COMMISSION OF THE
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Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact

Grant agreement number: 213380

Deliverable D4.3
Test Sites Catalogue

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Test Sites Catalogue

Michael O’Connor
UCC
Brian Holmes
UCC

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Summary

This report aims to give an overview of the various wave energy and tidal energy test sites that exist today as well as those that are proposed for the near future. The various independent full scale wave and tidal sites are described together with nursery and scale sites. A description is also given of test sites which device developers have created in order to test their own devices.

All the sites are described in terms of scale of devices tested, resource and met-ocean conditions, infrastructure and services available, licensing and permitting issues as well as the rationale behind the selection of the location of each site. Finally the importance of the spectral shape of the seaway at wave energy test sites is discussed as well as the role of test centres in the development schedule of wave and tidal devices.

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Nomenclature

ADCP	Acoustic Doppler Current Profiler
AUV	Autonomous Underwater Vehicle
AWAC	Acoustic Wave and Current
BIMEP	Biscay Marine Energy Platform
BS	Bretschneider
DanWEC	Danish Wave Energy Centre
ECN	Ecole Central Nantes
EIA	Environmental Impact Assessment
EMEC	European Marine Energy Centre
EPR	Ethylene Propylene Rubber
EPRI	Electric Power Research Institute
ES	Environmental Statement
FEPA	Food and Environment Protection Act
FERC	Federal Energy Regulatory Commission
FORCE	Fundy Ocean Research Centre for Energy
HMRC	Hydraulics and Maritime Research Centre
Hs	Significant Wave Height
IEA-OES	International Energy Agency- Ocean Energy Systems
Kts	Knots
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt Hours
kW/m	Kilowatts per metre
LV	Low Voltage
LVMS	Low Voltage Marine Substation
MAREN	Marine Energy
MCT	Marine Current Turbines
METCentre	Marine Energy Test Centre
M/S	Meters per Second
MSL	Mean Water Level
MW	Megawatt
NaREC	National Renewable Energy Centre
NNMREC	Northwest National Marine Renewable Energy Centre

NPS-KHPS	Navy Puget Sound-Kinetic Hydropower System
NRA	Navigational Risk Assessment
NREL	Neptune Renewable Energy Ltd
O&M	Operations and Maintenance
OPT	Ocean Power Technology
ORPC	Ocean Renewable Power Company
OWC	Oscillating Water Column
PLOCAN	Plataforma Oceanica de Canarias (Ocean Platform of the Canary Islands)
PM	Pierson Moskowitz
PTO	Power Take Off
PWP	Pelamis Wave Power
RDA	Regional Development Authority
REC	Runde Environmental Centre
RITE	Roosevelt Island Tidal Energy
ROV	Remotely Operated Vehicle
SAC	Special Area of Conservation
SCADA	Supervisory Control and Data Acquisition
SEAI	Sustainable Energy Authority of Ireland
SEM-REV	Site d’Experimentation en Mer pour la Recuperatuion de l’Energie des Vague
SOEC	Solent Ocean Energy Centre
SWAN	Simulating Waves Nearshore
Te	Average Energy Period
Tp	Peak Period
TPV	Third Party Verification
TRL	Technology Readiness Level
TT Centre	Tidal Testing Centre
Tz	Zero Crossing Period
UUV	Unmanned Undersea Vehicle
WAM	Wave Analysis Model
WEC	Wave Energy Converter

1 INTRODUCTION

1.1 SCOPE OF REPORT

This report will describe full scale wave and tidal energy test centres which have been set up to test various devices and aim to support device developers progression to commercialization. Nursery and scale test sites are also described. Also discussed are developer test sites which have been set up by device developers to test their own devices. All the sites are described in terms of their ability to support the development of devices from laboratory tests to full commercialization.

1.2 AIMS AND OBJECTIVES

- To list the infrastructure and support service requirements that test sites should have to enable them to fully support device developers
- To describe the various wave and tidal energy test sites that exist or are proposed for the near future
- To give an overview of the device development schedule and the test sites important role in device development

1.3 DESCRIPTION OF TEST SITES

The requirement of test sites, in terms of what support services and infrastructure they should provide to support the development of devices is discussed. Full scale sites are described in terms of the resource, infrastructure and services, licensing and permits and the reasons for the selection of the location of each site. Developer test sites are discussed as well as which devices have been tested at these locations. The importance of the spectral shape of the seaway at wave energy test sites and recommendations for how to compare spectra at different sites is also discussed. Finally the role of test sites in the development schedule of devices, and which test sites should be used at each stage is examined.

2 WAVE ENERGY TEST SITE REQUIREMENTS

The purpose of wave energy test sites is to make it technically and financially easier for device developers to carry out the extensive and expensive full scale testing of devices in real sea conditions. During open ocean testing of devices utilisation of established test centres should reduce the challenges facing unproven heavy engineering operations at sea as well as alleviating permitting, licensing and conflicts with other maritime users. Established centres should offer easier grid connection that includes performance monitoring instrumentation. Use of the centres could also satisfy the requirement for an independent reviewer to oversee and validate the data collection methodology. It is anticipated that service vessels and support industries will set up in the areas around the test sites which will gain experience in their fields, from which device developers should benefit from.

Full scale wave energy test sites should possess the following in order to fully support device developer's progress to commercialisation.

2.1 MET-OCEAN CONDITIONS

The site should have the correct met-ocean conditions of wave climate, water depth, sea-bed conditions, low current, no ice etc. The overall wave climate is required to probabilistically estimate the deployment, recovery, service and maintenance windows and seaway windows. Past data from the site for all these parameters should be available. In general the wave conditions should be similar to those of the proposed commercial sites.

2.2 GRID CONNECTION

An electrical grid connection should be available for full-scale pre-commercial devices. The connection voltage and power level should be at an appropriate level and onshore substations with monitoring equipment should also be available. The test sites should also provide convenient connection mooring berths for the straightforward deployment and recovery of devices.

2.3 WAVE MEASUREMENTS

Although the wave climate should have been established prior to use of the site, real-time measurements during the sea trials must be conducted. It is probable that this will be done on a separate acquisition system so synchronisation with device monitoring is essential. Attention should be paid to ensure that the selected wave recorder and data rates are appropriate to the wave conditions being monitored i.e. scaled in accordance to the device while maintaining the requirements for accurate sea state and spectral definition. Different types of wave recorder can be deployed but each should adhere to the same acquisition rate and duration. Ideally more than one directional recorder will be deployed on a station close to and up wind of the test berth but unaffected by the presence of the device or local topography and bathymetry.

The wave data should show that no dead spot or hot spot in the wave environment is likely to be within 500m of the WEC under test. It should also show that the wave measuring device (used to record the water surface elevation) is at a position where the wave environment is the same at the mean position of the WEC. Consideration should be given to differences in water depth between the position of the measurement device and the WEC, as well as bathymetry induced fraction of waves from the data site to the test sites and tidal current induced refraction of waves from the data site to the test site.

Actual sea state at the proposed test site should be measured by wave buoy or other device of at least comparable accuracy, from as early as possible in the development process. If feasible it should be done on a continuous basis leading up to and in any event, throughout the test period. The wave measuring device should record data that allow the directional wave spectrum to be estimated.

2.4 METEOROLOGICAL AND CURRENT MEASUREMENTS

As well as past wave climate data used to assess the suitability of a site, meteorological data and current measurements should be recorded simultaneously with the device testing so that device performance can be compared to the conditions experienced. Current measurement devices should be deployed (particularly for devices with deep drafts) as appropriate to allow for corrections for current to be made to wave measurements. Where it is impractical to permanently site current measurement devices, currents should be measured at sufficiently regular intervals to predict the corrections required. Currents should be measured and averaged over the top 2m depth of the water column or as required to correspond to the approximate energy capture axis of the WECS if different.

The test site should be equipped with a meteorological station or met-ocean buoy that will automatically record the wind speed and direction, wet bulb and dry bulb air temperatures and barometric pressure at intervals of one minute maximum. Precipitation rate may be measured over intervals of up to 30 minutes. A meteorological station should be sited as near to the offshore site as practicable. The data may be recorded as a series of thirty minute averages. It is important to synchronise these different systems to agree to tolerances. The principal guideline for data acquisition should be to install as many sensors as possible and gather as much information as possible as certain parameters may have an effect on a device which may not be initially clear.

Seawater density is a function of seawater temperature, salinity and pressure (depth). Sea temperature and salinity should ideally be measured by the wave rider buoy(s) and corrected if necessary to reflect the depth of the energy capture axis of the device under test.

To distinguish measurements from dry and wet periods, precipitation should be monitored by the meteorological station or other suitable means and documented in the test report. A daily summary from hourly readings or similar would be advantageous.

2.5 BATHYMETRY

The bathymetry of the test site should be surveyed and sidescan sonar surveys carried out. These ensure that the test area is free from obstacles or uneven seabed topology that could be considered to distort or interfere with wave consistency or WEC performance.

2.6 PROXIMITY TO SUPPORT FACILITIES

The site should be easily accessible with suitable travel and communication infrastructure. The site should be close to a service port and access harbour. These ports should allow for the local launch and recovery of the devices with a harbour nearby which can facilitate service vessels. The site should also be close to experienced marine engineering yards with mobile operating capability. If testing of a number of devices or arrays is to take place then local fabrication facilities may be required as the transportation of a large number of devices may not be feasible.

2.7 LICENSING AND PERMITS

One of the main benefits of test sites is that they can provide a pre-consented testing area which reduces the amount planning and licensing that device developers have to undertake. This can save both time and money. Test sites therefore should have in place simplified licensing and consenting regimes. As devices are likely to be tested in the open ocean for the first time at test sites, there should be an environmental monitoring programme in place so that the effect of the devices on the environment and the effect of the environment on the devices can up fully understood.

2.8 ONSHORE MONITORING FACILITIES

As well as measuring as many parameters as possible, test sites should have adequate onshore-data receiving facilities which will allow for the synchronisation and storage of the data for analysis. Onshore facilities should be in place to monitor the power output to the grid for comparison with the measured sea state and device parameters. As there are a series of test centres established it could become customary to use more than one test centre during a devices passage from pre-production through to pre-commercial stage. This may be required to satisfy future clients of the product that the published performance figures for the WEC are intersite portable. Therefore common methodologies for the testing of devices should be in place across different test sites that facilitate the comparison of different devices tested at different sites.

3 EMEC WAVE ENERGY TEST SITE SCOTLAND

3.1 INTRODUCTION

The European Marine Energy Centre(EMEC) on the Orkney Islands in Scotland, is one of the first well-established and grid-connected test sites within Europe and is the first one in the world to create a test base for tidal and wave energy devices [1]. EMEC is considered to be a representative site for the deployment of wave energy converters off the west coast of Scotland.

Figure 1 EMEC wave energy test site with Pelamis on test

It was established in 2002 to create a North Atlantic test base for both tidal and wave energy activities. Construction of the wave test facility was completed in October 2003 and became operational in August 2004, when Pelamis Wave Power (PWP) installed their ‘Pelamis 750’ device on site for full scale testing. During 2005 AW Energy from Finland undertook stand alone mechanical testing in the shallower waters at the test site.

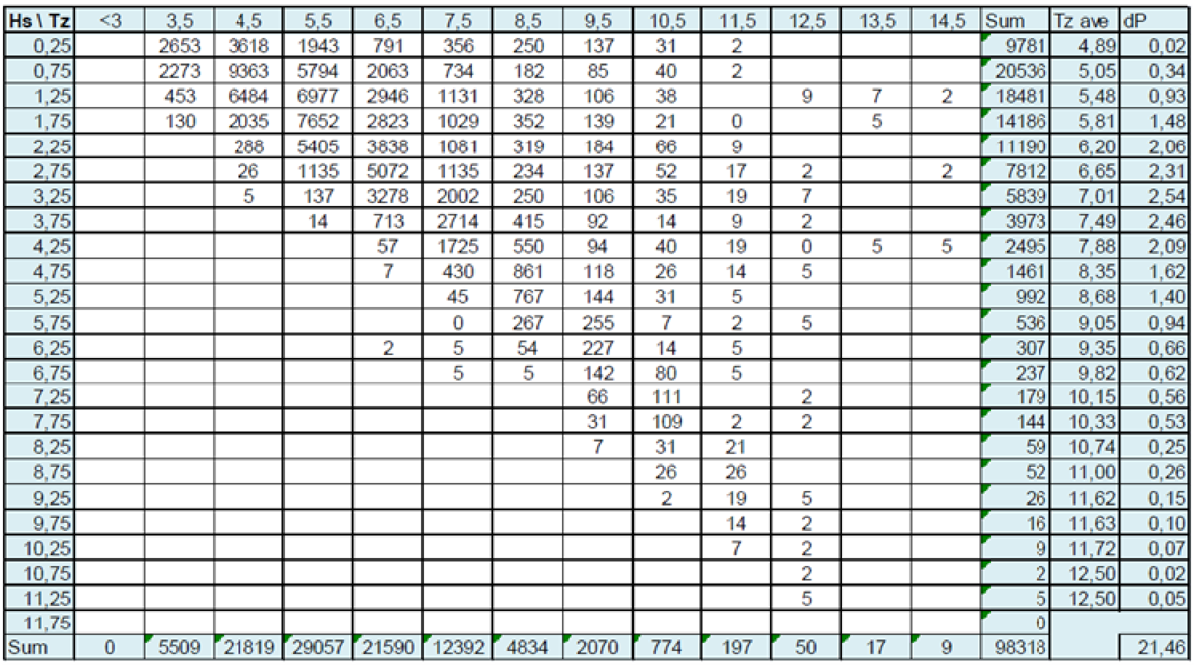
Aquamarine Power officially launched their nearshore ‘Oyster’ device on 20 November 2009 at EMEC. The second generation device built by PWP arrived in Orkney in July 2010 and has successfully completed the first phase of a planned work-up programme. E.ON have deployed the first Pelamis P2 device and Scottish Power Renewables will be deploying a second Pelamis P2 device on an adjacent berth in 2011[2].

EMEC’s facilities are based in and around the town of Stromness on the southwest side of Orkney. The main office and data centre overlook Stromness harbour, which offers facilities close to the sheltered deep water anchorage of Scapa Flow. A regular ferry service is operated from the mainland to Stromness with sailings up to 4 times a day. Stromness is 15 miles away from Orkney’s capital, Kirkwall, from which there are daily flights to the mainland [2].

3.2 RESOURCE

The data presented in Table 1 and Table 2 is based on a preliminary survey carried out in 2001. This preliminary survey estimated the wave energy resource at EMEC to be 21kW/m [1]. A more recent analysis of the wave energy resource was conducted in 2010[3] based on modelled wave data. It found that at the 50m deep water berths the net wave energy resource is 22kW/m. The report also found that there is significant sheltering of the site by the Outer Hebrides and Scottish mainland which reduces the wave energy resource by about 20% compared to more exposed sites on the western coast of Scotland.

Table 1 Joint probability diagram (Hs and Tz) for EMEC [1]



Hs \ Tz	<3	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	13,5	14,5	Sum	Tz ave	dP
0,25		2653	3618	1943	791	356	250	137	31	2				9781	4,89	0,02
0,75		2273	9363	5794	2063	734	182	85	40	2				20536	5,05	0,34
1,25		453	6484	6977	2946	1131	328	106	38		9	7	2	18481	5,48	0,93
1,75		130	2035	7652	2823	1029	352	139	21	0		5		14186	5,81	1,48
2,25			288	5405	3838	1081	319	184	66	9				11190	6,20	2,06
2,75			26	1135	5072	1135	234	137	52	17	2		2	7812	6,65	2,31
3,25			5	137	3278	2002	250	106	35	19	7			5839	7,01	2,54
3,75				14	713	2714	415	92	14	9	2			3973	7,49	2,46
4,25					57	1725	550	94	40	19	0	5	5	2495	7,88	2,09
4,75					7	430	861	118	26	14	5			1461	8,35	1,62
5,25						45	767	144	31	5				992	8,68	1,40
5,75						0	267	255	7	2	5			536	9,05	0,94
6,25					2	5	54	227	14	5				307	9,35	0,66
6,75						5	5	142	80	5				237	9,82	0,62
7,25								66	111		2			179	10,15	0,56
7,75								31	109	2	2			144	10,33	0,53
8,25								7	31	21				59	10,74	0,25
8,75									26	26				52	11,00	0,26
9,25									2	19	5			26	11,62	0,15
9,75										14	2			16	11,63	0,10
10,25										7	2			9	11,72	0,07
10,75											2			2	12,50	0,02
11,25											5			5	12,50	0,05
11,75														0		
Sum	0	5509	21819	29057	21590	12392	4834	2070	774	197	50	17	9	98318		21,46

3.3 MAIN SITE CHARACTERISTICS

The summary statistics for the EMEC wave test site (Table 2) are based on a preliminary survey carried out in 2001. The water depth is that of the test berths and EMEC mention separately that the 50 year design wave height at the site is 15m. A description of the sites infrastructure and services offered by EMEC is given in Table 3.

Table 2 Summary Statistics of the EMEC Wave Site[1]

EMEC Wave Site	59.00N	3.66W
Design significant wave height Hs	14-15	[m]
Design zero crossing period Tz	14	[sec]
Max wind speed	—	[m/s]
Max current speed	—	[m/s]
Max high water level	2.5	[m]
Min low water level	-1.7	[m]
Maximum ice thickness	—	[m]
Wave power annual average	21	[kW/m]

Table 3 EMEC wave test site Infrastructure and Services

EMEC Wave Site	
Scale	Full Scale Prototype
Water Depth	35-75m
Site Area	5km^2
Berths	Four (5MW each), located on 50m contour. 1-2km offshore.
Grid Connection	20MW. Four 11 kV subsea cables extend to 50m water depth, 1-2km from the shore and 0.5km apart. The cables are wet-type composite cables consisting of three 120mm^2 EPR-insulated stranded copper power cores designed for AC, three 2.5mm^2 copper signal/pilot cables and a 12 core single mode fibre optic bundle. The cable is then armoured with two layers of galvanised steel wire. The wave site cable conductor is 50mm^2 giving a nominal rating of 2.2MW. At the substation each cable terminates at an 11kV circuit breaker along with the tripping circuit. The fibres are terminated in the communications area of the substation. At the seaward end, each cable is capped using heat shrink caps and is fitted with a cable sock and buoy to allow retrieval to the surface. Developers install their moorings, cable connection and then the generating device and use umbilical cables to attach their device to the cables.
Wave Data Collection	Main wave measurements are carried out using two Datawell directional waverider buoys which continuously measure the significant wave height, energy period, mean direction and wave power as well as GPS position and sea surface temperature. A radio link provides a continuous feed from the buoy back to the main data centre where it is recorded on SCADA. The SCADA system also provides a drift alarm for each buoy using GPS. Data has been obtained since October 2002.
Weather Data Collection	An onshore Met station provides real time weather data, which is sent to the data station. Information is fed into the SCADA system and made available to all developers. The following is recorded: • Mean wind speed and wind direction every 5 minutes. • Mean air temperature, relative humidity, rainfall and barometric pressure every 30 minutes. • Over 24 hours: Average, min and max air temperature, relative humidity, total rainfall, mean wind speed, direction and average barometric pressure.
Other Data Collection	ADCP’s at the site provide secondary waves measurement and current measurements. An onshore former coastguard observation point has been converted to house cameras for monitoring activities out at sea. These can be remotely controlled from the EMEC data centre.
Substation/ Onshore Monitoring	EMEC has office and data acquisition facilities, including areas dedicated to specific developers in Stromness. Fibre- optic and VHF networks provide developers with direct access to their devices. The onshore substation connects to the national grid. This substation houses the main switchgear, backup generator and communications room, for supply from each offshore device to the national grid. It provides isolation switching for the devices under test and operates as an interface between EMEC and UK Grid. The electrical output performance of each of the devices is measured by equipment within the substation and transmitted to the data centre. Metered data is also provided to the developer through SCADA and the power data is logged in the data historian for historical trends. A two-way flow of information between devices under test, environmental monitoring equipment and EMEC’s data centre is maintained using the SCADA system which allows the devices to be controlled remotely, real time monitoring of their performance and round-the-clock assessment of their operating environment. The data is transmitted to the EMEC data centre via a fibre optic system. It gives the developer control of the high voltage circuit breaker feeding their device, for isolation purpose only. It also provides information on the health of the main systems, including the 11 kV and communications networks. All data is logged and archived to recognised standards.

3.4 LICENSING AND PERMITS

EMEC applies for the necessary licenses to deploy on behalf of client developers. To facilitate this EMEC has produced a set of EIA Guidelines for developers to follow. The purpose of these guidelines is to encourage and assist developers to consider, as fully as possible, the range and scale of impacts - positive as well as negative - that might result from the testing of their devices at EMEC. The process requires developers to produce an Environmental Statement (ES) along with a Navigational Risk Assessment (NRA), Decommissioning Plan and a Third-party Verification Report (TPV) [2]. EMEC then uses this documentation to accompany the appropriate license applications.

During the setting up of the EMEC facilities, Environmental Impact Assessments (EIAs) were performed for the wave and tidal sites. In 2002 the EIA for the wave site concluded that the site displayed a typical diversity for its location, with no particular sensitivities [2].The range of environmental issues which need to be addressed will therefore be typical of the industry as a whole.

3.5 REASON FOR TESTING AT THIS SITE/ RELATIONSHIP TO DEVELOPMENT STAGES

As EMEC is a commercial scale site it can be used to develop devices from Stage 4 of the development phase and in particular TRL8, the solo testing of a full scale prototype. It may also be used for Stage 5 TRL9 development phase testing of multi device arrays at an exposed ocean site. According to EMEC the site can be used for TRL stages 7-9: System Validation. With TRL 7-9 system validation consisting of the following

- TRL 7: System prototype demonstration in an operational environment
- TRL 8: Actual system completed and service qualified through test and demonstration
- TRL 9: Actual system proven through successful mission operation

EMEC is the world’s first full scale grid connected test site and as a result has, at this stage, more experience that others in the testing of full scale devices.

3.6 REASON FOR CHOOSING THIS LOCATION

The location around Orkney was chosen because of the proximity of a good wave regime, strong tidal currents, grid connection and sheltered harbour facilities [4]. The good wave energy resource at the site is considered to be representative for wave energy converters off the west coast of Scotland.

3.7 RELATIONSHIP WITH SCALE/NURSERY SITES

EMEC has recently developed Nursery sites for both wave and tidal devices. The Nursery wave site (see section 12.3) is intended to allow developers to trial scale devices, as well as full size prototypes, in less challenging sea conditions than those experienced at the full test site. The nursery site may therefore be used as a precursor to deploying full scale devices at EMEC.

4 WAVEHUB ENGLAND

4.1 INTRODUCTION

The WaveHub test site is a project in Cornwall South-West England, the location of the WaveHub is shown in Figure 2. It is intended to be the UK's first offshore facility for demonstration and proving of the operation of arrays of WEC's.

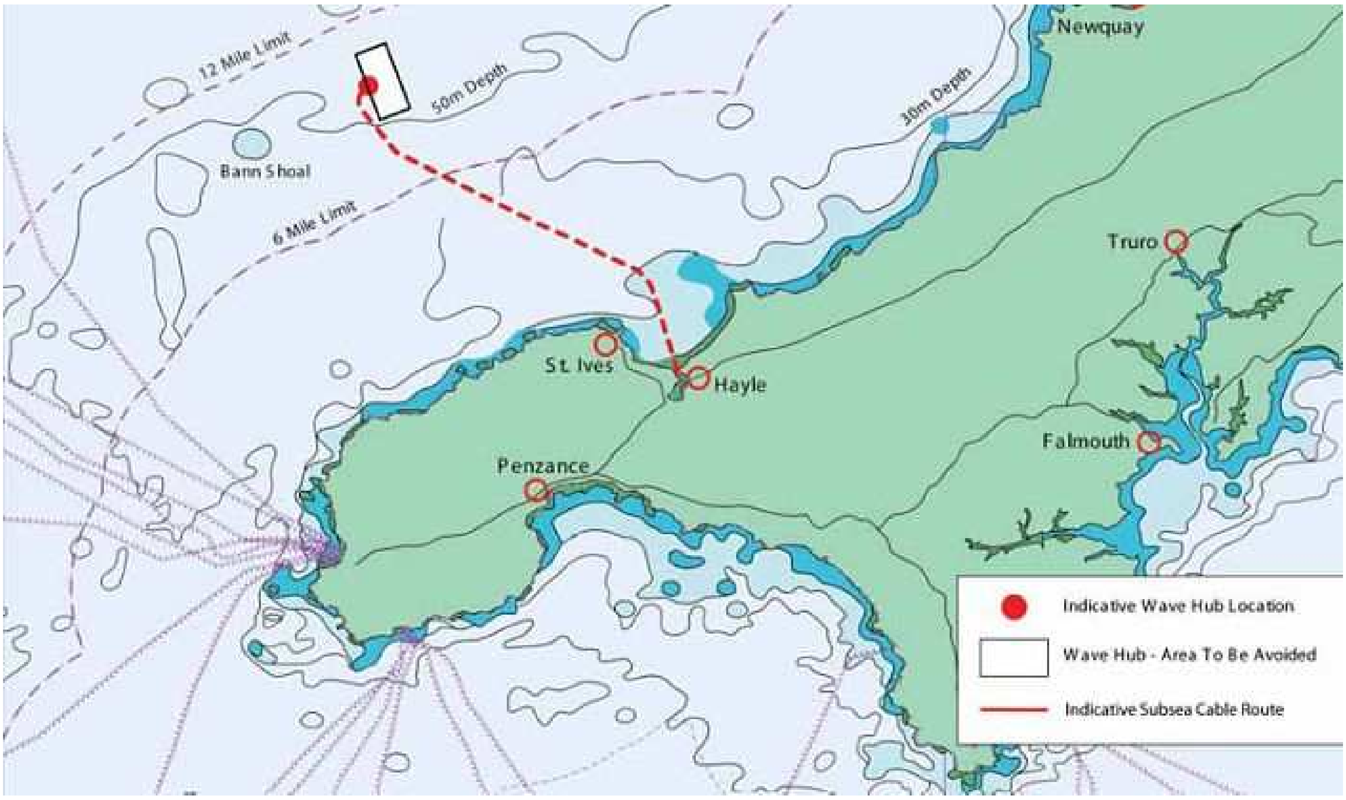


Figure 2 Location of WaveHub site [5]

The test site includes a 12 tonne 'Hub', shown in Figure 3, which was installed in 2010. This 'Hub' will make it possible to test four different technologies with grid connections at the same time with each developer able to lease a 1km x 2 km sea area for testing prototypes for a period of 5 years or more. The site will initially operate at 11kV, but could be upgraded to 33kV with each developer being allowed to generate a maximum of 4-5MW of power (20MW total capacity). This can be upgraded up to 50MW of generating capacity in the future once suitable components for operating the cable at 33kV have been developed [5]. WaveHub will itself collect data on the strength of incoming waves and purchase the electricity from testing developers [1]. A schematic of the WaveHub site is shown in Figure 4.

Figure 3 WaveHub subsea connector prior to deployment [5]

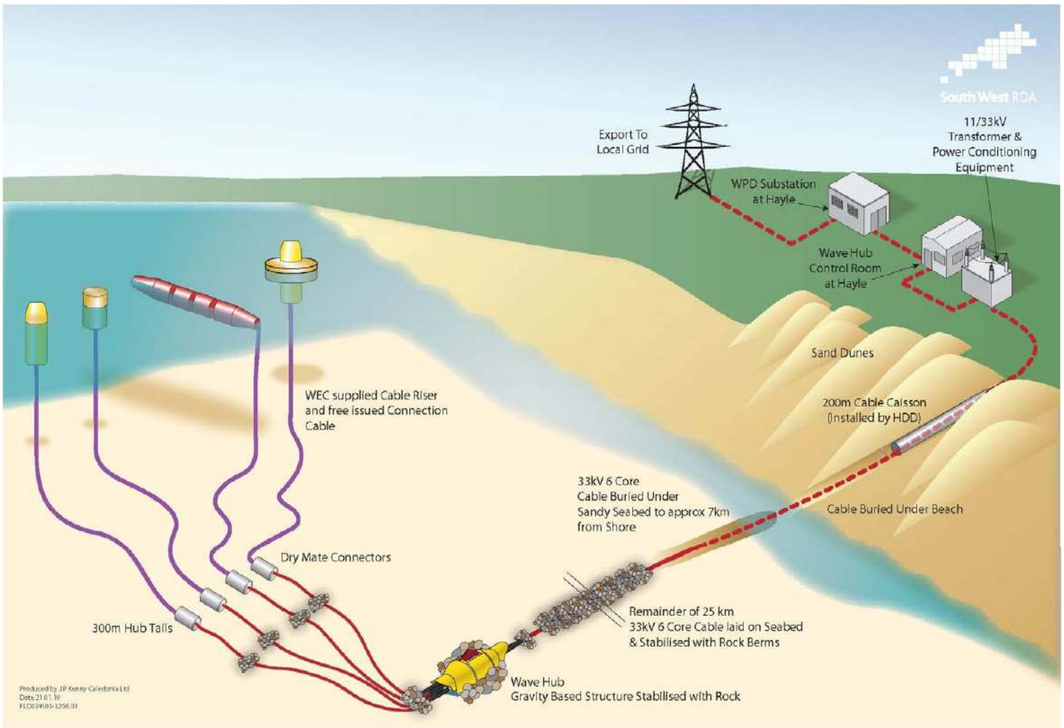


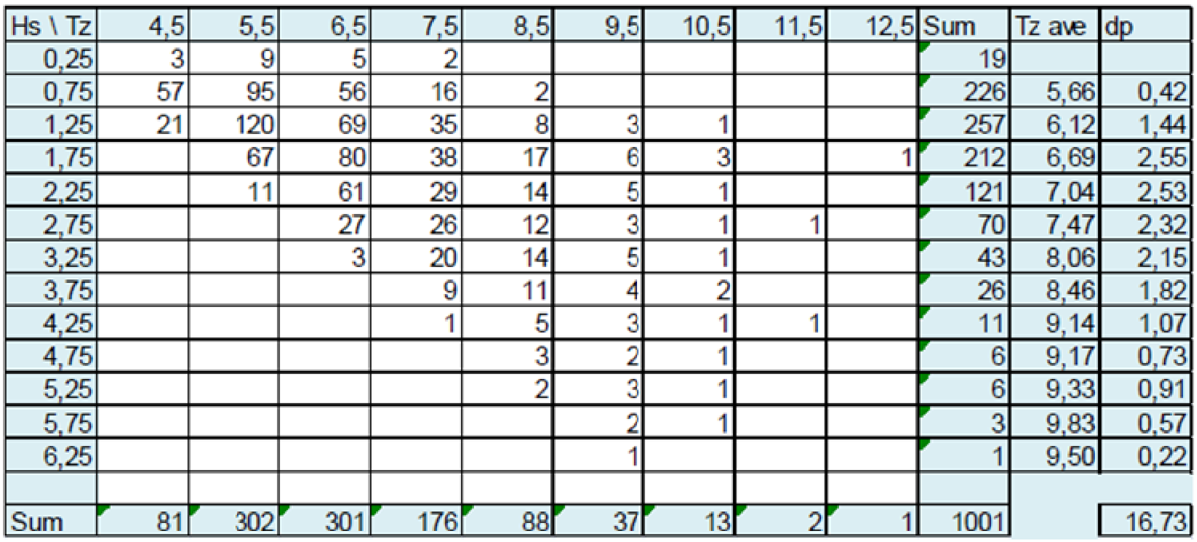
Figure 4 Schematic of WaveHub development [5]

WaveHub was first conceived in 2003 when the South West RDA (Regional Development Agency) considered which emerging renewable energy technologies would present the best opportunities for economic growth in South West England. A good wave climate and the available capacity in the electrical grid near the coast, made the concept of a consented grid connected site for the demonstration of wave energy devices the most attractive proposition as part of a wider UK offer to the marine renewables industry. Scoping and technical feasibility studies of the concept looked at options for site location, engineering considerations, legal and permitting issues as well as the business case for WaveHub. The project received its necessary consents from the UK government in the autumn of 2007 and was deployed in the summer and autumn of 2010. WaveHubs first customer is Ocean Power Technologies (OPT) [5] which intends to deploy an array of up to 5MW of its Powerbuoy technology, phased over several years.

4.2 RESOURCE

The average annual wave energy resource at the WaveHub site is 17 kW/m [1], a scatter diagram is shown in Table 4. A 2006 study by the Halcrow Group estimated the annual average wave energy resource to be between 16.9 to 18.5 kW/m at the WaveHub site[6]. This was based on a combination of modelled wave data and recorded wave data from two nearby locations.

Table 4 Joint probability diagram for Wave Hub all directions all year (2005-2006)[1]



Hs \ Tz	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	Sum	Tz ave	dp
0,25	3	9	5	2						19		
0,75	57	95	56	16	2					226	5,66	0,42
1,25	21	120	69	35	8	3	1			257	6,12	1,44
1,75		67	80	38	17	6	3		1	212	6,69	2,55
2,25		11	61	29	14	5	1			121	7,04	2,53
2,75			27	26	12	3	1	1		70	7,47	2,32
3,25			3	20	14	5	1			43	8,06	2,15
3,75				9	11	4	2			26	8,46	1,82
4,25				1	5	3	1	1		11	9,14	1,07
4,75					3	2	1			6	9,17	0,73
5,25					2	3	1			6	9,33	0,91
5,75						2	1			3	9,83	0,57
6,25						1				1	9,50	0,22
Sum	81	302	301	176	88	37	13	2	1	1001		16,73

4.3 MAIN SITE CHARACTERISTICS

The summary statistics for the WaveHub site are shown in Table 5, with a description of the sites infrastructure given in Table 6.

Table 5 Summary Statistics of the Wave Hub site [1]

Wave Hub	59.36N	5.67W
Design significant wave height Hs	14.4	[m]
Design peak period Tz	14.1	[sec]
Max wind speed	33.2	[m/s]
Max current speed	3.8	[m/s]
Max high water level	4	[m]
Min low water level	-4	[m]
Maximum ice thickness	—	[m]
Wave power annual average	17	[kW/m]

Table 6 Wave Hub Site Infrastructure and Services

Wave Hub	
Scale	Prototype Scale
Water Depth	50m
Distance to Shore	16km
Site Area	2km x 4km
Berths	Up to four connected at one time (4-5MW each)
Grid Connection	Wave Hub is connected to shore via an armoured subsea cable which consists of twin 300mm^2 33kV power triads and fibre optic cables. The cable is terminated onto two isolated busbars within the hub chamber on the seabed and each busbar will service two berthing areas via four 300m 'tails', one for each berth, made up of three core 120mm^2 33 kV cable, operating at 11kV. Each customer will connect to the WaveHub by means of an umbilical that will run from the lead device of each array to an 11kV dry-mate connector on one of the WaveHub tails. One half of the connector is fitted to the cable tail and the other half will be issued to the WaveHub customer. The connectors provide both electrical and fibre optic connection. Grid connection is via the Western Power Distribution substation at Hayle. The WaveHub system will operate initially at 11kV, capable of delivering 16-20MW of power. However once the industry has developed subsea components for 33kV operation the system can be run at 33kV, allowing WaveHub to accommodate up to 50MW of devices.
Wave Data Collection	Wave Data collected since 2005 [7]
Weather Data Collection	—
Other Data Collection	Nortek Acoustic Wave and Current (AWAC) instrument deployed since 2008[7]. AWAC measures directional waves, directional current profile and water levels.
Substation/ Onshore Monitoring	Onshore control room at Hayle. WaveHub's subsea cable connects to a new electricity substation at Hayle on the north coast of Cornwall via a pair of 400mm^2 33kV onshore cables on the beach. The substation comprises an 11kV/33kV transformer with associated switchgear and power factor correction equipment to ensure delivery to the grid within specification. Control and monitoring of wave energy devices is performed remotely via fibre optic cables within the main cable. Power metering is performed at the lead device on each array and at the substation exit breaker.

4.4 LICENSING AND PERMITS

WaveHub has the necessary consents and permits for up to 20MW of wave energy generation and holds a 25-year lease of 8 sq kms of seabed from The Crown Estate. WaveHub will grant an underlease to customers for a term to be agreed. A berthing agreement will set down the respective responsibilities of WaveHub and its customers. Key points from the berthing agreement will include:

- WaveHub will insure the WaveHub system
- WaveHub will enter into a Power Purchase Agreement to sell the electricity from the project into the UK trading system and will pay the proceeds to customers in proportion to their generation
- WaveHub will provide validated data on the prevailing wave resource
- WaveHub will co-ordinate collection of data to meet environmental monitoring obligations
- Customers will be responsible for insurance of devices, moorings and connecting cables, including third party liability
- Customers will be responsible for decommissioning of their devices and associated equipment [5]

WaveHub also has a licence for the installation of the ‘Hub’, its subsea cable and the stabilization and protection of the cable by rock dumping. Customers coming to WaveHub need to apply for their own FEPA (Food and Environment Protection Act) licences. WaveHub say they will advise and support these applications which will be able to draw on the existing environmental and other baseline data [5].

A continuous environmental monitoring programme will be managed by WaveHub in partnership with its customers.UK legislation allows for areas of sea surrounding obstructions to be closed to navigation up to a maximum radius of 500 metres. WaveHub has been granted a safety zone of this size around the hub unit [5].Customers may need to apply for separate safety zones around their devices, which WaveHub say they can assist with.

4.5 REASON FOR CHOOSING THIS LOCATION

The Cornwall location of the WaveHub was chosen as it has a long coastline facing the Atlantic, a good resource of between 20-40kW/m, without extreme winter storms. The South-West of England also has strong 400kV and 132kV electricity networks near the coast. There is also existing relevant technical expertise in the region and the combined expertise of two universities in Cornwall. The WaveHub project also has the backing of the south west of England regional development agency and other public bodies.

A 2008 study by Garrad Hassan [8], found that the availability of ports for assembly, deployment and O&M activities should not be a barrier to developments in the South-West as a wide range of appropriate facilities are available. The study also found that due to anticipated generation facilities coming on-line up to 2014, the gird in the southwest of England should be capable of accommodating somewhere in the region of 250MW of new generation. Therefore in the short term the available capacity that exists within the distribution and transmission network should allow a number of small (<20MW) projects and possibly a few larger (<50MW) projects.

The study found that the nearby area is subject to significant levels of maritime traffic, commercial fishing and military exercise activity. The coast adjacent to the offshore study area is of importance both ecologically and also as an area of significant leisure activity. It concluded however, that none of these factors have been found to preclude the development of wave energy projects within the offshore study area although any proposed development will be subject to significant scrutiny and the impact of the first developments will have a direct bearing on whether future developments obtain consent.

4.6 ADDITIONAL INFORMATION

In March 2011 the Falmouth Harbour Commissioners submitted a license application for a nursery wave energy test site in Falmouth harbour. Known as ‘FabTest’, it would allow developers to undertake tests to investigate structural integrity, response behaviour, mooring/umbilical behaviour, subsea components, monitoring systems and deployment procedures in moderate sea conditions before deploying their devices in more energetic offshore seas at WaveHub[5]. WaveHub are a partner in the project.

5 BIMEP SPAIN

5.1 INTRODUCTION

The Biscay Marine Energy Platform (BIMEP) test site is located off the coast of the village of Armintza, in the municipal area of Lemoiz, some 30 kilometres north of Bilbao in the Basque Country, Spain. The location of the site in relation to Bilbao and Bilbao harbour is shown in Figure 5. A wave energy test site was desired in the Basque country in order to provide infrastructure for research, demonstration and operation of offshore Wave Energy Converters which would place the Basque country at the forefront of marine energy and create a technological and industrial cluster around the industry. The site is due to be operational in the second half of 2011. The sites proximity to the nearest harbour and other onshore infrastructure is as follows:

- Distance to large town: 30 km
- Distance to nearest airport: 24 km
- Distance from nearest service port to site: 18km
- Distance from nearest access harbour to site: small harbour at 2km, larger ones at 11km and 18km.
- Distance from site to shore: nearest point: 1km
- Distance from closest test berth to shore: 2km [1].

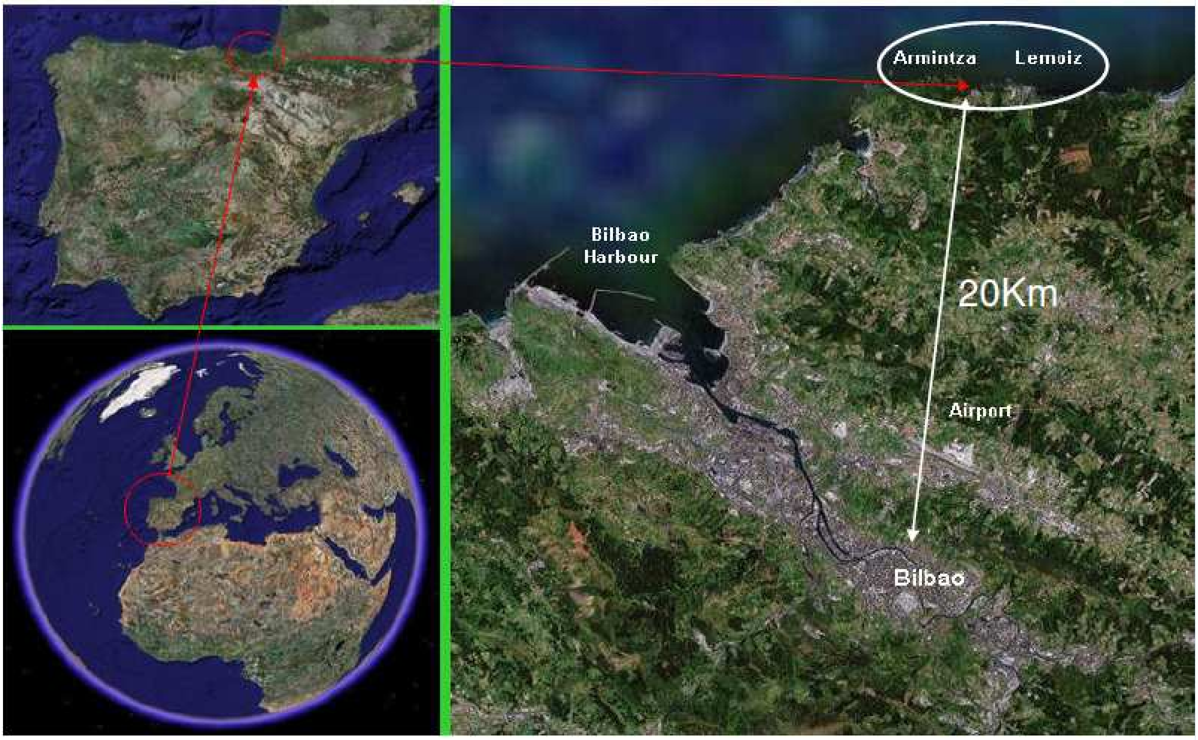
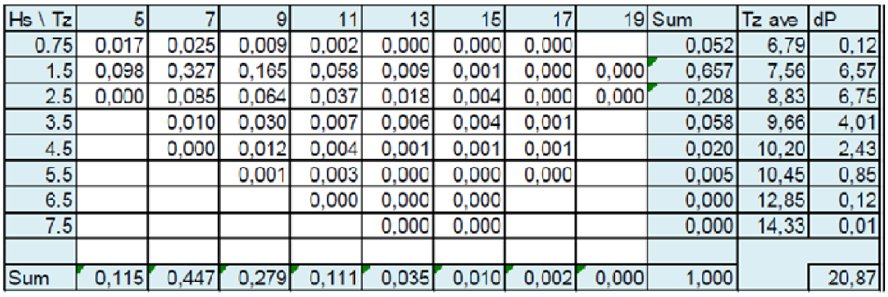


Figure 5 Location of BIMEP test site [9]

5.2 RESOURCE

The average annual wave resource at BIMEP is 21kW/m [1] with a scatter diagram shown in Table 7. However Zarraga and Amezaga state a higher wave energy resource for the site at 24kW/m[10].

Table 7 Joint probability diagram (all year, all directions) for the BIMEP site [1]



Hs \ Tz	5	7	9	11	13	15	17	19	Sum	Tz ave	dP
0.75	0,017	0,025	0,009	0,002	0,000	0,000	0,000		0,052	6,79	0,12
1.5	0,098	0,327	0,165	0,058	0,009	0,001	0,000	0,000	0,657	7,56	6,57
2.5	0,000	0,085	0,064	0,037	0,018	0,004	0,000	0,000	0,208	8,83	6,75
3.5		0,010	0,030	0,007	0,006	0,004	0,001		0,058	9,66	4,01
4.5		0,000	0,012	0,004	0,001	0,001	0,001		0,020	10,20	2,43
5.5			0,001	0,003	0,000	0,000	0,000		0,005	10,45	0,85
6.5				0,000	0,000	0,000			0,000	12,85	0,12
7.5					0,000	0,000			0,000	14,33	0,01
Sum	0,115	0,447	0,279	0,111	0,035	0,010	0,002	0,000	1,000		20,87

5.3 *MAIN SITE CHARACTERISTICS*

The summary statistics for the proposed BIMEP wave energy test site are shown in Table 8 with a description of the sites infrastructure given in Table 9. A schematic of this infrastructure is shown in Figure 6.

Table 8 Summary Statistics of the BIMEP [1]

BIMEP	43° 28’N	2° 51’W
Design significant wave height Hs	11.54	[m]
Design peak period Tp	15.4	[sec]
Max wind speed	47	[m/s]
Max current speed	1.4	[m/s]
Max high water level	5.37	[m]
Min low water level	-0.49	[m]
Maximum ice thickness	-	[m]
Wave power annual average	21	[kW/m]

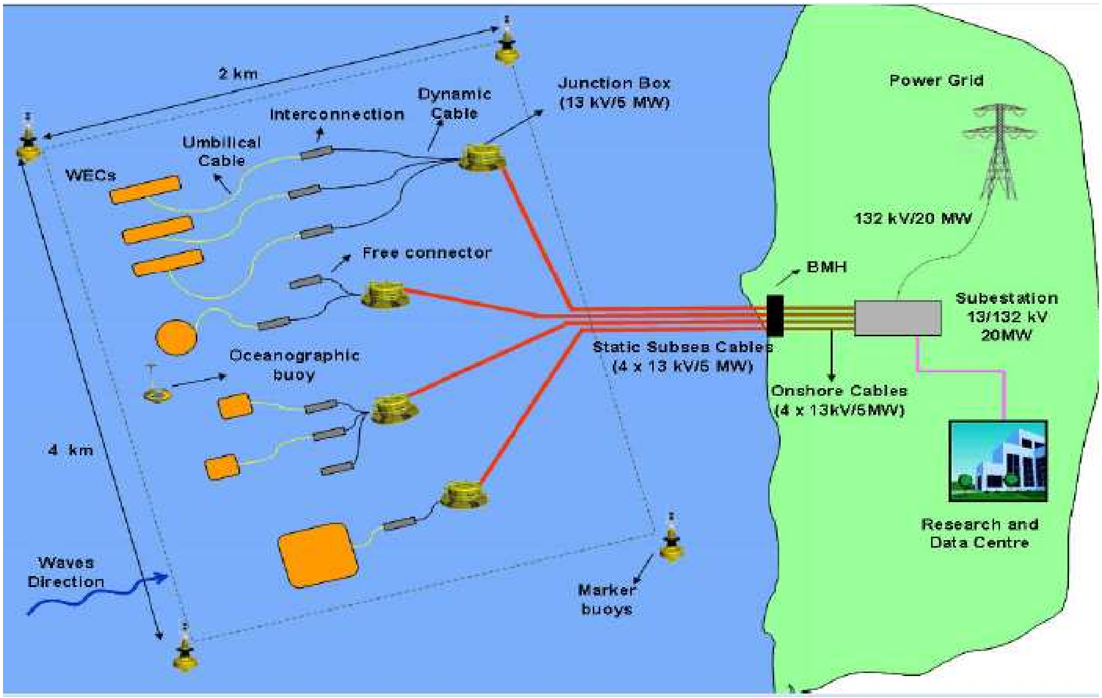


Figure 6 Schematic of BIMEP test site [9]

Table 9 BIMEP Infrastructure and Services

BIMEP	
Scale	Full Scale Prototype
Water Depth	50-90m. The seabed material consists of sedimentary material filling an old river bed, composed of gravelly sand to sandy gravel grain size sediment, in between rocky outcrops.
Distance to Shore	750m Offshore
Site Area	4km x 2km
Berths	Four 5MW submarine cables link to the onshore substation with four connectors. Possible for different devices to be connected.
Grid Connection	The WECs can be connected to the grid by means of 4 berths of offshore power connection points, one for each of the 4 export power cables. Each connection point consists of a 13.2 kV and a 5 MW submarine junction box, allowing several WECs to be connected to a single power cable. The berths are designed for easy connection /disconnection of WECs. The four 13kV/5MW underwater power cables are around 3-5km in length and are deployed from the onshore substation to each of the four junction boxes. The cable consists of three copper power cores and several fibre optic lines for communications.
Wave Data Collection	A directional wave buoy (WaveScan from FUGRO:Oceanor) has been deployed at the site. It can transmit real time data and store Spectral data which can be obtained from the measurements of the buoy.
Weather Data Collection	An Oceanographic Buoy is located in the middle of the site. This scientific buoy contains multiple sensors measuring a wide range of meteorological and oceanographic parameters (weather data, wave height, period direction, current speeds etc). The buoy transmits this data in real time to the research and data centre. It has been installed since February 2009 [9].
Other Data Collection	—
Substation/ Onshore Monitoring	The following is the onshore infrastructure at BIMEP • Onshore substation containing the electrical protection devices and the measurement and communications systems of the four power cables. It has a 13/30kV 20MW transformer to feed the power generated by the WECs to the local 30kV grid. • A research centre provides developers with all the facilities to support test activities and also house scientific activities related to wave energy such as environmental monitoring, site wave potential modelling and equipment optimization

5.4 LICENSING AND PERMITS

The licensing process for the site is underway as the application for permits covering the environmental, electrical and maritime usage of the site have been submitted to the relevant Spanish authorities.

5.5 REASON FOR CHOOSING THIS LOCATION

The location for the BIMEP site was chosen as it is one of the areas on the Basque coast with the highest wave resource (21kW/m). It is very close to Bilbao harbour (18km) and the city of Bilbao (30km) as well as the village of Armintza-Lemoiz which is the subsea landing point. This town provides good road access and a nearby coastal utility grid with 132kV 20MW capacity. According to BIMEP the offshore site does not conflict with any environmentally protected areas and the site is close to an open sea location which would allow for a future expansion of the infrastructure [9].

6 SEM-REV FRANCE

6.1 INTRODUCTION

The proposed SEM-REV (Site d' Experimentation en Mer pour la Recuperation de l'Energie des Vagues) offshore test site is being developed jointly by the Ecole Centrale Nantes (ECN), the French National Centre for Scientific Research (CNRS), the Pays de la Loire Region and the French State. The SEM-REV test site consists of an offshore zone including oceanographic monitoring instruments, sub-sea equipment and a high voltage cable linked ashore. SEM-REV has been in development since 2007 and plans to be fully operational in summer 2011. It is located off the west coast of France in the Pays de la Loire region 100km from the city of Nantes and approximately 15km from the town of Le Croisic, as shown in Figure 7.

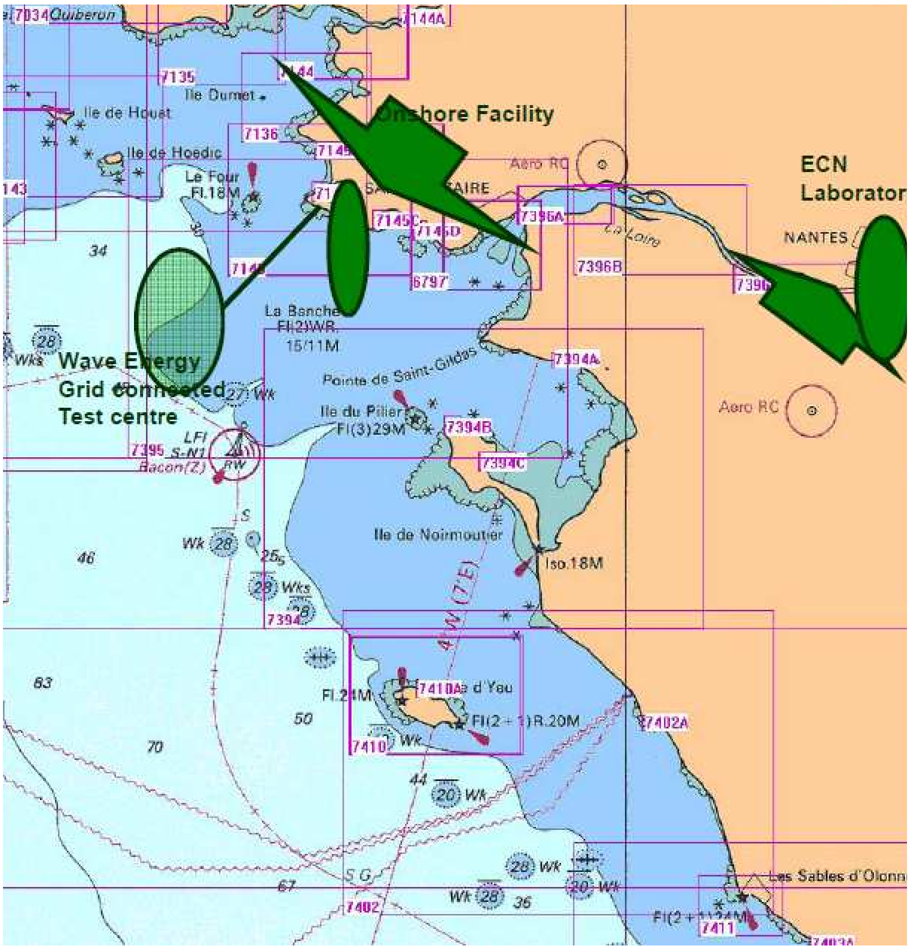


Figure 7 Location of the SEM-REV test site [11]

6.2 RESOURCE

The wave energy resource at the site was estimated by Mouslim [12] to be 14.4 kW/m. This was based on a hindcast covering 23 years with a time step of 3 hours. The sea state occurrences at the SEM-REV based on this 23 year hindcast is shown in Figure 8.

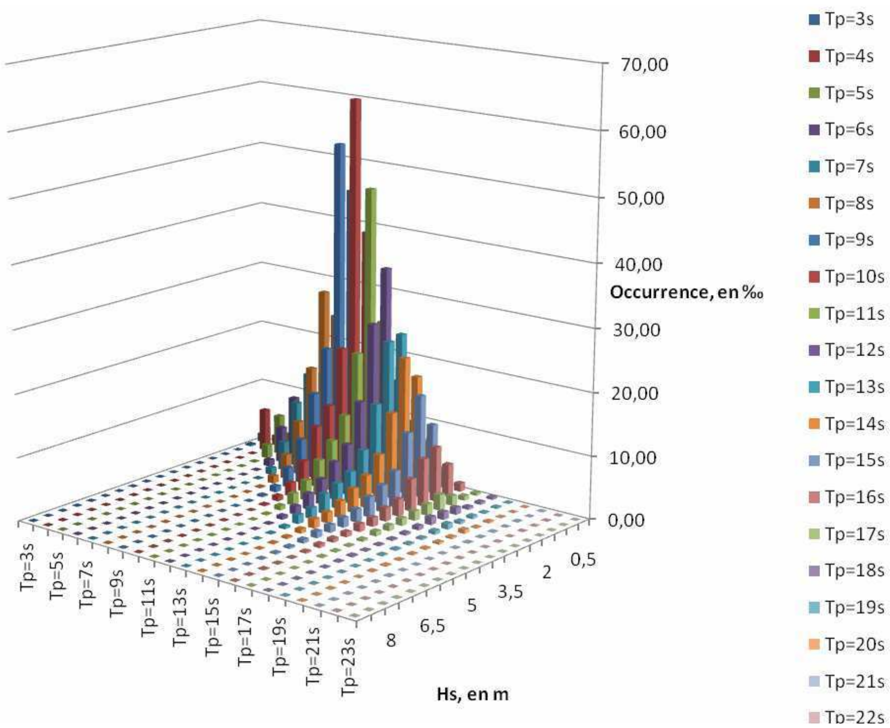


Figure 8 SEM-REV sea state occurrences [12]

6.3 *MAIN SITE CHARACTERISTICS*

A description of the infrastructure that is proposed at the SEM-REV site is given in Table 10

Table 10 SEM-REV Infrastructure and Services

SEM-REV	
Scale	Full-Scale Prototype
Water Depth	35m
Distance to Shore	15km Offshore
Site Area	1km x 1km
Berths	Three
Grid Connection	20kV connection
Wave Data Collection	2 directional waverider buoys will be used to measure the wave fields(Figure 9)
Weather Data Collection	An offshore weather and HF transmission buoy will measure the metocean conditions (Figure 9)
Other Data Collection	A matrix of current profilers will measure the currents as well as providing reconstruction of the wave data (Figure 9)
Substation/ Onshore Monitoring	The SEM-REV substation will assess the WEC power production. The power quality will also be assessed at the same point. Sea state measurements will be related to the real time monitoring of the power quality and the energy flux

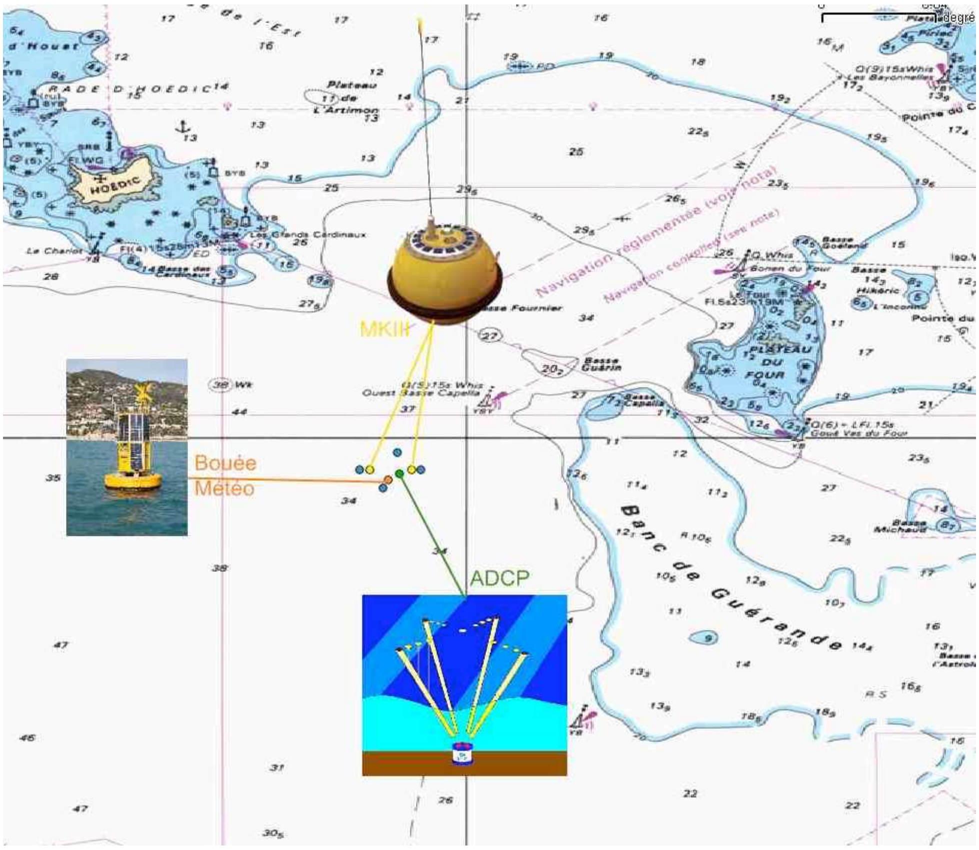


Figure 9 Location of Oceanographic sensors at SEM-REV [13]

6.4 LICENSING AND PERMITS

It is proposed that the SEM-REV permitting process will allow for a consented zone with pre-arranged permits which will enable developers to deploy easily at the site once they meet the sites requirements.

6.5 REASON FOR CHOOSING THIS LOCATION

The proposed SEM-REV site is close to Ecole Centrale de Nantes (ECN) where wave energy technology research and development has been carried out for more than ten years[14]. It is also close to heavy marine engineering infrastructure and suitable port for deployment and O&M, at St Nazaire.

7 BELMULLET IRELAND

7.1 INTRODUCTION

The Sustainable Energy Authority of Ireland (SEAI) plan to develop a National Wave Energy Test site located off the Annagh Head west of Belmullet. This site will provide grid connected moorings for wave energy devices for testing in the open ocean. It is proposed to operate the site for 20 years with devices onsite intermittently throughout the year. The location of the site together with a schematic of the infrastructure is shown in Figure 10.

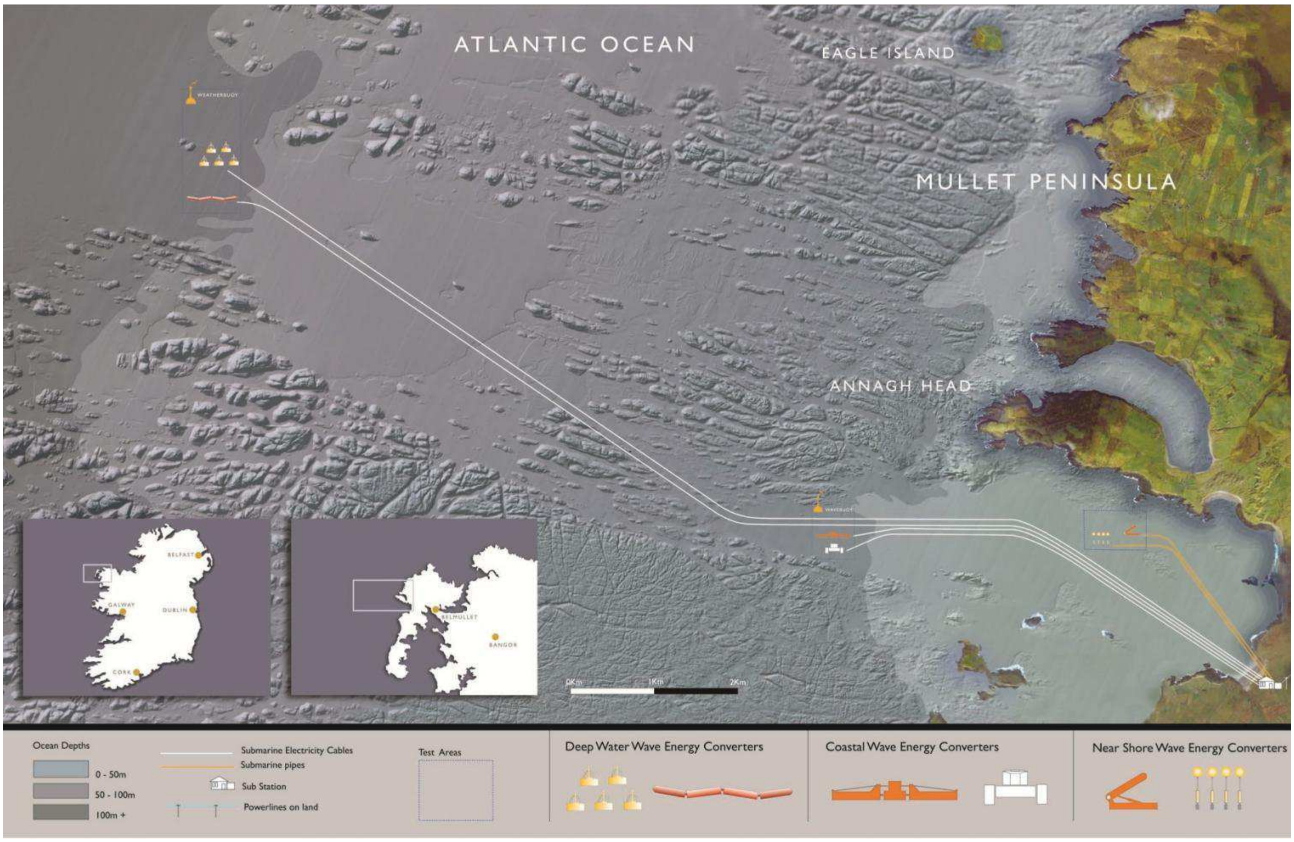


Figure 10 Location and schematic of Belmullet test site [15]

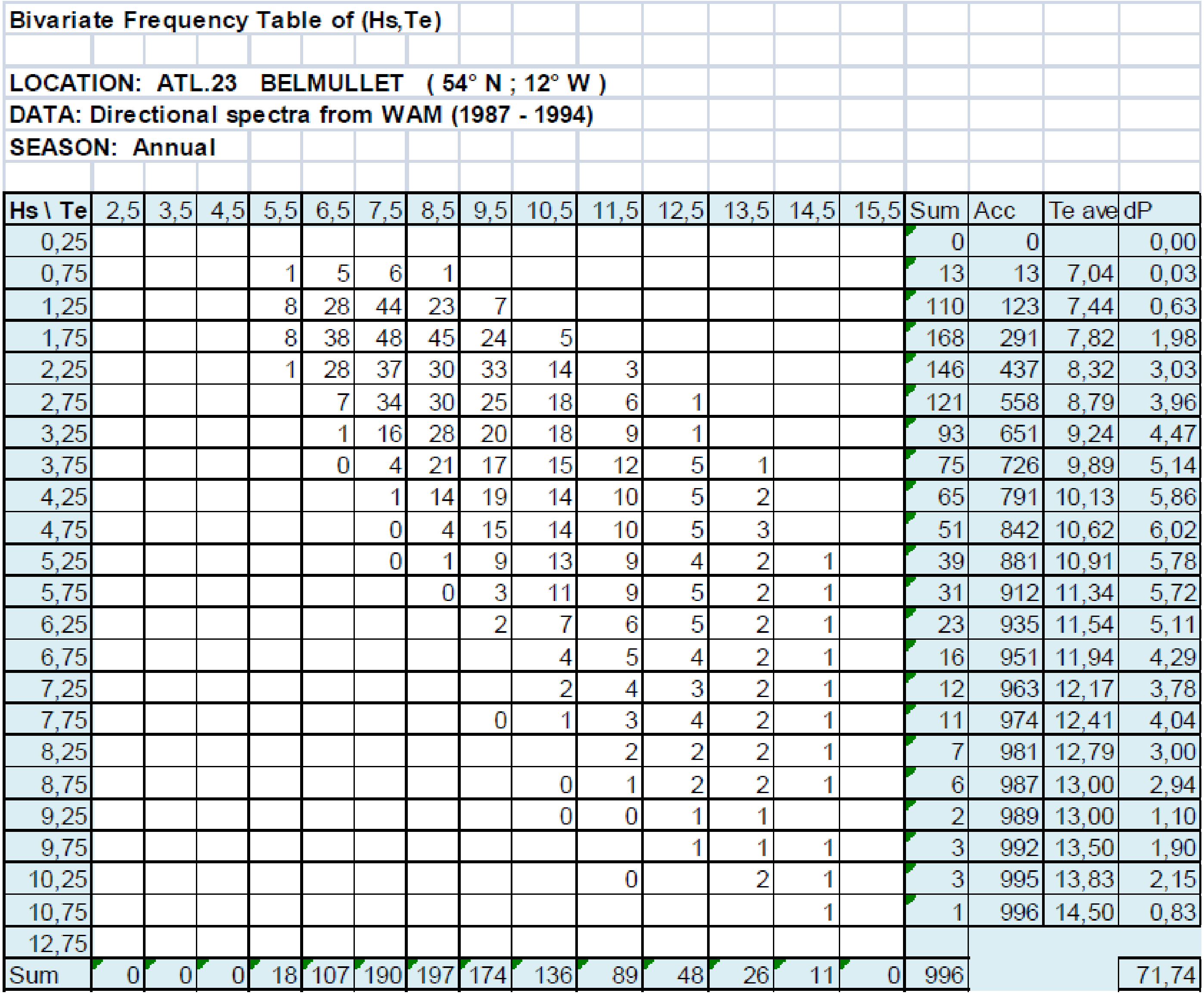
It is envisaged that the site will be operational in 2012 based on the following development schedule:

- July 2011: Decision on granting of Foreshore Lease and Planning Permission
- Summer 2012: Installation of sea bed cables and pipelines
- September 2012: Completion of construction of substation and turbine house
- October 2012: Test site ready for first full scale wave energy converters

Frenchport on the Annagh Peninsula has been identified as a possible location for launching and landing facilities for boat services to the test site and the construction of a slipway adjacent to the existing pier is being considered. It is also thought that Killybegs harbour in Donegal will act as a support base for activities requiring larger vessels.

7.2 RESOURCE

A scatter diagram for the area off the Belmullet coast is shown in Figure 11. It gives the average annual wave energy resource in this area as 72kW/m based on WAM model data from 1987-1994. A more recent study by Numerics Warehouse for the SEAI[16] based on 15 years of modelled weather and wave data assessed the wave climate specifically at the SEAI test site. It found average annual wave energy resource at the deep water (100m) location to be 70-75kW/m and at the mid-water location (50m depth) to be 55-60kW/m.



Bivariate Frequency Table of (Hs,Te)

LOCATION: ATL.23 BELMULLET (54° N ; 12° W)
DATA: Directional spectra from WAM (1987 - 1994)
SEASON: Annual

Hs \ Te	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	13,5	14,5	15,5	Sum	Acc	Te ave	dP
0,25															0	0		0,00
0,75				1	5	6	1								13	13	7,04	0,03
1,25				8	28	44	23	7							110	123	7,44	0,63
1,75				8	38	48	45	24	5						168	291	7,82	1,98
2,25				1	28	37	30	33	14	3					146	437	8,32	3,03
2,75					7	34	30	25	18	6	1				121	558	8,79	3,96
3,25					1	16	28	20	18	9	1				93	651	9,24	4,47
3,75					0	4	21	17	15	12	5	1			75	726	9,89	5,14
4,25						1	14	19	14	10	5	2			65	791	10,13	5,86
4,75						0	4	15	14	10	5	3			51	842	10,62	6,02
5,25						0	1	9	13	9	4	2	1		39	881	10,91	5,78
5,75							0	3	11	9	5	2	1		31	912	11,34	5,72
6,25								2	7	6	5	2	1		23	935	11,54	5,11
6,75									4	5	4	2	1		16	951	11,94	4,29
7,25									2	4	3	2	1		12	963	12,17	3,78
7,75								0	1	3	4	2	1		11	974	12,41	4,04
8,25										2	2	2	1		7	981	12,79	3,00
8,75									0	1	2	2	1		6	987	13,00	2,94
9,25									0	0	1	1			2	989	13,00	1,10
9,75											1	1	1		3	992	13,50	1,90
10,25										0		2	1		3	995	13,83	2,15
10,75													1		1	996	14,50	0,83
12,75																		
Sum	0	0	0	18	107	190	197	174	136	89	48	26	11	0	996			71,74

Figure 11 Plot of the average energy period Te ave as a function of the significant wave height Hs [1].

7.3 MAIN SITE CHARACTERISTICS

A description of the proposed infrastructure at the Belmullet site is given in Table 11.

Table 11 Belmullet Infrastructure and Services

BELMULLET	
Scale	Full Scale
Water Depth	20-100m
Distance to Shore	Up to 7km offshore
Site Area	21km^2
Berths	Three separate locations 1) Nearshore (10-25m water depth). Is not connected with an electric cable as nearshore developers may use water pipes to pump pressurised water to an onshore converter station, where electricity is generated e.g. Oyster. 2) Mid water (50m water depth), 2 subsea cables 3) Deep water (100m water depth), 2 subsea cables
Grid Connection	Total of 5MW (onshore grid constrained). Deep and mid-water sites will be grid connected to the onshore substation. It is proposed that four submarine electricity cables will be installed to a minimum of 1 metre below the seabed and will come ashore at Belderra beach. A small portion of the route near the 50 meter depth zone (about 2 miles out from Annagh Head) has a stony seabed and here the cables will be laid on top of the rock and protected using a rock berm or mattressing.
Wave Data Collection	There are two SEAI wave monitoring buoys already installed at the mid-water (2) and deep-water (3) areas off Annagh Head which are collecting data about wave conditions, weather and tidal currents. Data will shortly become available to the public[17].
Weather Data Collection	Proposed for weather buoy to be location close to deep water location (3)
Other Data Collection	An ADCP current profiler is proposed to be located at the deep water location (3)
Substation/ Onshore Monitoring	A turbine house located close to the near shore location (1) with water pipe connection. Devices under test at the near shore site will send compressed water via pipelines along the seabed to a turbine house which will be constructed on Annagh peninsula. Here, the pressurised water will be utilised to drive the turbine. The turbine is connected to an electrical generator which generates electricity and sends it to a small substation at Annagh Head and onto the electricity grid at Belmullet. An electricity substation will be located inland of the beach at Belderra. The electricity cables from offshore will continue underground to the substation. A dedicated overhead power line on wooden poles will transmit electricity from the substation to the electricity grid at Belmullet. An electricity meter will be included on each cable from the deep water test areas for monitoring purposes [18].

7.4 REASON FOR TESTING AT THIS SITE/ RELATIONSHIP TO DEVELOPMENT STAGES

By the time the site is proposed to be complete there will be a number of test sites available around the world. Each site will not only serve a specific application, but also a geographical area. Ireland currently has model scale testing facilities at the Hydraulics and Maritime Research Centre (HMRC) wave tank in Cork and a ¼ scale testing facility in Galway bay (see section 12.2). The Wave Energy Test Site in Belmullet is designed for testing of full scale, pre-commercial wave energy converters and is specifically intended to be the site used for the final testing of devices before they are considered fully commercial [15].

7.5 REASON FOR CHOOSING THIS LOCATION

Seven sites along the west coast of Ireland were initially identified as potential wave energy test sites. The Marine Institute and ESBI undertook an independent assessment of these locations to select the most suitable site. The consortium assessed approximately 40 marine side and 30 land side parameters. Belmullet was identified as the most suitable location based on the wave climate, water depths, proximity to good port facilities in Killybegs and reasonable cost of connection to local network[17]. The seabed geology was another critical deciding factor for the cable route.

8 PILOT ZONE PORTUGAL

8.1 INTRODUCTION

The Portuguese Pilot Zone was conceived in 2007 as a dedicated area to provide for testing of wave energy systems in Portugal. It is intended for demonstration, pre-commercial and commercial deployment, with a maximum grid integration of 250 MW [1]. The rated capacity of 250MW is made up of two parts. The first pre-commercial 80MW is to be integrated into the local distribution grid with the full commercial 250MW integrated into the transmission grid[14]. The Pilot Zone is located off the west coast of Portugal about 130 km north of Lisbon, near the village of S. Pedro de Muel shown in Figure 12.

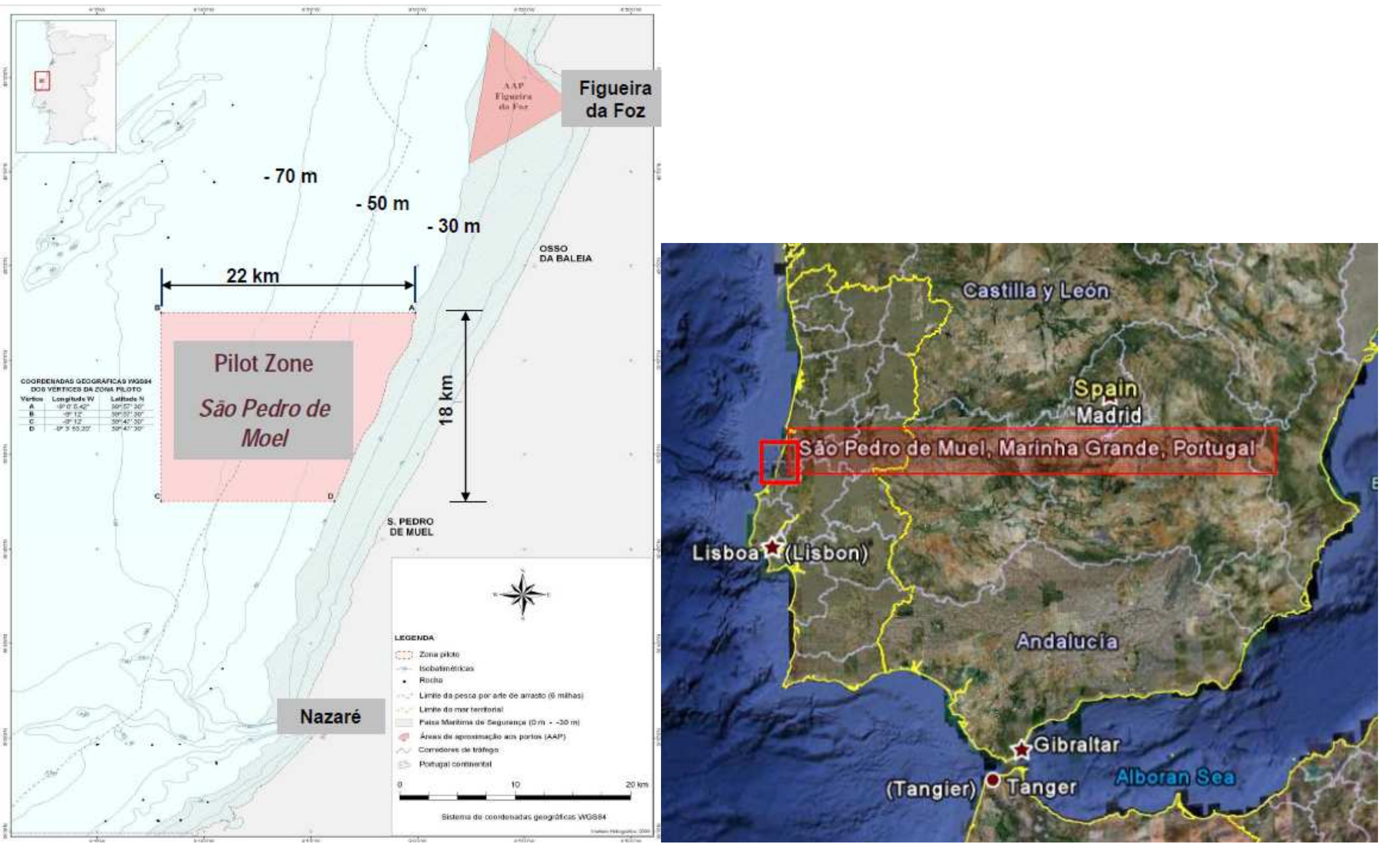


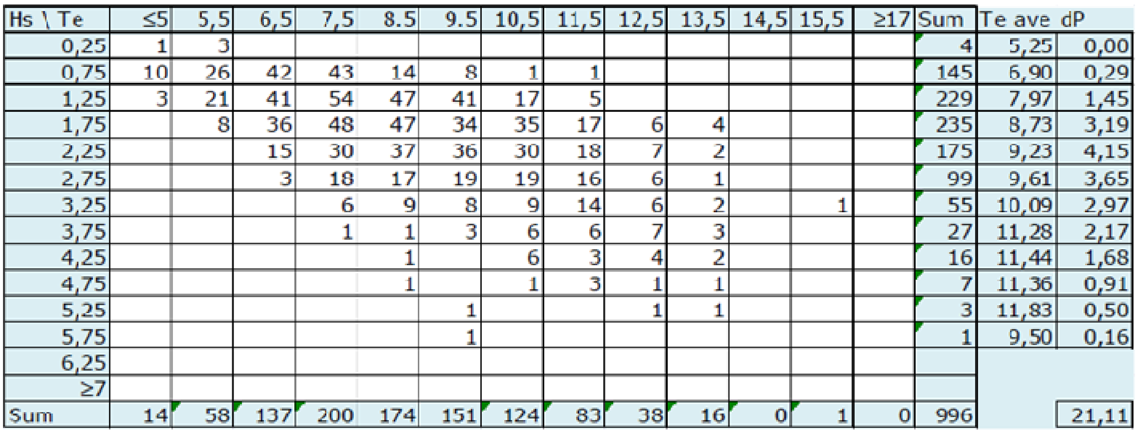
Figure 12 Location of Portuguese Pilot Zone[19]

8.2 RESOURCE

The scatter diagram in for the site (Table 12) is based on buoy data 2004 – 2005 at a 50m water depth taken from an IEA-OES Annex II report[1] . The report calculated the annual power as 23.3kW/m by using the full expression for group velocity taking the water depth into account. This value was then corrected to the 11-year period (1989 – 1999) resulting in a resource of 25 kW/m [1].

The Scatter diagram in Table 12, uses the deepwater approximation for wave power calculation and one year data resulting in the annual wave power average being 21.1 kW/m [1]. The linear relationship between significant wave height (Hs) and average energy period (Te) is shown in Figure 13.

Table 12 Joint probability diagram from the Pilot Zone Portugal [1]



Hs \ Te	≤5	5,5	6,5	7,5	8.5	9.5	10,5	11,5	12,5	13,5	14,5	15,5	≥17	Sum	Te ave	dP
0,25	1	3												4	5,25	0,00
0,75	10	26	42	43	14	8	1	1						145	6,90	0,29
1,25	3	21	41	54	47	41	17	5						229	7,97	1,45
1,75		8	36	48	47	34	35	17	6	4				235	8,73	3,19
2,25			15	30	37	36	30	18	7	2				175	9,23	4,15
2,75			3	18	17	19	19	16	6	1				99	9,61	3,65
3,25				6	9	8	9	14	6	2		1		55	10,09	2,97
3,75				1	1	3	6	6	7	3				27	11,28	2,17
4,25					1		6	3	4	2				16	11,44	1,68
4,75					1		1	3	1	1				7	11,36	0,91
5,25						1			1	1				3	11,83	0,50
5,75						1								1	9,50	0,16
6,25																
≥7																
Sum	14	58	137	200	174	151	124	83	38	16	0	1	0	996		21,11

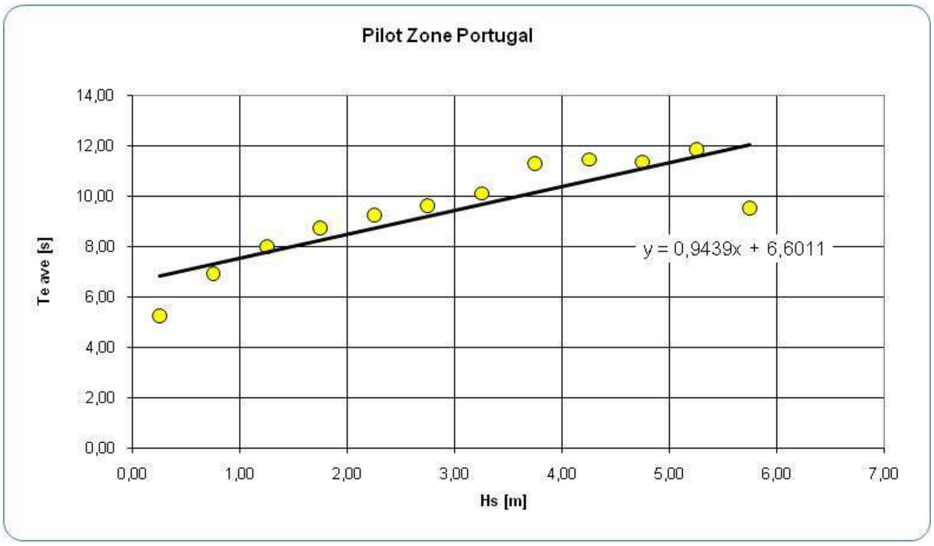


Figure 13 Relationship between Significant Wave Height (Hs) and the Average Energy Period (Te) at Pilot Zone [1]

8.3 MAIN SITE CHARACTERISTICS

The main characteristics of the Pilot Zone site are shown in Table 13 with the infrastructure and services provided shown in Table 14. The Pilot Zone is intended for full scale demonstration at pre-commercial and commercial level it is unclear if certain infrastructure, such as wave data measurement infrastructure and data collection systems, will be provided by the site or if the project developer will have to provide the infrastructure for the testing of the devices.

Table 13 Summary Statistics of the Portuguese Pilot Zone [1]

Pilot Zone Portugal	39° 54’N	9°06’ W
Design significant wave height Hs (At 30m depth)	11	[m]
Design energy period Te (At 30m depth)	19	[sec]
Max wind speed	25	[m/s]
Max current speed	3.4	[m/s]
Max high water level	-	[m]
Min low water level	-	[m]
Maximum ice thickness	-	[m]
Wave power annual average	25	[kW/m]

Table 14 Pilot Zone Site Infrastructure and Services

Pilot Zone Portugal	
Scale	Pre-Commercial/Commercial Scale
Water Depth	The pilot zone was defined between 30 and 90 m water depth. In the area sand is abundant; a geological survey is planned.
Distance to Shore	The distance from the 30 m bathymetric to shore is 4.5 km and the 50m bathymetric is 7 km off the coast.
Site Area	320km^2
Berths	No predefined number. Will depend on number of cables or connection points that the developer installs.
Grid Connection	Includes cable corridors (up to two) and onshore infrastructure. It does not include the subsea cable. Electrical cabling from the devices to the offshore connection point or shore is paid by the project developer [20]. The pre-commercial phase can be connected up to 80MW to the local distribution grid. For the full commercial site connection can be made up to 250MW to the transmission grid.
Wave Data Collection	—
Weather Data Collection	—
Other Data Collection	—
Substation/ Onshore Monitoring	—

8.4 LICENSING AND PERMITS

The pilot zone will be managed by a majority state-owned company specifically set up to manage the Pilot Zone. This company will be a one stop shop for all the required licensing and permits and will also be responsible for building the required infrastructure, monitoring the tests and operating the prototypes and wave farms. An initial feed in tariff of €0.26/kWh for the first five 4MW projects are available in Portugal. There are a range of reducing tariffs as the technology develops and deployments increase, dropping to €0.07/kWh when the capacity exceeds 250MW [21].

8.5 REASON FOR CHOOSING THIS LOCATION

The Portuguese Pilot Zone was envisaged to attract demonstration and industrial development to Portugal and create an industrial cluster associated with wave power. Another aspect in the development of the Pilot zone was the unknown environmental impacts of wave energy devices. Given that initial deployments of WEC would consist of only a few devices, by concentrating the initial deployment activities in a single zone, with a low environmental sensitivity, baseline studies of the impacts can be made. The Pilot zone site was chosen due to this low environmental sensitivity and the general lack of conflicts zones in the vicinity, together with the good wave energy resource.

8.6 ADDITIONAL INFO

As mentioned the site does not include the subsea cable and the cost of connecting the devices to the grid connecting point must be paid by the developer. It is unclear what resource or metocean measuring equipment is installed or is planned to be installed or what onshore monitoring stations there will be. It is also unclear if a device developer will need to provide this equipment and infrastructure.

9 DANWEC HANSTHOLM, DENMARK

9.1 INTRODUCTION

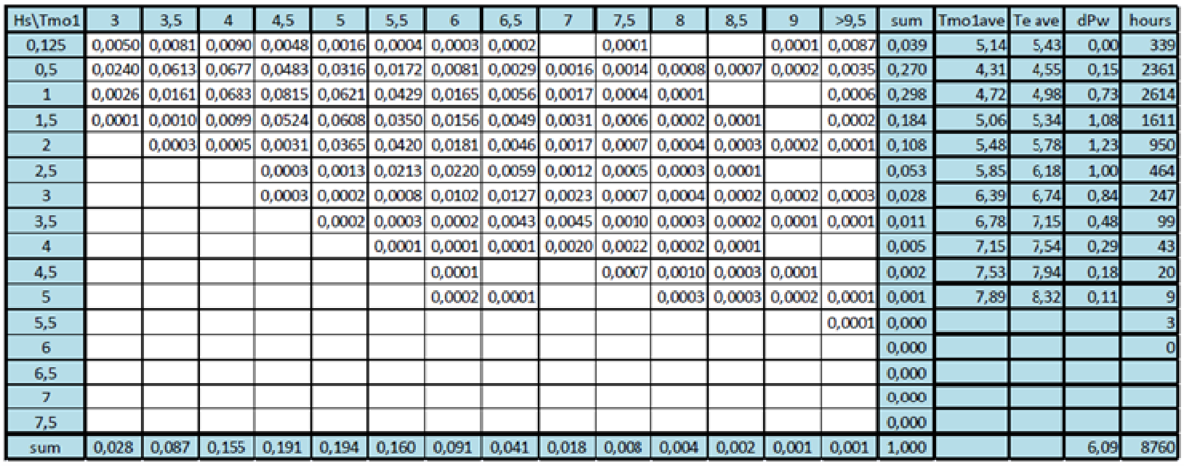
The Danish Wave Energy Centre (DanWec) is a prototype scale test centre that was formed in 2009. DanWec is supported by the Port of Hanstholm, the Port Forum of Hanstholm, the Municipality of Thisted and Aalborg University. It is located in Hanstholm in the North-West part of Denmark on the North Sea with a fetch of about 600km to the west – sheltered by the UK. Hanstholm has a large harbour including fishing industries and ferry traffic to Norway. The distance from the harbour to the test centre is about 2km. The test centre is intended for prototype scale and since 2009 WaveStar Energy has installed 1:2 scale platform including two floats of 5 meter diameter each installed with a generator power of 55 kW. There are also plans for Dexa Waves to test there in the future.

Figure 14 1:2 Scale WaveStar device on test at Hanstholm[22]

9.2 RESOURCE

The IEA-OES Annex II report [1] mentioned a study which analysed measured wave data from Hanstholm, over the period 2005 – 2009, at a water depth of 20 metres. The scatter diagram in Table 15 is based on this data and it shows that average annual wave power at Hanstholm is about 6kW/m. The linear relationship between Hs and Te at Hanstholm is shown in Figure 15.

Table 15 Joint probability diagram Hanstholm [1]



Hs\Tmo1	3	3,5	4	4,5	5	5,5	6	6,5	7	7,5	8	8,5	9	>9,5	sum	Tmo1ave	Te ave	dPw	hours
0,125	0,0050	0,0081	0,0090	0,0048	0,0016	0,0004	0,0003	0,0002		0,0001			0,0001	0,0087	0,039	5,14	5,43	0,00	339
0,5	0,0240	0,0613	0,0677	0,0483	0,0316	0,0172	0,0081	0,0029	0,0016	0,0014	0,0008	0,0007	0,0002	0,0035	0,270	4,31	4,55	0,15	2361
1	0,0026	0,0161	0,0683	0,0815	0,0621	0,0429	0,0165	0,0056	0,0017	0,0004	0,0001			0,0006	0,298	4,72	4,98	0,73	2614
1,5	0,0001	0,0010	0,0099	0,0524	0,0608	0,0350	0,0156	0,0049	0,0031	0,0006	0,0002	0,0001		0,0002	0,184	5,06	5,34	1,08	1611
2		0,0003	0,0005	0,0031	0,0365	0,0420	0,0181	0,0046	0,0017	0,0007	0,0004	0,0003	0,0002	0,0001	0,108	5,48	5,78	1,23	950
2,5				0,0003	0,0013	0,0213	0,0220	0,0059	0,0012	0,0005	0,0003	0,0001			0,053	5,85	6,18	1,00	464
3				0,0003	0,0002	0,0008	0,0102	0,0127	0,0023	0,0007	0,0004	0,0002	0,0002	0,0003	0,028	6,39	6,74	0,84	247
3,5					0,0002	0,0003	0,0002	0,0043	0,0045	0,0010	0,0003	0,0002	0,0001	0,0001	0,011	6,78	7,15	0,48	99
4						0,0001	0,0001	0,0001	0,0020	0,0022	0,0002	0,0001			0,005	7,15	7,54	0,29	43
4,5							0,0001			0,0007	0,0010	0,0003	0,0001		0,002	7,53	7,94	0,18	20
5							0,0002	0,0001			0,0003	0,0003	0,0002	0,0001	0,001	7,89	8,32	0,11	9
5,5														0,0001	0,000				3
6															0,000				0
6,5															0,000				
7															0,000				
7,5															0,000				
sum	0,028	0,087	0,155	0,191	0,194	0,160	0,091	0,041	0,018	0,008	0,004	0,002	0,001	0,001	1,000			6,09	8760

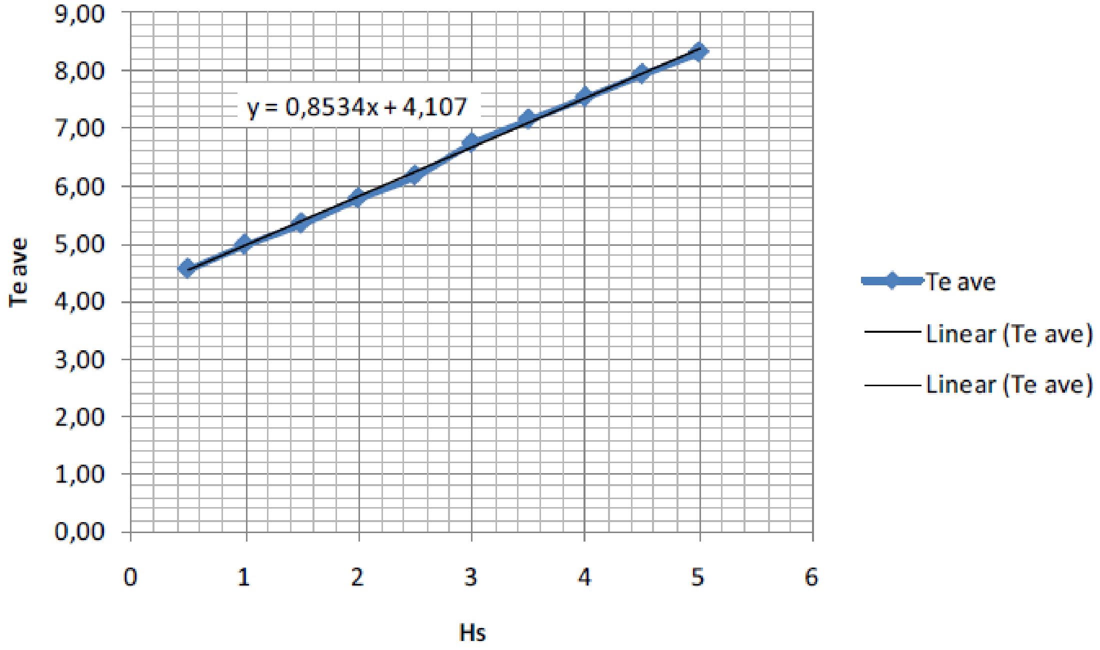


Figure 15 Linear relationship between Hs and Te at Hanstholm[1]

9.3 MAIN SITE CHARACTERISTICS

The summary statistics for Hanstholm are shown in Table 16 with the infrastructure present at the site described in Table 17.

Table 16 Summary Statistics of the Hanstholm site [1]

DanWec Hanstholm		
Design significant wave height Hs 10 Year	6.6	[m]
Design zero crossing period Tz 10 Year	10	[sec]
Max wind speed	30	[m/s]
Max current speed	3.4	[m/s]
Max high water level	1.6	[m]
Min low water level	-1.5	[m]
Maximum ice thickness	-	[m]
Wave power annual average	6	[kW/m]

Table 17 Hanstholm Infrastructure and Services

DanWec Hanstholm	
Scale	Prototype Scale. WaveStar device installed is 1:2 scale.
Water Depth	Depth 12-30m. Seabed is covered with sand and silt. At some locations this cover is washed away and chalk bedrock is exposed. Within 2km of the coast water depth reaches 30 meters in a local area of about 500m^2, further offshore the water depth decreases.
Distance to Shore	200m offshore. The shortest distance to the 30m depth location is about 2km
Site Area	—
Berths	—
Grid Connection	An 110kW Wavestar device has been grid connected since February 2010.
Wave Data Collection	Measured wave data from 2005-2009 in water depth of 20m.
Weather Data Collection	—
Other Data Collection	—
Substation/ Onshore Monitoring	—

9.4 REASON FOR CHOOSING THIS LOCATION

According to DanWEC, Hanstholm is the best location for a wave energy test site in Denmark due to it having the best wave energy resource in Denmark, near a port. As well as this, the site has good water depths close to land, existing 24/7 emergency technical marine assistance and is reasonable close to Aalborg University. The area also has an established history as a test site and the Danish industry trade organisation and leading Danish researchers have identify Hanstholm as the right place for Danish wave energy testing and demonstration [23].

10 METCENTRE, NORWAY

10.1 INTRODUCTION

The Marine Energy Test Centre (METCentre) is an offshore marine energy testing facility in Karmoy, Norway. METCentres objective is to provide infrastructure for the testing of new marine energy technology. METCentre manages and controls a 15MW sub-sea cable which is located about 13km west of Karmoy. The location of the test site is shown in Figure 16 with the cable route shown in Figure 17. The site was set up to test floating offshore wind turbines and as a result is located in deep water (200m). The site has been used to test the Hywind concept, the world first full scale floating offshore wind turbine. According to METCentre the site can also be used for the full scale testing of wave energy technologies.

Figure 16 Location of METCentre [24]

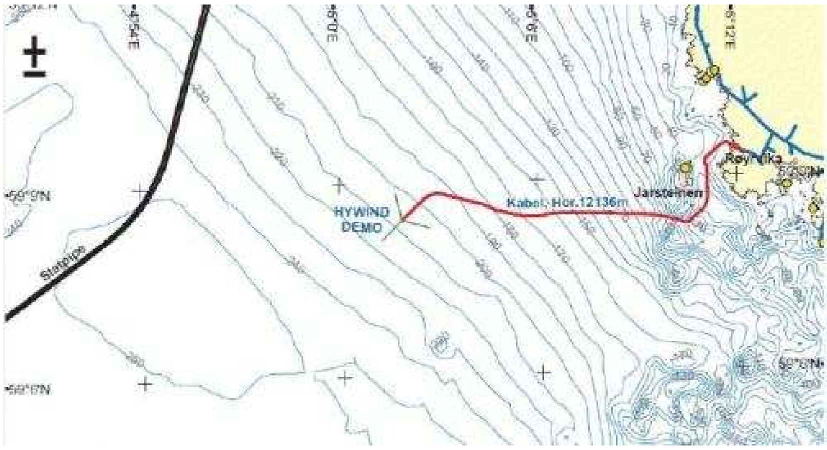


Figure 17 Sub-sea cable route at METCentre [24]

10.2 MAIN SITE CHARACTERISTICS

A description of the infrastructure and services provided at the METCentre site is given in Table 18.

Table 18 MetCentre Infrastructure and Services

MetCentre	
Scale	Full Scale
Water Depth	200m
Distance to Shore	12km offshore.
Site Area	—
Berths	—
Grid Connection	15MW submarine cable connected to 22kV onshore grid.
Wave Data Collection	METCentre mention that the site has established wave models and that METCentre can provide access to wave data. Details on wave measurement infrastructure unknown.
Weather Data Collection	METCentre mention that wind data exists and that the site has a good wind resource (as the site is used to test floating wind turbines)
Other Data Collection	—
Substation/ Onshore Monitoring	METCentre say they can provide O&M assistance, a work base and warehouse facilities and collaboration with research facilities. They say they can also assistance with site concession and permitting.

10.3 REASON FOR CHOOSING THIS LOCATION

As the site acts as a test centre for wind turbines as well as wave devices the site required a good wind resource and this was one of the main reasons for choosing the site off Karmoy. There are established wave models for the area, good wind conditions and the site is within 30 minutes drive of the airport[24]. The area also has significant experience in supplying equipment and services to offshore industry.

11 PLOCAN CANARY ISLANDS

11.1 INTRODUCTION

The Oceanic Platform of the Canary Islands (PLOCAN) is a planned project that will test marine technologies including marine renewable energy technologies. The infrastructure consists of an oceanic platform placed in depths between 50-100m close to the continental slope off the coast of Gran Canaria, in the Canary Islands (Figure 18). The project is a 50:50 partnership between the Spanish Ministry of Science and Innovation and the Government of the Canary Islands.

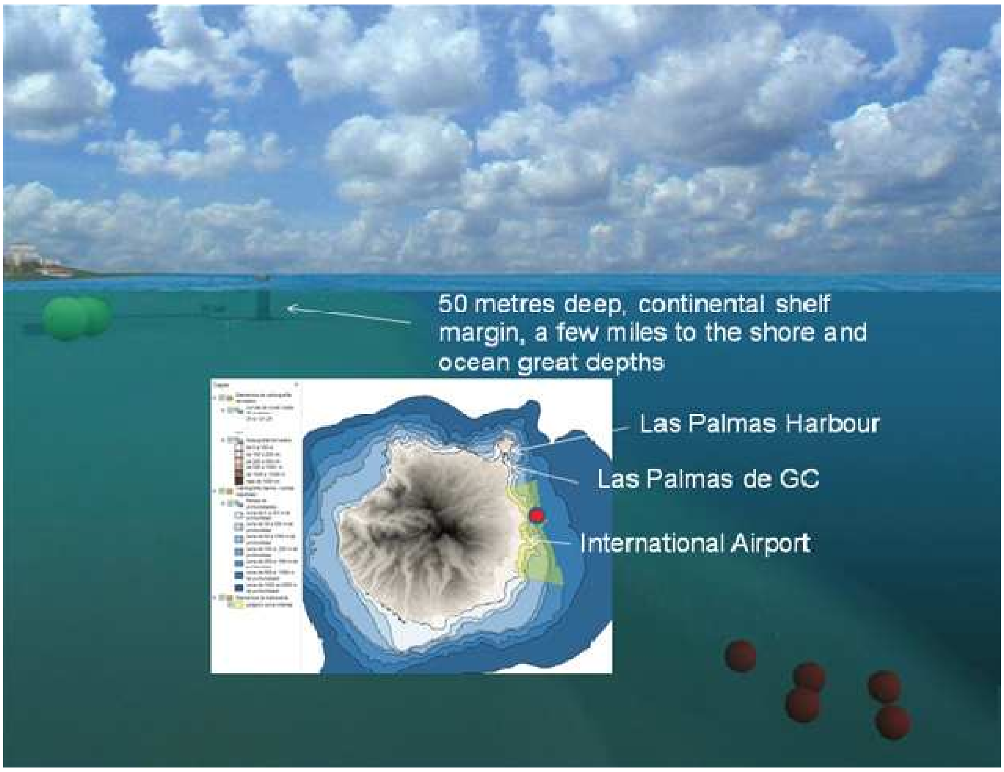


Figure 18 Location of PLOCAN platform [25]

PLOCAN will host a permanent deep-sea observatory and will provide direct access to deep water at a short distance from the shore. PLOCAN offers both onshore and offshore experimental facilities and laboratories, operational throughout the whole year thanks to the Canary Islands' climatic conditions. The services offered by PLOCAN are as follows:

- An ocean observatory for continuous and real-time monitoring of the ocean system.
- A test bed for the research, demonstration and operation of marine technologies, including those related to marine renewable energy.
- A base for underwater vehicles, such as gliders, ROVs (Remotely Operated Vehicles) and AUVs (Autonomous Underwater Vehicles).
- A training platform for researchers, enterprises and pilots for UUVs (Unmanned Undersea Vehicles).

Currently only the offshore oil and gas industry provide fixed offshore structures where this type of research and testing can take place. Construction is planned to start in 2011 and is due for completion in mid 2012. Figure 19 shows what the PLOCAN platform will look like when completed.

It is envisaged that a monitored test site for ocean energy, including offshore wind, tidal and wave energy, at the PLOCAN site will allow for specific testing of structural components and mooring systems as a result of the water depths available at PLOCAN. As with other test sites PLOCAN aims to reduce cost for developers by simplifying administrative permits, environmental protection guarantees and providing links with other service providers.

Figure 19 The planned offshore marine research platform PLOCAN [25]

11.2 RESOURCE

At Plocan's location on the east coast of Gran Canaria island the average annual wave resource is 4.2kW/m. The north coast of the island is more susceptible to the winter swells and as a result has a higher annual average resource of 8.1 kW/m[26]. The lower wave power in the east coast could facilitate testing at mid-scaled conditions during the whole year, and could avoid periods of inaccessibility as a result of avoiding winter swells. The annual distribution of significant wave height and period on the east coast of Gran Canaria is shown in Figure 20, with a joint distribution diagram shown in Figure 21.

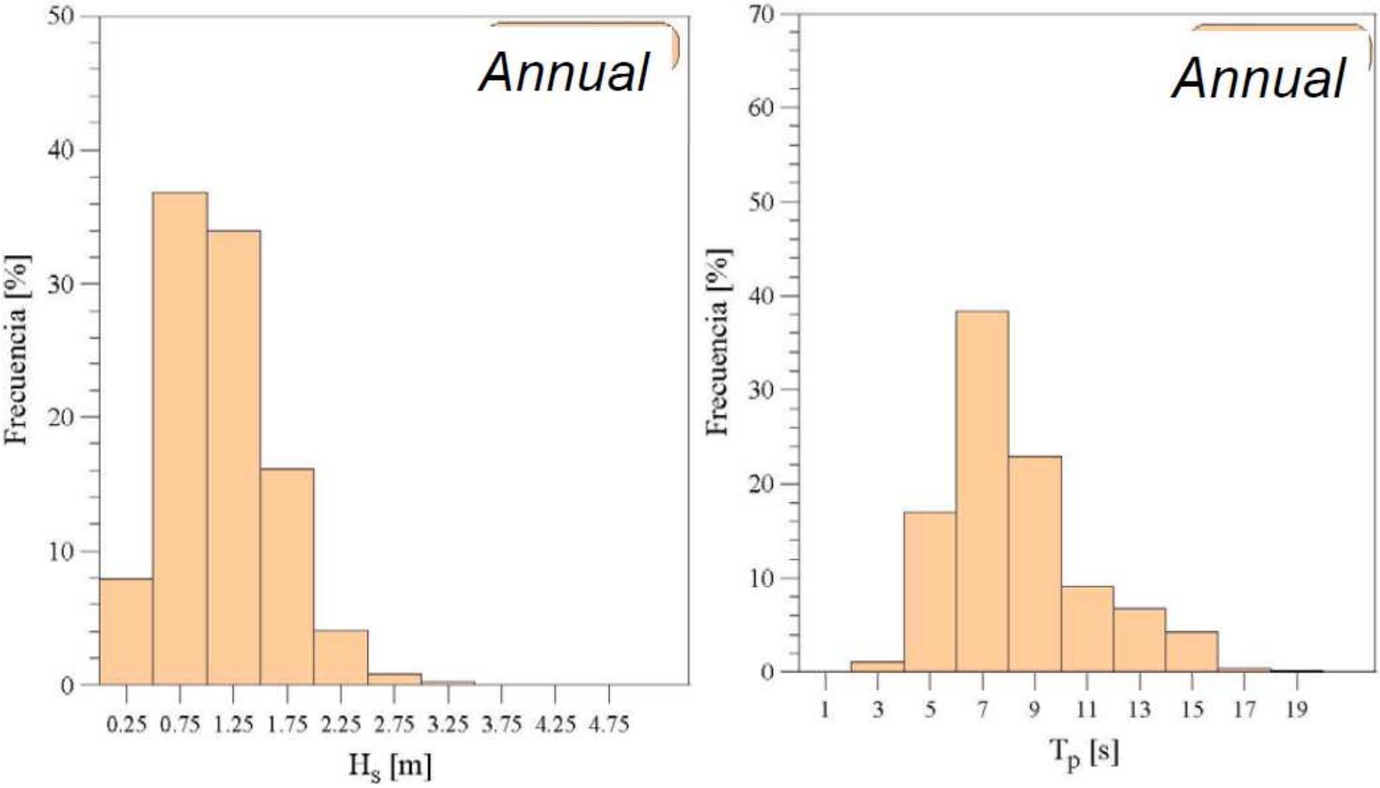


Figure 20 Annual Significant Wave Height (Hs) and Wave Period (Tp) distribution on the East Coast of Gran Canaria [27]

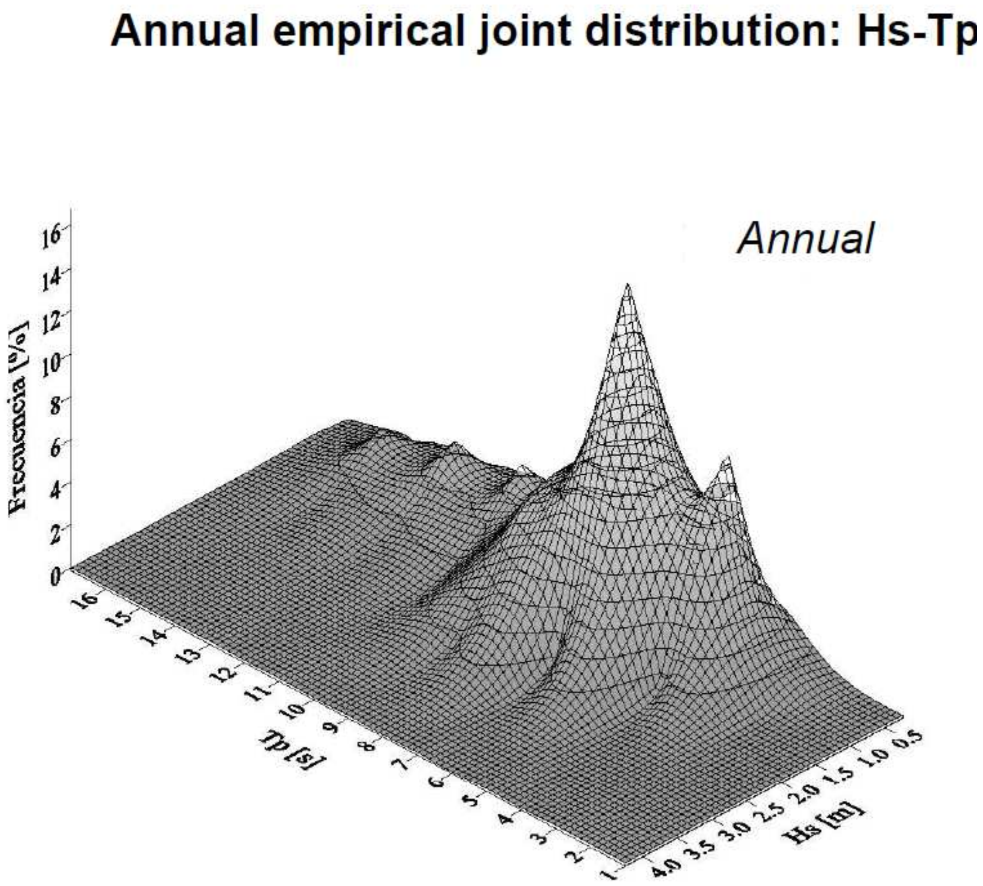


Figure 21 Joint Distribution of Significant Wave Height (Hs) and Peak Period (Tp) on the East Coast of Gran Canaria [27]

The return periods of extreme waves at the PLOCAN site is given in Table 19, based on a Weibull distribution of wave data at the site.

Table 19 Extreme wave return periods at PLOCAN based on Weibull distribution[27]

Return Period (years)	**10**	**20**	**50**	**100**	**200**	**500**
Significant Wave Height (m)	4.49	4.88	5.41	5.81	6.22	6.77
Maximum Wave Height (m)	7.18	7.81	8.66	9.30	9.96	10.83
Peak Period T_P (s)	11.1	11.4	11.9	12.2	12.5	12.9

11.3 MAIN SITE CHARACTERISTICS

A description of the infrastructure and services that are planned at PLOCAN is given in Table 20, with the location of the infrastructure shown in Figure 22.

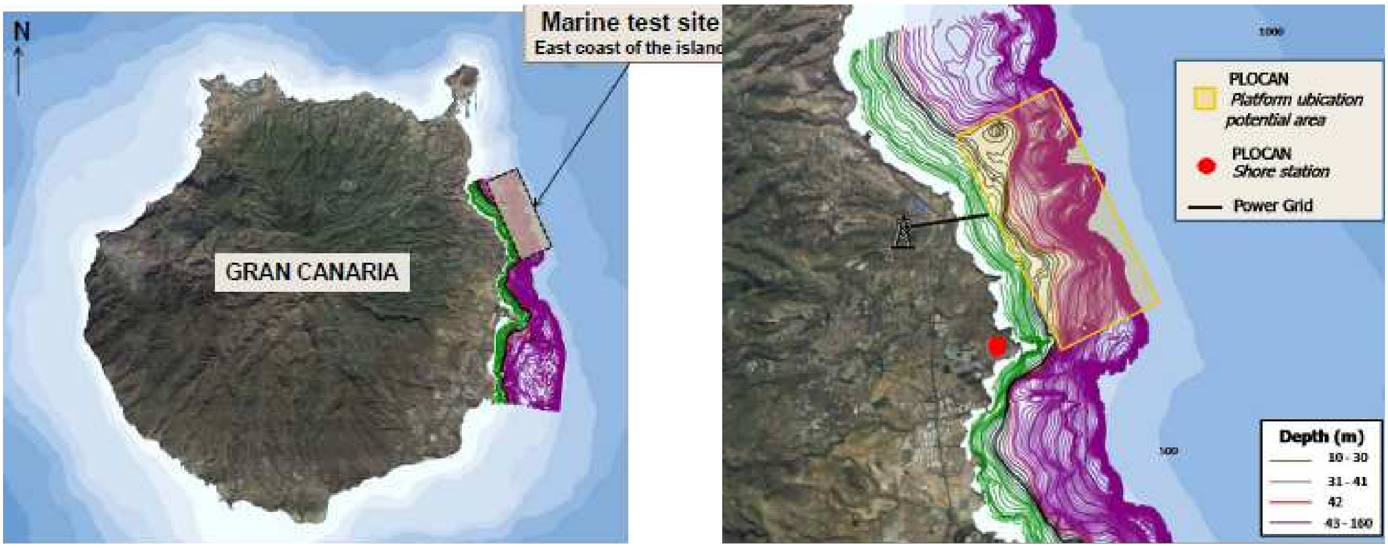


Figure 22 Proposed PLOCAN marine energy test site [27]

Table 20 PLOCAN Infrastructure and Services

PLOCAN	
Scale	Nursery scale or benign testing of larger scale devices.
Water Depth	50-100m
Distance to Shore	—
Site Area	Platform is 4km offshore
Berths	—
Grid Connection	The oceanic platform will be grid connected and will therefore act like a junction box from where a complete submarine electrical infrastructure can be deployed. This includes submarine power cables, distribution units and electrical transformer substation.
Wave Data Collection	An oceanographic buoy has been deployed onsite since May 2008
Weather Data Collection	—
Other Data Collection	—
Substation/ Onshore Monitoring	PLOCAN platform itself will acts as a substation, deployment base and a control centre for data analysis. It will provide all the support facilities at an offshore location close to where the devices will be installed.

11.4 REASON FOR CHOOSING THIS LOCATION

As well as the climate of the Canary Islands, the PLOCAN site was chosen due to the continental shelf which allows for operations to be carried out in deep water, 50-100m, only 4 km from the shore. The sites location on the Eastern side of the island offers protection from the winter swells. It should be said that the site was not chosen primarily as a test site for wave devices but with consideration for the other uses of the site in mind.

12 NURSERY / SCALE WAVE TEST SITES

Nursery or scale sites represent a move from laboratory tank testing, where the conditions are controllable, to a natural site in real seas were the conditions have to be accepted as they occur. These sites can reduce the technical and financial risk that would be required if a device went straight from the laboratory scale model test to a full size prototype deployed at an exposed ocean location. A typical scale test would involve testing of devices at 1:4 scale.

The benefits of scale tests are that the sea states are lower for operational procedures, accessing the test site involve shorter boat trips using smaller vessels and the support services are more readily available. These support services should include the following:

- Local heavy engineering infrastructure
- Tugs and similar vessels capable of handling the device
- Sheltered port with lifting facilities
- Adjacent harbour for service and personnel transport vessels
- On shore data acquisition station
- Grid connection (not essential)
- Low tidal elevation range and currents

Due to the scaling ratios, power production for scaled devices will be relatively small, in the range of 10-25kW for a 1-3MW full scale machine. It may not be economically feasible to lay subsea cables and grid connect scaled down devices for such a small amount of power. If this is the case, then a grid emulator can be used to electronically model a system as if it were grid connected. A grid emulator package should have the following characteristics

- The connection voltage and frequency must be at similar levels to those for which the device is designed to operate when connected to an electricity network.
- Loading capacity must be at least as high as the device peak electrical output
- Import capacity must be at least as high as is required by the device under normal operation
- The Impedance presented to the device must be within the range expected when grid connected

The sea states at scale sites must scale proportionately to represent the full ocean conditions that the prototype will eventually encounter. This involves adjusting both the wave height, which scales linearly, and the period which is a square root term. The linear ratio between the wave heights and the square root ratio between the wave period is obtained to verify that a particular scale site suit the open ocean requirement and at what scale. It is important to correctly scale the waves so all measured physical parameters can be scaled up. If this is not done then it is not possible to extrapolate data from the sea trials in any meaningful way.

Some sites may not have this scaled relationship to full ocean conditions but will nevertheless have a more benign wave climate than full scale sites. These nursery sites can be used to test full scale prototypes in more benign conditions prior to deployment in exposed locations and for establishing deployment and recovery procedures.

12.1 NISSUM BREDNING DENMARK

12.1.1 Introduction

The sheltered test site in Nissum Bredning was established in 1999, as part of the Danish wave energy program, as a site for developers to test their wave energy technologies at smaller scales in real sea waves. The test site has a fetch of about 10 km in south-western direction and is operated by the Folkecentre for Renewable Energy in Thy, Denmark [1]. Over 30 different types of wave power plants have been tested at Nissum Bredning for periods ranging from a few days to several years. These include the 20 kW WaveDragon prototype which was installed in 2003 and connected to the grid. WaveDragon has been in operation on and off since. In 2006 the WaveStar Energy device was build and installed at the site at the end of the pier 200m offshore(Figure 23). The WaveStar tests were of a 5.5 kW device comprising 40 floats of 1-meter diameter [1].Other devices, like the Wave Dragon, have been deployed in open water up to 500m offshore.

Figure 23 Wave Star device at the Nissum Bredning test site [28]

12.1.2 Resource

The average annual wave energy resource at Nissum Bredning is only 0.22kW/m [1], this is due to its sheltered location and limited fetch. The scatter diagram for the Nissum Bredning site is shown in Table 21.

Table 21 Joint probability diagram from Nissum Bredning [1]

Hs\ Tp	1,5	1,7	1,9	2,1	2,3	2,5	2,7	2,9	3,1	3,3	3,5	3,7	3,9	Sum	Tp ave	dP
0,05	3,3	11,1	6,6	3,6	2,4	3,3	0,8	0,7	0,7	0,3	0,1	0,1	0,1	33,1	2,00	0,00
0,15		1,6	2,2	1,4	0,6	0,8	1,4	1,7	1,5	0,8	0,4			12,4	2,47	0,00
0,25		0,1	1,3	1,1	1,6	1,3	0,4	0,9	0,5	1	0,7			8,9	2,57	0,01
0,35				0,8	1,3	3,7	1,6	1,2	0,7	1,6	1,6	0,2		12,7	2,80	0,02
0,45					0,7	2,6	1,9	1,9	0,8	0,4	0,7	0,1		9,1	2,79	0,02
0,55						1,7	2,5	1,3	1,2	0,5	0,1			7,3	2,81	0,03
0,65						0,2	1,1	1,5	1	1	0,3			5,1	2,99	0,03
0,75							0,1	0,2	1,3	0,7	1,8	0,5		4,6	3,33	0,04
0,85								0,2	0,4	0,3	0,8	1,4		3,1	3,48	0,03
0,95								0,1	0,1		0,2	0,6	0,9	1,9	3,70	0,03
1,05								0,1	0,1	0,1		0,4		0,7	3,44	0,01
1,15										0,1		0,2		0,3	3,57	0,01
1,25											0			0		0,00
1,35											0,2			0,2	3,50	0,01
1,45																
	3,3	12,8	10,1	6,9	6,6	13,6	9,8	9,8	8,3	6,8	6,9	3,5	1	99,4		0,22

12.1.3 Main Site Characteristics

The summary statistics for the Nissum Bredning site are shown in Table 22 with a description of the sites infrastructure given in Table 23.

Table 22 Summary Statistics of the Nissum Bredning [1]

Nissum Bredning		
Design significant wave height Hs, 1 year	1.3	[m]
Design zero crossing period Tz, 1 year	4	[sec]
Max wind speed	30	[m/s]
Max current speed	3.4	[m/s]
Max high water level	1.6	[m]
Min low water level	-1.5	[m]
Maximum ice thickness	0.15	[m]
Wave power annual average	0.2	[kW/m]

Table 23 Nissum Bredning Infrastructure and Services

Nissum Bredning	
Scale	Small Scale
Water Depth	The facility includes a 200m long bridge leading from the shore to a depth of 3m. The water depth increases to 5-8m some 500m offshore.
Distance to Shore	End of pier 200m offshore. Some devices have been tested 500m offshore.
Site Area	—
Berths	—
Grid Connection	0.5MW connection
Wave Data Collection	Yes (In-platform at the end of the pier)
Weather Data Collection	Equipment measuring wind speed, direction and air temp are located in a platform at the end of the pier.
Other Data Collection	—
Substation/ Onshore Monitoring	—

12.2 GALWAY BAY IRELAND

12.2.1 Introduction

The Marine Institute, in collaboration with the SEAI established an Ocean Energy Test Site for scaled prototypes of wave energy devices in Galway Bay. It is an Intermediate Scale Test Site (quarter scale Atlantic seas) facility which was designed to provide testing facilities for large scale prototypes to fulfil the requirements of Phase 2 (Process model) of the Development and Evaluation Protocols for Ocean Energy Devices. Both WaveBob and Ocean Energy deployed 1:4 scale devices at the site in 2006 and have been testing on and off since.

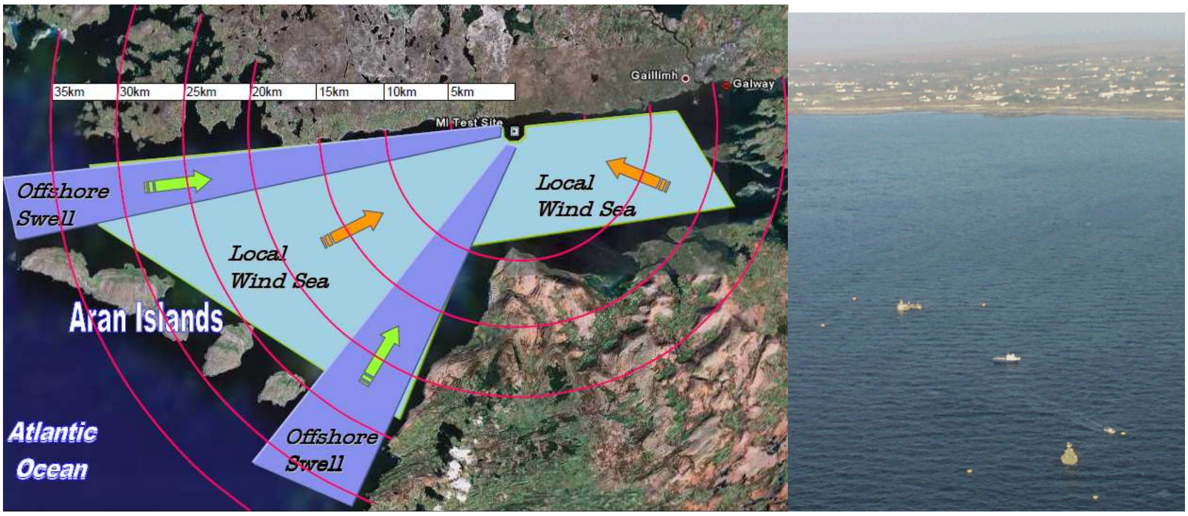


Figure 24 Location of Galway Bay test site with both Wavebob and OE Buoy deployed[29]

The Galway Bay test site is located at 1 mile east of Spiddal, County Galway, Ireland (Figure 24). To avoid conflict with shipping it is marked by navigation markers on four corners. The sites proximity to onshore infrastructure is as follows:

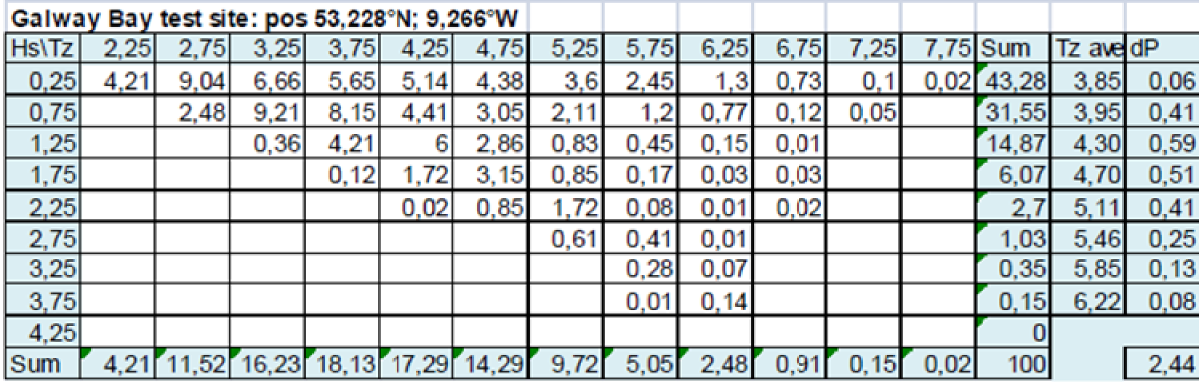
- Distance to large town – 15km
- Distance to nearest airport – 20km
- Distance from nearest service port to site – 20km
- Distance from nearest access harbour to site – 1.5km (Access Harbour is Tidal – 2 hours either side of high water)
- Distance from site to shore – 1km

Vessels and cranes are available in Galway Docks. A number of engineering companies exist in Galway, one heavy steel fabrication company is located on the Galway Docks site.

12.2.2 Resource

The average annual wave energy resource at the Galway Bay site is 2.44kW/m [1]. The scatter diagram for the site is shown in Table 24.

Table 24 Joint probability diagram Galway Bay [1]



Galway Bay test site: pos 53,228°N; 9,266°W

Hs\Tz	2,25	2,75	3,25	3,75	4,25	4,75	5,25	5,75	6,25	6,75	7,25	7,75	Sum	Tz ave	dP
0,25	4,21	9,04	6,66	5,65	5,14	4,38	3,6	2,45	1,3	0,73	0,1	0,02	43,28	3,85	0,06
0,75		2,48	9,21	8,15	4,41	3,05	2,11	1,2	0,77	0,12	0,05		31,55	3,95	0,41
1,25			0,36	4,21	6	2,86	0,83	0,45	0,15	0,01			14,87	4,30	0,59
1,75				0,12	1,72	3,15	0,85	0,17	0,03	0,03			6,07	4,70	0,51
2,25					0,02	0,85	1,72	0,08	0,01	0,02			2,7	5,11	0,41
2,75							0,61	0,41	0,01				1,03	5,46	0,25
3,25								0,28	0,07				0,35	5,85	0,13
3,75								0,01	0,14				0,15	6,22	0,08
4,25													0		
Sum	4,21	11,52	16,23	18,13	17,29	14,29	9,72	5,05	2,48	0,91	0,15	0,02	100		2,44

12.2.3 Main Site Characteristics

The summary statistics for the Galway Bay site are shown in Table 25 with a description of the sites infrastructure given in Table 26.

Table 25 Summary Statistics of the Galway Bay site [1]

Galway Bay		
Design significant wave height Hs (Estimate)	5	[m]
Design peak period Tp (Estimate)	10	[sec]
Max wind speed	—	[m/s]
Max current speed	—	[m/s]
Max high water level	2.5	[m, MSL]
Min low water level	-2.5	[m, MSL]
Maximum ice thickness	—	[m]
Wave power annual average	2.4	[kW/m]

Table 26 Galway Bay Infrastructure and Services

	Galway Bay
Scale	Intermediate 1/3 to 1/5 Scale
Water Depth	22m. The seabed material is mud, sand, gravel or rock.
Distance to Shore	1 km
Site Area	37 Hectares
Berths	There have been two devices installed simultaneously
Grid Connection	No. For a full scale device rated at 2MW, a scaled down device designed for Galway Bay will be rated at approximately 16kW. Production of electricity at this magnitude does not justify grid connection or the expense of a sub-sea cable.
Wave Data Collection	Directional wave rider buoy is currently deployed at the test site. Wave data is updated every 3 minutes. Measurements have been taken since 2005, directional buoy deployed since end 2008
Weather Data Collection	—
Other Data Collection	Developers have to manage and make their own arrangements for data acquisition.
Substation/ Onshore Monitoring	No onshore facilities at the site.

12.2.4 Licensing and Permits

The site access is pre-permitted with conditions set down by the Marine Institute. As well as providing for their own data transmission and acquisition developers must also supply their own moorings.

12.2.5 Reason for choosing this location

A wave climate recording and modelling programme, carried out by the Marine Institute in 2004, indicated the suitability of the site for testing of 1/3 – 1/5 scale devices and that the site scales very well with exposed locations off the west coast of Ireland.

12.3 EMEC NURSERY WAVE SITE SCOTLAND

12.3.1 Introduction

As well as full-scale test sites for wave and tidal devices, EMEC recently received funding from the UK government to support the creation of new nursery berths in Orkney, for both tidal and wave machines. The aim of the nursery berths is to provide facilities for the testing of scaled down devices or sea trials of full scale prototype devices in more gentle conditions than those experienced at the main wave and tidal test sites operated by EMEC.

The purpose of the new facilities is to make it easier for developers to bring concepts and test them in accessible, real sea conditions, without the need for some of the big vessels or large plant that have been used in the deployment of commercial-scale machines. They will also provide an area for rehearsal of deployment techniques. The location of the EMEC nursery wave and tidal sites in relation to the full scale sites at Orkney is shown in Figure 25. EMEC is currently in the final stages of the construction of the mooring points for the nursery sites. Each will be provided with four gravity base anchors of up to 600kN capacity with a variety of attachment points. The nursery berths are planned to be available in 2011.

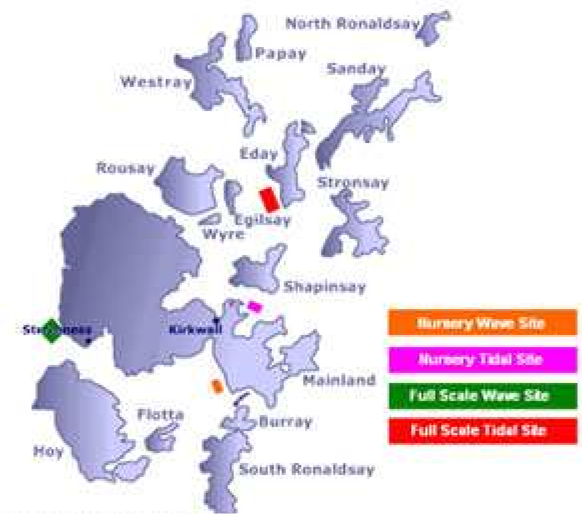


Figure 25 Locations of EMEC test sites around Orkney [30]

12.3.2 Resource

EMEC have, and continue to, assess the sites' energy resources using surface-mounted waverider buoys with integral downward pointing acoustic doppler profiler (ADCP) measuring currents. Multibeam sonar, sub-bottom profiling, and magnetometer surveys have also been completed, with further environmental surveys currently underway. According to EMEC [31] in the winter months the nursery site receives an average Hs of 0.5-1.0m and an average Tz of 3.0-3.5s, with a maximum Hs of 4m. This compares to Hs 1.5-2.0m & Tz 5.5-6.0m at the full scale wave site.

12.3.3 Main Site Characteristics

The services and infrastructure provided at the EMEC wave nursery site are described in Table 27.

Table 27 EMEC Nursery Wave Site Infrastructure and Services

EMEC Nursery Wave Site	
Scale	Scaled device or benign testing of full scale prototypes
Water Depth	—
Site Area	—
Berths	Two
Grid Connection	A novel Testing Support Buoy will be deployed at each berth. These connect to the device via an umbilical and house a loadbank to dissipate electricity generated by the device. Data from the device will then be transmitted to EMEC's SCADA system ashore, allowing developers to monitor the performance remotely.
Wave Data Collection	Surface Mounted Wave rider buoys will monitor the wave climate.
Weather Data Collection	There are onshore weather stations at the full scale wave and tidal sites. It is unknown if separate weather monitoring facilities will be available for the nursery sites.
Other Data Collection	Currents measured using ADCP
Substation/ Onshore Monitoring	The same onshore facilities exist as for the full scale sites.

12.3.4 Licensing and Permits

EMEC will allow developers to connect their devices at the nursery berths in three different ways:

- Use the leased area, providing own moorings and power dissipation
- Use the leased area and EMEC moorings but providing own power dissipation
- Use the leased area, EMEC moorings and EMEC Testing Support Buoy

12.3.5 Reason for choosing this location

EMEC chose a location in Scapa Flow, Northwest of St Marys Bay in Orkney as the site which best met their criteria for a nursery development site[30].

13 WAVE DEVELOPER TEST SITES

Developer test sites are sites which have been developed by device developers for the testing of their own devices. In doing so they have single handily undertaken the feasibility studies, site permitting, infrastructure and monitoring at a specific site. These are not therefore independent test centres where setup costs, site permitting and monitoring are shared and testing can be carried out whereby the performance of devices can be independently assessed by experienced operators.

These test sites also include sites where device developers have worked in conjunction with third parties such as universities, research centres or utility companies to set up test facilities which, as well as testing the developers device, also include other research such as environmental monitoring.

Unlike independent test centres such as EMEC, WaveHub or Belmullet, these sites only test one type of device and the site may be decommissioned when the testing is completed. It is unknown therefore if these sites could be used to test other devices, as is the case at independent test centres.

13.1 LYSEKIL SWEDEN

13.1.1 Introduction

The Lysekil Wave Energy Research Site has been developed by Uppsala University to undertake technical and biological wave energy research projects. The site is located on the Swedish West coast, about 100 km North of Gothenburg, near Lysekil, shown in Figure 26. The site is located 2 km offshore, between a northern and a southern navigational marker signalling the research area to avoid interference with shipping.

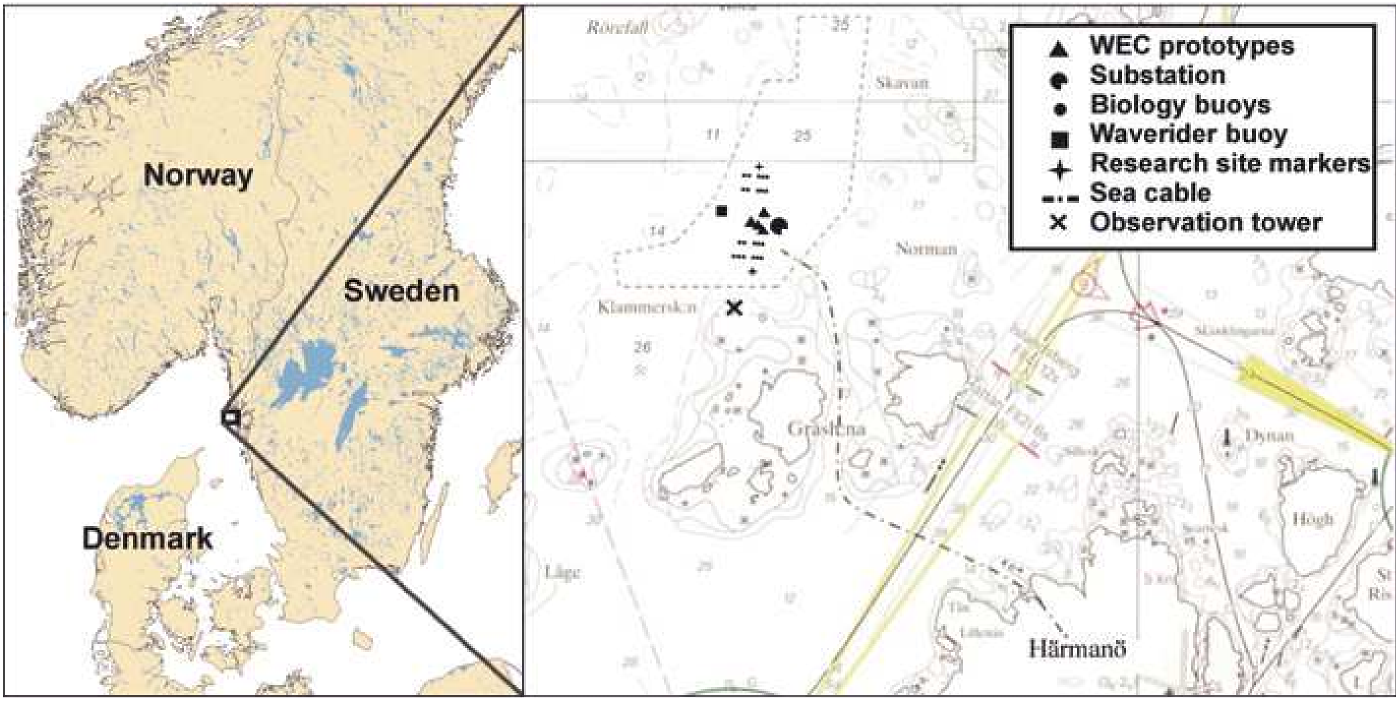


Figure 26 Location of the Lysekil Research Site[32]

The project was started in 2004 and has permission to run until 2013. The technical part of the project involves testing of a linear generator WEC concept at the site. The site has permission to use a maximum of 10 of these generators. The biological aspects of the project involves the installation of up to 30 'dummy' buoys which will replicate WECs so the impact of WECs on the environment and impact of environment on WECs can be studied. A surveillance tower for monitoring the interaction between waves and converters will also be installed[33]. A first prototype of the linear generator was deployed at Lysekil in 2006 and another two were deployed in 2009 [34]. The purpose of the slow deployment was that knowledge could be gained and lessons learnt so that adjustments could be made more gradually. The project will be concluded in 2013-2014, after which all the equipment will be removed.

13.1.2 Resource

The average annual wave energy resource at the Lysekil site, based on a study of eight years of satellite data is 2.6 ± 0.3kW/m[32]. A combined scatter and energy diagram for the Swedish coast off Lysekil is shown in Figure 27. The results are based on 8 years (1997-2004) of wave data which is a product of WAM and SWAN modelled data calibrated by buoy measurements.

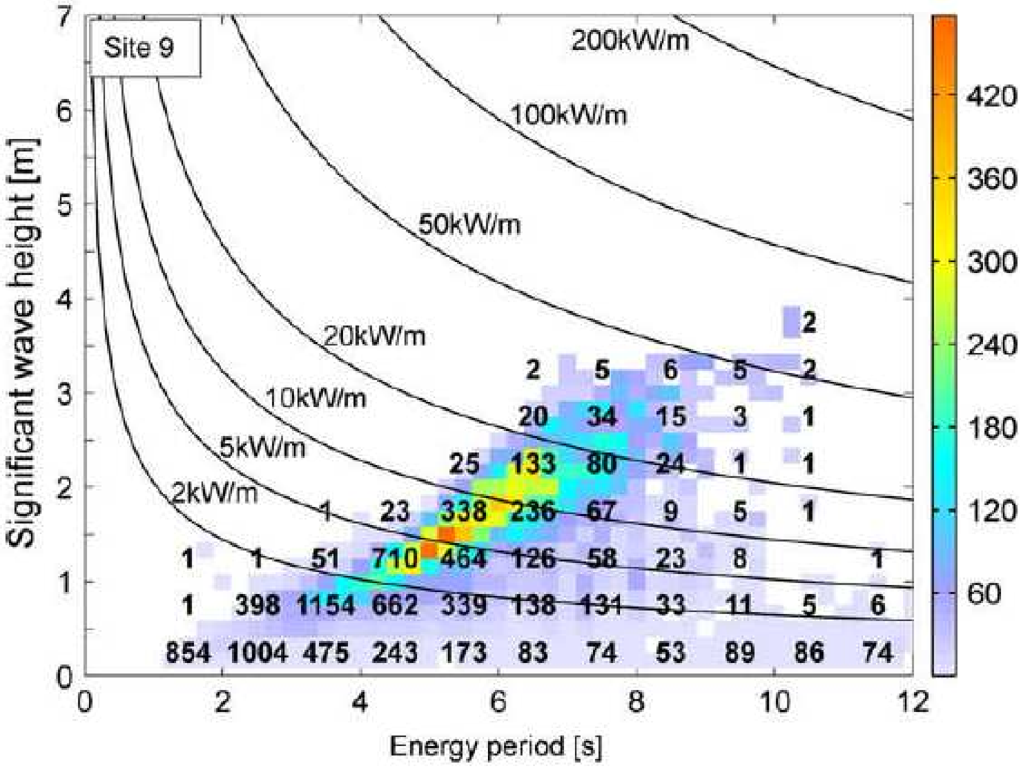


Figure 27 Combined scatter and energy diagram for the Lysekil site. Colours show the annual energy transport per meter of wave front (kWh/(m2 year))/ Numbers give average occurrence in hours per year[35].

13.1.3 Main Site Characteristics

A description of the infrastructure and services available at the Lysekil research site is given in Table 28.

Table 28 Lysekil Infrastructure and Services

Lysekil	
Scale	Full Scale
Water Depth	25m
Distance to Shore	2km
Site Area	$40000m^2$
Berths	Up to 10 grid connected linear generators together with 30 ‘dummy’ buoys.
Grid Connection	The grid connected linear generators will be connected to a LVMS (Low Voltage Marine Substation) which is deployed on the sea bed. The LVMS is connected to the land based measuring-station with one 1 kV three phase cable for energy transfer and one signal cable. The cable lengths between the LVMS and the measuring-station are 3.1 km, and the cable length between the WECs and the LVMS is 70m. Each generator will have an installed capacity of 10kW with the complete installation having a capacity of 100kW.
Wave Data Collection	Wave measurement buoy since 2004

Weather Data Collection	—
Other Data Collection	Close to Uppsala University 's Biological Station "Klubban", as well as to Kristineberg Marine Research Station
Substation/ Onshore Monitoring	The electricity and the data from the devices will be gathered at the land based measuring-station.

13.1.4 Reason for choosing this location

The location was chosen as it provides a good Swedish wave climate, access to harbours which offer modes of transport and other necessary facilities. It is close to Uppsala University's Biological Station 'Klubban', as well as to the Kristineberg Marine Research Station, both of which are co-operators in the project. It is also close to the main grid making grid connection easier and this was a decisive factor in the choice of the location. The project area is relatively close to land, which simplifies access. The average depth, 25m, was also a factor in the choice of the location as diving is required on a regular basis at the site. This depth makes diving relatively easy together with the flat sandy seabed. Smaller similar areas close to the project location are used as control areas, an important factor for the biological studies.

13.2 PORT KEMBLA AUSTRALIA

13.2.1 Introduction

Port Kembla Harbour on the eastern side of Australia is a site where the Oceanlinx OWC system has been tested. The Oceanlinx Mk1 full scale prototype was fitted out and first deployed in 2005 and was decommissioned during the second half of 2009. More recently Oceanlinx has used Port Kembla for testing of its 1/3 scale Mk3 pre-commercial device. It was installed in February 2010 and grid connected from March to May 2010. The tests were cut short however, as the device broke free from its moorings on May 14th which ended the testing several weeks early. The Oceanlinx devices were located in a licensed area within Port Kembla Harbour. The following are the distances to onshore facilities:

- Distance to large town: 3km
- Distance to nearest airport: 75km
- Distance from nearest service port to site: 1km
- Distance from nearest access harbour to site: 1km

13.2.2 Resource

The average annual wave energy resource at the Port Kembla site is 6.7kW/m [1] with the scatter diagram for the site shown in Table 29.

Table 29 Joint probability diagram from Port Kembla (all years all directions) [1]

Hs \ Te	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	13,5	14,5	15,5	16,5	17,5	18,5	19,5	20,5	Sum	Te ave	dp
0,125	16	68	38	10	2	2	72	18	29	49	39	32	13	4	2	0	0	0	0	0	394	7,59	0,00
0,375	0	177	68	48	188	393	316	834	1762	2226	1323	1619	748	131	79	25	1	0	0	1	9939	10,38	0,03
0,625	0	32	531	724	1896	3019	3695	5495	6414	7045	3842	4214	1841	699	481	130	28	3	0	0	40089	9,64	0,35
0,875	0	0	119	1332	2904	5221	7107	10412	10404	10206	3964	3761	1471	534	343	78	13	0	1	0	57870	9,18	0,95
1,125	0	0	1	656	1816	3961	5683	8114	8682	8980	3461	3230	1156	325	269	82	13	7	0	0	46436	9,33	1,28
1,375	0	0	0	62	601	1820	3254	4526	5285	5768	2171	1856	774	236	159	79	3	4	0	0	26598	9,59	1,12
1,625	0	0	0	0	59	598	1470	2157	2607	3118	1233	1072	526	155	129	53	5	0	0	0	13182	9,94	0,80
1,875	0	0	0	0	1	154	591	956	1224	1871	772	675	326	130	54	27	1	0	0	0	6782	10,28	0,57
2,125	0	0	0	0	0	25	168	417	774	1162	476	377	130	63	37	12	1	0	0	0	3642	10,48	0,40
2,375	0	0	0	0	0	4	63	251	480	726	368	293	62	39	35	9	0	0	0	0	2330	10,65	0,33
2,625	0	0	0	0	0	0	25	120	142	305	186	259	26	11	37	16	0	0	0	0	1127	11,08	0,20
2,875	0	0	0	0	0	0	6	56	40	147	108	210	25	8	21	12	0	0	0	0	633	11,51	0,14
3,125	0	0	0	0	0	0	3	19	31	112	112	148	28	4	7	7	0	0	0	0	471	11,58	0,12
3,375	0	0	0	0	0	0	0	9	11	53	83	126	26	4	6	9	0	0	0	0	327	11,98	0,10
3,625	0	0	0	0	0	0	0	6	11	18	51	87	16	1	6	9	0	0	0	0	205	12,15	0,08
3,875	0	0	0	0	0	0	0	5	15	13	36	44	21	1	2	4	0	0	0	0	141	11,92	0,06
4,125	0	0	0	0	0	0	0	0	8	11	39	30	9	2	2	2	0	0	0	0	103	11,94	0,05
4,375	0	0	0	0	0	0	0	0	4	13	23	22	17	0	0	1	0	0	0	0	80	12,00	0,04
4,625	0	0	0	0	0	0	0	0	2	11	25	21	9	1	0	0	0	0	0	0	69	11,89	0,04
4,875	0	0	0	0	0	0	0	0	1	5	10	24	7	1	0	0	0	0	0	0	48	12,21	0,03
5,125	0	0	0	0	0	0	0	0	0	4	2	5	6	4	0	0	0	0	0	0	21	12,69	0,02
5,375	0	0	0	0	0	0	0	0	0	0	1	6	2	3	0	0	0	0	0	0	12	13,08	0,01
5,625	0	0	0	0	0	0	0	0	0	0	0	3	0	2	0	0	0	0	0	0	5	13,30	0,00
5,875	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2	14,50	0,00
6,125	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2	12,50	0,00
Sum	16	277	757	2832	7467	15197	22453	33395	37926	41843	18325	18116	7239	2360	1669	555	65	14	1	1	210508		6,74

The linear relationship between the average wave period and significant wave height at Port Kembla is shown in Figure 28, as well as a comparison with the linear relationship found in Portugal. It can be observed that the waves at Port Kembla seem to be even more swell-dominated than the waves in Portugal

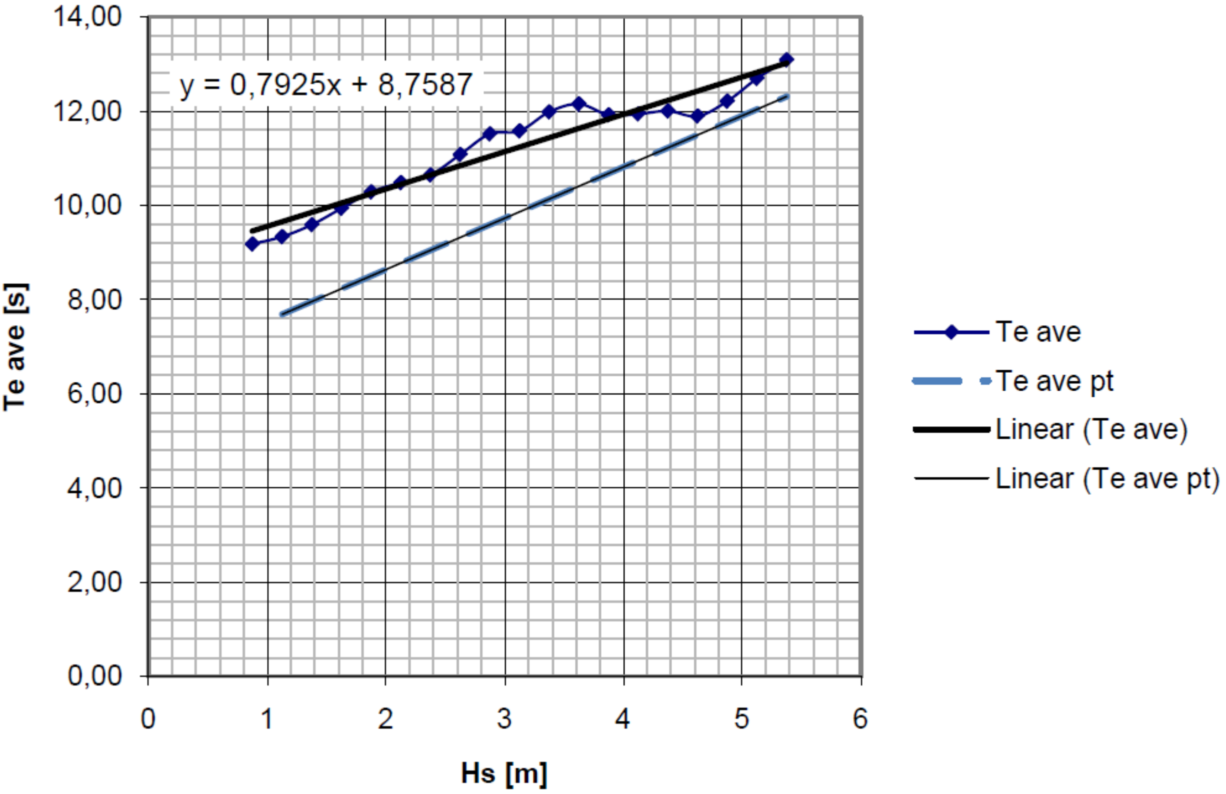


Figure 28 Fitted linear relationship between the average wave energy period ($T_{e\ ave}$) and the significant wave height (Hs) at Port Kembla. The linear relationship found at Portugal is shown with a dashed line[1]

13.2.3 Main Site Characteristics

The summary statistics for the Port Kembla site are given in Table 30, with a description of the sites infrastructure given in Table 31.

Table 30 Summary Statistics of the Port Kembla site [1]

Port Kembla	34^0 27'S	15^o 054' E
Design significant wave height Hs, 10 Year	6.6	[m]
Design zero crossing period Tz, 10 Year	10	[sec]
Max wind speed	50	[m/s]
Max current speed	1	[m/s]
Max high water level	1.25	[m]
Min low water level	-1.25	[m]
Maximum ice thickness	—	[m]
Wave power annual average	6.7	[kW/m]

Table 31 Port Kembla Infrastructure and Services

	Port Kembla
Scale	Oceanlinx have tested full scale and 1/3 scale devices onsite.
Water Depth	6m
Distance to Shore	The Oceanlinx structures were positioned 200m from the Port Kembla harbour breakwater.
Site Area	—
Berths	Only one device has been tested at any one time.
Grid Connection	The plant is connected to the local grid by an 11kV cable. Device capacity 500kW.
Wave Data Collection	—
Weather Data Collection	—
Other Data Collection	—
Substation/ Onshore Monitoring	Adjacent shore facilities include a security hut, trial generator and load bank plus switchboard enclosure for LV grid connection. Oceanlinx maintains a small office within the Port Kembla harbour for the administration and maintenance crew.

13.2.4 Reason for choosing this location

The site was chosen because it is close to the grid and heavy industry, and the project was supported by the local Council and Port Corporation. The site also has the right depth and seabed conditions [36].

13.3 RUNDE NORWAY

13.3.1 Introduction

The MAREN project (MARine ENergy) is collaboration between Vattenfall AB and the Norwegian utility company Tussa AS. The project will involve the testing of two Seabased AB WECs, at a wave energy test site in Norway. The MAREN test site is located off Runde Island (Figure 29) and also involves the Runde Environmental Centre (REC) who carries out the environmental monitoring of the site. The first deployment at the test site was in 2009 with the installation of two full scale wave energy converters and submarine switchgear[37]. The two WECs installed at Runde each consist of a buoy, linear generator, connecting wire and a gravity foundation with each WEC having a rated capacity of 20kW.

Figure 29 Location of the MAREN wave power test site off the island of Runde [38]

A 2007 study of the wave climate off Runde Island found the average annual wave energy resource to be 50 kW/m [39] with the region considered to have high potential for future wave power developments in Norway.

Figure 30 The two WECs being installed at the Runde test site, showing the buoys(in the water) together with the linear generator and gravity foundation (on the barge) [40].

13.3.2 Main Site Characteristics

The main infrastructure at the MAREN test site is described in Table 32.

Table 32 RUNDE Infrastructure and Services

	RUNDE
Scale	Full Scale
Water Depth	50m. Gravel substratum interspersed with rock and some sand
Distance to Shore	500m offshore
Site Area	—
Berths	Two
Grid Connection	The under-water switchgear Low Voltage Marine Substation (LVMS) and a sub-sea cable connect the 40kW generators to the 22kV grid. The LVMS receives the power from the two WECs. It is first rectified, then transformed to AC current and stepped up to 22kV and sent ashore.
Wave Data Collection	—
Weather Data Collection	Onshore Weather Station at REC
Other Data Collection	Data from the WEC and LVMS is integrated in the 3km sea cable running to the onshore connection point.
Substation/ Onshore Monitoring	The grid connection point is also where the radio signals from the measuring and power buoys are received. The physical performance of the generators and the ambient wave climate are monitored with measured data transferred to shore continuously. Monitoring and evaluation of data will take place at REC as well as by Tussa and Vattenfall though a shared IT system.

13.3.3 Licensing and Permits

The sites permit is valid until January 1, 2014. As the site is on the interface of two seas (North Sea to the south and Norwegian Sea to the North) and two major current systems (Norwegian Coastal Current and North Atlantic Current), together with a highly variable topography and narrow continental shelf, the marine environment around Runde has a high level of biological diversity. Therefore the permit is conditional on a number of issues in relation to environmental monitoring, buoy markings and agreements with local trawlers with regards to fisheries[38]. The continuous environmental monitoring programme collects the relevant information and has the option to disrupt testing in the case of unexpected results.

13.3.4 Reason for choosing this location

The actual MAREN test site was chosen on the basis of a number of criteria, including

- High wave energy
- Minimum interference with ship traffic
- Minimum interference with fishing
- Minimum interference with fish spawning areas.

In addition, water depth (~50m), bottom topography (uniform horizontal) and seabed substratum type (mainly gravel and sand) had to be amenable to deployment of the generators. Initially, five potential areas were evaluated, with ‘Måganeset’ off Runde Island chosen as the most appropriate site which best matched the selection criteria [41].

14 ALTERNATIVE WAVE TESTING FACILITIES

14.1 AGUCADOURA PORTUGAL

Agucadoura located near Oporto, in Portugal was the site for the world's first grid connected commercial wave farm. In 2008 three Pelamis WECs of 750kW each were installed at the site. The three grid connected berths had a combined capacity of 4MW. The commercial site was located in 40m water depth 5km offshore. The site also had an onshore monitoring station as well as an electrical substation. It is unknown what met-ocean measuring equipment was or is installed onsite. The commercial project stalled in November 2008 when Babcock & Brown, a majority stakeholder in the project, had their shares suspended due to the financial crisis and couldn't continue to fund the project. As a result the infrastructure remains at the site and it may be possible to use this infrastructure to turn the site into a test site for full scale devices.

14.2 ONSHORE FIXED OWC PLANTS

PLOCAN is a fixed offshore platform which may be used by developers who want to test their devices in an offshore environmental without it being too inaccessible. As well as this offshore fixed platform there are several onshore fixed OWC (Oscillating Water Column) installations. These installations include the Mutriku breakwater in Northern Spain, which will have a capacity of 0.3MW, made up of sixteen 18kW turbines. Another OWC plant is the PICO plant in the Azores. This was built in 1999 and has a 15kV 400kW grid connection.

These onshore sites may be used to test OWC components using real sea waves and would have the benefit of high accessibility, cheaper installation and grid connection without having to risk a whole device in a hostile offshore environment. They therefore could be used to test individual components prior to their deployment on scaled devices.

15 SPECTRAL SHAPE

Resource assessments, device performance predictions and monitoring of operational devices will often be based on summary statistics. However, the performance of many devices is highly dependent on the spectral shape of the seaway due to their resonant properties[42]. An example of the different spectral shapes with the same seaway summary statistics is shown in Figure 31. In this extreme example the summary statistics are H_{m0} = 1.2m, T_e = 4.65s and T_p = 5.37s. Three examples are shown, together with the resultant power output. In the first example the recorded spectral shape is similar to that of the Bretschneider resulting in a power output of 99% of the expected value based on the summary statistics. In the second example there is a clear bi-modal spectral record made up of both a local wind sea and a swell component, both with different peaks. A device with a resonant response based on the Bretschneider for this sea state would only produce 5% of the expected power, as the peak of the Bretschneider lies in the valley between the twin peaks of the actual sea state. In the final example the power output results are better than expected, 118%, as the peak of the recorded data coincides with the peak of the Bretschneider.

In all three cases all the spectral shapes are based on the same summary statistics. The reason for this is that the wave records associated with these spectra have the same variance i.e. the same total energy in the wave record and the same area under the wave spectrum.

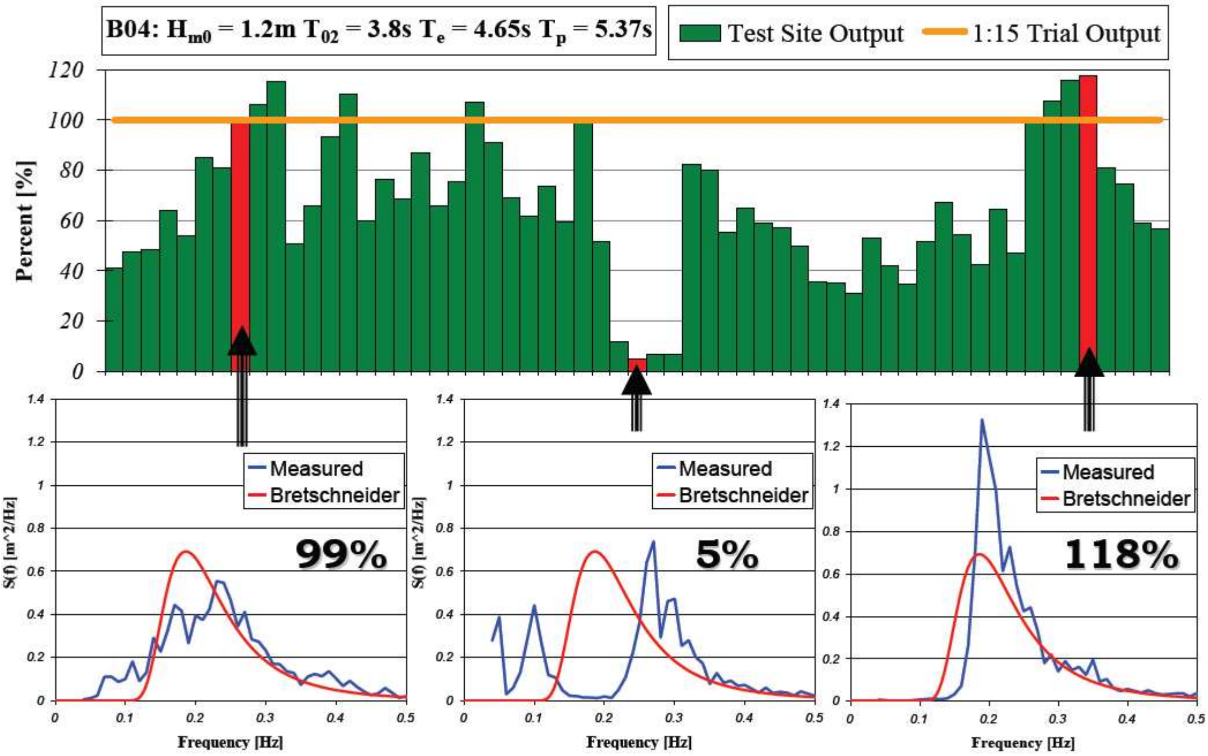


Figure 31 Example of different spectral shapes with the same summary seaway statistics[43]

As the spectral shape can have a large effect on the performance of devices, it is important to be able to compare the spectral shapes, as well as the resource and summary statistics, at different test sites. This will enable better comparisons to be made between similar devices tested at different test sites and results from different tests to be compared. There is currently no common method for presenting the spectral data from different test sites to enable comparisons to be made between the spectral shapes. In order to illustrate this, the following are some wave spectra obtained from various test sites. It can be observed that they are mostly presented in different formats making direct comparisons difficult.

15.1 WAVEHUB

The location of the WaveHub site means it receives both swell sea states propagating from the Atlantic, and frequent localised wind seas. Examination of spectral datasets for the site indicates frequent bi-modal or multi-modal sea states, i.e. seas comprising two or more separate wave systems, each with their own height, period and directional characteristics[6].

Figure 32 presents spectral data from the SWM dataset in a scatter diagram format. The SWM dataset is buoy data recorded at the WaveHub site from 30/01/05 to 08/11/05. For each bin of the scatter diagram, all spectra with parameters that fall within the bin limits are plotted (blue) and the mean spectrum for the bin calculated (red). This information is important for device developers considering deployment at Wave Hub because it gives an indication of where energy is found in the spectrum for different sea states. This will have implications for device tuning and power output predictions. The lower left bin for example (H_s = 0-1m, T_z = 3-4s), has spectral energy spread across a wide range of frequencies, with significant energy occurring between approximately 0.05 and 0.4 Hz. This is indicative of high levels of bi-modal sea states, and it can be seen that the mean of these spectra is itself 'bi-modal'. Comparing this with a bin containing larger wave states, e.g. H_s = 3-4m, T_z = 7-8s, it can be seen that the spectral energy is concentrated at frequencies below 0.2Hz with almost no indication of multi-peaked seas[6].

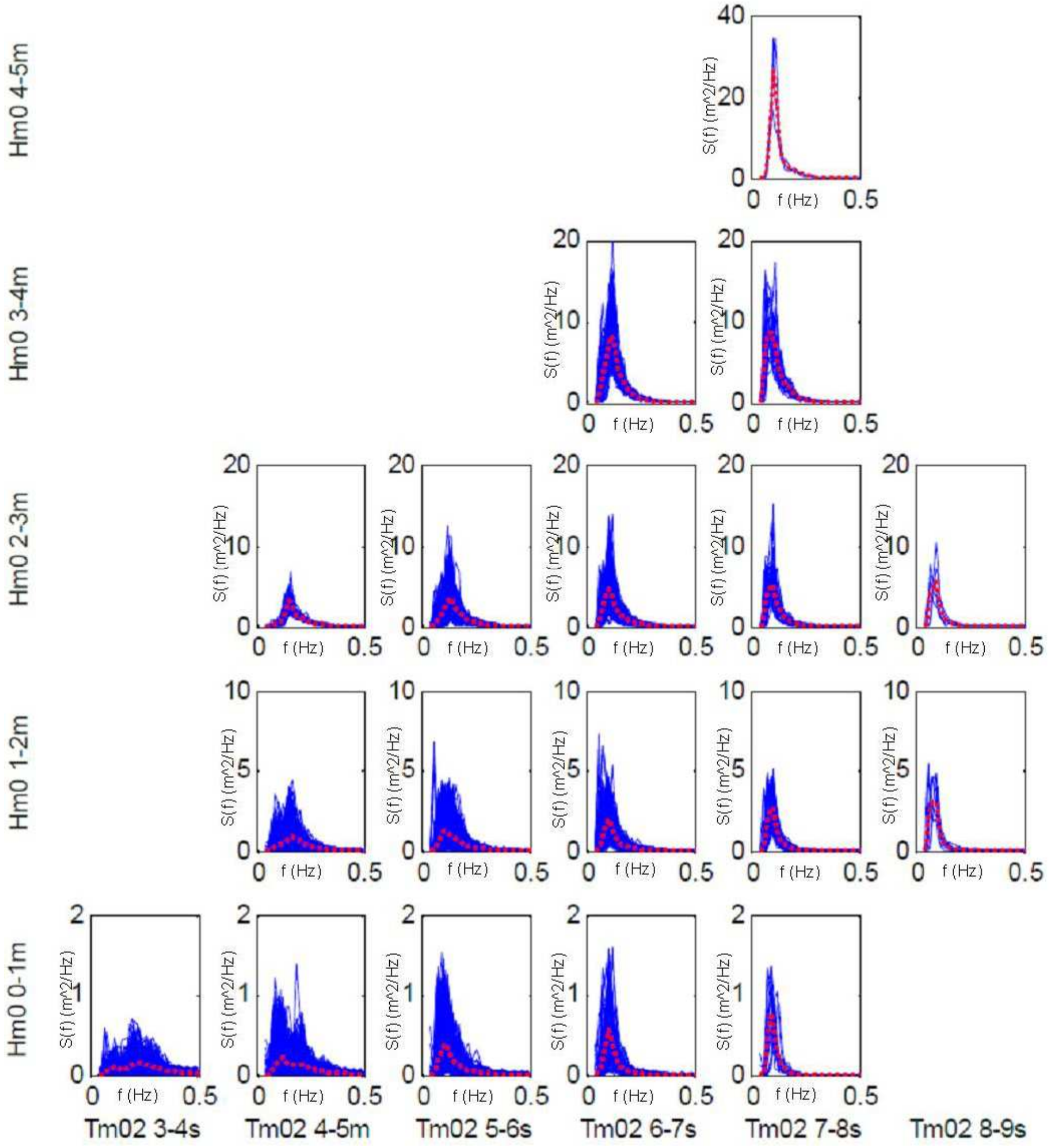


Figure 32 All spectral data and mean spectra plotted for each bin of the scatter diagram for the SWM dataset[6].

15.2 NISSUM BREDNING

Wavestar energy recorded the following wave spectra at the Nissum Bredning test site. The blue bars in each spectra are the correct measured spectral shapes (red bars are wrong). Table 33 gives details of the four tests which produced the spectra.

Table 33 Wave spectra measuring periods and summary statistics[44]

06/09/2006	Duration	Time	Hs (cm)	Ts (s)
Test 01	30 mins	11:40 – 11:50	29.73	2.36
Test 02	30 mins	11:55 – 12:25	30.52	2.5
Test 03	60 mins	12:25 – 13:25	36.8	2.67
Test 04	60 mins	13:32 – 14:32	38.1	2.74

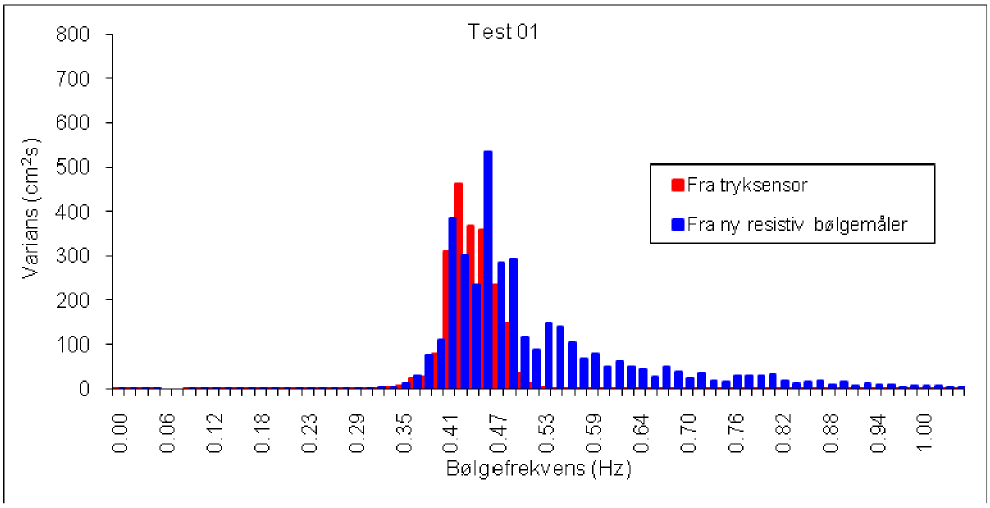


Figure 33 Nissum Bredning Wave Spectrum Test 01[44]

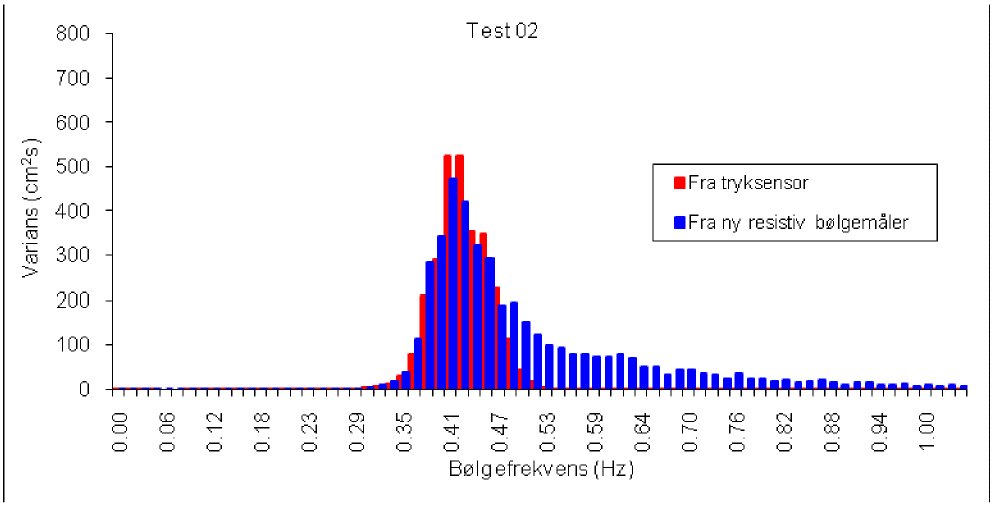


Figure 34 Nissum Bredning wave spectrum Test 02[44]

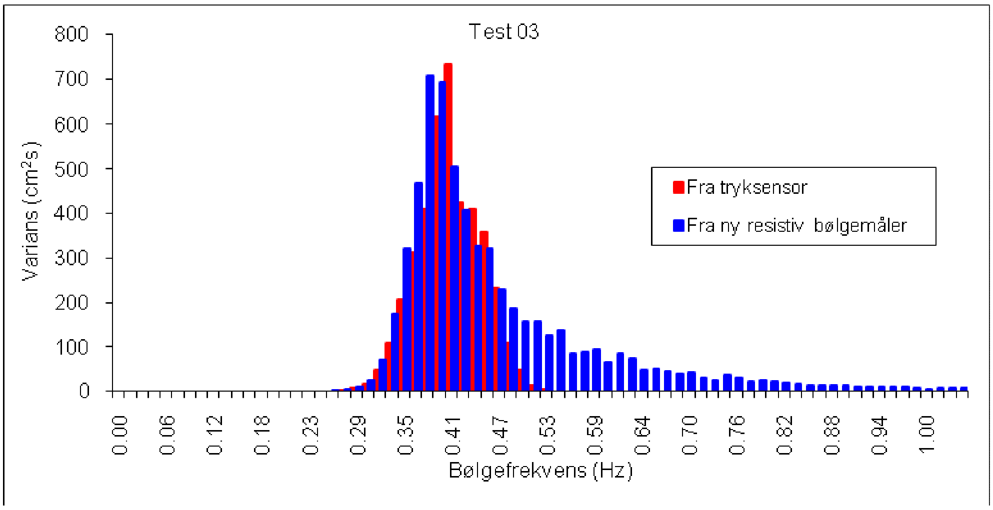


Figure 35 Nissum Bredning wave spectrum Test 03[44]

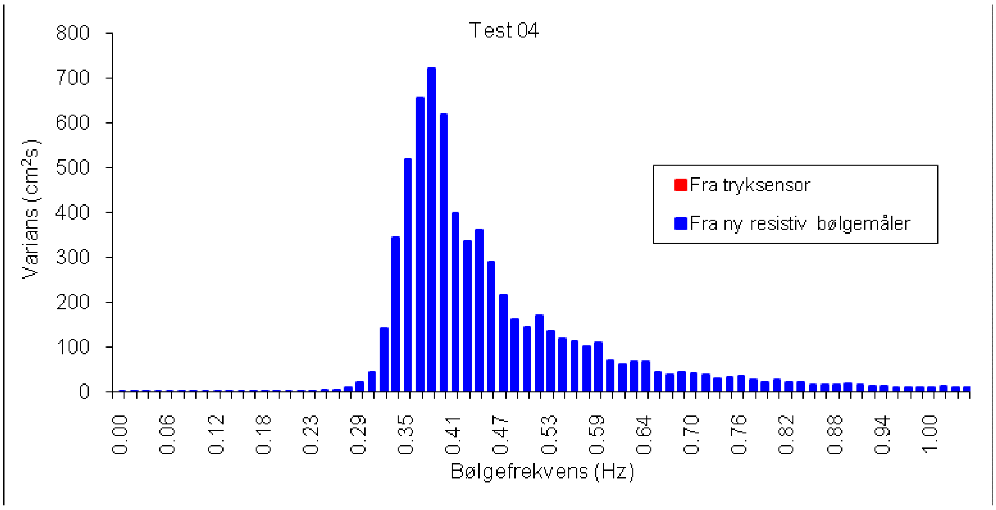


Figure 36 Nissum Bredning wave spectrum Test 04[44]

15.3 BIMEP

A wave resource estimation at the BIMEP test site was carried out in 2010[45]. As part of this, accumulated wave power flux spectra, predicted by the WAM model at the BIMEP station, were produced for 2009. These are shown for January-March 2009 (Figure 37), June-August 2009 (Figure 38) and January - December 2009 (Figure 39). As well as showing the seasonal variability in the power produced and the frequencies at which the most power is produced, these spectra show the direction of the various sea states.

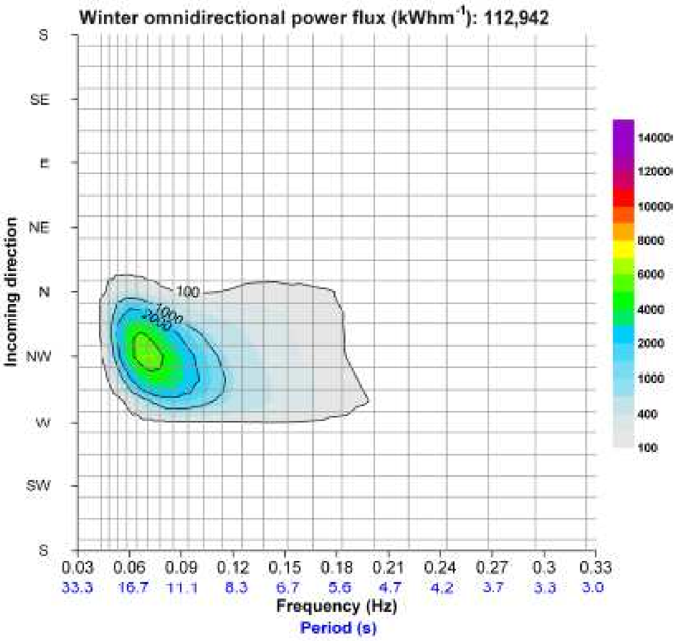


Figure 37 Accumulated wave power flux spectra predicted by the WAM model at BIMEP for January - March 2009. Contours lines shown are: 100, 1000, 2000 kWh/m[45]

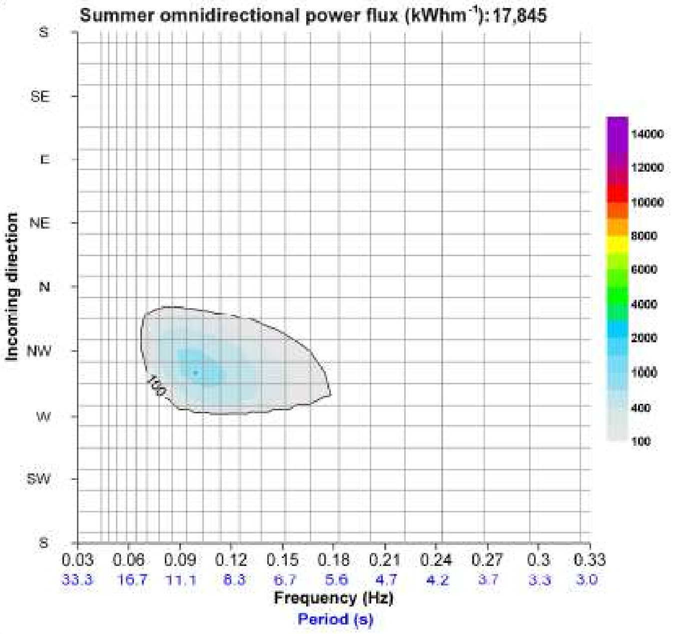


Figure 38 Accumulated wave power flux spectra predicted by the WAM model at BIMEP for June - August 2009 Contour line shown is 100 kWh/m[45]

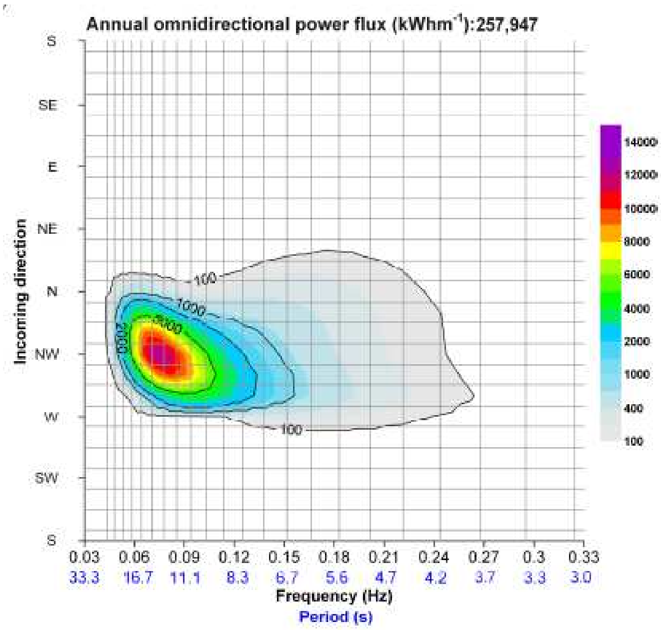


Figure 39 Accumulated wave power flux spectra predicted by the WAM model at BIMEP for January - December 2009. Contours lines shown are: 100, 1000, 2000 and 5000 kWh/m[45]

15.4 EMEC

A 2005 study on estimating power from wave measurements at EMEC[46] used four months of half-hourly spectral data (5718 spectra) to investigate a number of estimators of power. The months used were June & July and November & December of 2003, resulting in two months of summer data and two months of winter data. Figure 40 shows the average variance spectra for these two periods. The average spectra have been normalised by their respective maxima. Superimposed is a plot of group velocity for a depth of 50m. This has been normalised by the deep water value at each frequency.

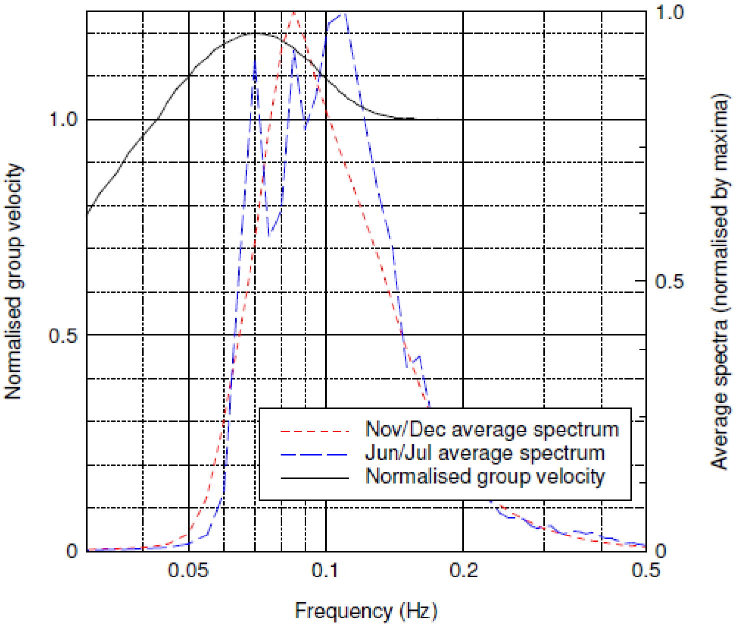


Figure 40 Normalised summer and winter spectra together with the variation of group velocity with Frequency in 50m depth.

15.5 LYSEKIL

Typical wave spectra for the Swedish Lysekil test site are shown below together with comparisons to the Pierson-Moskowitz (PM) and Bretschneider (BS) spectra. Measurements from a Datawell Waverider buoy were used with two data sets chosen to represent two typical sea states at this location. Data set A represents a calm sea state with *Hs*=1.13 m, *Te*=4.7 s, while Data set B represents a rougher sea state with *Hs*=2.52 m, *Te*=6.8 s. Figure 41 shows the results from Data set A together with a Pierson-Moskowitz and Bretschneider spectrum using the same summary statistics, with Figure 42 showing the same for Data set B. The legend in Figure 41 is incorrect and should be the same as the legend in Figure 42.

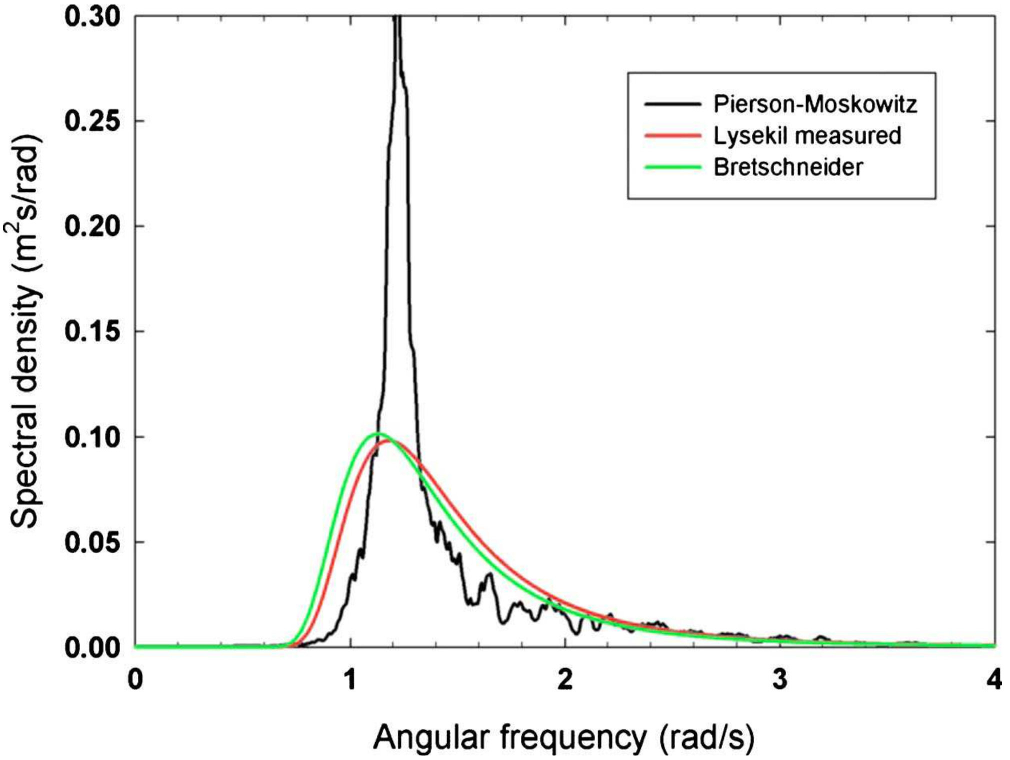


Figure 41 Spectrum calculated from data set A (Hs=1.13 m, Te=4.7s) together with fitted PM ($U_{19.5}$=7.3 m/s) and Bretschneider (*Hs*=1.13, w_m=1.13) spectra.

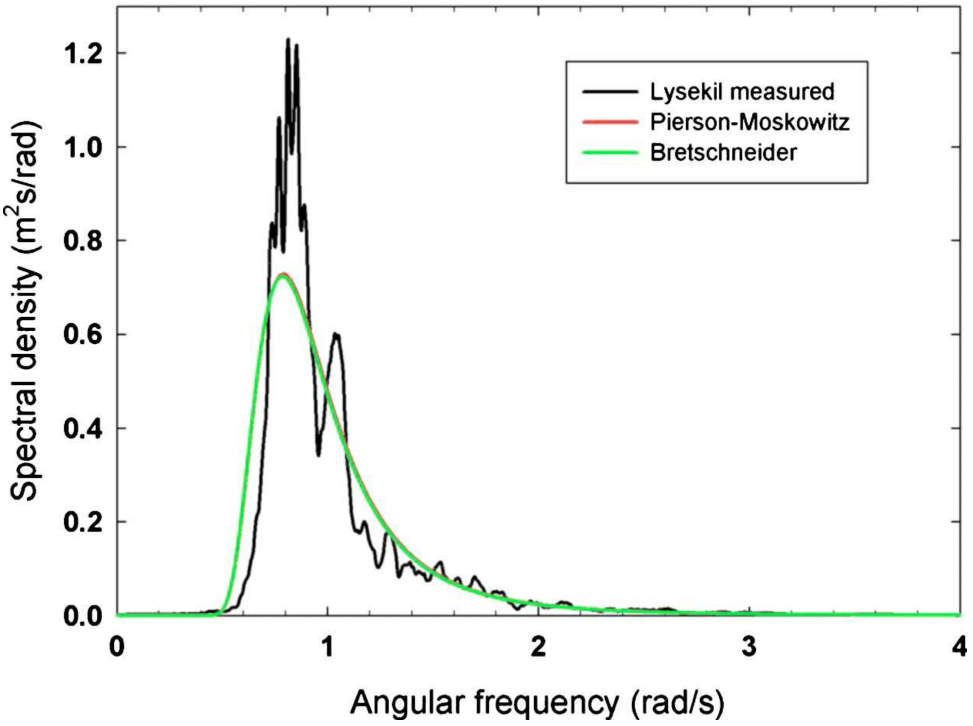


Figure 42 Spectrum calculated from data set B (Hs=2.52 m, Te=6.8s) together with fitted PM (U19.5=10.9 m/s) and Bretschneider (Hs=2.52, wm=0.78) spectra.

15.6 CONCLUSION

It is recommended that test centres produce wave spectra for their test sites and present them as has been presented for the WaveHub spectra (Figure 32) with the addition of a Bretschneider spectrum in each bin. This will enable a comparison to be made between the spectral shapes at various test sites, as they can all be compared to a Bretschneider spectrum for each bin or summary seaway statistic.

An example of such a comparison was given in [42] whereby the spectral shapes at the Galway Bay test site were compared to the WaveHub site. In this analysis a scatter diagram element was chosen with significant wave height, $1\text{m} \leq Hs < 2\text{m}$ and zero crossing period, $4\text{s} \leq T_z < 5\text{s}$. These ranges were chosen as they were common at both sites, having a percentage occurrence of 17.45% at Galway Bay and 19.09% at WaveHub, over the four winter months for which data was available at both sites.

Figure 43 shows the individual spectra that occurred within this single scatter element at both sites over the duration of the data set for Galway Bay and WaveHub respectively. The average of the spectral ordinates and the equivalent classical shaped Bretschneider spectra were also plotted against frequency. The summary statistics of the Bretschneider spectrum were the equivalent mid-points of the scatter diagram element, in this case $Hs = 1.5\text{m}$ and $Tz = 4.5\text{s}$[42]. The averaged spectra of each site for this combination of summary statistics are very different to each other and the classical shape of the equivalent Bretschneider spectrum. The WaveHub averaged spectrum has a distinctive twin peak while the Galway Bay average spectrum appears very broad.

This again shows that for the same summary statistics, two wave deployment sites can produce different spectral shapes and also that a WEC being excited in these conditions at both sites would produce significantly different power levels. It also highlights how the use of data from similar elements of the scatter diagrams and the inclusion of the classical Bretschneider shape enables valuable comparisons to be made between two different deployment sites.

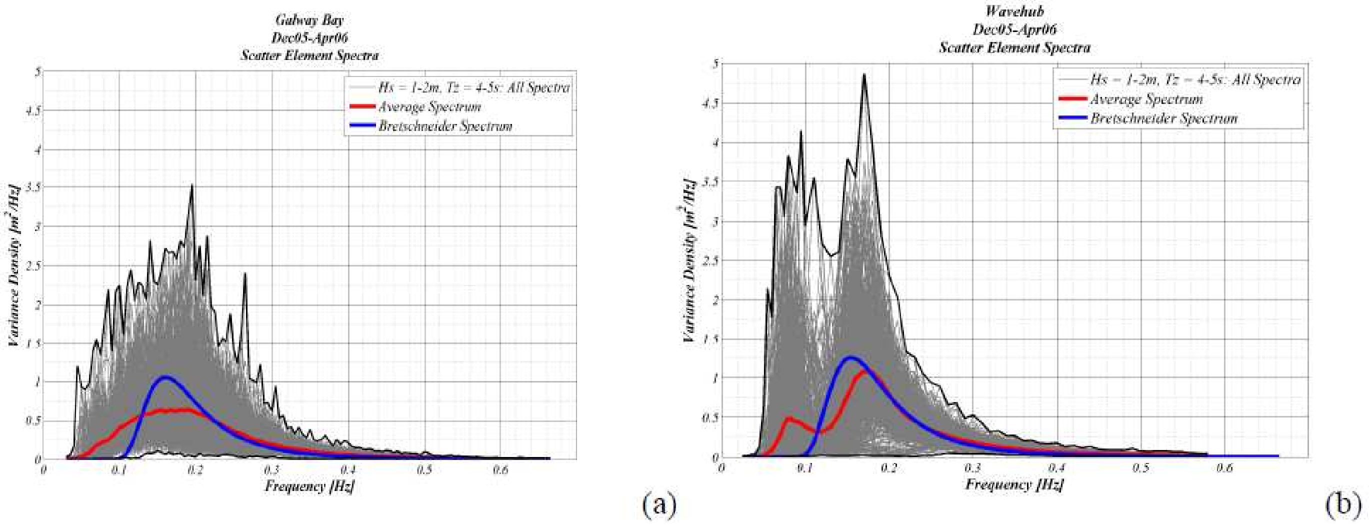


Figure 43 Individual, averaged and classical spectra within the selected scatter element, Hs: 1-2m and Tz 4-5s for (a) Galway Bay and (b) WaveHub [42]

16 TIDAL TEST SITE REQUIREMENTS

The purpose of tidal energy test sites is to make it technically and financially easier for device developers to carry out the extensive and expensive large and full scale testing of devices in real sea conditions. During open ocean testing of devices utilisation of established test centres should reduce the challenges facing unproven heavy engineering operations at sea as well as alleviating permitting and licensing issues and conflicts with other maritime users. Established centres should offer easier grid connection that includes performance monitoring instrumentation. Use of the centres could also satisfy the requirement for an independent reviewer to oversee and validate the data collection methodology. It is anticipated that service vessels and support industries will set up in the areas around the test sites which will gain experience in their fields, from which device developers should benefit from.

Tidal test sites should, in general, be similar to locations where commercial deployments are likely to take place. The following are typical criteria for a full scale tidal site:

- Strong peak tidal flow- a minimum cut-off value of 1.75 m/s (3.5knots)
- Depth greater than 20m
- For purposes of grid connection, maximum 5 miles from land
- Avoidance of commercial shipping lanes
- Avoidance of physical/geographical constraints
- Avoidance of conflict with other marine industry and conservation stakeholders.

As well as the above, full scale tidal energy test sites should possess the following in order to fully support device developer's progress to commercialisation.

16.1 MET-OCEAN CONDITIONS

The site should have the correct met-ocean conditions of tidal current velocity, water depth, sea-bed conditions, low waves, no ice etc. Past data from the site for all these parameters should be available. In general the conditions should be similar to those of the proposed commercial sites. Of particular interest are the occurring tidal velocities at the device. The physical processes controlling the ocean and atmosphere have been studied for a considerable time and are reasonably well understood. However, tidal energy is a new technology so the level of detail needed to fully investigate and understand a device's overall performance and loadings at sea are still being discovered. This leads to the recommendation of gathering as much environmental information as possible throughout the sea trial period.

Prior to carrying out any sea trials, design of the reaction subsystem components needs to be carried out for the intended deployment site. For this, met-ocean data needs to be obtained prior to deployment of the device. This includes both operational and extreme conditions. If the device is bottom mounted, geotechnical data is required. An understanding of the wave climate is also required to probabilistically estimate the deployment, recovery, service and maintenance windows.

16.2 GRID CONNECTION

An electrical grid connection should be available for full-scale pre-commercial devices. The connection voltage and power level should be at an appropriate level and onshore substations with monitoring equipment should also be available. The test sites should also provide convenient connection mooring berths for the straightforward deployment and recovery of devices.

The net electrical power of the tidal devices should be measured based upon measurements of current and voltage on each phase. The power measurement device should be mounted as close to the network connection point of the device as is practicable to ensure that only the net active power output, delivered to the electrical power network, is measured. Losses in cables and transforming equipment should be calculated by a method that is acceptable to a relevant accreditation body.

16.3 CURRENT MEASUREMENTS

Although the typical tidal current velocities should have been established prior to use of the site, real-time measurements during the sea trials must be conducted. Prior to deployment at the site the theoretical sea state statistics must be validated against measured records at the same station. Current measurements are important at tidal test sites primarily for the following reasons

- to establish the input power
- to establish turbulence intensity levels
- to input into device mathematical design models

- to determine the structural induced loading
- to establish directionality of the flow

Primarily empirical tidal data should be obtained from direct, contact measurement. The current measuring device must give an accurate representation of inflow to the device. In general the recording devices should be installed at positions close to the intended tidal device test location, to provide an accurate measure of tidal current conditions experienced in operation. Ideally an ADCP should be positioned 2 characteristic lengths (generally rotor diameters) directly upstream of the device. The device to be installed should be capable of recording the temporal variation in horizontal current velocity vertically throughout the water column. In many cases the ebb and flood flow velocities differ in magnitude, therefore two measurement devices are beneficial to quantify the inflow from the ebb and flood tides. This is even more important if there is a degree of ‘swing’ whereby the direction of the ebb and flood tides are not directly opposed. The measurement device should be located in a depth no more than ±10% of the intended location of the tidal device. It should also be a bottom mounted recording device.

The recording period required, in order to establish an accurate resource assessment, should be determined with consideration of the nature of the tides and the complexity of the ambient tidal signal in the project area. Due consideration should also be given to the possible stochastic influence of surges upon the tidal currents recorded during the resource measurement stage, and to the temporal position of the recording period within the equinoctial and the nodal cycles. The tidal current regime should be monitored from as early a date as possible in the development process. The effects of seasonal migration of currents need to be considered, since they do not necessarily retain the same position throughout the year and their potential capacity to relocate may exert an influence upon predicted long-term power capture.

16.4 METEOROLOGICAL AND WAVE MEASUREMENTS

Met-ocean data for a sea trial site should be obtained prior to deployment of the device. This is to ensure the correct environmental criteria have been used during the design of the device and that deployment & recovery will be possible in a practical time frame. Maintenance and service schedules must also be accommodated.

The wave field data is of significant importance as it affects installation, maintenance and may impact operation for certain tidal energy devices. The reasons for obtaining accurate wave data at a tidal test site are to determine the wave climate characteristics for operations (deployment, recovery, service etc.) at sea, to quantify wave-current interactions at the site and to cross reference with the extreme event horizons.

Wind measurements are also important to correlate with the concurrent waves, to establish the freeboard windage and general loading and to determine the heading control for the moorings. Other parameters should be monitored with regards to environmental effects, corrosion and marine growth.

In areas where the density of seawater would be expected to vary, a device for measuring the temperature and salinity should be deployed alongside the current meter. The recorded dataset of temperature and salinity should be investigated to consider the effects of varying water density upon the power resource.

16.5 BATHYMETRY

A survey of the bathymetry of the test site should be carried out to ensure that it is free from obstacles and topology that could affect the performance of the tidal devices, or adversely affect the local quality of the tidal currents. Sub-bottom profiling might also be required in situations where there is a considerable volume of suspended sediment, or layers of liquefied mud that may affect the device installation. Prior to the detailed design stage, an additional survey is likely to be necessary, as this may uncover issues that sonar surveys do not.

16.6 PROXIMITY TO SUPPORT FACILITIES

As with wave sites, tidal test sites should be easily accessible with suitable travel and communication infrastructure. The site should be close to a service port and access harbour. These ports should allow for the local launch and recovery of the devices with harbours nearby which can facilitate service vessels. The site should also be close to experienced marine engineering yards with mobile operating capability. If testing of a number of devices or arrays is to take place then local fabrication facilities may be required as the transportation of a large number of devices may not be feasible.

16.7 LICENSING AND PERMITS

One of the main benefits of test sites is that they can provide a pre-consented testing area which reduces the amount planning and licensing that device developers have to undertake. This can save both time and money. Test sites therefore should have in place simplified licensing and consenting regimes. As devices are likely to be tested in the open ocean for the first time at test sites, there should be an environmental monitoring programme in place so that the effect of the devices on the environment and the effect of the environment on the devices can up fully understood.

16.8 ONSHORE MONITORING FACILITIES

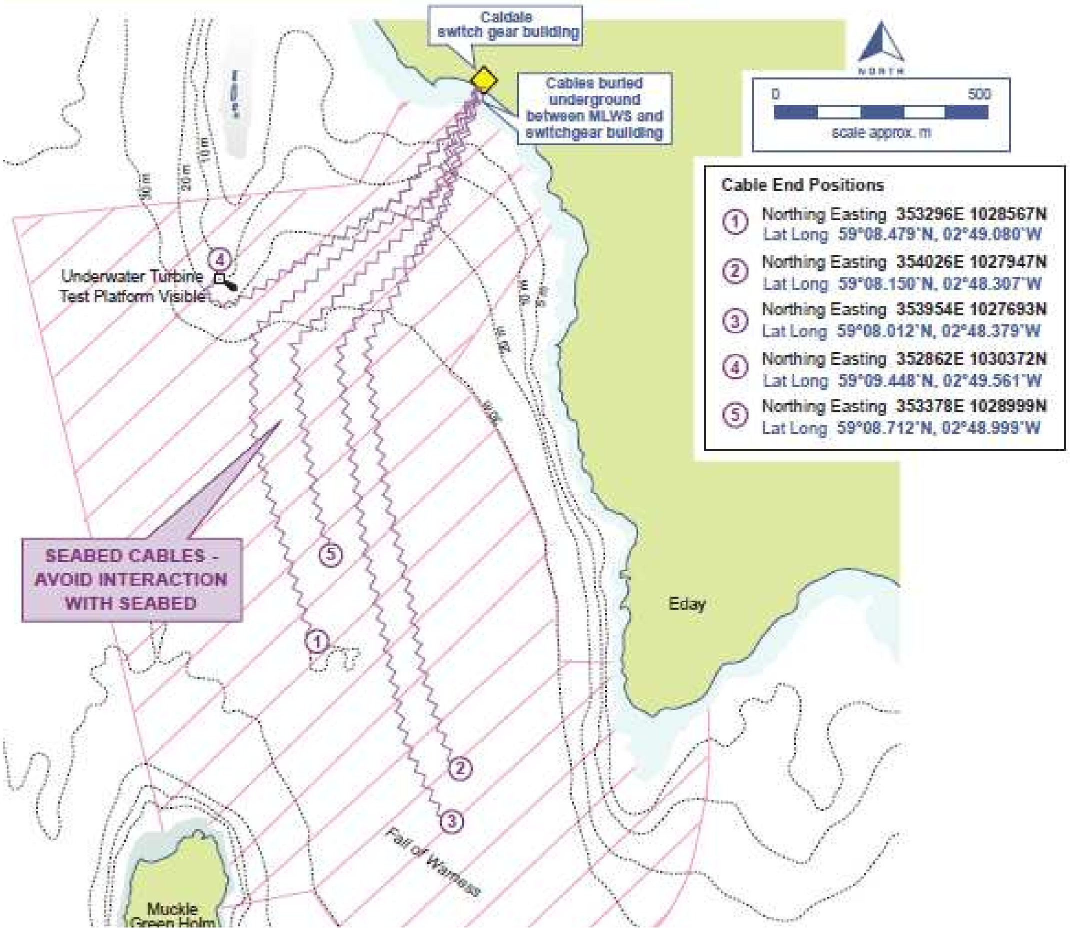
As well as measuring as many parameters as possible, test sites should have adequate onshore-data receiving facilities which will allow for the synchronisation and storage of the data for analysis. Onshore facilities should be in place to monitor the power output to the grid for comparison with the measured tidal currents, sea state and device parameters. As there are a series of test centres established it could become customary to use more than one test centre during a devices passage from pre-production through to pre-commercial stage. This may be required to satisfy future clients of the product that the published performance figures for the tidal device are intersite portable. Therefore common methodologies for the testing of devices should be in place across different test sites that facilitate the comparison of different devices tested at different sites.

17 EMEC TIDAL ENERGY TEST SITE SCOTLAND

17.1 INTRODUCTION

The EMEC tidal test site, at Fall of Warness, is located to the west of the island of Eday in the Orkneys. The site was officially opened in 2007 with OpenHydro being the first developer to deploy there (Figure 44). In 2010 both Tidal Generation and Atlantis Resources both deployed at EMEC with Hammerfest Strom, Voith Hydro and ScotRenewables all planning to install devices at EMEC in 2011. The site provides a full tidal regime with five grid connected berths. There is nearby access to sheltered water with harbour facilities at Kirkwall and Hatston, offering access for larger scale vessels. The same support facilities are available as for the wave energy test site, with EMEC operating both test sites from their Stromness centre [47]. An overview of the Fall of Warness tidal test site is shown in Figure 45, within which the locations of the five test berths can be seen. The position of the ADCPs at the tidal site, which primarily measure the velocity and duration of tidal currents flowing through the site together with water depths over the site, are shown in Figure 46.

Figure 44 OpenHydro turbine installed at EMEC [48]



Cable End Positions

①	Northing Easting	353296E 1028567N
	Lat Long	59°08.479'N, 02°49.080'W
②	Northing Easting	354026E 1027947N
	Lat Long	59°08.150'N, 02°48.307'W
③	Northing Easting	353954E 1027693N
	Lat Long	59°08.012'N, 02°48.379'W
④	Northing Easting	352862E 1030372N
	Lat Long	59°09.448'N, 02°49.561'W
⑤	Northing Easting	353378E 1028999N
	Lat Long	59°08.712'N, 02°48.999'W

Figure 45 Fall of Warness tidal test area [49]

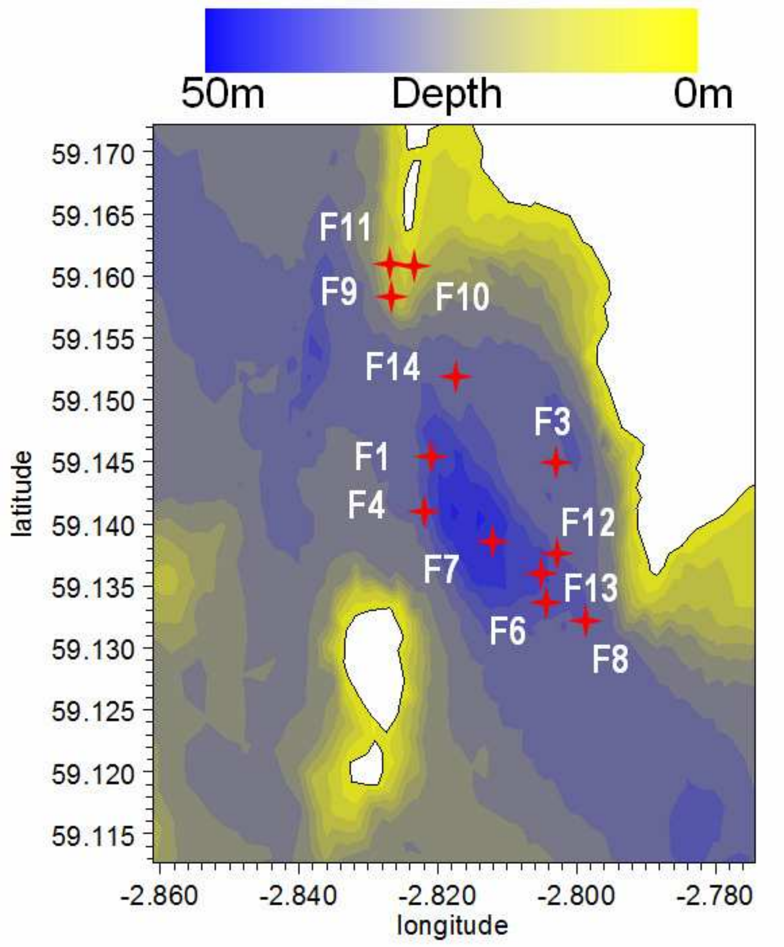


Figure 46 Fall of Warness tidal test site with the water depth and position of ADCPs shown[50]

17.2 RESOURCE

At the Fall of Warness site, the tidal stream flows up to 4 m/s (7.8 knots) in spring tides and 1.5m/s in neap tides [49]. The flow pattern at the Fall of Warness site, together with the locations of the ADCP measuring stations, is shown during high tide in Figure 47 and low tide in Figure 48.

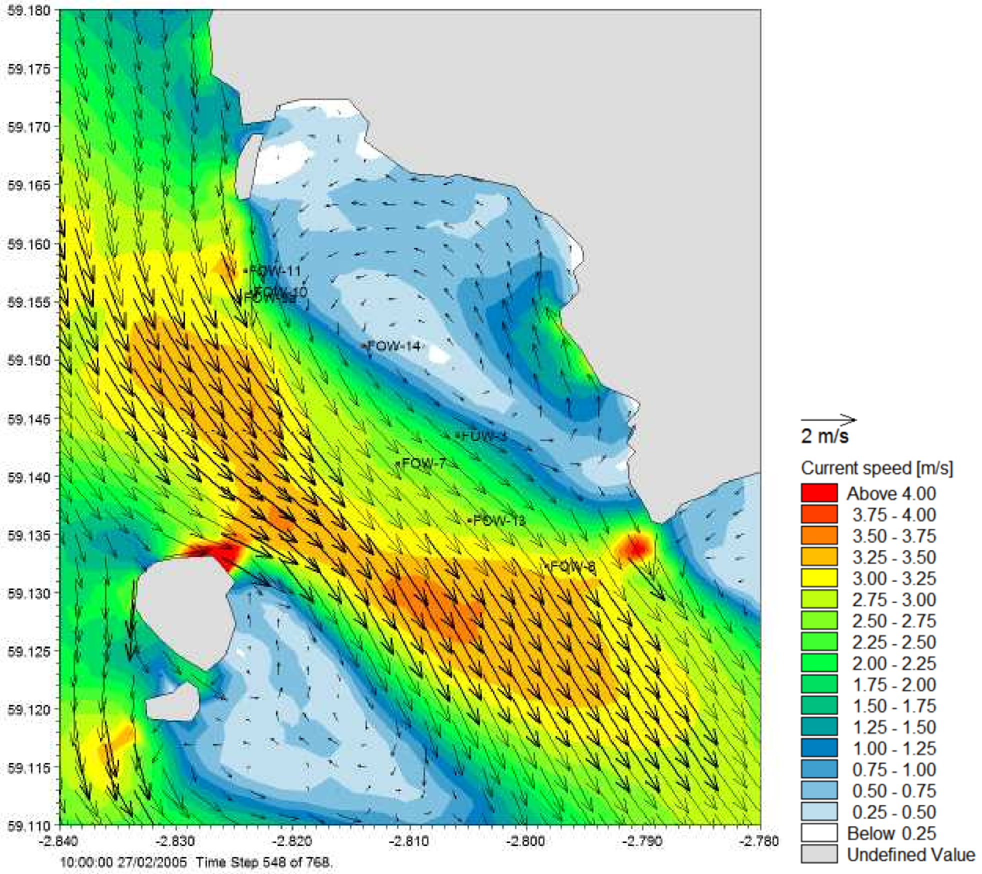


Figure 47 Flow pattern during high tide at Fall of Warness with measuring stations indicated [50]

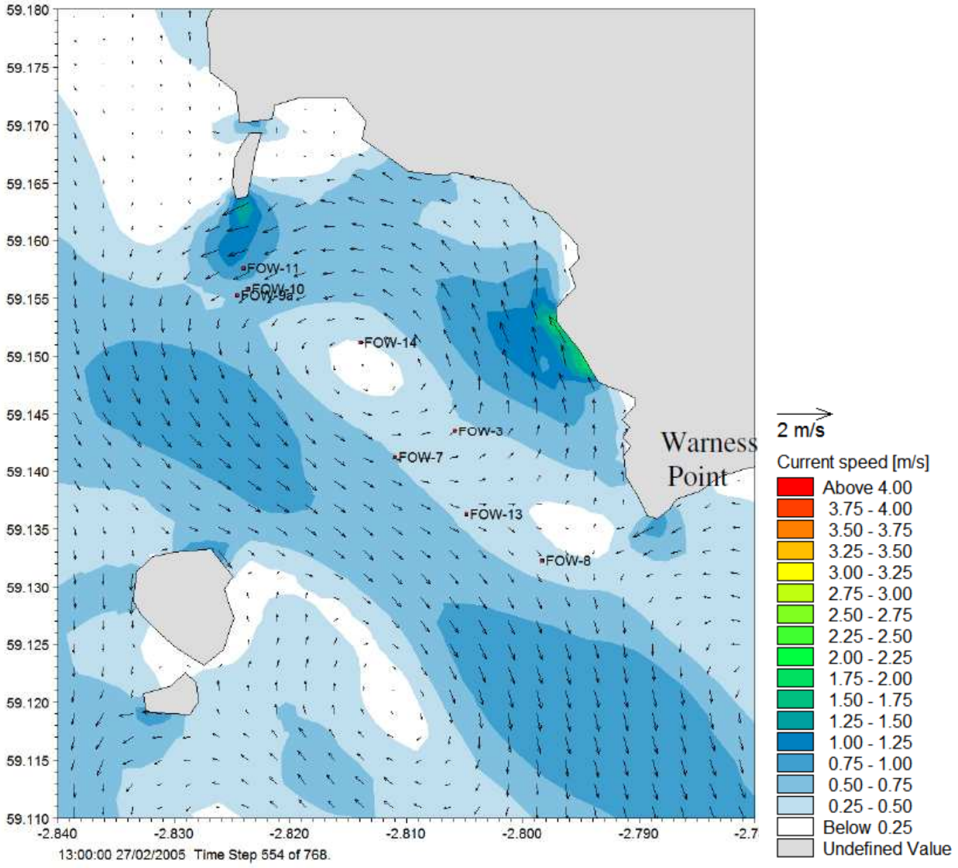


Figure 48 Flow pattern during low tide at Fall of Warness with measuring station indicated [50]

17.3 MAIN SITE CHARACTERISTICS

A description of the infrastructure and services available at the EMEC tidal site is given in Table 34.

Table 34 EMEC Tidal Site Infrastructure and Services

	EMEC Tidal Site
Scale	Full Scale
Water Depth	25-50m
Site Area	2km x 4km
Berths	Five grid connected berths
Grid Connection	Five 11kV subsea cables extend to the centre of the tidal stream. Developers are responsible for installing their devices, connecting to the test designated cable and removing their devices when testing is complete[49]. The subsea cables are connected to an 11kV coastal control and switching station.
Current Data Collection	Seabed mounted Acoustic Doppler Current Profilers (ADCPs) are used to acquire water level, current and wave data. The instruments measure the velocity and direction of current at high vertical resolution and high frequency sampling. A series of deployments have taken place to help characterise the tidal and wave conditions in the test area [49].
Weather Data Collection	A purpose built weather station on Eday island is located close to the test site. It provides developers with air temp, wind speed and direction, humidity, rainfall and barometric pressure [49].
Other Data Collection	It is intended to measure tidal power generation by comparing the real-time power generated against the tidal flow with the measurement of electrical power supplied to the grid via the substation allowing the assessment of the performance of each device [47].
Substation/ Onshore Monitoring	From each of the five berths, the subsea cables follow back along the seabed and then pass under the beach and into an external housing next to the Caldale substation on Eday island. An adjacent laydown area then provides an optional area for developers to use conditioning equipment for converting from the level at which they generate to grid compliant electricity. Underground ducts then connect the cables through to the switchboard in the substation building. The substation building has four separate areas: the HV switchroom, communications room, personnel room and the standby generator room. The adjacent building on site holds the Scottish and Southern Energy transformer where the 11kV is transformed to 33kV and fed into the national grid [47]. In Stromness EMEC has a suite of offices and data acquisition facilities, including areas dedicated to specific developers. Fibre-optic and data networks provide developers with direct and secure access to their own devices [49].

17.4 LICENSING AND PERMITS

The licensing and permitting regime is similar to the wave test site in that EMEC applies for the necessary licenses to deploy on behalf of client developers. The process requires developers to produce an Environmental Statement (ES) along with a Navigational Risk Assessment (NRA), Decommissioning Plan and a Third-party Verification Report (TPV). EMEC then uses this documentation to accompany the appropriate license applications [2]. An Environmental Impact Assessment, carried out in 2005 for the tidal site, showed that the particular environmental sensitivities are mainly a nearby breeding colony of grey seals (a European protected species) and a breeding colony of cormorants. This area is also used by other sea mammals and cetaceans, and other diving seabirds. The potential for impact on these sensitive species therefore needs to be adequately addressed by developers in any application for specific device deployment licenses [49].

17.5 REASON FOR CHOOSING THIS LOCATION

The tidal test site at the Fall of Warness, to the west of the island of Eday, was chosen for its high velocity marine currents which reach almost 4 m/s (7.8 knots) at springs tides.

17.6 ADDITIONAL INFO

Demand for existing tidal testing berths at EMEC exceeds supply and there is a significant waiting list for device developers to occupy berths. In addition, due to the adverse weather conditions, extreme tidal currents and wave activity, some devices have been damaged during deployment and operation[51].

18 FORCE BAY OF FUNDY CANADA

18.1 INTRODUCTION

Force (Fundy Ocean Research Centre for Energy) is Canada's leading research centre for in-stream tidal technology, located in the Bay of Fundy, Nova Scotia. Force is a non-profit institute supported by both public and private funding[52] whose purpose is to test the performance and interaction of tidal turbines in the Bay of Fundy environment. As a test centre it allows developers to share costs, limit potential impacts, test under similar conditions and supply power to the grid by providing a shared observation facility, submarine cable, grid connection and environmental monitoring at a pre-approved test site.

Forces test site is in the Minas Passage area of the Bay of Fundy 10km west of Parrsboro, Nova Scotia (Figure 49). Minas Passage is only 5km wide and bordered by Basalt cliffs. It is at the entrance to the Minas Basin, the region with the world's highest tides. OpenHydro became the first developer to use the test facility in 2009 when they deployed a 1MW device (Figure 50) onsite. There are plans for Alstom to deploy a Clean Current Turbine in Summer 2011 with an MCT turbine planned for deployment in Summer 2011 or 2012[53]. An Atlantis turbine is planned to occupy the fourth berth in 2012. The four berths at the site have so far not been grid connected however; this is expected to be completed in 2011 with the construction of the electricity substation and the cable deployments.

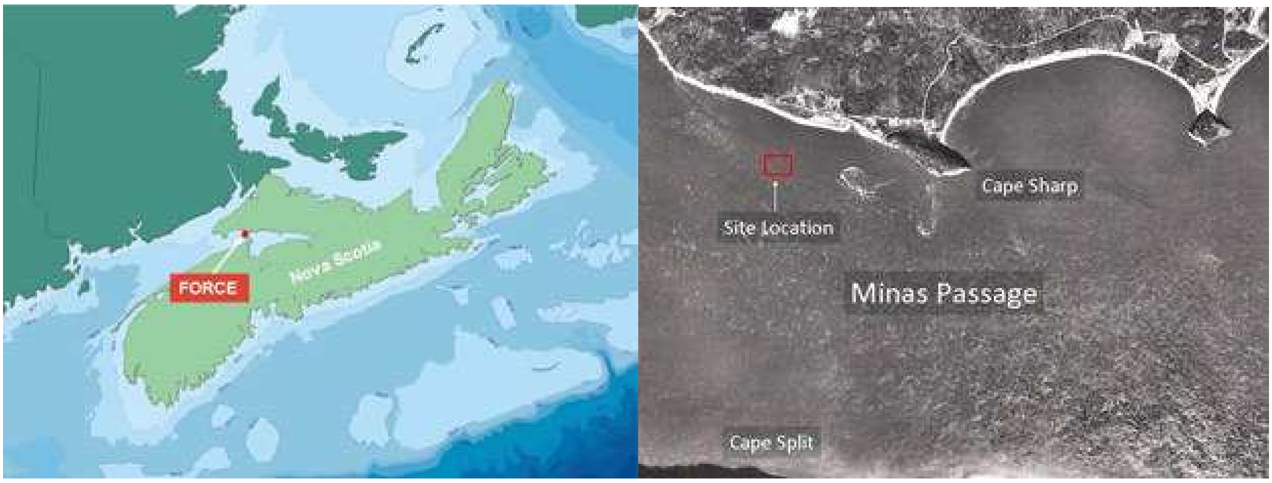


Figure 49 Location of FORCE test site [54]

Figure 50 OpenHydro turbine prior to installation in Bay of Fundy [55]

18.2 RESOURCE

At mid-tide the current in the Minas Passage is equal to the estimated flow of all the freshwater rivers and streams in the world combined. With the incoming tide, about 14 billion tonnes of sea water flows through Minas Passage into the Minas Basin, creating the highest tides in the world[52].

Tidal devices operating in the Bay of Fundy may experience tides moving at speeds up to 5 m/s (10 knots), expanding up to 5 km horizontally, and rising up to 16 meters vertically [52].The straight flowing and strong currents have eroded the seabed to depths over 135m providing a solid and stable foundation for the placement of the devices[54]. A simulation of the speed and direction of the flood jet through the Minas Passage is shown in Figure 51.

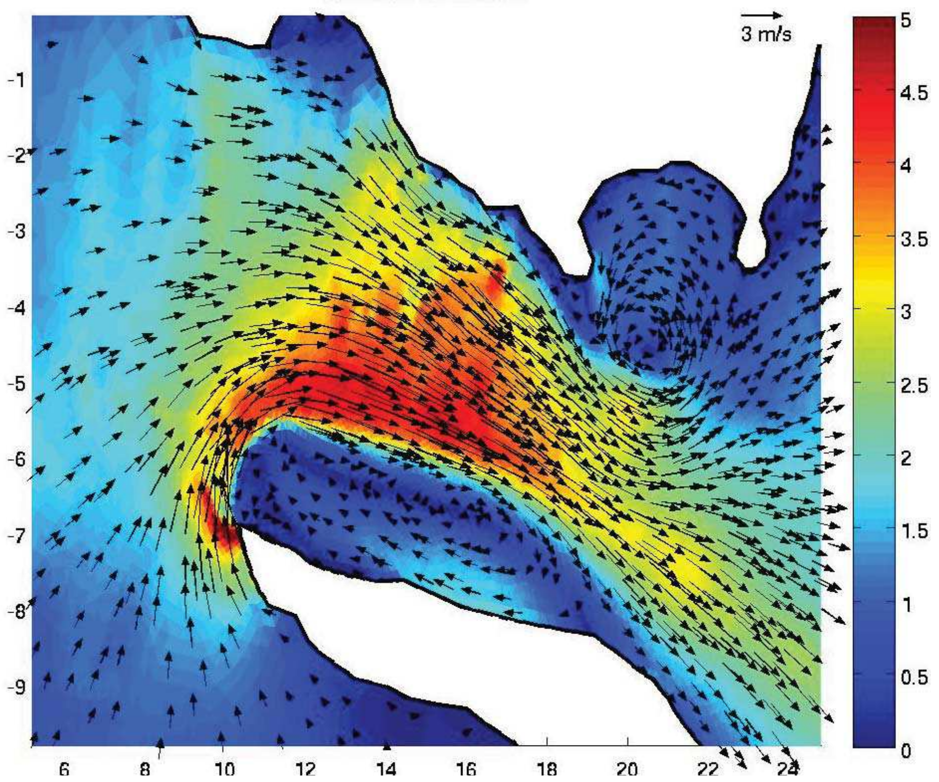


Figure 51 A plot of the speed and direction of the flood jet from high resolution 3D simulation of the flow through the Minas Passage. The asymmetry of the jet and the large eddies north and south of the jet are visible [56].

18.3 MAIN SITE CHARACTERISTICS

A description of the infrastructure and services available at the FORCE Bay of Fundy test site is given in Table 35

Table 35 Infrastructure and services provided at FORCE Bay of Fundy

Bay of Fundy	
Scale	Full Scale Prototype
Water Depth	45m at low tide with a sediment free bedrock sea floor
Distance to Shore	—
Site Area	—
Berths	Four berths to be grid connected in 2011
Grid Connection	The grid connected berths are planned to be connected via submarine cable to the onshore facility that contains the power conditioning equipment. The onshore facility is proposed to be connected to a purpose built transmission line to export the power. Each of the four subsea cables will have a capacity of 16 MW (64MW total). Each 34.5kV cable is designed to allow the addition of more devices in the future, which could total up to sixty-four 1MW devices[57].

Current Data Collection	Data collection has been underway, with the priority being site selection for the facility. Project partners have so far created • High resolution bathymetry maps • Preliminary ADCP data • 3D digital hydrodynamic model simulations [58]
Weather Data Collection	—
Other Data Collection	Once the test turbines are in place, information will be collected on the performance of the turbines, the effects of the turbines on the environment and the effects of the environment on the turbines. Sensor packages will monitor the turbine activity and stability of the gravity base to the changing tides and currents. Fish monitoring equipment will assess how mammals and fish behave both at the turbine sites and in nearby control locations. Repetitive surveys will assess seabed stability around the structures and samples and video will be collected to monitor possible change[54].
Substation/Onshore Monitoring	The proposed onshore electrical facilities will consist of a substation and power line to Nova Scotia Power's system. The substation will initially operate at 5MW but is capable of being upgraded if the site expands to include a commercial deployment. The proposed purpose built transmission line could also be upgraded to cater for any future expansion without significant investment[59]. The $370m^2$ onshore facility will also house a visitor centre and research facilities [54].

18.4 LICENSING AND PERMITS

The pre-approval of the site means that 'soft infrastructure' such as permits; approvals and environmental monitoring are provided. Developers intending to test their technology at FORCE will not be required to make an Environmental Assessment as long as the device either:

- Occupies one of the testing berths at Force
- Replaces one the turbines tested
- Is not predicted to have significantly different environmental impacts from the previous technologies tested[54].

Nova Scotia requires tidal devices to adhere to strict environmental safety standards; as a result devices undergo monitoring while in operation, and may be removed if required. FORCE receives ongoing monitoring oversight through an environmental monitoring advisory committee[52].

18.5 REASON FOR CHOOSING THIS LOCATION

The location of the Bay of Fundy test site was selected after 12 months and $1 million in research. The Bay of Fundy is a good site for tidal power development because of the very strong, uniform and predictable currents that results from the high tides. The regions where these currents occur are very wide and long, differing from most other regions of strong water flow that occur in narrow restricted passages[54]. A 2006 study by the EPRI [60] assessed the performance, cost and economic assessment of potential tidal in stream plant sites. Of the seven sites EPRI considered, the Minas Passage site had the largest tidal in stream energy resource and was five times larger than the second largest. It found that fabrication, assembly and installation could be performed out of Halifax Nova Scotia, Dartmouth Nova Scotia or Saint John New Brunswick. Operation and maintenance activities could be performed out of Parrsboro. A grid connection could also be established at a substation in Parrsboro.

18.6 ADDITIONAL INFORMATION

The strong tides at this site do create some operational difficulties. They make it difficult for survey vessels to hold position in the Minas Channel. Experience to date at the site suggests that it is difficult to deploy instrumentation and cables and there is a short window in which this can be done. The working time onsite is limited to periods when the current velocities are less than 3 knots (from half tide to low and back to half). Also the water levels can fluctuate by as much as 30 feet meaning that the local harbours at Halls and Parrsboro are only accessible for 2 hours on either side of high tide [53]. There have also been issues with the OpenHydro turbine installed at the site in 2009 in that the high flow has resulted in two of the turbines blades being lost [61].

19 SOLENT OCEAN ENERGY CENTRE (SOEC) ISLE OF WIGHT ENGLAND

19.1 INTRODUCTION

The Solent Ocean Energy Centre (SOEC) is a proposed development and support centre for tidal energy devices that will include a pre-consented 10MW demonstration site for single full-size devices and small arrays in the English Channel. It is proposed for the demonstration site to be located off St Catherine's Race on the south coast of the Isle of Wight (Figure 52). This site will provide ten grid-connected testing berths with the continued monitoring of array performance, device interaction effects and environmental impact. The centre will also consist of a pre-consented nursery site for testing of smaller scale devices or full scale prototypes in more benign conditions(see section 20.2), as well as plans for a commercial 100MW site which could have a potential capacity of up to 250MW [51].

Figure 52 Location of SOEC onshore support centre, nearshore nursery site and offshore deployment site [51]

Both the full scale and nursery sites will be supported by shore-side facilities for data analysis, monitoring and control. The shore side facilities include a Portside Facility and Technology Centre encompassing the following activities associated with tidal technology:

- R&D
- Manufacture and assembly
- Operational planning
- Deployment
- Operation and maintenance actions
- Performance monitoring
- Decommissioning [51]

Within the Portside Facility and Technology Centre, tidal device and project developers will be able to establish office bases, carry out design work and modifications in workshop units and assemble up to full-size tidal turbines for deployment in nearby sites. The facility will have suitable wharfage for deployment vessels and cranes to load devices on and off the vessels[51]. The location of the Portside Facility and Technology Centre has yet to be determined, but there are potential locations in the Solent region – principally Portsmouth, Southampton and the Isle of Wight. SOEC has had early discussions which indicate a strong interest from existing facility owners to re-equip their facilities to serve the tidal energy industry, once the offshore facilities have received full consent[51].

SOEC is supported by project partners and a steering group consisting of QinentiQ, Gifford, BAE Systems, Ricardo, Halcrow, The University of Southampton, Marine South East and the Renewable Energy Association. The Isle of Wight Council are the government lead and Envirobusiness are the project managers [51]. In early 2011 the Isle of Wight Council applied for £21m from the UK's Regional Growth Fund to finance the £30m project. The council will hear by June 2011 if the application has been successful and, providing that the further £9m can be raised, the project could be up and running by 2014 [62].

19.2 RESOURCE

A 2006 feasibility study into the case for establishing a research centre for ocean energy technologies on the Isle of Wight [63] identified the area off St Catherine's Race on the southern side of the Isle of Wight as having a peak tidal stream between 1.9-2.25 m/s (3.8-4.5 knots) with a water depth between 18 and 42m

19.3 REASON FOR CHOOSING THIS LOCATION

In the process of selecting a site it was envisaged that the full scale demonstration facility should be a suitable site for the long term deployment and monitoring of prototype devices under realistic in-service conditions. This facility should also be situated in an area in which an operational 'tidal energy farm' may eventually be located. As well as these, the 2006 feasibility study gave the following as the primary requirements for the offshore demonstration site

- Strong peak tidal flow- a minimum cut-off value of 1.75 m/s (3.5knots)
- Depth greater than 20m
- For purposes of grid connection, maximum 5 miles from land
- Avoidance of commercial shipping lanes
- Avoidance of physical/geographical constraints
- Avoidance of conflict with other marine industry and conservation stakeholders[63].

The study concluded that the area south of St Catherine's race would best meet these requirements although there may be some conflict with shipping and the area is close to a marine Special Area of Conservation.

19.4 ADDITIONAL INFO

In assessing the feasibility of a test site, consultation with device developers resulted in an expression of interest in a site located near the south of England. Although EMEC is an established test centre and a world leader in the field, developers expressed a preference for a site which could offer easier travel for engineers, greater device accessibility(which can be limited in EMEC due to shorter winter days and inclement weather) and strong tidal currents in a less aggressive wave climate[63].

According to the feasibility study an offshore test site at SOEC would have the following advantages over EMEC

- A stronger electricity network and substantial demand for electricity
- Less aggressive wave environment, permitting longer windows for deployment and maintenance
- Good national and International travel access
- Milder climate and longer daylight hours in winter

It is envisaged that developers may wish to test prototypes at SOEC in order to gain confidence in their survivability prior to future deployment in the harsher environment at EMEC [63].

20 NURSERY/SCALE TIDAL SITES

Nursery or scale sites will be used to perform full-system sea trials which will involve testing of large, rather than full, size devices. These trials represent the first time the device will be in a real sea environment. Their primary purpose is to verify all the systems and sub-systems at a scale large enough to assemble a fully operational power take-off (PTO) but still small enough for the device to be reasonably easily handled. This is an extremely important stage and the final opportunity for limited design changes and modifications to be carried out economically. This means extensive met-ocean monitoring should be conducted to assist in the major data analysis that accompany these trials. Because the tidal conditions should also be appropriately scaled, the acquisition rate and duration should be adjusted accordingly.

The tests will typically involve devices at reduced scales (1:2 to 1:4, in some cases down to 1:10) tested in locations with relative good tidal flows but with ‘benign’ sea states. Such sites offer relatively easy accessibility as sea states do not normally interfere with boat traffic, and light equipment can be used for deployment and maintenance. However, conditions such as wave action and turbulence are not benign with respect to the dimensions of the devices, making this phase the first seaworthiness proof, which is of particular importance to the hydrodynamic subsystem.

At this phase, the PTO subsystem will have to handle relatively small power levels (typically less than a few hundred kW). Grid connection may therefore not be a technical necessity and will depend mainly on its accessibility and cost. Focus is given to the PTO’s performance evaluation with different control laws. First insights on the PTO’s construction, installation, operation and maintenance will be also experienced.

The following are typical tidal nursery sites requirements:

- Water depth between 10-30 meters (minimum depth being governed by a requirement for useful demonstration of installation and operational methods, maximum by decompression times for divers on normal air-breathing apparatus)
- Relatively strong tidal current flows of 1-2 m/s (2-4knots)
- Shelter from wind with minimal exposure to waves
- Transit time to local harbour from site of less than 4 hours
- Nearby shore side facilities including lay down areas
- Avoidance of commercial shipping and activities by other marine stakeholders, such as fishing and dredging
- Avoidance of Special Areas of conservation (SAC’s) and other environmental constraints

20.1 EMEC NURSERY TIDAL SITE SCOTLAND

20.1.1 Introduction

As well as providing a test site for full scale tidal devices, EMEC is currently installing a nursery tidal site which will allow for testing of smaller scale devices or testing of full scale prototypes in a less benign seaway regime so that experience can be gathered before testing at a full scale. The nursery site will support devices of approximately 1/3 and 1/2 size of full scale[51].

As with EMECs nursery wave site, the purpose is to allow developers to test concepts in accessible real sea conditions without the need for big vessels or large plant required in full commercial scale deployment. EMEC consulted a number of developers about their requirements for testing in the early stages of a devices lifecycle. From their responses, nursery sites would need to accommodate tidal devices of 4m in height, 10m in length and with a 10 tonnes dry weight (excluding base)[64].

20.1.2 Main Site Characteristics

The site will have the same specially designed testing support buoys as for the EMEC nursery wave site, which will gather data and dissipate electricity generated by the machines whilst they are tested. These 7m diameter buoys will each form the core of the nursery test sites and take the place of the cables and substations that are at the EMEC full scale sites. These buoys will allow small scale devices to be tested more simply than on full scale sites. There will be two berths at the nursery site each with their own testing buoy.

According to EMEC, the sites energy resource have, and continues to be, assessed using surface-mounted wave rider buoys with integral downward pointing ADCP measuring currents. Multibeam sonar, sub-bottom profiling magnetometer surveys have also been completed, with further environmental surveys currently underway. Each berth will be provided with four gravity base anchors of up to 380kN capacity with a variety of attachment points, with the ability for this capacity to be increased. The nursery site will be served by the same onshore support facilities as for the full scale site.

20.1.3 Licensing and Permits

As with the EMEC wave nursery site developers will be able to choose between the following berth utilisation options:

- Use the leased area, providing own mooring and power dissipation
- Use the leased area and EMEC moorings but providing own power dissipation
- Use the leased area, EMEC mooring and EMEC Testing Support Buoy[30].

20.1.4 Reason for choosing this location

According to EMEC a nursery tidal site should have the following characteristics to allow developers to test devices in benign conditions:

- Water depth between 10-25 meters
- Current of 1-2 m/s (2-4knots) with minimal exposure to waves
- Transit time to local harbour from site of less than 4 hours
- Shore side facilities, including lay down areas, available nearby[64]

EMEC chose a site at Shapinsay Sound, off the Head of Holland in Orkney as its nursery tidal site after consultation with developers about their tidal resource needs, device sizes, shore side facilities and the speed and ease of local harbour access[65].

20.2 SOEC NURSERY SITE ISLE OF WIGHT ENGLAND

20.2.1 Introduction

As part of the SOEC it is proposed for a pre-consented nursery site which will be capable of generating 1MW of electricity. The proposed location for the site is adjacent to Fort Victoria in the western Solent (Figure 52). It is envisaged that the site will enable the early stage sea trials of single prototypes, sized almost up to full scale, and deployed from a fixed platform or on the seabed. Three grid-connected testing berths will be provided for companies to rent on a monthly basis. These provides companies with the means to test new products that have advanced beyond indoor tank testing but are not yet ready for full-scale demonstration, generating data in ‘real world’ conditions at low cost and risk. The nursery site will enable private sector firms to prove concepts and refine designing of full-size devices or component parts. Subject to approval and funding, the nursery site will be the first phase of the SOEC project and is planned to be operational in 2013[51].

20.2.2 Resource

The same 2006 feasibility study which assessed the full scale site, states that off Fort Victoria in the western Solent the peak tidal stream is 2.1 m/s (4.2 kts) with a water depth of 10-25m[63].

20.2.3 Main Site Characteristics

The nursery site will be a progression from tank testing into a real, but relatively benign, marine environment. Procedures will be developed, using divers, ROV’s, crane barges etc, under conditions that may be typical of those at permanent installations. There may be a requirement for different types of sea bed, from muddy through to rocky, for some applications- e.g. for testing the installation, performance and maintenance of mooring systems, gravity bases, ground anchors and other similar equipment. Procedures and equipment developed in the test tank will subsequently be subjected to these aspects of a real environment in this first type of marine facility[63]. Another use for this site will be short term trials for prototype tidal energy devices.

It is envisaged that small devices could be temporarily mounted on an existing structure (pier), or on purpose built platforms (e.g. a moored raft) for their proof of concept testing[63].

The primary site requirements for the proposed SOEC nursery site were

- Relatively strong peak tidal flow – a minimum cut-off value of 1.25 m/s (2.5 kts) was chosen.
- Depth between 10 and 30m (minimum depth being governed by a requirement for useful demonstration of installation and operational methods, maximum by decompression times for divers on normal air-breathing apparatus)
- Avoidance of commercial shipping

Secondary site requirements were identified as

- Shelter from wind and waves
- Proximity to harbour facilities
- Proximity to area for shore base, accessible by road
- Existing structure (e.g. pier) to carry power cable through surf zone
- Avoidance of marine leisure activities (Cowes Week etc)
- Avoidance of activities by other marine stakeholders, such as fishing and dredging
- Avoidance of Special Areas of conservation (SAC's) and other environmental constraints[66]

The 2006 feasibility study found that the site off Fort Victoria has an access harbour 1NM away at the Yarmouth Harbour entrance with a distance to shore of 0.1NM with road access and a pier. The study also found that although this site is inshore of a cardinal navigation buoy (Sconce), it is close to the marine traffic choke point of Hurst Narrows. The area is not a designated SAC and no other environmental constraints are marked on the Admiralty chart [63].

20.2.4 Reason for choosing this location

Consultation with potential clients for a nursery site established a need for a test site where strong tidal currents occur. The site should also be easily accessible by a small boat or rib, located in shallow water and relatively sheltered from waves. The 2006 feasibility study assessed four different sites in and around the Isle of Wight as potential nursery site locations. It concluded that the best site would be located off Fort Victoria in the western Solent as it had a good Peak tidal stream rate of 2.1 m/s (4.2 kts) with the correct water depth of 10 – 25 m and had a reasonable degree of shelter in all but south-westerly or westerly winds[63]. The SOEC nursery site has an advantage over EMEC in that EMEC's nursery site will not be grid connected, unlike the SOEC nursery site. There are also mooring option limitations and no dedicated portside facility at EMEC

20.3 NAREC TEES BARRAGE ENGLAND

20.3.1 Introduction

The National Renewable Energy Centre (NaREC), based in Northeast England, is dedicated to accelerating the deployment and grid integration of renewable energy and low-carbon-generation technologies, using wind, wave, tidal, solar photovoltaic (PV), and thermal power. NaREC has a tidal testing facility based at the River Tees Barrage which is essentially a lock in which the flow of water can be controlled [67]. This is not in an open sea location and NaREC does not provide a facility for long term open water deployment. In 2007 NaREC teamed up with Evopod to showcase the Tees barrage as a tidal testing facility. The testing of the 1/10 scale Evopod (Figure 53) involved the real time logging of flow velocity, turbine speed and generator power. It is not known if the testing facility has been used since.

Figure 53 Testing of the Evopod at the Tees barrage [68]

20.3.2 Main Site Characteristics

The Tees barrage facility can be used for controlled scale testing using the barrage lock infrastructure. The barrage is 6m wide and has channel depths of between 1m and 7m with a length of 35m. The flow through the barrage is greater than 1m/s and ADCP and data acquisition support is available[68]. NaREC also provides electrical generator test rigs.

20.4 TIDAL TESTING CENTRE THE NETHERLANDS

20.4.1 Introduction

The Tidal Testing Centre (TT Centre) is a scale tidal testing facility that utilises sluices from the Afsluitdijk barrage at Den Oever in the north of Holland. The site has been used by Tocardo BV who in 2005 tested their Aqua 2600 prototype at the site. In 2008 they installed their commercial demonstrator T50 turbine at the site [69]. This uni-directional turbine was grid–connected and fully operation at Den Oever until 2011 when Tocardo installed and commissioned its first bi-directional turbine at Den Oever. The TT Centre at the Afsluitdijk barrage is shown in Figure 54.

Figure 54 TT Centre Den Oever [70]

20.4.2 Resource

The sluice of the Afsluitdijk barrage at Den Oever (Figure 55) is 16m wide and has a depth of 4.2m. There are two tidal cycles per day with a single one directional cycle (0-max-0) taking approximately 3 hours. Depending on the strength of the local tide the max flow ranges between 1.5-4.5m/s and provides laminar flow. The operations are obviously dependent on the tides but scheduling options are available for the opening/closing of the sluice [69].

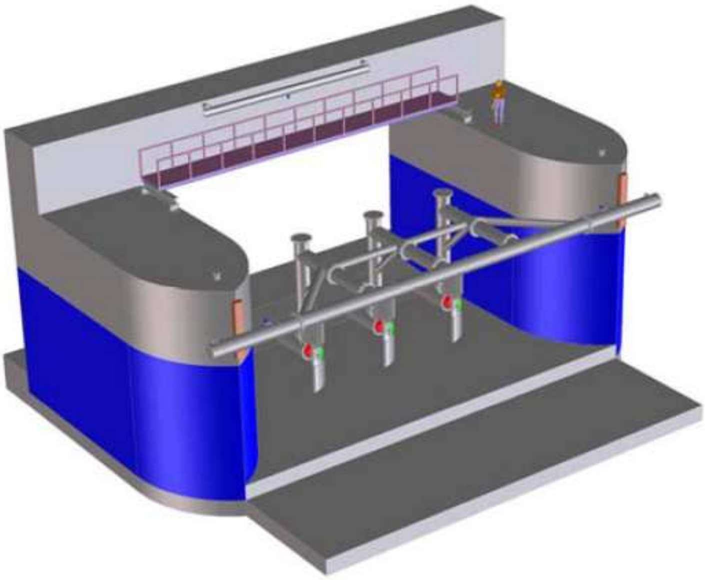


Figure 55 3-D representation of TT Centres sluice gate with turbines in place[69]

20.4.3 Main Site Characteristics

The sites flume is easy accessible by road or via boat. When the sluice is closed there is no water flow. Between operations (3 hours) the turbine can be inspected with a dingy or diver. The turbine can be mounted in a way so that it can be lifted from the flume to take it out of operation, for inspection or for safety reasons [69]. A description of the sites infrastructure and the services provided is given in Table 36.

Table 36 Infrastructure and Services available at TT Centre

	TT Centre
Scale	The sluice is a suitable size for 'intermediate scale' testing of offshore devices (best practice for offshore tidal scale testing is approx 1:3). It may also be suitable for 1:1 scale testing of small tidal power units [69]
Water Depth	4.2m
Distance to Shore	Onshore
Site Area	—
Berths	—
Grid Connection	Feed-in electrical grid-connection of 400V is available, with a capacity of 160kVA, and if needed is scalable to higher kVA
Current Data Collection	On-line 3D ADCP flow measurements are available, which provide a detailed flow profile of the sluice. Data is accessible via the data network of the tidal testing centre. Daily flow predictions are also available as well as scheduling options for opening/closing of the sluice.
Weather Data Collection	—
Other Data Collection	As well as the 3D ADCP, power metering is also available as is the ability for easy installation of extra sensors or cameras[69].
Substation/Onshore Monitoring	The Tidal Testing Centre provide the following engineering and testing support services: • Engineering support • Installation support • Mechanical and electrical support • Monitoring and control • Research support and capacity [69] The Tidal Testing Centre has 3 equipped offices that are within 500 m walking distance of the sluices which are available for the testing personnel.

20.4.4 Licensing and Permits

To be able to use the facilities, a permit is required. The permit deals with safety and environmental aspects and can be granted for a given project period. The Tidal Testing Centre applies for the necessary licences to deploy on behalf of client developers. To facilitate this, a set of EIA Guidelines are being developed. The purpose of these guidelines is to encourage and assist developers to consider, as fully as possible, the range and scale of impacts that might result from the testing of their devices at the TT Centre. The RijksWaterStaat (RWS) is the responsible body for granting such permits. A framework will be provided with RWS to speed up the permit procedure duration or even to establish a generic basic permit [69].

21 TIDAL DEVELOPER TEST SITES

Developer test sites are ad hoc sites where developers created a test site for the sole purpose of testing their own devices. In doing so they have single handily undertaken the feasibility studies, site permitting, infrastructure and monitoring at a specific site for the sole benefit of their own devices. These are not therefore independent test centres where setup costs, site permitting and monitoring are shared and testing can be carried out whereby the performance of devices can be independently assessed by experienced operators.

21.1 STRANGFORD LOUGH NORTHERN IRELAND

The world's first commercial scale tidal current turbine, a single 1.2MW twin rotor system from Marine Current Turbines (MCT) known as SeaGen, was installed in Strangford narrows, Northern Ireland in 2008 (Figure 56). Strangford narrows links the inland seawater lake of Strangford Lough to the sea located 25 miles SE of Belfast. Currents reaching nearly 10 knots (4.5m/s) sweep in and out of the 600m wide 30m deep channel[58].

As well as the tidal resource, Strangford has good accessibility, a grid connection, a QUB (Queens University Belfast) marine station and can rely on local skills base for assembly and O&M. The site is within a European marine site and hosts European protected species [71]. As a result there were restrictions on the operation of the SeaGen turbine from the time of its installation in July 2008 to March 2010. The restrictions were put in place to check that SeaGen operations did not have any adverse effect on marine life. In March 2010 the restrictions were relaxed allowing 24/7 operations for the first time [72].

The SeaGen system is connected to an existing grid connection adjacent to the sewerage substation south of Strangford, with a rating of 1.2MW. A 450m long 300mm diameter bore hole was drilled 20m below the sea bed so that, during installation, the 11 kV power cable could be pulled through the duct. In February 2008 temporary subsea mooring piles were installed to anchor the construction vessels to. These will remain in place until SeaGen is decommissioned [73].

Figure 56 Location of Strangford Lough site on the left with SeaGen installed at Strangford Lough on the right [71]

Also tested at Strangford narrows is a 1/10th scale Evopod floating tethered tidal turbine, which was installed close to QUB's Portaferry Marine Laboratory in 2008 and grid connected in 2011.

Figure 57 Evopod installed in Strangford narrows with SeaGen tidal turbine visible in background[74].

21.2 STRAITS OF MESSINA ITALY

Ponti di Archimede (PdA) tested a full scale prototype of their Kobold turbine at the Enermar pilot plant in the Strait of Messina, Italy (Figure 58) [75]. The Kobold Turbine is a vertical axis turbine suspended from a floating buoy. The prototype, installed in the Strait of Messina uses three blades with a 6m diameter turbine, generating up to 25 kW from currents of 2.0 m/s. The turbine was initially installed in 2001, and since 2005 has been supplying power to the local grid[76].

At the Messina site the peak current speed is 2 m/s (4 knots), the sea depth is 20 meters and the Kobold device was moored 150 meters offshore. The current changes direction every 6 hrs and 12 minutes and the amplitude period is 14 days [77].

In the first phase of the deployment the energy was used on board for experimental purposes, giving power to 1kW floodlights and to a 6kW 'fire-fighting' pump (Figure 59). In 2005 the Kobold turbine was grid connected by means of a submarine cable which involved the installation of a rectifier-inverter to provide a stable electrical output, in order to meet the grid requirements [78].

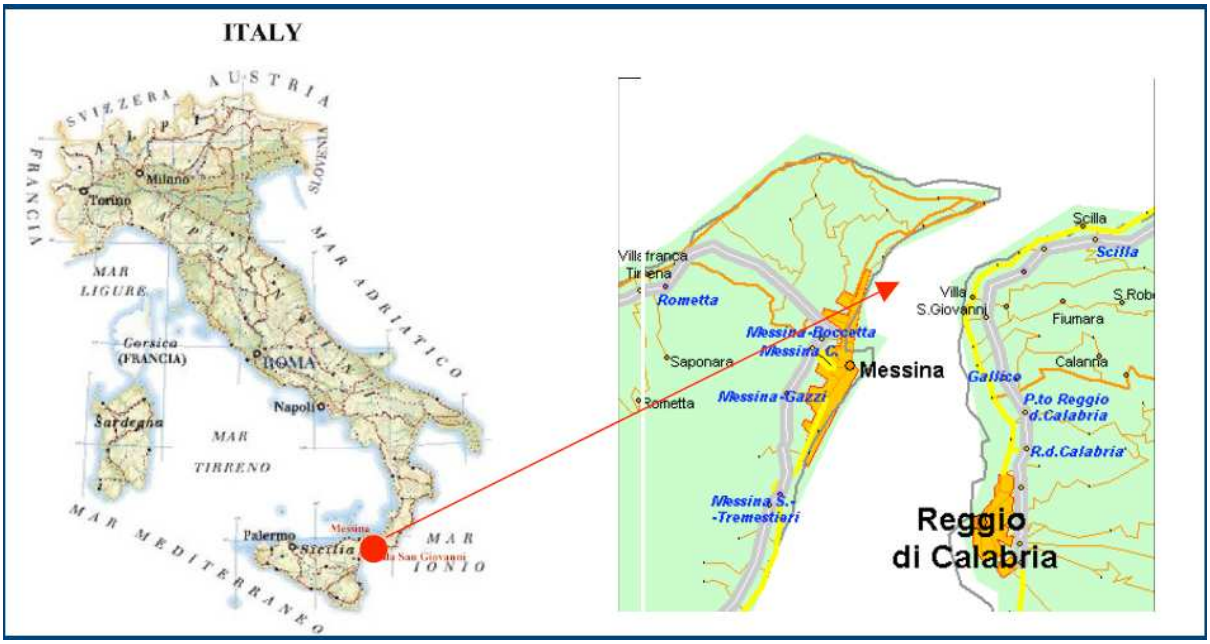


Figure 58 Location of the Kobold prototype[75]

Figure 59 Kobold turbine deployed in the Straits of Messina [79]

21.3 KVALSUND NORWAY

Hammerfest Strom selected Kvalsund in Northern Norway as a test site for the companies' prototype HS300 tidal turbine. Working with Statoil, ABB and Rolls-Royce, Hammerfest Strom connected the HS300, a 300 kW tidal current turbine, to the grid in late 2003 (Figure 60). Located in the Strait of Kvalsund in northern Norway, the turbine was deployed at a depth of about 50 m in an average current of 1.8 m/s [80].

The turbine has been through a complete deployment, operation, retrieval, maintenance and redeployment cycle. The site was selected due to its current velocity, water depth as well as sheltered location. The close proximity to Hammerfest with its support infrastructure made it a suitable location for a full scale laboratory [81].

The companies test facility in Kvalsund, consisting of the HS300 prototype, the subsea infrastructure and the onshore station continues to be used by Hammerfest Strom for R&D purposes, feeding information into both the HS1000 project and future developments of the next generation of the technology[82]. The HS1000 is a 1MW pre-commercial demonstrator to be deployed at the EMEC tidal test site in the Orkney Isles during the summer of 2011.

Figure 60 Hammerfest HS300 turbine during deployment at Kvalsund [81]

21.4 HUMBER ESTUARY ENGLAND

In summer 2010 Neptune Renewable Energy Ltd (NREL) tested their Proteus full-scale demonstrator tidal power generator in the Humber Estuary (Figure 61). They chose the Humber Estuary for the first deployment of Proteus as it had depths and tidal flow which suited the Proteus, whilst being close to NREL's base in East Yorkshire. Another benefit of the Humber for NREL was their ability to call on the expertise of local naval architects and engineering firms[83].

In November 2010 NREL announced that they had completed a series of in-water tests including powering-up and generation of electricity as proof of the commercial potential of the devices power curve [84].

Figure 61 NREL Proteus device in the Humber [84]

Also tested in the Humber Estuary, although a different location, was the Pulse Stream 100 (Figure 62). Pulse chose this location because the shallow water, only 9 m deep, allowed relatively easy to work in conditions. The site was also close to shore which allowed for easier grid connection. The Pulse turbine began generating electricity in May 2009 and exported power to a large chemical plant on the south bank of the estuary [85].

Figure 62 Pulse tidal device installed at the Humber estuary with the blades raised for maintenance [85]

21.5 RACE ROCKS CANADA

The race rocks tidal energy project was Canada's first free-stream tidal power project, located at Race Rocks Ecological Reserve, off Vancouver Island in British Columbia, 10nm southwest of Victoria. The multi-year demonstration project involved the installation, operation and monitoring of a ¼ scale 65kW free-stream tidal turbine generator from Clean Current Turbines[86].
The 3.5m diameter Clean Current tidal turbine generator was installed in 20 meters of water during the period July to September 2006 (Figure 63). Full scale models will be 14 meters (or more) in diameter and of more than 1MW in capacity (depending on the sites tidal regime). The hydraulic and electrical performance of the tidal turbine generator was tested using an offline load bank during this two month period[86].

Figure 63 Clean Current turbine during deployment at Race Rocks[87]

After the initial two months of testing was completed in 2006, the turbine was connected to the control system that feeds electricity into the battery storage at Race Rocks. According to Clean Current, the testing at Race Rocks has validated its performance claims for the direct drive permanent magnet generator and the flow enhancement duct design with tidal turbine generator having successfully extracted power in flows up to 6.6 knots[86]. Alstom plans to test a commercial scale Clean Current device at the FORCES Bay of Fundy test site in Summer 2011[53].

21.6 LYNMOUTH DEVON ENGLAND

Prior to installation at Strangford Lough, MCT tested a 300kW single rotor which was installed at a site 3km North-East of Lynmouth on the North Devon coast (Figure 64). This device was known as ‘Seaflow’ which was the precursor to the ‘SeaGen’ device tested at Strangford Lough. Seaflow was the first tidal turbine generator deployed in the open-sea in the world when it was installed in the Bristol Channel in May 2003. The location, between Foreland Ledge and Foreland Point on the North Devon coast was selected because of its 5+ knot spring tide tidal streams and easy accessibility. The 300kW 11m diameter Seaflow was fitted to a steel pile which was driven into the seabed (Figure 65).

The Seaflow trial tidal turbine was connected to a dump load (rather than grid connected) to reduce costs. In addition, the Seaflow prototype could only generate electricity from the tide in one direction[88].

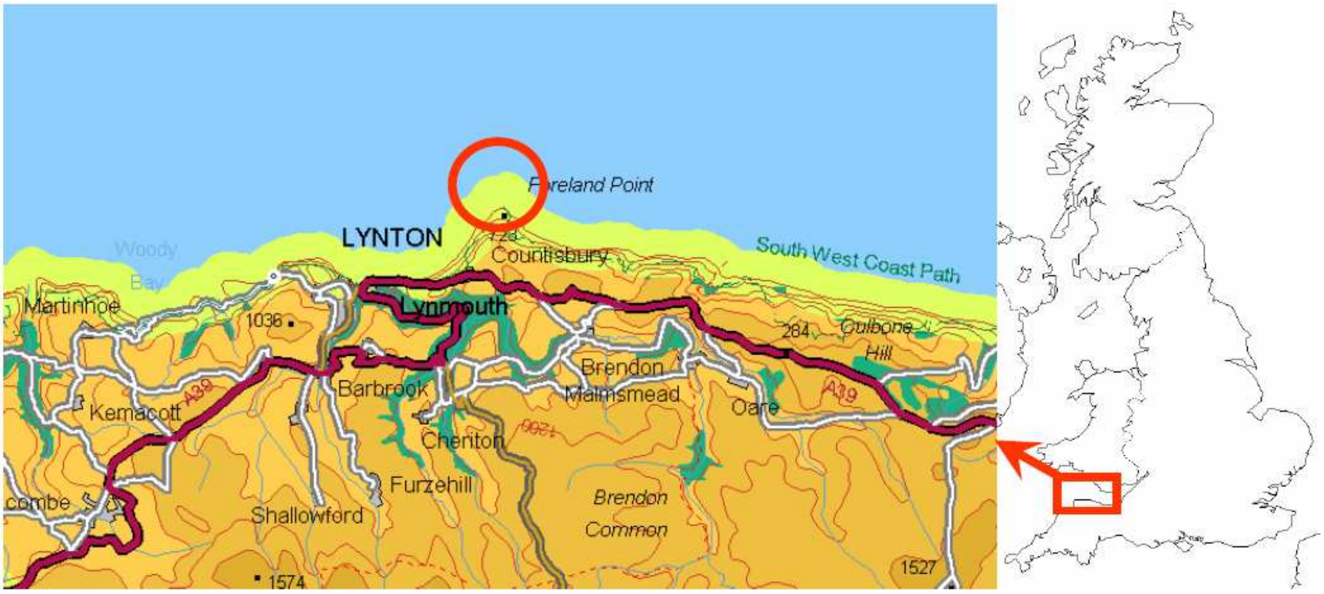


Figure 64 Location of the Seaflow site [89]

Figure 65 Seaflow installed off the north Devon coast in the Bristol Channel [89]

The Bristol Channel acts to constrict the tidal wave coming off the continental shelf, giving both large tidal ranges and high currents. These currents are faster further up the Channel than at the location where Seaflow was installed, but the depths decrease. The site chosen for Seaflow off Foreland Point, is about halfway along the Bristol Channel with high currents in depths of 20-30m. A detailed survey was made of the bathymetry, seabed type, and current regime, confirming that it was a suitable location. Official applications for permission to install were made in 2001. A licence to install under the Food & Environmental Protection Act (FEPA) was granted in 2002, which had to be renewed in 2003 as the installation began just outside the twelve month licence period. A rental agreement was made with The Crown Estate in 2003, after the other permissions were received, as this was conditional upon the granting of all other licences [89]. The device was decommissioned in October 2009 when the testing was complete[90].

21.7 EAST RIVER NY USA

Verdant Powers Roosevelt Island Tidal Energy (RITE) project, located in New York City’s East River, began in 2002. The project consists of three phases which aim to test, demonstrate and deliver commercial electricity from Verdant Power’s Free Flow Kinetic Hydropower System.

Verdant Power hope that the RITE project will demonstrate how its free flow system can be scaled for placement directly within a population centre [91]. The three phases of the RITE project are as follows:

- Phase 1 (2002-2006): Prototype Testing
- Phase 2 (2006-2008): Demonstration
- Phase 3 (2009-2012): MW-Scale Build Out [91]

Both Phase 1 and Phase 2 have been completed. The Phase 2 demonstration stage began in 2006 with the installation of the companies’ first full-scale (5m diameter rotor) Free Flow System turbine into the East River (Figure 66). Over a two-year period, six of these full-scale turbines were operated in an array at the RITE project site. According to Verdant Power, Phase 2 of the RITE project delivered the following:

- Verified hydrodynamic, mechanical and electrical performance with a total of 9,000 turbine-hours of operation
- Fully bidirectional operational passive yawing with high efficiency on both ebb and flood tides
- Grid-connected power with no power quality problems which delivered 70MWh to two local end users [91]

Figure 66 Location of the RITE project with the turbine being installed in September 2008 [91, 92]

Preparations for the RITE projects Phase 3 MW-scale build-out are now underway with Verdant Power’s submission of an application for a pilot license to the Federal Energy Regulatory Commission (FERC) in December 2010. If granted this license would allow Verdant power to build out the RITE project in the East Channel of the East River to a 1MW, 30 turbine array which will deliver power to local customers[91].

21.8 PUGET SOUND USA

21.8.1 Navy Puget Sound – Kinetic Hydropower System

As well as the RITE project in New York, Verdant power has other projects in the pipeline, including plans similar to the 3 phases of the RITE project, the CORES project in Canada. Verdant are also involved with the US Navy in the development of a tidal energy test site at Puget Sound in Washington State.

In 2008, the US Congress funded the Navy to develop, demonstrate and evaluate the feasibility of the Kinetic Hydropower System (KHPS) Turbine as an efficient non-polluting and economical technology for the conversion of tidal current energy into electrical energy. The Navy Puget Sound – Kinetic Hydropower System (NPS-KHPS) demonstration project is a tidal energy demonstration effort in which the Navy will gather operational and environmental data from a Verdant Power designed and built tidal energy system[93].

The NPS-KHPS project will be executed in two Phases. Phase I involves developing the KHPS technology, together with site and environmental permitting. If successful it will be followed by Phase II, which includes deployment and a 1-year operating demonstration followed by system removal. Phase I has been running since 2008 with Phase II of the project dependent on future Congressional funding. As well as funding, commencement of Phase II is also dependent on the completion of the turbine component testing element of Phase I, which has not yet been completed. Should funding be approved together with the completion of Phase 1, Phase II will involve the completion of the system design, fabrication of the device and a one-year demonstration. At the conclusion of the demonstration, the turbines and equipment will be removed[93].

A total of eight sites were initially considered as demonstration sites with only two potential sites remaining, Marrowstone North and Marrowstone South, these are shown in Figure 67. The final site selection will be based on the following criteria:

- Sufficient tidal flow
- Suitable range of depth and slope for installation of the turbines
- Proximity to Navy installations
- Avoiding or minimizing adverse effects on sensitive environmental resources
- Avoiding Tribal, commercial, and recreational fishing
- Avoiding interference with commercial and Navy vessel operations

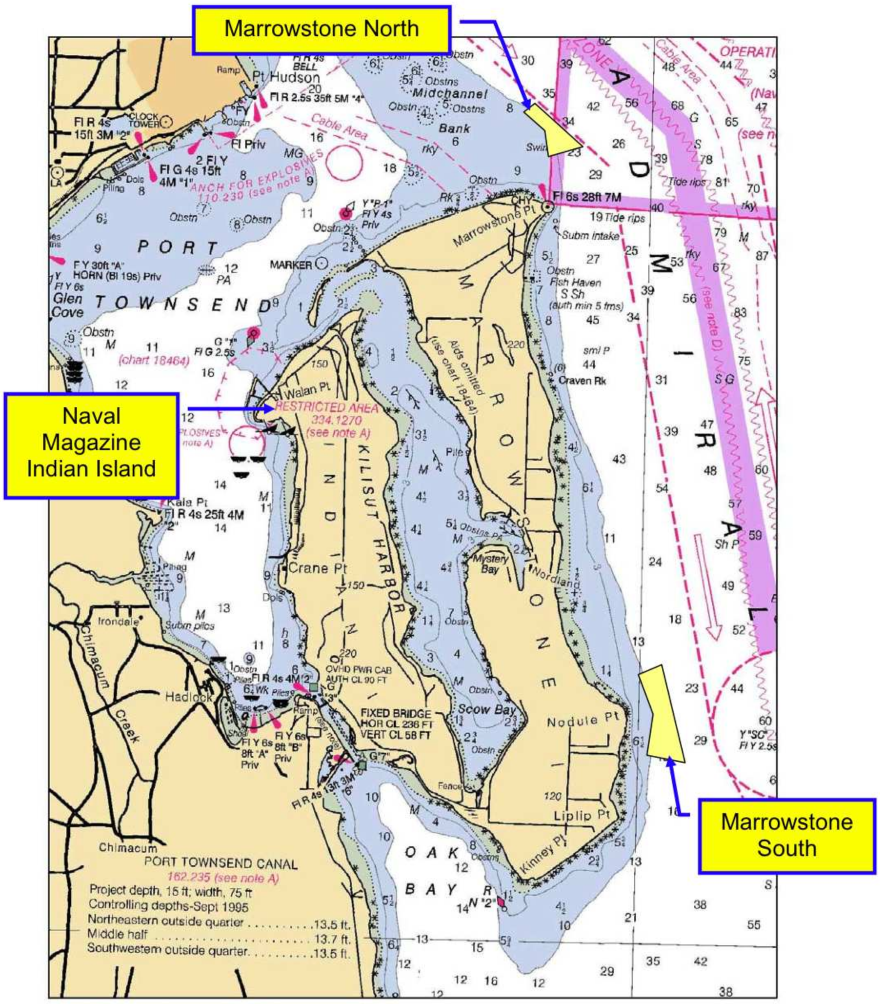


Figure 67 NPS-KHPS candidate demonstration sites[93]

21.8.2 Snohomish County

Also in Puget Sound, Snohomish County is pursuing a pilot energy plant in Admiralty Inlet. The purpose of the pilot plant project is to learn more about the performance and potential environmental impacts from tidal energy generation in Puget Sound. Initially a total of eight potential sites were considered in Puget Sound with the final decision being between Admiralty Inlet and Deception Pass (Figure 68). The final design and layout of the plant is subject to change but it is currently planned to be located approximately 1km west-southwest of Admiralty Head between the Olympic Peninsula and Whidbey Island in water depths of ~40-80m (Figure 69).

The plant will consist of two OpenHydro turbines and will be connected to the grid using a single subsea cable. The project will have a total capacity of 500kW. Snohomish County has partnered with the Northwest National Marine Renewable Energy Centre (NNMREC) to conduct multi-instrumental studies of the proposed project area. As part of this, NNMREC have placed a sea spider instrument cluster on the seabed to record long term measurements of the marine environment. These include:

- Acoustic measurements
- Water quality measurements
- Fish and marine mammal presence in the deployment area
- Seabed composition and videography
- ADCP to characterise the tidal currents in the project area[94].

Snohomish County is in the process of applying for a pilot licence application for the deployment of the OpenHydro turbines. Baseline studies have been completed and the application for a pilot licence was filed on December 31, 2009[95]. In autumn 2010 Snohomish County won a US Department of Energy grant covering half the costs of the $20 million pilot project [96]. It is hoped that the tidal turbines could be installed as soon as 2012.

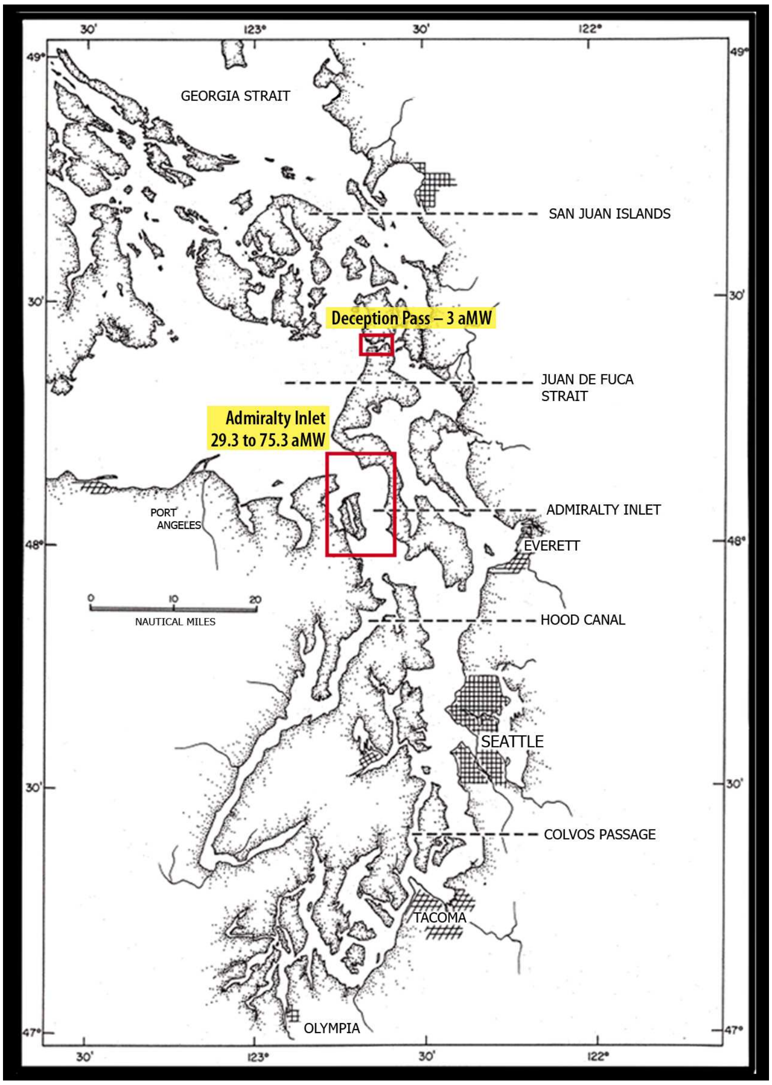


Figure 68 The final two candidate sites for Snohomish County's tidal demonstration site [94]

Figure 69 Proposed location of Snohomish County 500kW demonstration site [96]

21.9 COBSCOOK BAY USA

In 2008, the Ocean Renewable Power Company (ORPC) carried out a year long demonstration project which tested their prototype Turbine Generator Unit (TGU) at the companies FERC permitted site in Cobscook bay, adjacent to Eastport and Lubec, Maine. As a result ORPC became the first company to generate tidal electricity in the Bay of Fundy without the use of dams. In mid 2009 ORPC began the Beta TidGen project design phase which improved the prototype TGU design to complete a commercial-scale hydrokinetic power system. In early march 2010 ORPC launched the 60kW Beta TidGen system. ORPC fully commissioned the system and carried out testing on the project until December 2010 [97].

In late 2011 they plan to, with FERC approval, launch a commercial–scale TidGen Power System in Cobscook Bay, just west of Eastport. After running and monitoring a smaller system for a year, they intend to gradually expand its capacity to 5 MW. This larger project will be connected to the New England grid through Eastport’s Bangor Hydro substation[98].

Figure 70 Beta Pre-Commercial TidGen Power System during testing at Cobscook Bay [97]

21.10 ATLANTIS RESOURCES

Atlantis Resources have developed a number of tidal device concepts and have undertaken sea trails of both scaled devices and full scale prototypes. Atlantis has been operating its own dedicated grid connected tidal power test facility in San Remo, Victoria, Australia since 2006. In September 2006 Atlantis assembled and installed a grid connected 100kW ‘Aquanator’ device at San Remo [99]. Atlantis used the results of the Aquanator testing to develop its ‘Nereus’ concept. Tow testing of a 100kW 30 tonne Nereus in the open ocean took place in Victoria, Australia in December 2007[99]. In May 2008, the Aquanator turbine was removed and decommission from the San Remo site. This was followed shortly with the completion of the near-shore installation, grid connection and commissioning of a 150kW Nereus I, renamed as the AN-150 tidal current turbine in May 2008 at San Remo[100]. Environmental monitoring has been underway at the San Remo facility which include assessments of water quality inclusive of salinity, pH, dissolved solids, turbidity, impacts on local flora and fauna as well as noise and vibration monitoring[99]. In July 2008, the Nereus II or AN-400 tidal current turbine (Figure 71) was tow tested in an open ocean environment. In 2008, Atlantis unveiled its Solon (AS) series turbines[99]. Solon is a horizontal axis turbine targeted for deep open water deployment in water depths exceeding 40-50 meters. The turbine produced in excess of 500kW in 8 knots of water flow during testing. The five day tow testing program was conducted off the coast of Singapore and involved the mobilisation of the 20 tonne horizontal axis turbine (seven meters in diameter and eight meters in length), on a flat top barge pulled by two ocean going tugs[101].

Figure 71 AN 400 installed at San Remo[99]

22 RELATIONSHIP BETWEEN TEST SITES AND DEVELOPMENT PHASES

Table 37 lists the wave energy test sites from those with the lowest resource, to those with the highest. Table 38 lists the tidal energy test centres from those with the lowest current velocities, to those with the highest. During the development of both wave and tidal devices it is envisaged that they will progress from scale testing, to nursery testing to full scale prototype testing. This will involve testing at numerous sites as part of the device development schedule.

Table 37 Summary of test sites in order of resource

Site	Resource (kW/m)	Scale	Year opened/ due to open
Nissum Bredning	0.22	Nursery Scale	1999
Galway Bay	2.44	1/4 Atlantic	2006
Lysekil	2.6	Full scale testing of 10kW devices[1]	2006
PLOCAN	4.2	_	2012
DanWec	6	Prototype Scale	2008
Port Kembla	6.7	1/3 – Full Scale	2005
EMEC Wave Nursery	_	Nursery Scale	2011
MetCentre	_	Full Scale	_
Runde	50 (off the coast, may not be the same at the test site)	Full scale testing of 10-20kW devices.	2009
SEM-REV	14.4	Full Scale	2011
WaveHub	17	Full Scale	2011
BIMEP	21	Full Scale	2011
EMEC Wave	21	Full Scale	2004
Pilot Zone Portugal	21-25	Full Scale / Pre-commercial	_
Belmullet	55-60 (50m)/70-75 (100m)	Full Scale	2012

Table 38 Tidal test sites listed in order of tidal current velocities

Site	Tidal Currents (m/s)	Scale	Year opened/ due to open
NaREC Tees	>1.0	1/10 Scale device has been tested	2007
EMEC Tidal Nursery	1.0-2.0	1/2 - 1/3	2011
SOEC Nursery	2.1	Nursery Scale	2013
Tidal Testing Centre	1.5-4.5	1/3 Intermediate Scale (or full size for small units)	2006
EMEC Tidal	1.5-4.0	Full Scale	2007
SOEC	2.0-4.5	Full Scale	2014
Force Bay of Fundy	5.0	Full Scale	2009

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[1] Although the devices tested at Lysekil and Runde are 'Full-Scale' they are still relatively small in comparison to the full scale devices that are tested at sites which have a larger resource. For example the full scale devices tested at Lysekil and Runde are rated at 10-20kW, whereas the full scale Pelamis tested at EMEC is 750kW.

For both wave and tidal devices there are two Stages covered in the Sea Trial section of a device development schedule, each of which is further subdivided into two phases. These are shown in Table 39. Test sites will be used for Stage 3 TRL 6 'Full System Sea Trials' to Stage 4 TRL 8 'Prototype Exposed Site'.

Table 39 Device development schedule

Stage	Section	TRL	Timetable
S3	Sum-system Bench Tests	5	6-12 months
	Full-system Sea Trials	6	6-18 months
S4	Prototype Sheltered Site	7	1-2 years
	Prototype Exposed Site	8	1-5 years

22.1.1 Full-System Sea Trials

Although at a large, rather than full, size these trials represent the first time the device has been in a real sea environment. The primary purpose of the test schedule is to verify all the systems and sub-systems at a scale large enough to assemble a fully operational power take-off (PTO) but still small enough for the device to be reasonably easily handled. This is an extremely important stage and the final opportunity for limited design changes and modifications to be carried out economically.

Testing of WEC's at this stage would involve the testing of scaled down devices at nursery/scale sites such as Galway Bay, Nissum Bredning or the EMEC nursery site.

For tidal devices it would involve testing at equivalent scale/nursery sites such as the EMEC or the proposed SOEC nursery sites. It could also involve testing at tidal barrages such as at NaREC or the Tidal Testing Centre in the Netherlands which would provide greater control over the tidal currents as well as much greater device accessibility.

22.1.2 Prototype Sheltered Site

Following Stage 3 it is expected that a full, or approximately full, size prototype device will be constructed for sea trials. It could be anticipated that a shake-down period to prove the component, assemblies, manufacturing quality and instrumentation would be conducted at a station with a less aggressive climate than the final destination. Systems operation and control, especially fail safe and shut-down scenarios, should be practised. Device performance can be verified but survival modes must be deferred until subsequent site sea trials.

Wave device testing at this stage could also use some of the nursery sites, such as EMECs nursery site, prior to deployment at the full wave site. Other sites which could be used could be DanWEC, PLOCAN or even SEM-REV due to their relatively lower wave energy resource.

For tidal devices this could involve the testing of full scale devices at EMEC or SOEC's nursery sites, after which the device could progress to testing at the SOEC full scale site as this would have more benign weather conditions than EMEC.

22.1.3 Prototype Exposed Site

Once the operator is confident the pilot plant is functioning acceptably it should be transferred to a location with similar conditions to those expected at a typical power park. The sea trials are now specifically for proving rather than modification, so deployment should be for an extended duration to facilitate component lifecycle verification, full range performance verification and survival diagnosis. Met-ocean monitoring can be minimised to that required for offshore operations and may be a function of the degree of information necessary for the device PTO control.

Testing of WEC's at this full scale would involve testing at sites with a reasonable good wave resource such as the EMEC full scale site, BIMEP, or SEM-REV. A location such as the WaveHub could be used to test arrays of devices so that array effects could be quantified. Finally an exposed high wave resource site, such as Belmullet, could be used to test the device in extreme conditions.

Similarly for tidal devices, having completed testing of full scale devices in sheltered sites, devices would progress to sites with a higher resource such as SOEC or EMECs full scale site and eventually Bay of Fundy, which has the highest resource of all.

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