REPORT

Penmayn seaweed farm structure and mooring review

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Appendices

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1 Introduction

Royal Haskoning DHV (RHDHV) and Risk & Policy Analysts (RPA) have been appointed by the Marine Management Organisation (MMO) to review the design and moorings of the Penmayn Seaweed Farm in North Cornwall. The proposed farm will cover an area of 1 square kilometre within Port Isaac Bay. Its main infrastructure will consist of 480 long-lines, each 300 meters long, anchored with screw anchor moorings. The farm will be divided into 12 *patches*, each measuring 300m x 200m. Each *patch* will contain approximately 40-66 long-lines, each 250m long and spaced 3-5m apart, positioned at a maximum depth of 2 meters below the surface, with transit zones between the patches.

1.1 Project background

In August 2023, MMO granted a marine licence (Licence number: L/2023/00169/1) to Penmayn Limited for the 1 square kilometre Penmayn Seaweed Farm in Port Isaac Bay. Since the licence was issued, several residents from North Cornwall, represented by the Save Port Isaac Bay Group (SPIBG), have voiced their concerns and observations. Their concerns relate to the unsuitability of the chosen site for the seaweed farm, as well as the stability and suitability of the farm's design and mooring system.

In June 2024, at the request of SPIBG, AquaMoor Limited conducted an independent third-party review of the Penmayn Seaweed Farm's structure, mooring design, and associated documentation to assess its fitness for purpose. The review concluded that the farm's design does not adhere to best practices for specifying dimensions and mooring systems. It also found that appropriate design codes and standards were neither utilised nor referenced. Ultimately, the review determined that the site is unsuitable for such a structure due to the energetic wave climate, and *that the design is therefore not fit for purpose and if deployed may present a risk to the Safety of Life at Sea (SOLAS) (*AquaMoor Limited,2024)

1.2 Project objectives

The objective of this study is to provide the MMO with expert advice on the design and moorings of the Penmayn Seaweed farm as well as the related documentation included in the licence application. This assessment will evaluate whether the application's assumptions are accurate and if AquaMoor Ltd's third-party verification is correct in its assertion that there is a high risk of failure of the structure, which could pose a threat to life. As such, 4 critical questions, raised by the MMO, related to Penmayn's Seaweed Farm will be addressed:

1) Can the farm structure and mooring design for the seaweed farm withstand such forces acting on it as are reasonably foreseeable?
2) In the event of reasonably foreseeable damage to the installation or its moorings, will the infrastructure retain sufficient integrity to enable action to be taken to safeguard the health and safety of persons on or near it?
3) Can the construction, commissioning, operation, modification, maintenance and repair of the installation proceed without prejudicing its integrity?
4) Can the seaweed farm infrastructure be decommissioned and dismantled safely?

To address these questions, this study begins with an overview of seaweed farms, discussing the challenges and opportunities presented by this type of aquaculture. It introduces examples and provides an overview of best practices, standards, and guidelines related to seaweed farming. This is followed by Section 3 which focuses on local environmental data: the wave, wind, and current environment in the area, as well as information about the seabed. The evaluation of Penmayn's Seaweed Farm's design is conducted in Section 4, where the information provided in the marine licence, pertinent to the design of the structure, is reviewed against the guidelines. The answers to the four critical questions, along with recommendations, are included in the final Section 5.

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2 Overview of seaweed farming

This chapter provides a brief overview of the seaweed industry and its latest developments and opportunities in (Northwest) Europe. This was not included in the study scope but provides useful context for the technical review in the later sections that is the primary focus of this report.

2.1 Seaweed farming: A nascent industry in Europe

Seaweed will become an important raw material for Europe, given the vast range of organisations discussing its potential. It can therefore be expected that offshore and nearshore seaweed farms will become part of the European seascape.

The World Bank recently published their Global Seaweed New and Emerging Markets Report 2023 which provides an analysis of the commercial opportunities for new high-growth seaweed market applications that could increase the scale of seaweed cultivation and enhance value-added seaweed processing (The World Bank, 2023). The report focuses on ten relatively new and emerging seaweed applications that have the greatest market opportunities outside the established agar, alginate, carrageenan, food and aquaculture feed sectors. Figure 2-1 depicts the World Bank's view on the predicted seaweed market size.

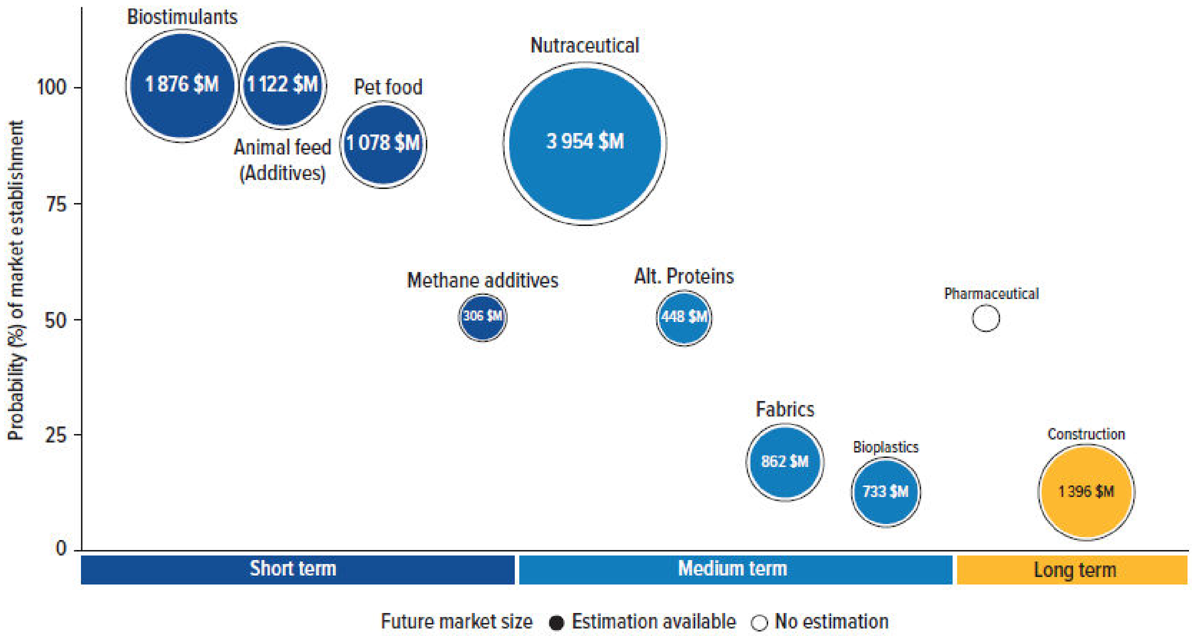

Figure 2-1: Predicted seaweed market size by 2030 with chance of market establishment indicated by colour on high-level market horizon timeline (The World Bank, 2023)

Members of the Global Seaweed Coalition (https://www.safeseaweedcoalition.org/) work together to establish a seaweed industry that provides safe products, safe working conditions and environmental protection as it grows. This coalition strives to help the seaweed sector develop into an industry that will make a significant contribution to the United Nations' Sustainable Development Goals through improving public health and food security, alleviating poverty, renewing marine ecosystems, and mitigating climate change. The Global Seaweed Coalition also published a seaweed manifesto (Lloyd's Register Foundation, 2020). This seaweed manifesto is a visionary document outlining how seaweed can contribute to delivering on the sustainable development goals. It defines a vision for the industry, explores the opportunities and benefits, as well as outlining the challenges and barriers for responsible development of the industry.

Seaweed for Europe (https://www.seaweedeurope.com) is a coalition to advance and scale up a sustainable and innovative seaweed industry in Europe. Its mission is to accelerate the sustainable seaweed industry in Europe. They have called seaweed the hidden champion of the ocean. They have published a report that quantifies the potential economic, social and environmental benefits of a sustainable seaweed industry in 2030 (Seaweed for Europe, 2020). The report also provides guidelines to ensure the growth of the industry is sustainable, resilient and fair, and suggests some concrete avenues to fast-track its development.

In Europe, the seaweed industry is a nascent industry, but it is expected to grow significantly in the next two to three decades. Figure 2-2 depicts the forecast by DNV (Det Norske Veritas, an international accredited registrar and classification society) for European marine aquaculture including seaweed. DNV anticipates a steep increase of the European seaweed industry starting in 2030. This figure was taken from their Ocean's Future 2050 Seafood Forecast (DNV, 2024a). DNV also published a separate Seaweed Forecast (DNV, 2024b). In this report, DNV forecasts the global seaweed demand and production to 2050, based on updates in DNV's Ocean's Future to 2050 model. By providing a most-likely forecast of seaweed demand and supply, DNV aims to contribute to anchoring industry growth ambitions.

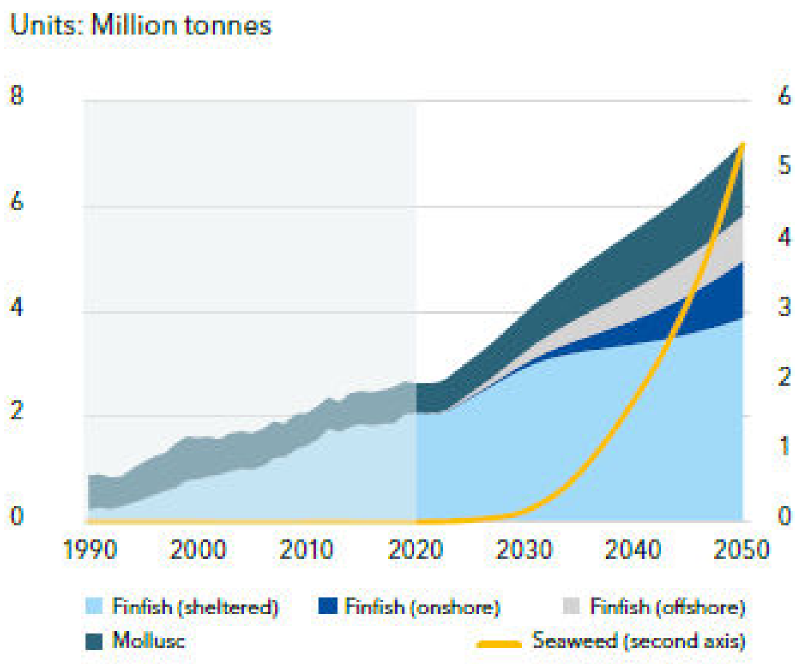

Figure 2-2: Forecast marine aquaculture in Europe (including seaweed cultivation) (The World Bank,2023)

Seaweed cultivation is also on the agenda of the European Commission. The European Commission has published a report identifying how the EU could help to establish a strong and sustainable EU algae sector (European Commission, 2024a; European Commission, 2024b; European Commission, 2024c).

Associations have been set up to advance a seaweed industry in their respective countries, for example:

- United Kingdom: http://theseaweedalliance.org.uk/
- Scotland: https://www.ssia.scot/
- Ireland: https://www.c-faarer.eu/irish-seaweed-association

- Norway: https://www.norseaweed.no/en
- The Netherlands: North Sea Farmers

One characteristic of Europe's seaweed industry, which hampers its scalability, is that wild harvesting accounts for nearly 99% of total production. The main difference lies in the way it is harvested: countries with a stronger seaweed economy, namely Norway, France, and Ireland, have increasingly turned towards mechanical harvesting to increase yields (with technologies adapted to the cultural habits of each coastal region), whereas other countries still resort to manual harvesting (or even diving like in Portugal). Yet wild harvesting is not compatible with the growing demand for seaweed: yields have decreased due to excessive harvesting and unpredictable weather patterns in previous years. In addition, the environmental impact of scaling these operations is uncertain and likely to deplete European natural stocks (European Commission, 2024c, Section 4.2).

To scale up the production of European seaweed, cultivation is required. In Europe different seaweed farmers cultivate seaweed in protected coastal areas, for example Ocean Rainforest, The Seaweed Company | Capturing the value of seaweed, Seaweed Solutions | Leading European Seaweed Farming, Transforming Seaweed Cultivation | Arctic Seaweed.

However, the space to cultivate seaweed in coastal zones is limited. Furthermore, there is significant competition with other activities in these areas, e.g. tourism, fishing, water sports, water transportation.

2.2 Seaweed farming in exposed locations

The next step therefore is to cultivate seaweed in more exposed nearshore or even offshore environments. The North Sea Farmers have setup a first commercial demonstration of a seaweed farm within an offshore wind farm in the Dutch North Sea, called North Sea Farm #1 (NSF1 - North Sea Farmers). This farm is fully exposed to the, at times harsh, wind, wave and current conditions of the North Sea. NSF1 has different purposes but one of them is to demonstrate that in challenging conditions within an offshore wind farm (proximity to wind farm, distance to the coast, depth, wind, waves, current, environmental and safety) it is possible to operate a commercially viable seaweed farm.

In nearshore and offshore conditions, the environmental loads on the structure (wind, waves and current loads) are significantly larger than in protected coastal areas. In the report related to aquaculture potential in English Waters (MMO, 2019) it is mentioned that studies on recommended wave height or current speed for seaweed farming are very limited (MMO, 2019, p 65). The tolerance of the farm to withstand severe nearshore or offshore conditions also depends on the farm type, shape, design, etc.
The MMO (2019) identifies, based on a few available sources, an optimal, suboptimal and unsuitable wave height and current speed for offshore and nearshore seaweed cultivation. Areas with waves higher than 6 m and current speeds larger than 1.5 m/s are considered unsuitable for seaweed cultivation, according to MMO (2019). Suboptimal wave heights are between 4 and 6m. It is also mentioned that the possibility of a catastrophic loss of the farm during storm events must be factored into the site placement, so a detailed study of the local wave climate should be considered.

To cultivate seaweed in near- and offshore environments, technology barriers must still be overcome. One of them is how to design a structure that can withstand the wind, wave and current loads at its location.

2.3 Current industry best practices

To provide future seaweed farmers with some direction for how to design a safe and reliable offshore seaweed farm, the North Sea Farmers have published a recommended design practice for offshore and nearshore seaweed growing systems (Aqitec et al, 2023). The North Sea Farmers identified a need for the seaweed industry to set up a design standard for seaweed farms, to support the industry with a standardised design approach that can be certified by independent parties. This in turn will enable successful permit applications, getting the assets insured and attracting investments into the industry. The North Sea Farmers document is only a first step in developing this industry-wide standard. The standard is based on the Norwegian Standard for floating aquaculture farms [Standards Norway,2024) and DNV offshore standards (DNV, 2021a; DNV 2021b).

The recommended design practice for offshore and nearshore seaweed growing systems aims to provide guidance for the industry on which technical criteria to use when designing an offshore or nearshore seaweed growing system, thereby aiding the process of obtaining permits for these systems. For this reason, Aqitec et al (2023) is not aimed at a specific design, but provides generic criteria that apply to a number of designs. The document strives to include relevant aspects for design of offshore and nearshore seaweed growing systems; whether it is applicable to a specific design should be assessed by the designer. It does not take into consideration local regulations and permit requirements, and it provides the designer with criteria to ensure an adequately safe design of the system itself. Handling operations (installation, seeding, harvesting, maintenance and decommissioning) are only in the scope of this document if they affect the design criteria of the system itself. For example, a limit state for the system can be defined during installation, however requirements for the installation equipment and procedures itself are beyond the scope of Aqitec et al (2023). Future versions may expand on the topics covered and provide more detailed guidance on installation, alternative materials, part degradation, inspection intervals, monitoring, operation, maintenance, life extension, and decommissioning.

At this point in time, Aqitec et al (2023) is the only guideline tailored to seaweed available to our knowledge. Combined with the Norwegian standards for floating aquaculture farms (Standards Norway, 2024) and other offshore standards (not only per se DNV, but others are available as well, e.g. British Standard (BS 6349-1-1:2013)), this is at the moment the only guidance available to design a safe and reliable nearshore seaweed farm. The Aqitec guidance forms the basis for the design review in Section 4.2, which also provides some more technical detail on the guidance’s content.

3 Local hydraulic and geotechnical data

3.1 Introduction

The review of the design requires information about local hydraulic conditions (waves and currents) and ground conditions.

As part of Licence Schedule 6 – Appendix 3, Penmayn included a chapter on Weather & Sea Conditions, presenting tide and wave data from the nearest monitoring station. Tide and wave monitoring is conducted using a step gauge located in Port Isaac Harbour (WGS84: Latitude: 50° 35' 39.083" N, Longitude: 04° 50' 03.881" W). The step gauge is installed on a breakwater, which is on the open coast but sheltered from the southwest by a headland (Port Isaac, 2022). It is situated in a limited water depth of 0.3m-2m.

Given that the proposed Penmayn Seaweed Farm is to be installed 3.5km NE of Port Isaac, at a water depth of -30mOD, RHDHV utilised a wave and a current model to estimate the wave and current climate further offshore and to compare these results with the wave and current conditions included in Licence Schedule 6. This is described in Section 3.2, followed by the resulting values for waves in Section 3.3 and currents in Section 3.4. Bathymetry and seabed information is presented in Section 3.5.

3.2 Numerical modelling

3.2.1 Wave model description

RHDHV's existing wave model of the Severn Estuary has been utilised for this wave modelling exercise to determine the wave conditions at the project site. The wave model was setup in DHI's (Danish Hydraulic Institute) MIKE software package, which includes MIKE21-SW Spectral Wave Model for simulating growth and transformation of wind and swell waves.

The wave model bathymetry around the Seaweed Farm development area uses EMODnet data which has a resolution of 100m x 100m.

The wave model domain covers the whole of the Severn Estuary as shown in **Figure 3-1** with the offshore model boundary of the MIKE21-SW model located at the edge of the Bristol Channel, extending from Trevose Head in the south to Milford Haven in the north. As illustrated in **Figure 3-1**, the wave model domain also encompasses the proposed location of the Penmayn Seaweed Farm in Port Isaac Bay.

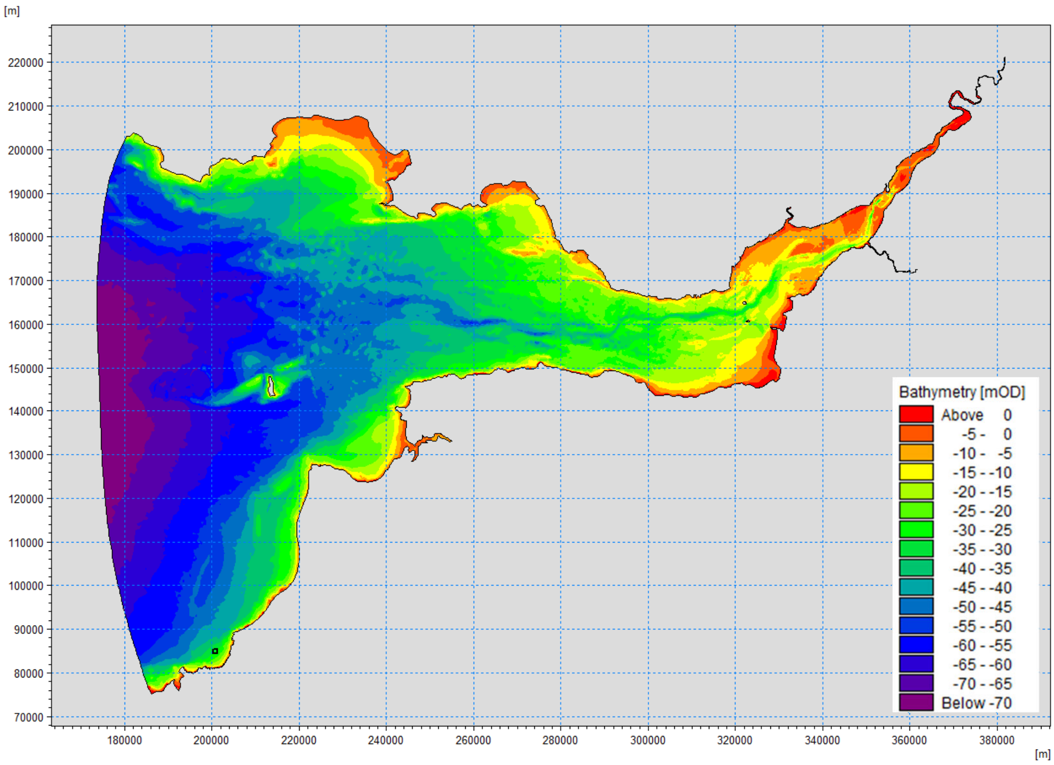

Figure 3-1: Wave model domain

The MIKE21-SW modelling software utilises a flexible, unstructured, and triangular mesh which enables the model to use a coarser grid (1,000m) in the areas further away from the proposed development site and finer mesh in the areas of greatest interest (200m). This approach enables higher computational efficiency whilst still maintaining sufficient accuracy of mesh coverage in areas of greatest interest in the present study. **Figure 3-2** shows the different mesh resolutions used in the wave model.

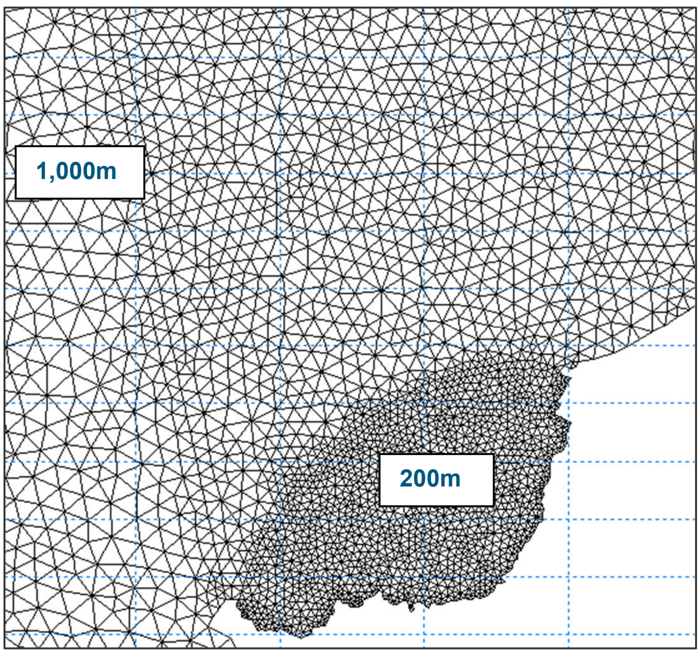

Figure 3-2: Wave model mesh resolution

The MIKE21-SW model is driven by an open boundary using the following wave input parameters at the offshore boundary:

- Significant wave height, Hs
- Spectral wave peak period, Tp
- Mean wave direction, MWD
- Directional standard deviation, DSD

Figure 3-3 presents the wave rose showing the significant wave heights for the offshore hindcast wave point located at the offshore model boundary. It shows that the predominant wave directions at this location are coming from West (270°N) and West-Southwest (240°N). Therefore, the wave modelling exercise has focused on these two wave directions.

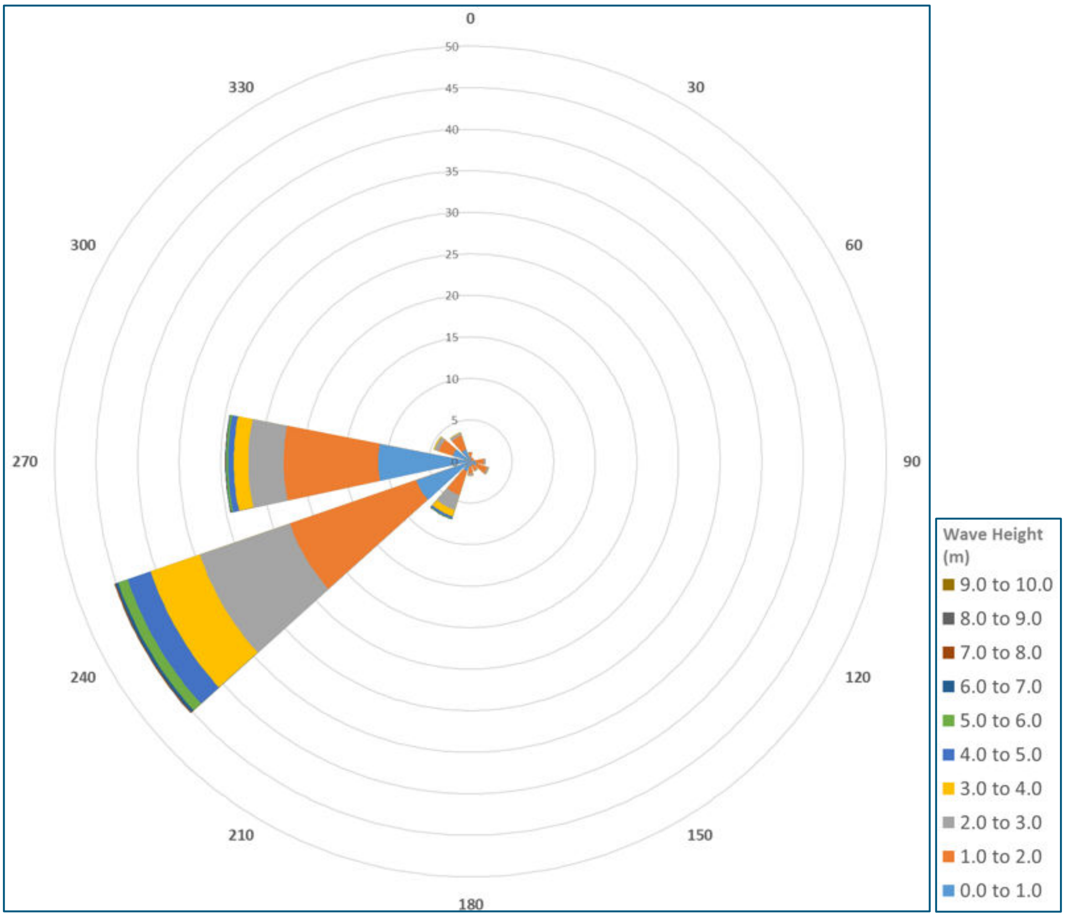

Figure 3-3: Wave rose showing significant wave height for offshore hindcast wave point

The wave model has been run for three return periods, namely 1 in 1 year, 1 in 10 years and 1 in 50 years, using offshore extreme wave height and period based on analysis of hindcast frequency tables (based on 40 years of data, 1983-2023; sourced from UK MetOffice).

Extreme wind was also applied to the offshore model boundary which was based on the relationship between wave height and wind data (ERA5 reanalysis atmospheric hindcast model).

The highest astronomical tide (HAT) of 4.0mOD at Port Isaac has been applied to the wave model to ensure a conservative approach.

Table 3-1 summarises the wave model settings that have been used.

Table 3-1: Summary of wave model settings

Model Setting	Selected Parameter
Basic Equations	Spectral formulation: Fully spectral formulation Time Formulation: Quasi Stationary
Spectral Discretization	360 degrees rose: 36 directions
Solution Technique	Low order, fast algorithm Iterations: 50
Diffraction	None
Wave Breaking	Gamma data: Constant value of 0.8 Alpha: 1
Bottom Friction (roughness height)	Varying in domain: offshore & site 0.05m, inshore 0.001m
White Capping	Dissipation coefficient varying in domain: offshore & site 2.5, inshore 1.1

Section 3.3 presents the wave model inputs and model results for all three return periods and both wave directions.

3.2.2 Hydrodynamic model description

RHDHV's existing hydrodynamic (HD) model of the Severn Estuary has been utilised for this modelling exercise to determine the current conditions at the project site. The hydrodynamic model was set up in DHI's (Danish Hydraulic Institute) MIKE software package, which includes the MIKE3-HD suite.

The wave model bathymetry around the Seaweed Farm development area uses EMODnet data which has a resolution of 100m x 100m.

The hydrodynamic model covers the whole of the Severn Estuary as shown in **Figure 3-4** with the offshore boundary of the MIKE3-HD model located at the edge of the Severn Estuary, extending from Ramsey Island in the north and Land's End in the south.

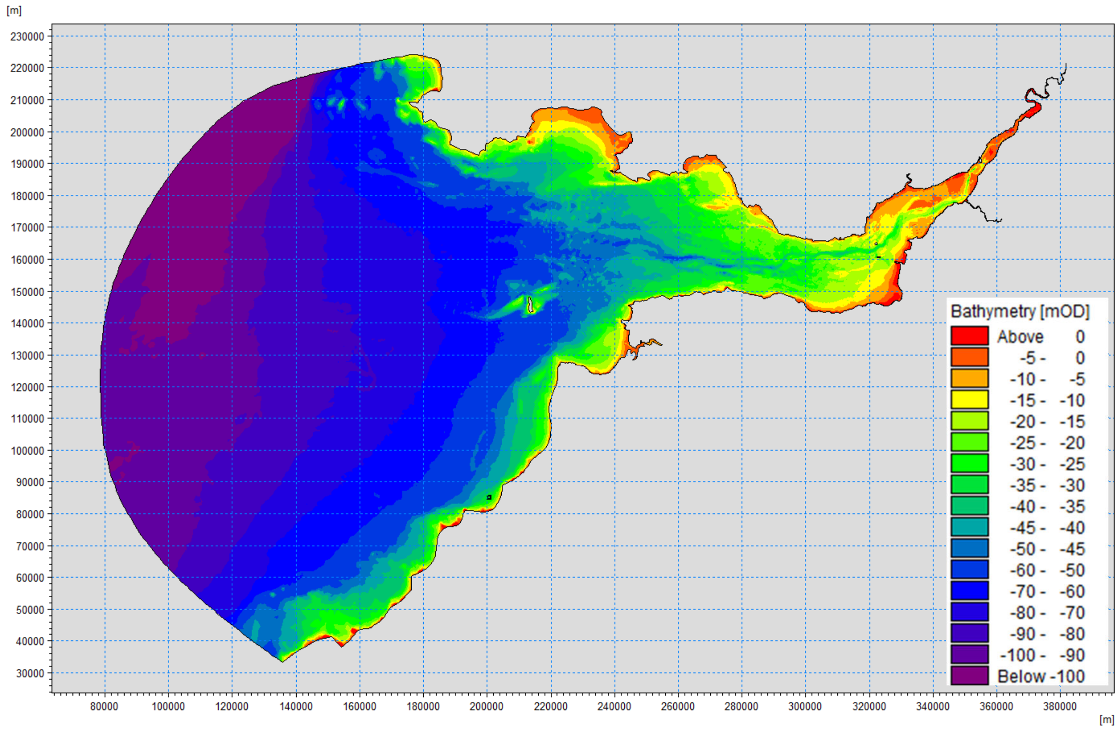

Figure 3-4: Hydrodynamic model domain

The MIKE3-HD modelling software utilises a flexible, unstructured, and triangular mesh which enables the model to use a coarser grid (1,000m) in the areas further away from the proposed development site and finer mesh in the areas of greatest interest (800m). This approach enables higher computational efficiency whilst still maintaining sufficient accuracy of mesh coverage in areas of greatest interest in the present study. **Figure 3-5** shows the different mesh resolutions used in the wave model.

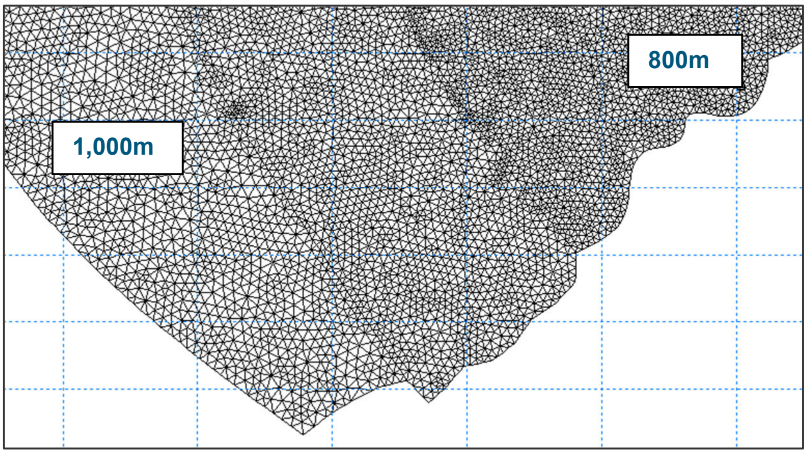

Figure 3-5: Hydrodynamic model mesh resolution

The MIKE3-HD model has an open boundary at its offshore extent, which is forced by a time varying water level, extracted from the DHI global tide model (DTU10), at 10km resolution along the boundary. The DHI global tide model is on a 0.125° x 0.125° resolution grid for the 10 major constituent tidal spectra.

The existing MIKE3-HD model had been run for a time period between late July to mid-September 2025. This time period was selected based on the observed high tidal elevations, which will produce higher tidal currents. Tidel levels are recorded by the Port Isaac tide gauge, and are reported in the Tidal Reports from 2011 to 2022 (Port Isaac, 2011-2022).

Table 3-2 summarises the HD model settings that have been used.

Table 3-2: Summary of HD model settings

Model Setting	Selected Parameter
Solution Technique (Time integration and Space discretization)	Low order, fast algorithm
Time Step	Min: 0.01s Max: 30s
Depth Correction	No Depth Correction
Flood and Dry	Drying Depth: 0.005m Wetting Depth: 0.1m
Density	Function of salinity (34.75PSU)
Horizontal Eddy Viscosity	Smagorinsky formulation: 0.28
Bed Roughness	Roughness: depth varying (0.12m - 0.18m)
Coriolis Forcing	Varying in domain
Wind Forcing / Pressure	Spatially varying ERA5 hindcast wind

Section 3.3 presents the hydrodynamic model results.

3.3 Wave conditions

The results from the Wave Model have been used to determine the significant wave height (Hs), which is the average height of the highest one-third of the waves observed over a given period, and the peak wave period (Tp), which corresponds to the most energetic waves in the wave spectrum. These parameters have been evaluated for three different return periods: 1 in 1 year, 1 in 10 years, and 1 in 50 years. These return periods are commonly used in industry practice to assess the Ultimate Limit States of seaweed growing systems (Agitec et al, 2023). Additionally, the wave direction has been computed. These results are presented in **Table 3-3** for the four corners of the Penmayn Seaweed Farm and its centre point, summarised in **Table 3-4**.

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Table 3-3: Input parameters and results obtained from RHDHV's wave model for 1:1, 1:10 and 1:50 yr Return periods at the 5 study points.

1:1 year	Inputs				Results - Hs (m)					Results - Tp (s)					Results - Wave Direction (m)				
Dir (degN)	Hs (m)	Tp (s)	Wind Speed (m/s)	WL (mAOD)	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5
240	8.4	14.4	26.7	4.0	5.8	5.7	5.3	5.4	5.6	14.3	14.3	14.3	14.3	14.3	273	275	278	276	275
270	7.2	13.5	25.2	4.0	6.7	6.6	6.4	6.4	6.5	13.5	13.5	13.5	13.5	13.5	286	287	289	288	287

1:10 years	Inputs				Results - Hs (m)					Results - Tp (s)					Results - Wave Direction (m)				
Dir (degN)	Hs (m)	Tp (s)	Wind Speed (m/s)	WL (mAOD)	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5
240	10.6	16.1	32.9	4.0	7.4	7.3	6.8	6.9	7.1	16.1	16.1	16.1	16.1	16.1	274	276	280	278	277
270	9.3	15.1	31.9	4.0	9.0	8.9	8.6	8.7	8.8	14.9	14.9	14.9	14.9	14.9	286	287	290	288	288

1:50 years	Inputs				Results - Hs (m)					Results - Tp (s)					Results - Wave Direction (m)				
Dir (degN)	Hs (m)	Tp (s)	Wind Speed (m/s)	WL (mAOD)	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5
240	12.1	17.2	37.3	4.0	8.6	8.5	7.9	8.1	8.3	16.9	16.9	16.9	16.9	16.9	275	277	280	278	277
270	10.8	16.2	36.5	4.0	10.4	10.4	10.0	10.1	10.3	16.2	16.2	16.2	16.2	16.2	286	288	290	289	288

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Table 3-4: Coordinates of Penmayn seaweed farm's four corners (P1 - P4) and its center point (P5)

Penmayn seaweed farm -study points	X coordinates (Easting)	Y coordinates (Northing)	Latitude	Longitude
P1	200293.5	85415.8	50° 38.04803298' N	004° 49.52665476' W
P2	201227.4	85423.0	50° 38.07103914' N	004° 48.73557876' W
P3	201237.9	84429.7	50° 37.53593496' N	004° 48.69473526' W
P4	200253.9	84438.4	50° 37.52042742' N	004° 49.52863992' W
P5	200749.5	84939.7	50° 37.80077102' N	004° 49.12490734' W

As shown in Table 3-3, the wave climate is characterised by relatively high and long waves, with the most severe conditions occurring with an incoming wave direction of 270 degrees (Westerly direction). The variability in wave parameters across the five study points is small, with P1 exposed to the highest and P3 to the lowest wave heights.

Even for a 1 in 1 year return period event, the wave climate in the study area is energetic, with significant wave heights reaching 6.7 meters and a peak wave period of 13.5 seconds. For a 1 in 50 year return period, the significant wave height can reach up to 10.4 meters with a peak wave period of 16.2 seconds.

3.4 Current conditions

As described in Section 3.2.2, a hydrodynamic model was used to determine current conditions at the five study points (Table 3.2). The model was run from late July to mid-September 2025 to predict current speeds during a period of significant tidal amplitude. This period was chosen due to the observed (Port Isaac, 2011-2022) high tidal elevations, which are expected to generate stronger tidal currents. The results of this analysis are presented in Figure 3-6 to Figure 3-8, showing current speeds for varying water levels over the selected time period. It should be noted that, although the currents are predicted for the period with the highest tidal change, these velocities provide an indication of the currents in the area and do not represent extreme current conditions at the site. To obtain extreme current data, the model would need to be run for a longer period (at least 10 years, ideally 40 years), which is beyond the scope of this study.

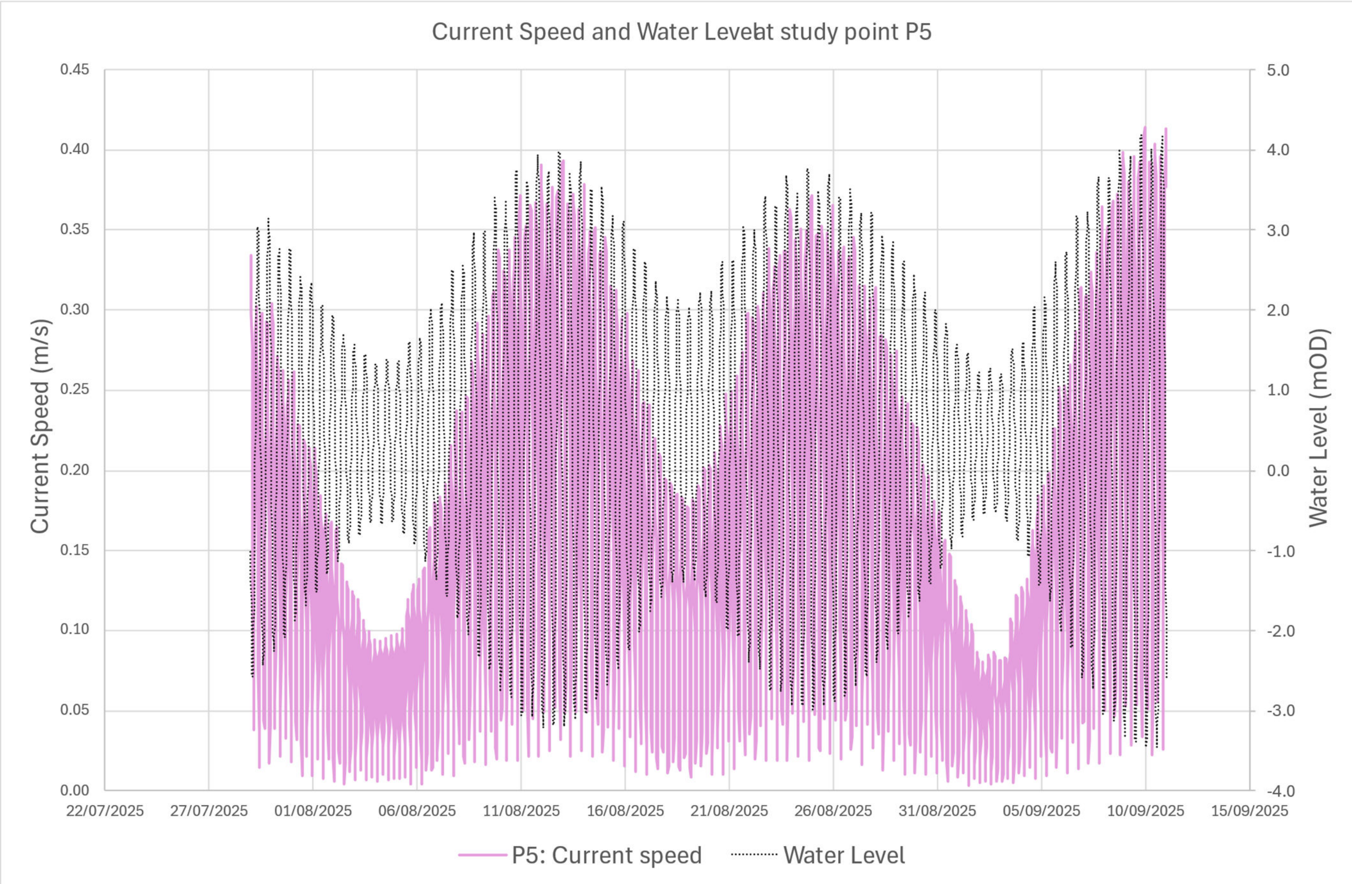


Figure 3-6: Current speed (m/s) and Water level (mOD) at study point P5

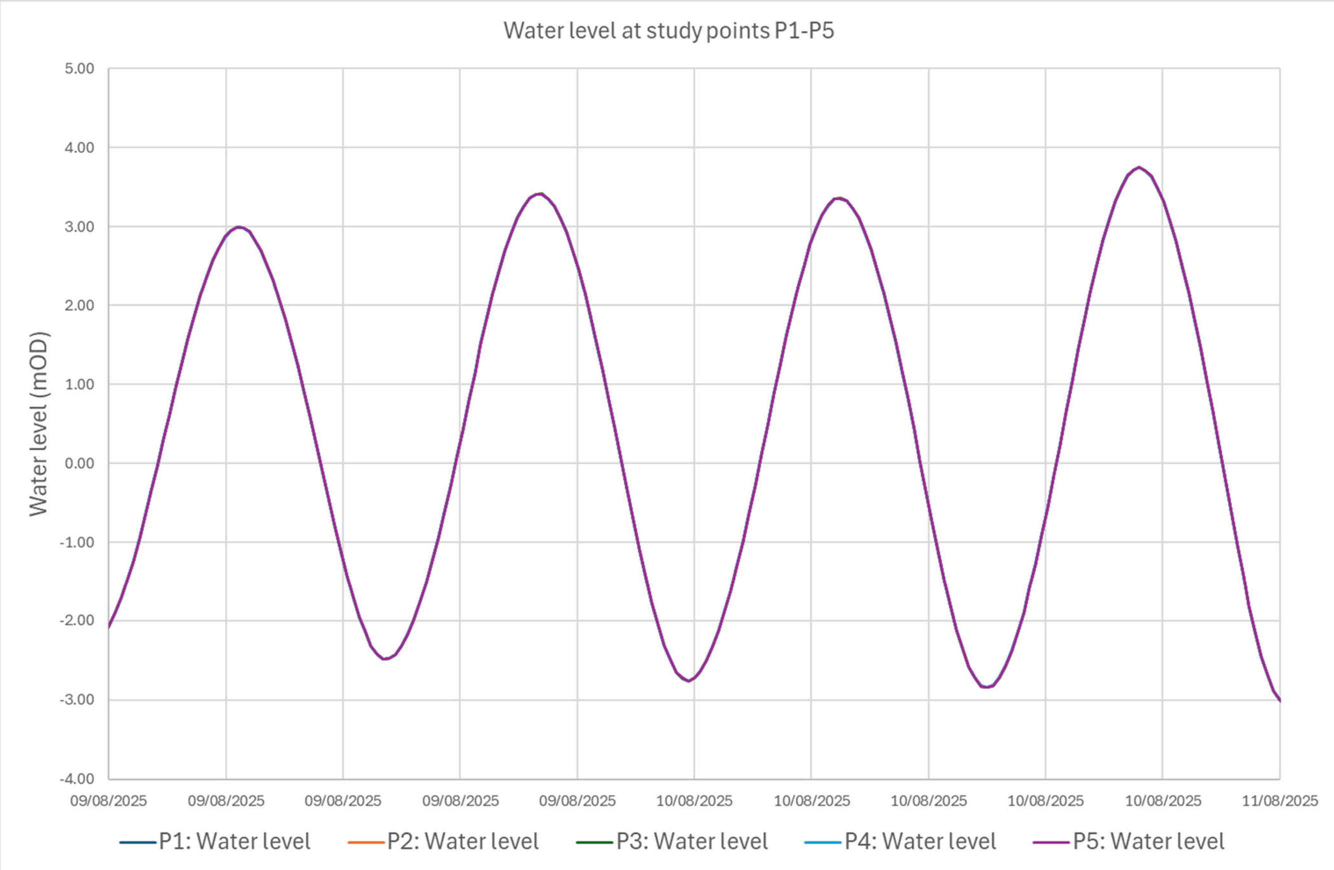


Figure 3-7: Predicted water levels (mOD) for tidal cycles between 9th to 11th August 2025 at study points P1-P5.

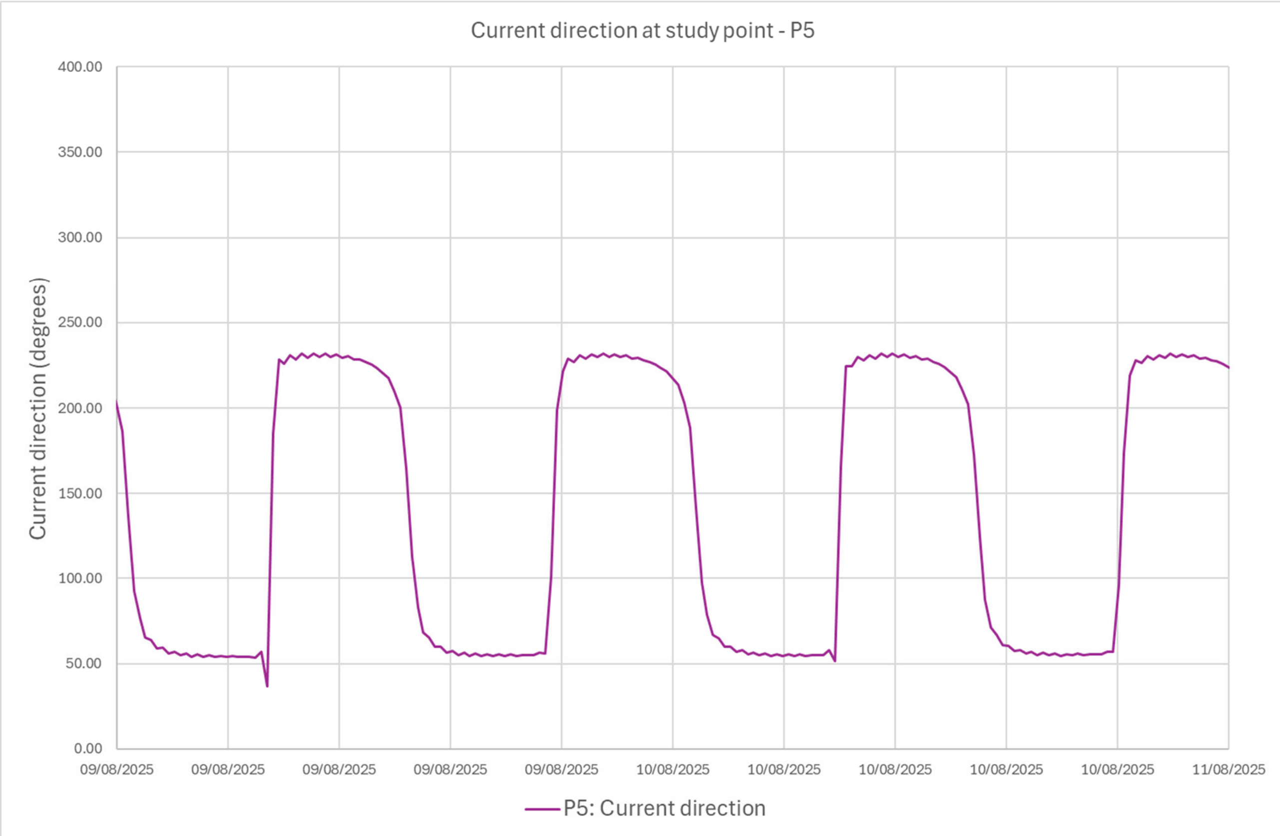


Figure 3-8: Predicted current direction (degrees) between 9th to 11th of August 2025 at study point P5.

The results presented in Figure 3-6 indicate current speeds for the period from July 22 to September 15, 2025, with an average speed of 0.18 m/s and a maximum speed of 0.46 m/s. The variability in current speeds across the five study points is minimal. It should also be noted that these currents are predicted as depth-averaged values throughout the water column. However, at the project location, in 30m deep water, the velocity in most of the water column (apart from near the seabed) will not vary much from the depth-averaged velocity.

3.5 Seabed information

3.5.1 Bathymetry

Figure 3-9 presents the bathymetry in Port Isaac Bay where the project site is situated. The proposed Penmayn Seaweed Farm is located around the -30mOD contour that runs in a south-west to north-east direction through the site.

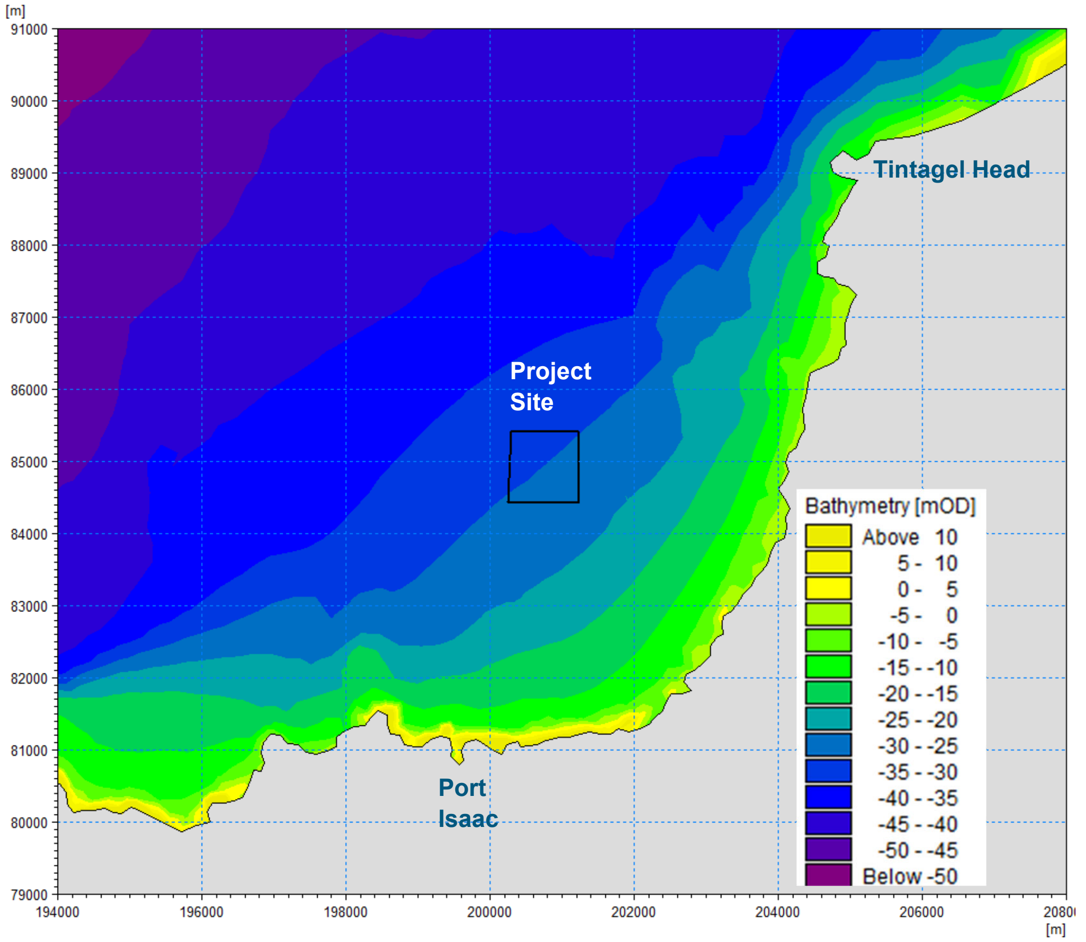


Figure 3-9: Bathymetry in Port Isaac Bay and near the project site (extracted from the wave model)

3.5.2 Seabed ground conditions

Limited desk-based information is available for the site. The British Geological Survey's Offshore GeoIndex (BGS, 2025) indicates that the site is underlain by Holocene seabed sediments consisting of slightly gravelly sand. Underlying these deposits is undifferentiated Devonian / Carboniferous age sedimentary rock (likely to consist of sandstone, siltstones and mudstones). There are no recorded Quaternary age deposits underlying seabed sediments in the area.

Grab samples to the west and north of the site (in an area shown as slightly gravelly sand) show that the surface sediment consists of greyish brown fine sand and very dark brown cobbles and granules respectively. Both the grab samples would not have sampled material from below about 30cm depth below seabed level, and so the form and thickness of the seabed sediment below the surface is unknown. There are no borehole or vibrocore records in the area held by BGS.

The nearest BGS seismic reflection survey line (#12) is located approximately 6.95km west of the centre of the site. The data from the sparker survey (provided by BGS as a .jp2 image from the 1971 survey) at the southern end of this line suggests that the superficial soils overlying rock in this area are around 10m thick, but insufficient data exists to confirm this assessment. It is possible that superficial soils at the seaweed farm site are similarly thick, but there is no available data to confirm this.

A summary of the data held by BGS and consulted via the Offshore Geoindex is given in Figure 3-10, below.

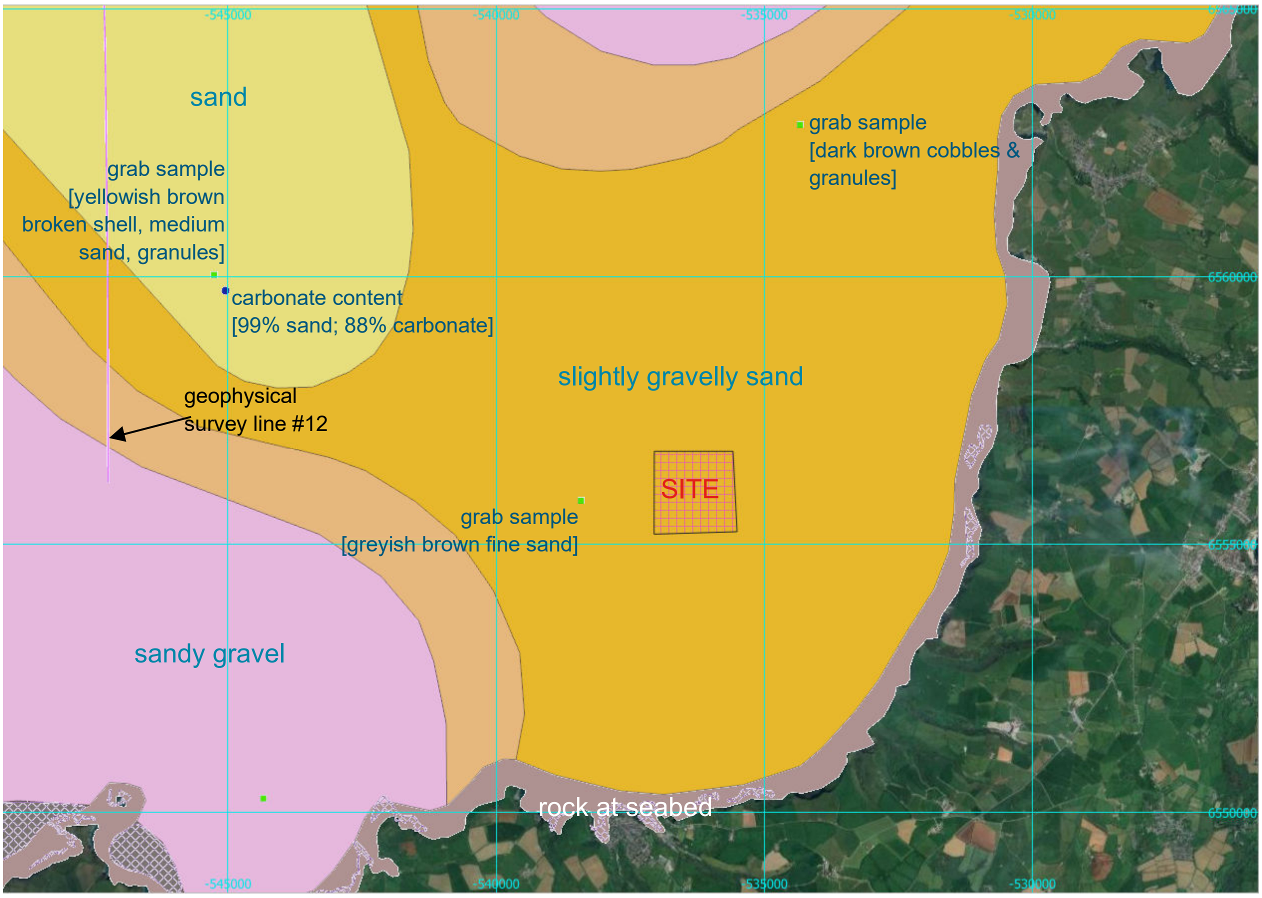


Figure 3-10: Seaweed Farm location with respect to sea bed conditions (grid spacing c3km)

Penmayn Ltd has not provided any investigation data with their application which would confirm the ground conditions at the proposed anchor locations.

4 Evaluation of Penmayn Seaweed Farm

This chapter reviews the information provided in the marine licence, pertinent to the design of the structure. It also provides a summary of the technical aspects of the currently available industry best practices, relevant for the design of a nearshore seaweed farm.

4.1 Reviewed documents

The following documents have been reviewed:

1. Marine Licence L/2023/00169/1 and its associated Schedules 1-10
2. Fielder Marine Services Third-Party Verification
3. Aquamoor Limited Third-Party Verification

Marine Licence L/2023/00169/1 and its associated Schedules 1-10

<u>Summary</u>

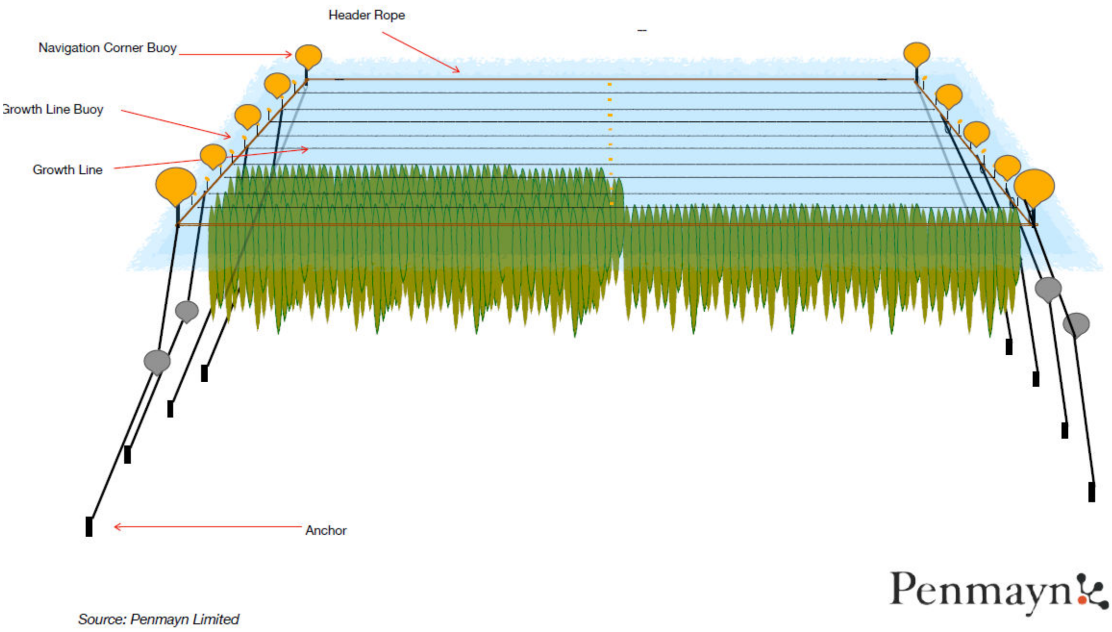
The Marine Licence contains the following documents:

- Decision letter
- Licence document
- Licence Schedule 2: Image of the Penmayn Seaweed Farm structure (see Figure 4-1, one 200x300m patch of the intended total of 12 patches)
- Licence Schedule 3: Anchor deployment methods
- Licence Schedule 4: Template for marine emergency action card
- Licence Schedule 5: Biosecurity protocol
- Licence Schedule 6: Navigation risk assessment (NRA) and emergency response plan
- Licence Schedule 7: Annex 1 to NRA – Risk/Hazard log
- Licence Schedule 8: Annex 2 to NRA – Aquaculture calendar
- Licence Schedule 9: Annex 3 to NRA – Monitoring
- Licence Schedule 10: Annex 4 to NRA – Keel clearance study

To understand if the proposed seaweed infrastructure is safe and reliable at the proposed location Schedule 3 and 6 are the relevant documents to review.

A description of the farm has been provided in Licence Schedule 6. The total farm will cover an area of 100 ha (1000 m x 1000 m; see Figure 4-1 and Figure 4-2). The main infrastructure of the farm is a series of long-lines anchored with screw anchor moorings. This will comprise of 10 anchors per block with approximate 66 lines per block at a length of 250m each. The lines lie at a maximum of 2m below the surface (current operating aquaculture sites around the Southwest have lines 2m below the surface as a minimum with no recorded incidents of significant interference with boats operating within the vicinity of the farms). The planned submergence levels will allow for safe clearance of differing vessel types and keel sizes operating in the area should they enter the farm site by mistake (see also Licence Schedule 10). The site will be marked in accordance with Trinity House guidelines.

In this same document it is stated that infrastructure will comprise a tried and tested system used in offshore farming. It states that it has proven stability in similar physical conditions within the Southwest, and that it will comprise of long-lines, similar to those used in mussel farming.



Source: Penmayn Limited

Distribution: MMO only unless by request for known stakeholders. Not for public distribution without consent.

Figure 4-1: Penmayn seaweed farm structure (Penmayn Limited, Licence Schedule 2)

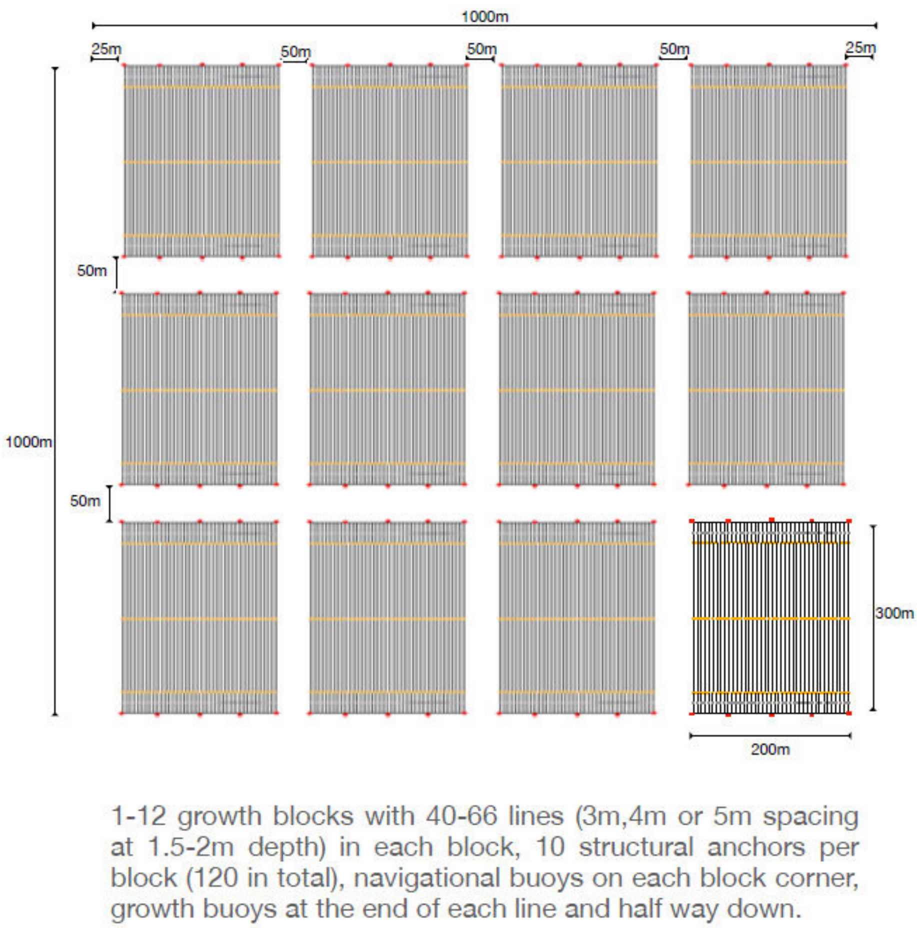


Figure 4-2: Penmayn seaweed farm layout (Penmayn Limited, Licence Schedule 6)

A generic description of how the screw anchors should be deployed is provided in Licence Schedule 3. This document has been provided by Fielder Marine Services Limited (www.fieldermarine.com), the partners of choice for the Penmayn Ltd farm installation. Fielder Marine Services have installed anchor systems and aquaculture infrastructure globally including in UK waters and indicated that they use best practice during planning and implementation.

Initial assessment

However, none of the documents provide proof that the proposed seaweed farm can withstand the wind, wave and current loads at the site. Other than just a mention that it is a tried and tested system and that is has proven stability, no calculations of the anticipated loads have been provided. A nearshore aquaculture structure for seaweed behaves vastly different in waves and current than other types of aquaculture structures:

- Fish farming requires nets, while seaweed or shellfish farming require a different structure, e.g. long lines
- Seaweed has different mass, buoyancy and drag properties than shellfish

It should be noted that although the concept design of Penmayn Seaweed Farm aligns with other variations of traditional culture rope systems (Tullberg, 2022), adequate design considerations have not been included to fully justify the design's validity.

The wave conditions at the site (see Table 3-3) can be considered challenging for seaweed cultivation. Referring to the indicative values provided by MMO (2019), the wave conditions are suboptimal for a wave height between 4 and 6m and above 6m the location can be considered unsuitable. At the proposed nearshore site the 1 in 1 year wave heights are around 6m. This means that multiple times per year the wave heights are suboptimal (i.e. 4-6m) and occasionally the wave heights are higher than 6m.

Schedule 3 provides a good explanation of how the screw anchors will be installed for various soil conditions of the seabed, but the exact soil conditions have not been taken into consideration. Information about the seabed conditions can be obtained (see Section 3.5) and it would have therefore been expected that the exact seabed conditions are considered when determining the way the screw anchors will be installed.

Section 4.2 in this report provides a detailed technical review of the design and discusses the processes and design considerations necessary for implementing a seaweed farm in accordance with best practices.

Aquamoor Limited Third-Party Verification

Summary

Aquamoor Limited carried out a third-party verification on the fitness for purpose of Penmayn Seaweed Farm structure and moorings on behalf of Save Port Isaac Bay Group. Their scope was:

- Verification of hydrodynamic and environmental data inputs
- Verification of calculation methods for forces, loads and factors of safety
- Check calculation outputs
- Review mooring design for the Penmayn Farm
- Review mooring specification and dimensioning for the Penmayn Farm
- Review assembly and installation considerations
- Report on fitness for purpose of the Penmayn Farm structure and moorings and regulatory compliance

Aquamoor concluded that the application for Penmayn does not follow best practice in designing, specifying and dimensioning a seaweed farm structure and its mooring system. They stated that the design approach adopted cannot be considered prudent or conservative for the chosen site. Appropriate design codes and standards have not been utilised or referenced. Hydrodynamic analysis of the structural design has not been utilised or referenced. The design and engineering process is not sufficiently rigorous. No documents have been identified as containing engineering analysis of the design.

It is their opinion that the structural and mooring design is such that the survivability and integrity of the Penmayn Seaweed Farm cannot be assured to a reasonable threshold.

Initial assessment
Royal HaskoningDHV shares this statement. Albeit Aquamoor does not refer to the recommended design standard for offshore and nearshore seaweed growing systems by the North Sea Farmers (Agitec et al, 2023), it does use, amongst others, the same standards on which the recommended practice is based (Norwegian Standard for floating aquaculture farms (Standards Norway, 2024) and DNV offshore standards (DNV, 2021a; DNV, 2021b)).The required design and engineering as outlined by these standards has not been followed.

Summary Fielder Marine Services Third-Party Verification
Summary
In this letter Graham Fielder, manager director of Fielder Marine Services, answers the same four questions as outlined in the introduction of this report, confirming their capability to install and maintain a seaweed farm for Penmayn Limited. With over 30 years of experience in aquaculture, including projects like Brixham and NZ Opotiki, Fielder Marine Services ensures the durability and safety of their installations. They also mention that the proposed anchors have a lifespan in excess of 25 years and the ropes specifically designed and built for aquaculture industry have a lifespan in excess of 10 years. Fielder Marine also confirm that the decommissioning of the farm can be done safely with minimal environmental impact.

Initial assessment
Although Fielder Marine Services highlights their extensive experience and asserts that the design can withstand expected forces and be safely constructed, commissioned, operated, modified, maintained, repaired, and decommissioned, they do not provide supporting evidence such as designs, calculations, or detailed method statements. The letter reads like an opinion rather than a third-party (independent) review.

4.2 Analysis of design

As introduced in Section 2.3, the recommended design practice for offshore and nearshore seaweed growing systems by the North Sea Farmers (Agitec et al, 2023) provides a good guidance of what should have been considered in the design process of a nearshore seaweed farm. This section provides a brief description of the items to consider. This is basically the same as what Aquamoor has done in their Limited Third-Party Verification.

4.2.1 Overview process to realise a nearshore seaweed farm

The recommended design practice includes an image which depicts different phases of the realisation of an offshore or nearshore seaweed farm, see Figure 4-3. To obtain a permit it is probably not required to have all design documentation ready, but it should be expected that the design basis and/or design philosophy and requirements are provided. This would give the organisation that will need to grant or reject the permit more evidence on which to base their decision.

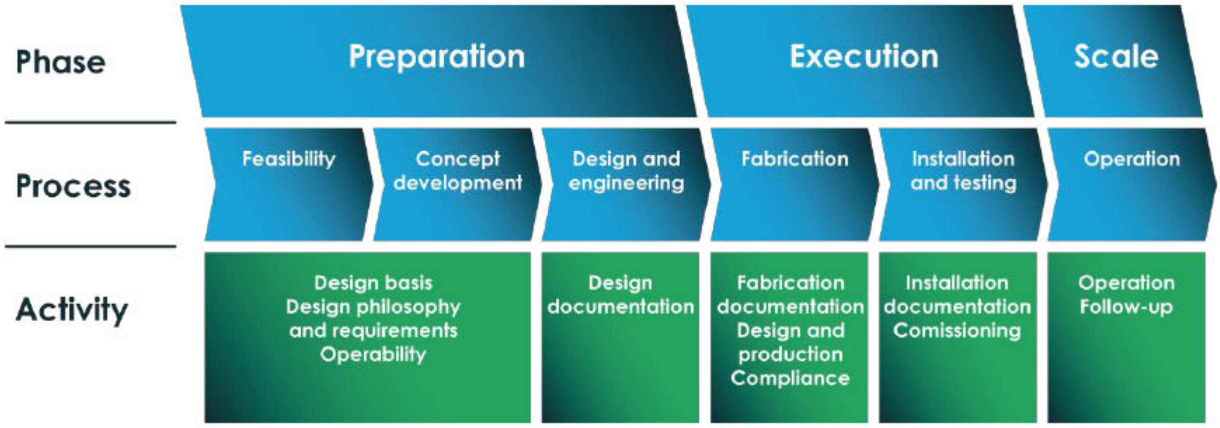


Figure 4-3: Process diagram realisation of an offshore or nearshore seaweed growing system (Agitec et al, 2023)

4.2.2 Analysis of water level and wind, wave and current conditions

The recommended design practice states that environmental data should be obtained and assessed according to NS9415 (Standards Norway, 2024). All relevant environmental conditions should be assessed. For a submerged offshore seaweed system, tides, waves and current are dominant effects. Marine growth is to be assessed. Other effects (may) include wind, ice, earthquakes, tsunamis and temperature. Such effects may be relevant in special locations and should be evaluated. As mentioned in Section 4.1, the submitted licence application does not include any design processes or calculations. The following analysis provides guidance on how water levels, wind, wave, and current conditions should be considered in the design process according to current best practices.

Water level
The following values for local water level need to be assessed:

- Tidal levels
- Extreme high and low water level with a return period of 50 years

Wind
Relevant wind conditions need to be assessed for wind-induced waves at the site and wind loads on the seaweed farm (if applicable). The design wind conditions are the extreme wind speeds with a return period of 10 and 50 years for multiple directions. It is preferred to determine the design wind conditions based on measurements. When using numerical calculations (e.g. model data) or hindcast data, the validity shall be documented through comparisons with relevant measurement series.

Waves
The design wave conditions are the extreme wave heights and periods with a return period of 10 and 50 years for multiple directions. Wave conditions shall be determined based on numerical modelling. Distinction needs to be made between sea (wind-induced waves) and swell waves. If ocean swells occur, the swell wave conditions need to be determined separately. Guidance to the numerical analyses (wave modelling) and the determination of the design wave conditions has been provided in NS9415 (Standards Norway, 2024).

Current
The design current velocity (return period of 10 and 50 years) needs to be assessed. The design current velocity needs to be representative of at least 5 and 15m depths measured from the surface.

The current conditions need to be determined using current measurements. Numerical analyses of current (e.g. hydrodynamic modelling) can be used to show the variation of the current picture in the seaweed farm area. Extrapolation from current measurements for a period to the design current conditions with a return period of 10 and 50 years has been explained in NS9415 (Standards Norway, 2024).

4.2.3 Assessment of design loads

The recommended design practice lists the general requirements for the design of the seaweed growing system. This is referred to as limit state and is applicable to all kinds of floating offshore structures (see for example DNV's document related to Position Mooring (DNV, 2021a)). Limit state refers to a level of severity or a condition beyond which a structure or component is no longer designed to fulfil its intended function. Limit states are used to ensure that a structure or component is designed and built to be safe and fit for its intended purpose. As mentioned in Section 4.1, the submitted licence application does not include any design processes or calculations. The following analysis provides guidance on which design loads and limit states should be considered in the design process for a seaweed aquaculture structure, according to best practices.

DNV (DNV, 2021a) defines the following limit states:

- Ultimate limit state (ULS): The ultimate limit state is the maximum load or stress that the structure can withstand before it potentially fails. This limit state is also known as the "failure limit state". The most severe ULS cases are considered to be the most severe waves, current and wind in combination with tidal level, wear, corrosion and severe fouling.
- Accidental limit state (ALS): The accidental limit state is the maximum load or stress that a damaged structure can withstand. Damage may occur due to accidental or extraordinary loading, such as a rogue wave or a collision. The most severe ALS cases are severe waves, current and wind in combination with reduced buoyancy or broken (mooring) lines.
- Serviceability limit state (SLS): The serviceability limit state is the load or stress that the structure can withstand in case of service. Cases include the handling of the system during inspection, maintenance and repairs. Severe SLS cases include the loading of the system during seeding and harvesting of the seaweed. To some extent a vessel may transfer loads to the mooring construction.
- Fatigue limit state (FLS): The fatigue limit state is the maximum load or stress that a structure or component can withstand over a given a load spectrum (wind, current, wave) without failing due to fatigue. The FLS is expected to be continuous loading caused by wave motion during the life of the components.

The recommended design practice defines different load combinations for each limit state. The load to be considered for ULS and ALS are extreme wind, wave and current conditions. For example, for the ULS, 1 in 50 year return period of the wind and waves, combined with a 1 in 10 year return period for current, and vice versa. For SLS and FLS operational (daily) conditions need to be considered. The recommended design practice also defines load and material factors, to cover any uncertainites in the structural assessment. Corrosion allowance and marine growth also need to be factored in.

For each limit state different load cases are defined.

ULS cases

The directional combination of current and wave should be assessed for at least 8 directional sectors. Combinations of current, waves and wind with the highest expected loads on the system should be identified, documented and used as load case. Effects to be included are: marine growth, extreme tidal levels and wear and corrosion.

ALS cases
The directional combination of current and wave should be assessed for at least 8 directional sectors. Combinations of current, waves and wind with the 1 year condition expected loads on the system should be identified, documented and used as load case. Effects to be included are: loss of buoyancy elements, broken mooring line, marine growth, tidal levels, wear and corrosion.

SLS cases
The loads being transferred by vessel operations to the system should be evaluated. Combinations of current, waves and wind that are operational limits for performing service to the system should be identified, documented and used as load case. Effects to be included are: operations during inspection, operations during seeding and harvesting, and operations during installation or repairs.

FLS cases
Components will be subjected to cyclic loading during the working life. The effect of the loads induced by incoming waves shall be evaluated. Unless substantiated otherwise, effects to be included are: seaweed yield, marine growth, and wear and corrosion.

The recommended design practice, based on Section 9.4 in NS9415 (Standards Norway,2024), further elaborates how to perform an analysis of the structural integrity of the seaweed growing system. The aim of the analysis is to determine the combination of simultaneous waves, current and wind that will result in design loads on components in the system.

4.2.4 Anchor selection

The seabed conditions have been derived from limited desk-based assessment conducted by RHDHV. In the documentation provided in support of their licence application, Penmayn has provided no confirmation of these, such as by geophysical surveying to determine the thickness of the superficial soils and depth to bedrock, nor intrusive investigation (e.g. by boreholes or vibrocores) to obtain physical data. As stated in the Aquamoor TPV report, Penmayn has not provided any indication of their assumptions about the ground conditions on site, other than those provided in the archaeological desk based assessment undertaken by Maritime Archaeology Ltd, which is limited to an indication of the type of sea bed sediment present at the site. The strength and stiffness of the ground at and around the anchor locations should have been determined, either by making some conservative assumptions based on similar soil types and an estimated thickness of the sediments, or by undertaking some form of ground investigation.

Penmayn appears to have assumed that the anchoring system will provide the requisite load resistance without either undertaking any kind of design or undertaking to subject the anchors to testing after installation. Overwater ground investigation is expensive, so it is understandable that Penmayn might be unwilling to shoulder the costs of such an investigation at an early stage. However, when ground investigation data is missing, the assumptions should be made clear, and while design codes (such as BS EN 1997-1) allow for observation-based design, with a suitable number of anchors subjected to pull-out tests to confirm that the required load capacity is achievable in the ground conditions on site, there is no indication that this will be carried out.

Cyclic or dynamic loading on the anchors is likely to be a factor at this location (BSI, 2012), which might degrade the strength of the soils within which the anchors are sunk if capacity is close to operational loads.

Since no design assumptions nor calculations have been provided, it is not possible to confirm that Penmayn’s proposed anchoring system is appropriate for the environmental and ground conditions present on the site.

5 Conclusion and recommendations

5.1 Overall findings

This study evaluated the design and mooring of Penmayn's Seaweed Farm as well as the related documentation included in the licence application. It was also in the scope of the study to assess AquaMoor Ltd's third-party verification, which asserted a high risk of structural failure posing a threat to life.

Based on the data obtained for this study regarding wind, wave, and current conditions at the proposed location for Penmayn's Seaweed Farm, it can be concluded that the wave climate at this site is energetic and significantly different from the wave climate recorded by the Port Isaac monitoring gauge (included in Licence Schedule 6). For a 1:1 return period event, the significant wave height (Hs) is 6.7 meters, and the peak wave period (Tp) is 13.5 seconds. Although not directly comparable, these values differ significantly from the wave data presented in Licence Schedule 6, which recorded the highest Hs during storms between 2010 and 2014 as 5.09 meters.

No explicit current measurements or data have been included in the Licence documents. However, a statement in the Navigational Risk Assessment (NRA) mentioned that the area is not significantly impacted by tidal changes. While the model used for this study suggests that the tidal current climate at Penmayn's Seaweed Farm is moderate, it is recommended that the design consider extreme current conditions as highlighted in Section 4.3.

Based on the review of the Penmayn's Seaweed Farm application documentation, it can also be concluded that the recommended design practices have not been followed. The ULS, also known as the "failure limit state", i.e. extreme wind, wave and current conditions in combination with tidal level, wear, corrosion and severe fouling, has not been analysed. The ALS, i.e. severe waves, current and wind in combination with reduced buoyancy or broken (mooring) lines, has not been analysed either. No proof has been provided that the system maintains its integrity during handling in the context of inspection, maintenance and repairs (SLS). An assessment of the structure to withstand fatigue loading has not been provided either (FLS).

5.2 Response to MMO's four questions

Based on the results from this study, the answers to the four critical questions posed by the MMO are the following:

Q (1): **Can the farm structure and mooring design for the seaweed farm withstand such forces acting on it as are reasonably foreseeable?**

R (1): It is not possible to ascertain from the information included in the Marine Licence application and related documents whether the Penmayn's Seaweed Farm can withstand the anticipated forces at the proposed location. The assumptions and design considerations in the application are very broad, and it is unclear whether appropriate hydraulic and geotechnical factors have been adequately taken into account. The proposed design does not seem to adhere to best practice standards, as highlighted in Section 4. Given the limited information included in the application, it is not possible to carry out the detailed analysis to determine whether the farm structure can withstand the foreseeable forces. However, based on our engineering judgement, the structure is likely to fail in the energetic wave climate at the proposed location without proper design considerations.
.

Q (2): **In the event of reasonably foreseeable damage to the installation or its moorings, will the infrastructure retain sufficient integrity to enable action to be taken to safeguard the health and safety of persons on or near it.**

R (2): The information provided in the Marine Licence and its associated documentation does not clearly indicate whether Penmayn's Seaweed Farm design has adequately evaluated and addressed the environmental conditions at the site that could damage the installation or its moorings. And in the event of line, anchor or buoy failure, it also has not been shown if there is sufficient redundancy to maintain sufficient integrity. Given the limited information included in the application, it is not possible to carry out the detailed analysis to determine whether the farm structure can retain sufficient integrity to enable action to be taken to safeguard the health and safety of persons on or near it. However, based on our engineering judgement, without considering the appropriate environmental conditions (waves, wind, currents, and seabed conditions), the structure is unlikely to retain sufficient integrity during adverse weather conditions.

Q (3): **Can the construction, commissioning, operation, modification, maintenance and repair of the installation proceed without prejudicing its integrity**

R (3): The proposed concept design of Penmayn's Seaweed Farm aligns with other established seaweed farms in Northwest Europe. However, critical aspects related to the design, installation, and maintenance of the anchoring system are not included in the licence application. If these aspects, together with the other design requirements discussed in Section 4.2 are not adequately considered, it could compromise the installation, commissioning, operation, modification, maintenance, and repair of the structure, ultimately affecting its integrity.

Q (4): **Can the seaweed farm infrastructure be decommissioned and dismantled safely?**

R (4): Although a risk assessment (Licence Schedule 7) has been conducted for the decommissioning of the structure, a detailed method statement should also be presented to ensure the seaweed farm infrastructure can be decommissioned and dismantled safely. It should be noted that without appropriate design considerations (such as ALS and SLS), it is likely that, given the hostile environment in which Penmyan's Seaweed Farm is proposed to be located, the structure will not retain sufficient integrity to be decommissioned and dismantled safely.

5.3 Recommendations

The concept design presented by Penmayn Limited for the Penmyan Seaweed Farm, while similar to other established seaweed designs, currently lacks the necessary detail to ensure its stability, survivability, and efficiency. It is recommended to first reconsider the suitability of the site, given its energetic wave climate, and to design the structure following best practices. This approach will reduce the risk of damage to the structure, potential harm to third parties, and give confidence in the structure's survivability.

Given the growing trend of seaweed farms and the increasing likelihood of seaweed farm applications, it is recommended that the Marine Management Organisation integrates minimum design requirements into the Marine Application process for such type of aquaculture. These requirements should be appropriate for the design stage at which the Marine Licence is granted. While a detailed design might not be necessary at the time of application submission, the outline design should already incorporate relevant design considerations, with a commitment to complete a full design before the structure is deployed. This would enhance the quality of assets deployed at sea, reduce the risk of damage, inherent to inappropriate designs, and mitigate harm to the environment and human health in case of structural failure or severe damage; while also making the consenting process more effective and efficient. Practically, these minimum requirements should ensure that applicants have appropriately considered environmental conditions and design loads following best practice.

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