TIGER TIDAL STREAM INDUSTRY ENERGISER

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Lessons learned from developing tidal sites in UK Channel

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Disclaimer

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Executive summary

This document details the steps needed to develop a commercial tidal stream energy site in the Channel region, using Perpetuus Tidal Energy Centre (PTEC) as an example.

The TIGER project has also published two 'Guidelines for development of tidal energy projects' – one on consenting, and the other on site selection and development. These are at: https://interregtiger.com/download/tiger-report-guidelines-for-development-of-tidal-energy-projects/. The TIGER project has also published a 'Tidal Stream Technology and Project Development (WP T1) - Final Lessons Learnt' report, which includes other lessons on site development and consenting, at: https://interregtiger.com/resources/.

The subjects covered include onshore construction and grid connection. Offshore works are detailed, including the numerous surveys required for device developers to conduct initial and detailed engineering, and for successful marine operations. Additionally, an example of the consents required for a tidal site are detailed, including the onshore and offshore permits, and compliancy surveys during operations.

Tidal site development is multi-faceted and requires different levels of information and funding at each stage. As the level of information, number of onshore and offshore operations and surveys, and modelling detail increases so does the cost, generally.

Funding support from multiple sources and governmental backing is essential for commencement of new tidal projects in UK and EU waters.

1 Introduction

There are many sites in the UK and channel region with potential for development of tidal energy. Prominent sites that have operated or been under development include the Orkney Islands, Caithness, Strangford Lough, Ramsey Sound and Anglesey (Figure 1,[1]). In the Channel region there have been proposals and development work for a number of sites, such as Portland Bill, PTEC and Raz Blanchard. PTEC is a proposed site located off the south coast of the Isle of Wight; PTEC will be used here as an example of site development and lessons learnt in information gathering for new tidal site development.

The TIGER project has also published two 'Guidelines for development of tidal energy projects' – one on consenting, and the other on site selection and development. These are at: https://interregtiger.com/download/tiger-report-guidelines-for-development-of-tidal-energy-projects/. The TIGER project has also published a 'Tidal Stream Technology and Project Development (WP T1) - Final Lessons Learnt' report, which includes other lessons on site development and consenting, at: https://interregtiger.com/resources/.

The following information will be discussed, including site description, onshore infrastructure and electrical grid connection, offshore conditions, operations and maintenance considerations, and consenting process.

Recommendations for each stage are given where applicable, though these may not be relevant for all site development in the Channel region and are intended as a guide only.

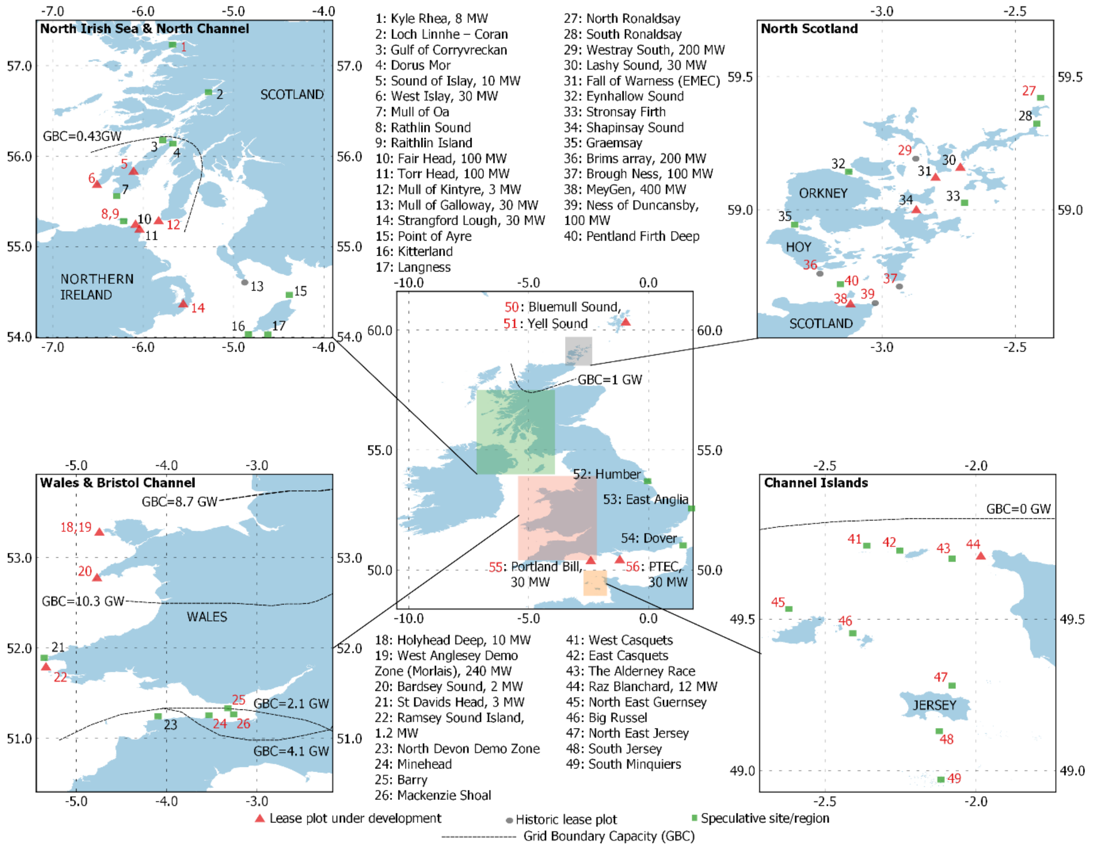


Figure 1 | Tidal sites around the UK and Channel [1]

2 Site description

The Perpetuus Tidal Energy Centre (PTEC) is a 30 MW tidal energy demonstration facility 2.5km south of the Isle of Wight, with potential expansion capacity up to 300 MW. It has been under development since 2012, when PTEC secured a seabed 'Agreement for Lease' from the Crown Estate [2].

EMEC has joined forces with PTEC to develop the commercial demonstration facility. This site will be eligible to bid into future UK Contracts for Difference (CfD) allocation rounds enabling tidal energy technologies developed in the UK to deliver predictable low carbon energy [3].

The site has been considered for commercial deployments and has the potential for expansion to facilitate large tidal arrays. A recent paper [4] compared the power that could be produced from offshore wind, solar photovoltaics, and tidal stream on the Isle of Wight, with clear favourability for tidal based on security of supply, reduction of power shortages/surpluses and reduced storage requirements. The site footprint is also significantly reduced compared to other power sources as shown in Figure 2.

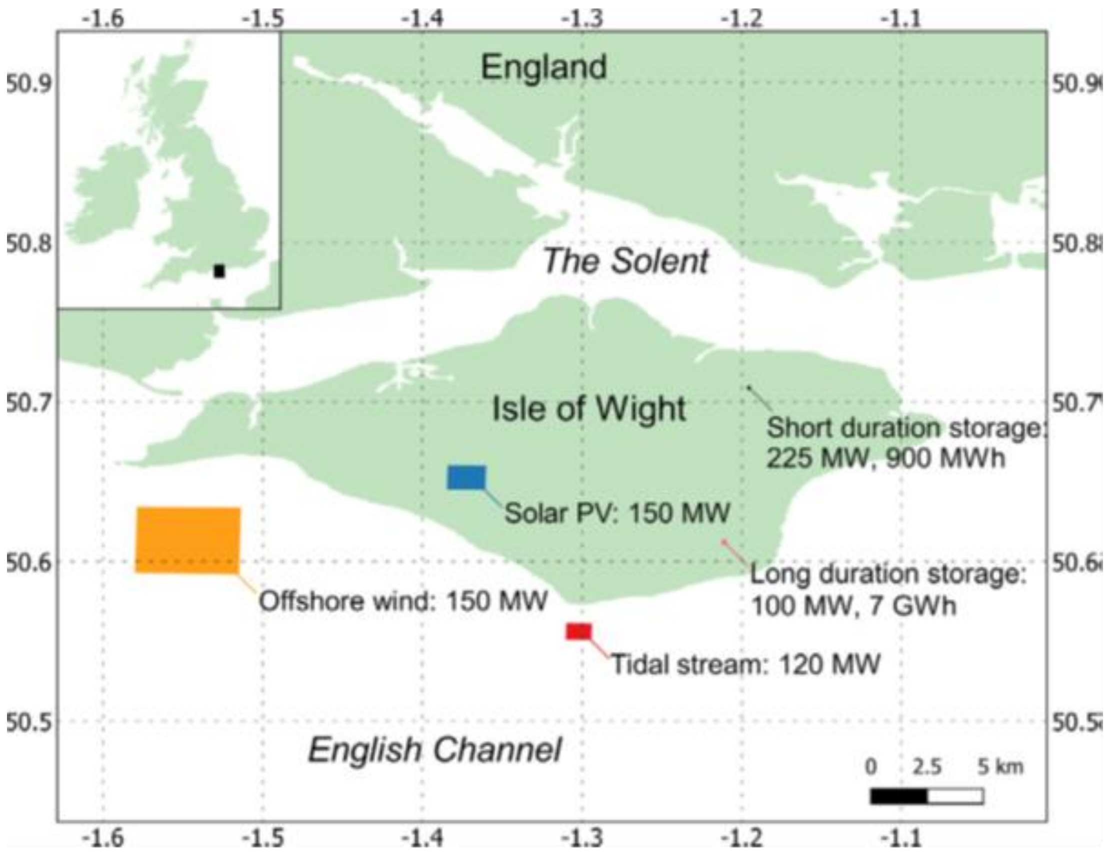


Figure 2 | Plan area of solar PV, offshore wind, tidal stream, and short duration and inter-seasonal energy storage on Isle of Wight [4]

2.1 Location

PTEC is located off the south coast of Isle of Wight, in the south of the UK, north of La Manche in the Channel (Figure 3). The site is located in a channel of approximately 50 m, with a tide up to ~3 m/s running NE–SW.

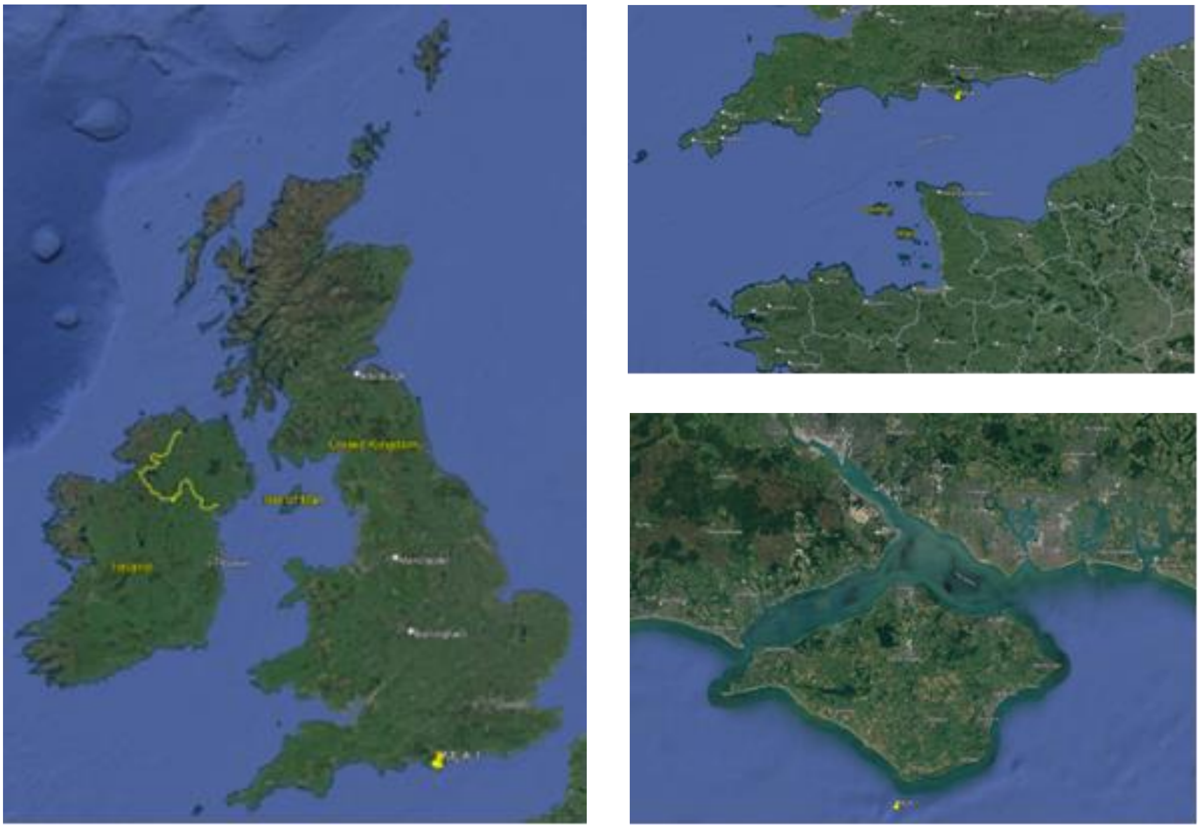


Figure 3 | PTEC location in relation to UK (left), Channel region (top right) and Isle of Wight (bottom right); Google Earth imagery

2.2 Onshore

2.2.1 Landfall

The proposed landfall point for the offshore cable is at Flowers Brook, near Ventnor (Figure 4 and 5, Google Earth imagery).

When selecting the landfall point several factors are considered, including the cable run to shore, bed material, wave conditions at shoreline, burial/pinning potential, distance to grid connection point, risk of mechanical damage to the cable, potential for environmental impact during cable installation limitations and consenting, e.g. site of special scientific interest (SSSI) or building restrictions.

For PTEC, five options were considered [8]. In order to minimise transmission losses and simplify control systems, it is desired that the onshore substation is as close to the landfall point as possible, and that the offshore cable distance is as short as possible. The current landfall site was selected based upon the desired substation location: the Flowers Brook site is outside SSSI, area of outstanding natural beauty (AONB) and heritage coast designations. The pre-existing structures for Southern Water also allowed minimal works and impact and the site has one of the shortest onshore cable-run distances. Alternative sites were also considered desirable, based on the available space for onshore buildings and short offshore cable routes.

Figure 4 | Proposed cable landfall point

Figure 5 | Flowers Brook onshore station site

2.2.2 Onshore Infrastructure

An example of onshore infrastructure is given in this section, using the proposed configuration for PTEC.

The site plan for which planning permission has been granted is shown in Figure 6 below. A single building would be constructed alongside the existing sewerage pumping station; the existing buildings are very well screened by trees.

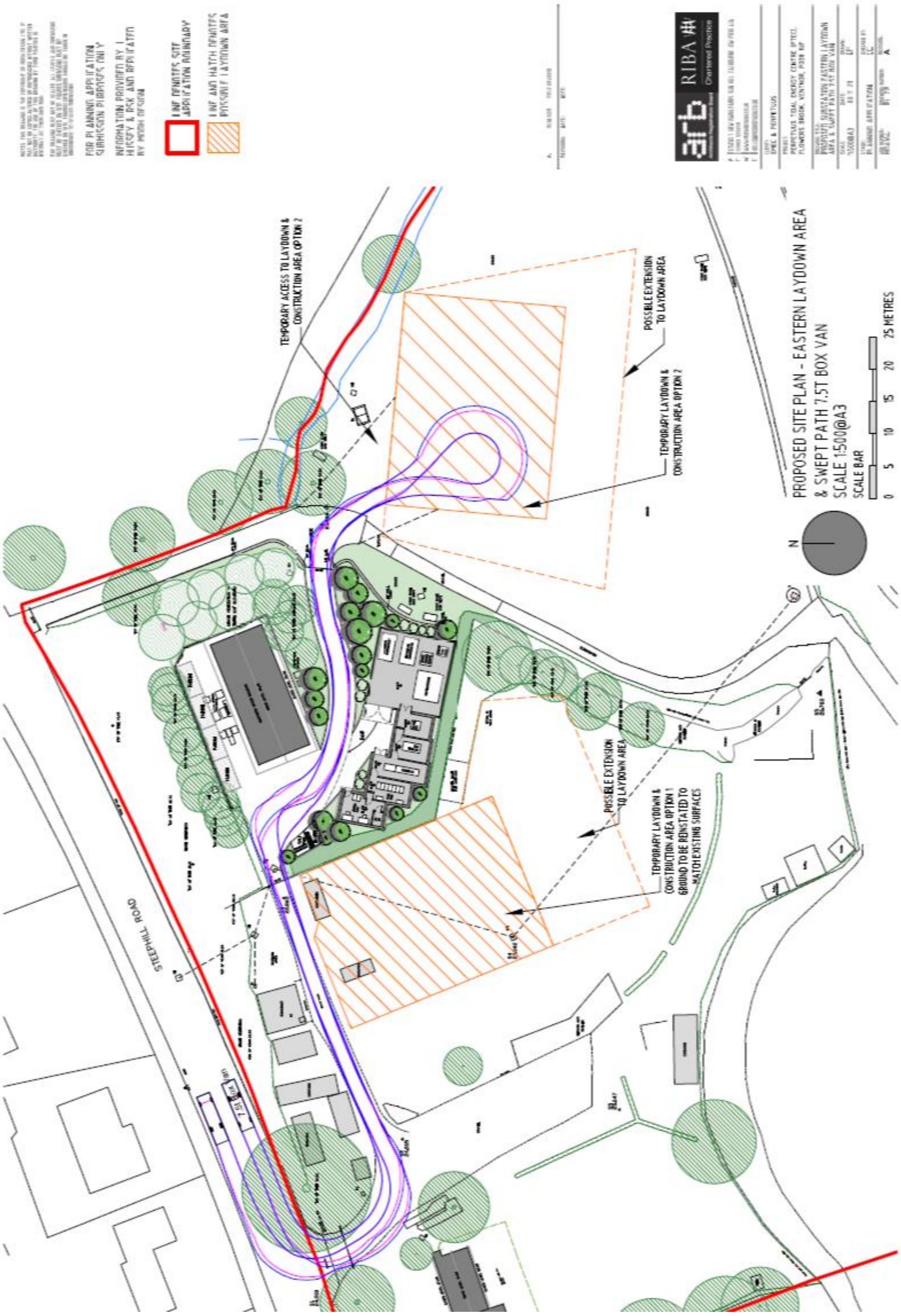


Figure 6 | Planned onshore infrastructure at Flowers Brook

The new substation building contains the electrical infrastructure necessary to safely connect the tidal power plant to the grid and control it. As can be seen in Figure 7, a typical substation building contains:

- Control Room
- Panel Room – where SCADA systems for individual berths are expected to be located
- High Voltage Cabinets – where berth switchgear is located
- EHV Switchboard – PTEC
- EHV Switchboard (Scottish and Southern),
- Main Transformer taking 33kV down to 11 kV
- Neutral Earthing Resistor to control the size of any fault currents to earth
- Harmonic Filters to smooth electrical output from berths
- Station Transformer

Given the compactness of the final PTEC substation site, extra land area will be temporarily required to facilitate construction. During the construction phase coastal path diversions and closures will be in place for a couple of months, depending on which laydown areas and cable routing methods are chosen. Sufficient space to facilitate all stages of construction should be available when selecting an appropriate substation location.

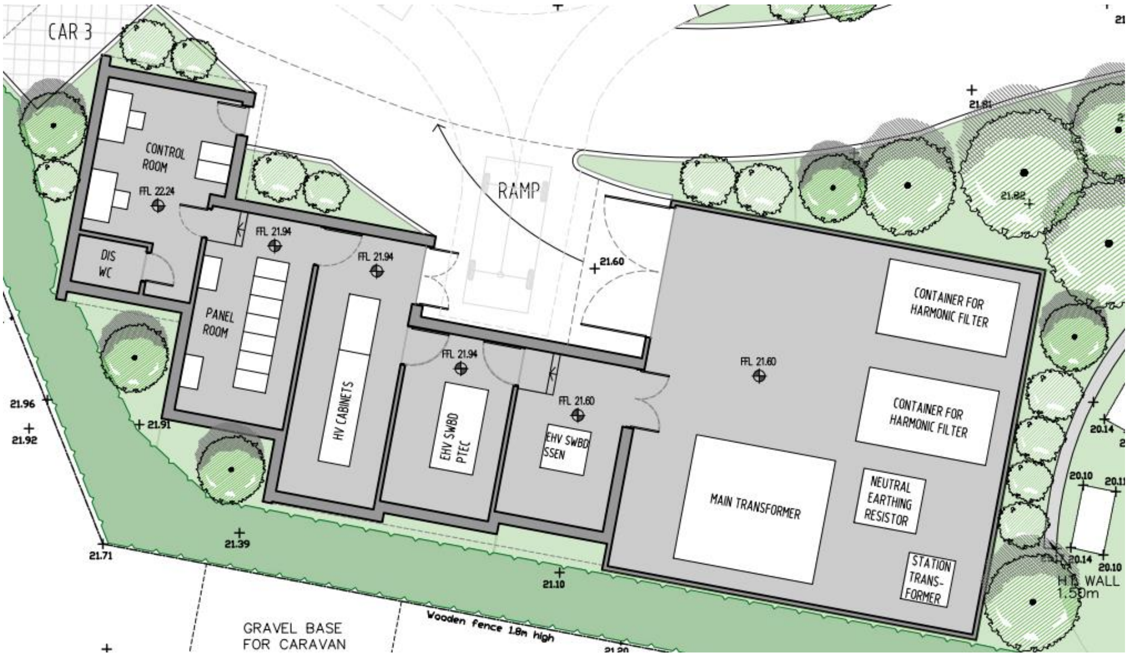


Figure 7 | Close-up of plan showing substation layout

The substation is also close to residential properties which overlook the Flowers Brook site, so noise level studies have been completed to confirm that these would be within the required standards (Section 4).

Cables from land to sea will need to be protected. Numerous options are available for this purpose including horizontal directional drilling (HDD) and land/sea trench solutions for cables.

The marine energy industry to date has been very mindful of visual impact of infrastructure. Substations at Meygen, Eday and Billia Croo have all taken measures to minimise visual impact including low profile buildings, vegetation and colours and materials in keeping with surroundings. The artists impressions show how well screened the new PTEC substation will be, blending in with the local landscape (Figure 8 and 9).

Full planning permission has been received for the PTEC site. The formal approval contains detailed requirements for the project developer (PTEC) to meet their obligations under the permission.

These are detailed in Section 5, Consents in this document.

Figure 8 | Artist's impression of substation looking down the access track to Flowers Brook courtesy of PTEC

Figure 9 | Artist's impression of substation looking up the hill towards the substation courtesy of PTEC

2.3 Electrical Infrastructure Overview

An example of required electrical infrastructure is provided. This section demonstrates elements that should be considered when designing the single turbine and array electrical connections.

2.3.1 Turbine-to-Grid

A high-level schematic for the entire electrical system from turbine through to grid connection is shown in Figure 10. The detailed design of the offshore element is still to be completed and so only a possible configuration is shown.

The array of tidal energy converters (TECs) could, within the constraints of the license, consist of up to 60 submerged tidal energy converters with a maximum of 30 surface piercing. The individual TEC size would range from 100 kW to 6 MW, and these could be connected in turn to 3 electrical hubs.

The Orbital O2 device (rated at 2 MW) is shown for reference, as it is a strong potential candidate device for deployment at the PTEC site.

To date, most TEC deployments in the UK have been individual turbines, mainly for the purposes of testing. They have been connected through a dedicated cable to the shore station.

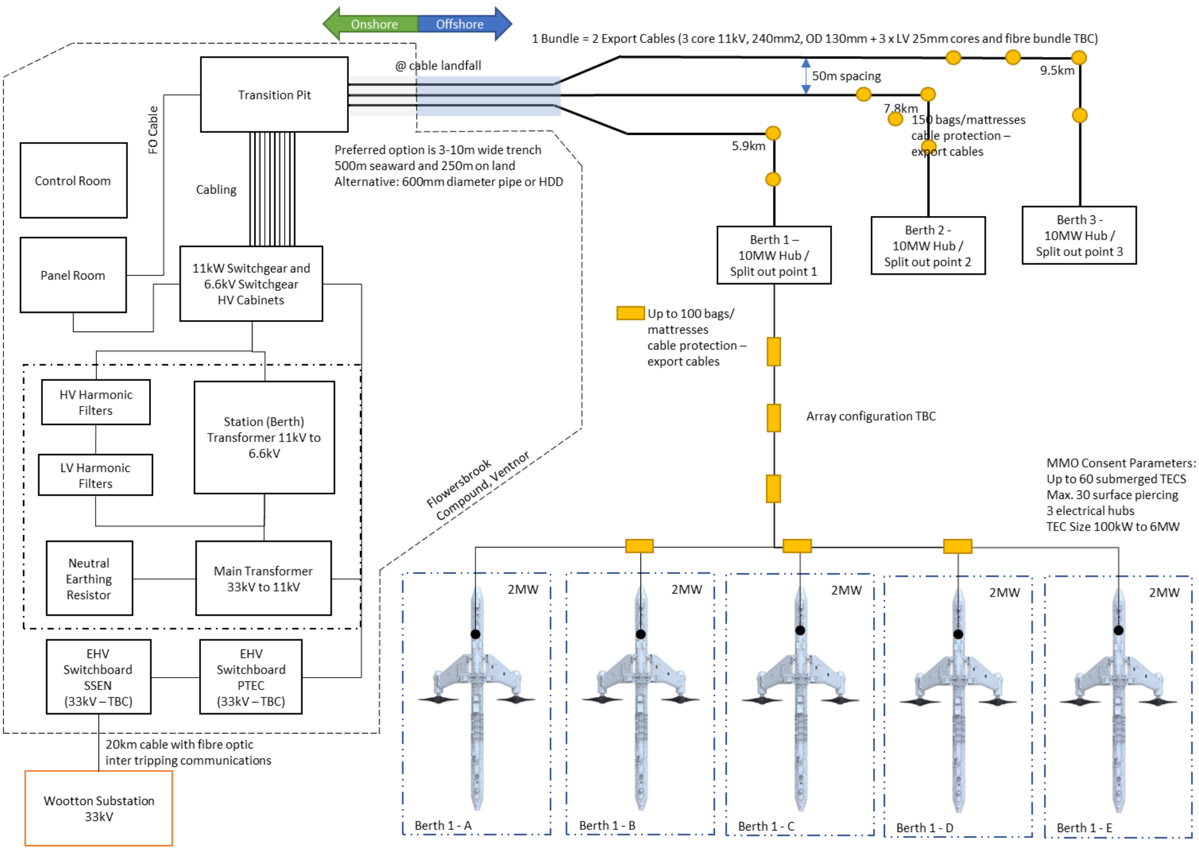


Figure 10 | Turbine-to-grid high-level schematic

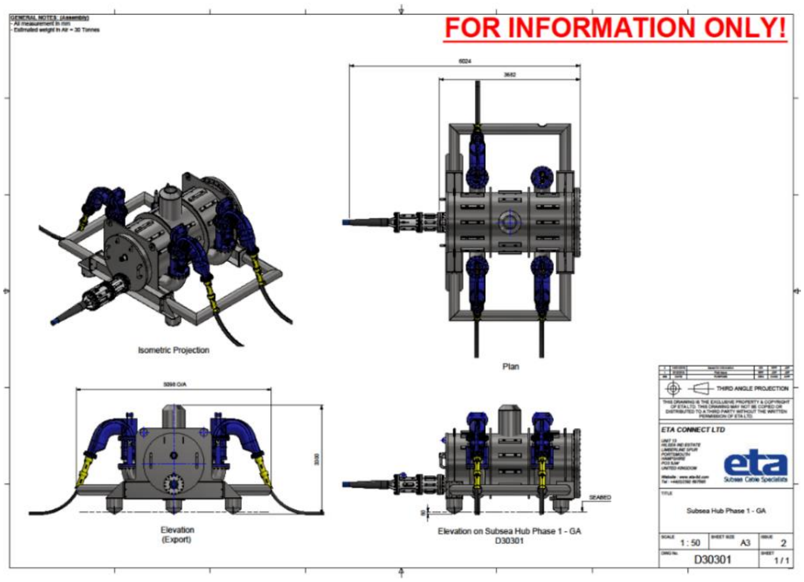


Figure 11 | A typical subsea hub for a tidal site

For the deployment of multiple turbines, it is envisaged that subsea hubs, e.g. Figure 11, will be increasingly deployed to minimise the cable requirements on site, particularly if the tidal energy site is a reasonable distance offshore.

However, the downside of utilising a subsea hub is that it adds complexity to the project, including additional marine operations. The detailed design of the array is a significant, multifaceted and complex piece of engineering work and one that still needs to be undertaken for the PTEC site.

The detailed design phase for PTEC will have the advantage of being able to build on existing UK industry experience, some of which is listed in Table 1.

Location	Operation Phase	Turbine	Cabling Method	Approx. Distance Offshore
Blue Mill Sound, Shetland	2016 with turbines 5 and 6 installed in 2023.	Nova M100-D rated at 100 kW @ 2 m/s. Blade diameter 8.5 m	Originally direct cable to shore for turbines 1–4 and sub hub for 5 and 6	Approx 200 m offshore, Cable runs approx. 1000–1400 m.
Meygen Phase 1	2018 with subsea hub installed in 2020.	1 x SAEs AR1500 and 3 x Andritz Hydro Hammerfest AH1000 MK1 – 1.5 MW each @ x m/s Blade diameter 16 m	HDD drilled cable to individual turbines with subsea hub installed later	Approx 2000 m offshore. Cable exits horizontal drilled pipe approx. 0.3 Nm offshore

EMEC Fall of Warness Test Site, Orkney (Figure 12)	Opened 2006. Operational 2008	Various devices. Current devices on site: Magallanes ATIR (1.5 MW) Orbital O2 (2 MW)	Cables terminated with dry mate connections or supplier specific terminations to suit turbine on test.	Approx 1000–1500 m offshore with cable runs up to approx. 4000 m.

Table 1 | UK development examples

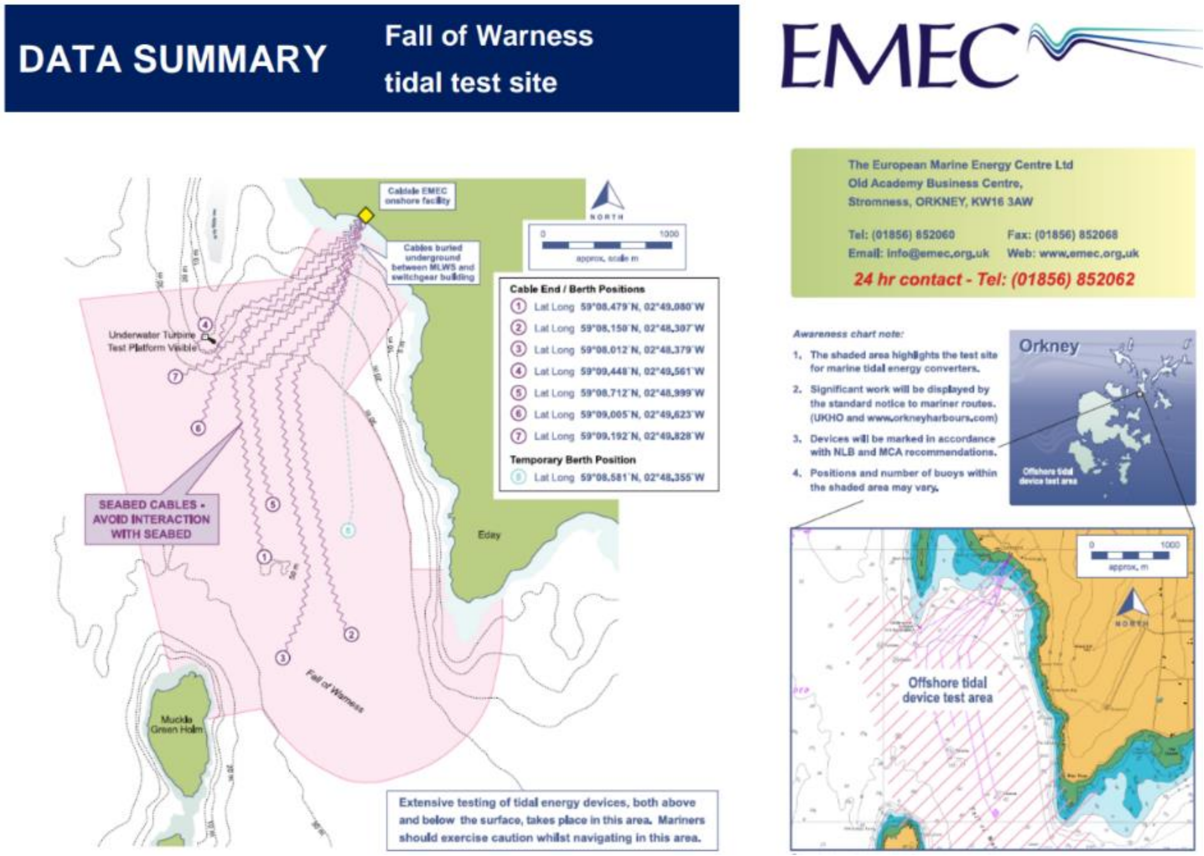


Figure 12 | EMEC tidal array berths

2.3.2 Grid Connection

2.3.2.1 Existing Infrastructure

The electrical network on the Isle of Wight operates at distribution voltages (132 kV or less) and is operated by Southern Electric Power Distribution Ltd (SEPD), a subsidiary of Scottish and Southern Energy. The simplified schematic in Figure 13 **Figure 13 | Isle of Wight network map, courtesy of Grontmij** shows the 132 kV and 33 kV networks and the principal sources of generation as of 2011.

The three 132 kV interconnectors to the mainland consist of submarine cables and onshore overhead lines. The summer rating of each is in the region of 100 MW. The two circuits terminating at Wootton Common substation serve the general power import and export to and from the Isle of Wight. The third interconnector, terminating at East Cowes, is reserved for generation at East Cowes, as described below, and does not contribute to the export capacity available for new generation.

Two main sources of generation are shown on the 2011 map. The first is East Cowes power station, which is a 140 MW open cycle gas turbine plant. It has historically been operated under contract to National Grid for short-term operating reserve or similar peaking and stability services and has historically had a capacity factor in the region of 0.5% [5]. An internal report by ITP consultants for PTEC estimated operation would be less than 200 hours per year.

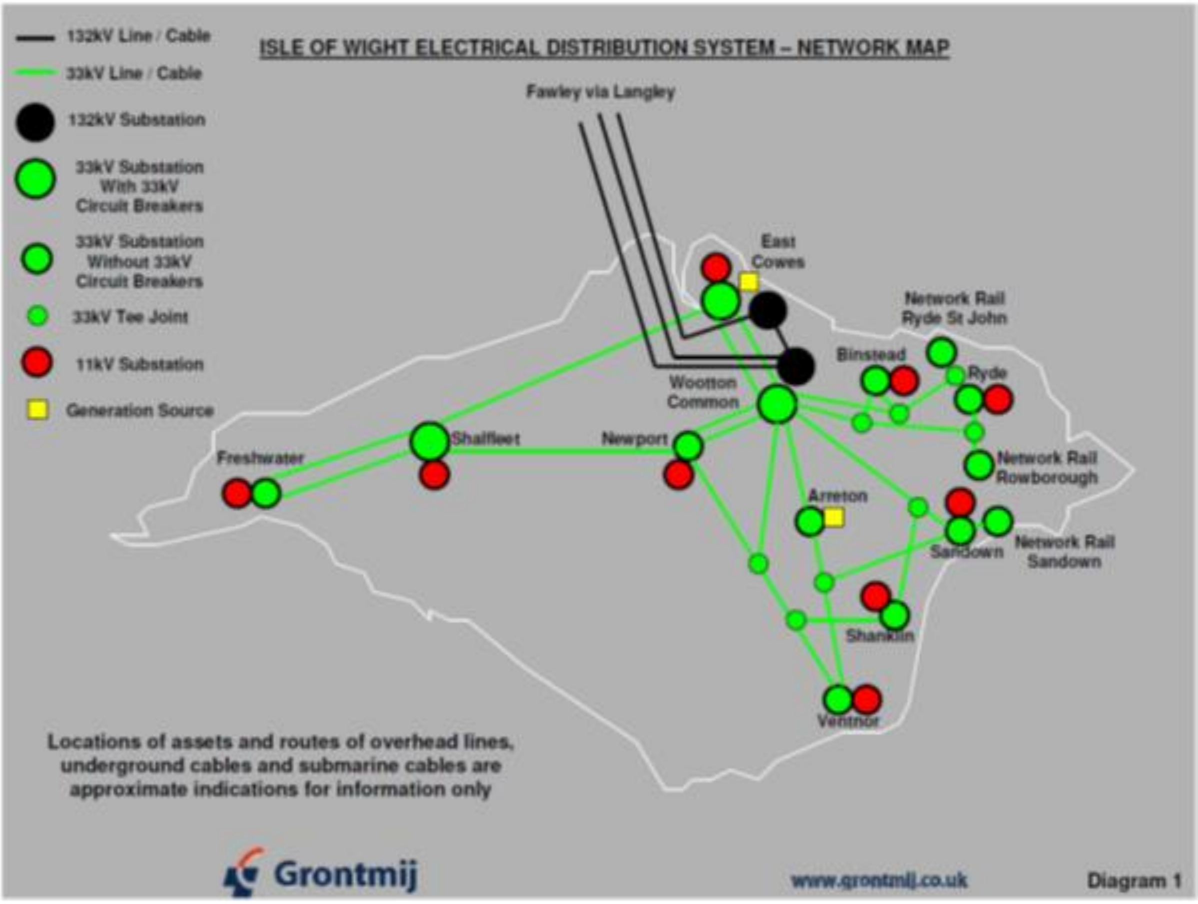


Figure 13 | Isle of Wight network map, courtesy of Grontmij

East Cowes has a 'firm' connection agreement [5], which provides continuity of the full export capacity under outage of a single circuit (for instance, loss of one interconnector). Furthermore, its ability to provide support to National Grid relies on its ability to increase power flows very quickly in response to a network event, which would not be possible if capacity on the mainland links were fully utilised by other generation. For these reasons, the capacity on the Cowes interconnector is not made generally available. This has been and remains a contentious issue [6].

The second source of generation in Figure 13 is at Arreton. This is a horticultural establishment using combined heat and power systems to provide heat and carbon dioxide to nurseries and power to the grid. The electrical capacity is 15.5 MW.

A significant volume of commercial solar PV has been added in the last decade and is not shown in the map. A study by consultants ITP for PTEC in 2014 found that in the region of 50 MW was connected at that time, with a further 20 MW having accepted connection offers. By 2021, around 90 MW was thought to be connected [5]. In addition, there is a significant but undocumented volume of domestic solar PV.

2.3.2.2 Grid Connection Activities

Work on acquiring a grid connection was carried out in two phases:

a. An application for a 30 MW connection was made early in the development process and a connection offer was made by SEPD in 2014, with an estimated go-live date in 2018. Connection design proceeded until 2016, when ring-fenced revenue support for tidal energy through the Contract for Difference (CfD) scheme was halted in Allocation Round 2 and the PTEC project was paused.

b. The project subsequently resumed in 2020 with the prospect of restored revenue support in future allocation rounds, and fresh connection applications were made in 2021. These culminated in identification of 20 MW as the most cost-effective capacity.

a) Initial application

The 2014 offer, for 30 MW capacity, would have connected to the SEPD 33 kV distribution network at Wootton Common 132:33 kV substation and would have required a lengthy (~19 km) underground cable circuit from Wootton Common to the proposed PTEC site at Ventnor. It also required significant reinforcement of one of the 132 kV circuits feeding Wootton Common. Connection costs were therefore high.

The 2014 connection offer was on a ‘non-firm’ basis and required automatic disconnection of the PTEC facility in the event of loss of one of the submarine cable circuits or other issues affecting the Isle of Wight 132 kV system, to prevent overload and/or preserve system stability. It also required automatic disconnection at times when Cowes East power station was in operation.

b) 2021 application

Two issues were noted from the initial application: first, the limited export capacity available on the Isle of Wight; second, the difficulty of obtaining the desired 30 MW at reasonable cost. These are discussed in turn below.

During the initial application phase, it was apparent that there was increasing interest in new generation, particularly commercial solar PV. As a consequence, the network was close to its capacity to accept new generation in the traditional manner of a non-firm connection, where the generator is entitled to generate to full capacity at any time when the distribution network is in its normal configuration. Such connections ensure the greatest use of generation assets, but result in inefficient use of network capacity, since the sum of contracted generation connections must not exceed the network capacity.

In response to the increasing volume of generation, SEPD in 2016 introduced an Active Network Management System (ANM) to allow them to offer flexible connections to new applicants. The ANM system allows generators to operate whenever there is spare network capacity and curtails generation as the network capacity limit is approached. The capacity limit is seasonal and is lowest in summer.

On the Isle of Wight, where the main limitation on export is the capacity of the 132 kV circuits to the mainland, use of an ANM system was seen as a cost-effective alternative to upgrade of 132 kV overhead lines or eventual installation of a further submarine cable, both of which (under the current charging methodology) would be funded by the developer.

An active network management system had previously been trialled on Orkney where, after initial teething problems, it had allowed a significant quantity of new generation to access the system.

New non-firm generation connections are no longer available in the Isle of Wight after introduction of the ANM, although existing connections retain their firm or non-firm status and therefore take precedence over newer, ANM connections as power flows approach the network limit. The 2021 grid connection application was therefore made for a flexible connection under the ANM regime. The ANM is described in more detail in Appendix A.

Curtailment of generation can be expected at times under the ANM. Although PTEC would be the lowest priority generator at the time of offer acceptance (see Appendix A for a description of order of curtailment), there has, to date, been very low take up of ANM connections on the Isle of Wight [5] and PTEC would have reasonable access to capacity remaining after the pre-ANM generators. As noted in Section 2.2.3.1 above, leaving aside the Cowes East power station, for which capacity is reserved, pre-ANM generation is predominantly solar PV.

The different periodicities of solar PV and tidal energy are to an extent complementary. Curtailment can be expected to be highest on sunny summer days, with high PV generation, low demand and network capacity at its seasonal lowest. Curtailment would be lower during winter months, and lowest or zero overnight. A report by ITP consultants for PTEC found that even with the favourable climate on the Isle of Wight, the annual capacity factor for solar PV installations was typically a bit less than 15%, suggesting that the degree of curtailment PTEC might expect on an annual basis would be modest. In a subsequent discussion with SEPD (May 2023), it was confirmed that the anticipated level of curtailment would be low under normal network conditions.

The second issue noted from the initial application was the high cost of a 30 MW connection, where the 19 km underground cable from Wootton Common to the PTEC site was a major contributor.

Options for capacity in the range 15–30 MW were discussed with SEPD in a pre-application meeting. It was thought possible, subject to further study, for a capacity below 30 MW to be obtained from local circuits, so avoiding the lengthy cable connection from Wootton Common. An SEPD feasibility study was considered but would have to be followed by a formal application, adding approximately three months to the process. Three separate applications, for 15, 20 and 30 MW, were instead made in parallel, as the most expedient way to explore options within the project timescale.

The connection design for the 30 MW offer was substantially as before, with a long underground cable from Wootton Common substation.

Both the 20 MW and 15 MW connection designs made a connection to an existing 33 kV overhead line close to Ventnor substation and so required a relatively short cable connection to the PTEC substation. The 20 MW connection would require upgrade of a section of 33 kV overhead line within the SEPD network.

The 20 MW and 15 MW connection costs were approximately 33% and 24% of the 30 MW costs. The 20 MW option was marginally more expensive in terms of cost per Megawatt, due to the need for reinforcement within the SEPD network but was closer to the project target capacity and was therefore the preferred option.

2.3.2.3 Lessons Learned

First and foremost, the last decade has seen an unprecedented increase in applications for generation connections. The Isle of Wight has to some extent been insulated from this due to the limited capacity for export to the UK mainland, but Southern England has seen a large uptake of solar PV and over the last few years the UK as a whole has seen large and increasing interest in battery storage connections. The consequences include networks approaching their full capacity, competition among developers for the remaining capacity and, where network reinforcement would be prohibitively expensive, introduction of flexible (constrained) connections to allow further generation to connect. There is also increased strain on the DNO system planning and connections teams.

To cope with this increasing volume, the connections process has evolved and continues to evolve and an application similar to PTEC, if started now, would be slightly different.

To streamline the process, SEPD (and other DNOs) have recently made a number of improvements to assist developers in their pre-application research, including making the long-term development statements and supporting data more easily available [25], publishing heat maps which show areas which are congested or likely to be subject to constraint [26], and publishing a network development plan and headroom report [27].

These should be fully utilised by a prospective developer, to be able to make the best use of the pre-application meeting and other contact with the DNO.

Although this information allows potential constraints to be seen down to the primary substation level, it generally will not be sufficient for the developer to determine whether their target capacity triggers a significant breakpoint in costs. For the PTEC application, the options to clarify this were either commissioning a feasibility study (with significant time penalty) or submitting multiple applications in parallel. The application process now includes a requirement for the DNO, if so requested, to inform the applicant of any cost 'tipping points'.

This usefully streamlines the process for both developer and DNO but should be treated with caution: it should flush out tipping points relating to a single point of connection to the existing DNO network but may not cover cases such as PTEC, which compared two different points of connection. Options should therefore be considered in the pre-application research and discussed at the pre-application meeting.

The timescale for acquiring and building a grid connection is appreciable and should be planned for. The application timeline is governed by regulation and allows the DNO 65 working days from application to issue a connection offer. The offer is then valid for a similar period, allowing the developer to clarify any issues, evaluate and plan. The timescale for construction varies with the complexity of the project and existing DNO workload, but for MW-scale projects is normally several years. Projects which require long cable or overhead line connections (for instance, the PTEC 30 MW option) require detailed route planning and may be vulnerable to delays arising from land rights issues.

Since the initial PTEC application in 2014, a queue management system has been introduced by all DNOs, to track project progress after offer acceptance, give priority to projects most ready to connect and to deter speculative applications. This consists of a series of milestones and dates, covering issues such as planning consent, project planning and financial commitment. If individual or cumulative milestone delays exceed a certain level, the connection date may be revised or, ultimately, the connection contract cancelled.

2.4 Offshore

2.4.1 Location

The offshore location of the PTEC site is South of St Catherine's Point, as shown in Figure 14. The Marine Licence Area (MLA) and the points of the boundary are given in Figure 15 **Figure 15 | PTEC Marine Licence Area (MLA), ADPs, tidal diamonds**

and Table 2.

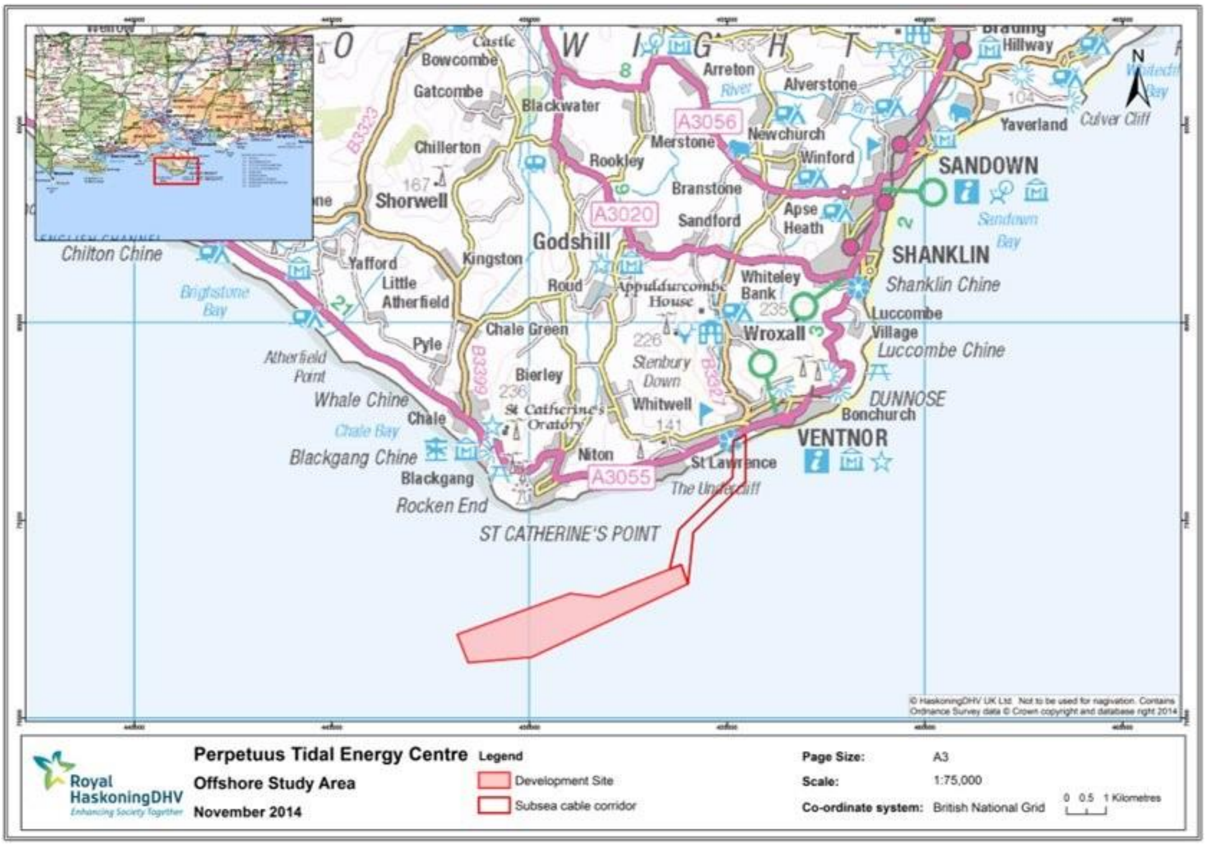


Figure 14 | PTEC site location

Figure 15 | PTEC Marine Licence Area (MLA), ADPs, tidal diamonds

	Latitude						Longitude					
Point	D	M	S	D	M	D	D	M	S	D	M	D
1	50	32	46.314	50	32.7719	50.5461983	-1	19	12.252	-1	19.2042	-1.3200700
2	50	32	23.274	50	32.3879	50.5397983	-1	18	58.356	-1	18.9726	-1.3162100
3	50	32	27.246	50	32.4541	50.5409017	-1	17	36.702	-1	17.6117	-1.2935283
4	50	33	25.926	50	33.4321	50.5572017	-1	14	14.994	-1	14.2499	-1.2374983
5	50	33	41.754	50	33.6959	50.5615983	-1	14	23.310	-1	14.3885	-1.2398083
6	50	33	15.846	50	33.2641	50.5544017	-1	16	9.150	-1	16.1525	-1.2692083
7	50	33	19.086	50	33.3181	50.5553017	-1	16	46.338	-1	16.7723	-1.2795383
8	50	32	46.314	50	32.7719	50.5461983	-1	19	12.252	-1	19.2042	-1.3200700
9	50	35	21.306	50	35.3551	50.5892517	-1	13	14.928	-1	13.2488	-1.2208133

Table 2 | MLA coordinates

When selecting and defining a tidal energy site the following elements must be considered:

- Bathymetry
- Bed material
- Depth and tidal heights
- Flow speed and direction
- Metocean conditions

Each of these elements are discussed in further detail in the following sections. It is important to consider the impact of each element on one another and that, when selecting a site, the best location may not solely be decided by the resource (see references [7],[8],[9] and [10] for further reading on this point).

Additionally, data collection methods and survey best practice have been reviewed in discussed in the TIGER deliverable T3.1.2 [11]; this provides further insight in the optimum methodologies for best accuracy data.

2.4.2 Bathymetry

The bathymetry of the tidal site should be defined for suitability for fluid dynamics, e.g. turbulence and wakes from underwater features, tidal device footprint (for stability and area), and operating depths. Ideally devices, and arrays, should be located in areas of minimal turbulence and wake which could reduce the amount of energy that is available and create additional dynamic loading on structures.

There are various stages to gathering the appropriate information for each stage of the site development. Initial studies can use online resources to assess the general area (Figure 16).

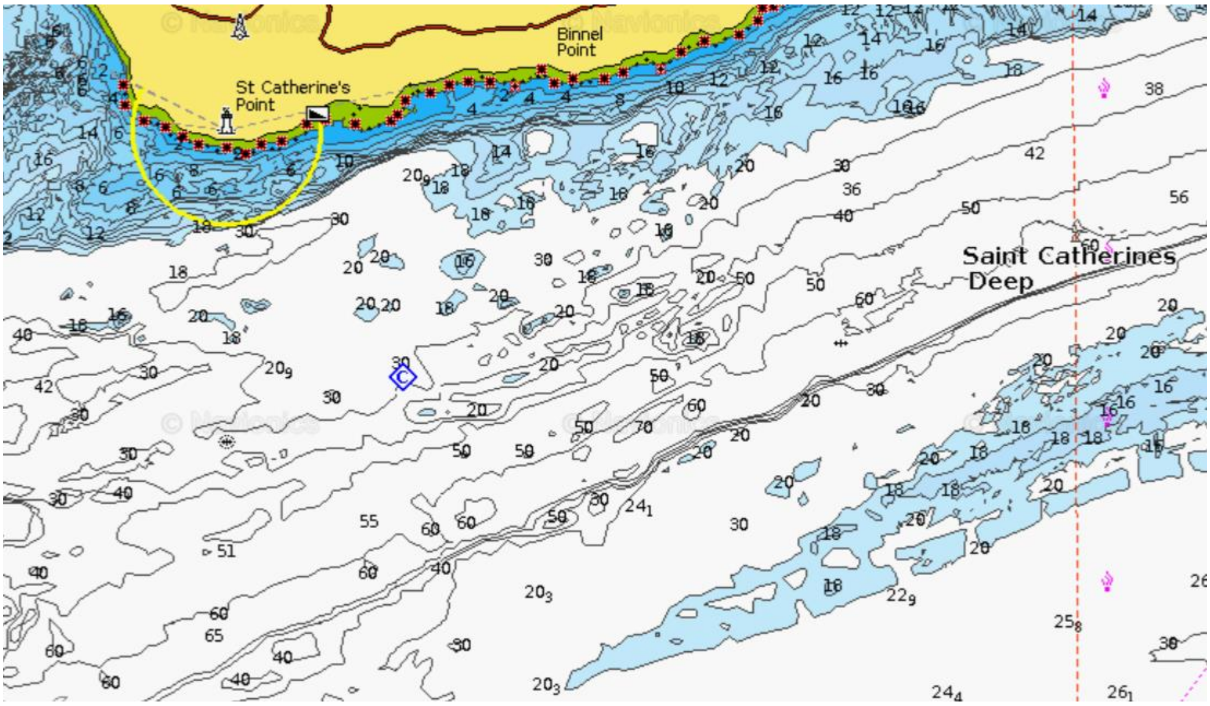


Figure 16 | Navionics.com map of St Catherine's Deep

St Catherine's Deep is identified as a potential site to expand development because it has some key features for tidal energy extraction:

- Channel of approximately 50–60m working depth, suitable for vessel and asset deployment and recovery
- Large, flat area, suitable for large footprint devices or mooring spreads
- No significant underwater features that could cause vortex shedding or wake upstream from devices in ebb or flood
- Short distance to landfall
- Gentle gradient to landfall
- No significant ridges, cliffs or gullies that could inhibit device installation or cable run.

Further analysis was conducted using bathymetric survey, multibeam and side scan SONAR, sub-bottom profiling and mapping. This produced a spatial map of the bed elevation (Figure 17) and bed slope (Figure 18) (as analysed from the surface). These maps were used to determine the following features across each proposed berth: approximate depths; gradient; sediment cover; bedrock scarp; ridges; and scour lines.

SONAR surveys are conducted to a standard and have a certain resolution. There will be a size of object, e.g. boulder or submerged material such as ordinance, that simply will not show on multibeam scans because of this. Higher resolution scans can be conducted but there will always be this limitation with data gathered from the surface. Sub-surface, close to bed, instrumentation will gather more accurate data, though this is more complex and generally more expensive.

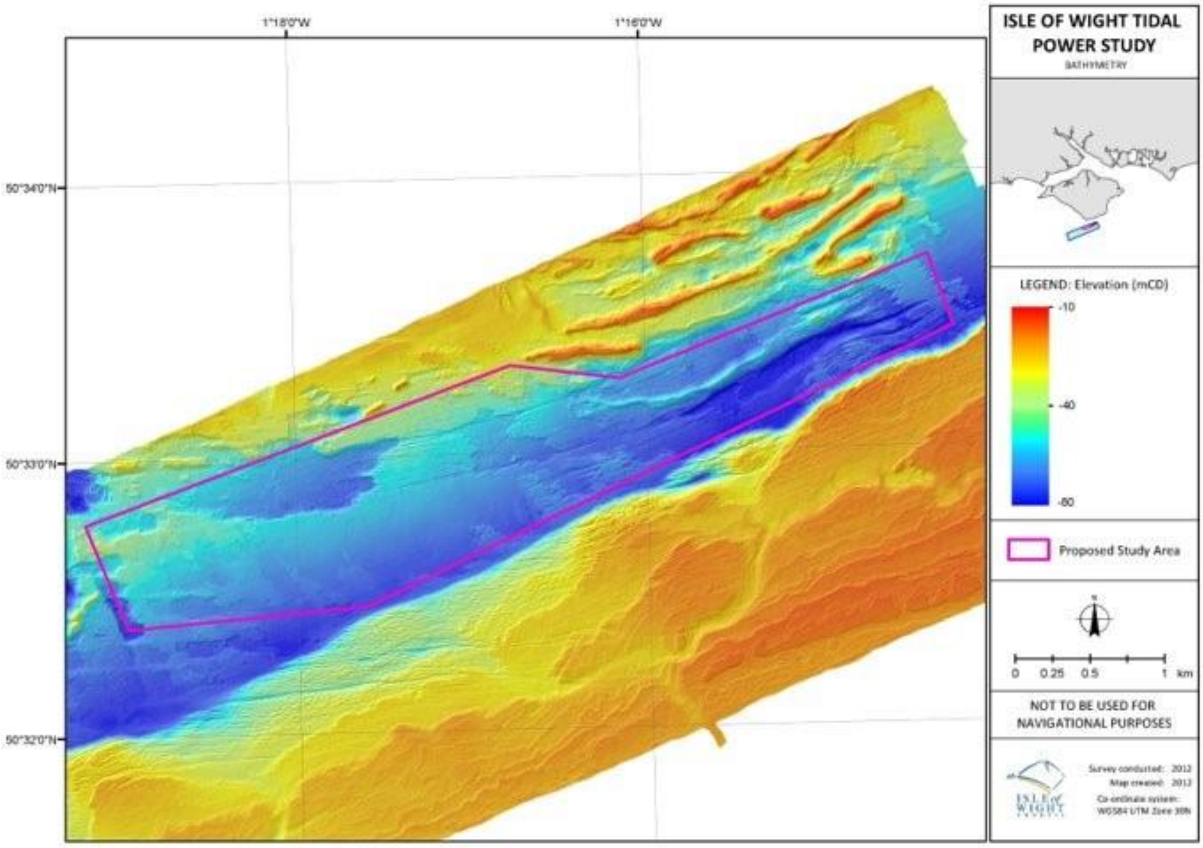


Figure 17 | PTEC bed elevation

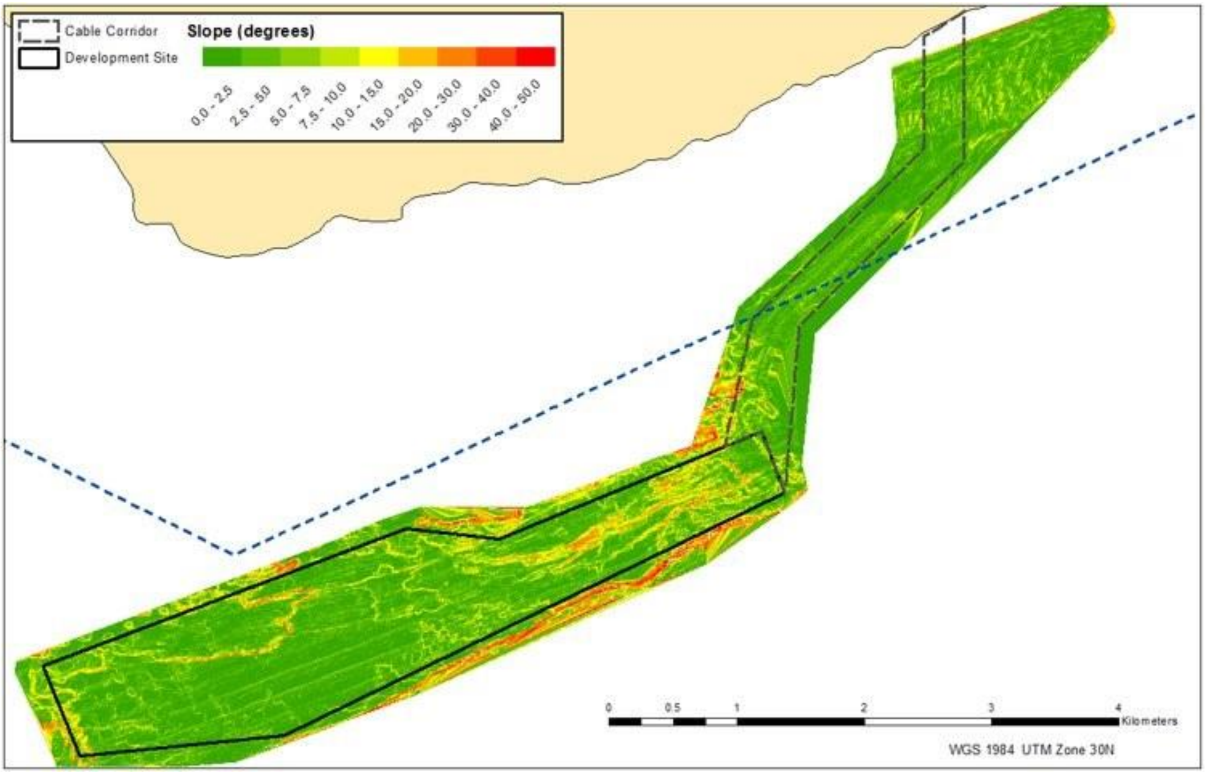


Figure 18 | PTEC bed slope

The next stages for reviewing the individual berths for developers would be:

- High accuracy/resolution bathymetry mapping
- Data from sub-surface, to reduce beam spread resolution issues, influence of vessel motion such as heave, and signal disturbance from measurement through depth and suspended particles
- Micro-sited analysis, e.g. at anchor positions.

In summary the following information should be gathered for the bathymetry at a tidal site:

Stage	Methods	Information
Feasibility	Online sources Drop cam survey	General bathymetry of area General gradient of area Key underwater features Areas and distances
Scoping/Pre-planning	SONAR surveys Photographic / Video	Bathymetry Significant obstructions Marine life identification

Detailed Planning	SONAR surveys Magnetometer Photographic / Video	High resolution mapping Sub surface mapping Location of any materials e.g., ordnance/wreckage Baseline marine life record
Marine Operations	Drop cam survey ROV Surveys SONAR surveys	Precise location information

Table 3 | Bathymetric information stages

2.4.3 Bed Material

The bed material at a tidal site will affect a number of factors, such as: material movement which could cause potential damage to assets, reducing anchor integrity, or scour; fixing mechanism, such as anchor type, positional accuracy and holding capacity; or environmental factors, such as flora or fauna prevalent in the area and impact of fixing mechanism on ecosystems.

Initially bed material can be determined from online sources, for example, that shown in Figure 19 [12] and Figure 20 [13]. This allows a baseline overview of expected material type, in the case of PTEC this would be rock. This can be followed by onsite information gathering, such as drop cam survey and grab samples (Figure 21).

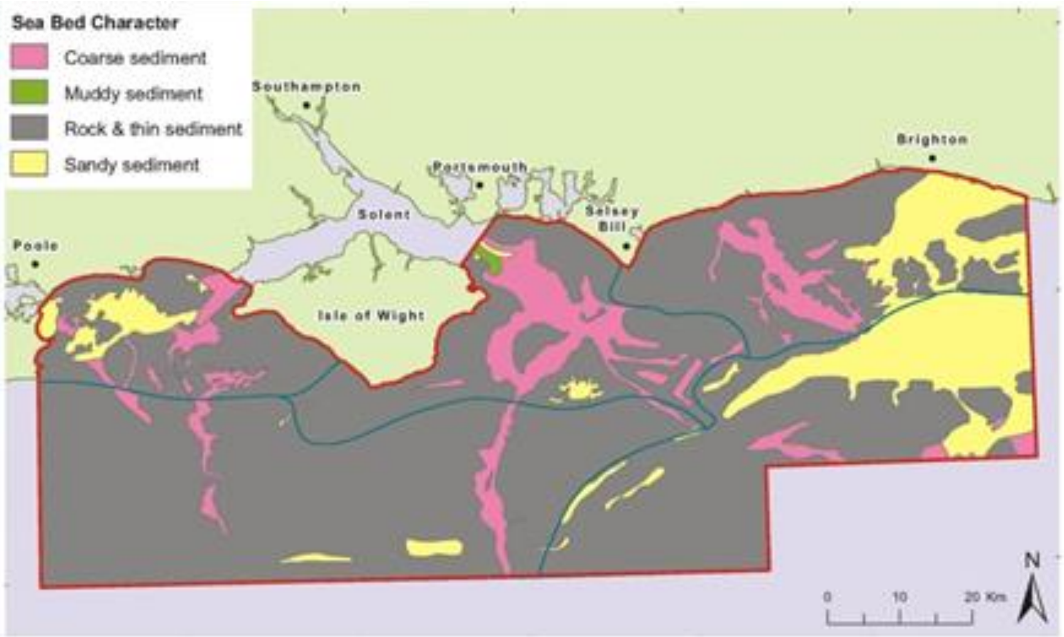


Figure 19 | Seabed material map [12]

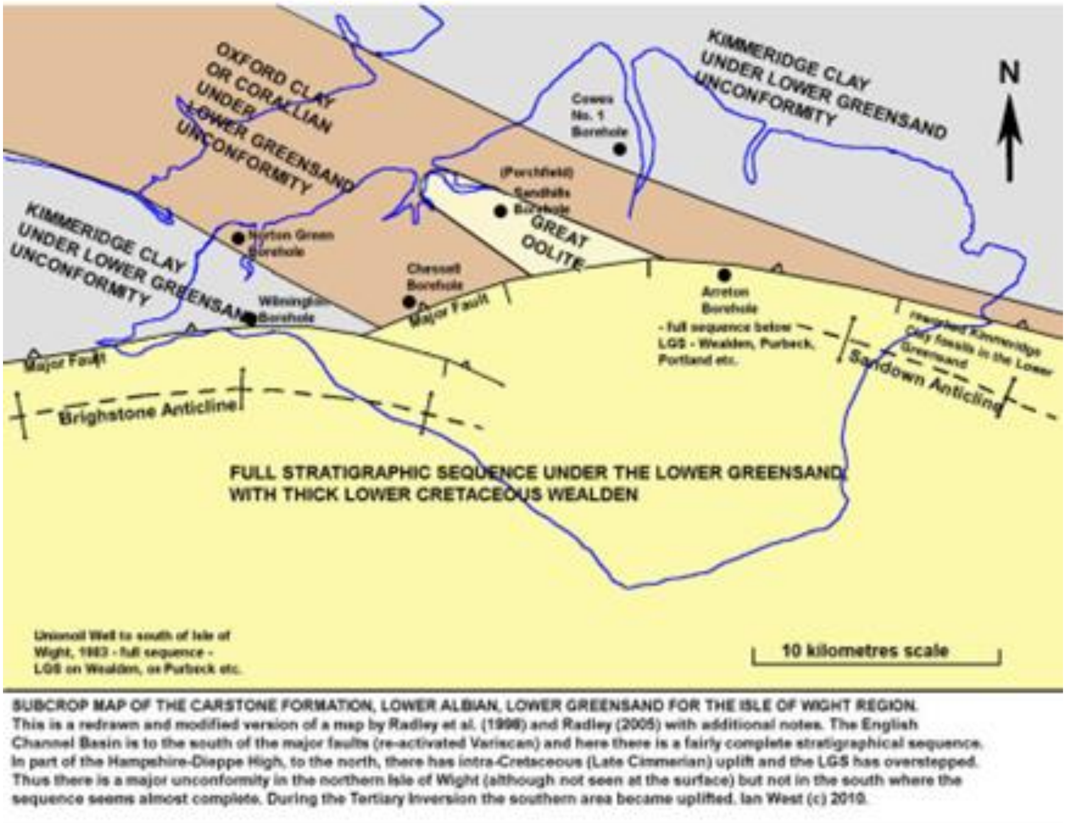


Figure 20 | Rock type map [13]

Figure 21 | Drop cam survey

Further analysis can be conducted by using the following methods:

- Swath bathymetric, multibeam and side-scan SONAR survey
- Sub-bottom profiling
- Grab samples
- Sediment samples
- Cone penetration test (CPT)

- Seabed core samples
- Full geotechnical analysis including laboratory tests on samples.

These will give information on rock features, such as the size of ridges or boulders and flatness of the area, though are limited by resolution as previously discussed (swath bathymetric and SONAR surveys). They will also provide information on rock type, hardness, and thus anchor suitability (grab samples, sediment samples). There will also be information on depth of material and thus anchor or pile holding capacity and integrity. Full geotechnical work up should be done on all specific device and anchor locations prior to deployment, and preferably dry and/or wet trials of any planned anchor or penetrating technology in an area of similar rock site. Summary example bed material stages are given in Table 4.

Stage	Methods	Information
Feasibility	Online sources Drop cam survey	General bed material of area General rock type of area
Scoping/Pre-planning	Swath bathymetric and side-scan SONAR survey Sub-bottom profiling Grab samples Sediment samples	Bed material maps Rock/sediment material Material profile/depths Device fixing type
Detailed Planning	Swath bathymetric and side-scan SONAR survey Sub-bottom profiling Grab samples Sediment samples Cone penetration test (CPT) Seabed core sample	High resolution mapping Fixing integrity and holding capacity Precise location definition
Marine Operations	Full geotechnical work up	Precise location information

Table 4 | Bed material information stages

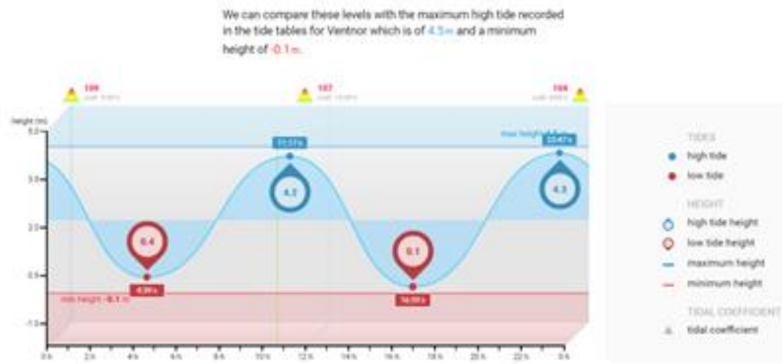
2.4.4 Depth and Tidal Height

The depth of the site uses the same information as the bathymetry. This will give depth relative to Chart Datum (CD) or similar baseline data. To determine the tidal range and expected height at site, and at landfall, several steps can be applied. First, as before, online publicly available information can be gathered.

For example, tidal heights at Ventnor and St Catherine's can be obtained from websites such as tides4fishing.com and Admiralty information from charts or Admiralty Total Tide

(Figure 22 [14]). These show that the tidal heights are slightly different but are approximately HAT (highest astronomical tide) 4.5 m/4.2 m (tides4fishing/Admiralty), LAT 0.1 m/0.6 m thus 4.6 m/3.6 m range.

Where there is differing information, it is important to check the source material, in terms of whether HAT or MHWS (mean high water springs) is being compared. Also, though the most official data should be used in general it is prudent to decide depending on the use at this stage. For example, when determining approximate worst load cases for engineering analysis then the worst-case values should be used, e.g. 4.6 m range rather than 3.6 m.



0051 Ventnor is a Secondary Non-Harmonic port

The tide type is Semi-Diurnal.

HAT	4.2 m
MHWS	3.9 m
MHWN	3.2 m
MSL	2.33 m
MLWN	1.7 m
MLWS	1.0 m
LAT	0.6 m

Figure 22 | Example tidal range at Ventnor (left); tidal heights for Ventnor (right)

This shows the importance of gathering local data. The obvious next stage for this type of information is a bed-mounted Acoustic Doppler Current Profiler (ADCP), or other surface tracking device. The bed ADCP measures through column velocities, but also the pressure and thus depth. The most accurate ADCP to use for depth is a 5-beam unit, where there is a beam pointing directly upwards, but a 4-beam unit is sufficient.

When using ADCP data it is important to gather neap and spring data, though mid-range is useful. The times should be referred back to a reference port, so that the information can be used for marine operations, e.g. HW Portsmouth. An example is shown in Figure 23, but note that this is fictitious, as this data is not currently available for PTEC.

To make the data more useful the data can be harmonically extended (if the data set is longer than 33 days). This will give a more accurate HAT and LAT at site.

This process can be repeated for any ADCP deployments in the site and should be conducted if an array is planned over a large area, since local bathymetry and topography will create forcings that affect local heights.

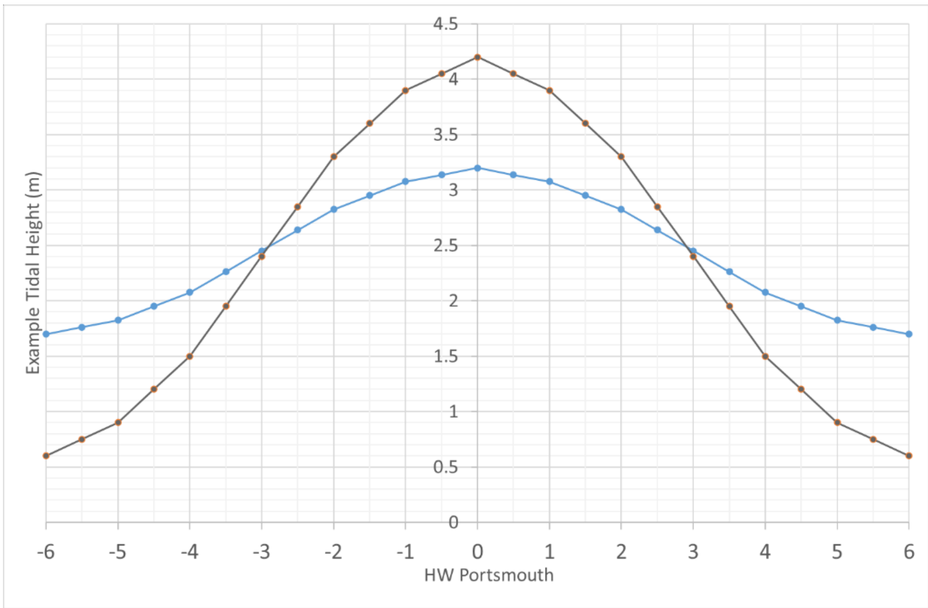


Figure 23 | Example tidal height plot from ADCP data using reference port

Stage	Methods	Information
Feasibility	Online sources Charts	Depths relative to CD Approximate HAT, LAT
Scoping/Pre-planning	Bathymetric survey ADCP	Depths relative to CD On site depths MHWS, MHWN
Detailed Planning	Bathymetric survey Harmonic extension Multiple ADCP	Depths relative to CD On site depth MHWS, MHWN HAT, LAT Spatial variation
Marine Operations	Bathymetric survey Harmonic extension Precise location ADCP	Precise location information

Table 5 | Depth and tidal height information stages

2.4.5 Flow Speed and Direction

Flow speed and direction information can be gathered from several sources and must be refined based on the stage of the site development. Initially data can be gathered from online and paper sources, such as tidal charts (Figure 24 [15], Figure 25).

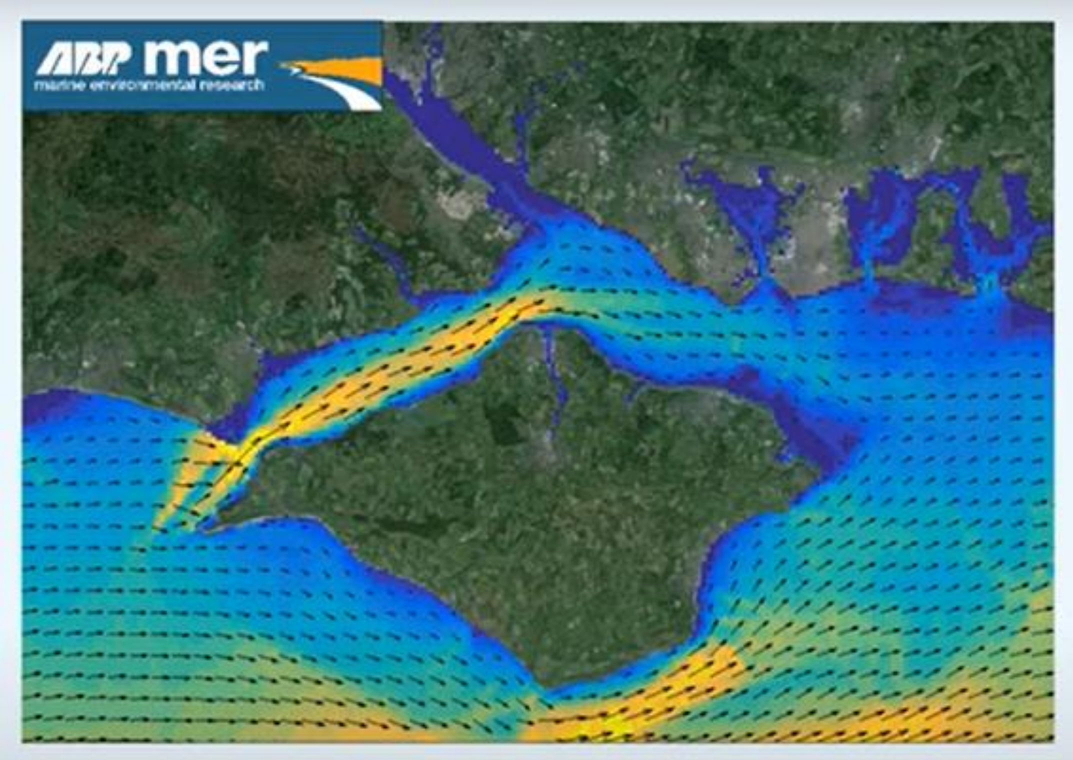


Figure 24 | Tidal simulation of Isle of Wight [15]

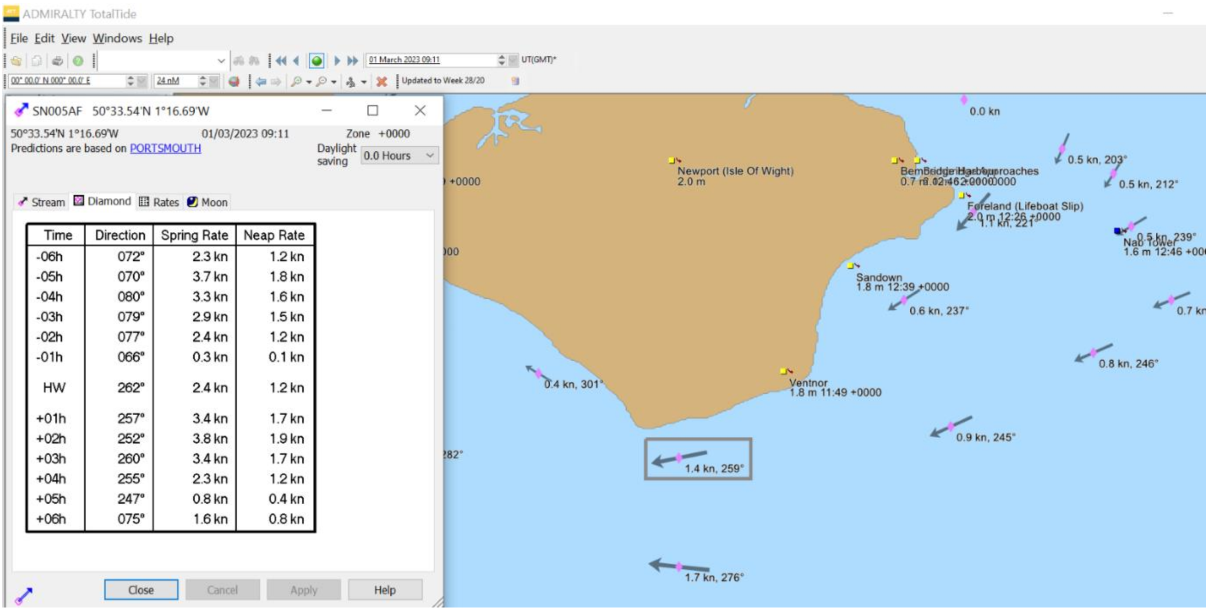


Figure 25 | Admiralty TotalTide tidal diamond flow speed and direction

This information, combined with bathymetry data, can be used to determine the following:

Device suitability – maximum and minimum flow rates, combined with depth, can be used to assess the suitability of different rotor sizes and rated capacity. Additionally, bidirectionality is usually desired to reduce yaw/sway or inflow angles.

Approximate position – target positions for refined data and initial device placement

Approximate array sizes – areas of suitable depth and flow speeds can be combined to assess the footprint of a proposed license area, and thus the array sizing based on device/s.

Note that there may be several locations within a target area that are identified as suitable for development, but other constraints are identified in the consenting phase; for example, the strait at Hurst Castle on the W end of the island has very high tidal flow, but the channel has high vessel traffic (assessed during consenting) which shows it cannot be developed at this time.

Next steps are to gather point data from ADCPs, for localised flow rates and use these to calibrate a numerical model, most likely 2-D (surface or depth-averaged) at this stage. PTEC has had several ADCP deployments. Initially ADCPs were deployed at the West, Centre, and East of the proposed MLA site to assess spatial variation along the ebb and flood direction. Further ADCPs were deployed around the Centre location but configured to acquire different types of information, namely tidal flow, wave heights and turbulence. Increasing the number of ADCPs allows localised flow data to be gathered, basic spatial variation determination, and enough data sets for both model calibration and validation. Note that ADCPs cannot always be retrieved, or the data can be corrupted. Multiple deployments therefore add contingency.

Figure 26 | PTEC Marine Licence Area (MLA), ADPs, tidal diamonds

	Latitude						Longitude					
Point	D	M	S	D	M	D	D	M	S	D	M	D
ADP1 Resource	50	32	54.481	50	32.9080	50.548467	-1	-16	-31.670	-1	-16.5278	-1.275464
ADP2 Wave	50	33	6.908	50	33.1151	50.551919	-1	-16	-38.294	-1	-16.6382	-1.277304
ADP3 Turbulence	50	33	1.670	50	33.0278	50.550464	-1	-16	-28.682	-1	-16.4780	-1.274634
IOW ADP 1 West	50	32	43.960	50	32.7327	50.54554444	-1	18	56.030	-1	18.9338	-1.31556389
IOW ADP 2 Centre	50	33	0.170	50	33.0028	50.55004722	-1	16	36.400	-1	16.6067	-1.27677778
IOW ADP 3 East	50	33	35.900	50	33.5983	50.55997222	-1	14	27.880	-1	14.4647	-1.24107778
Tidal Diamond SN005AF	50	33	32.400	50	33.5400	50.5590000	-1	16	41.400	-1	16.6900	-1.2781667
Tidal Diamond SN005AM	50	30	26.400	50	30.4400	50.5073333	-1	16	41.400	-1	16.6900	-1.2781667

Table 6 | ADP and tidal diamond coordinates

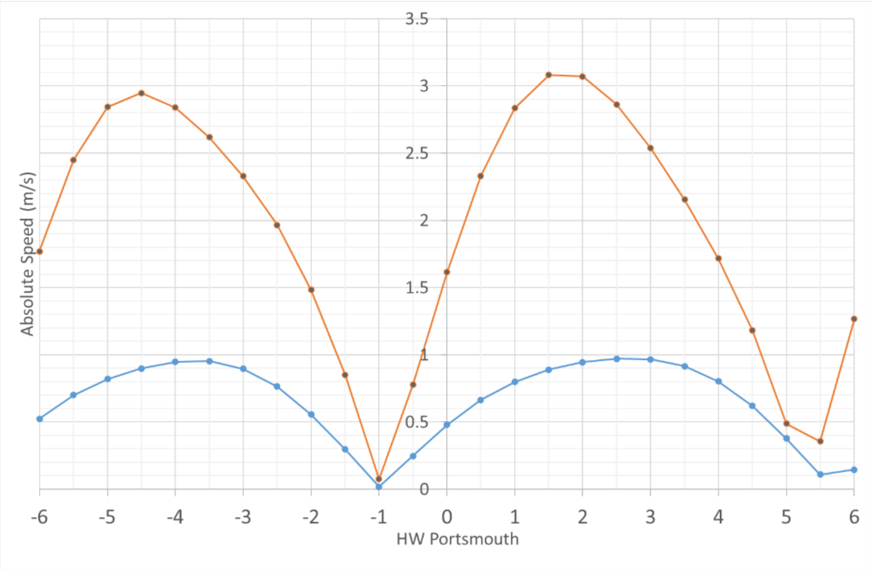


Figure 27 | Flow speeds for spring (orange) and neap (blue) tides at Centre ADCP

Note that the slack water times from the ADCP are approximately high water (HW) Portsmouth-1 and HW+5 to HW+6. The low water (LW) slack is quite different from the tidal diamond from Admiralty TotalTide (Figure 25) which shows the importance of gathering location specific data to maximise and optimise operational windows.

These data sets can be used to develop at 2D hydrodynamic model, using programs such as MIKE21 and Delft3D (note other software packages are available, these are just examples). Royal Haskoning created a MIKE21/MIKE3 model (Figure 28, Figure 29 [16]); this model analysed 5 layers throughout the water depth and produced time series of speed and direction at 20 locations within the grid (Figure 30).

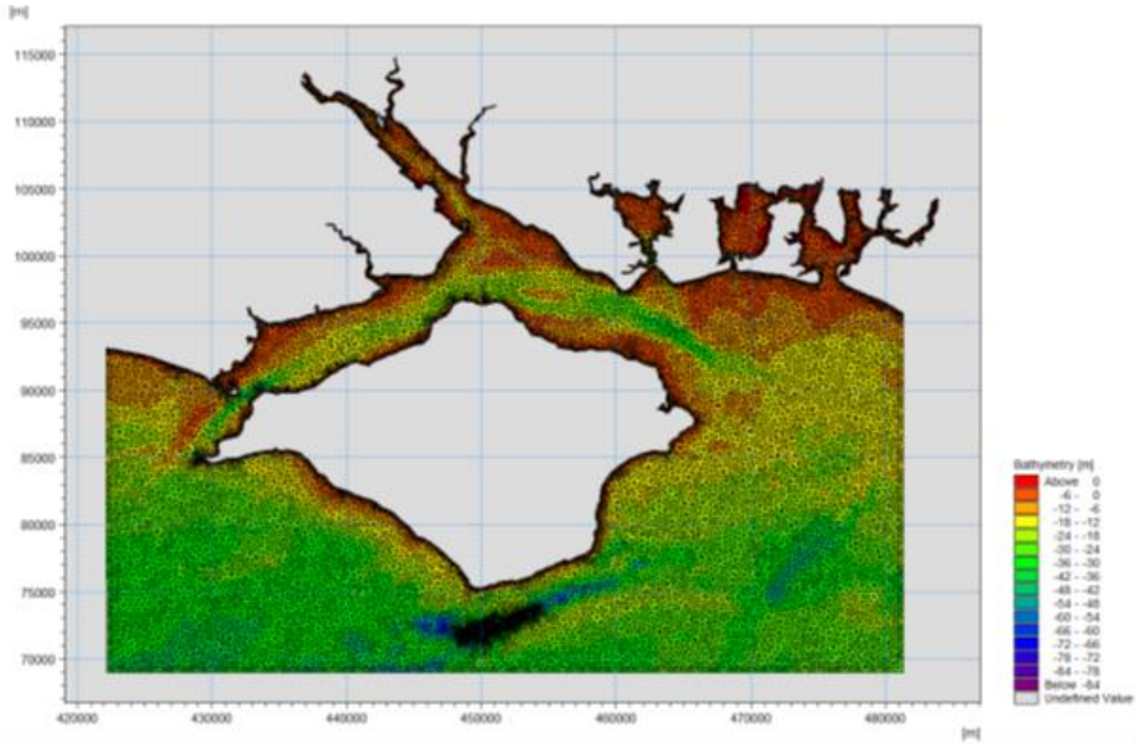


Figure 28 | MIKE21 hydrodynamic model of the PTEC site and wider surrounding seabed

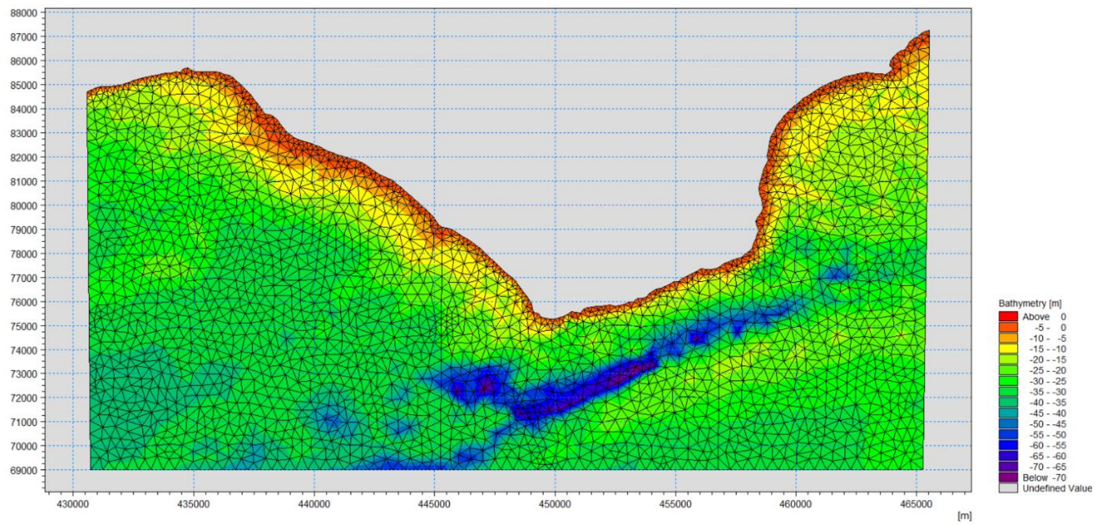


Figure 29 | Detailed MIKE3 hydrodynamic model of the PTEC site and local surrounding seabed

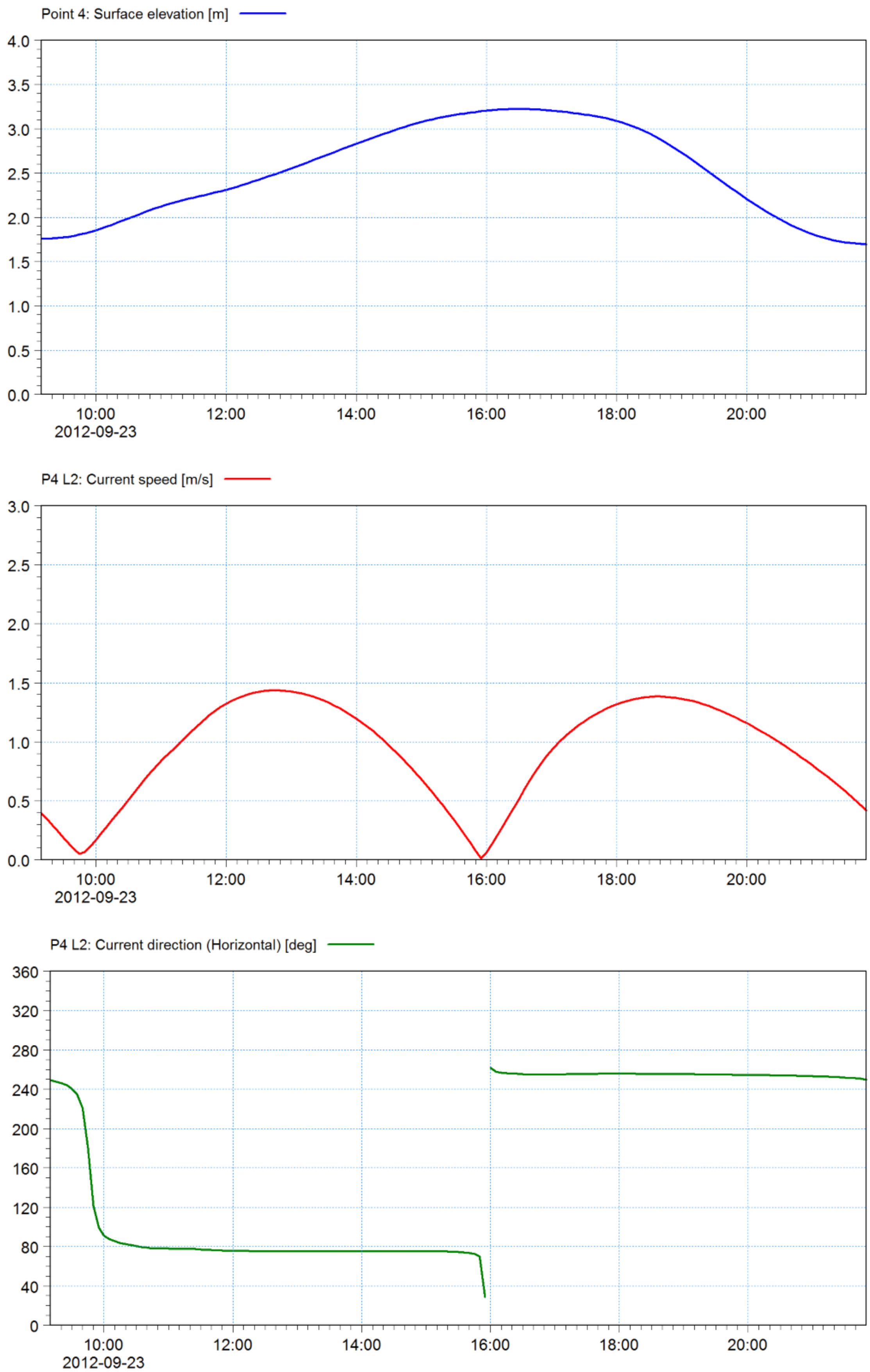


Figure 30 | MIKE21/MIKE3 time series of depth, speed and direction at a specific point

When devices are micro-sited, ADCPs should be deployed at specific locations to gather accurate information on:

- Tidal heights, including HAT, LAT, range
- Flow speeds, including spring and neap variation
- Flow direction, including bi-directionality
- Flow profile with depth
- Harmonic analysis, to cover project lifetime and/or 18.6-year tidal constituent cycle, if ADCP dataset over 33 days long
- Yield analysis
- Flow conditions at surface and bed, and slack windows for marine operations
- Flow structure, such as turbulence intensity and eddy sizes

Similarly, detailed 3-D modelling can be developed in order to gather:

- Higher temporal and spatial resolution data through the water column at all depths
- Bed, rotor depth, and surface flow speeds
- 1, 5, 10, 50, 100-year return values for load case analysis
- Site and array layout tool
- Cable corridor detailed information

If the model is developed using metocean and device information, the following can also be assessed:

- Wave-current interaction
- Array spacing
- Array device interactions
- Cable-device interactions

Further field data can be gathered to assist in this analysis, including further static/seabed ADCPs as well as transect data to measure wake from devices as installed.

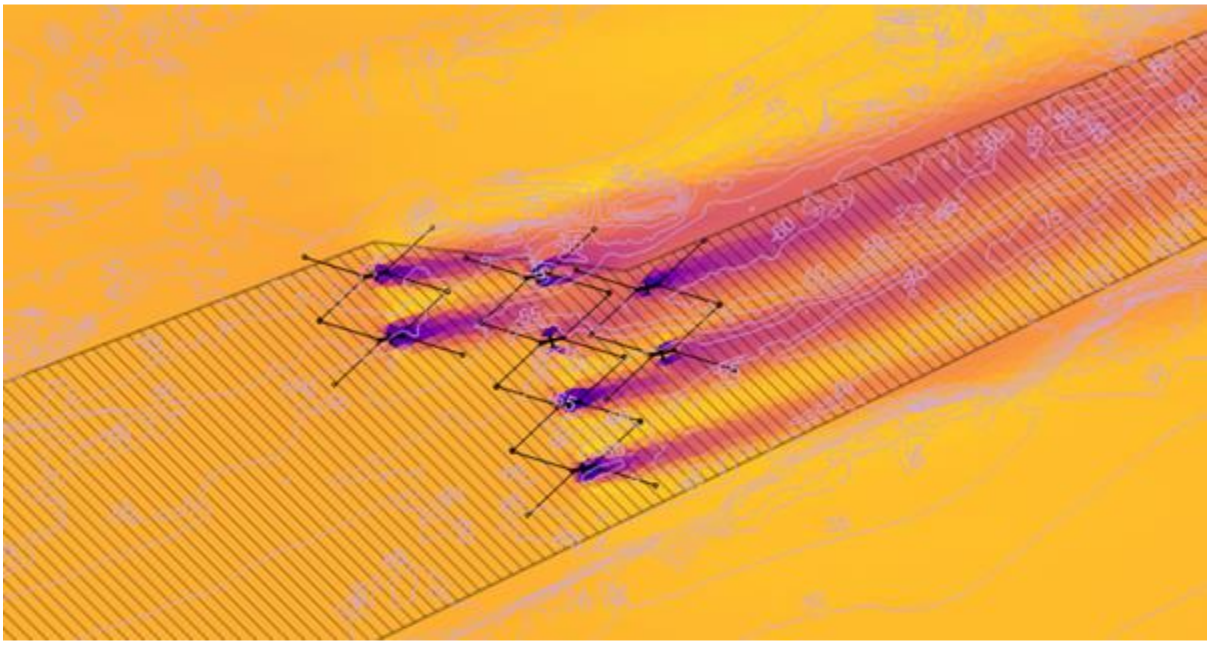


Figure 31 | Example of device interaction in an array

Stage	Methods	Information
Feasibility	Online sources Charts	Target areas Approximate flow speeds and directions Bi-directionality Approximate array development area
Scoping/Pre-planning	Bed ADCPs	Water depths Through column flow speeds Basic spatial variation Harmonic extension
Detailed Planning	2D modelling 3D modelling Bed ADCPs Transect ADCPs RADAR	Spatial variation Harmonic extension Yield analysis Operational windows Flow structures Wake and interactions
Marine Operations	Harmonic extension Precise location ADCP	Precise location information

Table 7 | Flow speed and direction information stages

2.4.6 Metocean

Some wave data metrics can be determined from the ADCP deployments since these instruments measure the sea surface. Specific data can be gathered by applying settings to ADCPs focused on gathering wave metrics. Wave buoys have traditionally been used for data but have not been proven successful in strong flows and so are not typically used in tidal energy sites. RADAR is also used to gather surface imagery and wave information, without being compromised by high velocity flows.

It is important when gathering wave data to focus on periods of extreme weather, such as winter periods or during anticipated storm events.

Hindcast data, both wind and wave, can be gathered from historical data set and models. This can be used to develop numerical hindcast models which can be used for return period analysis for load cases. BMT Argoss developed a SWAN model utilising hindcast model to assess the Isle of Wight Channel area and PTEC [17]. Example of the offshore wind roses are given in Figure 32 and spatial variation of wave height for winds from 240° (prevailing SW) and 100-year return from SWAN model are shown in Figure 33.

Modelling can be made even more accurate by taking in situ measurements and assessing wave–current interaction. Suggested data sources are given in Table 8.

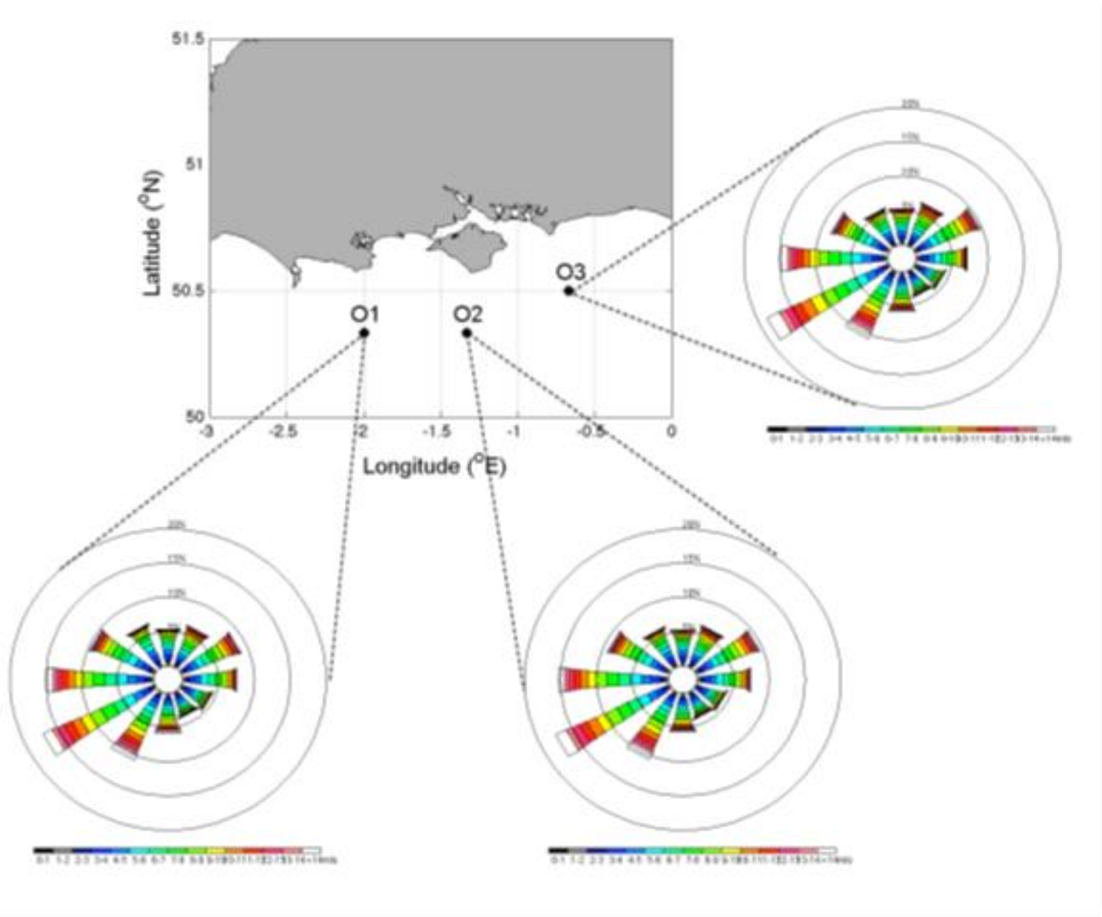


Figure 32 | Annual offshore wind roses

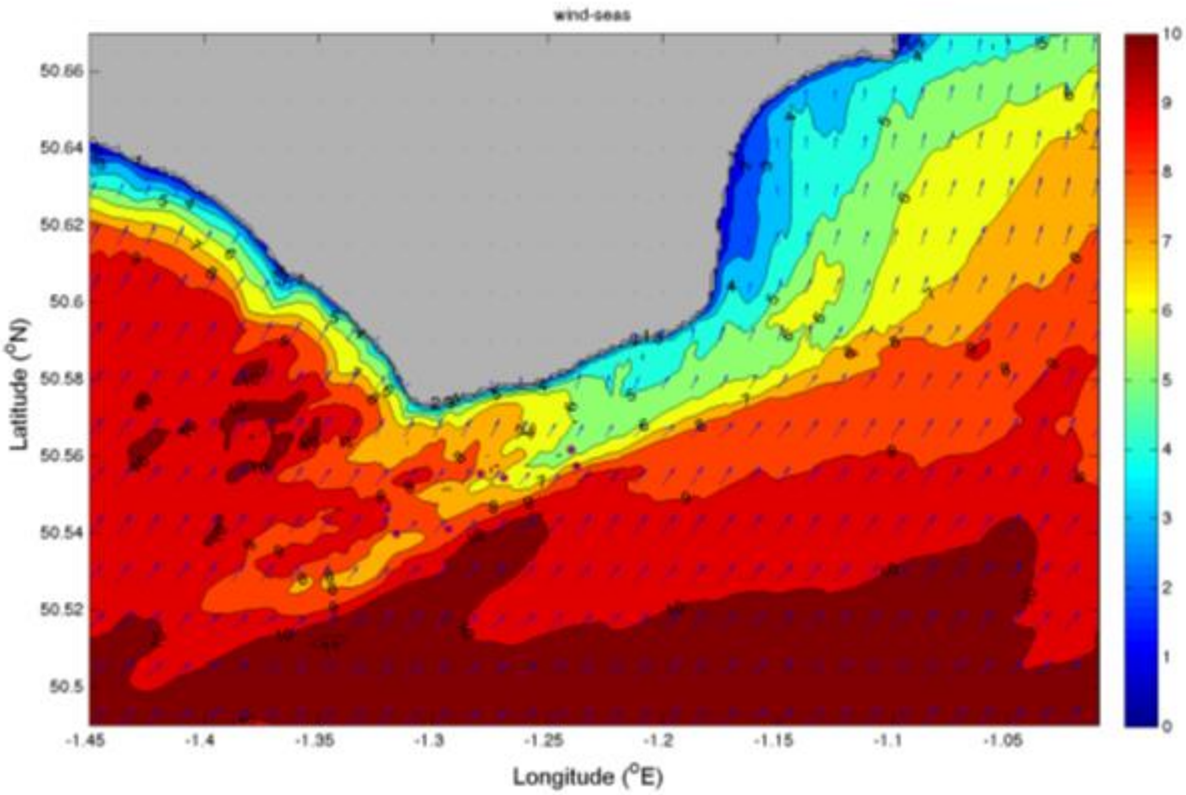


Figure 33 | Wave spatial variation from 240° wind, 100-year return

Stage	Methods	Information
Feasibility	Online sources Historical data	Historical wave Historical wind
Scoping/Pre-planning	Bed ADCPs Wave buoys Hindcast data	In situ waves Hindcast wind Hindcast waves
Detailed Planning	Hindcast modelling 2D modelling 3D modelling RADAR	Return periods Spatial variation Operational windows/limits
Marine Operations	3D modelling	Precise location information In situ wind and wave data Extremes from data Wave-current interaction

Table 8 | Metocean information stages

3 Operations and Maintenance

3.1 Access

3.1.1 Isle of Wight

Transport is affected based on location. Many tidal energy sites are in remote locations, such as Anglesey or Orkney Islands. The Isle of Wight is only accessible via ferry from mainland UK (Figure 34 [18]). This affects the ability to get materials, devices and personnel to site.

When considering a site and feasibility studies for transportation then accessibility must be considered. For example, if road and rail routes are not suitable for devices then they may need to be towed from a nearby (or far) port.

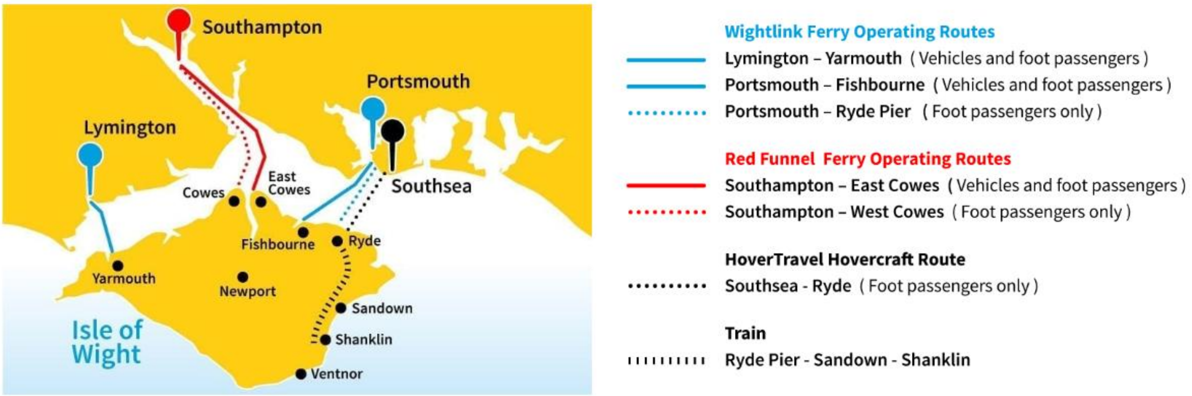


Figure 34 | Transport to and from the island

3.1.2 Flowers Brook

At specific locations onshore there may be limitations that should be carefully considered. For example, at PTEC the onshore infrastructure is expected to be built out at Flowers Brook (Figure 35Figure 35 | Example of onshore access limitations and natural habitat at Flowers Brook

). However, the access roads are not suitable for lorry access and will need to be expanded. Additionally, the lay down area is currently a natural habitat restoration site and so was assessed during consenting.

Figure 35 | Example of onshore access limitations and natural habitat at Flowers Brook

3.2 Ports

The ports and infrastructure close to site must be assessed for suitability for different levels of operations and vessels, e.g. Yarmouth, Cowes, Southampton, Portsmouth, Ventnor (Figure 36 [8]). Each port will have different suitability for different types of operation, e.g. personnel transfer for onboard operations can run a rigid inflatable boat (RIB) from Yarmouth or Cowes, but if a device needs to be towed in and lifted for large O&M, e.g. antifouling, then a larger port will be required. There may be options to develop ports to improve their suitability for different O&M activities; this would require upfront costs and additional consenting but may reduce cost and improve operational windows over the lifetime of a project.

Figure 36 | Local ports within 50 km

	Yarmouth	Cowes	Ventnor	Southampton	Portsmouth
On island	Yes	Yes	Yes	No	No
Accessible all states of tide	Yes	Yes	No	Yes	Yes
Access small vessels, e.g. RIBs and multicats	Yes	Yes	Yes	Yes	Yes
Access large vessels, e.g. DP	No	No	No	Yes	Yes
Access tidal devices, e.g. Orbital O2	No	Possible	No	Yes	Yes
Lift out tidal devices, e.g. Orbital O2	No	Possible	No	Yes	Yes
Steaming to site @ 5 knots	20nm 4h	25nm 5h	2.5nm 0.5h	30nm 6h	20nm 4h
Benefits	Access to mainland and to onshore	Access to mainland and to onshore Boatyards, cranes, and hard space	Shortest distance to site	Large dockyards for large vessel and device access	Large dockyards for large vessel and device access
Constraints	Ferry operations Small marina space	Ferry, blade, quarry, operations	Drying Small area Only slip launch, no hard for cranes	Ferry, dockyards, oil refinery operations	Ferry, dockyards, naval operations

Table 9 | Local ports

3.3 Vessels

Vessel type and availability is critical to the success of different marine operations, and will vary for operation type, tidal device and installation methodology.

3.3.1 Small Personnel Craft

Small craft such as RIBs are used for personnel access, for example, for onboard O&M and stakeholder demonstration. Floating devices particularly use RIB access, such as Orbital's O2 [19] and Sustainable Marine Energy's PLAT-I [20] (Figure 37). RIBs and RIB access is readily available at all ports on the island, and steaming time at 25 knots is generally under two hours to all ports on the island or Solent.

Figure 37| Small craft access to tidal devices: O2 (left), PLAT-I (right)

3.3.2 Medium Work Boats

Medium sized vessels, e.g. multicats and tugs are used for installation operations, on site O&M, inspections and site survey operations. These are becoming more common for installation operations for floating devices, e.g. Sustainable Marine's PLAT-I [20] (Figure 38), Magallanes's ATIR [21] and Minesto's Deep Green [22] (Figure 39).

Figure 38 | Medium work boats for marine operations: PLAT-I blade change (left) and install (right)

Figure 39 | Medium work boats for marine operations: ATIR install (left), Deep Green install (right)

Cowes Harbour has a medium work boat available, but limited availability. In order to avoid being constrained by a single supplier, other companies are available but on mainland UK (Southampton and Portsmouth). The other limitation of using these types of vessels at PTEC is that steaming time from the accessible ports in the Solent means that there is limited time on site available in a single personnel shift, and so considerations such as remaining on site with rolling shifts and shuttle transport to Ventnor may be more cost effective than day-to-day operations.

3.3.3 Large Technical Vessels

Larger or specialist vessels are required for significant operations, such as installing gravity-based foundations, towing large devices to site, anchor or cable operations. Examples of these are installation and recovery operations for SIMEC Atlantis's AR500 [23] and Sabella's D10-1000 ([24], Figure 40).

These types of vessels are not available locally and are generally brought in from specialist companies and locations nationally or internationally. The main constraint of these vessels is limited access ports. Local ports that are big enough are Southampton and Portsmouth, but space and access may be limited by port, ferry, cruise liner and naval operations.

Figure 40 | Large vessel operations: AR500 (left), D10-1000 (right)

3.4 Remote and Autonomously Operated Technology

3.4.1 The need for remotely operated technologies at PTEC

The PTEC site has some characteristics which create challenges absent at most other sites developed to date:

Increased Depth:

A general aim of most underwater intervention for many years has been to remove the need for divers from operations. This is going to be especially the case for PTEC for tasks conducted at or near the seabed, given its depth.

The PTEC site is 50–60m deep which, although only about 5–15 m deeper than EMEC's site at the Falls of Warness, puts it beyond the recommended HSE Air Diving limit of 50 m in the UK. Beyond this, mixed gas diving systems are required which are particularly expensive.

Fortunately, 50–60m is very shallow in the world of remotely operated technologies where systems are often designed for much deeper water operations.

Poor visibility:

Another characteristic of the site is that the underwater visibility is generally poor compared to test sites like EMEC, where underwater visibility is usually excellent. Poor underwater visibility makes underwater intervention more difficult but can be mitigated with careful marine operations planning and use of more high-tech imaging sonar systems to help locate objects underwater out of visual camera range.

With advances in underwater digital mapping using, for example, AUVs and towed systems which we discuss later, it may also now be possible to create a highly accurate digital twin of the site. Such a digital twin could be useful for such things as helping plan construction at the site; micro siting anchors for tidal turbine system, for example, monitoring sessile marine life across the site or perhaps even for creating an augmented reality overlay for operation on an ROV system in poor visibility.

Unexploded Ordnance:

The proximity of a former explosive dumping ground to the east of the PTEC site means that there is a mainly moderate risk of a presence of unexploded ordnance (UXO), except in the small easterly corner of the site where the risk is judged by surveys to be high.

Technologies capable of detecting buried or partially buried munitions appear to be available, and experience can be drawn upon from the offshore wind sector where companies have been managing the UXO problem.

3.4.2 General development in ROV technologies

The marine renewables industry over the last twenty years has developed marine operations to deploy remotely operated technologies. Much of this has been previously deployed in other sectors, for example, oil and gas and telecoms (subsea cabling).

Competition and the high cost of the larger scale oil and gas assets has presented challenges to some tidal projects in the past. However, this has also led to innovations in marine operations on tidal sites. Smaller multicat vessels have become a vessel of choice for most operators, given their versatility and much lower day-charter rates.

The smaller size of vessel in turn limits the size of remotely operated vehicle systems that can be operated from their deck footprint, principally smaller inspection class ROVs rather than classic larger work class ROV systems.

There have been also advances in remotely operated technology since the PTEC site was originally conceived in 2013. These technologies could help with all phases of the PTEC project from pre-construction surveys, construction and ongoing monitoring in a more cost-effective manner than was hitherto available.

3.4.3 Autonomous Underwater Vehicles (AUVs)

These vehicles are pre-programmed on the surface with a route to follow and then deployed to the site of interest. They utilise inertia navigation systems which enable them to navigate accurately underwater without reference to a GPS signal.

They can be equipped with various payloads such as sonar system, light and camera systems, and environmental systems to gather bathymetric and environmental data.

As they are untethered, they can roam more freely over the seabed enabling them to surface precisely defined areas of seabed.

Some systems are man-portable with an underwater duration of hours, capable of being launched from a small RIB. Other systems are much larger with a greater payload capability and operation duration but require suitable launch and recovery systems and larger vessels.

Figure 41 | Launching at REMUS AUV (left); launching a Hugin AUV (right) courtesy of HIL

3.4.4 Unmanned Surface Vessels (USVs)

Although unmanned systems have been around since World War II, where they were used mainly for military purposes, they are increasingly being used for survey work and environmental monitoring. These vessels offer cost effective solutions for multiple missions that might be required on the development and ongoing monitoring of a tidal site.

The regulatory framework for these craft is rapidly developing with 'The Maritime Autonomous Surface Ships Industry Conduct Principles & Code of Practice version 4' (2020). This code provides 'Industry Conduct Principles' in Part 1 and a 'Code of Practice' in Part 2.

These machines are becoming increasingly capable and while many can operate fully autonomously (Degree of autonomy = 4), for many operations they would probably operate remotely from an onshore control station (Degree of autonomy = 3) where the ship is controlled and operated with no seafarers onboard. On some missions it could operate in different modes at different stages of the operation.

The USV can be fitted with multiple sensors to achieve different tasks. A multibeam echosounder could be fitted for exam to gather bathymetric data.

However, in deeper water the resolution of such surveys is limited by the resolution of the sonar system which reduces with increased depth. Recent innovations include the ability to operate towed devices such as magnetometers and side scan sonar units from USVs, to be towed nearer to the seabed and affording a greater resolution of data.

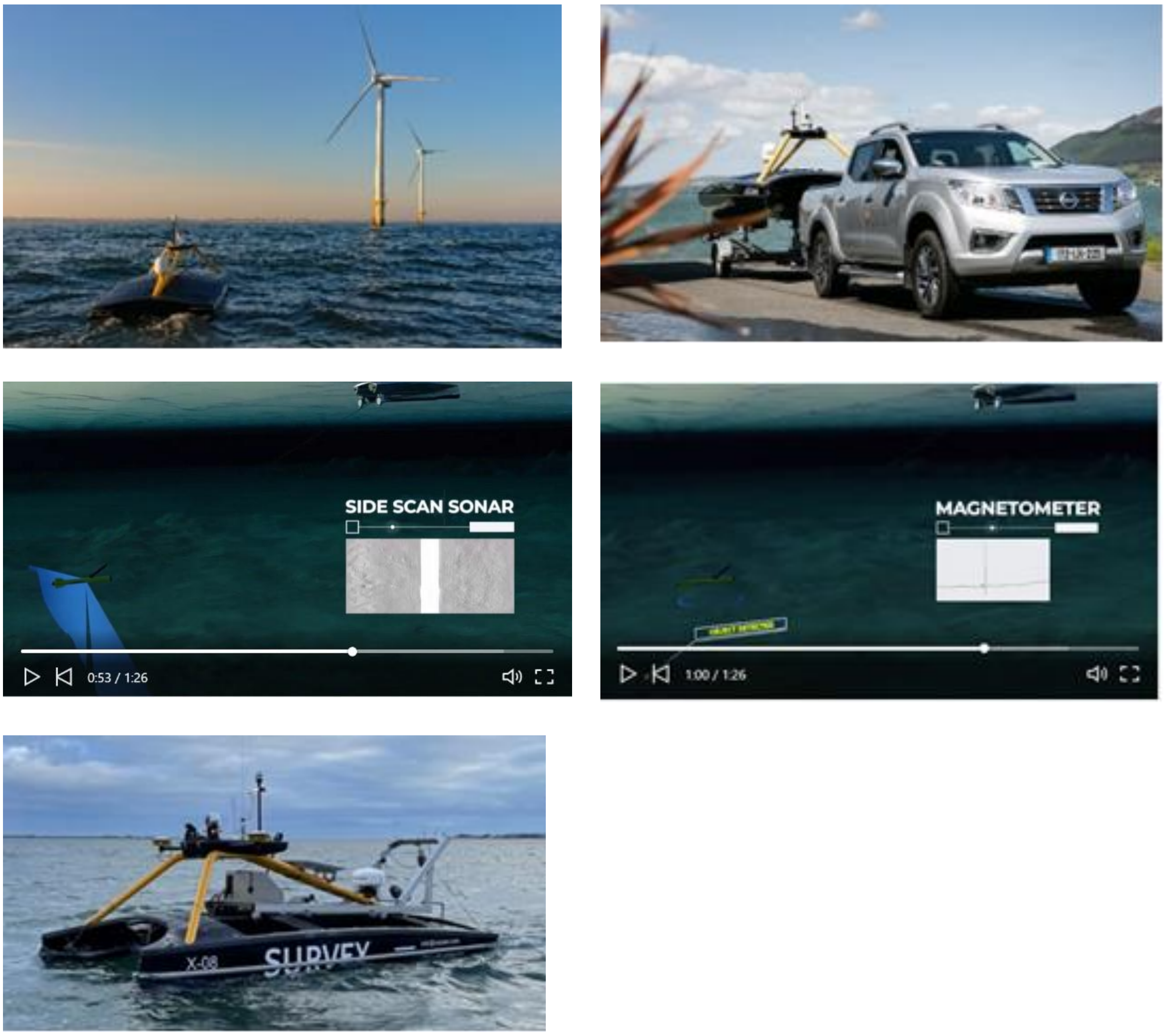


Figure 42 – Examples of Unmanned Surface Vessel (USV) courtesy of XOcean. Top left - USV at an offshore windfarm. Top right – Launch of USV. Middle left – USV towing a side scan sonar. Middle right – USV towing a magnetometer. Bottom left – USV fitted with LARS system for deploying towfish

This feature could be particularly useful in finding and mapping objects on the seabed prior to construction, e.g. wreckage, natural obstructions, unexploded ordnance.

3.4.5 Direct Embedment Anchoring

Anchoring a device to the seabed is not an insignificant task in a tidal energy site. Sites are often swept clean of sediment preventing the use of classic drag embedment anchors.

Gravity weights are simple and effective but can be large and expensive with a high carbon footprint.

Direct embedment anchoring solutions have been developed by several companies to provide more cost-effective solutions to anchoring to gravity anchors.

Figure 43 | Swift Anchor's groutless rock anchor (top) and Leask Marine's grouted anchor pile (bottom)

EMEC played a role in the development of these technologies by providing Sustainable Marine Energy Ltd a berth at the Falls of Warness, in which the first 'groutless rock anchors' were installed in 2016 and subsequently supported the development of the Leask Marine Subsea Drill rig, as part of the InToTidal project consortium.

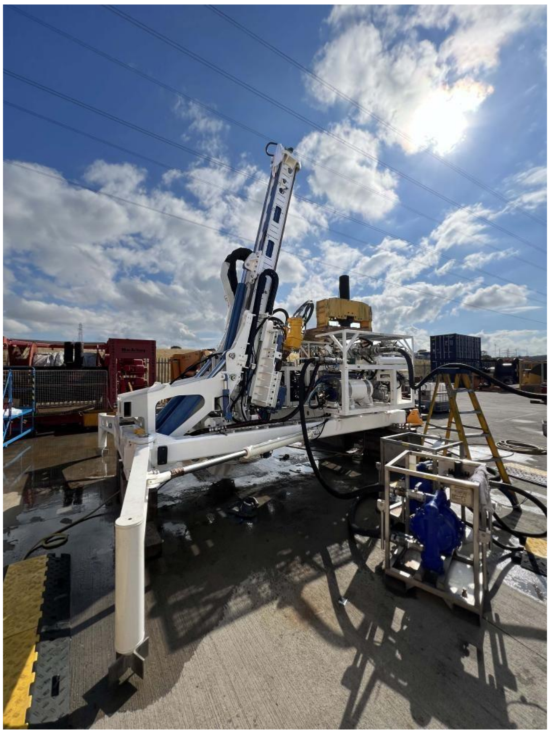


Figure 44 | LHS Swift anchor anchoring ROV and Leask Marine's subsea drilling rig

Figure 45 | Swift Anchor's remote intervention tool (RIT)

3.4.6 Subsea Tracked Vehicles

Subsea tracked vehicles have an advantage over large work-class ROV systems by virtue of their mass, which enables them to operate in higher tidal flows compared to work class ROV system. They can be equipped with much of the same tooling that work class ROVS are capable of operating, making them potential very versatile remotely operated work platforms.

The tasks that such vehicles could potentially accomplish include: survey; supporting deployment and recovery of equipment; supporting UXO clearance operations; connection of subsea electrical connections; and connection and disconnection of moorings, etc.

As most tidal sites have very small tidal windows, having a stable platform to undertake tasks on the seabed over a greater water velocity can potentially increase the operating window available to undertake meaningful work.

3.4.7 Towed systems

Towed systems, like the Macartney FOCUS ROTVs (Remotely Operated Towed Vehicle), are capable of operating in high current speeds of up to circa 5 knots, much higher than a conventional work class ROV which with struggle to hold station in a couple of knots.

Remotely Operated Towed Vehicles are generally used for surveillance and monitoring.

Figure 46 | SERDP funded muti-sensor Towbody (MuST) vehicle with eBOSS (courtesy of Edgetech)

These systems can be used for location of UXO. EdgeTech's Buried Object Sonar System (eBOSS), for example, has been mounted to a ROTV. This system capable of detecting, locating, classifying and identifying buried and partially proud objects such as munitions.

3.5 Site Conditions for Operations

There are limitations for operating at site, and ones that particularly affect PTEC include:

- Slack windows

- Steaming time
- Wave conditions
- Wave-current interactions
- Depth
- Visibility

Slack windows are defined by the operation that needs to be performed. For example, an ADCP deployment can occur in flow speeds below 1 m/s (~2 knots), so the window for that can be determined for springs, neaps, HW and LW. An example is shown below, where 1 m/s and 0.5 m/s slack windows are calculated from ADCP data for surface flows (for vessel and equipment overboarding).

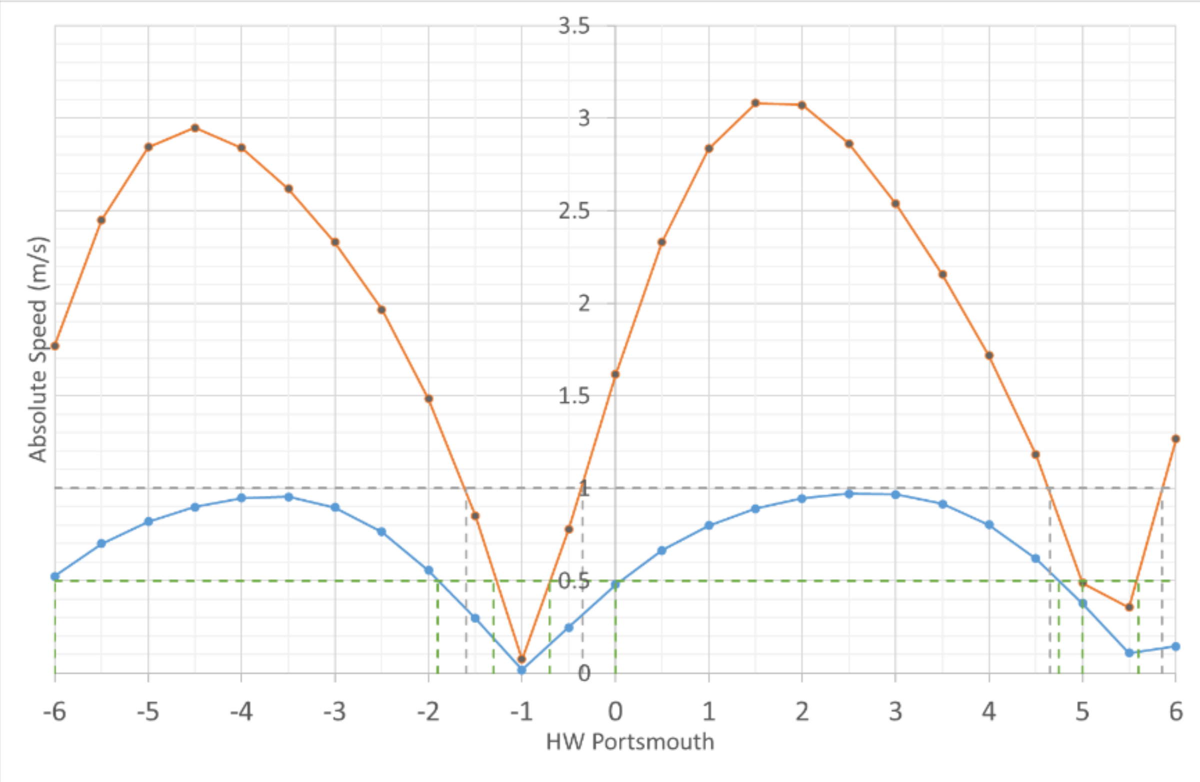


Figure 47 | Spring and neap tidal cycle, with operation windows for 1 m/s and 0.5 m/s

SPRING TIMINGS (coeff approx >90, range >2/3)							
	<1m/s	<0.5	0m/s	>0.5	>1m/s	Duration (<0.5 m/s)	Duration (<1 m/s)
HW	-01:36	-01:18	-01:00	-00:42	-00:21	00:36	01:15
LW	04:39	05:00	05:30	05:36	05:51	00:36	01:12
MID TIMINGS (coeff approx 70 - 90, range 1/3 - 2/3)							
	<1m/s	<0.5	0m/s	>0.5	>1m/s	(<0.5 m/s)	(<1 m/s)
HW	*-02:33*	-01:36	-01:00	-00:21	*00:43*	01:15	*03:16*
LW	*03:34*	04:52	05:30	05:48	*-04:40*	00:55	*03:45*
NEAP TIMINGS (coeff approx <70, range <1/3)							
	<1m/s	<0.5	0m/s	>0.5	>1m/s	(<0.5 m/s)	(<1 m/s)
HW	*-03:30*	-01:54	-01:00	00:00	*02:30*	01:54	*06:00*
LW	*02:30*	04:45	05:30	-06:00	*-03:30*	01:15	*06:00*

Table 10 | Spring, neap and mid-tide operation windows for 1 m/s and 0.5 m/s

Steaming to site is affected by weather conditions and sea conditions. For example, there will be operational wind and wave limits for vessel and crew, but if there is wind against the tide, the sea state will be more aggressive. Additionally, steaming into tide will take longer to get to site, shortening the operational time at site. Due to the nature of the island and the tides that act around it, when travelling from central Solent to St Catherine's it is very difficult to time the tide turn when turning the corner at Bembridge or the Needles, so at some point on the journey the tide will be against the direction of travel. Generally, it is best tidally to go from central Solent round Bembridge to East of the island, but this means steaming into prevailing SW winds to reach the site.

Wave conditions at site can affect success of operations for several reasons. First, due to exposure to prevailing SW winds there can commonly be swell at the site; SW wave direction is dominant in the offshore wind and wave roses from BMT Argoss (Figure 32, [17]). When the tide turns, if doing operations at slack water, the conditions can significantly change due to the wave-current interaction. While it may be safe to overboard equipment during, for example, the end of the flood, it may not be safe to retrieve equipment during the ebb. Conditions must be anticipated before operations commence.

The depth at site can limit operations; for example, the PTEC site is too deep for cost effective commercial dive operations. Additionally, scientific data can be affected by the depth; for example, swath bathymetry or side-scan SONAR taken from a vessel can lose accuracy due to beam spread and vessel motion, combined with distance from the seabed.

Visibility can be affected by particulates and light penetration. At PTEC site depth light penetration is low and so visibility from drop cameras is limited to torch coverage. Also torch light can back scatter off particulates, limiting visibility of cameras. Operations such as finding assets on the seabed can be complicated by this reduced visibility range.

3.6 O&M

3.6.1 At Site

The considerations for at site O&M are the same as the previous section. Other considerations could include shear profile for operations, shifts on site, and refuge locations.

The shear profile is important depending on the type of operation (Figure 48)[8]. If conducting long duration operations with an asset on the bed, e.g. an anchor drill rig, and an asset on the surface, e.g. the support vessel, the velocities during the tidal cycle and the bed and surface are important. This cannot be captured by 2D numerical modelling. Flow dynamics could cause differences in flow speeds for different assets, e.g. the tide may turn close to the bed before the surface due to local bathymetric features.

As mentioned previously, due to the distance of steaming to ports that can receive medium work boats, it may be beneficial to employ sufficient crew to do shifts on site and remain at PTEC for a couple of days to utilise several tidal widows. If steaming for a single personnel shift, there may only be a few hours operational time at site itself.

When working at site, there are limited places to seek refuge for the vessels or devices, due to exposure to SW. Figure 36 shows that the nearest ports are in the Solent, unless there is sufficient tide (or grounding out is not considered a significant risk) to go to Ventnor.

3.6.2 In Port

As detailed in Section 3.2 the different ports in the local area have different access and facilities. Considerations for in-port O&M will include locations for crane lifts, crane capacities, holding yard space, road access, deep water access and local constraints, e.g. ferry operations.

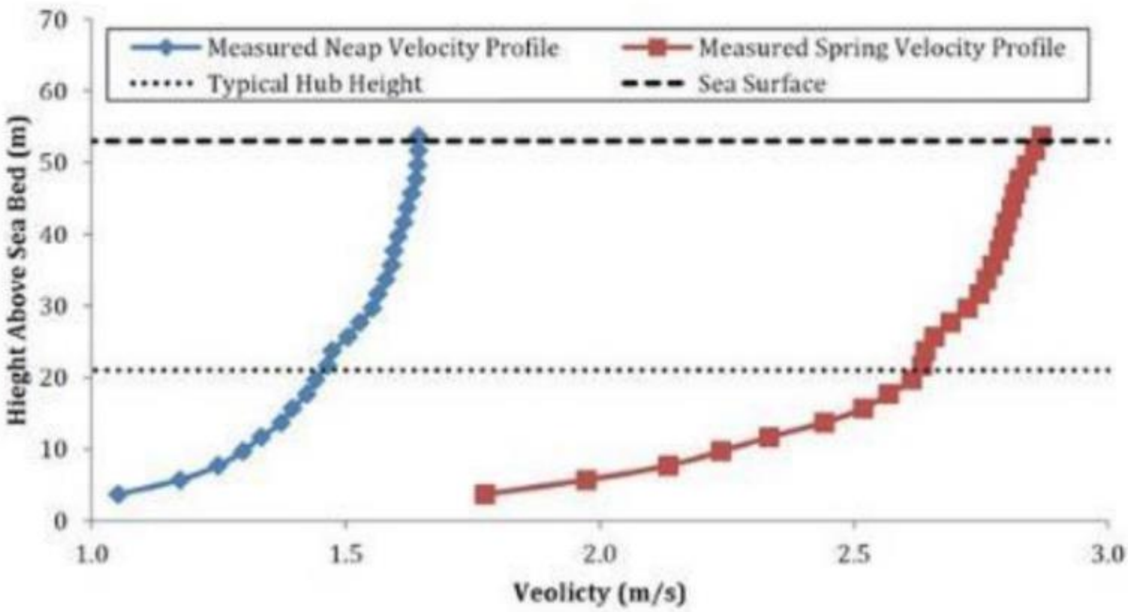


Figure 48 | Shear profile for neap and spring tides at PTEC

4 HSE Considerations

Successful Health and Safety Management is achieved by creating and maintaining a strong health and safety culture throughout the project. The following section sets out some key considerations in relation to Health, Safety and Environmental (HSE) Management when developing a tidal site. The purpose of this section is to offer some advice on health and safety considerations that are specific to the marine energy industry. Satisfying the requirements of this guidance should not be viewed as an indication of compliance.

4.1 Industry Guidelines

Responsibility to uphold a high standard of HSE best practice is of upmost importance especially during operations in the marine environment. This is done through strict adherence to all applicable UK safety, health and environmental legislation and relevant standards such as BS EN ISO 45001, BS EN ISO 14001 and BS EN ISO 9001.

EMEC has prepared a number of guidelines detailing relevant legislation within the marine energy industry, which can be used for reference [28–30].

4.2 Quality, Health, Safety and Environmental Management

Crucial to development of a tidal site is the implementation of a robust Quality, Health, Safety and Environmental (QHSE) Management System. Responsibility for the overall QHSE structure can be managed in a number of ways, however, due to the partnership between PTEC and EMEC, QHSE responsibility has been divided. In this scenario, PTEC act as the client and EMEC as development consultant and QHSE co-ordinator.

EMEC operates an Integrated Management System (IMS) which incorporates the requirements of ISO 9001 (Quality Management), 14001 (Environmental Management), 45001 (Health & Safety Management), 17025 (Laboratory testing) and 17020 (Inspection). EMEC's IMS is certified to ISO 9001, 14001 and 45001 by DNV and is accredited to ISO 17025 and 17020 by the United Kingdom Accreditation Service (UKAS).

All contractors working within the project are required to maintain and implement a Health and Safety (H&S) policy and demonstrate commitment to the protection of people, the environment and assets. In addition, contractors must maintain H&S management systems that clearly identify roles and responsibilities of its personnel. This includes ensuring competence, operational safety reviews and continuous performance monitoring.

4.3 Risk Management

In order to demonstrate compliance with CDM regulations, among others, an in-depth risk analysis should be conducted making use of recommended risk assessment tools. Hazard and risk identification through all phases of the project can be identified using Failure Mode Effect Analysis (FMEA), Hazard in Design (HAZID) and Hazard Operability Study (HAZOP), and used to eliminate or reduce risks.

It is good practice within Risk Management to maintain a risk register, this promotes the visibility of risks and enables the continuous monitoring and evolution of active risks. The risk register provides a framework in which risks are identified, recorded, categorised, assessed, mitigated and regularly reviewed.

4.4 Site H&S requirements

During site operations, H&S expectations must be clearly communicated through inductions, appropriate training, site access rules, permits to work systems and continuous improvement through incident reporting and hazardous observation systems.

Hazard Identification and Risk Assessments (HIRA) should be conducted before attendance on site to identify and mitigate or control hazards. Outcomes of the HIRA process should feed into Method Statements and 'toolbox talks', to ensure all those engaged in conducting work scopes are aware of the residual hazards and take appropriate steps to mitigate them. As an example, all relevant Personal Protective Equipment (PPE) identified within the risk assessment must be worn. The PPE shall be suitable for the individual, sufficient to provide adequate protection and replaced as required. All equipment must be: (i) certified; (ii) in date; (iii) be constructed in accordance to relevant European and British standards; and (vi) be 'CE' marked.

Specifically for tidal sites, both onshore and offshore, the effect of remote locations and adverse weather conditions must be taken into consideration. Appropriate lighting must be provided and measures taken to protect personnel from extreme weather conditions.

4.5 Emergency Response

All operational sites require an emergency response plan to ensure arrangements are in place in the event of an emergency occurring. Emergency response procedures should be registered with the local emergency and rescue services [31].

In an emergency there are a number of considerations, most significantly which ports or bays to tow to, e.g. in the case of a broken mooring line or significant storm beyond ALS cases, and local services, e.g. lifeboats and first responders.

The only two refuge points aside from the all-tide access ports detailed previously are Ventnor, where a device would be sheltered but will dry out, or Sandown Bay, where a device can shelter from westerly winds to a degree but stay afloat. Note that there is a military zone and conservation zone, so realistically it would be best to tow to the Solent, either Yarmouth, Cowes, Southampton or Portsmouth, depending on the asset.

In the event of an emergency, the nearest response must be considered. Fortunately, there are a lot of assets in the Solent region, coordinated by Solent Coastguard. There are 13 lifeboat stations with ~50 km and a Coastguard Helicopter at Lee-on-Solent (Figure 50). There is also St Mary's Hospital on the island, and access to Southampton General.

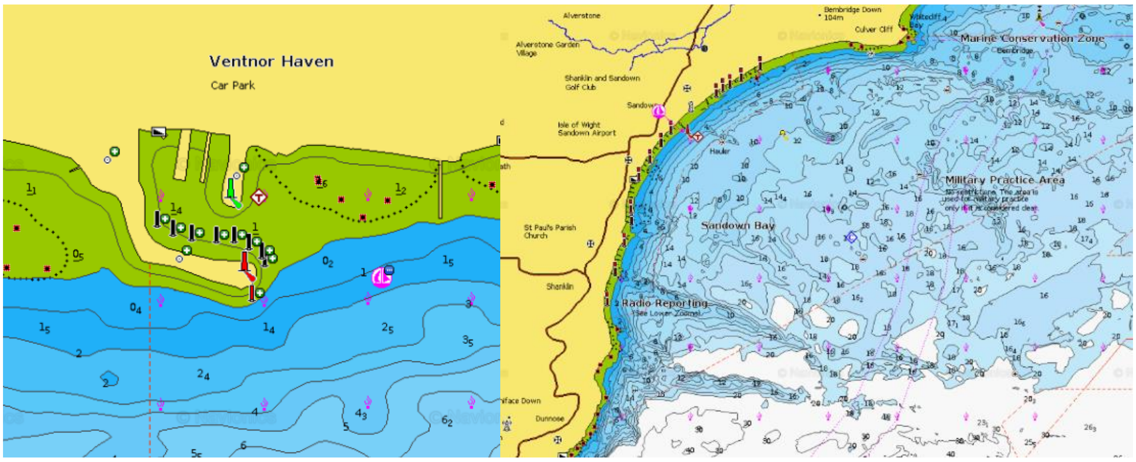


Figure 49 | Navionics.com chart of Ventnor (left) and Sandown Bay (right)

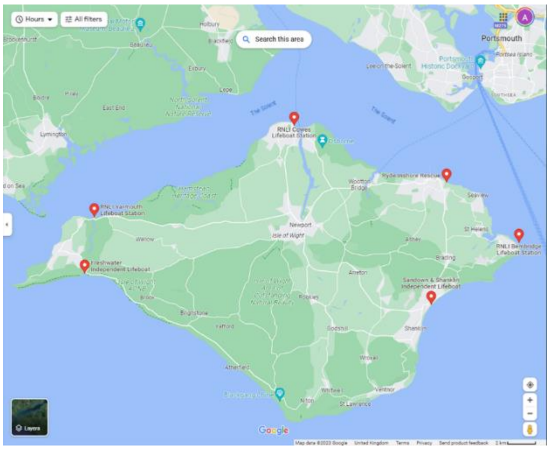


Figure 50 | Google map of lifeboat stations in the Solent and Isle of Wight

5 Consents

An overview of the consenting process for PTEC is given as an example for some of the considerations needed for a tidal site, though these are generally region specific.

5.1 Overview

In 2013, an Environmental Impact Assessment (EIA) was undertaken to support the onshore and offshore consenting process at the PTEC site. As part of this, PTEC created a project envelope which considered multiple tidal turbine and project variations. The key aim was to future-proof the project for changes in technology, to support the engineering design process and to consider key stakeholders.

Consent was achieved in 2016 but, as a result of a change in UK Government policy, there was a period of stasis until the project was revived in 2020. The UK Government then announced plans to make the UK a world leader in green energy.

In November 2021 this was cemented, with the announcement of £20 million per year in government support for the tidal stream energy sector through the Contract for Difference (CfD) scheme. The following month, in December 2021, PTEC resecured the onshore consents and extended consent for offshore activities.

The consenting activities, managed by EMEC, included onshore planning permission, an offshore marine licence (ML) [8] and offshore Section 36 (S36) consent.

5.2 Onshore

The onshore planning permission was granted in December 2021 and carried with it several conditions, with the majority that need to be discharged before works could be carried out. These can be reviewed in the planning permission documentation.

One of the conditions of the planning permission is, *'The development hereby permitted shall be begun before the expiration of 3 years from the date of this permission.'* This means that the planning permission will expire in December 2024 if pre-commencement conditions have not been satisfied. When developing a tidal site, a robust consents discharge plan must be created to ensure compliance with onshore consents within the planning permission expiration date.

5.3 Offshore

When preparing to develop an offshore tidal energy site there are several permissions that must be in place, including:

- Marine Licence (ML)
- Seabed Lease
- Navigational Risk Assessment (NRA)
- Notice to Mariners (NtM)

- Section 36 consent (S36)

5.3.1 Marine Licence

Marine and Coastal Access Act 2009 provides that a Marine licence (ML) is required for certain activities carried out within the UK marine area. At PTEC's location. the relevant authority is the Marine Management Organisation (MMO), an executive non-departmental public body sponsored by the Department for Environment, Food & Rural Affairs.

An overarching ML was granted in April 2016 and had several conditions attached to it which must be discharged before construction begins. These can be viewed with the granted marine licence. While the amount and scale of these conditions is extensive, the expiry date is October 2043; therefore, there is ample time to achieve these conditions before expiry.

5.3.2 Seabed Lease

The Lease allows the tenant to deposit items on the seabed. The relevant authority for PTEC's location is the Crown Estate. Crown Estate Lease means any lease, licence, or agreement between the Licensee and the Crown Estate relating to the use of Crown Estate property to enable the transmission of electricity over the licensee's transmission system.

The lease includes details of:

- Tenant's obligations
- Rental agreements
- The works that have been agreed to take place within the lease area
- Decommissioning agreements.

5.3.3 Navigational Risk Assessment

To ensure the risks to navigation for vessels transit to or adjacent to the site, regular Navigation Risk Assessments (NRAs) need to be conducted. An NRA determines the hazards affecting vessel navigation through an area, then analyses the mitigations that could be applied to minimise risk to as low as reasonably practicable (ALARP). The NRA must be in compliance with the Maritime and Coastguard Agency's (MCA) Marine Guidance Note (MGN) 654 for assessing Offshore Renewable Energy Installations.

5.3.4 Notice to Mariners

Notice to Mariners (NtM) must be published by the Admiralty prior to any works on site. The NtM provides safety information to all sea users in the local area.

5.3.5 Section 36 consent (S36)

The S36 consent was granted in April 2021 and has several conditions attached to it which can be viewed with the granted S36 documentation. As with the ML, the expiry date is April 2026; therefore, there is plenty of time to achieve these conditions before expiry.

5.4 Surveys

A variety of surveys could be required for development of a tidal site. The following list outlines key considerations relating to example surveys that may be required.

- Magnetometer
- Ambient noise
- Ornithology – offshore and onshore
- Marine Mammals
- Benthic habitat
- Marine Archaeology
- Onshore archaeology
- Atlantic salmon
- Terrestrial ecology
- Fisheries biomass

6 Conclusion

This document has summarised the stages and steps required for developing a tidal site in the Channel region, using PTEC on the Isle of Wight as an example. This includes work developing onshore, offshore and grid connection works. Surveys and consents are gathered constantly, and information must always be kept current and to a level of accuracy appropriate for the development stage.

Onshore, cable run and grid connection works have been optioned and designed to a certain degree but must be advanced with further project development. Offshore site information has been gathered appropriate to the stage of development, and this can be built upon and refined with further streamlining, e.g. once developer device type and requirements are known. There are also additional R&D activities that can be undertaken while the commercial funding mechanisms are sought. There may be opportunities to develop the site using state-of-the-art investigations, such as remote seabed surveying. Consenting is kept up to date where possible, but compliancy must be considered at all stages of development. As discussed above, the expiry of the S36 consent and the ML, in particular, has provided an urgency to this project in terms of initiation of work to discharge the conditions laid out by the relevant authorities.

As outlined above, the development is multi-faceted and requires different levels of information and funding at each stage. As the level of information, number of onshore and marine operations and surveys and modelling detail increases, so does the cost, generally.

A significant amount of money and effort has been expended to get PTEC to its current stage of development. In order to develop the site further there needs to be another step in the government support. Since PTEC is not designed to be a test site, only utilising commercial devices, it must have commercial support and contracts in place. UK Government funding to support development of sites is capped and PTEC missed the AR4, but it is hopeful to get support from future rounds. Further government funding support is required to secure the necessary private investment and shows the dependency of UK tidal site development on national government support.

While the delay to financial support for new tidal projects is certainly a significant hindrance, it does provide an opportunity for longer track records of devices at test sites, such as EMEC, and for R&D projects to advance to a point where they can yield commercially viable results. The advancement of the tidal industry over multiple sites and companies, and the shared learning that comes from these projects, is the only way to advance blue renewables in the UK and EU waters.

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Appendix A: Active Network Management System

The principle of operation of the ANM is that power flow is measured at crucial points in the network where thermal overload is likely, known as 'measurement points', and generators contributing to that power flow are required to reduce output so that the power flow remains within limits. For the Isle of Wight network, the measurement points are simply the three 132 kV circuits to mainland UK.

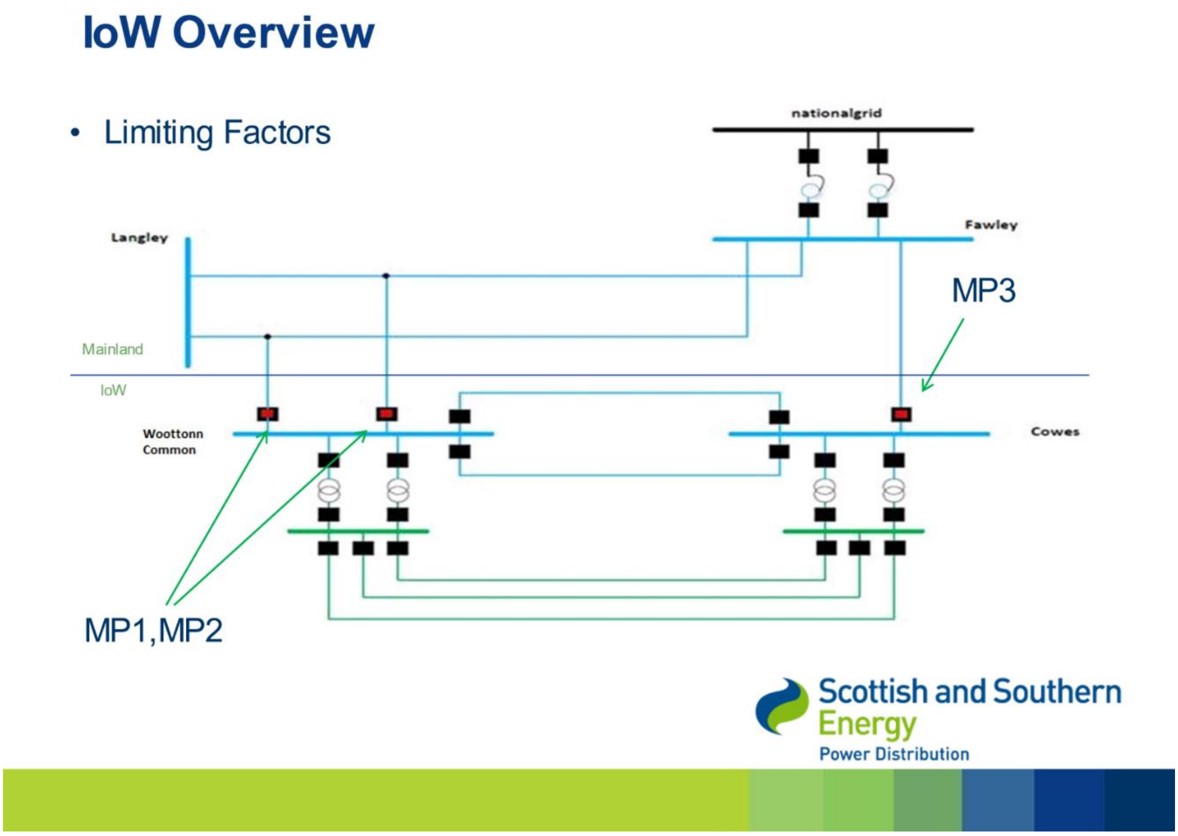

Figure 51 | Isle of Wight overview from SSEPD, courtesy of SSE

The ANM uses an automatic control system, operating in real time. The controls available to it, illustrated below, include a 'trim' instruction, which can issue a continuously variable power set-point to a generator, and a 'trip' signal, which will open an onsite circuit breaker to disconnect the generator.

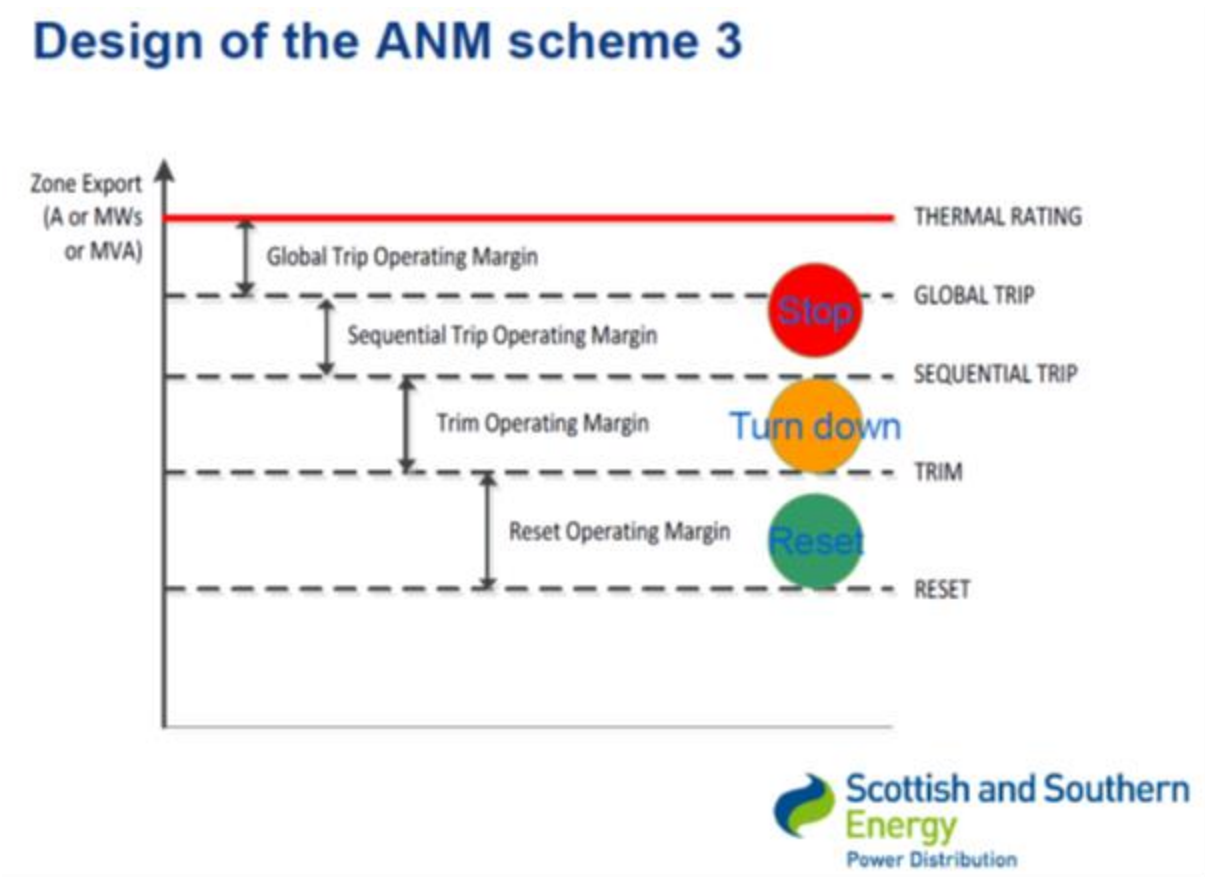

Figure 52 | Design of ANM, from SSEPD courtesy of SSE

The trim instruction operates over a hysteresis band between the trim and reset levels and (in the Orkney experience) is usually sufficient to maintain power flow at measurement points within the required limits. If a generator for any reason fails to respond to a trim instruction within a defined time, it may be tripped. The sequential trip control allows generators to be tripped in order of priority if power flow rises too far above the trim level. A higher 'global trip' level, if reached, will disconnect all generation, to protect the network. The system relies on communications between the generating site and central ANM controller (which for the Isle of Wight is at Wootton Common) and will fail safe by disconnecting the generator if communications are lost.

Such a scheme utilises the network up to a safety margin below its full capacity and allows a greater volume of generation to connect than would be possible under the traditional arrangements, but with the penalty of generation being constrained at times. The order of constraint is determined on a last-in, first-off basis, where the last generator to accept a connection offer is the first to be constrained. Figure 53 illustrates the case where the level of constraint is high enough for G3 (last to contract) to be constrained to zero output and G2 (second last) is partly constrained.

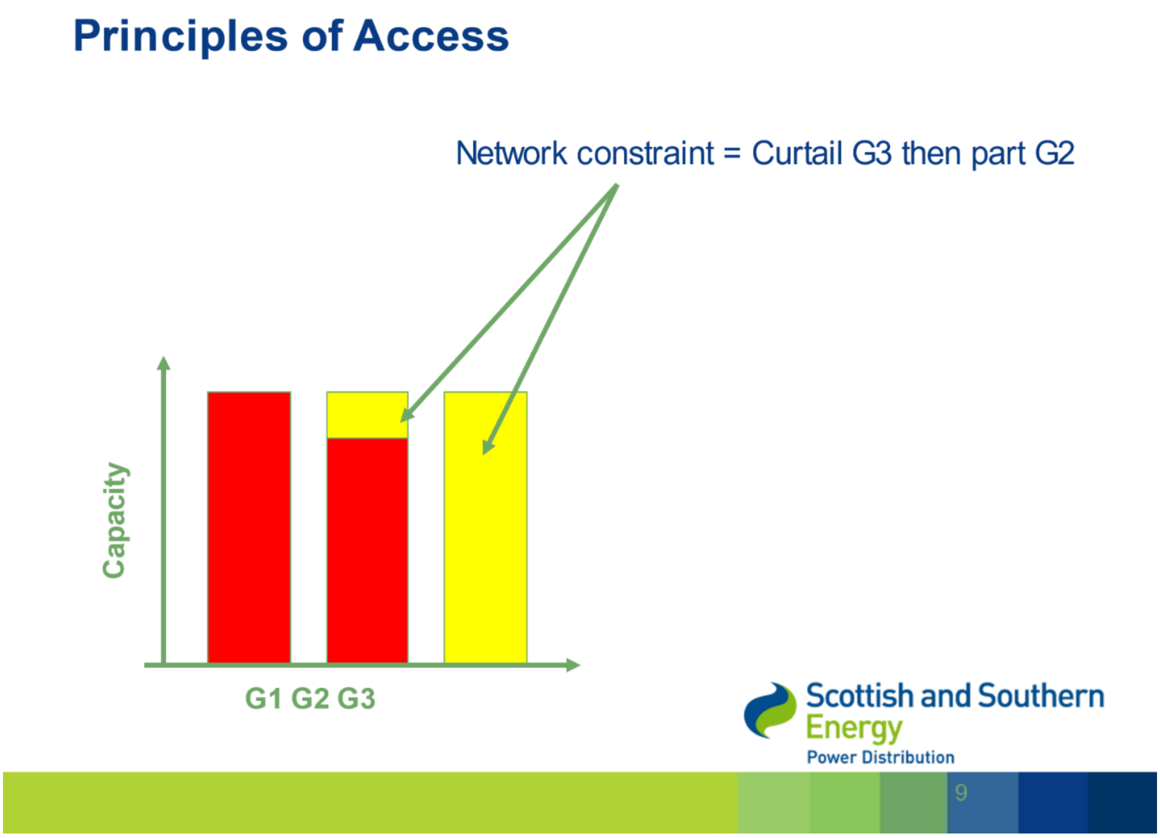

Figure 53 | Principles of access, from SSEPD courtesy of SSE

The ANM system is intended to manage power flow during normal network conditions and does not replace the requirement for generation to disconnect in the event of failure of any of the 132 kV circuits.

The Isle of Wight ANM implementation reserves 140 MW of export capacity for Cowes East [5] for the reasons described in section 2.2.3.1. This replaces the need in the 2014 connection offer to disconnect when East Cowes is in operation.

In contrast to the Orkney ANM, which has a large uptake, as at 2021, only one generator is thought to have connected to the Isle of Wight ANM [5]. The fixed costs associated with ANM integration are appreciable and have been cited as a barrier for smaller capacity connections but are less significant for a larger project such as PTEC.

TIGER TIDAL STREAM INDUSTRY ENERGISER

EUROPEAN UNION
European Regional Development Fund