South West of England Regional Development Agency

Wave Hub Development and Design Phase

Final design report

June 2006

Halcrow

South West of England
Regional Development Agency

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Executive Summary

The Wave Hub project is an exciting opportunity to ensure the UK continues to play a leading role in Wave Energy. This design concept of the Wave Hub was thoroughly researched in the Technical Feasibility Study (TFS) with the underwater system or "wet hub" emerging as the preferred way forward. A simplified description would be a 'socket' connecting Wave Energy Converters (WECs) to the national grid.

In this Wave Hub Development Phase, much more detailed work has been carried out to flesh out the design details. This work includes reflecting the results of various studies and investigations executed in parallel with the design. The design development has now progressed to a point where it is necessary to confirm design decisions and freeze the main elements in order to be able to complete the tender information.

The engineering design work carried out in the Wave Hub Development Phase has confirmed the technical feasibility of the 'wet hub' option. Suitable components have been identified which are generally either qualified, or under qualification, to oil and gas industry offshore standards or proven in service, thus minimising the cost and time needed for component development.

Further information has been elicited from WEC developers on their requirements and preferences. Extensive discussions have been held with an extended range of potential suppliers. It is probable that a complete offshore system, suitably qualified and proven, can only be supplied from one source.

Some final results and interpretative reports are awaited from a few of the parallel studies as well as guidance from the consenting processes but it is not expected that any of these will have a major effect on the engineering design as described here.

A design has been developed for a 20MW capacity system in a similar configuration to the TFS design. The system now operates at 24kV with transformation from 11kV (or possibly 6.6kV) for WEC connection. This is suitable for a connection at 33kV at Hayle, which matches commercial requirements and the capital available. The Termination and Distribution Unit

(TDU) is entirely passive and no maintenance is expected during the project lifetime. The Power Conditioning Units (PCUs) are designed so that they may be retrieved for maintenance.

The feasibility of trenchless construction of a cable duct under the dunes has been confirmed. It is now proposed that the main sub sea transmission cable be pulled ashore and through the duct, thus eliminating the jointing chamber on the beach.

The substation has been expanded in size to cater for a 24/33/0.4kV transformer and a possible power quality improvement unit to facilitate connection of the various WEC generators if the latter should prove necessary.

The budget cost for the 20MW capacity scheme at £17.3 million exceeds the TFS estimate. This cost increase arises from a number of factors, the most important of which are the uncertainties over costs of the main power cable and the installation. Both these factors are affected by an unstable market at present.

The operational and maintenance costs are estimated at £166,000 per year excluding management and overheads.

Other key issues affecting the through life cycle of the system like the Operation and Maintenance, Designers' Risk Assessment and the Decommissioning Plan are described within this document and appendices.

This report provides a synopsis of the final design as of May 2006.

The critical design decisions have been taken as follows:

(a) Total connection capacity of 20MW

(b) Provide four connection points of5MW capacity each

(c) There will be no provision for later expansion of system to a capacity of 30MW

Meetings are planned with selected Developers at which more information may be elicited. These meetings will also be an opportunity to provide them with more Wave Hub design information. Any major change requested by Developers at this stage is likely to cause delay and should be avoided.

The preferred design option has been developed following extensive discussions with a number of contractors and suppliers of subsea and onshore plant. There was however, reluctance by some to divulge details of plant or methodology which would have assisted in the design development. The preferred design option is therefore, the best gleaned and interpreted from the information given. It is neither a definitive option nor necessarily the best option. It is proposed that tenderers be given the option to propose alternative options in their tenders.

Contents

Abbreviations

SWRDA	South West of England Regional Development Agency
WHMC	Wave Hub management company
WPD	Western Power Distribution (the Distribution Network Operator)
TFS	Technical feasibility study
WEC	Wave energy converter
TDU	Termination and distribution unit
PCU	Power connection unit
SVC	Static VAr compensator
FLC	Full load current
MV	Medium voltage
FO	Fibre optic

List of drawings

1 Introduction

The engineering design concept for the Wave Hub was thoroughly researched in the Technical Feasibility Study (TFS). The underwater system or "wet hub" was the clear leader for the final choice. In this Wave Hub Development Phase much more detailed design has now been completed to flesh out the design details. A design freeze has now taken place to allow the preparation of suitable tender information. However it is worth nothing that subject to environmental and land-take issues, requirements from the WEC developers and further operator requirements the design may need to be revised, although major changes are not envisaged.

This report has been prepared for the use by the Wave Hub development teams and for eventual wider distribution. The purposes of this report are to:

- Document the principles of the design, key decisions and changes since the TFS
- Confirm the preferred design option
- Provide a starting point for developing tender specifications
- Focus on suppliers and options for specialist equipment.
- Review the capital cost estimate and Operation and Maintenance costs.

2 Basis for Design Development

2.1 *Design Development*

The preferred option developed under the TFS comprises:

- A 33kV connection to the WPD substation at Hayle
- Nearly 30km of 33kV cable to the demonstration site including a section in a directionally drilled duct under the sand dunes
- A termination and distribution unit on the seabed
- Four power connection units on the seabed rated at 5MVA each and transforming from 33 to 11kV
- A defined Wave Energy Converter (WEC) deployment zone of 4 x 2km
- Buoys and a remotely operated vehicle for maintenance and inspections

This selection was made after extensive analysis of a range of alternatives against criteria which included fit to functional specification, safety, risk to project, cost, environmental impact, flexibility and modularity. The availability of proven equipment was a core consideration for some of these criteria.

During the development phase the options for equipment supply have been thoroughly investigated. Further discussions have been held with the prospective users of the facility and detailed environmental and geotechnical investigations have been made as well as further consultations with interested parties. There has also been a study of the procurement strategy. The outcome of the work since March 2005 has been that the design concept remains but there are significant changes to the details. The revised design is discussed below, particularly for the core electrical system.

The TFS established that a connection capacity of 30MW is readily available at WPD Hayle 33kV substation while the Project Vehicle Study identified 20MW as the maximum capacity needed for the early years at least. Due to budgetary constraints and after consideration of the potential need for and difficulties in providing expansion capacity, the design is for a 20MW capacity connection. There will be no possibility to increase the capacity of this system in future without laying a new cable.

2.2 *Designers Health and Safety Risk Assessments*

As part of the design process, risk assessments were developed from a design team workshop in June 2005. These assessments were further developed as design proceeded with another design team workshop taking place in December 2005.

The risk assessments were divided into the following categories:

- General items
- Substation area
- Directional drill and beach area
- Sub sea cables and equipment
- Operation, maintenance and demolition

Appendix C presents the designers risk assessment sheets covering these categories. The scoring system for likelihood and consequences is indicated on the sheets. These risk assessments have continued to be developed as specifications are finalised at which point final versions of the sheets are signed off. The risk assessments indicate the design mitigations that have been identified for the risks and also anticipated measures that contractors could take.

In addition to the above categories, separate risk assessments have been carried out during design covering navigational risks and decommissioning planning. These assessments are separately reported.

3 Electrical Design Specification

3.1 *Introduction*

The technical feasibility study identified outline design proposals and potential suppliers of electrical plant for use as the electrical infrastructure in the Wave Hub project. The design development phase confirms and details the critical components of the concept and develops a performance specification suitable for inclusion in tender documents.

The following drawings show the proposed electrical arrangement:

- Dwg no.WGEHDD/100C: Protection and Earthing Schematic- Offshore
- Dwg no.WGEHDD/204A: Protection and Earthing Schematic- Onshore
- Dwg no.WGEHDD/200C: Proposed Onshore Site Layout
- Dwg no.WGEHDD/400: Proposed Fibre Optic Core Allocation Schematic
- Dwg no.WGEHDD/401: Proposed Control and Monitoring System Schematic

3.2 *Interface to the Wave Energy Converters*

At an early stage of design development, a further round of technical enquiries was made of the WEC developers potentially interested in using the facility. In parallel, three developers were selected by SWRDA as the first customers and negotiations were started. Halcrow made further enquiries with these to establish technical requirements and interfaces. They are Ocean Prospect Ltd (device by Ocean Power Delivery), Ocean Power Technologies and Fred Olsen Ltd.

Information such as generator characteristics, electrical system characteristics and the cabling interface were sought from the developers. Where information has been made available, their responses have been use to inform the infrastructure design and the network connection studies. Final negotiations with developers are ongoing to establish the exact details of connections to Wave Hub.

3.3 Cabling

3.3.1 *Power Cabling*

Since the initial TFS, there have been several changes brought on by further investigations and practicalities. At discussions with manufacturers and specialist suppliers, it was found that there were several issues that needed to be reconsidered such as:

- Elimination of a jointing chamber on Hayle beach. Contractors' tenders will be expected to give details of connection methods and modalities in their tenders.
- For ease of transportation/manipulation/installation, the cables interconnecting the PCUs to the TDU are to be 200m long
- The trailing 11kV cables from the PCUs for connection to the WEC devices are to be 200m long. The unattached cable ends for connection to the WEC devices are to be blanked off and weighed down to prevent movement.
- The main transmission cable will operate at 24kV, rather than the original 33kV in the TFS

3.3.2 *Signal cabling*

Changes to the design since the TFS include:

- Redundancy in the number of fibres. It is proposed to use 4 fibres per connection point (from WEC to shore)

To allow monitoring of the Wave Hub infrastructure with a robust system design, it is proposed that the fibres connected in a ring between PCUs. There would be 20 fibres from TDU to shore. Drawing no. WGEHDD/400 shows the proposed arrangement.

3.4 Subsea Plant

3.4.1 *Supplier section*

Halcrow approached a number of potential international suppliers of subsea electrical equipment and have so far established that only ABB/Vetco can apparently satisfy the complete project requirements. At a late stage, Alsthom also advised that they are able to provide the hardware but have not yet demonstrated this adequately.

3.4.2 *Transmission voltage*

The TFS design proposed a transmission voltage of 33kV. Following discussions with suppliers regarding technical status and availability of plant, it transpires that the connectors and switchgear required for this transmission voltage are not readily available. The decision was taken to select a transmission voltage of 24kV in order to favour equipment qualified or proven to offshore oil and gas industry standards.

The following drawing shows the proposed electrical arrangement for the standard connection arrangement:

- Dwg no.WGEHDD/102: Proposed Electrical Block Diagram

The TFS also envisaged an arrangement where the TDU was a separate item connected by cabling to separately placed PCUs. However in discussion with Tronic, another arrangement was discussed. The TDU and all 4 PCUs would be mounted on one large baseplate. This would obviate the need for inter-connecting cabling and a set of connectors. The PCU would be lowered on to the baseplate, located by guide pins. All connections would be of the wet mate stab type. This option could be allowed as an alternative in the Tender.

3.4.3 *Termination and distribution unit*

In the TFS, it was envisaged that the TDU would have 4 outputs to the PCUs. This was based on an overall export capacity of 20MVA. In order to keep the project within budget, SWRDA advised that the connection should be limited to a total of 20MVA capacity, comprising 4 berths of 5MVA each. It was also agreed that the TDU be a zero-maintenance unit i.e. a passive unit with sealed busbars and permanent connections. Vetco and Alsthom have indicated they should be able to provide this.

3.4.4 *Power connection unit*

The PCU's main function is to transform from the generator output voltage to the main cable voltage. For electrical protection the unit includes switchgear on both sides of the transformer. There also power metering points, connections for the fibre optics to the WECs and a low voltage supply to the internal monitoring and control systems.

Changes to the initial TFS requirements include:

- Installing a 24kV circuit breaker in the PCU to protect the higher voltage winding in place of a fuse link

- Locating the PCUs closer to the TDU
- Providing auxiliary LV power locally at the PCU

3.4.5 *Special power connections units*

The TFS concept was that all the PCUs would be of the same design. However, the WEC developers have made requests for different connection arrangements according to their preferences and state of development. The OPD Pelamis is designed to operate in a string of three devices linked to one connection point at 6.6 kV. Two strings (4.5MW) could be accommodated on one PCU by changing the transformer to 6.6 kV on the incoming side and providing two connection points instead of one at some extra cost. Other developers advise that they can connect at 11kV or 6.6 kV but may wish for more fibre optic capacity. Providing a special PCU arrangement for one developer is considered unsatisfactory in view of the loss of flexibility and increased cost.

3.4.6 *Connectors*

The connectors for both power and communications are highly specialised and can be expensive. Therefore the choice of connector for both practicality and cost has been an important factor in the design.

In the TFS, it was envisaged that all connectors would be of the dry mate connector type. This was found unnecessary and the connections into the TDU could be by fixed simple penetrators (glanded connections). The power connections at the PCUs would all remain with dry mate connectors. It was decided after discussions with suppliers that due to the potential difficulties of dry mating a FO cable at sea, wet mate connections should be used.

It was also decided that copper cores for low voltage power will not be provided to the WECs and in the main transmission cable, in order to simplify and standardise on the connection arrangement at each PCU.

3.4.7 *Procurement of subsea equipment*

Fundamental design parameters of the Wave Hub development programme are that all plant must be of proven design technology and be fabricated without significant development. Due to the very limited availability of manufacturers who are able to satisfy the technical requirements, this will present difficulties in obtaining a range of competitive quotations from manufacturers. Only ABB/Vetco and Alsthom have been identified after extensive enquiries as potential providers.

3.5 *Wave Hub Substation*

During design development, the substation equipment previously envisaged in the TFS was amended to now include the following:

- 24kV outdoor circuit breaker
- 24/33/0.4kV transformer
- 33kV indoor circuit breaker owned and operated by Wave Hub
- Static VAr compensator connected by busbar trunking (subject to a further stability study)

The transformer provides more flexibility to connect to the network and also links to the static VAr compensator. This equipment can be used to improve the quality of the power injected into the network if the supply quality from the WECs is not of an acceptable standard. Further system studies will be needed to determine the requirement when more details of the WEC performance are known.

4 Connection to WPD System

4.1 Connection Requirements

Connection arrangements with Western Power Distribution have been arranged through the standard process for a large generator. Western Power Distribution (WPD) continued to be very co-operative through the process of accepting what is to them an unusual connection. Refer to Appendix A WPD Connection Offer for the connection offer interpretative report.

The Instruction to Proceed with a Connection Offer was signed by SWRDA and submitted to WPD in early November 2005 and an offer was subsequently received and interpreted early in 2006. WPD subsequently suggested that, due to the proximity of the Wave Hub substation to the existing Hayle 33kV switchboard, there was no need for a separate exit point metering circuit breaker to be installed in the Wave hub substation. Halcrow agreed with this proposal and asked for the Connection to be arranged accordingly for the following reasons:

- There would no loss of functionality or security
- There would be a cost reduction (no circuit breaker and smaller building)
- Simpler operating procedures
- Less equipment to maintain and therefore overall improved reliability

There will be a requirement for a party to operate and maintain the 33kV circuit breaker at the Wave Hub substation. WPD have advised that if Wave Hub wished WPD to carry out those functions under contract, then the equipment would have to comply with WPD standards. The Wave Hub onshore equipment is designed to be compliant with WPD requirements.

WPD submitted two Connection Offers for:

- Connection at 33kV- the main Wave Hub power
- Connection at 230V- for substation building services

The HV offer includes a supply of up to 100kVA into the WECs. This may prove to be insufficient, depending on further negotiations with the developers, but it will be easy to amend the connection agreement if required.

SWRDA accepted both offers within the allowed 90 day period.

4.2 *Metering*

WPD require a separate metering room which can be accessed by the meter operator without entry to any room containing HV equipment. The metering room will contain:

- The export/import meters (duty/standby)
- The import meter for control building domestic services at LV

4.3 *System studies*

Since the type, number and timing of WECs to be connected is unknown at this stage WPD are processing the connection by determining the envelope of overall Wave Hub power injection and power quality which can be tolerated at the connection point. When a developer is ready to connect it will be necessary to run a system model in order to determine if the performance will be within the envelope. Similar logic applies to the influence of the Wave Hub components on the connection. Modelling will be required to examine the influence of the Wave Hub components. Insufficient component data is available to carry out this exercise at present and therefore it will be necessary for the contractor to have a system stability study carried out at the detail design stage. It is expected that the Wave Hub system will modify the power factor and harmonic content of the power it transmits, quite possibly in a beneficial way. This is unlikely to affect the design of connectors, transformers and cables, but it will affect the requirements for the SVC. The present provision for the SVC and busbar links is expected to be the worst case scenario.

5 Offshore Deployment Area

5.1 *Initial Deployment Area Location*

The conclusion of the TFS screening study was that such is the presence of constraints in the offshore area that there are two potential areas best suited for the Wave Hub: one close to Hayle, and one close to Newquay.

With the suitability of the onshore landing and electrical connection point, Hayle consolidates its leading position through its proximity to a relatively unconstrained offshore area in an appropriate depth of water. The preferred location offshore of Hayle is located in approximately 50-60m of water in a good wave climate, inside of the 12 nautical mile limit, outside the military exercise area, behind the Bann Shoal, avoiding known wrecks, and out of the known direct commercial shipping channels.

Conversely, Newquay, with a more difficult cable landing and a greater distance to the onshore electrical connection point, suffers from both shipping lane and military constraints forcing the site into water that is too shallow for most devices. Additionally, as the distance from the shore is reduced, fishing and recreational activity also becomes more evident. The proximity to the shore would also potentially result in greater impact on the coastal processes and in particular the surf at Newquay. To avoid these constraints at the Newquay site, would necessitate a move outside the UK territorial waters with the associated complications that this would bring to the consenting process.

The Hayle offshore site has clear advantages and was therefore selected as the most appropriate location for the Wave Hub detailed development following the completion of onshore and offshore screening within the TFS.

5.2 *Deployment Area Size*

The feasibility studies indicated that WEC deployment within a 2x4 km deployment area was an appropriate design solution / sea-take compromise. Since that time, more information has become available on the complex nature of the sea bed, WEC array parameters, and the short listing of likely WEC developers, which has confirmed that whilst this area is only just sufficient, the deployment area should remain at this size. This is adequate for at least four WEC arrays and their mooring splays.

Since the reaffirmation of the deployment area size and approximate location through further design and consultation, detailed offshore geophysical, geotechnical and environmental surveys have been completed for the proposed cable route corridor and offshore deployment area. These were completed in detail for the deployment site originally proposed and more coarsely for a larger area in the region thought to be relatively unconstrained and centred on the proposed location.

5.3 Offshore Deployment Area Relocation

Subsequently, through the detailed Navigational Risk Assessment consultations, concerns have been raised over the potential deviation of northbound vessels towards the Wave Hub site when giving way to vessels coming down channel from Avonmouth. Early indications from the traffic data recorded are that such a deviation is limited.

The risk is being quantified as part of the Navigational Risk Assessment for the proposal but in the first instance as an early mitigation measure to minimise this concern, the site has been moved 4km ENE to the very edge of the regional survey area, as illustrated in Figure 5.1. This site move was received positively by the MCA and other consultees in January 2006. Preliminary indications from environmental consultees were that further survey work would not be required at this stage; however the re-location takes the scheme right to the edge of the envelope where data is limited and it was decided that the prudent course would be to conduct additional marine life survey work.

This move has placed the site marginally within the MOD training area (D001). Initial indications from Defence Estates are that this is unlikely to raise problems with the military users of D001, although this is still be confirmed by Royal Air Force and Royal Navy.

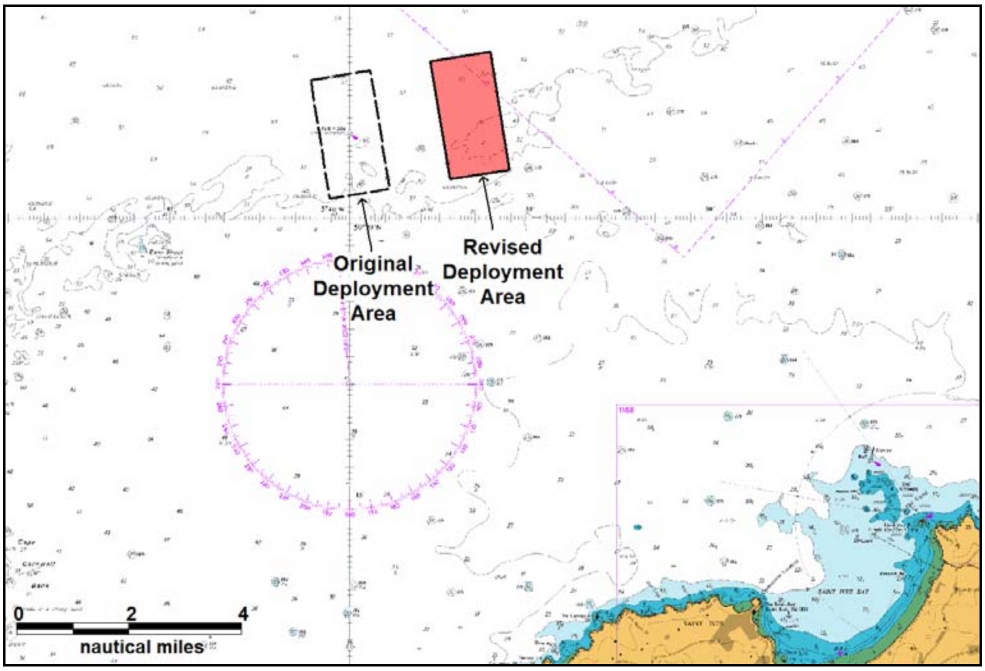

Figure 5.1: Chart Overview of the Revised Wave Hub Location

Therefore, this location is currently the preferred offshore Wave Hub site – constrained:

- to the West by potential marine traffic risks (see Figures 1.2 and 1.3 below),
- to the East by the MOD area and known wrecks,
- to the South by a relict cliff line with a change in depth (to ~37 m) and wrecks,
- to the North by the 12 nautical mile limit and more wrecks.

Excepting the MOD area, the revised site itself appears still to be free of any significant constraint and will now be carried forward as the basis for the consent application. Drawings WGEHDD\001 and 002 show the final site details and location in detail.

The ultimate location of the site will make little difference to the engineering design provided that it stays in the general area.

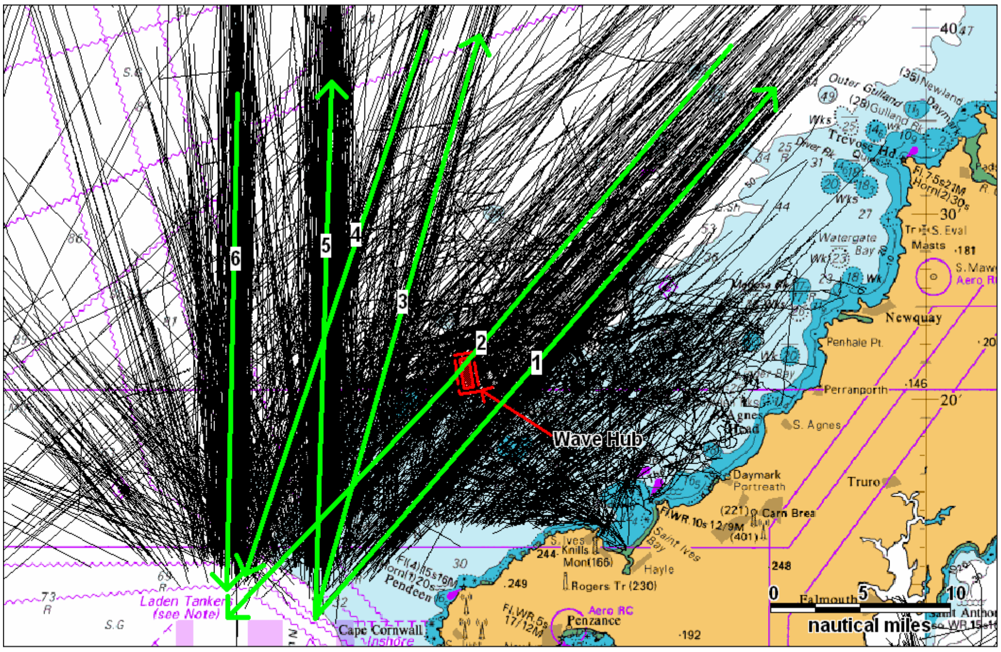

Figure 5.2: Main Routes Identified from Survey Data and the Revised Wave Hub location

From the limited regional geophysical survey data it appears that the new deployment site exhibits good sediment to the NE and SW of the area, with some larger rocky areas towards the centre. For this reason, the Wet Hub equipment is now shown in the SW corner of the deployment site, keeping to an area of likely sediment, minimising sub sea cabling where data is thin, and well out of the way of WEC anchoring extents. The proposed layout of the Wave Hub site and the Wave Hub sub sea equipment is shown in detail in Drawing WGEHDD 002.

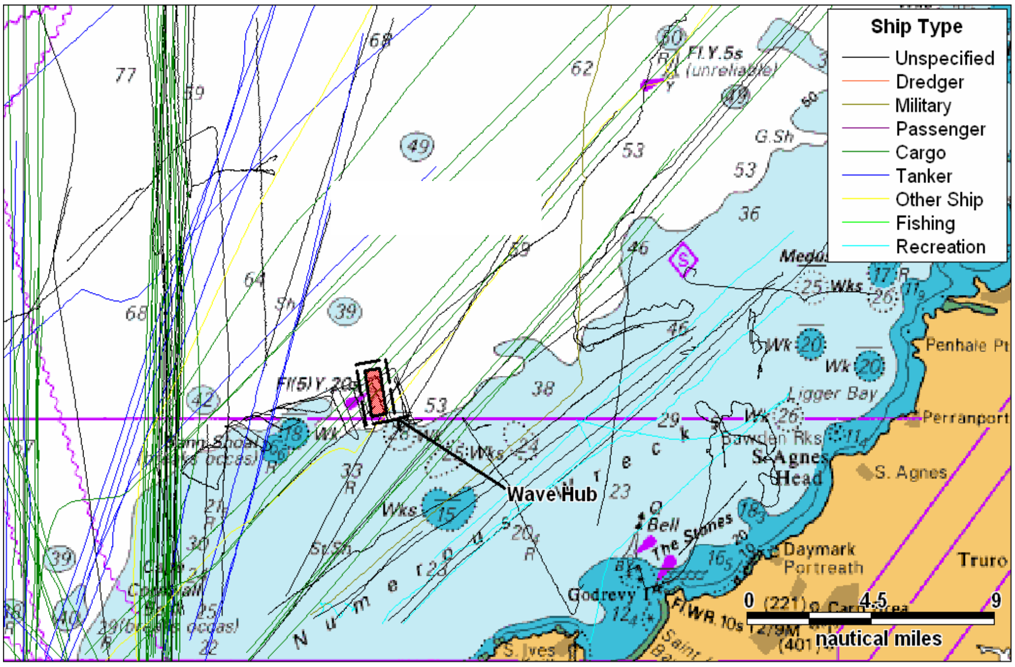

Figure 5.3: Overview Chart of Tracks recorded on 7 August 2005 – Busiest Day - with respect to the Revised Wave Hub Location

5.4 *Offshore Consenting and Approvals*

Parallel navigational safety approvals are now being sought. The first is through the main Section 36 consent application under the Energy Act, which will extinguish navigation rights in the deployment area around any Wave Energy Converter (WEC) present and establish 'Safety Zones' extending up to 500 m from the limit of swing of operational arrays or WECs. The second is through approval of the 2x4km Deployment Area as an Area To Be Avoided (ATBA), (as a minimum) through national and international navigational authorities. The first may well be required to cover any delay in obtaining the second.

The deployment area is now shown in all drawings as a 4km by 2km rectangle in which all Wave Hub and WEC plant (including moorings) will be deployed and inside of which the devices' zones of movement or swing must also be contained. This allows approximately 1km of the predominant WSW wave front per Developer. It is proposed that the WEC arrays be separated by at least 100m and within each array the location of devices will be subject to ground conditions and micro-sitting. If necessary, as arrays of WECs are connected and installed, an appropriate Safety Zone will be established.

The navigational safety marking requirements remain unchanged since the TFS and follow the IALA Recommendation 0-131 on The Marking of Offshore Wave and Tidal Energy Devices. The scheme will be specified in more detail along with the charting requirements in consultation with Trinity House as part of the ongoing Navigational Risk Assessment. The preliminary marking scheme is shown in Drawing WHEHDD\002 and uses both cardinal and special marks to warn other marine users of the Deployment Area.

5.5 WEC Layouts in the Deployment Area

The WECs may be floating or semi-submersible, will be connected to the Wave Hub by a flexible cable, and will be secured by a number of seabed moorings or fixings. The main device types will be oscillating water columns (partially submerged), buoyant moored devices (floating on or just below the surface of the sea), or hinged contour devices (floating on the surface of the sea). WEC units may take a number of forms, with varying outputs, operating ranges, numbers in an array, and deployment spacing or layout. A developer will be able to connect either a large scale device or an array of smaller devices to a PCU. An array can be built up until the maximum PCU capacity of 5MW input is achieved. Drawings WGEHDD 011, 012 and 013 show three illustrative layouts of various types of devices at the Wave Hub site.

Assuming the Wave Hub becomes operational in early summer 2008 it is expected that the first connection phase for WECs would also be in summer 2008. Negotiations for three of a possible four berths at the Wave Hub for the first deployment phase have commenced. These are currently for Ocean Prospect Ltd with Ocean Power Delivery's Pelarmis device, Fred Olsen with their FO3 Buldra Platform device, and Ocean Power Technology with their PowerBuoy device. The fourth slot available at the facility is expected to be determined later in 2006. There will be further connection phases for additional devices, second generation devices, or developer substitution in subsequent years.

It has been agreed with the Maritime Coastguard Agency and other marine stakeholders that WECs will require a device or array specific navigational risk assessment prior to obtaining approval for deployment at the Wave Hub site. The methodology to be followed and criteria that will need to be met will be agreed and detailed in the Wave Hub Navigational Risk Assessment.

5.6 Moorings for Navigational Marks and WECs

The majority of WEC developers still have very little information on appropriate mooring design. Due to the complex nature of the sea bed at the proposed offshore Wave Hub location and following the completion of the detailed offshore geophysical and geotechnical investigations and the coastal processes study, a mooring study was commissioned to confirm that the Wave Hub site was suitable for mooring the proposed WEC devices and to identify likely mooring solutions. The study would also provide a mooring solution for the navigational marker buoys.

The mooring study was carried out for the most extreme wave and climatic conditions expected at the Wave Hub site. Loads on the mooring design and used in the assessment were based on 1 in 100 year storm events. This was defined from the Wave Rider buoy data in addition to 16 years of data from the Meteorological Office.

As the WEC devices that will be initially installed at the Wave Hub site are not confirmed and the details of later WEC devices are unknown, this assessment used generic shapes to provide a representative assessment of relevant mooring solutions.

Two generic body shapes have been considered for the preliminary WEC mooring system design. These are:

- a square box with lateral dimensions of 50 x 50m, draft of 10m and freeboard of 5m.
- a cylinder with diameter of 10m, draft of 20m and freeboard (part above the water level) of 5m.

According to IALA recommendations preliminary indications are that the Class 2 HIPPO SUPER-LITE/3.02.0 navigational buoy is a suitable buoy for marking the Wave Hub offshore site, and this was used for the mooring design.

The resulting report (Wave Energy Converters Mooring System Study – WGEHDD1798R assessed both the WEC and navigational moorings for suitability of both the catenary spread mooring and single mooring line configurations. The report also specified suitable anchorage based upon the information available on the seabed conditions. It was found that the buoys can be moored with clump weight anchorages but the WECs will probably need to be anchored with drilled piles or rock anchors. The mooring lines and anchor systems installation and removal are detailed in the report.

6 Cable Routing

6.1 *Background*

The final TFS cable corridor route between the offshore site and the onshore Hayle substation was designed to avoid the constraints identified in the offshore screening study and the various desk top data collecting exercises. The proposed 500m wide cable corridor primarily avoided known wrecks and sudden mapped changes in topography such as relict shorelines. An offshore geophysical survey was completed where bathymetry, seismic, side-scan, and magnetometer data was captured and processed for the entire cable corridor. From this data, a preliminary cable route within the corridor was shown to be feasible, and the geophysical data was used for the specification of the detailed offshore geotechnical (Vibrocore and PCPT tests) and environmental investigations. Data from all three offshore surveys as well as the coastal processes study then informed the overall detailed offshore geo-hazard assessment that confirms it is possible to route a cable within the corridor without encountering any particularly adverse sea-bed conditions and without causing any particularly notable adverse environmental impacts.

6.2 *Cable Corridor Adjustments*

The move of the offshore Deployment Area 4km ENE necessitated an adjustment to the last 5km section of cable corridor. The proposed cable route shown in Drawing WGEHDD001 is that which will now form the basis of the specification and consent application. It deviates from the original surveyed route at the last possible moment, and passes over 1.5km of un-surveyed terrain. The sea-bed in this area is likely to be rock as it is offshore of the relict cliff line identified from the geophysical survey data. The cable route then passes along the centre of two regional geophysical survey lines into the SW corner of the deployment site such that at least partial data coverage is achieved in this last section of cable route. The revised cable route saves approximately three kilometres of cable and the total length of a cable within the corridor between the onshore substation and the offshore Wave Hub site is expected to be in the region of 25km.

The survey data will all be made available to the cable laying contractor and in the marine site report where the impacts of the various constraints as well as any data gaps along the cable corridor will be presented, allowing the contractor to finalise the actual cable route within the 500m corridor.

6.3 *Cable Specification*

Key features identified from the geophysical investigation data sets were an unmarked wreck, good sediment availability in St Ives Bay, and extensive rocky terrain seawards from there. Hence, the cable will be buried where possible (up to 1 metre below the sea bed) and particularly in St Ives Bay but further offshore it will be predominantly surface laid over the rocky sea-bed avoiding where possible, gullies, ledges and particularly uneven rock. The installation depth is up to 60 metres.

The cable will be an approximately 100mm diameter core and consist of copper wire conductors. The fibre optics cable will be housed in the interstices between the power cores. Given the nature of the sea-bed, a suitable cable armouring is also specified. The armouring will consist of galvanised steel wire wrapping.

6.4 *Cable Transition (Offshore to Onshore)*

Options for installing the cable between the Mean Low Water (MLW) mark and the duct to be installed by trenchless construction beneath the dunes represent a significant challenge to the project. The preferred depth of burial for the cable along Hayle Beach has yet to be confirmed but will be recommended as part of the coastal processes study. The TFS assumed a typical depth of 3m but this is now thought to be impracticable and 2m is more realistic.

A geophysical survey and exploratory borehole conducted along the proposed alignment of the cable route indicated the presence of loose sands approximately 5m deep at the toe of the dunes increasing to around 20m at the MLW mark. No near surface rock outcrops or other obstructions were encountered.

Options for installing the cable along Hayle Beach include both onshore to offshore and offshore to onshore. With either method it is considered that a cable plough could be pulled by a powerful barge to install the cable up to a depth of around 2m below ground level. An onshore to offshore approach is however considered preferable as this method has less construction difficulties and risks.

Whichever approach is adopted, an approximately 2 to 3 metre deep pit would need to be excavated to receive the trenchless installation of the cable duct beneath the dunes. With the onshore to offshore method a cable plough would then be positioned in this pit (this would require a crane on the beach to lift the plough) and the cable threaded through it. The plough could then be dragged out to sea as far as sediment cover was present and then the cable placed on the rocky seabed. The cable plough would then be recovered from the seabed.

If an offshore to onshore method were to be adopted, the cable plough would be pulled up the beach as far as possible by a barge. A winch located south of the exit pit of the directional drill would then drag the cable the remaining distance to the pit. Such a winch would need to be capable of sustaining considerable loads and would need to be anchored into the rock and/or very heavy ballast provided.

If a shallower burial depth (less than 2m) is accepted, then it is possible that a cable plough could be installed using land-based vehicles. This does not however obviate the problems of working below the MHW mark.

7 Onshore Route and Substation

7.1 Terrestrial Geotechnical Issues

7.1.1 Ground investigations

In order to inform the design of the onshore works, which include the construction of the sub-station compound and associated access track, the trenchless installation (directional drill) of the cable duct beneath the dunes and the laying of the cable along Hayle Beach to the MLW mark, a number of investigations were commissioned. These included a topographical survey of the entire site area, intrusive ground investigations works within the proposed sub-station site and along the route of the directional drill (comprising a number of deep boreholes and shallow machine-excavated trial pits with associated in situ and laboratory testing and monitoring) and a geophysical survey along Hayle Beach to the MLW mark.

7.1.2 Ground and groundwater conditions

Intrusive ground investigation works within the proposed sub-station compound and access track have revealed the presence of deep (more than 5m) variable made ground materials, comprising principally of gravelly sands with pieces of concrete and other man-made products including plastic, electrical wire, timber and metal. These are underlain by dune sands and river/beach gravels to bedrock at approximately 10m below ground level.

Rock head levels beneath the sand dunes were found to be well below the required elevation of the directional drill required to install the cable duct. The uniformly graded dune sands are underlain by sandy gravels at depth, but these are also below the proposed level of the drill vertical alignment.

Groundwater levels were recorded at depth (10m below ground level) in the proposed sub-station site and at depth beneath the sand dunes (i.e. below the proposed elevation of the directional drill).

7.1.3 Contamination

A number of samples of made ground taken from the proposed sub-station site, including spoil heaps located there, were tested for a range of chemicals to assess for potential contaminants and the aggressiveness of the ground conditions to concrete attack. Slightly elevated levels of arsenic and copper were encountered in a number of the samples analysed. These elevated levels are above the threshold for waste to be classified as inert and thus the materials may be considered stable non-reactive and require disposal at a licensed waste facility.

7.1.4 *Foundation design*

As a result of the variable depth, heterogeneity and past stress history of the made ground materials present, design of the foundations for the sub-station structures and buildings will need to minimise the potential for large total and differential settlements. Raft foundations will be required for the buildings and some form of ground improvement or piles founded at depth within the sands / gravels or bedrock will be required for heavier structures, such as the transformer.

7.1.5 *Trenchless installation of cable duct*

A specialist directional drilling sub-contractor will be commissioned to install a minimum 225mm inside diameter cable duct through which the power cable will be pulled from a pit on Hayle Beach to a cable splitter chamber within the sub-station compound. The exact method of drilling and bore stabilisation technique adopted (i.e. drill fluid and/or casing) will be determined by the drilling contractor, but this is considered likely to involve a pilot bore closely followed by wash over casing that would subsequently become the installed sleeve. Auger boring techniques may be adopted over an initial length to permit the installation of a larger diameter casing in order to minimise the length of wash-over casing that will come into contact with the sand deposits and therefore reduce the required drilling force. Completion of the directional drill is anticipated to take up to three weeks to complete. Much of the proposed site compound area will be required during these works and there will be little space left for other site activities to continue concurrently.

The proposed horizontal alignment of the directional drill is shown on drawing WGEHDD 201 and an illustrative vertical alignment is included on drawing WGEHDD 202.

7.2 Sub-station Building

The layout of the proposed onshore works is detailed on drawing WGEHDD 200C.

The geotechnical data from this area detail extensive made ground materials (see Section 7.1.2). The building, which will be relatively light weight, is proposed to sit on a concrete slab, within which trenches will be provided for the Wave Hub cabling.

This building has been sized to accommodate all associated electrical facilities for the Wave Hub. The various components and cable alignments have been discussed with WPD and wave energy converter manufacturers. As the manufacturers for the various Wave Hub components have not yet all been determined, the final size of the various electrical components are still unknown, and therefore some dimensions are based upon current industry standards. It is considered that the overall dimensions will not change significantly.

Electrical installations outside the building (from north to south) include:

- Cable splitter chamber, where the umbilical from Wave Hub will be split in to the 3 cores
- Cable sealing ends, where the power cables cores are terminated
- Outdoor circuit breaker
- Transformer (approx. 6m x 5m) which according to one manufacturer could weigh up to 65 tonnes and will need to be considered as an abnormal load
- Appropriate trenching and ducting will be provided between the electrical components and the building
- The building primarily contains the following compartments (from north to south):
    - Power quality room
    - Circuit breaker room
    - Metering room
    - Control room
    - Mess room. This has been included with associated facilities for the various operators who will be monitoring equipment or providing maintenance
    - Workshop/garage for the remotely operated vehicle

A potable water supply is proposed from a South West Water main and which would need to run along the access track. A proprietary cess pit is proposed for the waste water from the site.

Roof drainage is proposed to discharge to a soak away and other storm runoff will be directed away from the building to a swale. Water is to be kept away from the building and roads as far as possible, due to the susceptibility to long term settlement of the underlying made ground materials.

The building structure has been considered as a conventional brick clad masonry building for durability and aesthetic reasons. However a steel portal frame structure, with a colour-bond type cladding could be an option if considered appropriate.

The transformer may be relatively heavy in comparison to the new sub-station building and options for piling the base plinth to prevent excessive settlements have been considered.

7.3 Access Road and Compound

The access road is approximately 250m in length and lies over made ground materials, as does the compound track and turning area. The route coincides with a proposed new light industrial development by the present landowner and the design has been prepared on the basis that this will be a temporary access pending redevelopment. The proposal is to re-grade the track and compound area and surface them with a reinforced gravel track placed over the top. This will provide appropriate strength for the anticipated vehicle movements, but will require a maintenance regime as the gravel surface will rut and ravel over the short to medium term and potholes will develop if not maintained. It is assumed that longer term the access track will be replaced by new roads as part of the wider site redevelopment.

Providing an asphalt surface is an alternative option which would have a lower maintenance requirement but a higher capital cost and probably a short useful life.

A car parking area has been defined and the turning head will accommodate vehicles up to the size of a fire truck, as well as enable access and loading to the workshop area.

The compound is located within an area which is relatively flat, albeit with a number of existing spoil heaps. The objective is to maintain new works above, or only marginally below, existing ground levels, to avoid disturbance of the made ground materials.

7.4 *Fencing*

Security fencing to match the existing WPD sub-station is proposed. The alignment of this fencing is however flexible as shown on the drawing, with two alignment options, one of which will allow a future unimpeded thoroughfare to the north if required. The final alignment has to be resolved in the land negotiations.

7.5 *Landtake and Easements*

Drawing WGEHDD 200 also identifies the various land boundaries which will be crossed by the new substation and compound works and the Wave Hub umbilical as far as the ocean. The umbilical has been given an easement width of 10m.

7.6 *Services*

The building will be provided with lighting, heating, power, telephones, fire and intruder detection and lightning protection.

8 Budget Costs

8.1 Construction Cost Estimate

The construction cost has been a major influence on the system design, particularly in relation to the choice of the various connection components. Electrical equipment is normally highly reliable and low maintenance but this is particularly important in the sub sea location where the cost of a failure in both repair costs and loss of revenue are very high. The complexity of installation and the high cost of chartering suitable, specialised vessels have also been a major consideration. Consequently, the most reliable options have generally been chosen.

The cost of such specialised equipment can only be realistically provided by experienced manufacturers; there have been varying degrees of collaboration from the manufacturers in providing such information.

Throughout the design process consideration has been given to making provisions for expansion of capacity, for flexibility in operation and for specific requests from the WEC developers. Ultimately, these potential benefits have had to be balanced against the costs.

The main options which were considered on the basic design of a bare 20MW capacity system with no expansion possibilities are summarised here:

- Provide a six-way TDU offering an alternative connection point in case of failure in one of the PCUs or its connecting cable and possibly giving flexibility to accommodate more developers without sharing a connection point as well as an extra 5 or 10MW of capacity. The additional TDU connections could be provided with cable tails ready for connection of another PCU.
- Size the main cable to shore at 30MW instead of 20MW to give expansion capacity
- Include a power conditioning system in the substation in order to be able to improve power quality from the WECs into the network. This may be

required for technical reasons, depending on the output from the WECs, and is included in the design subject to later confirmation of the need.

The WEC developers all proposed different connection arrangements. While the Wave Hub might be adapted to meet each one's needs by providing different PCUs this would reduce overall flexibility and increase costs and would not help standardisation in the industry. The costs of the various requests were considered. There are options for the interface between the Wave Hub and the WEC which alter the distribution of capital cost between the two. The items considered included:

- Provide 24kV cable tails from the TDU, leaving the developer to provide the PCU and/or put all the transformation, protection and communications on board the WEC
- Provide additional fibre optic cores to meet requests from some developers. Although the inclusion of the fibres in the power cable is not expensive the connectors are. Developers would still have dedicated circuits but with less redundancy in the system.
- Provide one or two PCUs at a lower voltage and with a pair of connectors to suit one developer. This becomes more expensive than the basic design.
- Provide free issue connectors to developers

Nine options are ranked by cost as presented in Table 8.1. Option 3 has been selected to be taken forward.

The Technical Feasibility Study concluded that the 'wet hub' option was clearly the cheapest configuration with the possible exception of the 'floating hub', an option which was ruled out primarily on technical and safety grounds. The construction cost excluding project development, management and engineering costs was presented as:

Lower cost boundary	£9,906,000
Best cost estimate	£12,097,000
Upper cost boundary	£15,092,000

The significant increase in costs in this phase is accounted for by several factors.

- In-depth discussion with the manufacturers, where they have been forthcoming, has teased out extra costs for development and ancillary items that were not revealed in the TFS discussions.
- The inclusion of a transformer in the substation and the provision for power conditioning equipment there
- A longer cable duct with more expensive construction under the dunes due to the ground conditions found in the investigations
- Allowance for higher cost of sub sea cable. Cable prices were rising during the TFS work but have since soared due to a big increase in demand for offshore cables (and fewer European factories able to make them) and due to disruption in the market for copper. Currently it is impossible to get a budget quotation for cables. Suggested prices are about twice what they were in late 2004, leading to an increase of £2.2 million.

Due also to the increased offshore activity in the wind industry and the oil and gas industry the availability of offshore work vessels of all sorts has become very limited with vessels booking up long ahead. Charge rates are extremely volatile and rise quickly in these circumstances. The line item has been increased by £1.2 million.

While it may be reasonable to expect that between now and early 2007 when the cable is likely to be ordered that cable prices will stabilise at a more reasonable level, the prospects for lower vessel hire costs are very uncertain. These two items alone account for a large portion of the cost increase and the uncertainty in the overall price. Overall, the costs in Table 8.1 are probably nearer to the upper boundary of cost than the best estimate as presented in the TFS.

Table 8.1 Alternative configurations and costs

Option	Description	Specification				Cost Estimate	Comments
		Infrastructure capacity	**TDU**	**PCU (5MVA each)**	**Fibre optic cores per PCU/Developer**	**£000s**	
1	Bare minimum, only 24 kV cable tails from TDU for Developers' connections	20 MVA	4-way	None	4	12,100	Not recommended Risk that Developers will not connect at 24kV
2	Base line system 20 MW	20 MVA	4-way	3 No @ 11 kV & 1 No 24kV cable tail	4	16,000	Not recommended No expansion capacity High cost of installation of 4th PCU
3	Base line 20MW & spare PCU	20 MVA	4-way	4 No @ 11 kV	4	17,300	Allows for a 4th developer to connect easily
4	As option 3 with increased communications capacity	20 MVA	4-way	4 No @ 11 kV	8	17,500	Allows for a 4th developer to connect easily. Meets Developer requests for extra comms. capacity & redundancy
5	Base line expandable to 30 MW	30 MVA	6-way	4 No @ 11 kV & 2 No 24kV cable tails	4	19,000	Equivalent to TFS final design. High cost of installation of 5th & 6th PCU for expansion.
6	As 5 with increased communications capacity	30 MVA	6-way	4 No @ 11 kV & 2 No cable tails	8	19,100	Meets developer requests for extra communications capacity & redundancy
7	Base line expandable to 30 MW with adaptation to request for a 6.6 kV connection	30 MVA	6-way	3 No @ 11 kV, 1 No @ 6.6 kV & 2 No cable tails	4	19,400	Equivalent to TFS final design plus non-standard PCU for one developer
8	Complete 30 MW system	30 MVA	6-way	6 No @ 11 kV	8	21,700	Assumes demand will rise soon enough to justify investment now.
9	Complete 30 MW system with adaptation to one request for 6.6 kV connection	30 MVA	6-way	5 No @ 11 kV & 1 No at 6.6kV	8	22,100	

A breakdown of the construction costs for the selected option is shown in table 8.2. It should be noted that the estimate in the table does not include a contingency item.

Item	Description	£000s
1	Onshore building and civil works	250
2	Cable duct under dunes	280
3	Onshore transformer and switchgear etc	500
4	Power conditioning equipment (provisional)	250
5	Main power cable to offshore site	4,500
6	Termination and Distribution Unit	1,700
7	4 No. Power Connection Units with local cables	4900
8	Offshore installation	4200
9	Grid Connection charges and work	120
10	Ancillary equipment (buoys, ROV, vehicle, test equipment) and system integration	600
	TOTAL	17,300

Table 8.2 Summary of Construction Costs

8.2 *O&M Costs*

A very thorough review of O&M costs was carried out for the TFS. The scope of this included a study of Availability, Reliability and Maintainability of all the Wave Hub components on which to base the maintenance cost assumptions; a maintenance strategy based on local facilities and services available; system operations; and health, safety, environment and quality management. The study assumed a structure and resources for the Wave Hub operating company.

Annual maintenance and operation costs were estimated as shown in Table 8.3.

The annual costs are dominated by the estimated staff and business costs (the first six items in table 8.3) which contribute nearly 60 % of the total. However there has been development of the thinking on the operation and it is now thought likely that alternative operational arrangements will be made. These are likely to drastically reduce these costs because dedicated staff and facilities will be minimised. There could also be consequential savings on contracted services by using in-house capability. Environmental monitoring is still to be defined but it should be noted that there is a prospect of external support for some of this because of the lack of previous experience.

Technically there is little difference between the TFS design and the developed design and therefore the ARM study is still valid, with no new data available to improve upon the study. The discussion on the study on navigational issues and on resources for operation and maintenance is still valid.

The major repair cost is an annualised estimate which is derived from the industry reliability figures used in the availability modelling and which assumes that a transformer failure will occur once in 20 years. Hence, with 4 transformers, a failure event for each transformer has been assumed in the costing. These figures may be pessimistic as there is, at present, no long term data for these specific sub-sea transformers and associated equipments.

The operating costs do not include any element for navigational safety and mitigation controls beyond the area marking (buoyage) currently considered as required. Controls which could impact on the operating costs are the potential requirement for radar/Automated Identification System (AIS) monitoring of the site, continuous VHF Radio watch, provision of guard boats and of the means of notifying and providing evidence of infringement of safety zones. Consultation with regional MCA officers suggests that these measures will not be necessary, but further negotiations with the MCA to confirm the requirement need to be completed. The worst case scenario for costs would be a permanent guard vessel, estimated to cost in the order of £1m per year.

Leaving aside the management overheads, the direct operational and maintenance costs are summarised in Table 8.4. In this summary the environmental monitoring cost has been updated, although this is still heavily dependent upon the results of the consent application, and an additional sum has been allowed for periodic replacement or upgrade of the onshore communications which will have a normal lifespan of five to ten years.

Category	Best Estimated Cost (£)	Notes
WHMC Staff	137,500	Includes salaries and overheads for NI, pension, healthcare, life insurance etc.
Stakeholder, PR, Marketing	20,000	Includes all marketing costs but excludes travel and accommodation. Includes dues, memberships and conference/exhibition fees.
Board Members	20,000	Includes fees and costs for five WHMC board members.
Insurance	15,750	Public liability and indemnity. Excludes catastrophic loss or damage to offshore equipment.
Technical and legal consultants	15,000	Includes technical, economic and legal due diligence on potential WEC customers.
Office overheads and general business costs	49,350	Includes leases, security, rates, utilities, communications, IT support, financial fees, training, travel, accommodation.
Contracted Services – On call support	30,000	Includes marine and onshore contract services for general boat hire, quayside crane hire, building and site maintenance, and workshop consumables.
Contracted Services – Infrastructure Support	5,000	Includes for building and site maintenance, waste disposal, vehicle maintenance and fuel, office equipment and supplies.
Contracted Services – HV operations and maintenance	5,000	Specialist High Voltage Maintenance contract. Excludes Utility equipment capitalised in connection fee.
Contracted Services QHSE	10,000	Quality, Health and Safety and Environmental audits, equipment and training.
Environmental monitoring	38,500	Estimate until requirements for post construction environmental monitoring are better defined.
Annual Scheduled Maintenance	30,880	Includes routine annual maintenance of navigational buoys, sub-sea cable inspections, PCU cleaning and waverider buoy.
Annual Unscheduled Maintenance (minor repair)	9,680	Minor unplanned repairs to buoys, met equipment and substation based equipment.
Refurbishment (long term)	7,950	Annualised estimate to cover planned refurbishment of buoys in years 5, 10 and 15.
Unscheduled Major Repair	28,575	Annualised estimate to cover unscheduled major repairs to PCU, TDU and offshore cables. N.B This does not include cost for complete replacement in case of catastrophic damage or failure. This is covered by a separate contingency fund in the economic model.
TOTAL ANNUAL COST	**423,185**	

1. No allowance for 24/7 navigational and safety cover if required as a result of Navigational Safety Assessment.

2. WEC maintenance is assumed to be responsibility of individual array owners.

Table 8.3 - Summary of estimated annual operation and maintenance costs (from TFS)

Category	Best Estimated Cost (£)	Notes
Contracted Services – On call support	30,000	Includes marine and onshore contract services for general boat hire, quayside crane hire, building and site maintenance, and workshop consumables.
Contracted Services – Infrastructure Support	5,000	Includes for building and site maintenance, waste disposal, vehicle maintenance and fuel, office equipment and supplies.
Contracted Services – HV operations and maintenance	5,000	Specialist High Voltage Maintenance contract. Excludes Utility equipment capitalised in connection fee.
Contracted Services QHSE	10,000	Quality, Health and Safety and Environmental audits, equipment and training.
Environmental monitoring	35,000	Estimate until requirements for post construction environmental monitoring are better defined. At present this is primarily for noise and cetacean monitoring and for analysis of ROV video data along cable route. It also allows for waverider buoy data analysis.
Annual Scheduled Maintenance	30,880	Includes routine annual maintenance of navigational buoys, sub-sea cable inspections, PCU cleaning and waverider buoy.
Annual Unscheduled Maintenance (minor repair)	9,680	Minor unplanned repairs to buoys, met equipment and substation based equipment.
Marine refurbishment (long term)	7,950	Annualised estimate to cover planned refurbishment of buoys in years 5, 10 and 15.
Upgrading/replacement of communications equipment	4,000	Based on 20% of capital cost per year
Unscheduled Major Repair	28,575	Annualised estimate to cover unscheduled major repairs to PCU, TDU and offshore cables. N.B This does not include cost for complete replacement in case of catastrophic damage or failure. This is covered by a separate contingency fund in the economic model.
TOTAL ANNUAL COST	**166,085**	

Table 8.4 Update of estimated annual operation and maintenance costs

9 Conclusion

The engineering design work carried out in the Wave Hub Development Phase has confirmed the technical feasibility of the 'wet hub' option. Suitable components have been identified which are generally either qualified to oil and gas industry offshore standards or proven in service, thus minimising the cost and time needed for component development.

Further information has been elicited from WEC developers on their requirements and preferences. Extensive discussions have been held with an extended range of potential suppliers but it is clear that a complete offshore system can only be supplied from one source.

Some final results and interpretative reports are awaited from the parallel studies as well as guidance from the consenting processes but it is not expected that any of these will have a major effect on the engineering design.

A design has been developed for a 20MW capacity system in a similar configuration to the TFS design. The system now operates at 24kV with the possibility of transformation to 11kV for WEC connection. This scheme is for a connection at 33kV at Hayle. The TDU is entirely passive, no maintenance expected, and all of the PCUs are to a set standard.

The feasibility of trenchless construction of a cable duct under the dunes has been confirmed. It is also now proposed that the marine umbilical cable be pulled ashore and through the duct, thus eliminating the jointing chamber on the beach.

The substation has been expanded in size to cater for a 24/33/0.4kV transformer and a possible power quality improvement unit to facilitate connection of the various WEC generators.

The main elements of the power string are, from the WEC end:

- Connection to WEC
- Up to 3km 11 kV cable to location of PCU by developer
- Dry mate connector on to short length cable to PCU

- PCU comprising:
- 11kV circuit breaker
- 5MVA transformer, 11/24kV
- 24kV circuit breaker
- Dry mate connector
- Approx. 100 – 200 m 24kV cable
- TDU with penetrators in and out
- Approx. 25km of 24kV cable
- On shore cable splitter chamber
- Cable sealing ends
- 24kV circuit breaker
- 20MVA transformer 24/33/0.4kV
- 33kV cabling from transformer to circuit breaker
- 0.4kV busbar trunking from transformer to SVC
- Static VAr Compensator
- 33kV circuit breaker
- 33kV connection to WPD 33kV Hayle substation (by WPD)

Each PCU will also provide four fibre optic cores for connection to WECs.

The engineering specifications to accompany tender documents have been prepared in parallel with this report. There is some limited scope to review and value engineer the design, particularly in relation to the high cost connectors of various types and the number of fibres to be provided. This design is considered to be extremely robust and will require, over its lifetime, very little maintenance arising from to normal operations thereby reducing the overall cost.

In parallel with this report and the Wave Hub tender specifications, the draft connection specifications for developers have been developed. More detailed electrical information has been requested from the developers to enable further development of the specifications. In the course of connection negotiations with them it may be possible to accede to adaptation to minor agreed requirements of the developers but some could incur extra costs.

The budget cost for this final scheme exceeds the TFS estimate at £17.3 million. However some of extra cost is due to huge uncertainty over the cost of an installation vessel and some due to the unstable supply situation for cables for which the estimate has been increased by over 80%.

Appendix A – Wave Hub Connection Offer Interpretative Report (WGEHDD1714R)

A.1 *Introduction*

The distribution network operator which has responsibility for electricity distribution in North Cornwall is Western Power Distribution (WPD). This area includes the proposed electrical connection point for the Wave Hub infrastructure.

WPD were requested to make two Connection Offers:

(i) Under the 'Instruction to Proceed' dated 26 October 2005, WPD were requested to submit a Connection Offer for a 20MVA connection at 33kV
(ii) By verbal request, WPD were requested to submit a Connection Offer for an LV connection to the substation building

The two offers dated 31 January and 01 February were received by Halcrow Group Limited on 02 February 2006. A revised low voltage connection offer was issued on 20 February at Halcrow Request.

A.2 *Connection Offer for a Low Voltage supply*

A1.2.1 *Provisions of the Offer*

The salient points of the Offer are summarised in Table 1 as follows:

Table A1 Summary of the LV supply Offer

Date and validity	Dated 01 February 2006. Valid for 90 days (to 02 May 2006).
Customer	Assumed to be SWRDA
Conditions	• Acceptance of the Connection Offer for the 33kV connection • Provision of a metering room (located as shown on drawing no. WGEHDD/200 in the substation building on the western boundary of WPD 132kV compound) with ducted service cable entry and space for cut-out and meter • The works must be completed within 18 months from the date of acceptance of the Offer, otherwise WPD may amend or withdraw the Offer
WPD works	• Provision of a branch joint in to an existing 11kV cable • Provision of an 11/0.4kV transformer rated at 50kVA in WPD 132/33kV bulk supply point substation compound

	• Provision of 400V service cable in to the meter room • Provision of fused cut-out in the meter room
Type of supply	230V single phase of rating 15kVA (equivalent to 65A)
Connection charge	£14,616.13 plus VAT (17.5%) Required at least 7 days before connection is made
Start date	Estimated as 6 months from acceptance of the Offer (to allow for plant lead times and programming the works)

Following an initial review of the Offer, we considered the potential load demand of the substation. The load schedule summarised in Appendix A, shows that the maximum demand is 65A, equivalent to 15kVA. It is preferable to allow a spare capacity of 25%. We approached WPD who advised that an LV supply of 80A (18.4kVA) can be provided utilising standard metering and fuse cut-outs. Alternatively, supplies of 2 or 3 phases were offered. We requested a re-quote for the 80A supply. WPD responded with their letter dated 20 February 2006, offering the same conditions as above but with the revisions in Table 2:

Table A2 WPD revision of the LV supply Offer conditions

Date and validity	Dated 20 February 2006 Valid for 90 days (to 21 May 2006)
Type of supply	230V single phase of rating 18.4kVA (equivalent to 80A)
Connection charge	£14,631.08 plus VAT (17.5%) Required at least 7 days before the connection is made

WPD also advise that:

- The customer must appoint an electricity supplier before the connection can be energised.
- There are contestable and non-contestable elements of the work. The contestable elements are those to be carried out outside the WPD site boundary. The customer can elect to have these works carried out by another party, the Wave Hub contractor in this case. The non-contestable elements are those carried out within the WPD site boundary which is the vast majority of the works. Although there is no breakdown of the work elements in the Offer, we recommend that WPD carry out all elements of the work because:
    - WPD will co-ordinate all the works
    - The contestable element is a relatively small part of the total

- The customer reads the Specific and General Conditions for Connection Works. The Specific Conditions are mainly technical and can be taken in to account in the design. We recommend that the General Conditions be reviewed.

Under separate communication, WPD advised that the cost above assumes that the LV supply is separately installed from the 33kV supply. If both connections were established at the same time, then there would be a reduction of approximately £450 because some of the LV cable could be installed in the same trench as the 33kV cable.

A1.2.2 *Actions*

The customer needs to take the following actions:

- Agree (or otherwise) that WPD should carry out all the contestable works
- Complete and return the 'Letter of Acceptance' to WPD before 02 May 2006. The commencement date for the works can be agreed with WPD later.
- Appoint an electricity supplier before the power is required.
- Appoint a meter operator before the power is required.

A1.3 *Connection Offer for a 33kV supply*

A1.3.1 *Provisions of the Offer*

The salient points of the Offer are summarised in Table 3 below:

Table A3 Salient points of the 33kV supply Offer

Date and validity	Dated 31 January 2006. Valid for 90 days (to 01 May 2006)
Customer	Assumed to be SWRDA
Conditions	• The 33kV Wave Hub circuit breaker shall be equipped with current and voltage transformers which are to be adopted by WPD for protection and metering purposes. • Provision of interlocking and inter-tripping between the 33kV Wave Hub circuit breaker and the 33kV WPD circuit breaker • Provision of isolating and earthing facilities at the 33kV Wave Hub circuit breaker • Compliance with Engineering Recommendations for limitations on voltage fluctuation, imbalance and harmonic distortion • Compliance with Engineering Recommendations for protection and earthing. • The Installation works by Wave Hub, the Adoption agreement and all grants and way leaves must be completed within 18

	months from the date of acceptance of the Offer; otherwise WPD may terminate the Connection Works Agreement.
WPD works	• Provision of a 33kV circuit breaker in Hayle 33kV substation with cable protection • Provision and termination of cabling from above to Wave Hub 33kV circuit breaker • Adoption voltage and current transformers fitted into Wave Hub 33kV circuit breaker • Provision of metering panel and terminating cabling • Provision and termination of cabling for protection, interlocking and inter-tripping • Extension of WPD earthing system into the substation compound • Installation of a harmonic current data recorder (permanent) • Witnessing of commissioning tests at £370 plus VAT/day
Type of supply	33kV, 3 phase of: • export capacity 20MVA • import capacity 100kVA
Connection charge	£106,906.10 plus VAT (17.5%) with proposed instalments: • 10% on acceptance of Connection Offer • 45% 1 week prior to commencement of WPD works • 45% prior to energisation
Connection date	Estimated as 12-18 months from acceptance of the Offer (to allow for plant lead times and programming the works) If the Connection Works is not completed within 24 months of the Connection Works Agreement, there could be additional charges.

The Connection Works Agreement is formed by the customer signing and returning to WPD a copy of the Connection Offer. The agreement will not be acted upon by WPD until the customer also provides a Letter of Indemnity to guarantee meeting WPD's costs.

WPD also advise that:

- The customer must enter into three further agreements:
  - Adoption Agreement for any assets provided by the customer and adopted by WPD, prior to commencement of the connection works
  - Connection Agreement setting out the terms and conditions for connection to the WPD distribution system, prior to energisation
  - Responsibility Schedule under S22 of the Electricity Safety, Quality and Continuity Regulations to define responsibilities for operation, maintenance and control, prior to energisation
- The customer must confirm if the generating station is to be licensed and whether an agreement has been made with National Grid Transco (NGT). Under separate correspondence, WPD have advised that the capacity of connection required is below that which requires licensing or an agreement with NGT.
- The customer must grant way leaves and access for WPD to lay their cables on SWRDA land prior to commencement of the connection works
- The customer must appoint an electricity supplier before the connection can be energised.
- The customer must appoint a meter operator before the connection can be energised. As the connection capacity is greater than 100kW, half hourly metering is mandatory. WPD have offered to provide this service.
- Prior to operation of a WEC, WPD must do an assessment to determine if the parallel connection will cause non-compliance with any Engineering Recommendation or other statutory Code or cause system instability. This would be chargeable to the customer plus two days of WPD engineering time.
- If the customer would like WPD to carry out any operational or maintenance procedures on the 33kV circuit breaker, the equipment must comply with WPD specifications.
- There are contestable and non-contestable elements of the work. The contestable elements are those that may be undertaken by the customer. The customer can elect to have these works carried out by another party, the Wave Hub contractor in this case. The non-contestable elements are those works that can only be carried out by WPD which is the vast majority of the works. WPD have provided a breakdown of the works as follows:
  - Non-contestable works: £104,702.45
  - Contestable works: £2,203.65

The contestable works include those elements to be carried out outside of the WPD site boundary and are therefore quite minimal.

We recommend that WPD carry out all elements of the work because:

- WPD will co-ordinate all the works
- of the relatively small contestable element

Schedule 1 attached to the Connection Offer comprises 2 parts:

(a) Part 1 lists the items required to be provided by the customer:

- 33kV circuit breaker with current and voltage transformers
- weatherproof accommodation for WPD apparatus and metering room
- control cabling for interlocking and inter-tripping
- control circuits in the 33kV circuit breaker for interlocking and inter-tripping
- cabling between 33kV circuit breaker and metering panel
- earthing system

(b) Part 2 defines the technical requirements for the following:

- 33kV circuit breaker
- inter-tripping and interlocking
- substation and metering rooms
- site earthing
- safety

Under separate communication, WPD advised that the Connection Offer does not reflect the latest location of 33kV circuit breaker room. (The drawing was received after the Offer was sent out). Because the room location is closer than advised when the Offer was under preparation, the Connection Charge will be reduced by approximately £1,500 +VAT. This small difference will be covered by a variation in the Connection Agreement.

A1.3.2 *Actions*

The customer needs to take the following actions:

- Agree (or otherwise) that WPD should carry out all the contestable works
- Complete and return the Connection Offer Schedule to WPD before 01 May 2006. The commencement date for the works can be agreed with WPD later.
- Complete and return the Letter of Indemnity on SWRDA headed paper
- The Letter of Indemnity and Connection Offer Schedule should be returned at the same time

- Appoint an electricity supplier before the power is required
- Appoint a meter operator before the power is required
- We recommend that SWRDA consider the contractual clauses 6 to 22 of the Connection offer. (note that clause 19 permits assignment of the Connection Works Agreement by consent of the other party)

Appendix B – Decommissioning Plan

SWRDA Wave Hub - Decommissioning Plan

Prepared for:	Halcrow Group Ltd Ash House Sowton EXETER EX2 7LB
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Report No:	ARC-059-006-R1
Revision:	0
Date:	May 2006

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0	May 06	D Cantello/ E Wood	T Lambert	J Abbott	First Issue
1	22 May 06	D Cantello	T Lambert	J Abbott	Client comments - Incorporated

Contents

APPENDICES

Glossary

AtN	Aids to Navigation. Those aids, including visual marks, lights, buoyage, electronic devices etc. provided for the mariner to assist in the safe navigation of the vessel
BAT	Best Available Technique
BPEO	Best Practicable Environmental Option
CD	Chart Datum. By international agreement, Chart Datum is a level so low that the tide will not frequently fall below it. In the UK, this is normally approximately the level of Lowest Astronomical Tide.
Defra	Department for Environment, Food and Rural Affairs
DfT	Department for Transport
DTi	Department for Trade and Industry
EIA	Environmental Impact Assessment
GLA	General Lighthouse Authority. The general name given to those authorities with responsibilities for Aids to Navigation in specific geographical areas. In the waters around the UK and Republic of Ireland, these authorities are: Trinity House, Northern Lighthouse Board and the Commissioners for Irish Lights
HIRA	Hazard Identification and Risk Assessment
Hs	Significant Wave Height
IMO	International Maritime Organisation
MCA	Maritime & Coastguard Agency
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
MSL	Mean Sea Level. The average level of the sea surface over a period (normally 18.6 years)
ODN	Ordnance Datum, Newlyn
ORCU	Offshore Renewable Consents Unit
OSGB	Ordnance Survey Great Britain
OSPAR	Oslo and Paris (Convention on the protection of the marine environment of the NE Atlantic)
PCU	Power Connection Units
RNLI	Royal National Lifeboat Institution
RSPB	Royal Society for the Protection of Birds

SSSI	Site of Special Scientific Interest
SWRDA	South West Regional Development Agency
TDU	Terminal Distribution Unit
Tidal Stream	A distinction is drawn between tidal streams, which are astronomical in origin, and currents, which are independent of astronomical conditions and which, in the waters around the British Isles, are mainly of meteorological origin
UNCLOS	United Nations Convention on the Law Of the Sea
WEC	Wave Energy Converter
WPD	Western Power Distribution

1.0 Introduction

This report has been prepared by ARC Ltd for Halcrow acting on behalf of South West of England Regional Development Agency (SWRDA) and presents the initial Decommissioning Plan for the Wave Hub Facility and associated Wave Energy Converters (WECs).

The report forms part of the consent requirements for the commissioning of the Wave Hub facility as required by the Department of Trade and Industry (DTi) in accordance with the Energy Act 2004. This report has been prepared in conjunction with the Environmental and Social Impact Assessment report.

2.0 Background information

2.1 Wave Hub Concept

The concept of the Wave Hub project proposed by SWRDA is to support and encourage developers of Wave Energy Converter (WEC) devices through the final demonstration and pre-commercialisation stage of development, allowing them to install and operate arrays of WECs in commercial scale conditions over a number of years. It is intended that WECs will remain connected to the Wave Hub for a specified period in order to achieve the developer's aims and then be removed from the site to enable other WECs to be connected.

To achieve this aim SWRDA will provide the Wave Hub infrastructure and establish an operating company such that several different WEC development companies can install WECs or arrays of WECs in a context of lower risk and reduced complexity.

The proposed facility is for a fixed, offshore seabed infrastructure which will support the deployment of developers WEC devices. The WECs will all be located in a deployment area of 4km x 2km and each WEC (or small array of WECs) will be connected to one of four seabed based Power Connection Units (PCUs) by an umbilical cable at 11kV. The PCUs contain transformer units and switchgear and transmit electrical power from the WECS at 24kV to a single, seabed based Termination and Distribution unit (TDU). This combines the power output from all WECs on the system into a single 24kV cable which will conduct electricity from the offshore infrastructure to a new onshore substation facility at Hayle, adjacent to the Hayle Western Power Distribution (WPD) electricity sub station, allowing connection to the regional and national electricity supply.

The Wave Hub concept is shown in Figure 2.1.

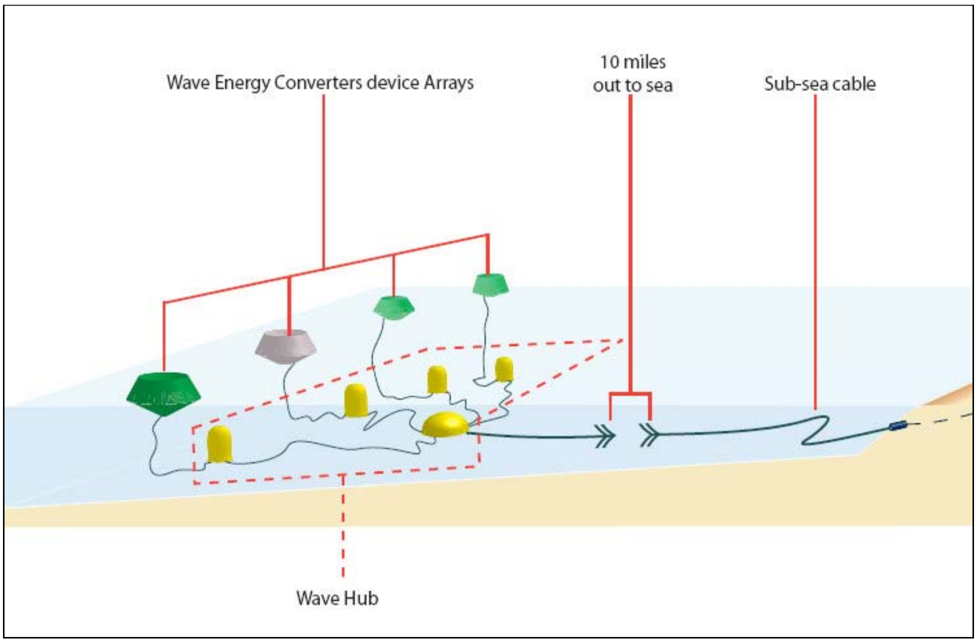

Figure 2-1 Wave Hub Design Concept

2.2 Layout of Facilities

2.2.1 Onshore Infrastructure

2.2.1.1 Access Road and Compound

The onshore site encompasses an existing 250m non-tarmacadam access track that leads from Hayle Harbour to the proposed location of the site compound which is positioned adjacent to an existing transformer station on the lee side of high sand dunes that border Hayle Beach. It is assumed that over the project life this access track will be replaced by new road as part of the wider site redevelopment and will, therefore, not be decommissioned.

A car parking area and the turning head, designed to accommodate vehicles up to the size of a fire truck will be adjacent to the workshop area.

To the north of the compound, is an area defined as an approximate temporary works location which will be used for the drill pit and storage. This is the point where the cable exits the dunes to enter the substation.

2.2.1.2 Substation Building

The onshore infrastructure comprises a new substation which will be situated adjacent to the existing substation facility at Hayle operated by WPD. The onshore infrastructure consists of a single storey substation building on a concrete slab within which trenches will be provided for the Wave Hub cabling. The building will accommodate all associated electrical facilities for the Wave Hub. The facilities will include:

- Power quality room.
- Circuit breaker room.
- Metering room.
- Control room with space for WEC developers’ transmission equipment.
- Mess room with associated facilities for the various operators who will be monitoring equipment or providing maintenance on an occasional basis.
- ROV workshop and garage.

At the north end of the building, there will be an outdoor area which will accommodate:

- Cable splitting chamber.
- Cable sealing ends.
- Outdoor 24kV circuit breaker.
- 24kV/33kV transformer.

Since this equipment includes exposed high voltage conductors, the area will be bounded by fencing of the same height as that of the main WPD compound. Security fencing matching the existing WPD sub-station has been proposed.

A low voltage electrical supply will provide for building services and power for communications. A water supply will be provided from the local main and a septic tank will be installed at the substation for foul drainage. Surface water run-off will be drained to a swale adjacent to the access road.

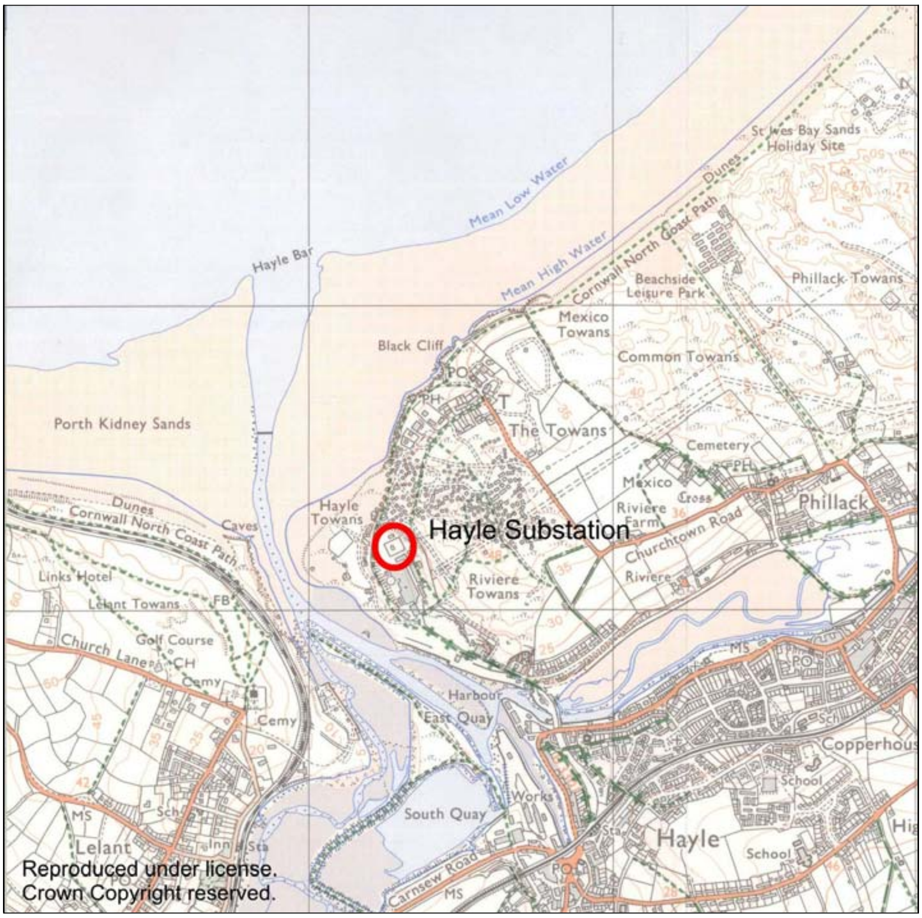

Figure 2-2

Figure 2-2 Onshore Infrastructure Location Plan

2.2.2 Cable

The indicative cable route is approximately 25km in length and is shown in Figure 2-3 Cable Corridor and Route The cable will pass through a horizontally drilled and lined duct beneath the dunes between the substation and the beach, thus avoiding large scale excavation of the sensitive dune area. It will be buried up to 3m below the beach level. Offshore the cable will be buried to the maximum practical depth, between 1 and 3m below the seabed surface where sufficient sediment makes this possible, such as in St Ives Bay. Elsewhere, where there is insufficient sediment to allow burial, the cable will be surface-laid. The cable will be held in place by its own weight. There will be no rock protection over the cable where it will lie on the seabed's surface.

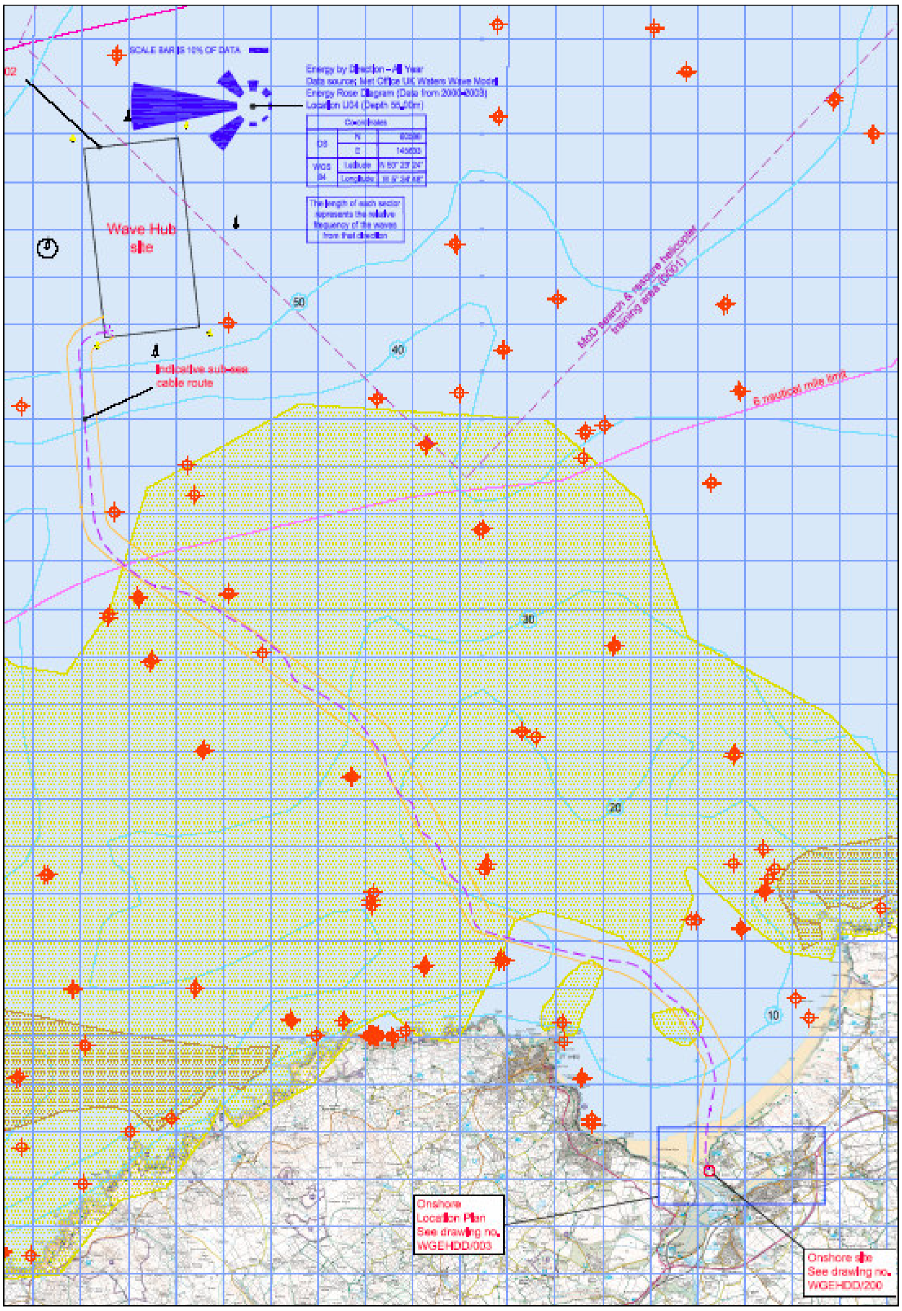

Figure 2-3 Cable Corridor and Route

2.2.3 Offshore Infrastructure

Wave Hub's offshore infrastructure (i.e. the PCUs and TDU), the WECs and all associated moorings / anchoring systems will be positioned within a 4km by 2km deployment area situated in approximately 50m of water and within 12 nautical miles offshore as shown in Figure 2-3 Cable Corridor and Route.

The Ordnance Survey grid references and latitudes / longitudes for the four corners of the deployment area for the Wave Hub deployment area are:

North-east corner: OSGB N59694 E142066 / WGS84 N50°22’50’’ W5°37’56’’;

North-west corner: OSGB N59918, E144053 / WGS84 N50°22’59’’, W5°36’06’’;

South-west corner: OSGB N55943, E144501 / WGS84 N50°20’52’’, W5°35’34’’;

South-east corner: OSGB N55793, E142514 / WGS84 N50°20’42’’, W5°37’14’’.

The deployment area will be an Area to be Avoided (ATBA). The deployment area will be demarcated by appropriate navigation aids as required by Trinity House. It is probable that there will be a requirement for four Class 2, three metre diameter, steel or plastic cardinal buoys 500 -1000 metres to the north, east, south and west of the deployment area, and four special marks buoys of similar dimensions and construction delineating the corners of the deployment area. All 8 buoys will have associated moorings.

Figure 2.4 provides an example layout for WEC devices within the deployment area.

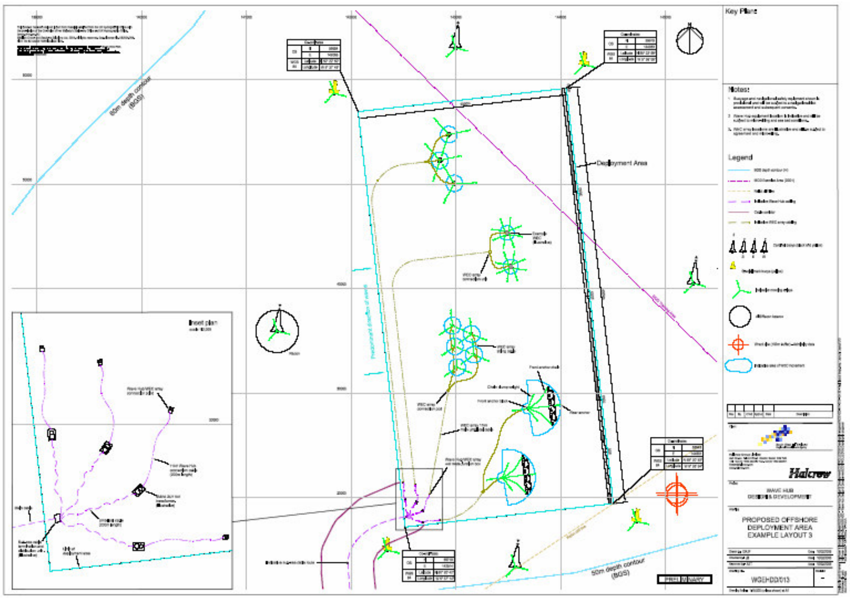

Figure 2-3 Example Layout of WECs

Different developers will be able to connect either individual WECs or arrays of WECs to a PCU (i.e. a PCU array) at any one time. Developers will be able to build up the number of WECs in a PCU array and to replace WECs with larger scale devices.

The Wave Hub will have a maximum output of 20MW. This output effectively limits the scale and/or number of WECs and WEC arrays that can be connected to the Wave Hub.

2.3 Environmental Conditions

The baseline environmental conditions at the Wave Hub site have been summarised from the information provided in the EIA.

2.4 Weather

To be provided.

2.5 Sea Conditions

The baseline conditions for water levels, offshore wave conditions, tidal streams and currents have been summarised from the EIA and are presented in Tables 2.1 to 2.3 below.

Table 2-1 Water Level Data

Typical Water Levels	Water Level (m)(ODN)
Mean High Water Spring (MHWS)	+3.3
Mean Low Water Spring (MLWS)	-2.5
Extreme Water Levels	
1 in 2 year return period	+3.7
1 in 50 year return period	+3.8
1 in 100 year return period	+3.9
Figures above include predicted sea level rise of 5mm/yr (Defra, 2004) for a 20 year period. Figures exclude surge 1 in 50 yr return period surge at St Ives = 1.0m (Pugh, 1987)	

Table 2-2 Wave Conditions

Typical Wave Conditions	Hs (m)	T (s)
Typical summer surf (38% prob of occurrence between 1 May and 31 Aug, 45 days/ 122 days)	1	7
Mean wave climate	1.6	5.4
Classic surf (0.3% prob of occurrence, approx 1 day per year)	4	16
Extreme Wave Conditions (all directions)		
1 in 1 year return period	10.4	12.1
1 in 50 year return period	13.8	13.9
1 in 100 year return period	14.4	14.1

Table 2-3 Tidal Stream

Tidal Stream	m/s
Typical Tidal Stream (which typically run parallel to the coast)	1.0 to 1.2
Extreme Tidal Stream: 1 in 50 year return period	1.6

2.6 Onshore environment

The onshore site is located in an industrial area beside the Hayle estuary, to the north of Hayle town. It comprises a ‘bowl’ in which a current substation and disused power station are situated, surrounded by a high crest of dunes, behind which lie the estuary and a wide sandy beach.

The proposed sub-station and access track are located in a former sand pit that was worked during the late-19th and early-20th centuries, which created a distinctive ‘bowl’ shape within the sand dunes. From the 1930s onwards the area was developed into a power station which was subsequently demolished during the late-1970s to early-1980s. During this period made ground materials were deposited across much of the site, including the area of the proposed sub-station and access track. Further dumping of materials in recent years has resulted in a number of large spoil heaps within the site compound.

In the site of the substation, intrusive ground investigation works have revealed the presence of deep (>5m) variable made ground materials, comprising principally of gravelly sands with pieces of concrete and other man-made materials including plastic, electrical wire, timber and metal. These are underlain by dune sands and gravels to bedrock at approximately 10m below ground level. Slightly elevated levels of arsenic, copper and hydrocarbons were encountered in a number of samples of the made ground, these elevated levels are above the threshold for waste to be classified as inert and thus the materials may be considered stable non-reactive for disposal purposes to landfill.

The cable duct running 10-12m below the dunes is in an area of uniformly graded sands well above the level of base rock encountered (at between 7m at MHW and >15m MLW).

Groundwater levels were recorded at depth (10m below ground level) in the proposed site compound area and at a depth greater than the cable duct beneath the sand dunes.

The Wave Hub substation site itself is of little ecological value, although the dunes around it constitute a fragile habitat. The estuary is of significant importance for nature conservation, particularly migrating birds, and is designated as a Site of Special Scientific Interest (SSSI) and an RSPB Nature Reserve. The beach in front of the dunes is covered by two county-level designations: Area of Great Scientific Value, and Cornwall Nature Conservation Site.

The beaches of St Ives Bay are very popular for recreation and water sports, particularly surfing, and the dunes host a number of caravan parks and holiday cottages that cater for thousands of tourists. The site itself is of low visual amenity, being a disused power station in an industrial area. The overall landscape, however, is of high value, including wide sandy beaches, St Ives Bay, the Hayle estuary and the extensive sand dune systems to the north. There are no sites of heritage or archaeological importance in or very close to the site.

2.7 Offshore environment

Offshore, the Wave Hub site extends from St Ives Bay to the 12 nautical mile limit. The area is of importance to marine life, particularly cetaceans (whales, dolphins and porpoises), basking sharks, fish (the area supports spawning and nursery grounds for several important commercial species) and the marine communities inhabiting the rocky outcrops amongst the sediments of St Ives Bay. St Ives Bay and the Hayle estuary are designated as a Special Marine Area, in recognition of their national importance for marine and estuarine life.

The area also supports a range of fisheries of importance to the local economy, including a shellfish industry that is the mainstay of the Hayle port, and the lucrative Dover sole fishery exploited by trawlers in the deeper waters (>30m). The area is also popular to recreational users including sailing, diving and angling. In terms of landscape value, the sea is one of the few remaining ‘wild’ vistas in the country, and the coastline on either side of St Ives Bay is designated as both an Area of Outstanding Natural Beauty and Heritage Coast. There are a large number of wrecks, some of which are designated as Protected Wrecks, within the area. There are no known sites of archaeological or palaeontological importance in the nearshore.

Part of the intended wave hub site area lies in a designated Ministry of Defence military exercise area, and coastal shipping lanes pass close to, and through, the intended area. There are no known sites of contamination, and no licensed offshore dumping or aggregate extraction areas. The bathing waters of St Ives Bay consistently score highly for water quality.

Sediments in the offshore and transition zone (60m to 10m charted depth) are comprised of patchy and thin, typically less than 1m, layers of sands and gravels which overlie mudstone/ shale bedrock and which become increasingly intermittent towards the offshore zone (40m charted depth). Since no major features have been observed it is speculated that little change has occurred on the seabed over the last 100 years. Due to the depth of water, sediment movement is limited except during storm conditions.

St Ives Bay is believed to be a sediment sink. However, since sediment inputs from the River Hayle and from offshore are limited the system can be considered as a 'closed' sediment system. The beaches are comprised mainly of sand. The beach profile demonstrates typical seasonal changes with lowering of beach levels and the creation of an inter-tidal bar during winter. Beach levels can reduce by up to 1.8m following storms. The dunes to the west of the proposed cable landfall are eroding and this could potentially extend eastwards in future. Rapid accretion occurs in the channel at the mouth of the estuary, which was previously dredged and sluiced to maintain a shipping channel. The alignment of the channel appears to be stable.

2.8 Legislative Requirements

The decommissioning plan must satisfy the requirement of the licence agreements issued by the Crown Estate, all UK applicable legislation and international obligations.

Current guidelines for decommissioning of offshore structures are contained in such documents as:

- MCA Marine Guidance Note 275(N) Proposed Offshore Renewable Energy Installations – Guidance on Navigational Safety Issues. (Reference[1])
- Department of Trade and Industry (DTi) Guidance on Consenting Arrangements in England & Wales for a Pre-commercial Demonstration Phase for Wave and Tidal Stream Energy Devices (Marine Renewables) Nov 2005. (Reference[2])
- DTi Guidance Notes for Industry – Decommissioning of Offshore Installations and Pipelines under the Petroleum Act 1998. (Reference[3])
- Guidance notes for the decommissioning of offshore renewable energy installations (section 6.2 of the Guidance Notes for the Offshore Wind Farms Consents Process), March 2004. (Reference[4])
- DTi Electricity development consents branch informal discussion paper on decommissioning standards for offshore renewable energy installation, March 2006. (Reference[5])

The Department for Environment, Food and Rural Affairs (Defra) is in the process of drafting a new Marine Bill which includes marine renewables in its scope and is intended to improve marine consenting procedures. The proposal will also include the possible creation of a new marine management organisation to support the Marine Bill functions. The Marine Bill, if enacted, will impact on the Wave Hub decommissioning consenting process and its requirements will require to be reflected in the decommissioning plan.

In addition, the DTi is issuing further guidance on the preparation of decommissioning programmes. This is due in October 2006. It is therefore proposed that the decommissioning plan as submitted should be resubmitted within a 5 year period for further review and amendment as required to satisfy any provisions detailed in the licence agreement and any requirements of the October 2006 guidance and the Marine Bill.

2.8.1 International obligations

International requirements have their origins in the United Nations Convention on the Law of the Sea (UNCLOS), 1982 as implemented through the International Maritime Organization (IMO). Applicable standards issued by the IMO include:

- International Maritime Organisation Guidelines and Standards for the Removal of Offshore Installations and Structures on the Continental Shelf and in the Exclusive Economic Zone, adopted by IMO Assembly on 19 October 1989, (Resolution A.672 (16)). (Reference[6])

The UK is also a signatory to the 1992 OSPAR Convention (International cooperation on the protection of the marine environment of the North-East Atlantic). OSPAR Decision 98/3 was adopted to implement OSPAR's offshore oil and gas industry strategy. It sets out binding requirements for the disposal of disused offshore oil and gas installations. Whilst there is no equivalent decision for offshore renewable energy installations, OSPAR has produced guidance documents on offshore wind-farms, incorporating ideas on their decommissioning namely:

- Problems and Benefits Associated with the Development of Offshore Wind-Farms, Biodiversity Series, OSPAR Commission 2004. (Reference[7])

2.8.2 Licence Provisions

The Wave Hub licence, as issued by the Crown Estate, shall include provisions pertinent to the decommissioning plan. Due to the DTI's intention to issue new guidance in October 2006 of guidance, it will be likely that one of these provisions will be to review and re-submit the decommissioning plan within a 5 year period for further review and amendment as required to satisfy any further provisions detailed in the licence agreement and any requirements of the October 2006 guidance.

2.8.3 Relevant UK legislation.

At the present time the decommissioning plan must satisfy the following UK legislation. It is inevitable that legislation will be amended over the life of the project and this shall be taken into consideration during future amendments to this decommissioning plan and to the final decommissioning programme. The present consents regime is illustrated in Figure 2-5.

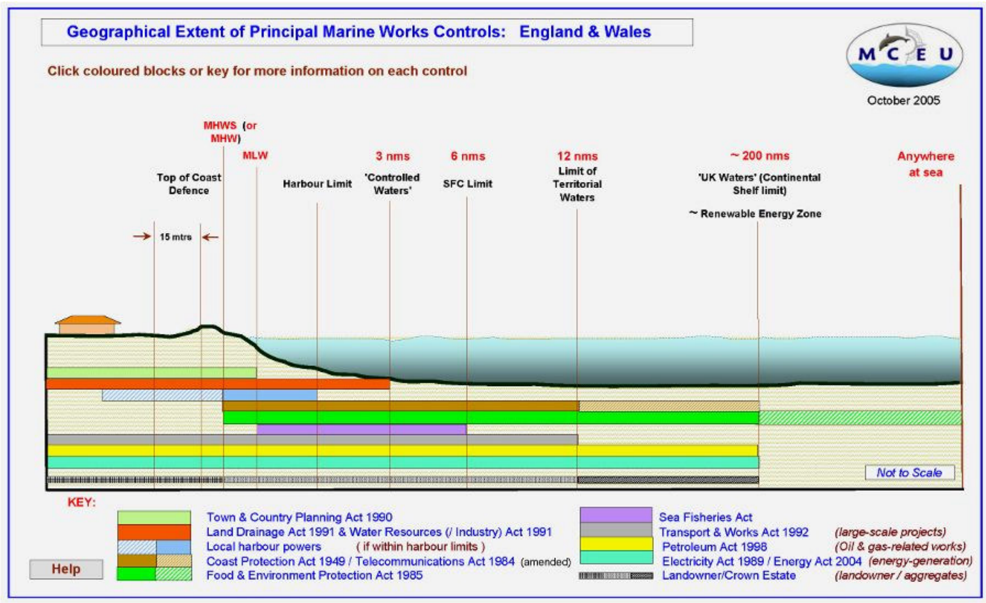

Figure 2-4 Geographical Extent of Consents

The Energy Act 2004

The Energy Act 2004 (Sections 105 to 114) contains provisions on decommissioning offshore renewable energy installations. Section 105(8) of the Act stipulates that a decommissioning programme must include:

- ❑ Measures to be taken for decommissioning the relevant object (renewable energy installation or related electric line).
- ❑ An estimate of the expenditure likely to be incurred in carrying out those measures.
- ❑ Provision for determining the times at which, or the periods within which, those measures will have to be taken.
- ❑ Provision about restoring the place to the condition that it was in prior to the construction of the object (where it is proposed that the object will be wholly or partly removed from that place).
- ❑ Provision about whatever continuing monitoring and maintenance of the object will be necessary (where it is proposed that the object will be left in position or will not be wholly removed).

The Coast Protection Act 1949

The Coast Protection Act 1949 ("CPA") contains provisions for the safety of navigation. Under section 34(1) of the CPA, consent is required for removal of any object or materials from the seabed if the operation, causes or is likely to result in obstruction or danger to navigation. This provision applies to the seabed located in the territorial waters adjacent to Great Britain and to the UK Continental Shelf extending beyond such waters. Whilst the CPA is not applied where operations are being carried out in accordance with a consent given under section 36 of the Electricity Act 1989, a CPA consent would be required for the decommissioning of objects and materials installed via such operations, as well as for the removal of any cables or installations not covered by a Section 36 consent.

The Food and Environment Protection Act (FEPA) 1985

FEPA contains provisions to protect the marine ecosystem and human health and to minimise nuisance and interference to other legitimate uses of the sea. A FEPA licence is required for the deposit of substances or articles within UK controlled waters. A FEPA licence would, therefore, be required if it was proposed to deposit any substances or articles (e.g. rock gravel or grout bags) during decommissioning.

Water Resources Act 1991

The Water Resources Act makes it an offence to cause or knowingly permit any poisonous, noxious or polluting matter to enter controlled waters.

The EU Habitats and Birds Directives (Directives 92/43/EEC on the conservation of natural habitats and 79/409/EEC on the conservation of wild birds)

The Habitats Directive has established a European network of sites to promote the conservation of habitats, wild animals and plants, both on land and at sea. A project which would be likely to have a significant effect on one of these sites must be subject to an appropriate assessment. Where a renewable energy installation would be likely to have a significant effect on one of these sites, the impacts that may be caused by decommissioning are likely to have been addressed in an appropriate assessment done prior to the original grant of Section 36 consent. If that is not the case, however, for whatever reason, and the decommissioning would be likely to have a significant effect on the site, an appropriate assessment should be undertaken prior to approval of any updated decommissioning programme.

Waste Management Legislation

Waste is predominantly regulated through the Environmental Protection Act 1990 and the Waste Management Licensing Regulations 1994. Once a decommissioned installation is deemed to be "waste", it will need to be handled in compliance with waste management legislation administered and enforced through the Environment

Agency (in England and Wales) and the Scottish Environment Protection Agency (in Scotland).

The Hazardous Waste (England and Wales) Regulations and the List of Waste (England) Regulations 2005 implement the European Parliament and Council Directive on Waste Electrical and Electronic Equipment (2002/96/EC). These regulations are enforced by the Environment Agency.

Health and Safety

Decommissioning operations will be required to comply with all relevant health and safety legislation appropriate to such work. By virtue of the location of the works and their nature i.e. the decommissioning of offshore renewable energy structures and the associated infrastructure within the territorial waters, The Health and Safety at Work etc Act 1974 (Application Outside Great Britain) Order 2001 Article 8 (1) states that the prescribed provisions of the Health and Safety at Work (HASAW) etc Act 1974 apply. Hence, the offshore works as well as the onshore will be required to comply with the HASAW Act and all its relevant statutory provisions e.g. Construction (Design and Management) Regulations 1994, etc.

3.0 Description of Items to be Decommissioned

The Wave Hub infrastructure has, for the purpose of this report, been subdivided into four categories, namely:

- Onshore infrastructure.
- Offshore infrastructure.
- Cable.
- WECs.

The complete list of the items to be decommissioned with a description of the item, are presented in Tables 3-1 to 3-4 below for the four categories respectively.

Table 3-1 Onshore Infrastructure

Infrastructure	Description
Cable Splitter Chamber	Concrete chamber
Cable trenches	Concrete ducts
Transformer area	Cable sealing ends, 24 kV circuit breaker, 24kV/33kV transformer, fencing
Substation Building	Single storey brick-clad building on concrete slab over made ground. May be a steel framed, clad building

Infrastructure	Description
Foundation slab	Reinforced concrete raft foundations and/or some form of ground improvement or piles founded at depth within the sands / gravels or bedrock may be present in transformer area.
Access road, compound track and turning area	250m metalled road
Car parking area	Concrete over made ground.
Drill pit and storage	Concrete lined excavated pit.
Security fencing	1.9m high secure fencing surrounding transformer.
Low voltage electricity supply	Trenched service cable.
Water line from mains	Trenched water supply.
Septic tank	Buried Plastic Tank and associated sewerage pipes.

Table 3-2 Offshore Infrastructure

Infrastructure	Description
4 x 11kV cables between WEC umbilical and PCU	Approx. 800m of 3 core armoured subsea 11kV cable with integrated fibre optic communication conductors.
4 x Power Connection Units (PCUs)	A water-tight protective casing containing 11kV circuit breaker 11/24 kV 5MW transformer, 24kV circuit breaker, metal frame, and sited on concrete/steel base.
4 x 24kV cables between PCU and TDU	Approx. 800m of 3 core armoured subsea 24kV cable with integrated fibre optic communication conductors.
Termination and Distribution Unit (TDU)	A passive unit which provides a connection from the 4 x 24kV cables from the PCUs to the single 24kV cable to the shore substation. Contains busbars enclosed in oil-filled water tight protective casing. Sited on concrete/steel base.
8 x Navigation Buoys	4 x Class 2, 3m steel/plastic Cardinal buoys and 4 x Special Mark steel/plastic buoys

Table 3-3 Cable

Infrastructure	Description
24kV Cable	Approx 25km of 3 core, armoured subsea 24kV cable with integrated fibre optic communication conductors.

Table 3-4 WECs

Infrastructure	Description
WECs	To be specified by developer
11kV Cable	Up to 3km of 3 core, armoured subsea cable with integrated fibre optic communication conductors per WEC
Moorings	Chain/Man Made Fibre rope (or as otherwise specified by developers)
Anchors	As specified by developers. WEC anchoring systems will be device dependent but may range from easily removable clump weights to rock anchors. Tubular anchor piles between 1-1.2m diameter and between 10-15m long.

4.0 Inventory of Materials

This section provides an inventory of the materials making up the constituent parts of the Wave Hub infrastructure. The quantity of each material is also listed where this is known or an estimate can be made. At this point in the Wave Hub project, without the detailed engineering specifications, being available, some elements of the final design have not been fixed e.g. the requirement is for a substation building to meet stated requirements. However, the exact method/type of construction would be left to the successful tenderer to propose and complete. The available information is presented in Tables 4.1 – 4.4 below for the four categories respectively.

Table 4-1 Onshore Infrastructure Materials

Infrastructure components	Materials	Quantity
Substation Building (inclusive of Power circuit room, Circuit breaker room, Metering room, Control room, Mess room, ROV workshop and garage.	Brick	To be provided
	Concrete/re-bar	To be provided
	Steel framework	To be provided
	Cladding	To be provided
Foundation slab	Concrete/re-bar	To be provided
Cable trenches	Concrete/re-bar	To be provided
Drill pit and storage	Concrete/re-bar	To be provided
Transformer area	Steel casing	To be provided
	Transformer oil	To be provided
	Copper windings	To be provided
Electrical Switchgear (24 kV circuit breaker)	(tbc) Sulphur Hexafluoride (SF6) gas	<50kg per unit

SCADA and other IT/ communication equipment	Computers/servers/printers/ multiplexers and associated network wiring	To be provided
Fencing	Steel Fencing	To be provided
Car parking area	Concrete	To be provided
Septic tank	Sewage	To be provided
	Plastic tanks and sewerage system	To be provided

Table 4-2 Offshore Infrastructure Materials

Infrastructure components	Materials	Quantity
1 x Termination and Distribution unit Bus-bars Steel case Steel frame	copper bus-bar	c 100kg
	Steel	To be provided
	Oil in enclosed container	<1000ltrs
4 x Power Connection Units 11kV circuit breaker 11/24 kV transformer 24 kV circuit breaker Metal frame Protective casing and base plates	Copper	To be provided
	Steel case and frame	To be provided
	Transformer oil	To be provided
	Concrete	To be provided
	Steel base	To be provided
8 x Navigation buoys (including electronics & moorings)	Steel casing	To be provided
	Plastic casing	To be provided
	Steel mooring cable and anchors	c100te

Table 4-3 Cable Materials

Infrastructure components	Materials	Quantity
24kV Cable (approx. 25km in length)	Copper	(Depending on specification chosen to meet design requirement, the cross sectional area (CSA) of each of the cores may be between 400 and 630mm^2. Hence, quantity may vary between a total of 269te and 565te.
	Steel wire armour sheath	To be provided
	Fibre optic communication	To be provided

	conductors.	
24kV Cable (4 x 200 m connecting cables between TDU and PCUs)	Copper Steel wire armour sheath Fibre optic communication conductors	Copper - Between 1 and 2te
11kV Cable (4 x 200m between PCU and WEC umbilical)	Copper	Copper core 3 x 120mm^2. Approx 1te

Table 4-4 WEC Materials

Infrastructure components	Materials	Quantity
WECs	To be specified by developer	To be specified by developer
Umbilical Cable	To be specified by developer	To be specified by developer (up to 3km)
Mooring lines	Chain and/or man made fibre ropes	To be specified by developer
Anchors	Tubular anchor piles 1-1.2m diameter and 10-15mlong.	To be specified by developer

5.0 Removal and Disposal Options

This section provides a general description of the alternative removal and disposal options for the components of the project as detailed in the description of items to be decommissioned. It includes a short list of options and the reasons for selection of the chosen option.

As far as is practicable the decommissioning solutions proposed are consistent with international obligations, as well as UK legislation, and have a proper regard for safety, the environment, other legitimate uses of the sea and economic considerations and are in line with the principles of sustainable development.

IMO RESOLUTION A.672(16) (Reference[6]), requires “abandoned or disused offshore installations or structures on any continental shelf or in any exclusive economic zone to be removed, except where non-removal or partial removal is consistent with the following guidelines and standards.” Whilst strictly referring to oil and gas installations, it is considered that the principles reflected in the requirements will be incorporated in the forthcoming guidance to the renewable industry.

In instances where the removal of a part of the installation is not the best solution, other options can be considered only in situations where one of the following is satisfied:

- The installation or structure has the potential to serve a new use, such as enhancement of a living resource.
- Where entire removal would involve extreme cost.
- Where entire removal would involve an unacceptable risk to personnel.
- Where entire removal would involve an unacceptable risk to the marine environment.

The removal and disposal options favour, as far as possible, the complete removal and subsequent reuse, recycling or disposal of on land, of all installations at the end of the project life.

The installations shall, however, be removed in their entirety in the instance they fall into any locations which are "approaches to or in straits used for international navigation or routes used for international navigation through archipelagic waters, in customary deep-draught sea lanes, or in, or immediately adjacent to, routeing systems which have been adopted by the IMO".

Where parts of an installation or structures are proposed to be left on the sea-bed the following provisions have to be made:

- Advance notice to mariners of the specific position, dimensions, surveyed depth and markings of the installation or structure.
- advance notice to appropriate hydrographic services to allow for timely revision of nautical charts.
- notification of non-removal or partial removal to the IMO.
- where necessary, properly marked with aids to navigation.

In deciding the removal methodology for decommissioning the following considerations have been taken into account:

- Best Practicable Environmental Option (BPEO). That is the option which provides the most benefit or least damage to the environment as a whole, at an acceptable cost, in both the long and short term.
- Safety of surface and subsurface navigation.
- Other uses of the sea.
- Health and safety considerations.

The decommissioning plan considers four areas namely;

- Onshore infrastructure.
- Offshore infrastructure.
- Cable.
- WECs.

Each of these areas are considered separately below.

5.1 Onshore Infrastructure

Decommissioning of the onshore infrastructure will involve the complete removal of the infrastructure as described in Section 6. No alternative disposal options are proposed.

5.2 Offshore infrastructure

The offshore equipment is predominantly seabed laid and is intended to be easily recoverable. There is little intrusive work on any of the offshore infrastructure although some parts of the 24kV cable will be buried to a depth of 1-3m closer inshore where this is possible. Some of the WECs may require rock anchors but, at this stage, the exact nature of these is not known. Therefore, it is intended that the majority of the offshore infrastructure shall be removed for offsite disposal in as described in Section 6.

5.2.1 TDU/PCUs

The TDU and 4 PCUs are intended to be easily recoverable in case of failure. Whilst the individual units and their locations may have become marine habitats for certain species, the removal of the TDUs and PCUs will reduce the risk to fishing vessels e.g. trawlers, when the area is subsequently opened to fishing. Given the ease with which the TDUs/PCUs can be removed, the preferred option is to remove them for subsequent re-cycling.

Two different disposal options were considered for the concrete base-plates and steel grid on which the TDU and PCUs will probably sit:

1. Leave the bases *in situ*.
2. Bring to shore for disposal

Leaving the bases in situ would present a lesser hazard than the whole TDU/PCU structure but may still present a significant hazard to trawlers which use the area dependent on the exact design/construction of the base-plate. It may, however be possible to reduce the protrusion of the plates to an extent whereby it would be acceptable to leave the remains in situ. At the present time, with the exact design of the structures unknown, it is not possible to determine if this is an acceptable solution.

Removal of the base-plate would be possible and would involve lifting and removal of the steel grid base plate for PCU. The concrete base-plate would, probably, require to be broken up and the remains brought to the surface.

The preferred disposal option, given the current knowledge of the system, is for the complete removal of the base-plates in order to remove any risk to vessels engaged in trawling.

Aids to Navigation

All aids to navigation (AtN) (i.e. 4 cardinal and 4 special mark buoys) will have been subject to periodic maintenance and replacement involving lifting and recovery onboard a suitable vessel several times during their life and should be in suitable condition to be refurbished and re-used. Any components that have reached their end of their operational life would be sent for recycling.

It is proposed that the lifting and removal of AtN is conducted by the buoy maintenance vessel used to conduct the periodic maintenance (e.g. MV PATRICIA, Trinity House operating out of Swansea or similar).

5.3 Cable

The cable length has been considered as three elements; namely:

- ❑ 11kV cables between PCUs and WEC connection points. (Approx..800m total).
- ❑ 24kV interconnecting cable between TDU and PCUs (Approx. 800m total).
- ❑ 24kV cable between substation and point offshore navigable by removal vessel. (Approx. 25km).

11kV Cables Between PCUs and WECs

These four lengths of cable shall be removed completely for onshore recycling as outlined in section 7.

24kV Interconnecting Cables between TDU and PCUs.

These four lengths of cable shall be removed completely for onshore recycling as outlined in section 7.

Offshore cable.

The offshore cable presented three disposal options for consideration. These were:

- ❑ Leave the cable *in situ.*
- ❑ Remove all cable for onshore recycling/disposal.
- ❑ Partial removal of cable for onshore recycling/disposal.

The 24kV cable contains between, approximately, 269 and 565te of copper depending on whether 400mm^2 or 630mm^2 cross sectional area core cable is selected as meeting the specification requirement. At present (May 2006) rates[1], this represents a potential value of £1m - £4m when recovered.

Recovery of the subsea cable is possible by the reverse process of laying i.e. to use a cable layer to recover the cable onto a cable drum. The cost of a cable layer at May 2006 prices[2] is between £17k and £35k per day depending on capability. The capability is based partially on the ability to recover cable buried at specified depths. Recovery could be completed within 3-4 days, hence, there would appear to be a strong economic case for recovery.

It may not, however, be able to recover the cable buried near inshore where the vessel would be unable to navigate. As this is probably to be buried to a depth of, between 1m and 3m whilst the cable on the beach, will be buried to a depth of 3m, the cable within the 10m contour (approximately 1km) would require another means of recovery (possible involving a mixture of excavation and winching).

Preliminary guidance on leaving cables in situ when buried has been provided by DTI in an informal discussion paper (Reference[5]). On the basis of this guidance it is considered that there may be a case for leaving the near shore section of the cable in situ given the technical difficulties in removing the cable which could make the removal uneconomic. Also, the near shore area is a sensitive area (especially around the rocks of St Ive's Bay) and the potential; environmental impact of sediment disturbance is high in this region. Leaving the cable in situ raises the issue of potential cable exposure in the future and the risk that this may present to other maritime users. The cable would be monitored over the life of the installation in order to assess the risks of the cable becoming exposed during that period. The requirements for ongoing monitoring would then be based on these observations and any other guidance.

It is therefore proposed that the decommissioning option for the near shore section of the cable is reassessed in the light the final design with regard to burial depths and technical feasibility.

5.4 WECs

The WECs and their mooring lines shall be removed completely as discussed in Section 6. Two disposal options were presented for the WECs anchors. These are:

- Leave *in situ*.
- Remove for offsite recycling/disposal

Where an anchor can be used by another device there is good reason for it to be left *in situ*. When there is no future use required for the anchor it shall as far as practical be retrieved and brought to shore for reuse or recycling.

[1] $7.1/kg; London Metal Exchange
[2] Global Marine

Preliminary guidance on the decommissioning of foundations below the seabed has been provided by the DTi (Reference[4]). Where an installation's foundations extend some distance below the level of the sea-bed, removing the whole of the foundations may not be the best decommissioning option, given the potential impact of removal on the marine environment, as well as the financial costs and technical challenges involved. In these cases, there is a case for rock anchor foundations to be cut below the natural sea-bed level at such a depth to ensure that any remains are unlikely to become uncovered. In the event of this proposed course of action, it shall be decided on a case by case basis as part of the developer's individual decommissioning plans.

6.0 Selected Removal and Disposal Option

The decommissioning plan considers 4 areas namely;

- Onshore infrastructure
- Offshore infrastructure
- Cable
- WECs

Each of the different areas are considered separately below:

6.1 Onshore Infrastructure.

Decommissioning of the onshore infrastructure will involve;

- Disconnection of all electrical lines and other utility services.
- Emptying and removal of the septic tank
- Draining of the transformer.
- Offsite removal of all components from within the substation.
- Destruction of the substation building and removal of all building rubble.
- Removal of ground contaminated by the activities of Wave Hub and resurfacing for Brown field redevelopment.
- Infilling of the cable pit and landscaping the surrounding area.

Electrical Supplies and other Utilities/Services.

Electrical and water mains shall be terminated in accordance with the applicable safety requirements. It is intended that the electricity and water mains will remain in situ for future site use.

Septic Tank

The septic tank contents shall be removed for offsite disposal and the septic tank shall be removed. The septic tank hole shall subsequently be in-filled with sand and soil from the surrounding area. The hole shall be suitably compacted to ensure that it does not represent a subsidence hazard.

Transformer

The transformer will be some 30–60 tonnes in size. It will be drained of transformer oil on site using a licensed waste oil collection company. The oil will be removed for offsite treatment and oil recycling facilities. The transformer casing and windings will be lifted and removed by road transport for refurbishment and re-use or sent for recycling as scrap metal as determined by survey at the time.

Substation Components

All components shall be removed from the substation and shall be taken offsite and shall as far as practical be reused and recycled. The ultimate route of disposal will depend on the component and the legislative requirements at the time. It is proposed that, as part of the submission of the final decommissioning programme, a complete inventory of all the site equipment and components shall be compiled with the appropriate disposal options listed for each component.

Substation Building

The building shall be removed without disturbing the underlying ground to as far as practical. The concrete foundations shall be left in situ. Only areas that have been identified in the site survey as being damaged or being contaminated shall be removed. Building rubble shall be removed by truck for disposal to landfill. Building rebar shall be removed for recycling.

It is anticipated that the access road will be developed into a metalled road over the project life for other site users. The road shall be kept open for the future use of the site.

Contaminated Ground

Prior to decommissioning an environmental survey shall be undertaken of the wave hub site by an accredited auditor to assess whether any of the site has been contaminated by the Wave Hub project. Where contaminated areas are identified, the report will detail recommended clean up and disposal options for the contaminated material. In contaminated areas the site shall be cleaned up and resurfaced with concrete in order that the area is able to be used for future brown field development.

Cable Pit

The cable pit shall be removed and the void shall be bulldozed and infilled with sand and soil from the surrounding area. The pit shall be appropriately compacted to ensure it presents no future hazard from ground subsidence. The site shall be landscaped in accordance with the local topography such that the area is returned to the original contours as far as practicable.

6.2 Offshore infrastructure

The decommissioning of the offshore infrastructure involves:

- AtN & mooring lifting and removal.
- TDU/PCU & interconnecting cable lifting and removal.
- Cable removal

TDU/PCU

The TDU and PCUs along with their interconnecting cable shall be lifted from their bases and removed by vessel for on shore dismantling and recycling. All components of the TDU and PCUs can be recycled. The oil can be drained and sent for recycling whilst the steel shells and any internal switchgear, transformers etc shall also be recycled.

Aids to Navigation

All aids to navigation (AtN) (i.e. 4 cardinal and 4 special mark buoys) shall be lifted and brought to shore along with their moorings and anchors. The buoys and their moorings will have been subject to periodic maintenance and replacement and should be in suitable condition to be refurbished and re-used. Any components that have reached their end of their operational life will be sent for recycling.

It is proposed that the lifting and removal of AtN is conducted by the buoy maintenance vessel used to conduct the periodic maintenance (e.g. MV PATRICIA, Trinity House operating out of Swansea).

6.3 Cable

11kV Cable between PCUs and WECs

The four 11kV cables (approximately 200m each) between the WEC umbilical positions and will be recovered by the cable recovery vessel for onshore recycling.

24kV Interconnecting Cables between PCUs and TDU

The 24kV interconnecting cables (approximately 200m each) between the PCUs and TDU will be recovered along with the units themselves by the cable recovery vessel for onshore recycling.

24kV Offshore Cable

The 25km of 24kV cable shall, as far as practicable, be recovered by a cable laying and recovery vessel. The 24kV cable will be separated from the TDU at the connector and recovered onto a suitable capacity cable drum onboard the vessel. The cable shall then be brought ashore for recycling. The vessel will limited to an extent dependent on its draught and other capabilities in recovering the near shore section of cable. The cable will be cut at the end terminated and buried at a suitable point offshore.

Further assessment will be required with regard to the potential removal of the nearshore and beach sections of cable.

6.4 WECs

The WECs shall be removed from the wave hub following their trial periods. It is not envisaged that the same WEC shall remain on the wave hub for the duration of the project. Each WEC shall be removed and brought onshore for reuse as far as practical. Where the WEC has exceeded its operational life it shall as far as practicable be recycled.

WEC device moorings (including anchors) shall be removed and brought ashore with the WEC device for subsequent disposal by re-use or re-cycling. Pile anchors may, as discussed in Section 5.4, be cut below the natural sea-bed level at such a depth to ensure that any remains are unlikely to become uncovered. In the event an anchor is to remain *in situ* this shall be decided on a case by case basis as part of the developers individual decommissioning plans.

The removal of WECs and mooring lines shall be done by vessels appropriate to the task and engaged by the developers. Developers will be required to provide a decommissioning plan to meet the requirements of the appropriate consenting authority. Appendix A shows the structure of such a plan and the headline issues to be addressed.

7.0 Hazard Identification & Risk Assessment

A formal Hazard identification and Risk Assessment was carried out on the selected decommissioning option. The Hazard Identification and Risk Assessment (HIRA) is intended to determine all potential hazards to personnel (including the public) and the environment impact associated with both the decommissioning activities and the equipments being removed and to estimate the risks that they may present.

The HIRA was conducted using a systematic approach (based on guidance in ISO 17776:2000(E) -Guidelines on tools and techniques for Hazard Identification and Risk Assessment). This provides assurance that, so far as is possible, all such impacts have been identified and that low frequency/high impact risks are captured as well as high frequency/low impact ones.

The identified hazards (issues) were assessed for the risk that they present to:

- Personnel involved in the decommissioning activities.
- Members of the public (particularly other users of the marine environment).
- Other adjacent equipment/structures (whether part of Wave Hub or not).
- The environment (including social, cultural and heritage aspects).

The Results of the Hazard Identification & Risk Assessment are included in Appendix B.

7.1 Environmental Issues

The environmental component of the HIRA incorporates the identification of environmental issues normally carried out by the more narrowly focussed Environmental Issues Identification (ENVID) process. This section defines and documents the environmental requirements to ensure that prior to and during decommissioning, minimum harm to the environment is achieved. This can be justified by ensuring that the management methods applied for the significant environmental issues are consistent with the following requirements:

- Best Available Technology (BAT) for each significant environmental issue. This needs to demonstrate that:

    1. Environmental sensitivities relevant to the project, as identified in the EIA, are to be considered in defining BAT for the significant environmental issues;

    2. Legislative requirements are met.

- The principles of Best Practicable Environmental Option (BPEO), for the significant environmental issues, have been considered, where appropriate.

This assessment covers the evaluation of all environmental aspects (including potential ones) associated with decommissioning activities. The following are the main potential environmental receptors that have been discussed during the ENVID, which are applicable during decommission operations:

- Nature conservation.
- Fisheries.
- Tourism and recreation.

- Landscape and visual amenity.
- Heritage and archaeology.
- Land and sea use.
- Traffic and transport.
- Air and climate.
- Water.
- Soil, geology, hydrogeology and geomorphology.
- Coastal processes, waves and currents.
- Solid and other wastes.
- Nuisance (noise, vibration, odours, light).
- Socioeconomic.

The environmental impacts associated with the decommissioning of the Wave Hub project are reported in Table 7.1. The timing of decommissioning is important to avoid or minimise the environmental impacts that have been identified. Table 7.1 shows the months in which key environmental impacts should be as far as possible avoided. This information should be balanced with the practical restraints put on the project with regard to weather and sea state. Periods of heavy weather will not only make operations more difficult they will increase the associated risks to health safety and the environment. The window of opportunity has therefore been proposed as during the month of September. Increased care would be required during this period to avoid disturbance to fishing pots in the near shore areas and impacts to the last of the season's recreational users.

Table 7-1 Restrictions on time table for decommissioning by month

Environmental receptor	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Bird nesting seasons (scrub onshore)		■	■	■	■	■	■	■				
Seabird vulnerability	■	■	■									
Bird migration through Hayle Estuary	■	■	■							■	■	■
Dover Sole Peak Fishing season (>30m offshore)	■	■	■									
Fish breeding seasons (St	■											■

Ives Bay)												
Shell fish (St Ives Bay out to 30m)												
Peak Spawning periods												
Recreation and tourisms (St Ives Bay)												

8.0 Waste management

When considering the management of waste arising from the decommissioning of the Wave Hub, all waste shall be brought to land for reuse, recycling, incineration with energy recovery or disposal. No waste shall under any circumstances be disposed of to sea.

The choice of waste management options have been based on an assessment of the Best Practicable Environmental Option (BPEO). That is, the option which provides the most benefit or least damage to the environment as a whole, at an acceptable cost, in both the long and short term. In determining the BPEO, three key considerations have been taken into account:

- The waste hierarchy; re-use should be considered first, followed by recycling, incineration with energy recovery and, lastly, disposal.
- The proximity principle; waste is required to be disposed of as close to the place of production as possible, thus reducing the environmental impact of transporting waste.
- Self-sufficiency; waste should not be exported from the UK for disposal (although export for re-use or recycling may be considered).

9.0 Stakeholders Issues

Stakeholders have been consulted with regard to the development and operation of the Wave Hub facility and their views and requirements taken into account. The stakeholders and required consultation processes are described in the EIA. Those stakeholders will be consulted again as part of the decommissioning consent programme described in Section 14 and in the light of the Marine Bill and future guidance.

10.0 Licenses Associated with the Disposal Option

The licenses and permits that will be required for the selected disposal option of wave hub are listed below:

11.0 Pre and Post Decommissioning Monitoring and Maintenance

11.1 Pre decommissioning

The following studies have been identified as being required prior to decommissioning the Wave Hub project.

- Offshore Cable Survey – this survey is required to identify the exact location and condition of the cable prior to lifting.
- Onshore Phase 1 and 2 Environmental audit of substation facility – the purpose of this audit is to ascertain whether there has been any contamination arising from the Wave Hub project (e.g. from disturbance) to the ground in the vicinity of the sub station. The audit findings will be used to ascertain the requirement for the removal and/or subsequent clean up of areas of the site. The typical cost for the environmental audit will be between £5k and £10k depending on the amount of intrusive investigation (i.e. bore holes and soil samples) required.

11.2 Post decommissioning.

Upon completion of decommissioning, a survey shall be undertaken to verify sea bed clearance. This survey shall ensure that all infrastructure and debris has been removed. It will identify the location of any debris that has accidentally been left on the sea bed which may have arisen from the project or as part of the decommissioning operation itself.

Where an installation is not removed entirely, some post decommissioning monitoring will be required. The IMO standards require the adoption of a specific plan to monitor accumulation and deterioration of material left on the sea-bed to ensure there is no subsequent adverse impact on navigation, other uses of the sea or the marine environment. Monitoring could identify any new or increased risks posed by remaining materials (for example, where cables and foundations may have become exposed due to natural sediment dynamics). Appropriate action could then be taken to mitigate the risks.

After decommissioning has been completed a visual landscape assessment shall be undertaken to ensure that the wave hub project area has been returned to, as far as is possible, the condition to which it was in, prior to the start of the project. The typical cost for a landscape assessment would be in the region of £8k.

12.0 Supporting Studies

At the time of writing this report, no supporting studies have been identified as being required to be undertaken during the decommissioning phase of the project.

13.0 Costs

An estimate of the costs associated with all the identified activities relating to the preferred decommissioning option, including post-decommissioning inspection and maintenance are detailed in the table below. These costs have been expressed in £ sterling at current rates (2006). Due to the fact that the design and/or the equipment or structures have not yet been finalised, the figures are, in most cases, extremely tentative. They will require review once the infrastructure specifications are decided.

Table 13-1 Estimated Costs

Activity	Asset	Rate	Time	Cost
Surveys				
Pre-Decommissioning Survey – subsea cables/TDU/PCUs	Survey vessel/ROV Personnel	£5k/day	5 days (inc. mob/ demob)	£25K ± 50%
Pre-Decommissioning Survey – Phase I & II Environmental Audit of Onshore infrastructure	Personnel	N/A	N/A	£7.5k ± 30%
Landscape Assessment	Personnel	N/A	N/A	£8k ± 30%
Post-Decommissioning Survey	Survey vessel/ROV personnel	£5k/day	3 days (inc. mob/ demob)	£15k ± 50%
Monitoring (Periodicity to be determined)	Survey vessel/ROV personnel	£5k/day	3 days (inc. mob/ demob)	£15k ± 50%

Onshore Structures				
Electrical De-commissioning	Personnel/ Plant	N/A	N/A	£20k ± 50%
Civil Structure	Demolition Team/Plant	N/A	N/A	£30k ± 50%
Land fill (Transport & Disposal)	Personnel/ Plant		N/A	£5k ± 50%
Offshore Infrastructure (including 24kV cable)				
24kV Cable	Cable Vessel	£30-65k/day (Av. £47.5k)	4 days (inc. mob/ demob)	£190k ± 50%
PCUs/TDU & interconnecting cabling (11kV and 24kV)	Cable Vessel			
Aids to Navigation (8 buoys)	Buoy recovery Vessel	N/A	2 days	£4k ± 50%
ESTIMATED AVERAGE COST)				**£319.5k**
Upper Estimated Cost				**£476.6**
Lower Estimated Cost				**£162.3**

14.0 Programme

This section of the report looks at the programme of events required prior to initiation of the decommissioning phase of the Wave Hub Project.

This programme should be viewed as preliminary guidance only as, at the time of writing this report, the DTi Guidance for the decommissioning of offshore wave energy installations has not been issued (expected to be issued October 2006).

At the project application stage a decommissioning programme shall be submitted to the DTi ORCU. The DTi ORCU shall act as coordinating body for the receipt of consent applications. The Secretary of State may then make requests for amendments to the decommissioning programme including more detailed costings or demonstration of the arrangements in place to ensuring funds are available. Upon approval of the decommissioning programme the Secretary of State may request revisions to the programme possibly at 5 year intervals. In addition, it is proposed that certain disposal options considered within this report are reassessed in light of more detailed engineering design and future technology available. The areas that have been proposed for reassessment include:

- Detailed inventory of substation equipment and components as detailed in Section 4.
- Removal of cable from near shore (<10m contour) as detailed in Section 6.
- Removal of nearshore and beach section of cable as discussed in Section 6.

At any time during the project life the Wave Hub Owner is obliged to notify the Secretary of State of any modifications to be made to the programme or of change of ownership of the project.

Upon realising a date for project end the owner shall submit a final decommissioning programme to the DTi ORCU for discussion and review at least 2 years prior to project end. It has been proposed that the decommissioning will take place during the month of September to minimise identified environmental impacts (see Section 7.1 of this report). A 2 year period will allow ample review and amendment time to the programme. It is anticipated that the approval process will take approximately 10 months. Upon approval of the programme the operator is required to apply for all associated consents and licences for conduction the actual works. This shall include but not be limited to:

- Marine works consents: Secretary of State
- Marine works: Maritime and coastguard authority
- Traffic routing: Highways Agency
- Demolition works: Local Planning authority
- Waste management licences: Environment Agency

Other bodies shall also be communicated with including:

- MOD
- Fisheries
- General Public

A diagram showing the proposed programme is shown in Figure 14.1

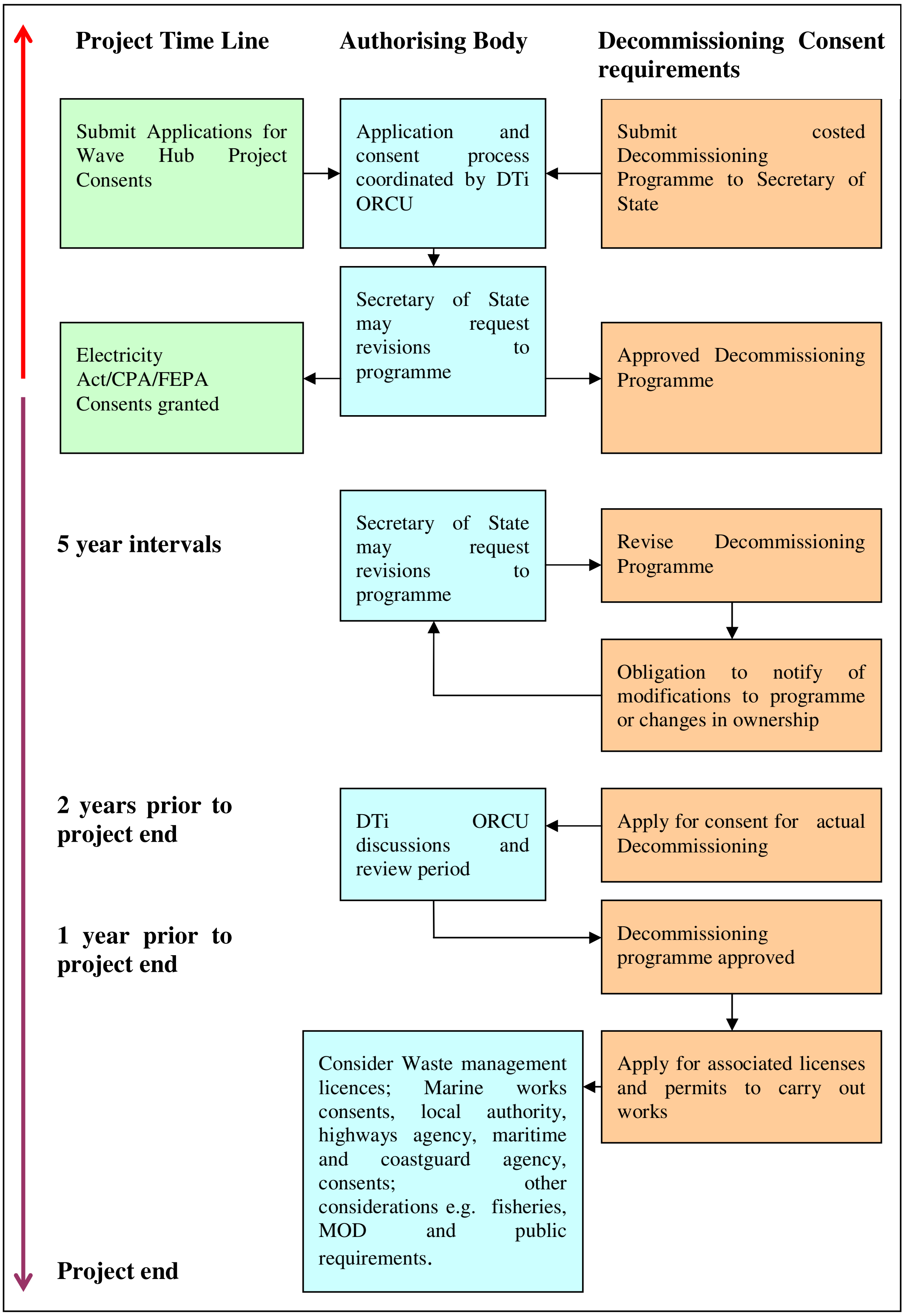

Figure 14-1 De-commissioning Programme

15.0 References

[1] MCA Marine Guidance Note 275(N) Proposed Offshore Renewable Energy Installations – Guidance on Navigational Safety Issues.

[2] Department of Trade and Industry (DTi) Guidance on Consenting Arrangements in England & Wales for a Pre-commercial Demonstration Phase for Wave and Tidal Stream Energy Devices (Marine Renewables) Nov 2005.

[3] DTi Guidance Notes for Industry – Decommissioning of Offshore Installations and Pipelines under the Petroleum Act 1998.

[4] Guidance notes for the decommissioning of offshore renewable energy installations (section 6.2 of the Guidance Notes for the Offshore Wind Farms Consents Process), March 2004.

[5] DTi Electricity development consents branch informal discussion paper on decommissioning standards for offshore renewable energy installation, March 2006.

[6] International Maritime Organisation Guidelines and Standards for the Removal of Offshore Installations and Structures on the Continental Shelf and in the Exclusive Economic Zone, adopted by IMO Assembly on 19 October 1989, (Resolution A.672 (16)).

[7] Problems and Benefits Associated with the Development of Offshore Wind-Farms, Biodiversity Series, OSPAR Commission 2004.

Appendix A

Developer’s De-Commissioning Plans Scope of Work

1.0 Developer's Decommissioning Plans

Each device developer will be required to complete a decommissioning plan for their device taking into account the standards and guidance appropriate at the time. The outline provided below is based on guidance currently available with regard to the decommissioning of offshore structures. It will be subject to review and update in the light of consenting authorities requirement and guidance as subsequently issued.

Introduction

Executive Summary

Background Information

Relevant background information, supported by diagrams, including:

- The relative layout of the facilities to be decommissioned (installations, subsea equipment and navigational aids).
- The relative location, type and status of any other adjacent facilities which would have to be taken into consideration.
- Information on prevailing weather, sea states, currents, seabed conditions, water depths etc.
- Any fishing, shipping and other commercial activity in the area.
- Any other background information relevant to consideration of the draft decommissioning programme.

Description of Items to be Decommissioned

A full description, including diagrams, of installations, cables, navigational aids and shore structures.

Inventory of Materials

For all items described above, an inventory listing the amount, type and relative location of all materials including, transformer oils, lubricants, heavy metals, sacrificial anodes and other controlled materials should be included.

Removal and Disposal Options

This section will provide a general description of the alternative removal and disposal options for the items described above. It will include a short list of options and the reasons for rejecting those not short-listed.

Selected Removal and Disposal Option

This section shall describe the proposed decommissioning option. It should include:

- The removal and disposal option, describing the removal method and the disposal route.
- An indication of how the principles of the waste hierarchy will be met, including the extent to which the installation or any part of it, will be re-used or recycled.
- Details of any cleaning or removal of waste materials, including cleaning methods; cleaning agents and disposal of residues.
- Details of any materials and remains on the seabed after decommissioning.
- Water clearances above any remains.
- Predicted degradation, movement and stability of any remains.

Risk Assessment

This section should include the results of the Risk Assessment (RA) of the selected decommissioning option. It will be an assessment of the likely effects of the project on project personnel, the public, and the environment and the measures envisaged to avoid, reduce to tolerable level (As Low As Reasonably Practicable - ALARP) and, where necessary, remedy any significant adverse affects should they occur. The RA will include the following:

- Impacts on the marine environment, including exposure of biota to contaminants associated with the installation, other biological impacts arising from physical effects, conflicts with the conservation of species, with the protection of their habitats, or with mariculture, and interference with other legitimate uses of the sea.
- Impacts on other environmental medium, including emissions to the atmosphere, leaching to groundwater, discharges to surface fresh water and effects on the soil.
- Other consequential effects on the physical environment which may be expected to result from the option.
- Impacts on amenities, the activities of communities and on future uses of the environment.

Stakeholder Issues

A description is required of the consultation processes undertaken, including a summary of the statutory consultations with interested parties and the extent to which they have been taken into account in the programme.

Costs

Estimates of cost should be included for all identified activities relating to the preferred decommissioning option, including post-decommissioning inspection and maintenance.

Licences Associated with the Disposal Option

This should indicate any other licences or permits that are required in order to carry out the proposed decommissioning option.

Pre- and Post-Decommissioning Monitoring and Maintenance

The requirements for pre and post –decommissioning surveys shall be addressed.

Supporting Studies

The requirement for supporting studies such as a Fish Ecology Study, shall be identified and addressed here.

Programme

A programme of required actions shall be included which will indicate the sequence of activities, including consent applications, required for the de-commissioning to be completed successfully.

Appendix B

De-Commissioning Hazard Identification & Risk Assessment

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Decommissioning Hazard/Risk Assessment:

Area	Hazard ID	Guideword	Hazard	Consequence	Risk Index L	Risk Index C	Risk Index I	Controls / Mitigation Measures To Be Taken	Risk Index after Mitigation L	Risk Index after Mitigation C	Risk Index after Mitigation I	Design Mitigation Action Owner (Initials)	Target Date	Date Action Taken	Anticipated Measure That Could Be Applied By The Contractor (or Others)
Note:				Likelihood (L): 1 - Unlikely to occur in relevant period. 2 - Likely to occur in relevant period. 3 - Likely to occur several times in the relevant period	Consequence (C): 5 - Death or total systems loss 4 - Major injury or illness. Major damage or environmental impact. 3 - Lost time injury or illness. Damage or environmental impact. 2 - First aid incident. Routine maintenance repair 1 - Very minor. Little consequence.				Index (I): Likelihood x Consequence (See also CIRIA SP125). 10-15 Very High Risk - not acceptable. Apply mitigation. Seek director approval if significant risk remains. 6-9 High Risk - Apply mitigation. Seek director approval if risk cannot be reasonably and practically be reduced below "this" level. 1 - 5 Low Risk - May be accepted if all reasonably practicable control measures in place.						
Wave Hub Decommissioning Phase															
Pre-de-commission-ing survey	1	Marine	Marine transport used to conduct offshore surveys	Collision between survey and other vessels/devices/buoys leading to vessel being sunk, or crew injured. Vessel, deviceor equipment may be seriously damaged. Potential release to marine environment	2	5	10	Survey vessel lit/marked in accordance with International rules for the prevention of collision at sea appropriate to its size and task.	1	5	5				
	2	Pressure hazards	Diving operations may be required in inshore area to survey cable condition.	Risk of diving accident	1	5	5	Use of ROVs preferred where possible. Diving only used close inshore where ROV use impractical i.e. within surf line, hence minimising risk of diving incident Use of SQEP Diving contractor.			0				
	3	Asphyxiates	Work over water during marine surveys	Risk of drowning/hypothermia	2	5	10	Provision of harnesses and lifejackets and, where appropriate, protective clothing whilst carrying out unavoidable works.	1	2	2				
	4	Height	Work at heights during survey	Fall leading to death/injury	2	5	10	Provision of appropriate edge protection/safe system of work/personal fall prevention equipment	1	5	5				
	5	Environment	High sea state/wind	Exceeds seakeeping capability of survey vessel	2	4	8	Work boat meets MCA Code for workboats and operating area	2	2	4				
Onshore Sub Station and Data Centre Demolition	6	Height	Lifting operations during demolition.	Lifting equipment collapses or topples. Load is dropped or collides with worker(s) or structure. Injury to workers. Death of workers. Loss of Structure. Damage to equipment	2	5	10	Specify complex or heavy/high lifts plans e.g. transformer. Specify adequate and SQEP personnel to contractor for lifting operations. Provide hard-standings for lifting operations. Provide lifting attachments and C of G markings for complex or heavy equipment.	1	5	5				
	7	Height	Falls from height	Injury/death of operators	2	5	10	Most demolition of shoreside structure is by means of plant. Building is single story Provision of appropriate edge protection/safe system of work/personal fall prevention equipment	1	5	5				
	8	Height	Structural collapse during demolition	Death/injury to operators	3	5	15	SQEP contractor Safe methods of working, appropriate plant	1	5	5				
	9	Electricity	Conflict with existing services during demolition e.g. existing live underground / overhead HV Cables.	Fire. Explosion. Electrocution. Flooding. Injury to workers. Death of workers. Loss of Structure. Loss of Service. Damage to equipment	2	5	10	Detailed site survey to locate and map all services before start of construction. All Wave Hub services to be isolated Local confirming surveys prior to excavation. Protection of overhead services and exclusion of high vehicles/structures from vicinity of live WPD equipments. WPD overhead/ adjacent equipments are sufficiently distant from area of operations not to present a hazard	1	5	5				
	10	Ergonomic	Manning levels / Lone working etc	Injury to workers exacerbated by lack of others to notify emergency services Lack of suitable qualified personnel to assist (E.G 1St aider)	2	4	8	No lone working during demolition phase Adequate provision of communication for site security personnel 1st Aid facilities	1	2	2				
	11	Access	Landside traffic conflicts during demolition - site access, narrow bridge	Driver(s) or pedestrian(s) may be injured or killed. Vehicle(s), structure or equipment may be seriously damaged.	2	5	10	Traffic Management. One-way systems. Contractor to provide banksmen during unavoidable manoeuvres.	1	5	5				
	12	Entrapment	Landside excavations during demolition / removal of cable coneection pit affecting dune stability	Collapse of dunes into work area. Death of workers. Loss of Structure. Damage to equipment	2	5	10	Ensure support of excavations is clearly specified in method statement. Segregate vehicles and workers from excavations.	1	5	5				
	13	Pressure hazards	Systems under pressure	Release leading to injury/death of operators	2	4	8	All Systems isolated and de-pressurised prior to demolition	1	4	4				
	14	Pressure hazards	Bottled gases used for cutting and burning equipment	Risk of fire/explosion	1	4	4	Proper stowage provided by contractor	1	4	4				
	15	Biological	Sewage from septic tank during tank removal	Operator ill health	2	3	6	Tank to be drained and cleaned before removal. Method statement and Risk Assessment to reflect hazards	1	3	3				
	16	Noise	Noise from demolition activities exceeds statotory levels	Damage to operators hearing	2	3	6	Contractor takes appropriate action to reduce/protect against noise	1	3	3				
	17	Toxic/nuisance substances	Masonry/cement dust released during demolition	Adverse effect on demolition workers. Nuisance effect on adjacent housing	2	3	6	Use of dust suppression measures on site where appropriate Appropriate PPE for operators	1	2	2				
	18	Toxic /nuisance substances	Dust / fumes ffrom grinding/cutters	Adverse effect on demolition workers. Nuisance effect on adjacent housing	2	3	6	Use of dust suppression measures on site where appropriate Appropriate PPE for operators	1	3	3				
	19	Ground Conditions	Adverse geological conditions	Damage to structures/cables/installation equipment	3	4	12	Ensure full and adequate survey of WaveHub construction area	1	4	4				

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Decommissioning Hazard/Risk Assessment:

Area	Hazard ID	Guideword	Hazard	Consequence	Risk Index L	Risk Index C	Risk Index I	Controls / Mitigation Measures To Be Taken	Risk Index after Mitigation L	Risk Index after Mitigation C	Risk Index after Mitigation I	Design Mitigation Action Owner (Initials)	Target Date	Date Action Taken	Anticipated Measure That Could Be Applied By The Contractor (or Others)
Note:				Likelihood (L): 1 - Unlikely to occur in relevant period. 2 - Likely to occur in relevant period. 3 - Likely to occur several times in the relevant period	Consequence (C): 5 - Death or total systems loss 4 - Major injury or illness. Major damage or environmental impact. 3 - Lost time injury or illness. Damage or environmental impact. 2 - First aid incident. Routine maintenance repair 1 - Very minor. Little consequence.				Index (I): Likelihood x Consequence (See also CIRIA SP125). 10-15 Very High Risk - not acceptable. Apply mitigation. Seek director approval if significant risk remains. 6-9 High Risk - Apply mitigation. Seek director approval if risk cannot be reasonably and practically be reduced below "this" level. 1 - 5 Low Risk - May be accepted if all reasonably practicable control measures in place.						
	20	Extreme Weather Conditions	flooding of site from extreme tidal level or rain accumulation	Damage to structures/cables/installation equipment	1	4	4	Site level is same as WDP Substation - assume withstand	1	3	3				
	21	Waste	Personnel are exposed to transformer oils during draining operation	contaminated poils can be carcinogenic and /or cause determititis	2	4	8	Risk Assessment/Method statement for activity to be produced by contractor	1	4	4				
	22	Waste	Battery electrolyte	Burns etc to operators/ removing batteries	2	3	6	Risk Assessment/Method statement for activity to be produced by contractor	1	3	3				
	23	Environment	high wind/blown sand	Sand injury to personnel / damage to machinery	3	1	3	None - risk tolerable	3	1	3				
	24	Health Hazards	Manual Handling during demolition	Musculo-skeletal Injury of workers during demolition.	2	3	6	Competent contractor. Use of method statements and risk assessments.	1	3	3				
	25	Fire/Explosion	Fire during demolition	Injury to workers. Death of workers. Loss of Structure. Damage to equipment	2	5	10	Minimise flame cutting, welding, hot working processes. Use of Hot Work procedure. Contractor to provide adequate fire-fighting equipment.	1	5	5				
	26	Environmental Hazard	Contaminated land in area of sub station	Release to wider environment (including marine environment) by disturbance /removal	3	3	9	Environmental Management Plan	1	3	3				
	27	Environmental Hazard	Noise	Disturbance of birds during nesting periods - programme adjustments cause project delay	2	4	8	Environmental Management Plan	1	4	4				
	28	Security	Trespassers / visitors	Injury to persons/children	2	4	8	Fencing of demolition areas at SubStation site and beach "pull through" areas. Security manning	1	4	4				
Offshore i.e. Subsea Cable/ TDU/PCU and fibre optic link AtN buoys	29	Electricity	Live systems	HV electricity risk of shock	2	5	10	Permit to work. Procedures for test. SQEP personnel (Authorised persons)	1	5	5				
	30	Height	Lifting operations during removal	Lifting equipment collapses or topples or load is dropped or collides with worker(s) or structure leading to death/injury/damage.	2	5	10	Specify complex or heavy/high lifts plans. Specify adequate and SQEP personnel to contractor for lifting operations. Provide hard-standings for lifting operations. Provide lifting attachments and C of G markings for complex or heavy equipment.	1	5	5				
	31	Control philosophy	Vessel Mooring activities during installation of navigation buoys	Damage to power & Data cables.	2	3	6	Sequencing operations where possible to remove Navigation buoy after cable/subsea equipment removal. Noting cable routes on marine installation charts Close supervision of installation Approved mooring plan	1	3	3				
	32	Control philosophy	Lifting Operations	Damage to Power & Data cables.	2	4	8	Vessel will be DP capable - not required to anchor/moor Permit-to-Work RA & Method Statements Tailored Weather forecasting for offshore de-commissioning period	1	4	4				
	33	Access	Loss of structural stability during transportation	Loss of equipment. Injury to staff. Staff at risk from: drowning, hypothermia, exposure	1	5	5	Detailed design and specification of transport procedure. Specify adequate and SQEP personnel to contractor for transport operations. Provide adequate lifting attachments and C of G markings for complex or heavy equipment.	1	5	5				
	34	Adjacent Land Use	Marine traffic conflicts during de-commissioning	Collision between vessels and construction vessels/platforms/barges may be sunk, or crew injured. Vessel, structure or equipment may be seriously damaged. Potential release to marine environment	2	4	8	Navigational Risk Assessment for de-commissioning phase iaw MCA Guidance Notification to and liaison with marine authorities (including MCA, Harbour Authorities). Navigation buoys still mark Wave Hub area. Notices to Mariners	1	4	4				
	35	Extreme Weather Conditions	Extreme Weather during decommissiong.	Loss of Structure. Injury to staff. Staff at risk from: drowning, hypothermia, exposure	3	5	15	Obtain detailed meteorological data for entire offshore decommissioning period. Vessel operates within known operational envelope. Suspend operations and recall staff if risk is notified. Ensure that time at risk is minimised. Ensure operations are planned for low-risk periods (e.g. spring/summer). Ensure adequate time in programme so that contractor is not pressured into taking risks.	1	5	5				
	36	Health Hazards	Manual Handling during de-commissioning	Musculo-skeletal Injury of workers during construction.	2	3	6	Specify lightweight materials. Design in lifting attachments to heavy equipment/materials. Prefabrication where possible.	2	2	4				
	37	Security	Public access tp beach during cable removal operations	injury to public	3	4	12	IT IS NOT YET CLEAR WHETHER REMOVAL OF THE NEAR SHORE & BEACH SECTION OF THE CABLE IS VIABLE Fence/ warning signs/ security/lighting Sub Contractor H&S Plan - Method statement/procedure Liaison with local authority	1	4	4				
	38	Human Error	Incorrect carrying out of procedure during recovery operations	Collapse of structure during construction or operation. Injury to workers. Death of workers. Loss of Structure. Damage to equipment	2	5	10	Ensure all critical assembly procedures are clearly marked or cross-referenced on construction drawings. Minimise site assembly of structural assemblies (prefabrication).	1	5	5				

Halcrow

Decommissioning Hazard/Risk Assessment:

Area	Hazard ID	Guideword	Hazard	Consequence	Risk Index			Controls / Mitigation Measures To Be Taken	Risk Index after Mitigation			Design Mitigation Action Owner (Initials)	Target Date	Date Action Taken	Anticipated Measure That Could Be Applied By The Contractor (or Others)
					L	C	I		L	C	I				
Note:				Likelihood (L): 1 - Unlikely to occur in relevant period. 2 - Likely to occur in relevant period. 3 - Likely to occur several times in the relevant period	Consequence (C): 5 - Death or total systems loss 4 - Major injury or illness. Major damage or environmental impact. 3 - Lost time injury or illness. Damage or environmental impact. 2 - First aid incident. Routine maintenance repair 1 - Very minor. Little consequence.				Index (I): Likelihood x Consequence (See also CIRIA SP125). 10-15 Very High Risk - not acceptable. Apply mitigation. Seek director approval if significant risk remains. 6-9 High Risk - Apply mitigation. Seek director approval if risk cannot be reasonably and practically be reduced below "this" level. 1 - 5 Low Risk - May be accepted if all reasonably practicable control measures in place.						
Post Decommissioning Survey	39	As for Pre-decommissioning survey													

Appendix C – Designers Risk Assessment

Final versions of the Designers Risk Assessments will be available after final review of the specification

1. Final DRA 2006 Sub sea cables and equipment WGEHDD

2. Final DRA 2006 Sub station area and approaches WGEHDD

3. Final DRA 2006 Directional drill and beach cable laying WGEHDD

4. Final DRA 2006 General Items WGEHDD

5. Final DRA 2006 OM and demolition Phases WGEHDD

Appendix D – Electrical Design Philosophy

Electrical Design Philosophy

D.1 Introduction

The technical feasibility study identified outline design proposals and potential suppliers of electrical plant for use as the electrical infrastructure in the Wave Hub project. The design development phase develops the outline design into a performance specification suitable for inclusion in tender documents.

This section describes the following:

- The thoughts and processes behind the development of the design
- Manufacturer involvement and a discussion of equipment procurement
- Design choices and the selection of equipment for a complete 20MW capacity system

The method is to take each plant item or area in turn, comprising the following:

- Interface to the wave energy converter devices
- Cabling
- Sub sea plant
- Termination and distribution unit
- Power connection unit
- Connectors
- Wave Hub substation
- Control and monitoring

The following drawings show the proposed electrical arrangement:

- Dwg no.WGEHDD/100: Protection and Earthing Schematic- Offshore
- Dwg no.WGEHDD/204: Protection and Earthing Schematic- Onshore
- Dwg no.WGEHDD/200: Proposed Onshore Site Layout
- Dwg no.WGEHDD/400: Proposed Fibre Optic Core Allocation Schematic
- Dwg no.WGEHDD/401: Proposed Control and Monitoring System Schematic

D.2 Interface to the Wave Energy Converters

At an early stage of design development, 3 Developers were selected as probably having a device ready for connection to Wave Hub in 2007. The following Developers were visited to introduce the project and again contacted or visited to establish technical requirements and interfaces:

Table D.1: First stage of WEC developers contacted

Developer	Device Name	Location
Ocean Power Delivery	Pelamis	Edinburgh
Ocean Power Technologies Inc	PowerBuoy	Warwick, UK & New Jersey, USA
ORECon	MRC1000	Plymouth

Subsequently in September 2005, the following Developers were identified by SWRDA as having a device with potential for early occupation of Wave Hub.

Table D.1: Second stage of WEC developers contacted

Developer	Device Name	Status	Outcome*
Ocean Prospect Ltd (Device by Ocean Power Delivery)	Pelamis	Submitted EoI	Selected
Ocean Power Technologies	PowerBuoy	Submitted EoI	Selected
Wave Dragon	Wave Dragon	Possibly ready for 2008	Not selected
Wave Bob Ltd	Wave Bob	Possibly ready for 2008	Not selected
Fred Olsen Ltd	FO3	Submitted EoI	Selected
SeaPower international	Floating wave power vessel	Not in contention	Not selected
Ecofys	Wave Rotor	Device not functional	Not selected

* Selected Developers are those that received 'preferred Developer' status as granted by SWRDA in their letters dated 15 December 2005.

In order to co-ordinate the interface with the sub sea plant provided by Wave Hub, and to establish the parameters for the grid connection, the following information was sought from the selected Developers:

- Generator characteristics: voltage, power rating, type and quantity
- Electrical system characteristics: power factor control, harmonic currents, protection
- Cabling interfaces: MV power, LV power and fibre optic cables

The responses from the Developers have been incorporated in to the infrastructure design where possible. Final negotiations with the Developers will require agreement on the technical specifications for connection and might, in some cases, redefine the extent or detail of equipment supply by Wave Hub.

D.3 Cabling

D.3.1 Power cabling

(b) TFS requirements

In the TFS, it was envisaged that the following items would be required:

- Connections between the WECs and PCUs: 11kV dynamic sub sea cable with fibre optic cores, 4 lengths of up to 2km each, but dependant upon the type and arrangement of WECs installed
- Connections between the PCUs and TDU: 33kV static sub sea cable with fibre optic cores, 4 lengths of approx. 100m. each
- The main transmission cable from the TDU to a jointing chamber on Hayle beach: 33kV static sub sea cable with fibre optic cores, 29km.
- Extension of the main transmission cable from the jointing chamber on Hayle beach to the onshore substation: 33kV 'dry' cable with fibre optic cores, approx. 300m.
- Cable joint between the 33kV sub sea cable to the dry type cable in a chamber on Hayle beach.

(c) Design development

Suppliers

We approached the following international suppliers of sub sea cable:

Table D.3 List of sub-sea cable suppliers

Manufacturer	Location	Remarks	Status
ABB	Norway	Able to manufacture suitable cable	Meeting held 08/11/2005
Nexans Deutschland Industries GmbH	Norway- dynamic cables Germany- static cables	Bought Alcatel Cables	Meeting held 03/08/2005
Pirelli	Italy- static cable Brazil- dynamic cable	Bought Siemens Cables	Meeting held 29/07/2005
AEI Cables Ltd	UK	Factory closed	Not considered
Amer-cable	USA	Unable to manufacture lengths required	Not considered
Draka Norsk Kabel	Norway	Unable to manufacture to 33kV	Not considered
Siemens GmbH	Germany	Sold HV cable manufacturing facility to Pirelli	Not considered
Habia Cable	Sweden	Unable to manufacture to 33kV	Not considered
Mitsubishi who contacted 3 suppliers: J-Power	Japan	All declined to offer	Not considered

(ex-Sumitomo) Exsym and another			
Oceaneering Multiflex	Edinburgh	Able to manufacture suitable cable	Meeting held November 2005

The 4 manufacturers who are able to provide suitable cabling for the project all stated that, due to current high demand for sub sea cables for wind farms, lead times are currently up to 12 months.

Cable Jointing

Cable manufacturers have advised that it is uneconomic to manufacture lengths of 33kV cable in quantities of less than 5000m. They have suggested that the main transmission cable be continuous from the TDU to the onshore substation, possibly with a change in armouring design onshore. This would obviate the need for a joint and chamber. It is proposed that the manufacturers are asked for proposals in their tenders.

DESIGN CHOICE: no cable joint

Operating Voltage

For the reasons explained in the clause D1.4.2 Transmission Voltage, the main cable will operate at 24kV rather than at the original 33kV proposed in the TFS.

Cable Lengths

The PCUs could either be clustered around the TDU or could be located near to the WEC connection. Electrically, there is no advantage either way. We propose that the former be adopted for reasons of transport practicality. Since the TDU will be permanently connected to the input and output cabling, the whole assembly must be loaded on to the cable laying vessel with cabling attached. It will be much simpler if the attached cabling is say 200m rather than up to 3km.

DESIGN CHOICE: TDU-PCU cables to be 200m

Unconnected Cable

At discussions with suppliers, it was established that the ends of the cables provided for connection to a WEC device should be fitted with floats so that the cable is suspended 1 - 2m above the seabed when disconnected. This would stop the end of the cable from being buried in the seabed if lying unconnected for a long time.

Suppliers also recommended against supporting the cable such that the unconnected cable end is floating say 5m below the surface. The constant movement would be detrimental to the life of the cable, so additional armouring would be required to stiffen the cable against movement. This adds considerable cost and difficulty with handling.

An alternative is to terminate the WEC connector cable and blank it off, then weigh the cable end down with heavy duty chain to prevent movement. This would allow easy identification and facilitate lifting of the cable to the surface for attachment of the WEC device.

DESIGN CHOICE: Terminate WEC connection cable and attach chain

D1.3.2 *Signal Cabling*

a) TFS requirements

Signal cabling is required for the following functions:

- Monitoring of WEC devices by the Developers
- Control of WEC devices by the Developers
- Limited control and monitoring of WEC devices by Wave Hub
- Monitoring of Wave Hub infrastructure PCU device
- Control of circuit breakers in Wave Hub infrastructure PCU device

Fibre optic cores are used by all Developers for transmission of information because:

- They are cheap and widely available
- They can be incorporated in to power cables easily
- FO cores can transmit large amounts of information
- Transmission is at high speed
- FO cores do not suffer from interference from power frequency cables and have low loss over large distances

The disadvantages are that:

- FO cores are delicate and susceptible to breakage and therefore standby fibres are required
- Redundancy requires additional connectors
- Sub sea connectors are expensive
- There is the potential for loss of information at the connectors

b) Design development

Developers have declared their requirements as follows:

Table D.4 WEC developers requirements

Developer	Device	Fibre Optic Cores		
		WEC to PCU	**PCU to TDU**	**TDU to shore**
Ocean Prospect/OPD	Pelamis	2 pairs per string of 3 devices	2 pairs per string	2 pairs per string
OPT	PowerBuoy	4 pairs minimum	2 pairs	2 pairs
Fred Olsen	FO3	3 pairs	2 pairs	2 pairs

It is prudent to include a degree of redundancy in the number of fibres provided but the connectors are expensive and multiplexing signals onto the fibres without losing security is common practice.

OPD have also requested a pair of copper cores for a back-up power supply to their fibre-optic hub. However, in order to standardise the connections, this will not be provided.

DESIGN CHOICE: 4 fibres per connection point (from WEC to shore)

c) Wave Hub Infrastructure

Monitoring of the Wave Hub infrastructure PCU device and the control of circuit breakers will require a control and monitoring system in the PCU. The communication circuits for these control and monitoring systems will need to be resilient and have a degree of redundancy. To meet these requirements a ring network is proposed. 2 pairs of fibre will be required from each PCU to the TDU and 2 pairs of fibre from the TDU to shore. The optic fibres will be spliced at the TDU to form the ring.

Drawing no. WGEHDD/400 shows the proposed arrangement.

DESIGN CHOICE: 4 fibres from each PCU to TDU and 20 fibres from TDU to shore.

D1.4 Sub sea Plant

D1.4.1 Supplier Selection

We approached the following potential international suppliers of sub sea electrical equipment:

Table D.5 Sub-sea electrical equipment suppliers

Company	Source of identification	Location	Potential plant	Discussion	Outcome
GE Energy	TFS	USA	PCU, TDU	GE Energy advised that they have not developed any plant for sub sea use.	Not for consideration
Areva T&D Ltd	TFS	France	PCU, TDU	Areva T&D are the former division of Alsthom responsible for transmission and distribution systems. Areva T&D advised that they have not developed any plant for sub sea use.	Not for consideration for sub sea plant but are approved by WPD for 33kV switchgear.
Groupe Schneider	Scottish Enterprise	France	PCU, TDU	Groupe Schneider advised that they have not developed any plant for sub sea use.	Not for consideration
Taylor transformers	Scottish Enterprise	UK	Transformers	Taylor advised that they have not developed any plant for sub sea use.	Not for consideration
Framo Engineering	www.Subsea.org	Norway	PCU, TDU	Framo Engineering has developed plant for sub sea use in conjunction with ABB who are the principal marketer. Framo have a fabrication, assembly & test facility at Fusa, Norway which was visited.	May be considered in conjunction with other manufacturers.
Mitsubishi	Industry	Japan	Unknown	Power rating too low	Not for consideration
Siemens	TFS	Norway	PCU, TDU	A meeting was held with Matthew Knight, Business Development Manager on 29 July 2005. Subsequently, Siemens advised that they have not developed any plant for sub sea use.	Not for consideration for sub sea plant but are approved by WPD for 33kV switchgear
Alsthom	Areva	UK	PCU, TDU	Alsthom initially advised that they have not developed any plant for sub sea use. However at a meeting 07/03/2006, they advised that they are able to meet the requirements	May be suitable but yet to be demonstrated.
ABB/Vetco	TFS	Transformers-Finland Switchgear-Norway	All	Vetco was the 'offshore technology' subsidiary of ABB but is now an independent company. However, the patents are shared by ABB, and Vetco have close ties and do all the offshore manufacturing for ABB.	Suitable

(a) TFS design – 33kV Transmission voltage: Option 1

This is the outline design proposed in the TFS with small refinements.

The main elements of the sub sea string are, from the WEC end:

- Dry mate connector to connect to WEC

- Up to 2km 11kV cable (or 33kV cable)
- Dry mate connector
- PCU comprising:
    - 11kV circuit breaker
    - 5MVA transformer, 11/33kV
    - 33kV circuit breaker
- Dry mate connector
- Approx. 100m 33kV cable with options as follows:
    - 33kV 3 core cable with conductors of the same area as the main umbilical (i.e. the same cable as the main umbilical)
    - 33kV 3 core cable with conductors of 50sqmm (only 1km of this cable would be required which is below the minimum economical manufacturing length)
    - 33kV 3 core cable with conductors of the same area as the 11kV cable (and use this same cable for the 11kV cables of 2km)
    - 33kV single core oil filled hoses
- TDU with penetrators in and out
- Approx. 28km 33kV cable
- Cable splitter chamber
- Cable sealing ends
- 33kV circuit breaker
- 30MVA transformer 33/33/0.4kV
- 33kV cabling from transformer to circuit breaker
- 0.4kV busbar trunking from transformer to SVC
- SVC
- 33kV circuit breaker
- 33kV connection to WPD 33kV Hayle substation (by WPD)

(b) Supplier discussion

Detailed discussions were held with ABB/Vetco regarding the technical status and availability of sub sea plant. It transpires that the plant required for a transmission voltage of 33kV, as proposed in the TFS, is not as developed as was originally believed. A transmission voltage of 24kV was suggested as the equipment is at a more advanced stage of development.

The potential problems with option 1 are:

(i) There is no current design of 33kV sub sea circuit breaker. There is a current design of a 24kV sub sea circuit breaker which is now undergoing qualification for use in the oil and gas industry. It will require development to fit a 33kV unit in to a 24kV pod.

(ii) The current design of a 33kV circuit breaker has a motorised spring charge mechanism which requires maintenance every say 2-3 years. The 24kV unit has a magnetic actuator which requires no maintenance. There is therefore a choice between:

   (i) accepting a device which requires regular maintenance and maintaining it
   (ii) accepting a device which requires regular maintenance and not maintaining it but repairing it when it fails
   (iii) accepting time and cost to develop a device which requires no maintenance.

ABB/Vetco also advised that there is no current design of 5MVA sub sea transformer. The nearest proven design is for a 1.6MVA unit. The nearest unproven design is of a 3.5MVA transformer with 1 MVAr reactor enclosed in the same pod. This was seen under test at Framo Engineering test facility. The supplier stated that the limiting parameter is the cooling for which the current design is good for up to 8MVA. They could therefore see no problems with extending the existing design to accommodate a 5MVA transformer.

c) Design development- 24kV transmission: Option 2

This design was proposed to overcome the problems associated with the 33 kV TFS design and to adopt oil and gas industry standards where possible.

The main elements of the power string are, from the WEC end:

- Dry mate connector to connect to WEC
- Up to 2km 11kV cable
- Dry mate connector
- PCU comprising:
- 11kV circuit breaker
- 5MVA transformer, 11/24kV
- 24kV circuit breaker
- Dry mate connector
- Approx. 100m 24kV cable
    - 24kV 3 core cable with conductors of the same area as the main umbilical (i.e. the same cable as the main umbilical)

  - 24kV 3 core cable with conductors of 50sqmm (only 1km of this cable would be required which is below the minimum economical) manufacturing length
  - 24kV 3 core cable with conductors of the same area as the 11kV cable (and use this same cable for the 11kV cables of 2km)
  - 24kV single core oil filled hoses
- TDU with penetrators in and out
- Approx. 28km 24kV cable
- Cable splitter chamber
- Cable sealing ends
- 24kV circuit breaker
- 30MVA transformer 24/33/0.4kV
- 33kV cabling from transformer to circuit breaker
- 0.4kV busbar trunking from transformer to SVC
- SVC
- 33kV circuit breaker
- 33kV connection to WPD 33kV Hayle substation (by WPD)

The potential problems with option 2 are:

(a) The current design of connector is up to 700A at 24kV (qualified at 20 deg C). A 30MVA connection requires a penetrator rated at 720A. It is generally felt however, that, since the temperature of the sea will normally be substantially less than 20 deg C and allowing for diversity, the rating of the penetrator will be adequate.

(b) The main transmission cable would probably require 630sqmm cores. There is a doubt over the availability of connectors to accommodate this core size. However, this can be overcome by reducing the conductor area to allow the use of a proven connector.

The decision was taken to select a transmission voltage of 24kV in order to prefer equipment qualified or proven to offshore oil and gas industry standards, and particularly to:

- Obviate development work of a suitable 33kV circuit breaker
- Obviate the increased risk of failure associated with the closing mechanism

DESIGN CHOICE: 24kV transmission voltage

Having decided upon a transmission voltage of 24kV, we should consider the possibility of using fuses instead of a circuit breaker to protect the higher voltage winging of the PCU transformer.

The decision was taken to use a circuit breaker because:

- Transformer FLC is 120A. Largest fuse at 24kV is 160A. Minimum size required is 180A for inrush
- ABB/Vetco advise little price difference between fuses and circuit breaker
- 24kV circuit breaker is already under-going qualification for sub sea use
- Circuit breaker provides far superior co-ordination and sensitivity to fuses

DESIGN CHOICE: 24kV circuit breaker in PCU

The following drawing shows the proposed electrical arrangement for the standard connection arrangement:

- Dwg no.WGEHDD/102: Proposed Electrical Block Diagram

d) Arrangement option

The TFS envisaged an arrangement where the TDU was a separate item connected by cabling to separately placed PCUs.

In discussion with Tronic, another arrangement was discussed. The TDU and all 4 PCUs would be mounted on one large baseplate. This would obviate the need for inter-connecting cabling and a set of connectors.

The PCU would be lowered on to the baseplate, located by guide pins. All connections would be of the wet mate stab type:

- 11 or 6.6kV power
- 24kV power
- Fibre/copper.

We understand that this arrangement is proven in the oil/gas industry.

We recommend that the stab option be allowed as an alternative in the Specifications.

D1.4.3 *Termination and distribution unit*

a) TFS requirements

In the TFS, it was envisaged that the TDU would have 4 outputs to the PCUs. This was based on an overall export capacity of 20MVA.

b) Design development

Quantity of connection points

During design development, it became apparent that a unit with 5 or 6 connection points could be more economic in the long term (if demand is there) because:

- Discussion with WPD has established that a maximum export capacity of 30MVA is feasible with connection at 33kV. This would require 6 connection points (as each connection point is limited to 5MVA maximum)
- Even if the power export is limited to 20MVA (requiring 4 connection points), an extra connection point or 2 would provide redundancy of sub sea equipment.
- It is probable that not all WEC devices will simultaneously output the full 5MVA available at each connection. An extra connection point or two would allow connection of up to 5 or 6 groups of devices even if the agreed connection capacity is limited to 20MVA.
- It may be possible to arrange up to six WEC device groups within the current 4x2 km reservation.
- It is possible that the area reserved for the WEC devices could be expanded in the future.
- It would be technically prudent to design for a maximum generation and connection condition now. Expansion of the Wave Hub infrastructure in the future would be disproportionately expensive.

In order to keep the project within budget, SWRDA advised that the connection should be limited to a total of 20MVA capacity, comprising 4 berths of 5MVA each.

DESIGN CHOICE: 4 connection points with a total capacity of 20MVA

Design Life
The TDU is a passive unit comprising lengths of busbar enclosed in an oil-filled water-tight enclosure. A key requirement is that there should be no moving parts or electronic components. It should not contain any part which requires maintenance. This being the case, it is assumed that there will never be any reason to retrieve this unit from the seabed. The unit should have a life to match that of the whole infrastructure, nominally 25 years. The above defines the connector requirements.

DESIGN CHOICE: TDU to be a passive unit, non-retrievable

Suppliers
Of all the potential suppliers of sub sea equipment approached, as listed above, only Vetco and possibly Alsthom have similar equipment in service.

In the meeting held 08/11/2005, Vetco advised that they have manufactured a 4 connection point unit rated at 24 kV and it is proven in service. Vetco advised that they can manufacture a unit with 4, 5 or 6 connection points rated at 24 kV as an extension of current technology. Although this would require development of existing designs, Vetco advised that increase in number of connection points was not seen as requiring an extensive change of design and would not involve long lead times.

In the meeting held 07/03/2006, Alsthom advised that they have designed equipment but were not specific in the applications.

D1.4.4 *Power Connection Unit*

a) TFS requirements

In the TFS, the PCU was envisaged to comprise:

- Transformer, 5MVA, 33/11kV
- 11kV circuit breaker
- 33kV fuses

During feasibility stage, it was determined that sub sea transformers of 5MVA are commercially available but a single unit of 20MVA would require development. It was therefore decided that each connection to an array of WEC devices from one Developer would have a dedicated PCU of 5MVA rating.

The TFS proposed that protection on the 33kV side of the transformer is afforded by fuses. The FLC of a 5MVA transformer is 87.5A. Commercially available fuses at 36kV range up to 63A.

b) Design development

Transformer protection: 33kV side

During a meeting with ABB held on 06 July 2005, and subsequent conversation on 05 August, it was determined that the proposed fuses on the 33kV side of the transformer are not available due to the high current rating required.

There are 3 solutions:

(a) Install 2 fuses in parallel per phase. Fuses must be linked to interrupt all 3 phases simultaneously. This solution is not preferred as blown fuses must be changed and this would require lifting the PCU to the surface.

(b) Install a 33kV circuit breaker within the TDU: 4 would be required. This is inconsistent with the requirement for installation of only passive devices in the TDU. Further, in the event of failure or maintenance of any one of the

33kV circuit breakers, then all must be opened in order that the unit be lifted to the surface, isolating all the WEC devices until the TDU is returned to the seabed.

(c) Install a 33kV circuit breaker in the PCU. This is the only option which is consistent with the overall design philosophy and is therefore the selected option.

DESIGN CHOICE: provide circuit breaker to protect higher voltage winding

Cable Connections
Criteria for cable connections are:

- The PCU houses components which will require periodic maintenance and must therefore be retrievable
- The PCU must have power and fibre connections (the fibre cores are for circuit breaker control, protection and metering)
- Cable attachments must be 200m to allow lifting of the PCU to the surface and to accommodate vessel movement

PCU Location
The PCUs should be located near to the TDU because:

- An 11kV cable is cheaper than the equivalent length of 24kV cable
- Transport of the following plant items, all permanently attached together:
    - main transmission cable
    - the TDU
    - 4 lengths of cabling to the PCUs: these should be as short as possible
- Uncertainty of location of the WEC devices

DESIGN CHOICE: locate PCUs near to the TDU

LV Power Supply at PCU
Discussions with suppliers revealed the requirement for a local LV power supply (240/110/24V) for the protection relays in the PCU. This could be derived from the following sources:

On-shore Substation
This would require copper cores in the main sub sea transmission cable and penetrations and connectors through to the PCU. The volt drop from shore would probably be around 60%. This complicates the installation (more connections) and increases the cost. If there was ever a problem with the continuity of the cores in the main transmission cable, there would be a loss of protection at all transformers. In this event, the Wave Hub could not be used until the problem was rectified.

Locally at the PCU
Provide a 24kV/110V output from a transformer fed from the grid side of the 24kV circuit breaker. This would normally be energised by the grid and would not depend upon the WEC device generation for power.

DESIGN CHOICE: provide auxiliary LV power locally at the PCU

c) Component function

The PCU houses components which perform functions as described.

11kV Circuit Breaker

- Protects the transformer 11kV winding in the event of a fault on the 11kV cable
- Protects the 11kV cable to the WEC device in the event of a fault on the transformer 11kV winding

11/24kV Transformer

- Steps up the voltage output from the WECs to that suitable for transmission

24kV Circuit Breaker

- Protects the transformer 24kV winding in the event of a fault on the 24kV transmission cable
- Protects the 24kV transmission cable in the event of a fault on the transformer 24kV winding

D1.4.5 *Special Power Connection Units*

The TFS concept was that all the PCUs would be of the same design. However, the WEC Developers have made requests for different connection arrangements according to their preferences and state of development. The OPD Pelamis is fully designed to operate in a string of three devices linked to one connection point at 6.6 kV. Two strings (4.5MW) could be accommodated on one PCU by changing the transformer to 6.6 kV on the incoming side and providing two connection points instead of one at some extra cost. Other Developers advise that they can connect at 11kV or 6.6 kV. Providing a special PCU arrangement for one Developer is considered unacceptable as all connection points are to be standard.

D1.4.6 *Connectors*

a) TFS requirements

The TFS concluded that dry mate connectors should be used for power connectors due to the extreme costs of wet mate connectors.

Although it was established that sub sea connectors would be required for the signal cables, there are no details in the TFS.

At the TFS stage, before detailed discussion with Developers, the requirement for connectors for LV copper cores was not appreciated.

b) Design development - power connectors

The following items are required:

Table D.6 Power connectors electrical requirements

Item	Qty	Voltage	Power	Current	Cable	Fibres	Type	Location
1	1	24kV/3ph/50Hz	20MVA	480A	300/400sqmm	56	Penetrator	TDU in from shore
2	4	24kV/3ph/50Hz	5MVA	100A	50sqmm	16	Penetrator	TDU out to PCU
3	4	24kV/3ph/50Hz	5MVA	100A	50sqmm	16	Dry mate	PCU in from TDU
4	4	11kV/3ph/50Hz	5MVA	300A	70/95sqmm	8	Dry mate	PCU out to WEC
5	4	11kV/3ph/50Hz	5MVA	300A	70/95sqmm	8	Dry mate	WEC connector

Taking each item in turn:

Item 1- TDU output (grid side): connection to shore

This is proposed to be a fixed connection glanded termination or penetrator because:

- It is assumed that there will never be a need to retrieve the TDU from the seabed therefore, once in service, there will be no need to disconnect
- It is possible to make the connection at the cable manufacturer's premises
- It is possible to transport the TDU on the cable laying vessel with the main transmission cable attached
- This is the most economical connection

DESIGN CHOICE: fixed connection

Item 2- TDU input (PCU side): connection to PCU

This is proposed to be a set of fixed connection glanded terminations or penetrators because:

- It is assumed that there will never be a need to retrieve the unit from the seabed therefore, once in service, no need to disconnect
- It is possible to make the connections at the cable manufacturer's premises

- It is possible to transport the TDU on the cable laying vessel with the cables attached. These cables would be 200m long
- This is the most economical connection

DESIGN CHOICE: fixed connection

Item 3- PCU output (grid side): connection to TDU

This is proposed to be a set of dry mate connectors because:

- There must be the facility to disconnect the PCU so that it could brought to shore for maintenance
- It is possible to terminate the cables at the cable manufacturer's premises
- This is the most economical connection for the functionality required

DESIGN CHOICE: dry mate connection

Item 4- PCU input (WEC side): connection to WEC

This is proposed to be a set of dry mate connectors because:

- There must be the facility to disconnect the PCU so that it could brought to shore for maintenance
- It is possible to terminate the cables at the cable manufacturer's premises
- This is the most economical connection for the functionality required

DESIGN CHOICE: dry mate connection

Item 5- WEC output: connection to WEC

This is proposed to be a set of dry mate connectors because:

- There must be the facility to connect and disconnect the WEC
- It is possible to terminate the cables at the cable manufacturer's premises
- This is the most economical connection for the functionality required

DESIGN CHOICE: dry mate connection

Wet mate connectors would be the most convenient for operation of the Wave Hub. However, it has been established that they are three times more expensive at MV than the equivalent dry mate connectors.

At meetings with Developers, we are advised that they propose to use the following suppliers:

Table D.7 Advised suppliers

Developer	Supplier	Remarks
OPD	Gisma, Germany	Supply up to 6.6kV only. Possibly up to 11kV in 2007
OPT	Ocean Design Inc., USA	MV wet mates via ABB/Vetco
ORECon	Unknown	Propose to use dry mate connectors

We approached the only supplier of sub sea cable connectors in the UK, Tronic Ltd and held meetings on 03 October and 03 November 2005.

Tronic manufacture:

(a) 11kV dry mate connectors

(b) 11kV wet mate connectors

(c) 33kV wet mate connectors

(d) Fibre optic (FO) wet mate connectors

Dry mate connectors are proposed for isolation of the PCU such that disconnection could be carried out on the surface.

Problems associated with surface disconnection are:

- When lifting the PCU, there would be high stresses on the connectors on each side of the unit. Stresses could be reduced by floating the attached cables with buoys. Cables would then need to be dynamic with design for movement.

c) Design development- signal connectors

The design is based around the following parameters:

- OPT initially requested 16 fibres from their WEC device. If we assume that all 6 WEC devices require 16 fibres each, 96 fibres would be required in total.
- Jointing these fibres would require an excessive quantity of connectors (ODI manufacture an 8-way FO connector, requiring 12 in total)
- The number of fibres could be reduced by multiplexing. However, this would require the multiplexer to be located in the TDU. The multiplexer would require a power supply and is electronic equipment. This is not

permitted for reasons given above. Multiplexing on the PCU is to be considered.

- Fibres must therefore be continuous from source (WEC device or PCU) to shore
- To reduce the quantity of connectors, each WEC Developer will be offered 4 fibres which we believe to be adequate for their requirements and allow some redundancy. Total number to be 20 fibres to shore.
- Tronic advised potential difficulties of dry mating a FO cable on a boat. The conditions must be carefully controlled to exclude damp and contamination and alignment must be ensured. Tronic therefore do not recommend dry mate FO connectors. All these difficulties are obviated with a wet mate connector.

DESIGN CHOICE: wet mate connection, 4 fibres per connection

d) Wave Hub Control and Monitoring System

The design is based around the following parameters:

- A fibre optic ring for the control and monitoring system requiring 4 fibres to be provided between the PCU and TDU and 4 fibres between the TDU and Shore.
- The fibre ring to be formed by fibre splicing at the TDU.

DESIGN CHOICE: wet mate connection, 4 fibres into and out of each PCU, 4 fibres to shore (total of 20 fibres to shore)

e) Design development- LV copper connectors

OPD have requested 2 LV copper cores to provide a back up power supply to their fibre hub. OPD require only 2 fibres. Tronic manufacture a connector with 2 fibre and 2 copper elements.
Neither OPT or Fred Olsen require LV copper cores.

In order to standardise on the connection arrangement at each PCU, copper cores will not be provided.

DESIGN CHOICE: copper cores will not be provided

D1.4.6 *Procurement of Sub sea Equipment*

One essential requirement of the Wave Hub development programme is that all the plant must be of proven design technology and able to be fabricated without significant development. Globally, there are very few manufacturers who are able to satisfy the technical requirements for sub sea plant in general. This will present difficulties in obtaining a range of competitive quotations from manufacturers.

We have identified only one definite manufacturer, ABB-Vetco which has the designs or proven technology to manufacture most of the plant required. ABB has stated that it is able to carry out the development work to satisfy all the technical requirements for Wave Hub without affecting manufacturing lead times. At a late stage, Alsthom also advised that they are able to provide the plant required but this has not yet been demonstrated. All other manufacturers have significant quantities of development work to carry out.

D1.5 Wave Hub Substation

D1.5.1 TFS Requirements

In the TFS, this was envisaged to comprise:

(a) 33kV 'synchronising' circuit breaker owned and operated by WHMC
(b) 33kV 'metering' circuit breaker owned and operated by WPD
(c) Control and monitoring equipment

D1.5.2 Design Development

The local distribution network operator, Western Power Distribution (WPD) has a list of approved suppliers of MV switchgear as follows:

Table D.8 WPD approved MV switchgear suppliers

Manufacturer	Model	Status
Siemens	NX+	Technical information received
ABB	ZX1.2	Technical information & quotation received
Areva	WS	Technical information received

With design development, the following equipment is now envisaged:

(a) 24kV outdoor circuit breaker
(b) 24/33/0.4kV transformer
(c) 33kV indoor circuit breaker owned and operated by WHMC
(d) Static VAr compensator connected by busbar trunking
(e) Control and monitoring equipment

The reasons for those items additional to those envisaged in the TFS are as follows:

a) 24kV outdoor circuit breaker

- The circuit breaker provides automatic protection in the event of:
    - Transformer earth faults on the 24kV side (which would not be seen by the 33kV side)
    - Transformer phase to phase faults

- The transformer requires the facility for isolation for maintenance. It can be isolated on the 33kV grid side by the Wave Hub 33kV circuit breaker.

- Due to limited space within the circuit breaker, a separate relay panel is required in the 33kV switch room

DESIGN CHOICE: 24kV outdoor circuit breaker required

b) Isolation transformer

- The transmission voltage from the Wave Hub is at 24kV. A transformer is necessary to allow the voltage to be matched to that of the grid (33kV).
- Variations in generated voltages and control of power export to the grid if required can be accommodated by use of an on-load tap changer.

DESIGN CHOICE: transformer required

c) Busbar trunking

- The SVC has been rated at a preliminary value of 4MVAr. This requires a 6000A connection which can only be sensibly achieved using busbar trunking (rather than cabling).

DESIGN CHOICE: busbar trunking required but is subject to contractor's stability study (see below)

d) Static VAr compensator (SVC)

The function of this device is to:

- Control the power factor of export to the grid
- Control VAr output
- Limit harmonic current export
- Regulate voltage and therefore flicker effects
- Limit transient effects and over-voltages

DESIGN CHOICE: SVC required but rating is subject to contractor's stability study

e) Control building power supply

There are 2 options for sourcing power for the control building:

Option 1: from the local WPD LV network

Option 2: from the Wave Hub isolation transformer via a 400 V tertiary winding or a separate 33 kV/400 V transformer

We recommend option 1 for the following reasons:

- would The supply would be available during installation and commissioning
- It is a secure supply, not dependant upon the operating status of the Wave Hub
- Additional land is not required for a transformer
- The costs be included as part of the Connection Agreement

Perhaps the only disadvantage is that the supply would require separate metering and another agreement with a meter operator.

DESIGN CHOICE: source LV supply from WPD network

A services distribution board for supply to domestic lighting, heating and power for the SCADA system and outlets is required and could be wall mounted in the metering room.

f) Control and monitoring equipment

The control room will house:

- Fibre optic termination equipment
- WEC device communication equipment
- SCADA workstation

There will be the facility to control and monitor the Wave Hub plant from the SCADA workstation.

There will also be the facility for Developers to attached computing equipment locally or remotely via broadband internet connections.

Confidentiality will be ensured such that the Developers may only access their own WEC device.

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