggle to exceed the 13m threshold. The entirety of Cork Harbour also lies within a 30km radius of Cork Airport (just out of frame in Figure 26), thus requiring consultation with the relevant aviation authority if FIU wet storage were to occur here. The total theoretically available area for FIU wet storage in Cork Harbour is 16Ha (Table 18).

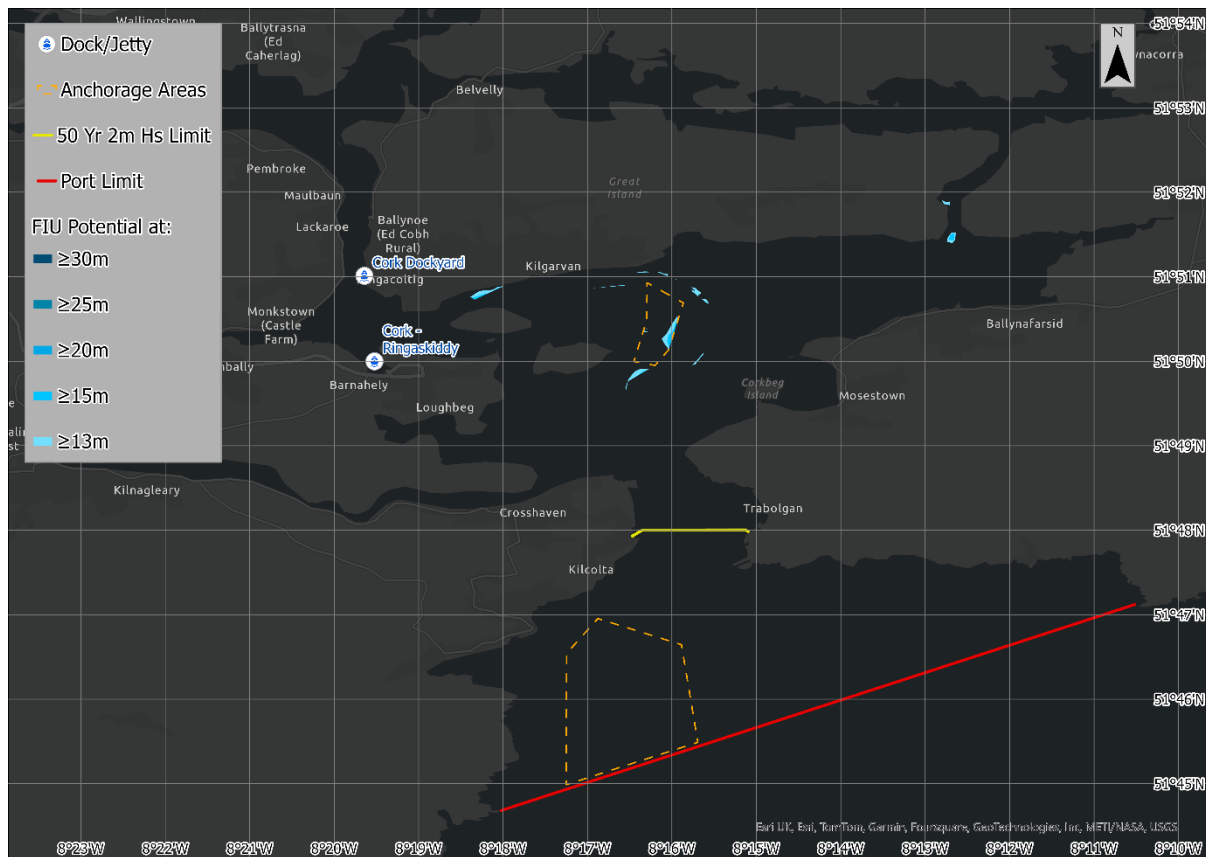


Figure 26. FIU wet storage suitability in Cork Harbour.

Table 18. Wet storage particulars for Cork Harbour.

FIU wet storage: Cork Harbour	
Wet storage potential	Limited
Wet storage area theoretically available	16Ha
Designated anchorage areas	Included
Within 30km of Airport*	Yes
Within SAC (at potential area)	No
Within SPA (at potential area)	No
Access channel min. width (at 13m min. depth)	186m
Other constraints	Depth the primary concern

*See Section 4.2.4 – Stakeholder considerations.

4.2.2 Planning and environmental considerations – scenario analysis

This section examines key planning and environmental considerations likely to warrant consideration in the designation or identification of a site for wet storage. An evaluation of a proposed project for the purposes of planning and environmental assessment, will consider the specific impacts likely to occur given the particulars of a project, in relation to a broad range of factors including: people, flora, fauna, soil, water, air, landscape and cultural heritage.

Given the strategic nature of this study, this assessment considers only those strategic considerations relevant to the siting, development and operation of a wet storage facility. The key impacts that are considered relevant to this higher-level assessment are those arising due to:

- The development of the wet storage facility and all associated construction activities, which could include dredging, installation of mooring systems, erection of navigational aids etc.
- Activity relating to assembled turbines, including tow-out of turbines to the designated wet storage facility, securing and storage of the turbines / turbine elements, reverse ‘towing in’ of any elements from the wet storage facility into port.
- Operational interactions with maritime users arising from the location of the designated wet storage facility, including the implementation of exclusion zones during its construction and operation.
- Interactions arising from the location, development and operation of the wet storage facility, including impacts on landscape and seascape views/settings and associated impacts on socio economic activities such as tourism, heritage etc.

For clarity, this assessment does not consider cumulative impacts that may arise due to the operational reliance of a wet storage facility on other developments/infrastructure such as: turbine fabrication or assembly; port-side activity and utilisation of port infrastructure; the construction, operation and decommissioning or an ORE project, etc.

As the Shannon Estuary and Bantry Bay were determined to have the most extensive potential for wet storage in the study area, the scenario analysis was carried out at each of these locations, and their suitability, with regard to planning and environmental considerations, is assessed.

4.2.2.1 Shannon Estuary

4.2.2.1.1 Protected sites

As shown in Figure 27, the Shannon Estuary contains a number of European Sites designated for nature conservation, and there are other sites in the wider vicinity that warrant consideration. The presence of these designations renders this a sensitive ecological environment, with an obligation for environmental and ecological protection.

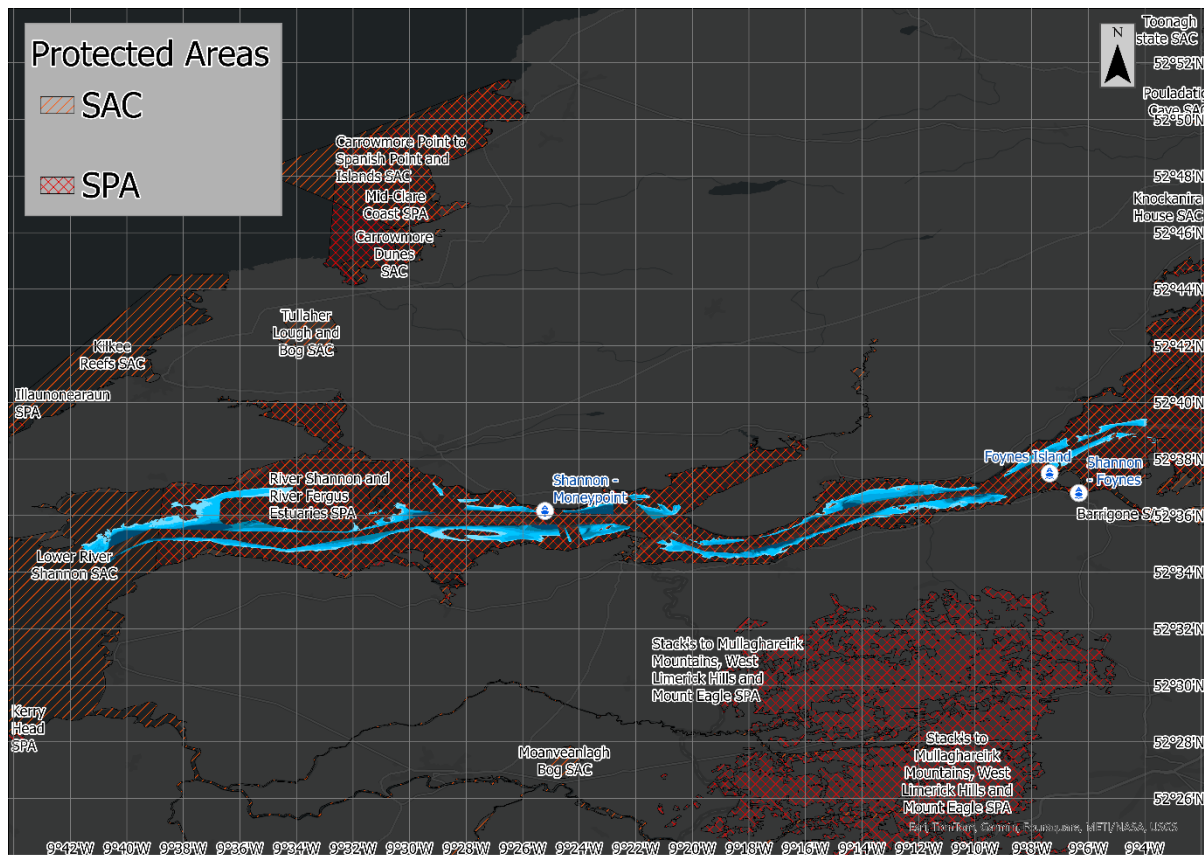


Figure 27. Protected areas at the Shannon Estuary.

The development of a wet storage facility within the estuary will give rise to construction works and activities of a temporary (construction and decommissioning) and permanent (for the duration of operations) nature. As described in Section 3, during construction it may be necessary to carry out dredging of a marine area for wet storage. The installation of mooring systems will necessitate the development of anchor piles, catenary lines etc. Associated with this development there will be temporary construction activities with potential impacts including underwater noise and vibration, increased particulate matter, etc. These elements will remain *in-situ* and be maintained for the operational life of the facility, as will ancillary elements such as navigational aids, with potential impacts arising due to their construction, continued presence and decommissioning. For the duration of operations, turbines will periodically be moved into and out of the area and anchored, with the associated movement of large scale under and over water elements, vessels etc.

In line with the requirements of the Birds and Habitats Directives, the potential impacts that may arise from all such activities will need to be considered, having regard to the qualifying special conservation interests of European Sites and the associated conservation objectives. This will help to determine the suitability of a facility within a given location and ensure the appropriate mitigation measures are taken and incorporated into any specific project proposal, particularly in the specification of construction methodologies, etc.

4.2.2.1.2 Land use, landscape and seascape

In terms of land-use patterns, as shown in Figure 28, the Shannon Estuary is a multi-functional zone supporting a wide range of activities, including port functions, aquaculture, fishing, marine tourism, recreation/leisure activities, industry/business, energy generation, fuel storage, aviation and agriculture (set within a diverse rural and scenic coastal landscape).

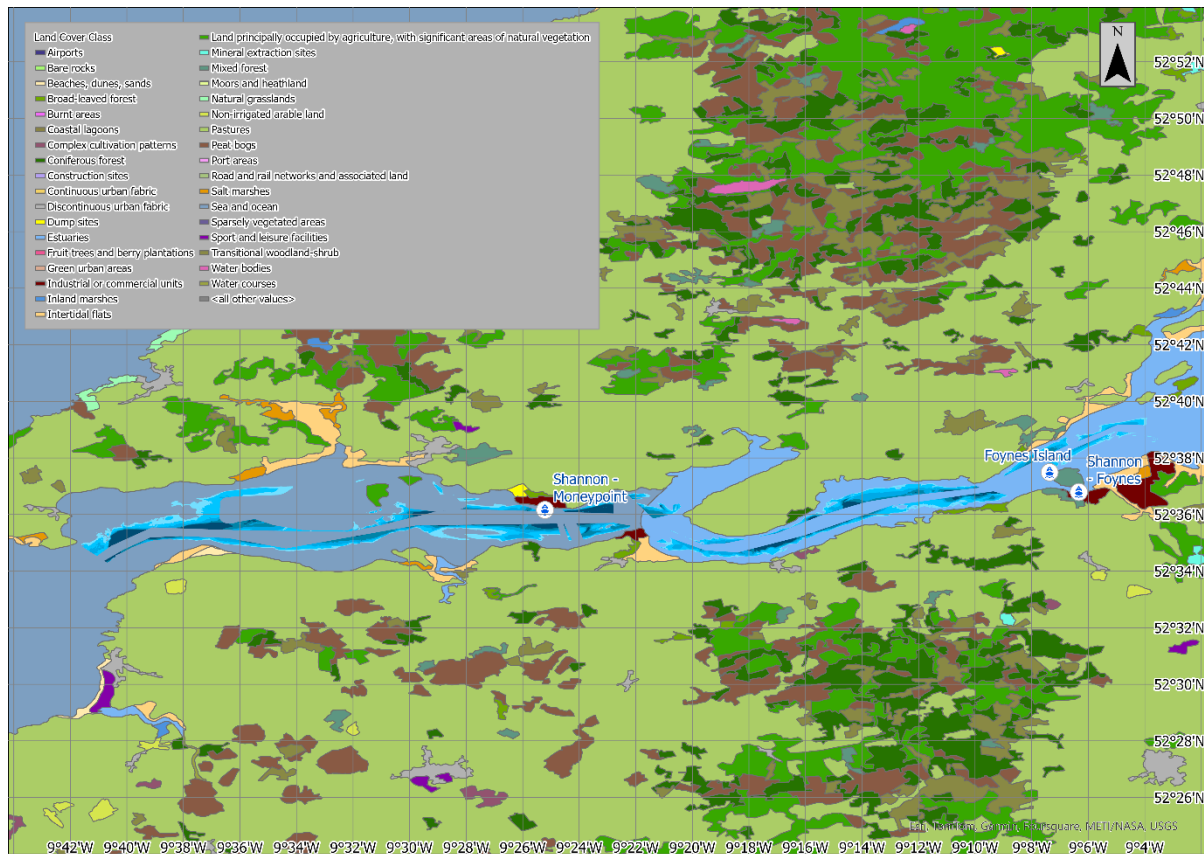


Figure 28. Land cover classifications at the Shannon Estuary.

Given the relative remoteness of the identified sites from the shore, the key ‘land-use’ consideration will be any operational interactions between the development and other maritime users, such as those that could arise from the imposition of exclusion zones during its construction and operation. Given the criteria that inform site identification, including the screening out of navigation and shipping channels, it is anticipated that such interactions would be localised and could be mitigated by design.

The Shannon Estuary is set within a scenic, coastal landscape, characterised by contrasting rural activity, including settlements and activities associated with agriculture and clusters of industrial activity at locations including Moneypoint and Tarbert Generating Stations, Shannon Foynes Port and to the east Shannon Airport. Such activities are predominantly located within the coastal zone and are associated with large-scale maritime activities, including jetties and port areas. The estuarine coastal zone also accommodates a significant number of scenic viewpoints.

The relative landscape sensitivity of the Shannon Estuary is reflected in the characterisation and policies set out in statutory development plans for the counties of Clare, Kerry and Limerick (see Figure 29). These documents set out prescribed policies for landscape protection/management and provide a basis for the objective evaluation of landscape impact.

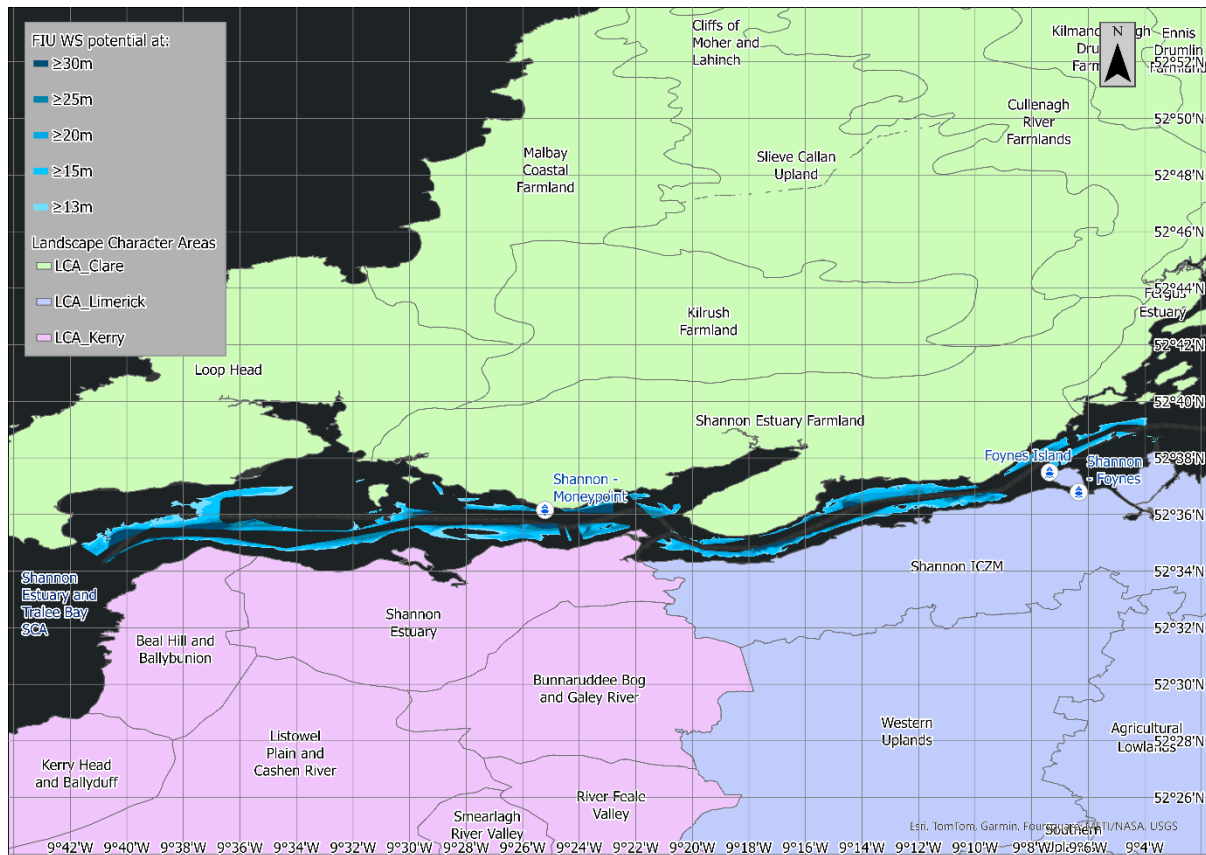


Figure 29. Landscape and Seascape Character Assessment Areas (LCA/SCA) at the Shannon Estuary.

The Clare County Development Plan identifies the majority of the coastal zone on the north of the Estuary as ‘heritage landscape’ - areas where natural and cultural heritage are given priority but where development is not precluded; with significant areas classified as comprising the ‘Shannon Estuary working landscape’ - a designation that reflects the significance of the estuary as a location for nationally significant economic and natural resources, sheltered deep water marine access, high voltage electricity transmission/generation capacity and international airport access, and, by way of favourable policy, creates an opportunity for the development of large-scale shipping, transshipment, logistics, manufacturing and associated economic and service activities, with two localised clusters of strategic development land for the development of the marine industry at Moneypoint and Inishmurry, Carrihacon.

The Kerry County Development Plan designates much of the coastal plain on the southern side of the Estuary as ‘visually sensitive’ - with a consistent area of sensitivity designated from Carraig Island,

westwards to Ballybunnion, and southwards. To the east, a localised area of sensitivity is identified at Tarbert Bay.

The Limerick County Development Plan identifies the Shannon Estuary in LCA06 Shannon Coastal Zone and establishes a policy framework that can be broadly described as accommodating development while ensuring a level of landscape and environmental protection.

Impacts on landscape and seascape arising from the development and operation of a wet storage facility within the Shannon Estuary would typically be experienced within the estuarine coastal zone, with some potential for changed views from adjoining elevated viewpoints or scenic routes. The significance of those impacts will depend on the degree to which the facility is utilised, i.e. the number of units stored at any given time. It is noted that the prevailing landscape policies identify landscape sensitivity, but equally accommodate new development and landscape change. The presence of designated scenic routes, views and prospects along the coastal zone, particularly in Counties Clare and Kerry, and including the Wild Atlantic Way, is noted. It is further noted that such viewpoints are currently set within a somewhat diverse landscape, again noting the presence of large-scale industrial facilities within the coastal zone.

Given the inherent nature of a proposed wet storage facility, a cluster of large-scale wind turbines set within an open maritime area, the potential significance of any additional impacts on such viewpoints, and any associated impacts on socio-economic activities (such as tourism and heritage), will be proportionate to the distance between a proposed facility and the sensitive receptor, i.e. the distance from the shoreline. As noted above, the impact will also vary depending on the degree to which the facility is utilised at any given time.

4.2.2.1.3 Fisheries

The impact on fisheries in the Shannon Estuary is low (Figure 30). Most of the inshore fishing activity in this region is concentrated outside the estuary, with only minimal overlap observed within the estuary itself. An exception to this is pot fishing activity, which appears to be carried out in the southwestern parts of the estuary along the Kerry and Limerick side. These are the only locations where the distribution of inshore fisheries data intersects with zones identified as having potential for wet storage in the Shannon Estuary. This highlights the limited conflict expected to arise between existing fisheries and the offshore wind sector at this location. The low level of overlap suggests that strategic planning for wet storage could proceed with minimal disruption to local fishing communities, provided that these specific areas are carefully managed. This insight is important for policymakers and stakeholders aiming to balance economic development (that development of offshore wind can provide) with the preservation of traditional livelihoods and marine ecosystems. Sustainable development strategies that prioritise both environmental conservation and economic growth in the Shannon Estuary region are essential in this regard.

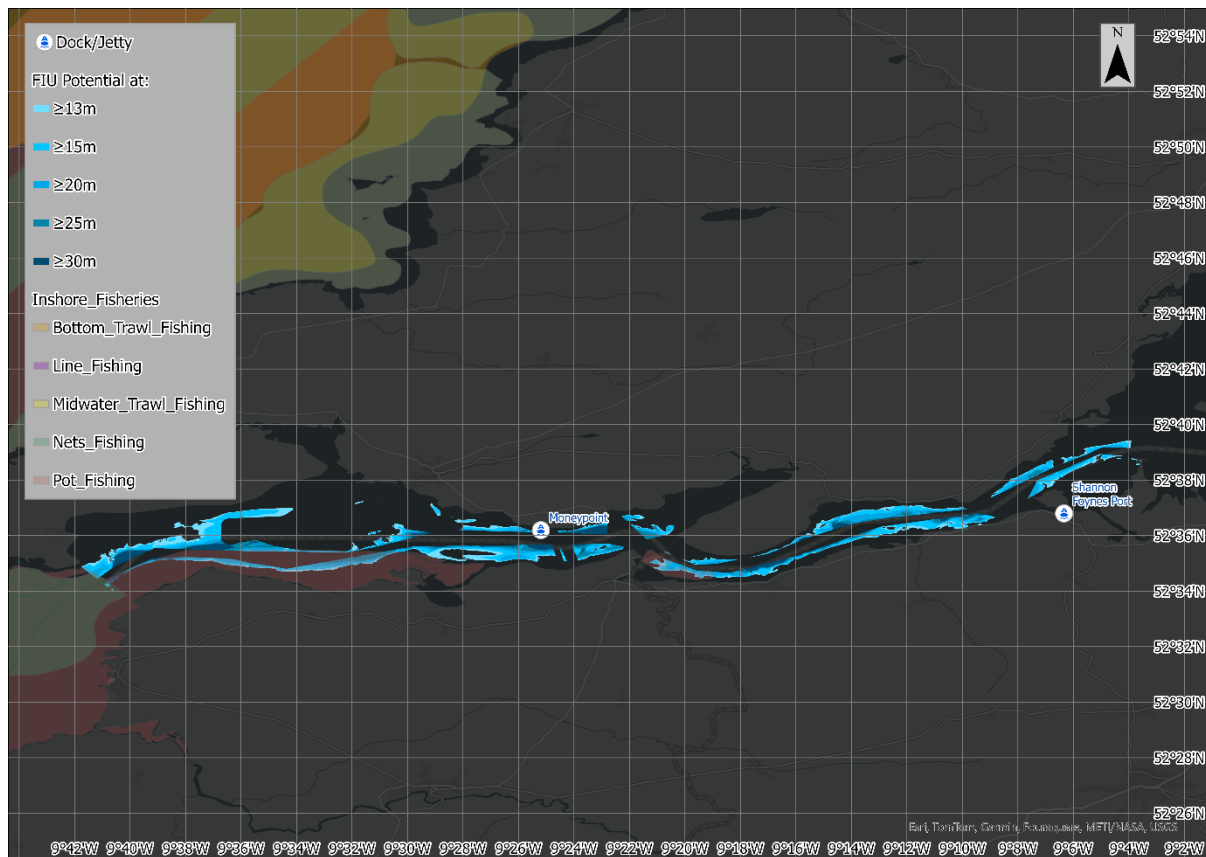


Figure 30. Inshore fisheries data overlaid on potential FIU wet storage areas at the Shannon Estuary.

4.2.2.2 Bantry Bay

4.2.2.2.1 Protected areas

As shown in Figure 31, Bantry Bay is proximate to a number of European Sites designated for nature conservation, but the bay itself is not located within such a site. The potential impacts on European Sites described above for the Shannon Estuary, are also relevant to the assessment of Bantry Bay, noting the potential for impacts is lessened by the distance to such sensitive receptors. Again, the requirements of the Birds and Habitats Directives will apply, and it will be necessary for all activities associated with a wet storage facility to be considered, having regard to the qualifying special conservation interests of those European Sites and the associated conservation objectives, to determine the suitability of any such wet storage proposal.

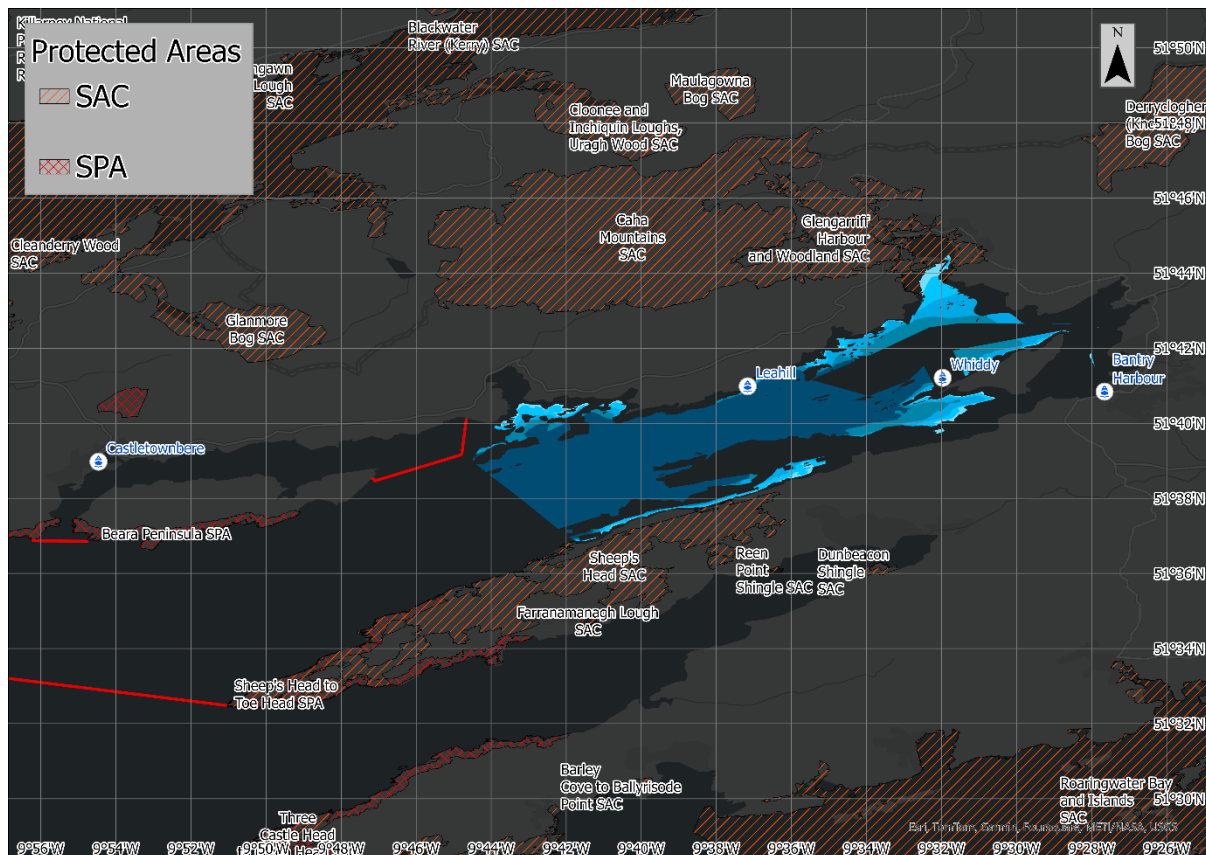


Figure 31. Protected areas at Bantry Bay.

4.2.2.2.2 Land use, landscape and seascape

As shown in Figure 32, the established pattern of land use in the Bantry Bay area is inherently linked to the prevailing landscape setting. Overall, the bay is set within a rural, coastal and highly scenic area, with the Beara Peninsula to the north and Sheep's Head Peninsula to the south. In terms of land use patterns, the area is rural with small settlements, typically located along the coastal plain. Bere Island is located at the mouth of the Bay, with Whiddy Island (noted as accommodating oil terminal facilities) sited near the head of the Bay.

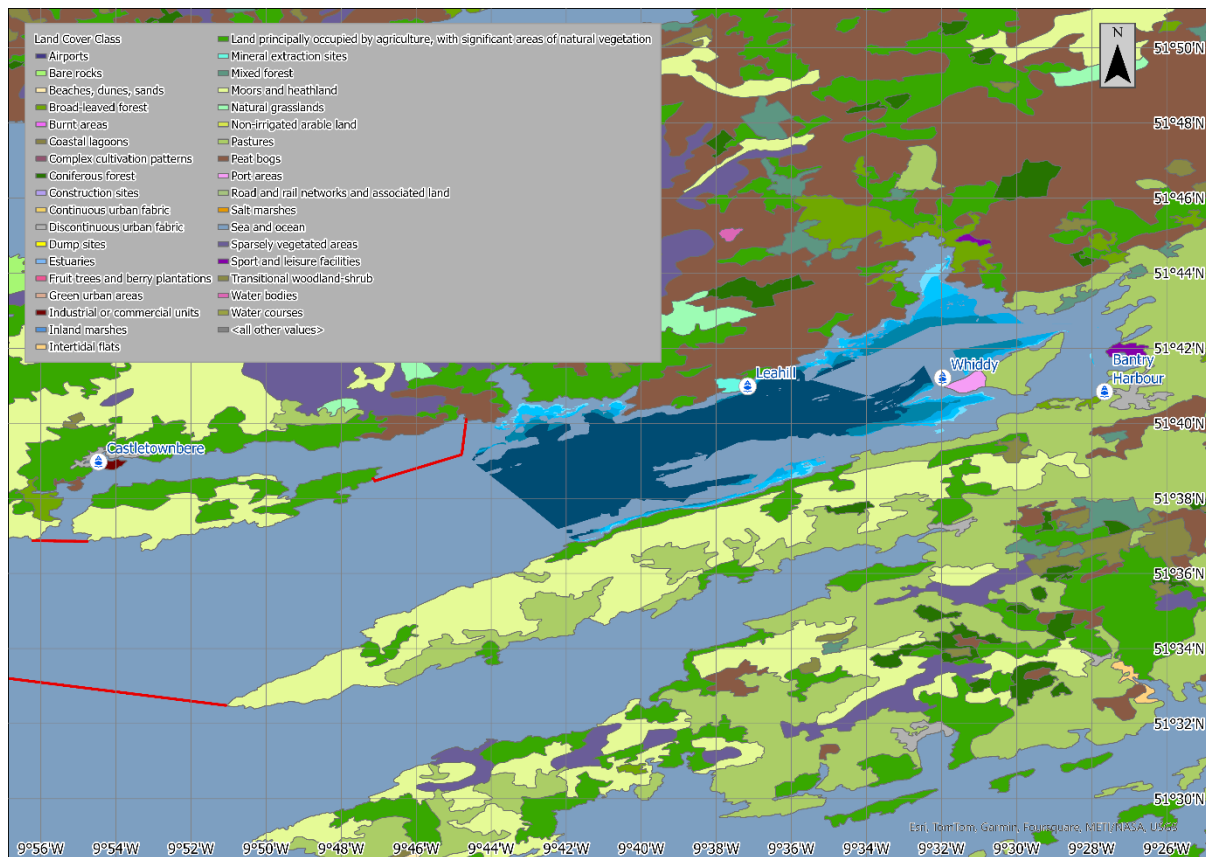


Figure 32. Land cover classifications at Bantry Bay.

Again, per the commentary set out above for the Shannon Estuary, key ‘land use’ consideration will be any operational interactions between the development and other maritime users, such as those that could arise from the imposition of exclusion zones during its construction and operation. Given this process has screened out navigation and shipping channels, it is anticipated that such interactions would be localised and could be mitigated by design.

Bantry Bay is set within a highly scenic, coastal landscape. The relative landscape sensitivity of the bay is reflected in the characterisation and policies set out in the Cork County Development Plan, which again provide a basis for the objective evaluation of landscape impact. That plan designates the surrounding landscape as a ‘high value landscape’ and affords it a high level of landscape protection (Figure 33).



Again, noting a proposed wet storage facility will comprise a cluster of large-scale FSSs or FIUs set within an open maritime area, the potential significance of any additional impacts on the landscape and designated viewpoints (and any associated impacts on socio-economic activities such as tourism and heritage) will be proportionate to the distance between a proposed facility and the sensitive receptor, i.e. the distance from the shoreline. As noted above, the impact will also vary depending on the degree to which the facility is utilised at any given time.

The impact on fisheries in Bantry Bay is shown in Figure 34. Most inshore fishing activity types are concentrated towards the west of the bay. However, coverage of bottom-trawling and pot fishing activity extends east into the areas identified for potential wet storage. Pot fishing activity in particular appears to be widespread throughout the bay, and the southwest coast in general. It is apparent that wet storage

in Bantry Bay would likely need to intersect areas of pot fishing activity due to this widespread coverage. Any such site designation for wet storage within these areas identified as accommodating pot fishing activity, or any other fishing activity for that matter, should be in accordance with the relevant fisheries policy guidance (Fisheries Policy 1), which states that “proposals that may have significant adverse impacts on access for existing fishing activities, must demonstrate that they will, in order of preference: a) avoid, b) minimise, or c) mitigate such impacts” and that “if it is not possible to mitigate significant adverse impacts on fishing activity, the public benefits for proceeding with the proposal that outweigh the significant adverse impacts on existing fishing activity must be demonstrated” [57].

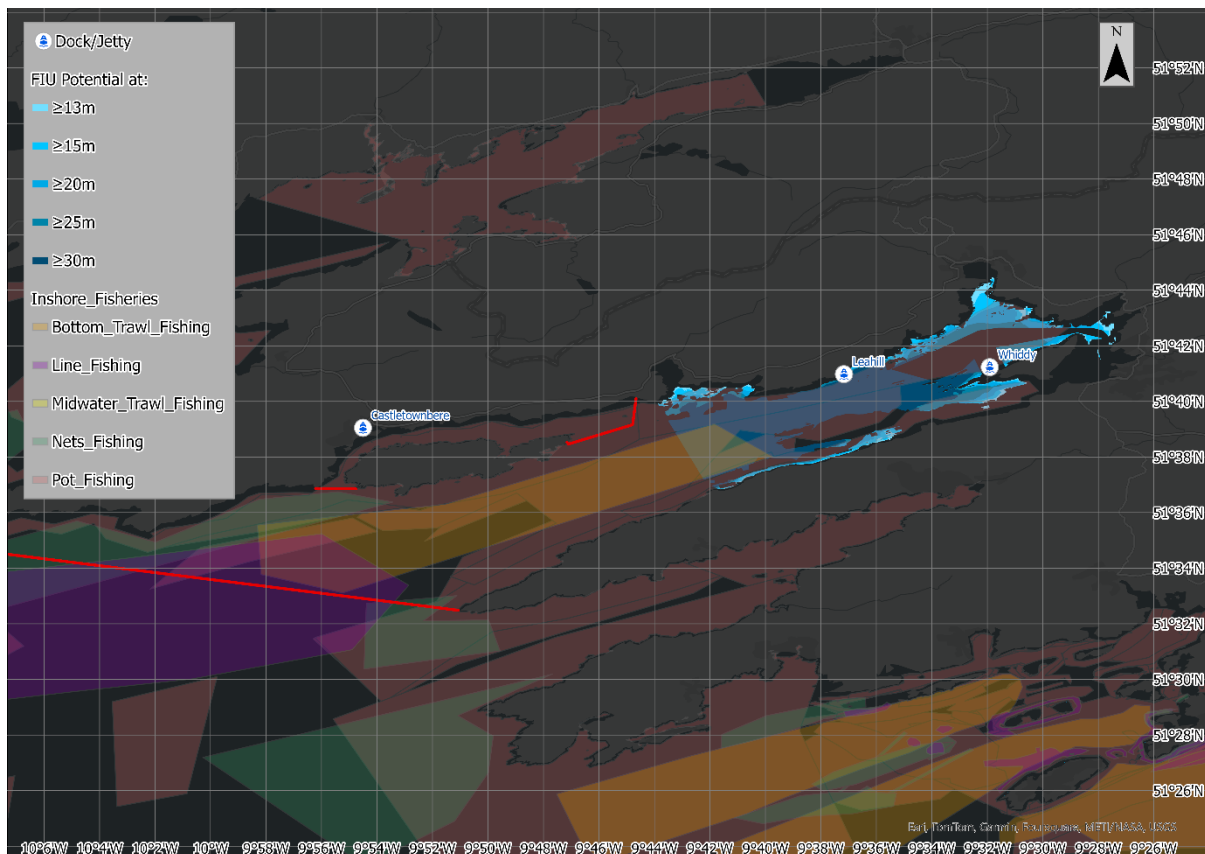


Figure 34. Inshore fisheries data overlaid on potential FIU wet storage areas at Bantry Bay.

4.2.3 Consent

The consenting process for FLOW wet storage in Ireland requires thorough geophysical and environmental investigations before progressing to formal approvals. Developers must conduct detailed seabed and subsea surveys, typically accompanied by an Environmental Impact Assessment (EIA) and/or Appropriate Assessment (AA) as part of the Maritime Area Consent (MAC) application process. These comprehensive studies evaluate ecological sensitivities and geological conditions, ensuring potential risks are identified and mitigated from the outset. The findings form the technical foundation for subsequent regulatory decisions while addressing key environmental protection requirements.

Following these assessments, developers engage with the Maritime Area Regulatory Authority (MARA) through an optional pre-application consultation before formally submitting their MAC application. The submission includes all required environmental studies, technical documentation, and applicable fees. MARA reviews the application for completeness before publishing it for public scrutiny, with a statutory decision typically issued within 90 days. This streamlined maritime consenting phase provides developers with relatively prompt certainty regarding their offshore operations while maintaining robust environmental oversight.

The process then moves to terrestrial planning approvals, where developers must secure permission from An Bord Pleanála or An Coimisiún Pleanála. After initial consultations, a comprehensive planning application is submitted, incorporating the granted MAC, all environmental assessments, and detailed project designs. This phase involves more extensive scrutiny than the maritime consent process, often requiring 18-24 months for determination due to complex technical evaluations and mandatory public participation requirements. The extended timeline reflects the need to balance project viability with environmental protection and stakeholder interests, ensuring all floating offshore wind developments meet Ireland's stringent planning and sustainability standards. A general roadmap for this process has been produced as part of this study and is shown in Figure 35.

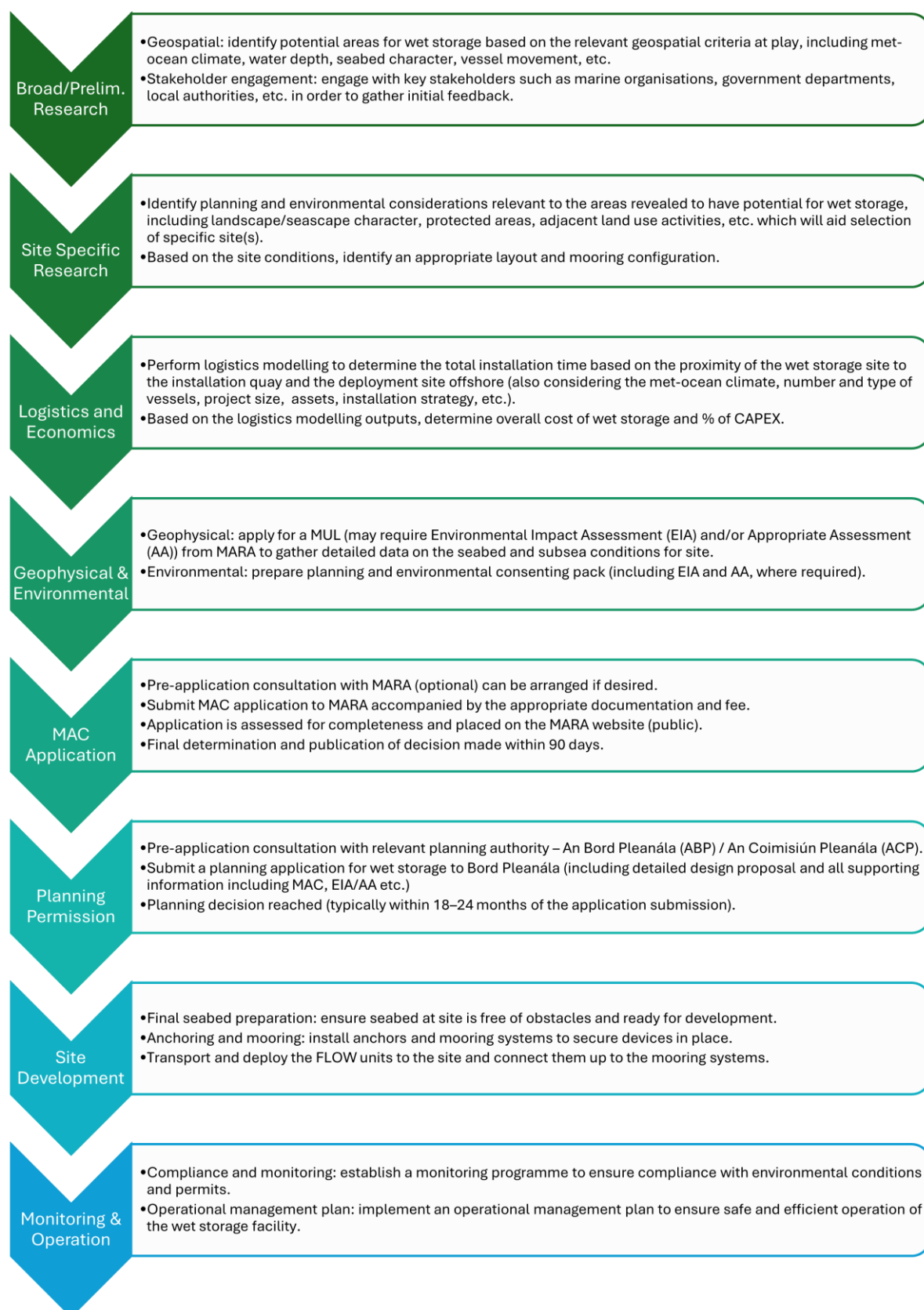


Figure 35. Indicative consenting roadmap for wet storage (relevant to ROI only).

4.2.4 Stakeholder considerations

The stakeholder engagement process for this study provided critical insights that both validated the technical approach and highlighted crucial operational and regulatory considerations for wet storage. Engagement with port authorities informed some of the final alterations of the site suitability assessment for the respective port jurisdiction areas concerned. A recurring theme across multiple discussions was the central role of risk mitigation and insurability. Stakeholders from industry and insurance bodies stressed that robust mooring systems, immediate tug access, and comprehensive contingency plans in the event of a unit breaking loose are not just recommendations, but will be fundamental to securing insurance, with some suggesting that developers may need to self-insure or face policy caps. The importance tug-base proximity for rapid emergency response in the event of station keeping failure was also a point raised in this regard.

Engagements further clarified the complex regulatory landscape governing potential wet storage sites. Regulatory bodies highlighted that while a Marine Area Consent (MAC) would be required for the long-term use of a site, consenting may be more straightforward within existing port jurisdiction areas. Aviation authorities detailed stringent obstacle limitation surfaces (OLS) around airports (generally within a 30km radius) referred to as safeguarding zones, necessitating early and continuous dialogue to ensure that stored or transiting WTG units do not interfere with low-flying aircraft. Concerns were also raised regarding the movement of helicopters which would need to be addressed in the development of a wet storage site. Other operational considerations raised included the need for exclusion/buffer zones around sites designated for wet storage, 24-hour monitoring, managing ballast water responsibly, and preparing oil spill contingency plans as required by the Irish Coast Guard.

Some stakeholders advised challenging certain initial assumptions, such as the restrictive wave height thresholds and the focus solely on port limits, suggesting these may overlook viable areas (as taken into account for Belfast). The concept of "temporary" storage was also questioned, with feedback indicating that these sites may be required for decades across various project phases (operation and decommissioning).

Overall, the engagement process has yielded important strategic guidance that shaped the study's scope and provided insights into some of the issues warranting consideration in the development of a site for wet storage. The collaborative dialogue carried out with stakeholders as part of this study has established a network of engaged and informed stakeholders who have expressed a keen interest in the final outcomes and a willingness to support future work in this area going forward.

5 Layout and Mooring Analysis

Wet storage allows for staging flexibility in large scale deployments of FOWTs and helps logistical challenges associated with assembly timelines, weather windows and towing availability. However, a crucial part of identifying suitable sites is the design of array layouts and mooring systems that are appropriate for the relatively shallow waters at wet storage sites. The mooring system design and array layout determines the number of units that can be stored at a given site.

Designing a suitable wet storage mooring system requires the platform excursions and mooring loads to remain below acceptable thresholds. When storing these platforms in arrays, additional complexity arises from hydrodynamic interactions between neighbouring units as well as the additional loads in shared anchors and the spacing requirements between the platforms.

This chapter presents the numerical and experimental work carried out to evaluate the mooring system behaviour and array layout spatial requirements for the two primary sites identified through the GIS investigation described in Section 4. The investigation focused on the technical performance of mooring systems and the effects of storing multiple platforms in arrays. Tidal variation and its influence on line tension was not assessed. The lowest astronomical tide (LAT) was assumed at each site. Soil characteristics, which determine anchor suitability, were also not assessed. Pile-driven anchors were assumed.

5.1 *Methods*

Two hypothetical wet storage sites at the Shannon Estuary and Bantry Bay were selected for the layout and mooring investigation based on the site suitability analysis. The Shannon Estuary site is a sheltered location with a water depth of 15m and a 50-year return significant wave height of 2m. Bantry Bay is less sheltered compared to the Shannon Estuary site, but has a greater available water depth of 40m and a 50-year return significant wave height of 8m. These environmental conditions are the basis of both the numerical and experimental tank testing conditions. The floating structure used for this study was the UMaine VoltturnUS-S 15 MW semi-submersible platform (Figure 36) [58].

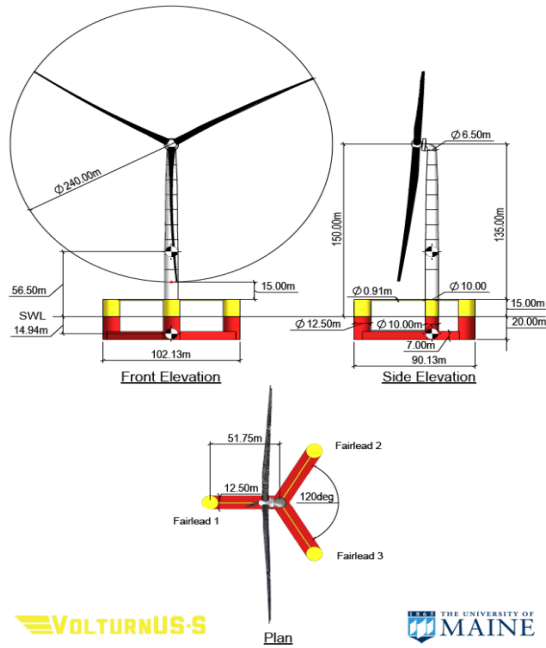


Figure 36. VoulturnUS platform [58].

Four model configurations are considered throughout this investigation:

- Operational configuration: fully integrated unit (FIU) with tower, nacelle and full ballast.
- Bantry Bay configuration: stand-alone floating substructure (FSS) platform (tower and nacelle removed) but fully ballasted as in the operational case.
- Shannon Estuary FIU: fully integrated unit, but de-ballasted to achieve a draft of 12m.
- Shannon Estuary FSS: tower and nacelle removed and deballasted to a draft of 12m.

The Shannon Estuary models have some ballast removed to increase the under-keel clearance due to the site's limited water depth. Although the operational condition is included in the study, the focus is on the other three configurations. For consistency across sites, the lowest astronomical tide (LAT) was assumed as the reference water depth. Site-specific tidal variation and soil properties were not incorporated into this analysis. Anchors were modelled as pile-driven anchors, providing sufficient resistance to the assumed uplift and horizontal forces.

5.1.1 Numerical modelling

Numerical simulations were carried out using ANSYS AQWA to iteratively design a mooring system focusing on maintaining platform excursions, line tensions and anchor uplift forces below thresholds defined at the start of the project, while also minimising the anchor radius of the mooring system (the horizontal distance from fairlead to anchor). The defining force limits on the anchor system were the snatching loads, with maximum threshold set to 10MN and a maximum uplift force on the pile driven anchor set to 1MN.

Initial simulations focused on single platform mooring systems at both the Shannon Estuary and Bantry Bay. These mooring systems were then applied to arrays of platforms making use of shared anchors where possible. The goal was to assess the effects of arrays on the mooring system and determine the minimum spacing between stand-alone platforms in arrays and the effects of shared anchors on the uplift forces acting on the anchors. The anchors for these simulations are assumed to be pile driven. Due to the spatial limitations of tank testing, the array sizes were limited to five platforms.

ANSYS AQWA is a linear potential flow solver used to model hydrodynamic loads on floating structures and relies on the following assumptions:

- The bodies have zero or negligible forward speed.
- The fluid is homogeneous, incompressible, and inviscid, and the flow is irrotational.
- Incident waves are of small amplitude relative to wavelength (i.e., non-breaking, small-slope).
- Motions are assumed to be linear, harmonic, and of small amplitude (first-order).
- Drag on Morison elements is represented using linearised damping rather than full nonlinear viscous forces.

Capabilities within these assumptions:

- Linear and second-order wave loadings are modelled using radiation–diffraction theory and quadratic transfer functions (QTFs).
- Time-domain simulations are generated using convolution methods to include radiation memory effects, with nonlinear Froude–Krylov and hydrostatic restoring forces estimated relative to the instantaneous wave surface.

Limitations of the software include:

- Viscous and nonlinear effects such as vortex shedding, wave breaking, slamming, and green water loads are not fully resolved.
- Forward speed effects and strong current–wave interactions cannot be captured accurately.
- Large-amplitude or strongly nonlinear platform responses are not represented accurately.
- Mooring dynamics are simplified; highly nonlinear behaviour such as line-seabed interaction, material hysteresis and snap loads are only approximated.
- Predictions are most reliable for regular and irregular wave conditions within the linear wave regime.
- A limited number of cells are allowed for each simulation, limiting the mesh resolution of the numerical model.
- QTF cannot be applied to more than three bodies within the numerical model; array models can't make use of the QTF.

The mesh for the numerical models was comprised of elements of 0.75m for the wetted surface of the model and 1.5m for the body above the still water level of the models. The QTF could not be enabled for the array models. To maintain consistency across the solitary and array simulations, QTF was disabled for the single platform layouts.

5.1.1.1 Iterative design

At first, the research started under the assumption that drag embedded anchors (DEAs) would be used for the single platforms and potentially the arrays. As a necessity to maintain minimal uplift forces on these DEAs, the use of catenary mooring lines was investigated. These mooring systems require a significantly greater anchor radius relative to the depth in shallow water than deeper water, thus resulting in mooring solutions that require a very large mooring footprint and long mooring lines. Mooring accessories were introduced in these mooring systems to tackle the challenge of reducing the mooring radius and uplift forces on the anchors. Figure 37 and Figure 38 illustrate some examples of the mooring system iterations performed throughout the study.



Figure 37. Early iteration of DEA mooring system for Bantry Bay.

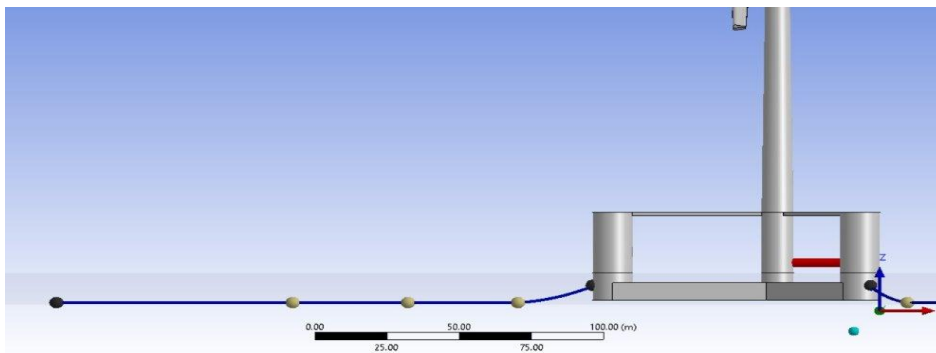


Figure 38. Early iteration of DEA mooring system for the Shannon Estuary.

It was decided that DEAs were going to be replaced with pile driven anchors (PDAs), allowing significantly greater uplift forces acting on the anchors and facilitating the investigation of semi-taut and taut mooring systems. An example of a taut mooring system simulated in the Bantry Bay environment is provided in Figure 39. Taut mooring lines were investigated to try to minimise the anchor radius of the mooring system. Various different polyester ropes and chain dimensions were tested in the mooring system. On top of this, it is shown in Figure 39 that the mooring lines are no longer evenly spaced radially around the platform to reduce the spatial requirements of the arrays.

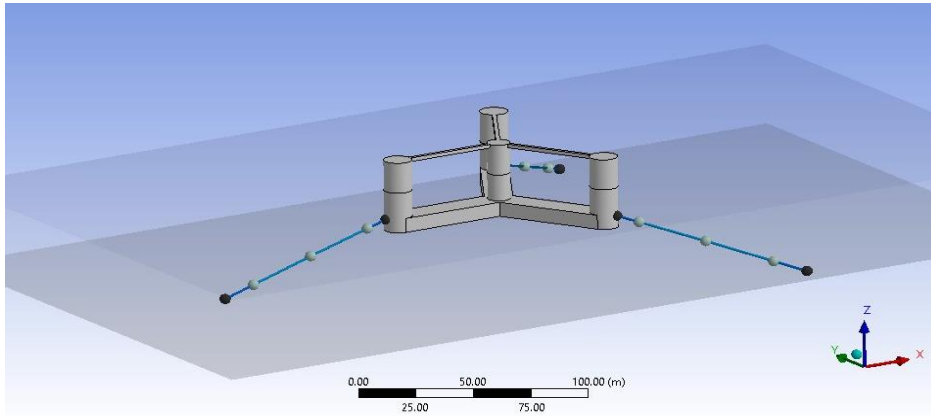


Figure 39. Taut mooring line iteration of mooring system.

After numerous iterations of taut mooring systems, it was found that the peak forces acting on the mooring lines were exceeding the predefined snatching load limits. Despite the smaller anchor radius associated with the taut mooring systems, it was exchanged for semi-taut mooring lines. Numerous iterations in both the Shannon Estuary and Bantry environmental conditions were performed before arriving on the final mooring system for each. The anchor radius is more than 50 metres smaller than the minimum required spacing between each unit in the array for the Shannon Estuary, meaning that minimal space is used, while also maintaining station keeping performance and limiting the mooring forces below the mooring force limits.

5.1.1.2 Shannon Estuary model description

As stated above, two models were used for the Shannon Estuary, the first being a stand-alone floating substructure (FSS) with no tower, ballasted to a draft of 12m and the second configuration being the fully integrated unit (FIU) with tower and nacelle mounted, also ballasted to a draft of 12m. The properties described below in Table 19 are a result of the scaled-up mass properties of the physical models, as these values were used to update the numerical model after tank testing was completed.

Table 19. Mass properties of the stand-alone platform and the fully assembled platform in the Shannon Estuary configurations.

Parameter	Stand-alone Platform	Fully Assembled FOWT
Mass (T)	16640	16870
vCoG from keel (m)	7.26	17.84
I_{xx} ($kg \cdot m^2$)	1.13×10^{10}	8.60×10^9
I_{yy} ($kg \cdot m^2$)	1.13×10^{10}	8.60×10^9
I_{zz} ($kg \cdot m^2$)	2.01×10^{10}	1.53×10^{10}

5.1.1.3 Shannon Estuary mooring and array layouts

The finalised mooring system for the FSS and the FIU in an array or in a single platform configuration is described here. The mooring system consists of three semi-taut mooring lines per platform, made up of chain and polyester rope sections with clump masses and inline buoys. The array layout was limited by the narrow spaces available in the Shannon Estuary and hence is a straight line of platforms with a shared anchor between each neighbouring unit, as illustrated below in Figure 40.

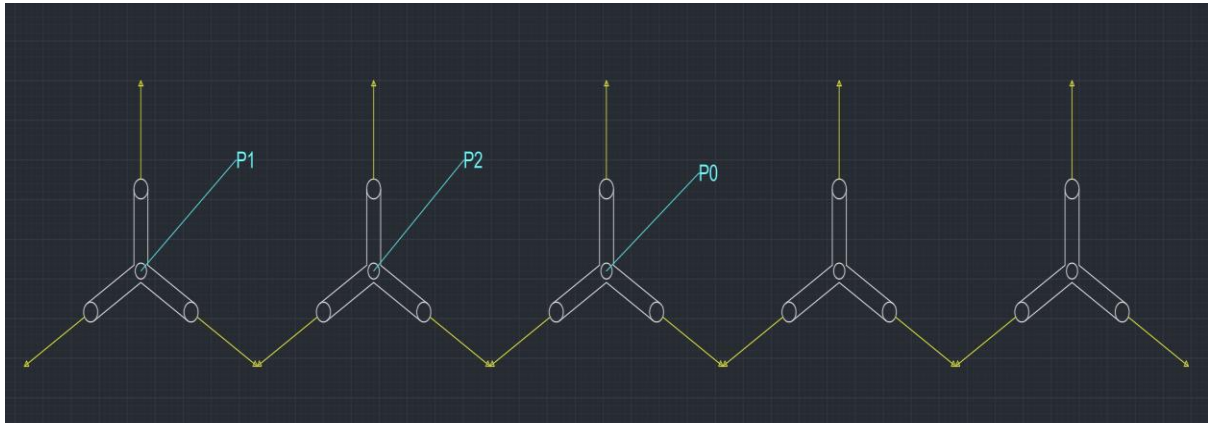


Figure 40. CAD illustration of the Shannon Estuary array layout.

The following describes the setup shown in Figure 40. P0 is the platform at the centre of the tank. This platform is in the same position as the model being tested in the single platform configuration. P1 is the platform on the leftmost position of the array in the front row (if there are multiple rows). P2 is the platform that is between P1 and P0, but is not necessarily in the same row as the other models as in the case for Bantry Bay. The minimum spacing assumed to be acceptable between the FSS units is 100m, whereas the spacing required between FIUs is assumed to be 600m, which in-turn prevents the use of shared anchors in the arrays of FIUs. Table 20 provides a description of the mooring line composition and a description of the mooring line materials at full scale. The mooring accessories and their locations are described in Table 21. The properties provided are the full-scale properties used for the numerical model.

Table 20. Description of the mooring line construction for the Shannon Estuary.

Parameter	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6
Type	Chain	Chain	Chain	Rope	Rope	Chain
Section Length (m)	20	15	13	2	9	5
Mass / Unit length (kg/m)	230	230	230	16.4	16.4	230
Nominal Diameter (mm)	115	115	115	160	160	115
Stiffness EA (MN)	11294	11294	11294	68.7	68.7	11294
Maximum Tension (MN)	12.61	12.61	12.61	6.87	6.87	6.87

Table 21. Description of Shannon Estuary mooring accessories.

Parameter	Joint 1-2	Joint 2-3	Joint 3-4	Joint 4-5	Joint 5-6
Type	Weight	Weight	-	Buoy	-
Structural Mass (kg)	1000	500	-	0	-
Displaced Mass of Water (kg)	0	0	-	0	-
Added Mass (kg)	65	50	-	333.33	-
Drag Coefficient (m ²)	0.14	0.14	-	0.352	-

Figure 41 provides a visual representation of the mooring system described in Table 20 and Table 21. The clump masses are represented by yellow spheres and the inline buoys are illustrated by the blue spheres. The joints between sections 3-4 and 5-6 have no mooring accessories attached. Instead, it is a change in mooring line material.

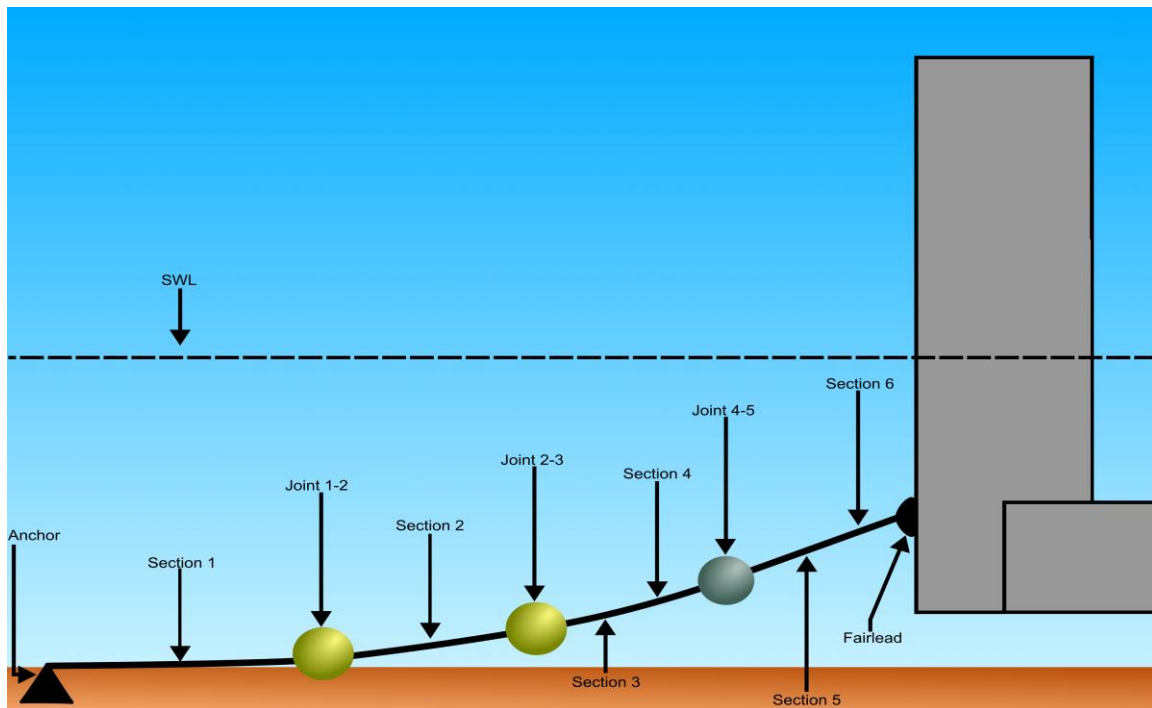


Figure 41. Illustration of mooring line composition.

5.1.1.4 Bantry Bay model description

The Bantry Bay environment being deeper (40m depth) than the Shannon Estuary site (15m depth), allowed for a greater draft in the floating platform using the full ballast of the model. The larger significant wave heights obtained in the 50-year return period analysis for Bantry Bay present undesirable conditions to include the tower and nacelle while in wet storage due to the likelihood of requiring heavier moorings as well as the accumulation of unnecessary fatigue, while not producing any revenue. The mass properties of the model are given in Table 22.

Table 22. Bantry Bay platform mass properties.

Parameter	Value
Mass (T)	17680
vCoG from keel (m)	4.52
$I_{xx} (kg.m^2)$	1.29×10^{10}
$I_{yy} (kg.m^2)$	1.29×10^{10}
$I_{zz} (kg.m^2)$	2.33×10^{10}

5.1.1.5 Bantry Bay mooring and array layout

The mooring system for the Bantry Bay environment is a larger version of the Shannon Estuary mooring system. Heavier clump masses and polyester rope with greater stiffness are introduced to this mooring system. Tables 23 and 24 below describe the mooring system components.

Table 23. Description of the mooring line construction for the Shannon Estuary.

Parameter	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6
Section Length (m)	Chain	Chain	Chain	Rope	Rope	Chain
Mass / Unit length (kg/m)	40	37	28	15	15	10
Nominal Diameter (mm)	230	230	230	16.4	16.4	230
Stiffness EA (MN)	115	115	115	160	160	115
Maximum Tension (MN)	11294	11294	11294	68.7	68.7	11294
Type	12.61	12.61	12.61	6.87	6.87	12.61

Table 24. Description of Shannon Estuary mooring accessories.

Parameter	Joint 1-2	Joint 2-3	Joint 3-4	Joint 4-5	Joint 5-6
Type	Weight	Weight	-	Buoy	-
Structural Mass (kg)	2000	2000	1000	0	-
Displaced Mass of Water (kg)	0	0	-	500	-
Added Mass M_A (kg)	122	122	-	333.33	-

As shown in Figure 42, the same naming convention is used to denominate the platforms within the array. In this case, the array is a 3x2 configuration with five platforms. The 3x2 layout indicates there are two rows, the first containing three platforms and the second row containing two platforms. The array is laid out such that the aft anchors of the first row can be shared with the mooring line attached to the stern of the models in the second row.

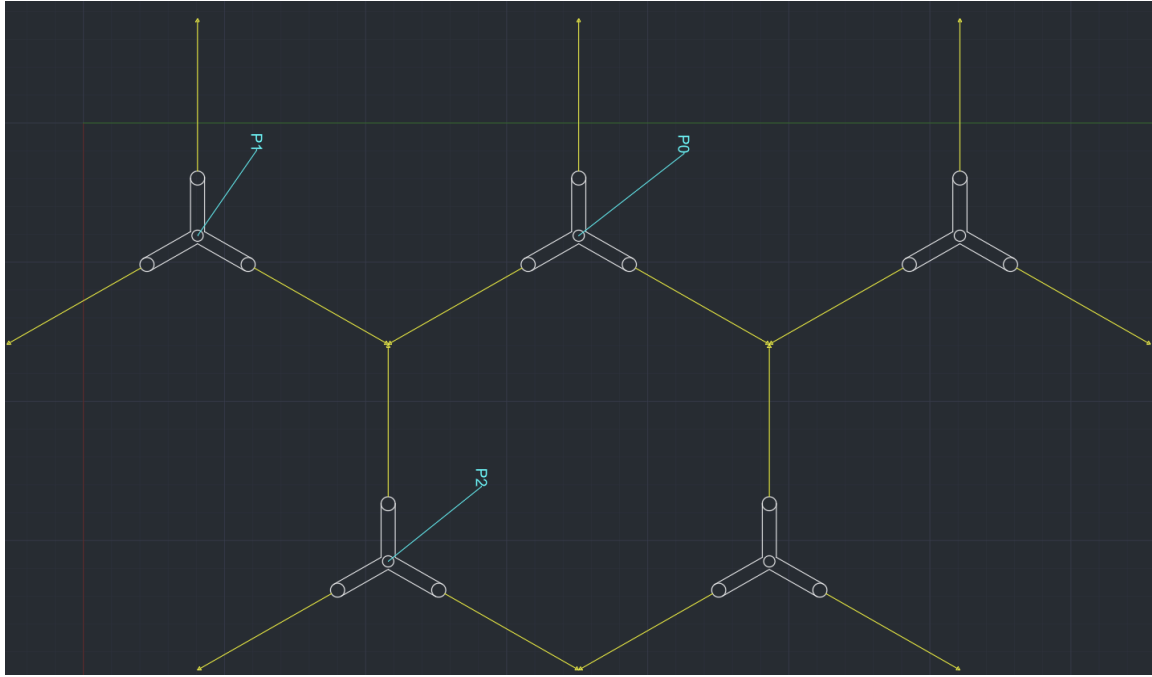


Figure 42. CAD drawing of the Bantry Bay array layout.

5.1.2 Physical modelling and tank testing

Five 1:100 scale models were fabricated for experimental testing carried out in the Deep Ocean Basin (DOB) at the Lir National Ocean Test Facility (NOTF) in Cork (Figure 43). The DOB has a moveable floor to adjust the water depth and a wave maker with 16 hinge force feedback paddles capable of generating peaks at $H_s = 0.6\text{m}$, $T_p = 2.7\text{s}$ and a $H_{\max} = 1.1\text{m}$. The DOB is 35m long, 12m wide and has a maximum depth of 3m.

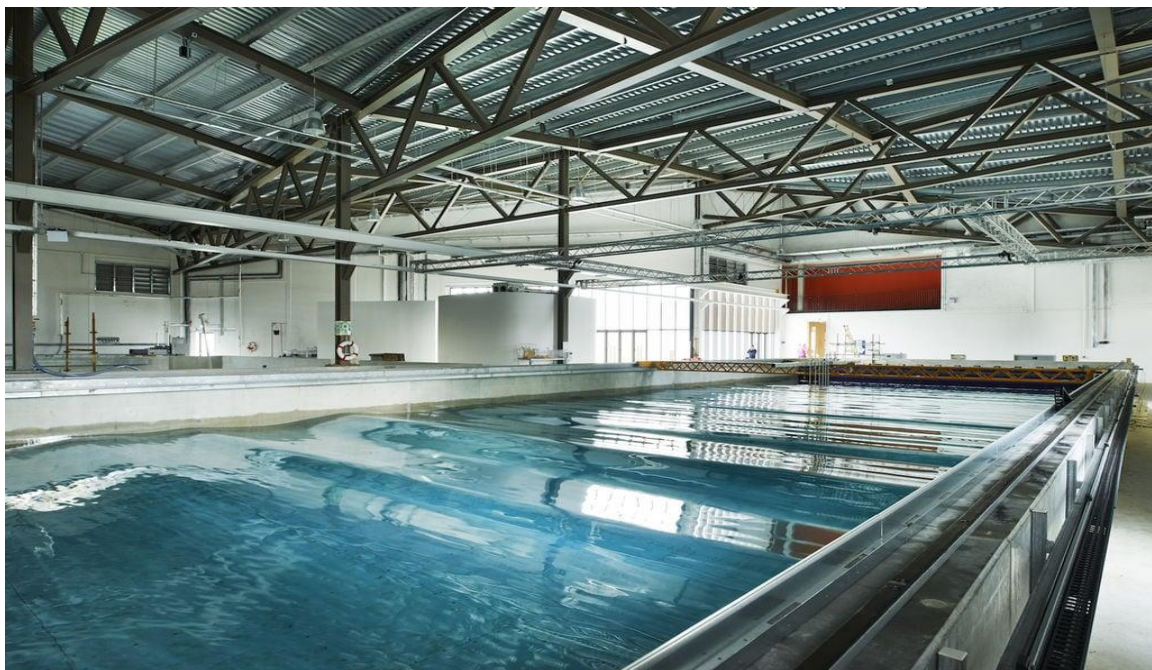


Figure 43. The DOB at Lir NOTF.

5.1.2.1 Scale model fabrication

Five 1:100 scale models were fabricated out of aluminium. The models were constructed with removable towers for the FSS configurations and with removable lids on the outer columns. The outer columns house stacks of masses that were used to adjust the mass of the platform for each configuration. The CAD properties and the measured properties are given below in Table 25 for each configuration.

Table 25. Model scale target mass properties of each test configuration.

Parameter	Operational conditions	Shannon Estuary FIU	Shannon Estuary FSS	Bantry Bay FSS
Total Mass (kg)	19.59	16.63	16.63	17.86
vCoG (m)	0.145	0.168	0.053	0.051
$I_{xx} (kg.m^2)$	3.176	2.712	1.136	1.277
I_{yy}	3.176	2.712	1.136	1.277
$I_{zz} (kg.m^2)$	2.301	1.494	2.021	2.301
Draft (m)	0.20	0.12	0.12	0.177

Figure 44 shows the fully assembled scale model. The removable tower attaches to the central column of the platform and can be removed depending on the configuration required. The tower is attached via 3x10mm nuts that screw into threaded holes on the top of the central column. Figure 45 shows the stand-alone configuration where the tower has been removed. This is the model that is used to test the Shannon Estuary stand-alone configuration and the Bantry Bay configuration.



Figure 44. Fully assembled model (FIU).



Figure 45. Model with tower removed (FSS).



Figure 46. Ballast weights stack.



Figure 47. Disassembled weight components.

Figure 46 shows the stack of weights that are used to fully ballast the platform. There are three of these stacks in each model (one for each outer column). The mass of the platform can change the configuration of the weights in the stack. Figure 47 shows the components of the weights used to construct the stack. There are two outer rings, two middle rings and a central cylinder mass. Depending on the required ballast of the platform, different variations of the weight stacks can be constructed using different sets of rings.

5.1.2.2 Deep ocean basin measurement systems

The motions of platforms in the tank were measured by Qualisys Track Manager (QTM) motion tracking software. A four-camera system is installed over the DOB which measures the motions of tracking markers that are attached to the platforms. To properly track the motions of a model, four markers are attached in different known locations and a bone structure in the QTM software is constructed from the markers for the cameras to detect. The markers are then given a position relative

to the CoM of the platform to allow the motions and rotations of the model to be accurately measured. The cameras circled in Figure 48 are some of the cameras that make up the QTM tracking system.



Figure 48. The DOB and the QTM cameras (circled yellow) positioned above the tank.

To measure the free surface elevation of the incident waves, a series of wave probes are used. A line of five probes were placed in front of the models and an additional probe was installed close to the wall of the wave basin directly in line with the front of the models when they were at rest. The additional wave probe is used to determine the actual free surface elevation as close as possible to the models. Figure 49 shows the five wave probes that are in front of the models, such that the incident wave is measured before reaching the models.

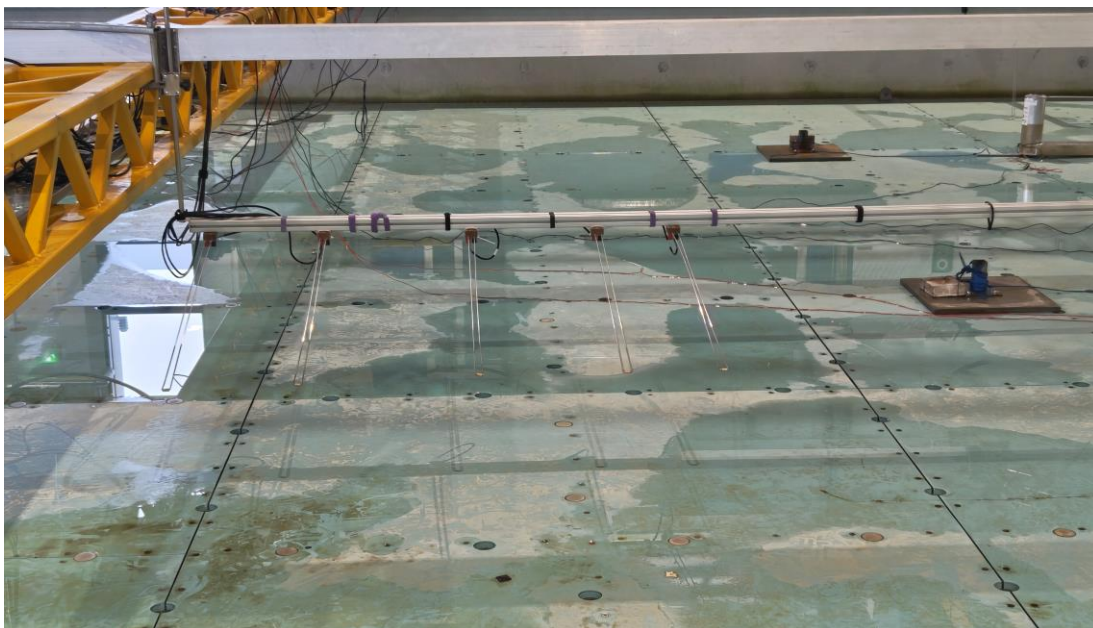


Figure 49. Five wave probes attached to the instrument bridge of the DOB.



Figure 50. Futek load cell during calibration process.

To measure the mooring forces, a series of 50N and 500N load cells were used. The Futek LSB210 Submersible miniature S-Beam Jr. load cells were chosen to measure line tension due to their small form factor and low weight. Figure 50 provides an example of these LCs used for the line tension measurement. Each load cell has the eyes attached to the top and bottom with a light weight neutrally buoyant string tied in a loop around the eye. These loops allow the LC to be attached to the mooring lines and fairleads. The 50N load cells were reserved for the mooring lines that required the higher resolution measurements while the 500N load cells were used for mooring lines deemed less vital for the resolution of the 50N load cells.

5.1.2.3 *Mass properties validation*

The mass properties were measured to validate the models against the CAD specifications. The models were weighed on a scale to measure the total mass of each configuration. The scales used to measure the mass of the platforms was an ADAM GFK150 scales with an accuracy of 150kg x 0.01kg. A trifilar was set up to experimentally measure the I_{zz} of the models in each configuration. A trifilar system is a suspension system that makes use of three equal-length ropes to suspend a platform for moment of inertia measurements. The ropes were attached to points on the platforms equidistant from the point of the centre of gravity of the platform and a small displacement about the vertical axis was induced before allowing the platform to oscillate freely.

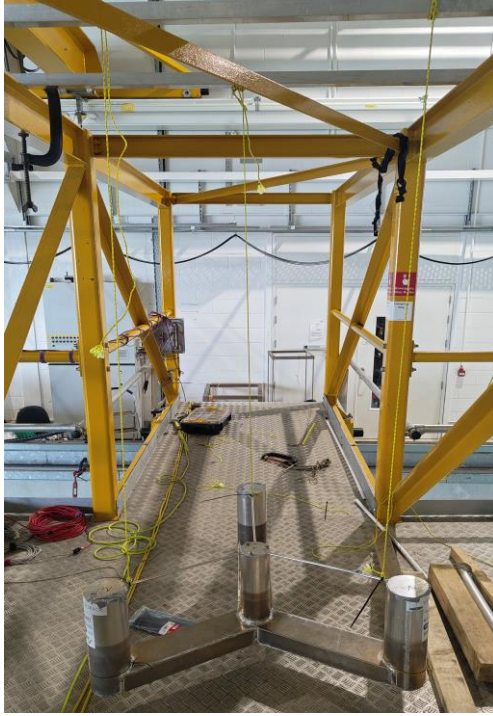


Figure 51. Trifilar experimental setup with the Bantry Bay model configuration in place.

Figure 51 shows the trifilar setup for the Bantry Bay configuration. The yellow rope is attached to angle iron at the top and attached close to the outer columns on the bottom. A stopwatch was used to measure the time taken for 10 oscillations, measured three times to obtain a mean. This value could then be used to determine the period of the oscillations and, using Equation 1, the value of I_{zz} was calculated. This process was repeated for each configuration.

$$I_{zz} = \frac{mgR^2T^2}{4\pi^2L} \quad (1)$$

I_{zz} is the moment of inertia about the z-axis (kg.m^2), m is the mass of the object (kg), g is the gravitational acceleration (m.s^{-2}), R is the radial distance from the centre of mass to the rope attachment point on the object (m), T is the oscillation period (s) and L is the length of the suspending ropes (m).

The inertial properties of the models about the x and y axes were measured using a bifilar setup, which is the same principle as the trifilar experiment but makes use of two points to suspend the model attached to the outer columns at the vCoG point. Equation 2 was used to determine I_{xx} and I_{yy} from the oscillations of the platform during the bifilar experiments.

$$T = 2\pi \sqrt{\frac{4Il}{Mgd^2}} \quad (2)$$

T is the period of oscillation (s), M is the mass of the model (kg), l is the length of the rope (m), g is the acceleration due to gravity (m.s^{-2}) and I is the moment of inertia of the platform about the axis of rotation (kg.m^2).

A plumb bob setup was used to determine the CoG of the operational configuration and the fully assembled Shannon Estuary configurations. The platform was suspended from a rope such that an angle of inclination was induced. The angle was then measured using the Qualisys cameras in the tank. The point in which the line suspending the platform intersects with the central column of the platform was marked and the distance from the centre of the central column to this point was measured.



Figure 52. Plumb bob experimental setup.

Figure 52 shows the plumb bob method setup. The crane is used to suspend the model from a rope at a point that is off the CoG such that a lean is induced in the platform. This angle was measured using the QTM cameras and the point in which the white rope intercepts the model distance from the vertical axis of the platform is measured. The vertical CoG was calculated using Equation 3.

$$vCoG = \frac{A}{\tan(\theta)} \quad (3)$$

A is the horizontal distance from the point of interception of the rope and the vertical axis of the platform and θ is the measured angle of the platform when suspended. Once the vCoG for these configurations were known, it was calculated for the FSS configurations using the mass and known vCoG of the tower and FIU configurations.

5.1.3 Tank testing configurations

Initial free decay tests to validate the behaviour of the platform were performed first, as no mooring system is used. Subsequently, the single platform conditions were tested for the Shannon Estuary environmental conditions. The single platform Bantry Bay test was performed next followed by the array tests for Bantry Bay and then the array tests for the Shannon Estuary. Additional depth is included in the tank testing due to the anchoring method being raised off the tank floor. The gamma was set to $\gamma = 3.3$ and remained constant for each JONSWAP spectrum. Further details are shown in Tables 26-28.

Table 26. Model scale conditions for Bantry Bay and Shannon Estuary configurations.

Parameter	Shannon Estuary	Bantry Bay
Scale (λ)	100	100
Water depth (m)	0.21	0.46
Max H_s (m)	0.02	0.08
Array layout	5x1	3x2

Table 27. Irregular wave parameters tested in the wave basin for the Shannon Estuary setup.

Shannon Estuary wave parameters	Wave 1	Wave 2	Wave 3
Spectrum type	JONSWAP	JONSWAP	JONSWAP
H_s (m)	0.02	0.02	0.02
T_p (s)	0.05	0.08	0.12
Wave heading (deg)	0	0	0

Table 28. Irregular wave parameters tested in the wave basin for the Bantry Bay setup.

Bantry Bay wave parameters	Wave 1	Wave 2	Wave 3
Spectrum type	JONSWAP	JONSWAP	JONSWAP
H_s (m)	0.08	0.08	0.08
T_p (s)	0.08	0.12	0.15
Wave heading (deg)	0	0	0

The wave parameters tested in the DOB for the models are the scaled down parameters determined from the 50-year return period identified at each site. The two sites are characterised by shallow water that is scaled down by 1:100 for the testing. This introduces the possibility of shallow-water effects on wave propagation within the tank. However, as this depth reflects the physical site characteristics, the test programme was designed around these conditions. The potential for depth-induced wave interaction was considered an inherent aspect of the Shannon Estuary and Bantry Bay environments.

5.1.4 Free decay tests

Decay tests were performed on each model configuration without mooring in the heave, roll and pitch DoFs. The model was placed in the tank with the QTM system recording the motion of the model, which is displaced in a single DoF and allowed to oscillate freely. This was repeated three times per DoF for each configuration to obtain the average decay behaviour of the model. The results were processed in MATLAB and damping coefficients were calculated for each DoF.

5.1.5 Platform RAO analysis

The response of the platforms across a range of frequencies is investigated via the RAO analysis, which makes use of an irregular wave defined by a broad spectrum in order to have significant energy distributed across a broad spectrum of frequencies. The motions of the platform in each DoF as a result of the wave excitation is converted from the time domain to the frequency domain via the Welch method [59]. The power spectral density of the wave and the platforms response in a single DoF can then be used to determine the RAO of the platform in a given DoF using Equation 4 [59]:

$$RAO = \sqrt{\frac{S_{xx}(\omega)}{S_{\eta\eta}(\omega)}} \quad (4)$$

$S_{xx}(\omega)$ is the power spectral density (PSD) of the platform's motion in a given DoF and $S_{\eta\eta}(\omega)$ is the PSD of the wave calculated from the time series of the free surface elevation.

5.1.6 Shannon Estuary mooring and anchors

The mooring lines used for the Shannon Estuary tests were composed of a rope segment and two springs. The springs were selected to match the force displacement curve obtained from the numerical model. Each line contains a low stiffness spring and a high stiffness spring. The low stiffness spring is used to replicate the mooring behaviour for small platform displacements, and the high stiffness spring is used to replicate the mooring response under high platform displacements. To ensure that the low stiffness spring only acted within the small displacement range determined from the force displacement curve, its extension was limited using a string tied between each end of the spring. This string prevents extension beyond the target limit. Once this threshold was reached, any further extension is provided from the high stiffness spring.

Tension was measured with the LC installed in line with the mooring system. The LC was connected directly from the fairlead to the end of the spring assembly. The total length of the mooring line included the LC and the additional string used to connect it to the spring and fairlead. Figure 53 illustrates this arrangement. The larger diameter spring (on the right) is the low stiffness spring, and the smaller diameter spring (on the left) provides the higher stiffness. The string used to limit the extension of the

low stiffness spring can be seen protruding from each end. Large LCs were attached to the floor of the tank using channel iron to act as anchors and to measure the vertical loads acting on the anchors.



Figure 53. Spring setup used for mooring lines in the DOB.

Figure 54 provides an example of the mooring setup before the floor of the tank is lowered to the appropriate depth. The holes in the tank allow for the anchoring systems to be attached to the floor. To set the anchor positions in the correct locations, channel iron was attached to the floor in two locations such that the target anchor point was between the two attachment points. If a load cell was being used to measure uplift forces, it was attached to the channel iron and the mooring line was attached to the other side of the LC. Otherwise, 13mm bolts were attached to the channel iron and a combination of nuts and spacers were used to set the anchor point to the same height as the LCs. This method was consistent for every configuration tested in the DOB.

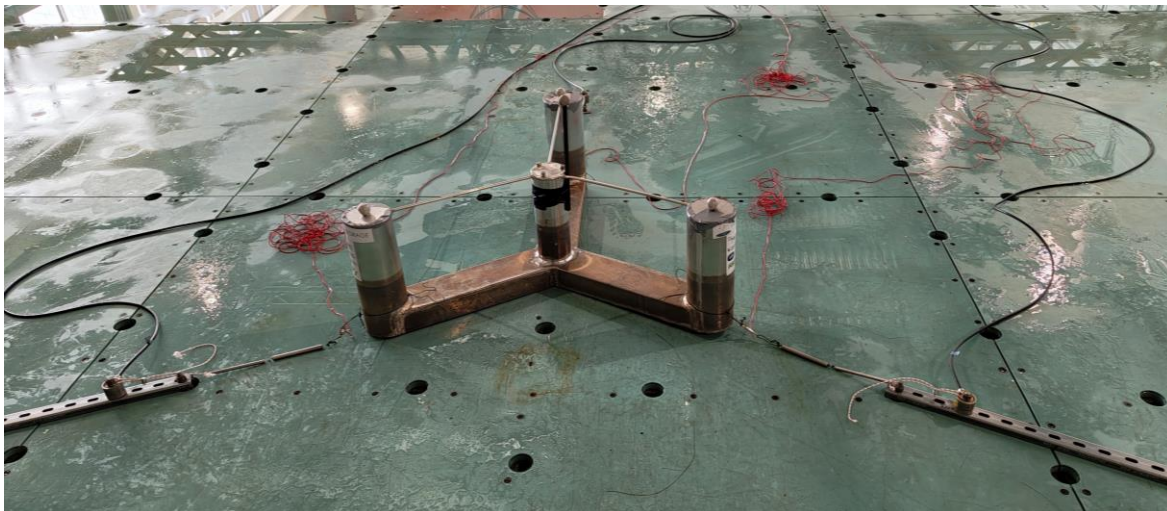


Figure 54. Dry experimental setup of the singular FSS model.

Figure 55 shows an example of the anchor point previously described. In this case, channel iron is not used. A 20mm steel plate is adopted for the anchor points in which the channel iron could not be reached. These anchor points are reserved to the rightmost positions in the tank where no measurements are recorded. Additionally, these anchor points were used only for the array tests. Figure 56 shows the

single FIU model test configuration in the DOB. No steel plates are in use for anchoring in this case. The location of the wave probes relative to the model can be seen in the image. Figure 57 shows the Shannon Estuary FSS array test setup. Both channel iron and steel plate anchoring methods are visible in the image of this configuration along with the additional wave probe which can be seen mounted to the wall of the DOB in the foreground of the image. Figure 57 also provides a reference of the scale of the wave used for the Shannon Estuary test conditions.



Figure 55. Anchor point used for wave basin tests.

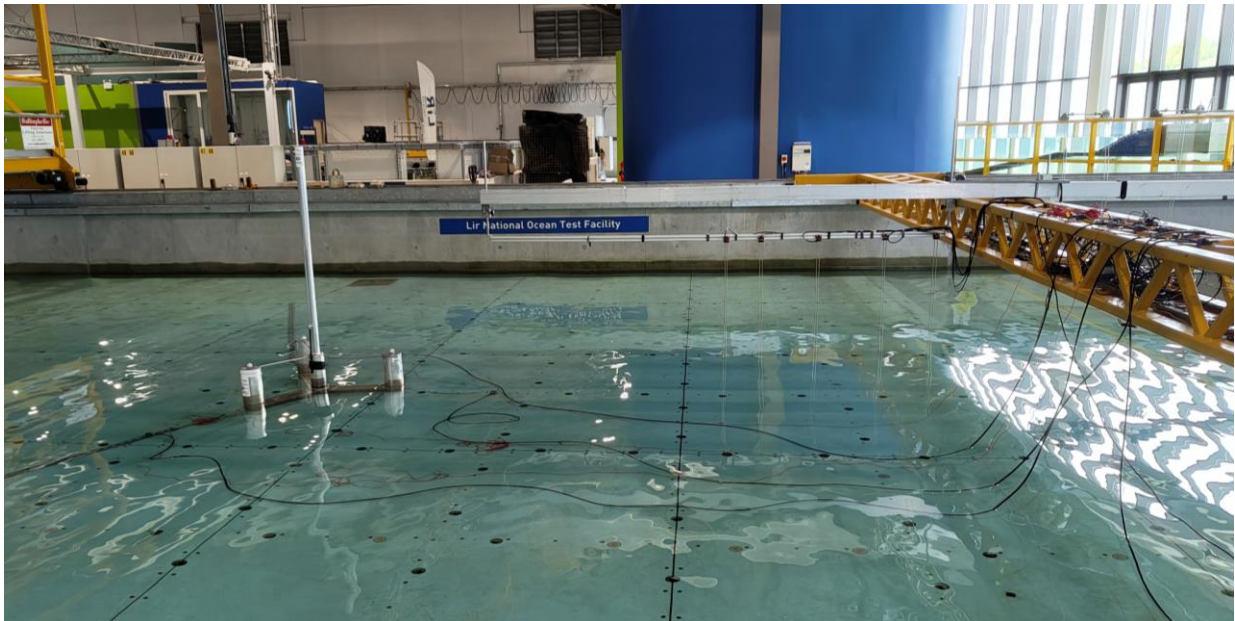


Figure 56. Shannon Estuary FIU model setup.

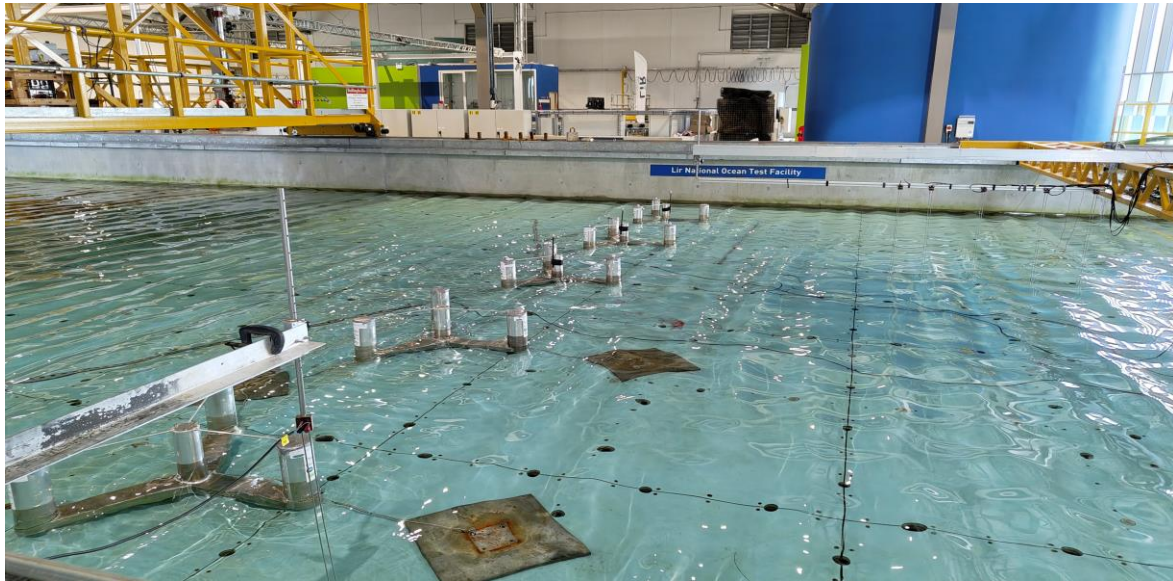


Figure 57. Shannon Estuary FSS array test.

5.1.7 Bantry Bay mooring and anchors

The mooring line composition and anchoring methods remain consistent across the Bantry Bay and Shannon Estuary configurations. The spring properties and line lengths are different for each water depth configuration. Figure 58 shows the test setup for the Bantry Bay FSS array tests. This image provides a good reference for the waves used in the test condition as well as the diffracted and reflected waves from the platforms. The image also provides a view of the tracking markers attached to the models for the QTM system. The three leftmost models are tracked for each array (Shannon Estuary and Bantry Bay layouts).

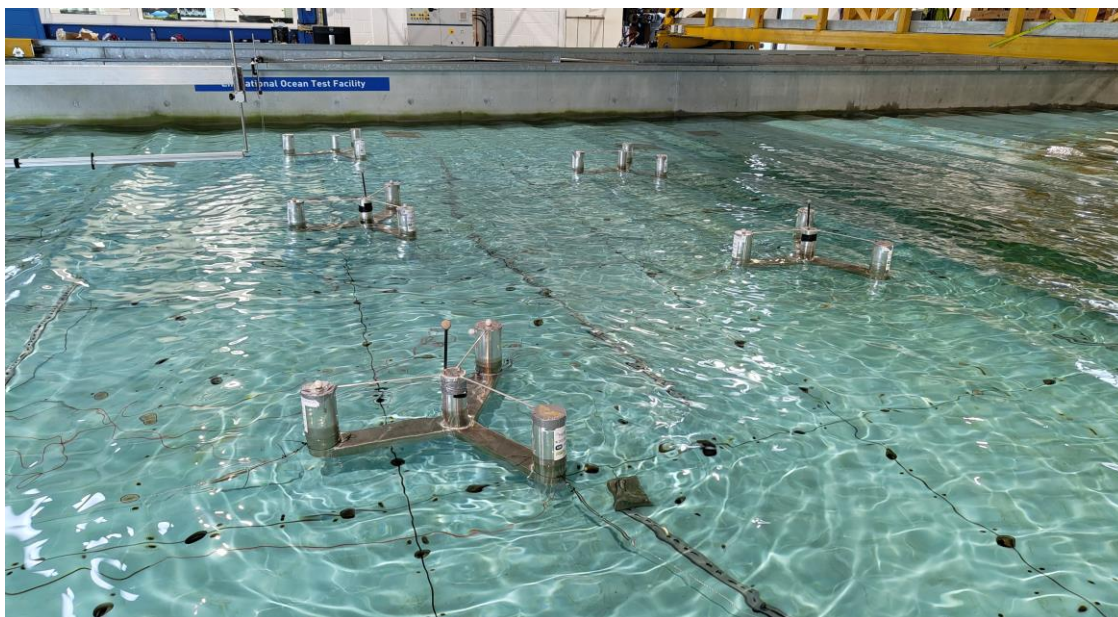


Figure 58. Bantry Bay FSS array test setup.

5.2 Results

5.2.1 Platform mass properties validation

5.2.1.1 Moments of inertia

The trifilar and bifilar results are summarized and tabulated in Table 29. The relative errors are comparing the measured results of the physical models to the moments of inertia predicted by the CAD model used for the fabrication process. As shown in the table, the moment of inertia about the z-axis is within 5% relative error for each configuration, with the lowest error of 0.51% on the Shannon Estuary stand-alone configuration and the largest error of 2.3% on the operational condition model. The numerical models within ANSYS AQWA make use of the measured properties of the platforms to ensure a reliable representation numerically.

Table 29. Summary of the trifilar results for each configuration.

Model configuration	Mean period (s)	Mass (kg)	I_{zz} (kg.m ²)	I_{zz} relative error for CAD and fabricated model (%)
Operational (model scale)	2.02	19.48		19.48
(full scale)	-			
Shannon Estuary FIU (model scale)	1.75	(19.48×10 ⁶)	2.35	(19.48×10 ⁶)
(full scale)	-			
Shannon Estuary FSS (model scale)	2.02	(2.35×10 ¹⁰)	2.301	(2.35×10 ¹⁰)
(full scale)	-			
Bantry Bay (model scale)	2.11	16.87		16.87
(full scale)	-			

In Table 30, the moment of inertia about the x-axis is within 6% relative error for each configuration except for the Shannon estuary FSS model, with the lowest error of 1.12% on the Shannon Estuary FIU configuration and the largest error of 63.7% on the Shannon Estuary FSS model. The errors listed in the table are comparing the measured moments of inertia against the values calculated in SolidWorks before fabrication. Therefore, the numerical models are updated with the measured results provided.

Table 30. Summary of the bifilar results for each configuration.

Model configuration	Mean period (s)	Mass (kg)	I_{xx} (kg.m ²)	I_{zz} relative error for CAD and fabricated model (%)
Operational (model scale)	1.80	-	1.80	-
Operational (full scale)				
Shannon Estuary FIU (model scale)	-	19.48	-	19.48
Shannon Estuary FIU (full scale)				
Shannon Estuary FSS (model scale)	(19.48×10 ⁶)	3.12	(19.48×10 ⁶)	3.12
Shannon Estuary FSS (full scale)				
Bantry Bay (model scale)	(3.12×10 ¹⁰)	3.18	(3.12×10 ¹⁰)	3.18
Bantry Bay (full scale)				

5.2.1.2 Plumb bob and CoG

The operational configuration and the Shannon Estuary FIU configuration plumb bob results are shown in Table 31. These results were used to determine the vCoG of the other model configurations.

Table 31. Plumb bob results to calculate the vCoG for the various configurations.

Parameter	vCoG from keel (m)
Operational condition	13.35
Shannon Estuary FIU	17.84
Shannon Estuary FSS	5.80
Bantry Bay	5.45

5.2.2 Decay

The exponential fit is evaluated using the normalised RMS error value (NRMSE). A NRMSE value below 10% is deemed to be a suitable fit for the exponential decay curve. Figures 59-61 illustrate the time series decay motion of the platform in each configuration in heave, roll and pitch. The legend provides the average period between crests at model scale. This is the value that is used to determine the full-scale natural period of the platform in each configuration.

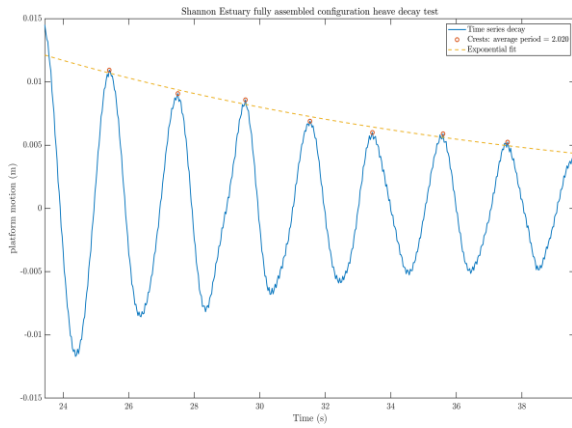


Figure 59. Shannon Estuary FIU time series heave decay.

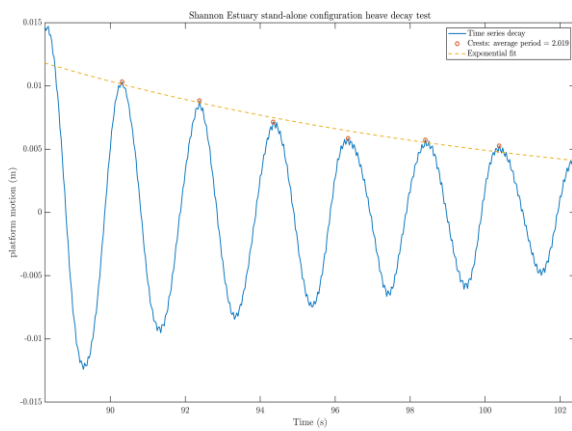


Figure 60. Shannon Estuary FSS time series heave decay.

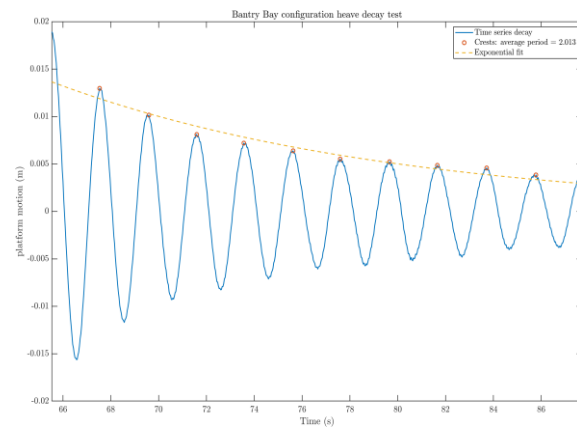


Figure 61. Bantry Bay FSS time series heave decay.

Tables 32-34 provide the comparison of the natural period of each model configuration found through the numerical and experimental analysis as well as the full-scale damping coefficients calculated through the experimental decay tests which has been scaled up and applied to the numerical model.

Table 32. Heave decay results.

Heave decay	Experimental T_n (s)	Numerical T_n (s)	B (Ns.m ⁻¹)	T_n relative error (%)
Shannon Estuary FIU	20.02	21.13	2.033×10^5	5.54
Shannon Estuary FSS	20.19	21.13	2.244×10^5	4.66
Bantry Bay	20.13	20.46	2.734×10^5	1.64

Table 33. Roll decay results.

Roll decay	Experimental T_n (s)	Numerical T_n (s)	B (Ns.deg ⁻¹)	T_n relative error (%)
Shannon Estuary FIU	22.84	24.31	8.029×10^5	6.44
Shannon Estuary FSS	14.17	15.27	1.537×10^6	7.76
Bantry Bay	14.22	15.27	2.040×10^6	7.38

Table 34. Pitch decay results.

Pitch decay	Experimental T_n (s)	Numerical T_n (s)	B (Ns.deg ⁻¹)	T_n relative error (%)
Shannon Estuary FIU	22.72	24.31	7.287×10^6	6.99
Shannon Estuary FSS	14.12	15.27	1.247×10^6	8.14
Bantry Bay	14.20	15.27	2.195×10^6	7.53

5.2.3 Station keeping performance

The following section provides the results obtained through physical tank testing and the numerical model related to the station keeping performance of the mooring systems. Station keeping performance describes the platform's ability to maintain its intended position under environmental loading. The station keeping is evaluated by the maximum horizontal excursions in surge and sway, as well as the RAOs in surge.

The maximum excursion results presented are for the Wave 3 load cases (0 degree wave heading, $H_s = 2\text{m}$ and $T_p = 12\text{s}$). This load case resulted in the largest excursions for the Shannon Estuary test conditions. Figure 62 shows the platform excursions from the time series surge and sway motions for the FIU in the Shannon Estuary. The red circle is the radius around the resting position of the maximum excursion from the origin of the platform. The maximum excursion reached by the platform is 1.38m at full scale.

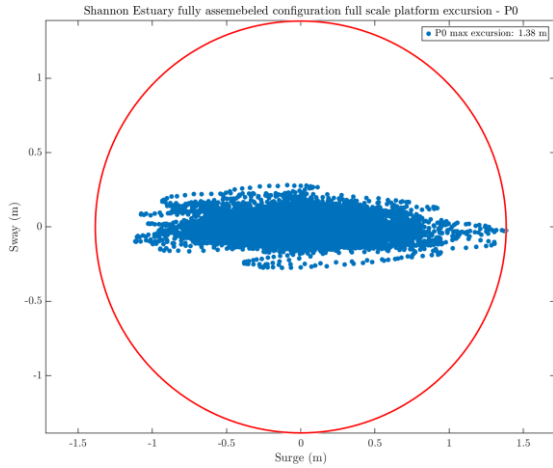


Figure 62. Shannon Estuary FIU single platform time series motion in surge and sway.

The maximum offset from the origin achieved by the platform in the Shannon Estuary FSS layout is 1.12m, as shown in Figure 63. Figure 63 compares the platform excursions in the array layout. This is 1.07m (0.05m less than for that of the single platform test).

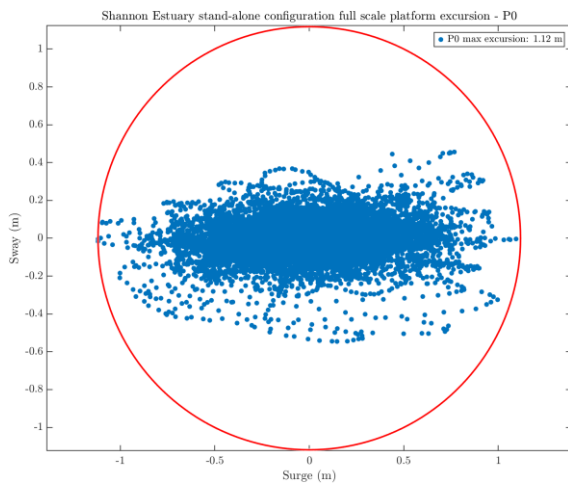


Figure 63. Shannon Estuary FSS single platform time series motion in surge and sway.

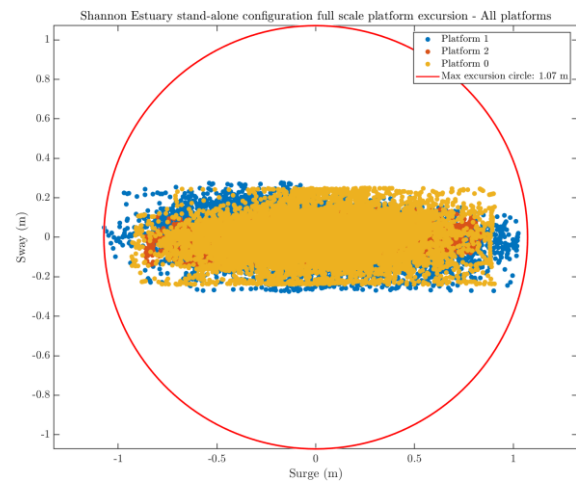


Figure 64. Shannon Estuary FSS array time series motion in surge and sway.

The RAO results were experimentally tested in the DOB with a broad-spectrum wave. Figure 65 and Figure 66 plot the surge RAOs calculated from the time series wave elevation and surge motion measured in the DOB for the FIU and the FSS models respectively. Figure 66 also shows the spectra calculated for the FSS platforms in the array as well as the single platform layout for comparison.

The surge RAO across the FIU and the FSS models show a sharp increase in the magnitude at low frequencies up to the peak frequency with an exponential decrease in magnitude as frequency increases. The FIU reaches its maximum magnitude at $f = 0.02188\text{Hz}$. The single platform has a peak frequency of $f = 0.02813\text{Hz}$. The surge peak frequency of P0 in the array = 0.02813Hz . The peak frequency for

P0 in the array differs to the peak frequency of P0 in the single platform tests by 0.0031Hz, a relative difference of 12.4 %. In the array, $P1 = 0.03125\text{Hz}$ and $P2 = 0.03125\text{Hz}$.

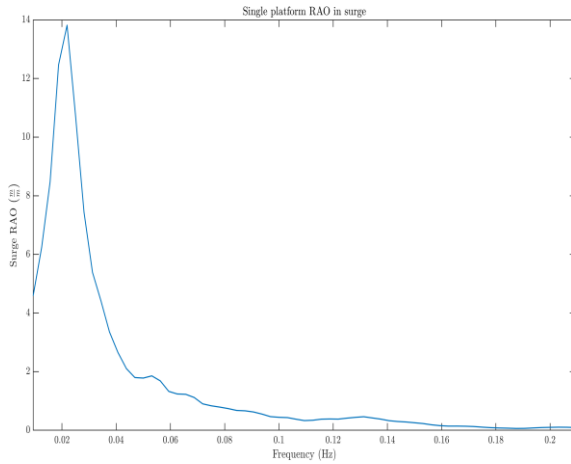


Figure 65. Shannon Estuary FIU single platform surge RAO.

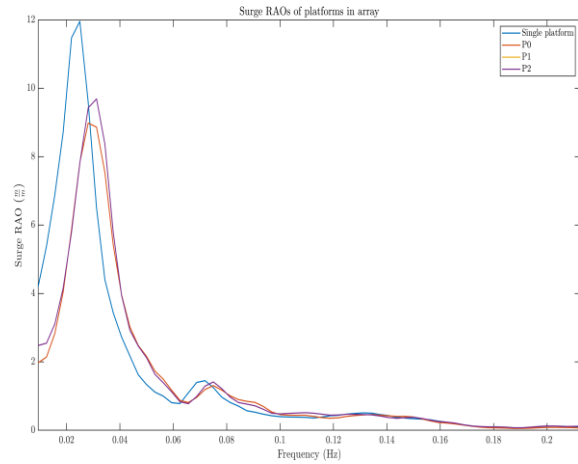


Figure 66. Shannon Estuary FSS array configuration surge RAO.

The wave conditions used for the Bantry Bay analysis are the Wave 3 conditions. Again, this wave was chosen due to the maximum excursions measured during testing for these conditions. The full-scale surge and sway motions for the Bantry Bay scenario are significantly greater than for the Shannon Estuary, with the maximum extent of the displacement from the origin of the platform in Bantry Bay at 7.69m and the Shannon Estuary FIU reaching a maximum excursion of 1.38m. Similar to the Shannon Estuary stand-alone layouts, the maximum excursion reached by any of the models in the array layout is less than that of the model in the single platform layout. The maximum excursion in the array = 6.44m, which is 1.25m less than the single platform case. Time-series results are shown in Figure 67 and Figure 68. A summary of the excursion analysis particulars is provided in Table 35.

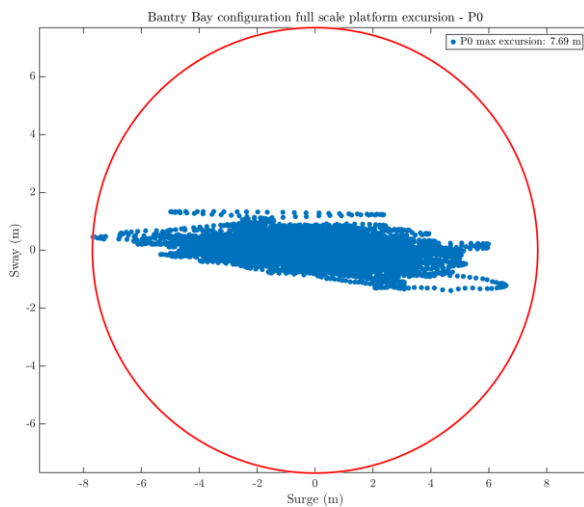


Figure 67. Bantry Bay single platform time series motion in surge and sway.

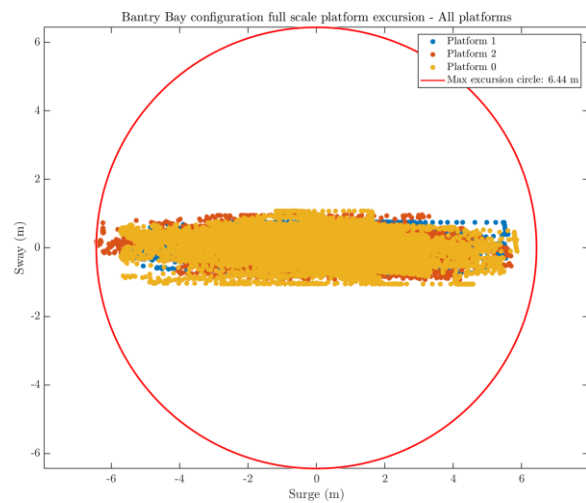


Figure 68. Bantry Bay array time series motion in surge and sway.

Table 35. Summary of the maximum excursions across each platform in the different configurations.

Scenario	P0 single max excursion (m)	P0 max excursion (m)	P1 max excursion (m)	P2 max excursion (m)
Shannon Estuary FIU	1.38	NA	NA	NA
Shannon Estuary FSS	1.12	0.94	1.07	0.87
Bantry Bay FSS	7.69	5.87	5.62	6.44

For the Bantry Bay array, the platform in the second row achieves a greater maximum excursion than the two platforms in the front row. The leftmost platform in the Shannon Estuary array achieves the greatest excursion in that configuration. The leftmost platform in the Bantry Bay array also achieves a greater maximum excursion compared to the other platform in the same row.

The numerical results obtained from the analysis conducted in ANSYS AQWA are provided in Table 36 for the FSS platforms in the Shannon Estuary and Bantry Bay singular platform and array layouts. It is evident that the AQWA model significantly overestimates the maximum excursions of the models when compared to the results obtained through the physical testing. The overestimation is significantly greater in the Shannon Estuary tests when compared to the Bantry Bay results. The maximum relative error on the maximum excursion in Bantry Bay is obtained by P1 in the array, with an error of 48% and the minimum obtained by the P0 solitary platform having an error of 1.56%. The minimum error obtained for the Shannon Estuary numerical simulations is again on P0 in the single platform layout, with an error of 108% and a maximum error of 240% on P2 in the array.

Table 36. Numerical model excursion results.

Scenario	P0 single max excursion	P0 max excursion	P1 max excursion	P2 max excursion
Bantry Bay Numerical Results (m)	7.81	8.39	8.34	7.68
Bantry Bay Relative error (%)	1.56	42.93	48.40	19.25
Shannon Estuary Numerical Results (m)	2.33	2.83	2.81	2.96
Shannon Estuary Relative error (%)	108.03	201.06	162.62	240.23

As for the Bantry Bay RAO results, Figure 69 provides the surge spectra for the solo platform and array configuration of each platform. In surge, the single platform peak frequency varies slightly compared to the platforms in the array. The peak frequency of the platforms in the array is 0.02500Hz, whereas the peak frequency for the stand-alone platform is 0.02188Hz. The shift in the peak frequency is 0.0031Hz, which is a relative difference of 14.2%.

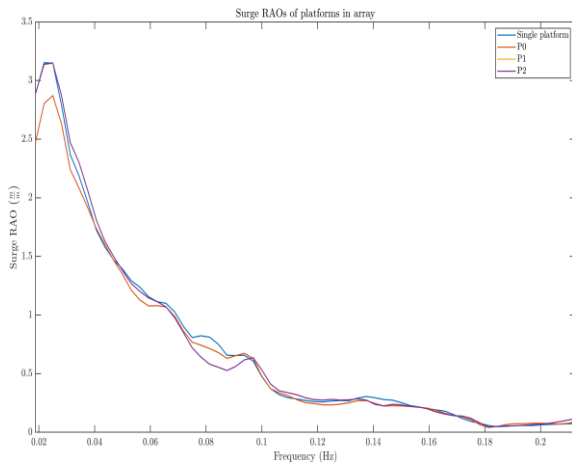


Figure 69. Bantry Bay surge RAO for singular platform and platforms in an array.

Table 37 provides a summary of the surge peak frequency results for the Shannon Estuary FIU, FSS singular platform and platforms in an array as well as the Bantry Bay singular platform and platforms in an array. The singular platforms for the Shannon Estuary FIU and Bantry Bay FSS configuration have matching peak frequencies, whereas the Shannon Estuary FSS singular platform surge peak frequency matches that of the Bantry Bay platforms when moored in an array.

Table 37. Summary table of surge RAO peak frequency results.

Scenario	Single platform	P0	P1	P2
Shannon Estuary FIU platform surge f_p (Hz)	0.02188	NA	NA	NA
Shannon Estuary FSS platform surge f_p (Hz)	0.025	0.02813	0.03125	0.03125
Bantry Bay FSS surge f_p (Hz)	0.02188	0.025	0.025	0.025

The accelerations experienced by the nacelle during wet storage were numerically modelled in ANSYS AQWA for the Shannon Estuary FIU only, as this is the sole configuration in which the nacelle is considered. Three DoFs are considered in this analysis; surge, heave and pitch, as they result in the highest acceleration magnitudes. Figure 70 shows the time series acceleration in surge and heave and the rotational acceleration in pitch.

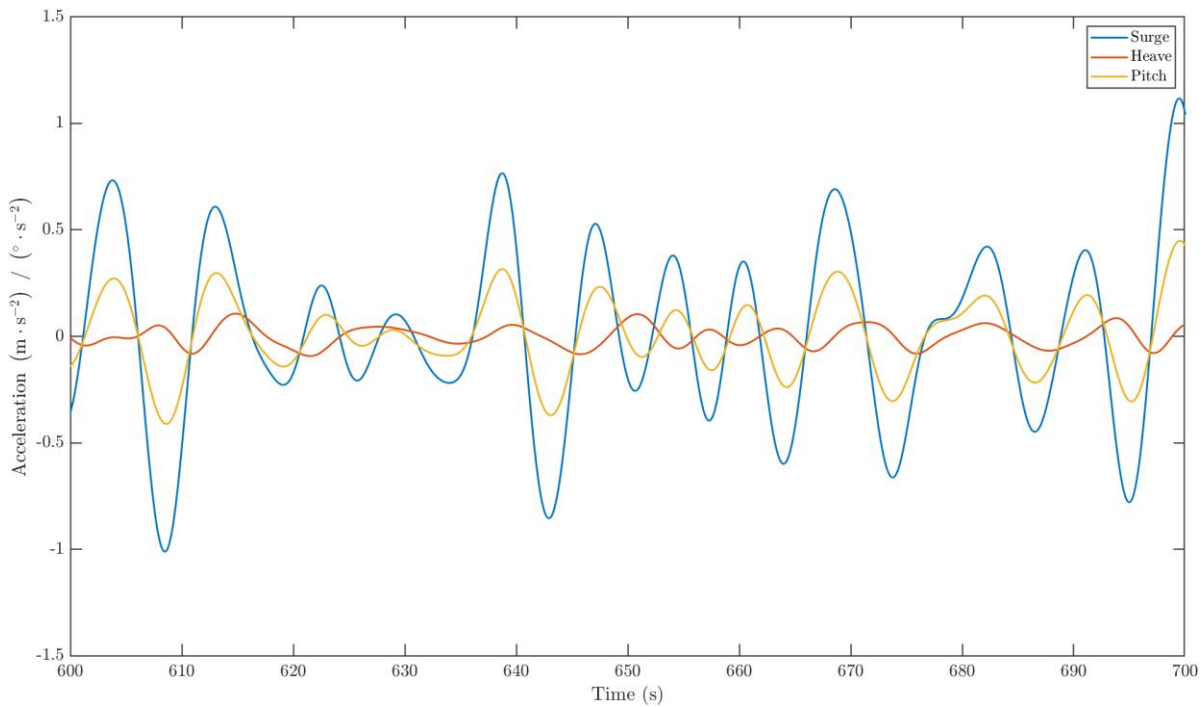


Figure 70. Shannon Estuary FIU nacelle accelerations.

For the corresponding statistical results provided in Table 38, the peak value represents the absolute maximum acceleration at the nacelle. The mean is that of the absolute accelerations in order to evaluate the magnitude of the mean acceleration experienced at the nacelle independent of direction. The surge obtains the largest accelerations across the statistical results provided below when compared to the heave accelerations. A direct comparison cannot be made with the pitch accelerations due to the pitch being rotational acceleration, where the surge and heave are linear acceleration.

Table 38. Shannon Estuary FIU nacelle acceleration statistics.

Parameter	Peak values	Mean	RMS	95 th percentile
Surge (m.s ⁻²)	1.452	0.383	0.475	0.933
Heave (m.s ⁻²)	0.241	0.052	0.065	0.125
Pitch (deg.s ⁻²)	0.613	0.171	0.211	0.410

5.2.4 Mooring forces

Figure 71 provides reference for examining the individual line results on each platform configuration. The anchors will be discussed as A1, A2 and A3. The lines are referred to as L1, L2 and L3. The incident wave direction is towards A1/L1 as shown.

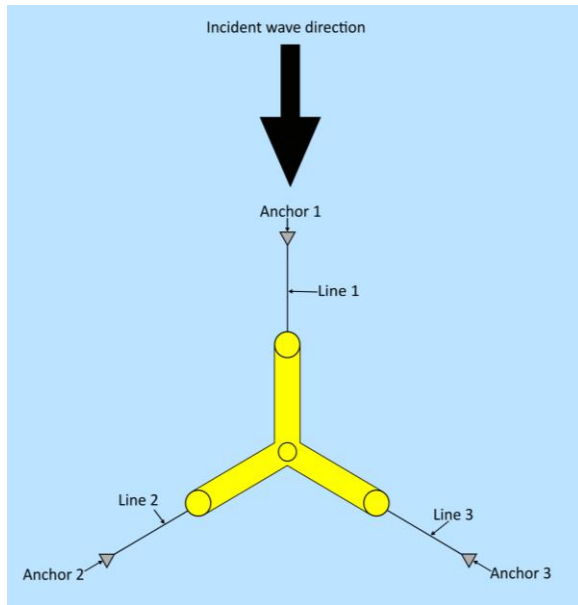


Figure 71. Illustration of line and anchor notation.

5.2.4.1 Shannon Estuary FIU – line tensions

Figure 72 shows the time series of tension acting on L1 for the Shannon Estuary FIU at full scale. Some statistical results are provided in Table 39 for each mooring line measured in this test setup. L1 and L3 obtain the same maximum tension. L3 obtains a higher mean value and the SD of the tension on L1 is larger than that of L3. These results make it difficult to determine which line maintains higher maximum loads throughout the time series due to the limited resolution of the load cells available.

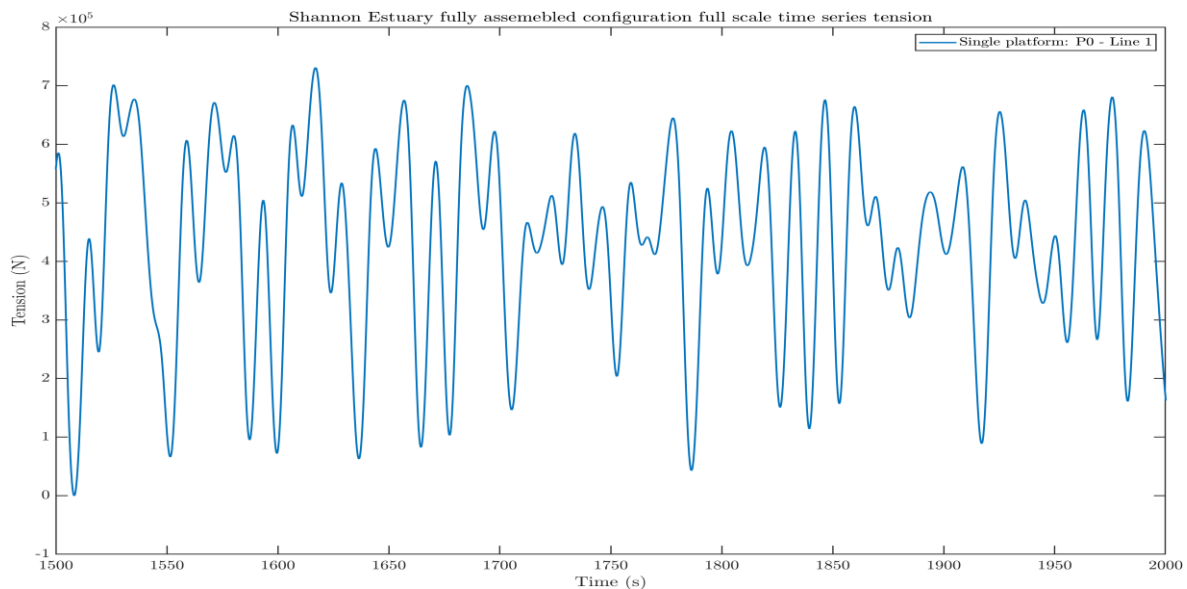


Figure 72. Section of the time series tension on L1 for the FIU model at the Shannon Estuary.

Table 39. Summary of the statics of the forces acting on the mooring line for the Shannon Estuary FIU.

P0 (single)	Max (MN)	Min (MN)	Mean (MN)	RMS (MN)	SD (MN)
L1	0.8	0.0	0.4	0.5	0.2
L3	0.8	0.3	0.5	0.5	0.1

The spectral analysis on the mooring lines measured for P0 are presented in Figure 73. Two peak frequencies exist for both L1 and L3. The low frequency peak of the curve for both lines occurs at 0.025Hz. The higher frequency peaks on each line are 0.07188Hz and 0.07969Hz for L1 and L3 respectively. The low frequency peak is close to the peak frequency of the surge RAO of this configuration. The maximum load on both L1 and L3 is below the maximum snatching limit of 10MN (Figure 73).

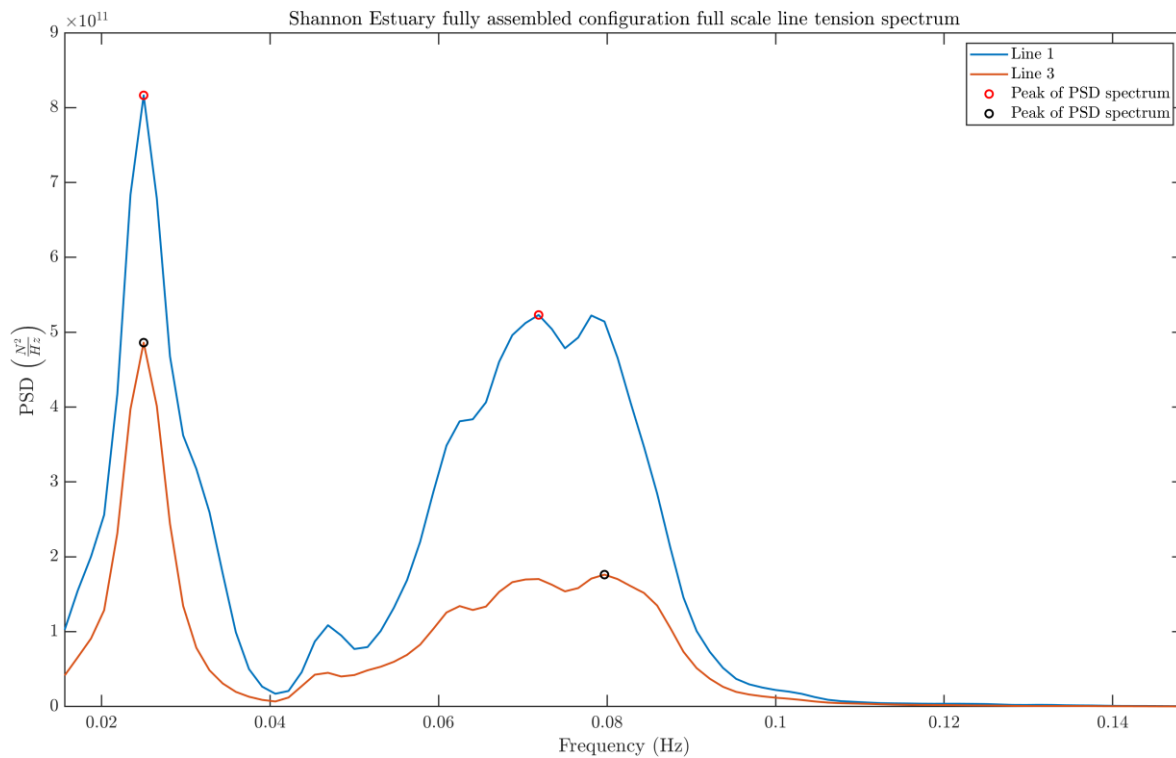


Figure 73. Shannon Estuary FIU line tension PSD plot.

5.2.4.2 Shannon Estuary – line tensions

As shown in Figure 74, the time series tension on L1 in the array configuration follows the curve of L1 in the single platform configuration. However, on average across the time series shown, the tension on the line in the array is higher than the line in the single platform configuration.

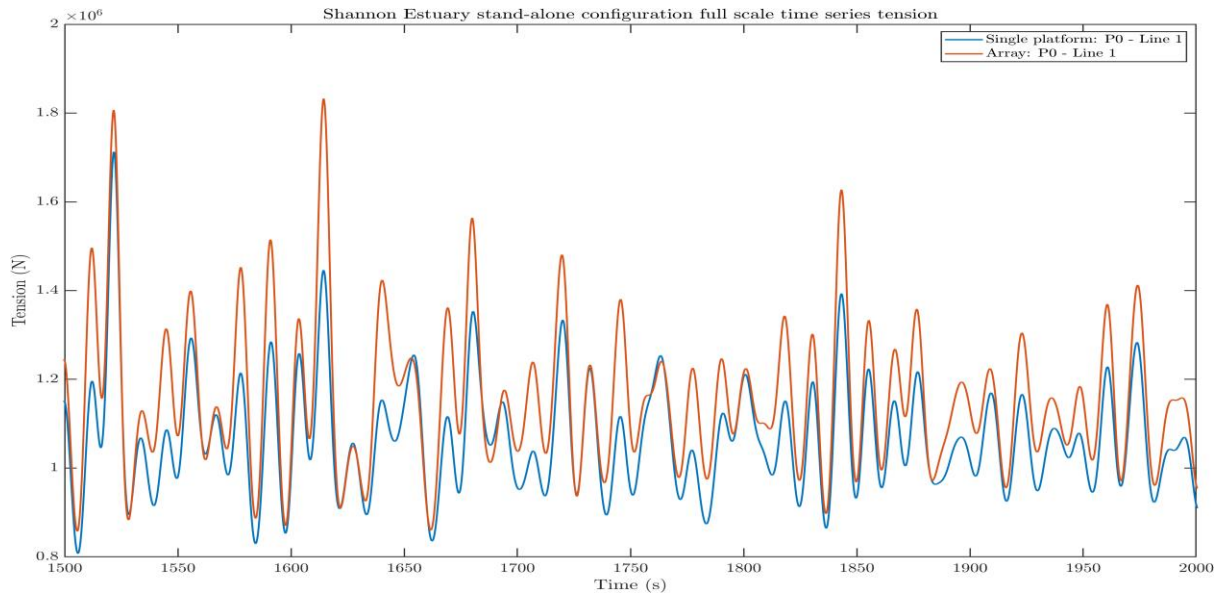


Figure 74. Section of the time series tension on P0-L1 in the Shannon Estuary FSS array and single platform configurations.

L2 in Figure 75 only has one dataset due to the setup of the tests. LCs were not installed on platforms P0 or P1 at L2. The same is true for Figure 76. The mooring loads on L1 and L3 increase on P0 when in an array compared to when tested without neighbouring platforms. P0 in this solitary case achieves greater maximum loads than the other platforms tested in the array. The RMS of the tension on the mooring lines is greatest on the central platform in the array (P0), similar to the maximum tension results. P2-L1 has the second highest RMS followed by P0 in the singular layout. P1-L1 obtains the lowest RMS.

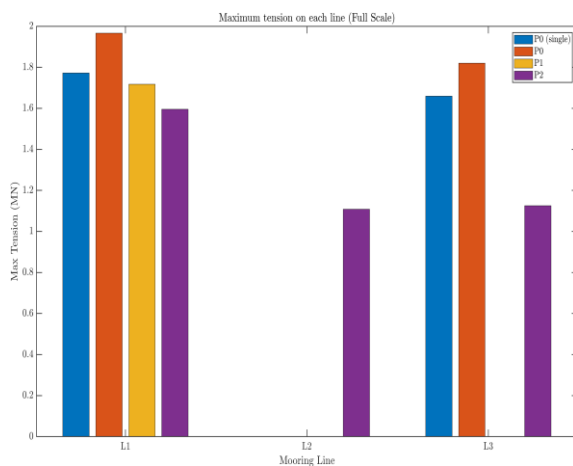


Figure 75. Bar chart of the maximum tension on each line, comparing Shannon Estuary FSS single platform and array configurations.

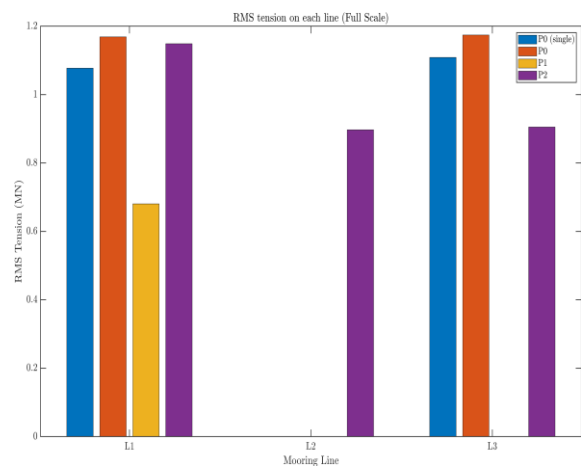


Figure 76. Bar chart of the RMS of the tension on each line, comparing Shannon Estuary FSS single platform and array configurations.

Tables 40-43 provide additional information regarding the statistical results of the forces acting on the mooring lines in each configuration. The maximum line tension achieved is on L1 in the array layout.

The mean and RMS on P1 are reduced when compared to the other platforms and P0 (single). It is also evident that the maximum loads experienced at each mooring line never reach the snatching load limit of 10MN. The spectral results for the Shannon Estuary FSS configuration are presented in Figure 77 and Figure 78. For the single platform and the array layout, a dual peak spectrum is created for the line tensions on both L1 and L3.

Table 40. Summary of the statics of the forces acting on the Shannon Estuary FSS single platform mooring lines.

P0 (single)	Max (MN)	Min (MN)	Mean (MN)	RMS (MN)	SD (MN)
L1	1.8	0.8	1.1	1.1	0.1
L3	1.7	0.9	1.1	1.1	0.1

Table 41. Summary of the statics of the forces acting on Shannon Estuary FSS P0 mooring lines.

P0	Max (MN)	Min (MN)	Mean (MN)	RMS (MN)	SD (MN)
L1	2.0	0.8	1.2	1.2	0.2
L3	1.8	0.9	1.2	1.2	0.1

Table 42. Summary of the statics of the forces acting on Shannon Estuary FSS P1 mooring lines.

P1	Max (MN)	Min (MN)	Mean (MN)	RMS (MN)	SD (MN)
L1	1.7	-0.1	0.6	0.7	0.3

Table 43. Summary of the statics of the forces acting on Shannon Estuary FSS P2 mooring lines.

P2	Max (MN)	Min (MN)	Mean (MN)	RMS (MN)	SD (MN)
L1	1.6	0.9	1.1	1.1	0.09
L2	1.1	0.8	0.9	0.9	0.04
L3	1.1	0.7	0.9	0.9	0.06

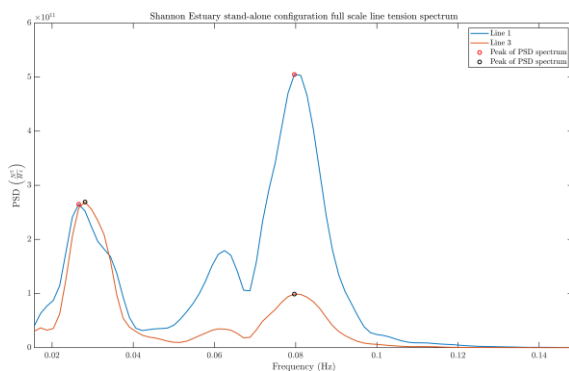


Figure 77. Shannon Estuary FSS - single platform configuration line tension PSD plot.

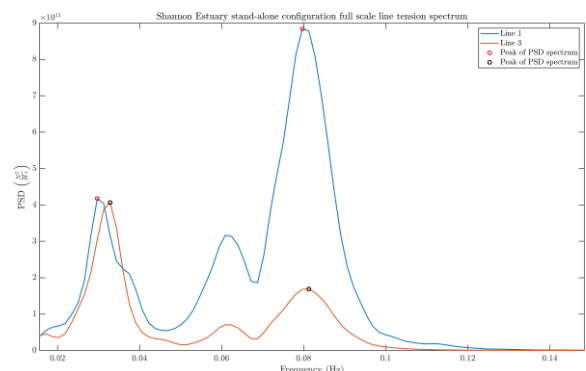


Figure 78. Shannon Estuary FSS - array configuration line tension PSD plot.

For the single platform tested in the DOB, the low frequency peak occurs at 0.0266Hz on L1 and 0.0289Hz on L3. This peak in the spectrum occurs close to the same frequency as the RAO peak

frequency of the models in surge ($f = 0.0219\text{Hz}$). The higher frequency peak is reached at 0.07812Hz and 0.0820Hz on L1 and L3 respectively. An additional peak of 0.0625Hz is evident on L1 and 0.0609Hz on L3. These frequencies are close to the pitch peak frequency in the platform's RAOs ($f = 0.0688\text{Hz}$).

The line tension PSDs for P0 in the array are similar to the single platform case. A dual peak curve is obtained for both L1 and L3. The low frequency peaks are achieved at 0.0297Hz and 0.0328Hz on L1 and L3 respectively, and the high frequency peaks occur at 0.0798Hz and 0.0813Hz on L1 and L3 respectively. Similar to the single platform case, an additional peak is achieved in both L1 and L3 close to the pitch RAO peak frequency with the smaller peak on L1 and L3 at 0.0609Hz .

5.2.4.3 Bantry Bay – line tensions

Contrary to the Shannon Estuary load case, Figure 79 shows that the line tension acting on P0-L1 in the single platform configuration is on average greater than P0 in the array layout. The statistical results for each line in the Bantry Bay tests are presented in Tables 44-47. The absolute maximum recorded force in the Bantry Bay tests is obtained at P1-L1. The largest mean tension force is also recorded at P1-L1. A negative mean and minimum tension are recorded at P2-L2, and a negative minimum tension is also recorded at P2-L3. The maximum tensions exerted on the mooring lines in the Bantry Bay configurations never reach the maximum snatching load of 10MN .

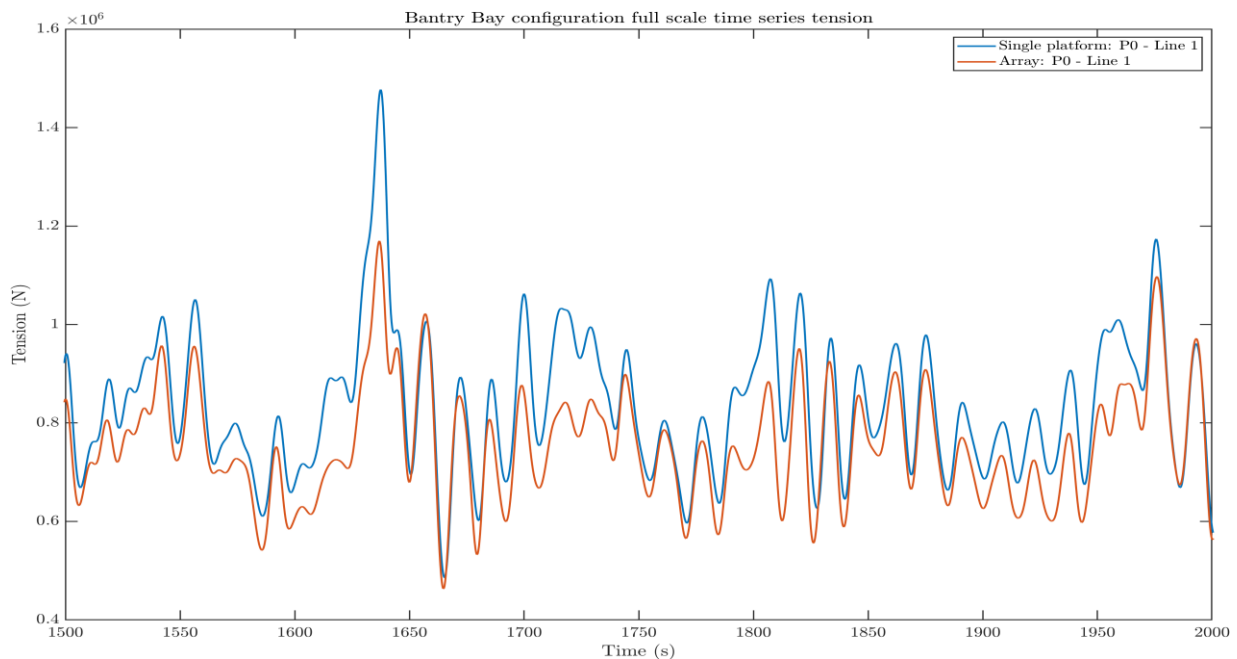


Figure 79. Section of the time series tension on P0-L1 for the Bantry Bay singular platform and array configurations.

Table 44. Summary of the statics of the forces acting on the Bantry Bay single platform mooring lines.

P0 (single)	Max (MN)	Min (MN)	Mean (MN)	RMS (MN)	SD (MN)
L1	1.48	0.49	0.84	0.85	0.14
L2	-	-	-	-	-
L3	1.22	0.64	0.81	0.81	0.06

Table 45. Summary of the statics of the forces acting on the Bantry Bay P0 mooring lines.

P0	Max (MN)	Min (MN)	Mean (MN)	RMS (MN)	SD (MN)
L1	1.4	0.5	0.76	0.78	0.13
L2	-	-	-	-	-
L3	1.0	0.6	0.75	0.74	0.05

Table 46. Summary of the statics of the forces acting on the Bantry Bay P1 mooring lines.

P1	Max (MN)	Min (MN)	Mean (MN)	RMS (MN)	SD (MN)
L1	1.6	0.6	0.98	0.99	0.15
L2	1.0	0.6	0.73	0.73	0.06
L3	1.1	0.6	0.82	0.83	0.08

Table 47. Summary of the statics of the forces acting on the Bantry Bay P2 mooring lines.

P2	Max (MN)	Min (MN)	Mean (MN)	RMS (MN)	SD (MN)
L1	1.6	0.6	0.92	0.94	0.12
L2	0.1	-0.4	-0.17	0.18	0.06
L3	0.7	-0.3	0.32	0.36	0.17

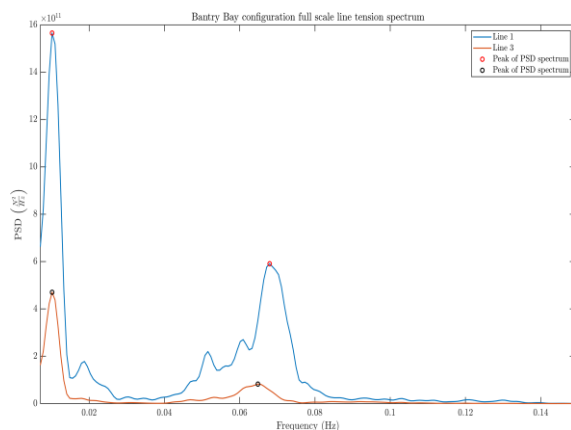


Figure 80. Bantry Bay - single platform configuration line tension PSD plot.

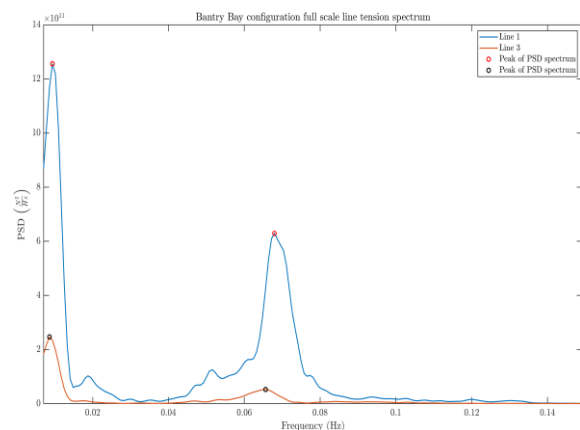


Figure 81. Bantry Bay - array configuration line tension PSD plot.

For the singular platform in Bantry Bay, the low frequency and high frequency peaks are observed at 0.0103Hz and 0.0675Hz respectively (Figure 80 and Figure 81), labelled f_{p1} and f_{p2} in Table 48. An additional minor intermediary peak is observed at 0.0516Hz. L3 has a low frequency peak close to that of L1, measured at 0.01Hz (the high frequency peak has shifted significantly compared to L1 with

the peak at 0.0648Hz). The peak frequencies of the line tensions acting on L1 for the same platform in the array layout were found to be 0.0094Hz and 0.0675Hz for the low and high frequency peaks respectively and 0.0084Hz and 0.0653Hz on L3. Again, a lower peak is observed on L1 at a frequency of 0.0516Hz.

Table 48. Line tension spectral analysis summary.

Scenario	L1 f_{p1} (Hz)	L1 f_{p2} (Hz)	L3 f_{p1} (Hz)	L3 f_{p2} (Hz)
Shannon Estuary FIU	0.0250	0.0719	0.0250	0.0797
Shannon Estuary FSS (singular platform)	0.0266	0.0781	0.0289	0.0820
Shannon Estuary FSS (P0 in array)	0.0297	0.0797	0.0328	0.0813
Bantry Bay (single platform)	0.0103	0.0675	0.0100	0.0648
Bantry Bay (P0 in array)	0.0094	0.0675	0.0084	0.0653

5.2.4.4 Shannon Estuary uplift forces

The uplift forces measured in the DOB could not be used due to inconsistent offsets and noise induced by the LCs used for measurement. The uplift forces instead are taken from the numerical model and a comparison between P0 in the single platform and array layouts is made. Single platform forces are greater than the forces on both the single anchor and the shared anchor in the array. Maximum force at A1 is reduced from 1.822MN to 1.184MN, a 35% reduction in an array. A3 experiences a 20% reduction in the array, going from 1.785MN to 1.420MN. Additionally, the mean values are significantly lower in the array when compared to the singular platform case, with a reduction of 80% in A1 and 94% in A3. For the singular platform case, A1 shows higher maximum uplifts than A3, but this reverses in the array layout test. In this case, Table 49 shows that the experimental uplift forces on the anchors exceed the 1MN limit, with A1 on the singular platform exceeding the limit by 0.822MN and the shared A3 in the array exceeding the limit by 0.42MN.

Table 49. Shannon Estuary uplift force results summary.

Scenario	Max (MN)	Mean (MN)	RMS (MN)	SD (MN)
Singular platform A1	1.822	0.1027	0.2554	0.2339
Singular platform A3	1.785	0.0951	0.2383	0.2200
Array A1	1.184	0.0206	0.0940	0.0918
Array A3	1.420	0.0566	0.1548	0.1441

5.2.4.5 Bantry Bay uplift forces

As with the Shannon Estuary tests, the uplift forces measured during testing for Bantry Bay are unsuitable for this analysis and are instead taken from the numerical model. A comparison between P0 for the singular platform and array layouts is made. Table 50 provides the statistical results obtained from the numerical modelling of the Bantry Bay test conditions.

Table 50. Bantry Bay uplift force statistical results.

Scenario	Max (MN)	Mean (MN)	RMS (MN)	SD (MN)
Single platform A1	1.822	0.1027	0.2554	0.2339
Single Platform A3	1.785	0.0951	0.2383	0.2200
Array A1	0.0764	0.0013	0.0040	0.0038
Array A3	0.2157	0.0034	0.015	0.014

Singular platform forces are greater than the forces on both the single anchor and the shared anchor in the array. Maximum force at A1 is reduced from 1.822MN to 1.184MN, a 35% reduction. A3 experiences a 20% reduction in the array, from 1.785MN to 1.420MN. Additionally, the mean values are significantly lower in the array when compared to the singular platform case, with a reduction of 80% in A1 and 94% in A3. For the singular platform case, A1 shows higher maximum uplifts than A3, but this reverses in the array layout test. The uplift forces exerted on the singular platform exceed the 1MN limit, but the array layout maintains uplift forces below 1MN, even on the anchor shared between three mooring lines at A3.

5.2.5 Platform motion response results

The following section provides results that are linked to the platform's motion response to wave interactions and not the response of the station keeping performance of the mooring system. The RAO results are determined using the same method as for the surge results provided in Section 5.2.3. Figure 82 and Figure 83 plot the heave and pitch RAOs of the singular FIU in the Shannon Estuary. The heave RAO approaches close to 1m/m as the frequency decreases. For frequencies greater than the peak frequency, the magnitude approaches 0m/m. A similar trend exists in the pitch RAO with the magnitude approaching 0.5 degrees/m at the lower frequencies. The peak frequencies calculated for heave and pitch are 0.04688Hz and 0.04375Hz respectively.

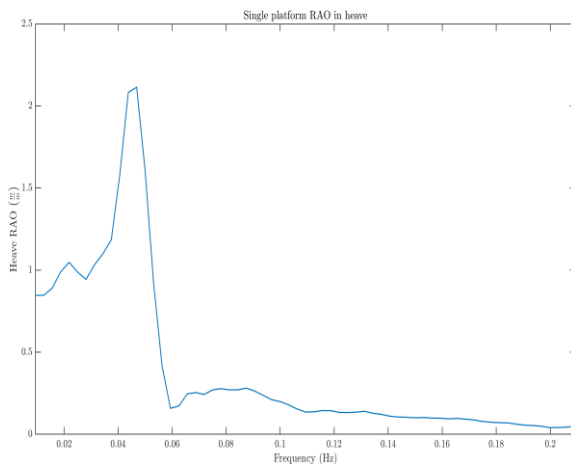


Figure 82. Shannon Estuary FIU singular platform heave RAO.

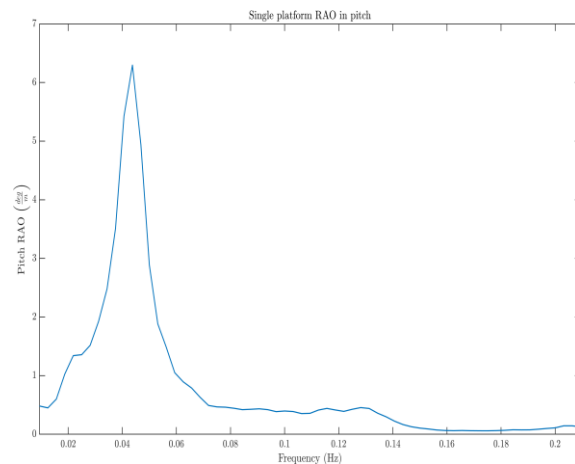


Figure 83. Shannon Estuary FIU singular platform pitch RAO.

The pitch and heave results for the FSS platforms in an array are presented in Figure 84 and Figure 85 respectively. The heave and pitch RAOs demonstrate a consistent spectrum across each platform in the array and the solitary platform. The heave frequency for all platforms in the array is 0.04688Hz, a difference of 0.0031Hz. This is the same as the frequency difference between the peak frequencies of the P0 configurations in surge. In this case, it is a 7.1% relative difference. The pitch peak frequency is constant across each platform and both array layouts with $f_p = 0.06875\text{Hz}$.

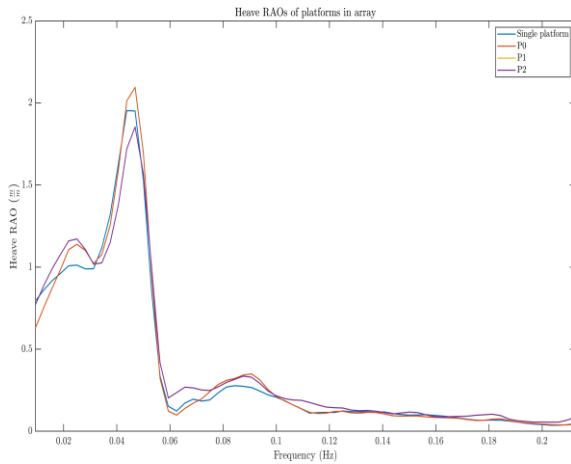


Figure 84. Shannon Estuary FSS array configuration heave RAO.

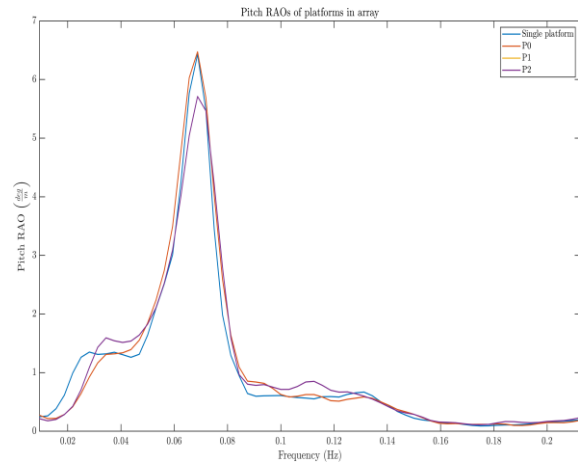


Figure 85. Shannon Estuary FSS array configuration pitch RAO.

The heave and pitch RAO results for the Bantry Bay singular platform and platforms in the array are presented in Figure 86 and Figure 87 respectively. The RAO peak frequency for heave and pitch match for the models in the array and the model tested alone. The results are given in Table 51 and Table 52. A similar pattern to the surge RAO results is evident here, where the f_p of the Shannon Estuary FIU matches the Bantry Bay f_p for the singular platform setup, which is not the case for the Shannon Estuary test. The Shannon Estuary platforms in the array match the array results obtained for Bantry Bay. This pattern does not exist in the pitch results, with all the peak frequencies matching across the arrays and singular platforms, with the exception of pitch f_p in the Shannon Estuary FIU case.

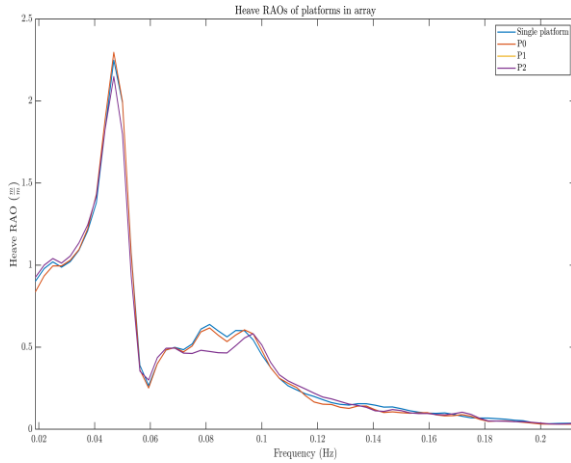


Figure 86. Shannon Estuary FSS array configuration heave RAO.

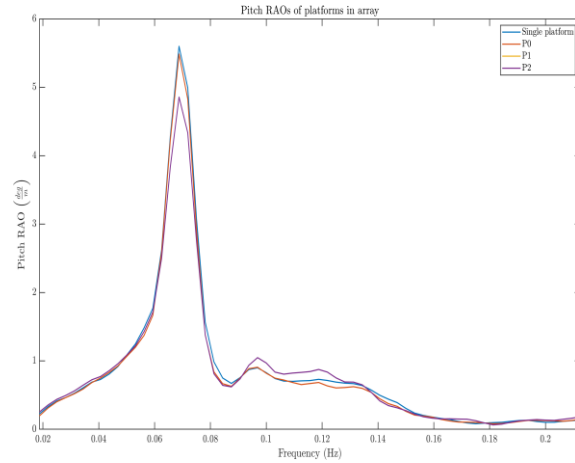


Figure 87. Shannon Estuary FSS array configuration pitch RAO.

Table 51. Summary of heave RAO peak frequencies for each configuration.

Scenario	Singular platform	P0	P1	P2
Shannon Estuary FIU heave f_p (Hz)	0.04688	NA	NA	NA
Shannon Estuary FSS heave f_p (Hz)	0.04375	0.04688	0.04688	0.04688
Bantry Bay heave f_p (Hz)	0.04688	0.04688	0.04688	0.04688

Table 52. Summary of pitch RAO peak frequencies for each configuration.

Scenario	Single platform	P0	P1	P2
Shannon Estuary FIU pitch f_p (Hz)	0.04375	NA	NA	NA
Shannon Estuary FSS pitch f_p (Hz)	0.06875	0.06875	0.06875	0.06875
Bantry Bay pitch f_p (Hz)	0.06875	0.06875	0.06875	0.06875

5.3 Discussion

5.3.1 Decay and natural period results

The decay tests presented demonstrate that the heave natural periods for all configurations were close to 20s (Table 32), which is consistent with the expected values for the UMaine VoltturnUS model platform, with typical heave natural periods in the range of 15-25s. The FSSs exhibit shorter pitch natural periods of ~14s (Table 34), close to typical barge type platform of pitch periods in the range of 9-16s, while FIUs had longer periods in pitch of ~22s, closer to the typical semi-submersible pitch period of ~25s.

This shift in natural pitch period is due to the removal of the tower and nacelle which alters the CoG and inertial properties of the floating structure. The results presented in Table 33 and Table 34 show that the numerical model overestimates the natural periods in pitch and roll, highlighting the limitations in capturing the damping effects when modelling potential flow solvers.

5.3.2 Hydrodynamic interactions and RAOs

The RAO analyses showed consistent shifts in the peak response frequencies between singular platform and array configurations in surge. For the Shannon Estuary FSS configuration, the surge RAO peak frequency increased from 0.025Hz for a singular platform to 0.028Hz for P0 in the array, a 12.4% increase (Table 37). A similar result was observed for the Bantry Bay configuration, with the surge peak frequency shifting from 0.0219Hz for the singular platform to 0.025Hz for P0 in the array, a 14.2% increase. This suggests that the interbody hydrodynamic interactions between neighbouring platforms in arrays alters the response of the platforms in surge, while pitch and heave responses remained relatively unaffected, as was shown in Table 51 and Table 53.

Figure 58 provided a reference to the magnitude of the reflected and radiated waves produced within the array of platforms for the Bantry Bay environment. These waves could potentially interfere with O&M vessels due to the proximity of the units. Further work on measuring the effects of the diffraction and radiation of the units in an array should be carried out in the future.

5.3.3 Platform excursions

Maximum excursions were reduced in arrays relative to singular platform cases. For the Shannon Estuary FSS configuration, P0 excursions reduced from 1.12m to 0.94m, a reduction of 16% (Figure 63 and Figure 64). The maximum excursion in the array, of 1.07m, is achieved at P1. This is a 4% reduction when compared to the singular platform scenario.

While the Bantry Bay singular platform configuration experienced the highest excursions of all the configurations tested, the excursions reduced from 7.69m to 5.87m for P0 in the array, a 23.7% reduction, as was shown in Table 35. This mooring system was expected to obtain the largest platform excursion despite both models being tested under scaled 50-year return period wave conditions. The Bantry Bay mooring system has longer mooring lines and is operating in deeper water with considerably higher significant wave heights ($H_s = 8\text{m}$ vs 2m) and longer peak wave periods ($T_p = 15\text{s}$ vs 12s).

The reduction in platform excursions within arrays indicates that the array hydrodynamics provide some passive motion reduction in the surge and sway of the platforms. However, excursions were not uniform across the array edge platforms for the Shannon Estuary (P1) and the second-row platform (P2) in Bantry Bay experienced larger displacements than the central platforms. This non-uniformity of platform excursions needs to be further investigated, as the edge platforms could experience more excursions due to wave reflections off the DOB walls during physical testing.

It was found that the numerical model significantly overestimated the platform excursions in both water depth configurations. This again is due to the limitations of the numerical model approximating the behaviour of the platforms. Additionally, for the Shannon Estuary FIU, the maximum excursion was measured to be 1.38m compared to 1.12m for the Shannon Estuary FSS. This increase in maximum

platform excursions indicates that the difference in the mass and inertial properties of the FIU induces a greater displacement from rest than that of the FSS unit.

5.3.4 Nacelle accelerations

From the results provided in Section 5.3.3, the Shannon Estuary FIU linear accelerations are dominated by the motion in surge, which is expected due to the behaviour of semi-submersible platforms. Surge accelerations remain significant, especially the peak results obtained from the numerical model. In contrast, the heave accelerations are relatively small when compared to surge. These results show the importance of considering rotational effects in addition to translational motions when accessing nacelle loads as non-negligible loads may be induced while in wet storage.

5.3.5 Line tensions and uplift forces

The results obtained through the physical testing show that the mooring line tension across the range of tests conducted does not exceed the maximum snatching load of 10MN defined as the threshold at the start of the project. The maximum tension load measured across the entire project is on L1 of P0 for the Shannon Estuary FSS array at 2MN. This is still more than five times less than the lower end of the snatching load limits. For both sites, the mooring line tensions were higher in the array layouts compared to the singular platform configurations for the central platforms P0. For the Shannon Estuary stand-alone array, P0 line tensions reached 2MN as mentioned above, but the singular platform layout has a maximum tension of 1.8MN.

The spectral analyses of the forces acting on the mooring lines showed a dual peak spectrum with the lower frequency peak corresponding to the surge response and the higher frequency peak corresponding to the wave peak frequency, as was shown in Figure 77 and Figure 78. When investigating the results from the physical testing, the RMS and SD are also higher in the array cases. The dual peak spectrum demonstrated in the line tension PSD results are likely a result of second order wave effects interacting with the floating structures, resulting in a low frequency peak in the PSD. The Shannon Estuary FSSs had a higher PSD at the wave excitation frequencies with a lower PSD at the low frequency peak. The opposite is true for the Bantry Bay configuration. It is difficult to directly compare the configurations due to the difference in the model properties and water depths they are operating in. However, the difference in the PSD behaviour between the models could be due to the higher mass, greater draft and change in the moments of inertia for the Bantry Bay setup that alter the behaviour of the platform such that the second order wave effects have a greater influence on this configuration.

The uplift forces acting on the anchors within the numerical modelling results show that, for all cases except the Bantry Bay array layout, the uplift forces exceed the 1MN limit. When comparing the array and singular platform uplift forces for the Shannon Estuary and Bantry Bay scenarios, it was shown that, in both cases, a reduction in the uplift forces acting on the anchors is present in the array layouts. This was an unexpected result, particularly the magnitude of the uplift forces on the shared anchor in

the Bantry Bay scenario, where it was assumed that the uplift forces would be significantly greater than the singular platform case due to the presence of three mooring lines attached to the anchor. This result requires further investigation as the forces obtained through ANSYS AQWA could potentially be underestimated due to the limitations associated with potential flow solvers. Additional tank testing and CFD analyses are required to develop a better understanding of what the actual uplift forces would be.

5.3.6 Notable Limitation

It is important to note, at the small wave heights used with the JONSWAP Spectrum at 1:100 scale (Table 27 and Table 28), wave generation and measurement may be subject to increased noise and limitations inherent to the basin's physical and instrumentation constraints. Consequently, results at this scale should be interpreted with caution, particularly in relation to signal fidelity and repeatability.

6 Conclusion

6.1 *Site suitability*

The geospatial and strategic planning assessment has successfully identified and evaluated potential areas for the wet storage of FLOW components around the coast of Ireland. The application of a rigorous MCDA model, integrating critical met-ocean data, bathymetry, seabed character, and other key constraints, has provided a robust, evidence-based foundation for strategic decision-making in this regard.

The analysis conclusively demonstrates that the Shannon Estuary and Bantry Bay offer the most significant potential for hosting large-scale wet storage facilities for FIUs, with extensive sheltered areas meeting the stringent geotechnical criteria. Belfast Lough presents considerable potential outside its formal port jurisdiction area, while Lough Foyle and Cork Harbour are notably constrained, primarily by water depth, offering very limited opportunity.

Beyond the geospatial screening, the planning and environmental scenario analysis underscores that site suitability is not solely a function of physical and technical parameters. The Shannon Estuary, despite its appropriate geophysical characteristics, is a highly sensitive ecological zone, requiring meticulous project-level assessment and mitigation to ensure compliance with the relevant environmental directives. Conversely, Bantry Bay, while located within a high-value scenic landscape, presents fewer direct conflicts with European protected sites, though engagement with inshore fisheries will be crucial if wet storage is to be considered here.

The findings highlight a critical path for the development of wet storage sites in support of a FLOW industry in Ireland. The identified areas, particularly the Shannon Estuary and Bantry Bay, represent strategic national assets in this regard. Their successful designation and development will require:

- Early and continuous stakeholder engagement: proactive consultation with statutory bodies, environmental agencies, fisheries representatives, local communities, and aviation authorities is essential to de-risk future projects and navigate the complex consenting roadmap.
- Consideration in future Designated Maritime Area Plans: integrating wet storage requirements into the future National DMAP process will provide a plan-led, evidence-based framework, resolving potential conflicts at a strategic level and providing greater certainty for investors, project developers and port authorities.
- Port infrastructure synergy: the location of these wet storage zones must be strategically aligned with planned port upgrades and assembly facilities, ensuring a cohesive and efficient national supply chain for FLOW.

By leveraging this geospatial evidence and adhering to a proactive, plan-led approach that diligently addresses environmental and planning considerations, Ireland can unlock its potential for FLOW development, positioning its ports as key enablers in the nation's transition to a secure, sustainable energy future.

6.2 *Layout and mooring*

The layout and mooring study investigated the feasibility of wet storage for FLOW components at the two sites identified as particularly promising for wet storage in Ireland, the Shannon Estuary and Bantry Bay. This was performed through numerical modelling and physical testing of 1:100 scale models in the DOB at the Lir National Ocean Test Facility. The experimental mooring systems used were iteratively designed to maintain mooring forces below the given threshold of 10MN snatching loads and 1MN uplift forces while aiming to minimise the space required to store an array of floating bodies.

It was found that wet storage of arrays of floating structures reduces the excursions of the platforms when compared to solitary platform configurations, suggesting some hydrodynamic shielding effects in said arrays. However, the edge platforms for the Shannon Estuary and the platforms in the second row of the array for Bantry Bay experience the highest excursions despite the reduction when compared to the solitary case. Further work is required to determine if this is a result of reflections from the walls of the DOB during physical testing.

The numerical modelling results demonstrate that shared anchors are feasible in arrays of FSSs due to the reduction of uplift forces on the anchors and line tensions, which is consistent with the experimental results showing reductions in the platform's excursion in the arrays. These hydrodynamic interactions induced in the arrays could be used to reduce mooring loads in wet storage when storing several structures at a time. Additional work is required to further investigate the anchor uplift forces through physical testing, as there is potential for the numerical model to underestimate the uplift forces induced on the anchors.

Results obtained through wave basin testing demonstrate surge RAO peak frequencies increased by 12-14% in arrays compared to the solitary units, while little to no changes are induced in the pitch and heave RAO peak frequencies. Consideration for resonance effects in array configurations is required as well as the single platform models.

Numerical modelling for nacelle accelerations demonstrate that the FIU models were dominated by pitch induced motions, indicating that even in wet storage conditions, turbine components may be subjected to significant loading.

The potential flow solver overestimated the excursions of the platforms in arrays and may be underestimating the vertical forces exerted on the anchors within the arrays. This indicates that the

limitations of potential flow solvers in shallow nonlinear conditions may be unsuitable for precise evaluation of the behaviour of platforms within arrays.

The findings confirm that wet storage is technically feasible at both the Shannon Estuary and Bantry Bay. Shared anchors can reduce the number of anchors required to store a given number of platforms while reducing the spatial requirements for wet storage areas as well as potentially reducing platform excursions and mooring line loads passively. However, further work is required to investigate the uplift forces and the effects of different wave headings interacting with the arrays.

In conclusion, wet storage offers a viable and promising solution for effective roll-out of FLOW deployments in Ireland. The study provides experimental and numerical evidence on shared anchors, mooring loads and platform behaviour in arrays for wet storage conditions and highlights the need for additional modelling and tank testing to develop a set of robust guidelines for future wet storage designs.

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Appendix A. FSS Wet Storage Potential.

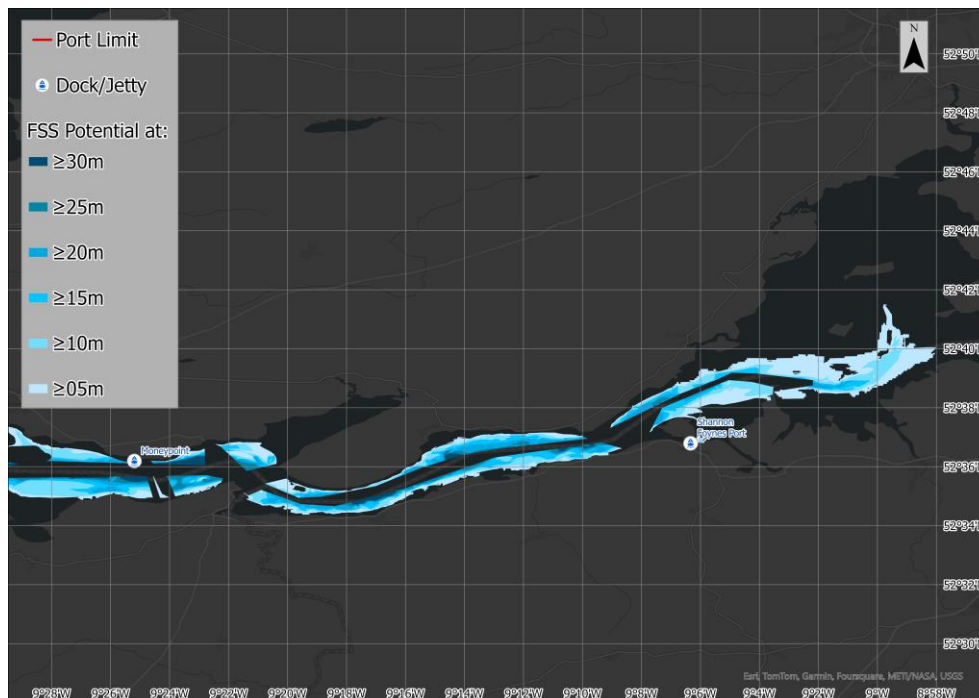


Figure A. FSS wet storage potential at Shannon (upper) with port limits applied.



Figure B. FSS wet storage potential at Shannon (lower) with port limits applied.

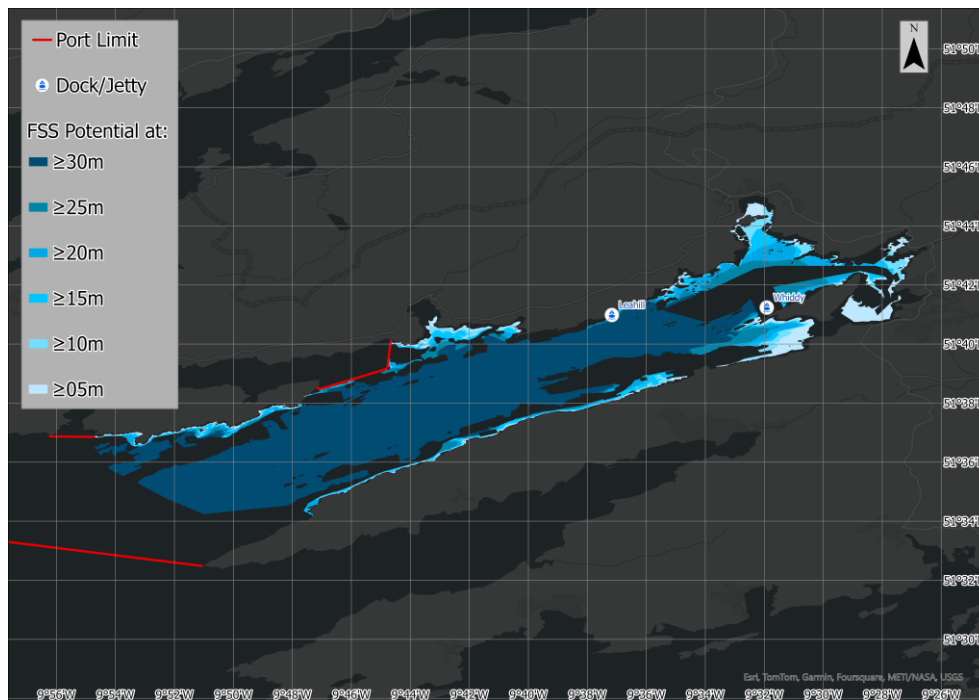


Figure C. FSS wet storage potential at Bantry Bay with port limits applied.

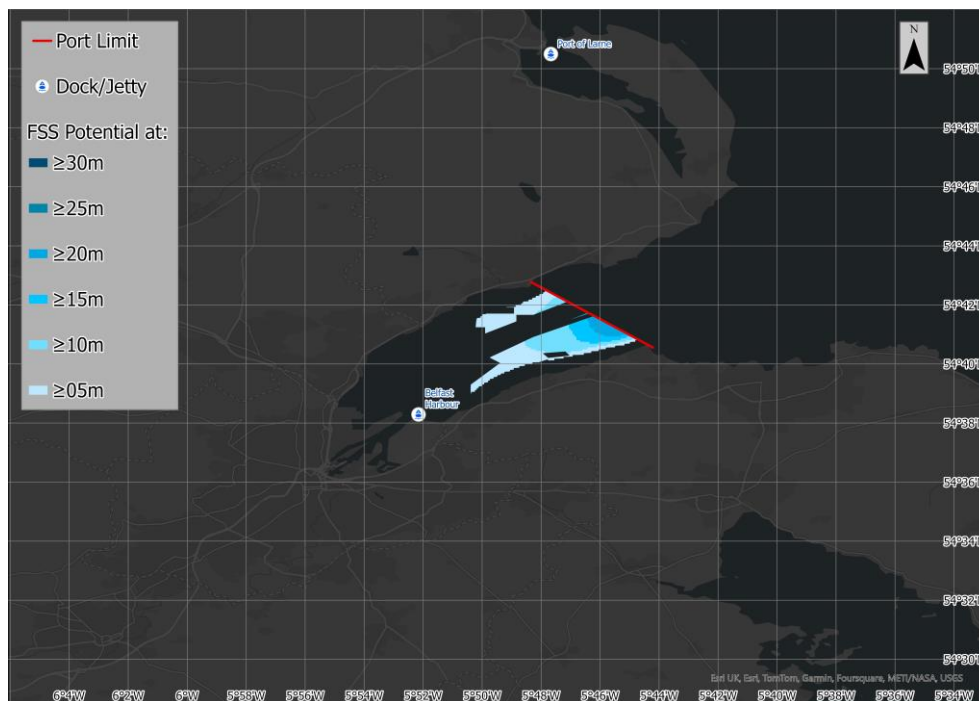


Figure D. FSS wet storage potential at Belfast with port limits applied.

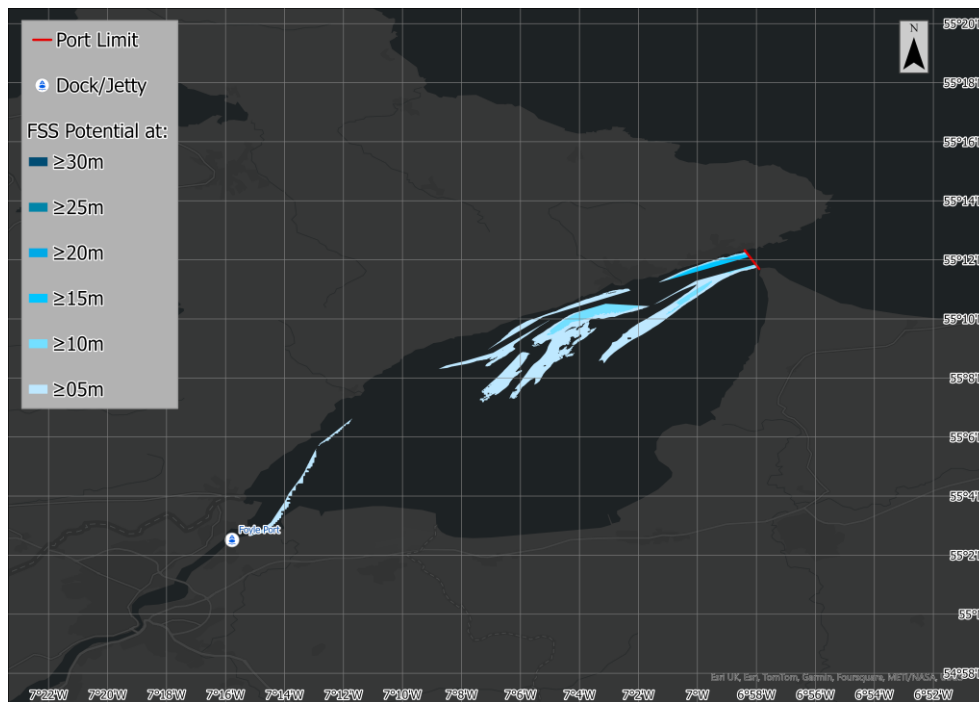


Figure E. FSS wet storage potential at Foyle with port limits applied.

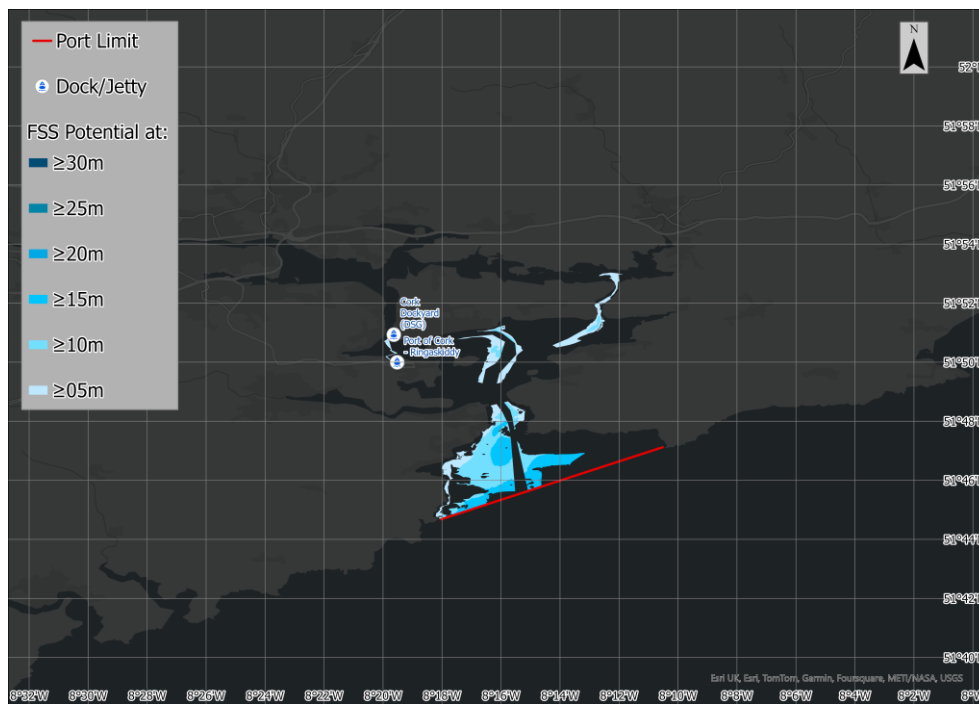


Figure F. FSS wet storage potential at Cork with port limits applied.

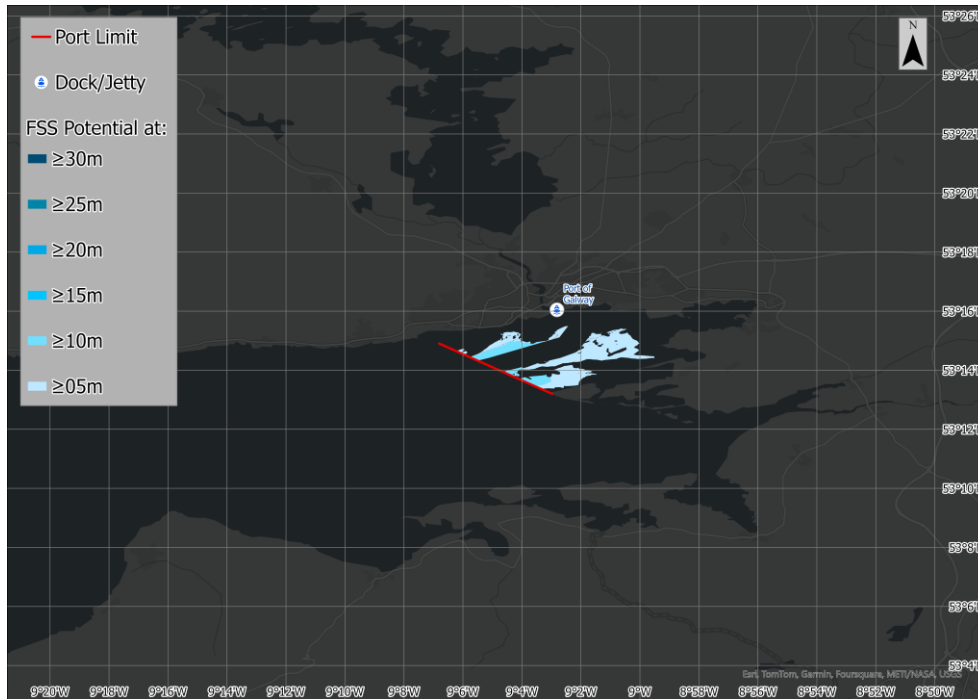


Figure G. FSS wet storage potential at Galway with port limits applied.

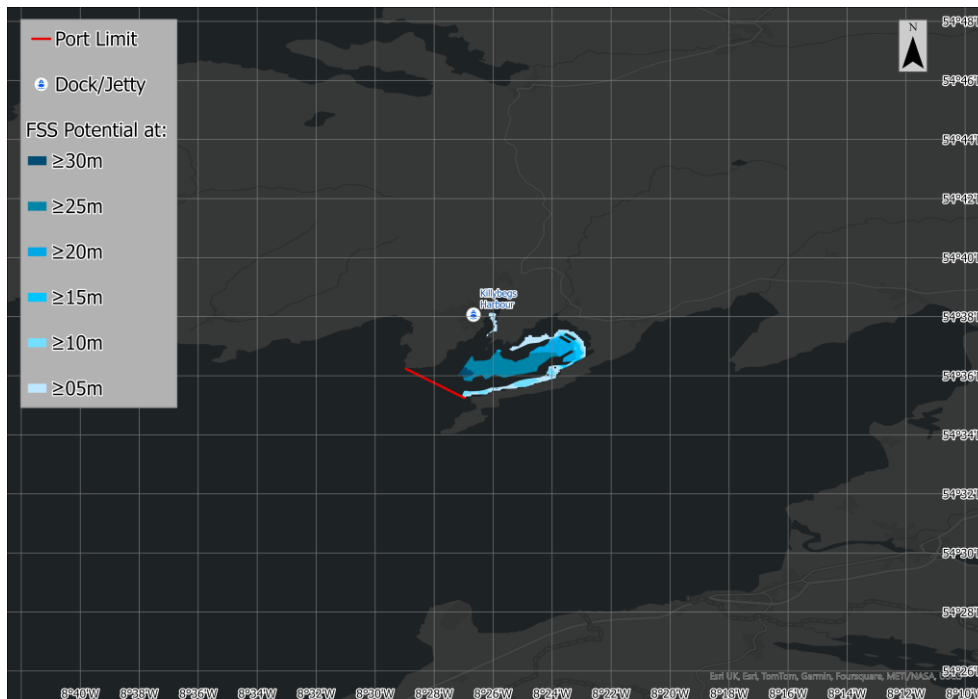


Figure H. FSS wet storage potential at Killybegs with port limits applied.

