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Guidelines for the use of metocean data through the life cycle of a marine renewable energy development

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Summary

A good understanding of metocean (meteorological and oceanographic) data is fundamental to the success of all marine renewable projects as this information will serve to characterise the available resource for energy yield, the design requirements for survivability of the project and the strategy for maintenance and accessibility.

This guide has been developed to identify and recommend uses of metocean data through the life cycle of a marine renewable energy development and serve as a helpful reference to inform project developers, engineers, marine surveyors, environmental consultants and other key stakeholders who will benefit from a wider appreciation of metocean issues. The document includes a review of metocean data types, data sources and identifies the importance for good data management.

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Glossary

Bathymetry	A description of water depths across the seafloor.
Boundary layer	The interface between two fluids (air-sea or sea-seafloor).
Demurrage	An ancillary cost that represents liquidated damages for delays, occurs when a vessel at berth is prevented from the loading or discharging of cargo within the stipulated laytime.
Design wave	Deterministic wave used for design of an offshore structure.
Diurnal	An event that occurs twice daily.
Downscaling	An analytical technique to introduce higher levels of spatial detail.
Downtime	A period of time when weather prevents safe access to site or operations on site.
Extreme value	A statistical value representing a rare event.
Forecast	The assessment of future weather conditions.
Harmonic constituents	Components of the tide.
Hind-cast	The assessment of past weather conditions.
In situ	In the place of origin.
Long-term	A period typically spanning several years, and where the timescale exceeds the duration of one cycle of events.
Long-range	A forecast predicting weather conditions typically up to 30 days (one month) ahead.
Maintenance	Any activity associated with ensuring plant and equipment remain in, or are returned to, proper working order.
Marginal extremes	An expression of peak events which occur at low frequencies.
Medium-range	A forecast predicting weather conditions from three to seven days (ie one week) ahead.
Meridional	Along a meridian of the globe or in the north-south direction.
Metadata	Information that describes a dataset.
Metocean	The combination of oceanographic and meteorological data.
Multi-variate	Statistical consideration of more than one variable at a time.
Neap	The period of the tide when the sun and moon are out of phase.
Nowcast	A short-term weather forecast for expected conditions in the next few hours.
Omni-directional	From many directions.
Operations	Activities associated with day-to-day production.
Rectilinear	A tidal current which flows alternately in approximately opposite directions.
Return period	Average period of time between exceedances of that value.

Scatter diagram	The graphical presentation of two or more metocean variables, eg significant wave height verses a representative wave period (T_z or T_p).
Secular trend	The long-term upward or downward trend in a time series, as opposed to a smaller cyclical variation with a periodic and short-term duration.
Semi-diurnal	Having a period or cycle of approximately one-half of a tidal day.
Service life	The expected lifetime, or the acceptable period of use in service, for an offshore installation.
Short range	A forecast predicting weather conditions over the next three days (day).
Short-term	A period typically spanning several days or months, and where the timescale is less than one cycle of events.
Snagging phase	Period at the end of the build process when a list of any quality defects in the build is produced. It is usually accompanied by a description of the work required to rectify the defect, the party responsible for the work and a target completion date.
Spectrum	A mathematical description of a series of winds or waves expressed in frequency space and/or directional space.
Spring	The period of tide when the sun and moon are in phase.
Standard error	An expression of the uncertainty in a value, being an estimate of the standard deviation of the sample mean.
Surge	A large change in sea level (either positive or negative) generated by extreme meteorological events.
Swell	Wind-waves remote from the area of generation.
Synoptic	A summary of representative conditions.
Tidal ellipse	The path traced out by a tidal current vector in a rotary flow regime.
Uni-variate	Statistical consideration of a single variable.
Wavelength	The horizontal distance between two identical points on two successive wave crests or two successive wave troughs.
Wave steepness	Ratio of wave height to wavelength.
Weather day	An event when weather conditions exceed a set of predetermined criteria and prevent safe site access incurring contractural downtime.
Windage	The tendency of a vessel to move sideways away from the wind because of the forces of the wind on the topsides and above-deck structures.
Zonal	Along a latitude circle or in the east-west direction.

Abbreviations and acronyms

ADCP	Acoustic doppler current profiler
AGI	Association for Geographic Information
AHWG	Ad Hoc Working Group on marine renewable standards
BADC	British Atmospheric Data Centre
BERR	Department for Business, Enterprise & Regulatory Reform (formerly DTI)
BODC	British Oceanographic Data Centre
BWEA	British Wind Energy Association
CCO	Channel Coastal Observatory
CCW	Countryside Council for Wales
CD	Chart datum
CDM	Construction (Design and Maintenance) Regulations 2007
CEC	Commission of the European Commission
COWRIE	Collaborative Offshore Wind Research Into the Environment
CPA	Coast Protection Act 1949
DAC	Data Archive Centre
DCLG	Department for Communities and Local Government
DEFRA	Department for Environment, Food and Rural Affairs
DIMP	Data and information management plan
DISP	Data and information stewardship plan
DMTWG	Data Management Technical Working Group
DNV	Det Norske Veritas
DP	Dynamic positioning
DTI	Department of Trade and Industry (now integrated into BERR)
ECMWF	European Centre for Medium Range Weather Prediction
EDMED	European Directory of Marine Environmental Data
EIA	Environmental Impact Assessment
EMARC	Emergency Monitoring And Response Centre
EMEC	European Marine Energy Centre
EO	Earth observation
ERRV	Emergency rescue and recovery vessel
ES	Environmental statement
ESA	European Space Agency
FEPA	Food and Environment Protection Act 1985
FMECA	Failure modes and effects and criticality analysis
GETADE	Group of experts on technical aspects of data exchange
GGOWL	Greater Gabbard Offshore Wind Limited

GIS	Geographical Information System
GL Wind	Germanischer Lloyd WindEnergie
GPRS	General Packet Radio Service
GSM	Global system for mobile communications
HSE	Health & Safety Executive
IALA	International Association of marine aids to navigation and Lighthouse Authorities
IEC	International Electrotechnical Commission
IOC	Intergovernmental Oceanographic Committee (UNESCO)
ISO	International Standards Organisation
LAT	Lowest astronomical tide
MAWS	Marine automatic weather station
MCA	Maritime and Coastguard Agency
MCEU	Marine Consents and Environment Unit (now integrated into MFA)
MCP	Measure correlate predict
MDIP	Marine Data and Information Partnership
Met	Meteorological
MFA	Marine and Fisheries Agency
MRDF	Marine renewable deployment fund
NAO	North Atlantic Oscillation
NESS	North European Storm Study
nm	Nautical mile
NTSLF	National tidal and sea level facility
NWP	Numerical weather prediction
O&M	Operations and maintenance
OGP	International Association of Oil & Gas Producers
PDF	Probability density function
POL	Proudman Oceanographic Laboratory
PDS	Project design statement
RAG	Research Advisory Group
RCM	Reliability centred maintenance
REZ	Renewable energy zone
RMS	Root mean square
ROV	Remotely operated vehicle
SAR	Synthetic aperture radar
SCADA	Supervisory Control And Data Acquisition
SEA	Strategic environmental assessment
SIMORC	System of Industry Metocean data for the Offshore and Research Communities
SOLAS	Safety of life at sea
SWRDA	South West Regional Development Agency
TEC	Tidal energy converter

UK	United Kingdom
UK Gemini	UK GEo-spatial Metadata INteroperability Initiative
UKHO	United Kingdom Hydrographic Office
UKOOA	United Kingdom Offshore Operators Association
UNESCO	United Nations Educational, Scientific and Cultural Organisation
VTS	Vessel Traffic Services
WEC	Wave energy converter
WGMDM	Working Group on Marine Data Management
WMO	World Meterological Organization
XML	eXtensible Mark-up Language

Symbols

CO_2	carbon dioxide
d	water depth (m)
f	frequency (Hz)
H_{max}	maximum wave height (m)
H_{rms}	root mean square wave height (m)
H_s or H_{sig}	significant wave height (m)
m^n	n^{th} moment of the spectrum
S(f)	represents the spectrum in frequency (f) space
T_e	energy period (s)
T_p	peak period in the spectral record (s)
T_s	duration of the sea state (s)
T_z	zero crossing period (s)
U_{10}	mean wind speed averaged over a 10 minute sampling period (m/s)
U_c	current speed (m/s)
δU	standard deviation of the mean wind speed (m/s)
θ	mean wave (or wind) direction (degrees North), noting winds and waves are expressed as travelling from
θ_c	mean current direction (degrees North), noting currents are expressed as travelling to
λ	wavelength (m)
λ_p	wavelength at peak period (m)

1 Introduction

1.1 PURPOSE AND LIMITATIONS

The aim of this document is to offer guidance and identify good practice to the marine renewables industry on the subject of metocean data.

This document serves as a reference source for project developers, engineers, marine surveyors, environmental consultants and other key stakeholders who will benefit from a wider appreciation of metocean issues. The guide is not intended as a substitute for established literature, moreover, it provides a route map to these existing texts, identifying their relevant usage. Note that the majority of existing metocean standards are established for offshore installations which are more likely to be found in deeper water than the present phase of marine renewable developments.

Renewable energy is an integral part of the UK Government's long-term aim of reducing CO_2 emissions by 60 per cent of 1990 levels by 2050, and with an interim target set for 10 per cent of electricity supply from renewable energy by 2010 (DTI, 2007). The Scottish Government (formerly the Scottish Executive) has set a target that 18 per cent of the electricity generated in Scotland (as a proportion of demand) should come from renewable sources by 2010, rising to 40 per cent by 2020. In order to reach these targets it is expected that an increasing emphasis will be placed on production from sites located in offshore environments.

Presently the leading technology is wind energy, and the first commercial round (Round 1) to exploit this offshore resource has seen the construction of size-limited wind farms around the UK coast. This activity has generally been regarded as a demonstration phase for offshore wind technology and with the objective to build experience for the industry. The second commercial round (Round 2) is already progressing through the consents phase and involves larger projects designed to provide a significant contribution to meeting UK renewable energy targets. As such, the scale of these new projects has not been as limited as with Round 1, and in some cases is up to 25 times larger in footprint. In addition, these new projects tend to be sited further offshore and in deeper water, targeting areas where the wind resource is greater. Design, construction, operation and eventual decommissioning of these Round 2 projects presents additional challenges to the industry which are yet to be fully tested.

The UK Government is yet to invite a commercial round for wave and tidal energy projects. In the interim, the Department for Business Enterprise and Regulatory Reform (formerly DTI) announced the Marine Renewables Deployment Fund (MRDF) to assist the demonstration phase for a limited number of the more advanced technologies. These new wave and tidal projects face similar challenges for offshore development as wind projects, but will deliberately select sites that offer more energetic metocean conditions. It is noted that consideration of metocean data is a key requirement for all types of marine renewable schemes and through all stages of project life cycle.

These guidelines have been developed by an informed group of marine practitioners who collectively bring together proven experience in supporting a variety of offshore developments, including both oil and gas projects and the present phase of marine renewable schemes. The guidelines draw from established practices across more mature offshore industries and are combined with the present experience from the marine renewables sector.

1.2 STRUCTURE OF THESE GUIDELINES

This guide initially identifies the range of present marine renewable interests (Chapter 2) and is then followed by an introduction to the subject of metocean data relevant to project development (Chapter 3). The further structure of the guide is based upon providing guidance in the potential use of metocean data to support sequential stages through the life cycle of a generic marine renewables project. Chapter 4 provides details of this project life cycle (Figure 1.1), with Chapter 5 to Chapter 10 developing in depth, the specific metocean issues for each stage of the life cycle. A summary of key points is given in Chapter 11.

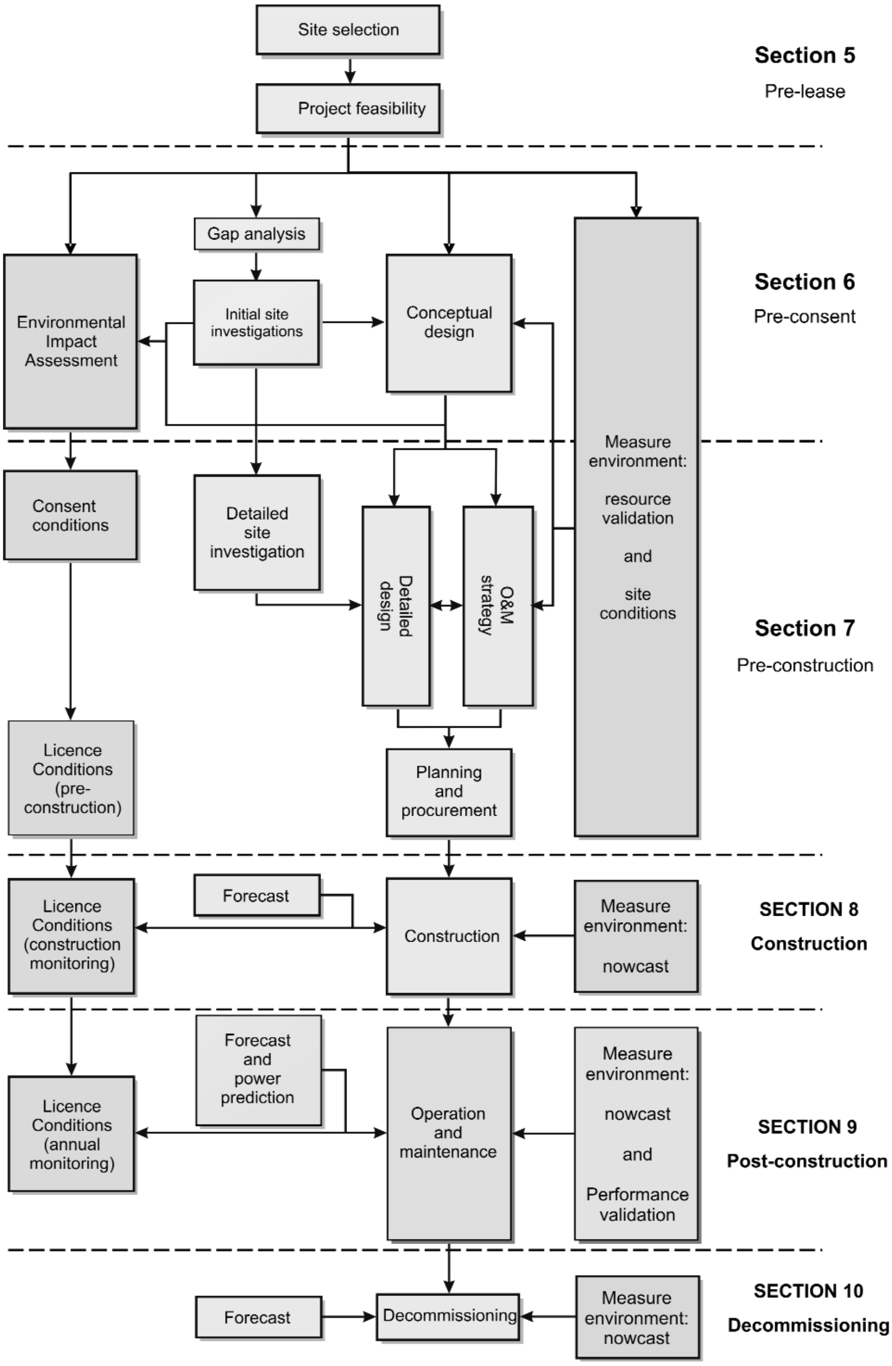


Figure 1.1 ***Schematic of document structure against project life cycle (adapted from Figure 4.1)***

1.3 HOW TO USE THESE GUIDELINES

These metocean guidelines are intended to serve as a reference tool for developers, engineers, marine surveyors, environmental consultants and other key stakeholders who will benefit from a wider appreciation of metocean issues to support project development. The guidelines are not intended as a substitute for established standards, more importantly they are a route map to these existing texts, identifying their relevant usage.

The guidelines are structured so that as each phase of project development is advanced the further requirements of using metocean data are readily identified, along with recognition to what currently represents good practice within the marine renewables industry. In this manner, the guidelines provide an entry point to each stage in the project life cycle, identify what metocean data should be available at this point in the project development, what uses should be made of the data to support key activities, the potential linkages between activities, and what data and understanding should become available from this exercise to support a subsequent stage of project development.

2 Current status of marine renewable projects

2.1 OVERVIEW

Marine renewable projects considered in this document focus on offshore wind, wave and tidal stream developments, and with specific interest to issues related to the UK. A brief review of the current status of these technologies is offered to draw contrast between the stages of development and various ongoing support activities.

2.2 PRESENT STANDARDS

At the time of publishing these guidelines, existing standards and guidance which refer to the use of metocean data for marine renewable studies are fragmented and have been written for specific aspects of offshore wind, wave and tidal development. These documents have also tended to focus on discrete stages in the development path from testing, consenting, design and decommissioning, and may not necessarily be applicable to each type of development.

Separately, there are many familiar and established standards in use for coastal engineering, and offshore oil and gas industries, however these texts may not always be immediately transferable to marine renewable projects. As an example, offshore oil and gas interests may target deeper water locations worldwide and installations will generally comprise of single manned platforms. In contrast, marine renewable projects are presently being considered at sites closer to shore, in shallower water, are likely to be in a dispersed arrangement of smaller installations, targeting areas which provide high energy metocean conditions and will be unmanned apart from periods of maintenance. These contrasting issues amplify the need for a focused consideration of metocean issues related to these types of new projects.

This guide does not attempt to substitute for any existing codes, regulations, standards or guidelines relating to offshore development. Rather, the aim is to identify and draw attention to existing literature that is considered relevant and to illustrate their potential role in assisting marine renewable development, but also to highlight any present limitations in their application where these might exist.

Additionally, note that there is active interest in developing a set of bespoke standards across the range of disciplines (eg metocean, engineering, risk management, health and safety) to underpin development of the marine renewables industry. The present document forms part of this overall strategy, and with the deliberate aim of highlighting emerging good practice.

The bibliography provides a list of present standards across marine renewable and oil and gas industries.

2.3 OFFSHORE WIND

The UK is already advancing the development of several offshore wind farm projects, starting in 2000 with the first *proof of concept* installation of two offshore turbines off Blyth Harbour.

From the success of Blyth the UK Government invited a first commercial round of offshore wind projects (Round 1). These projects were restricted to a maximum of 30 turbines and for an area of seabed no larger than 10 km². The primary aim of Round 1 was to build experience for the industry. Sites were generally selected on the basis of good wind resource, proximity to grid and viability of construction in relatively shallow water. Nominally, the majority of sites remained close to the shore (<10 km) and in shallow depths (<20 m). To date, five Round 1 projects have proceeded through construction: North Hoyle, Scroby Sands, Kentish Flats, Barrow and Burbo Bank, with construction of further projects scheduled in 2007 and onwards.

With a continued interest from the wind industry for larger scale projects DTI commissioned a strategic environmental assessment (SEA) for a second commercial round of developments (Round 2) for England and Wales. Three interest areas were considered:

1. Greater Wash.
2. Thames.
3. North West.

Within each SEA area planned developments have been limited from the nearshore area through the specification of coastal exclusion zones which generally extend from around 8 to 13 km off the coast. The exclusion zones recognise the potentially higher sensitivity of shallow coastal waters to wind farm development, in particular the possible disturbance to birds, visual impact, as well as the potential impact on inshore fishing and recreational activities. The size of Round 2 projects generally far exceeds those from Round 1, with some of the biggest projects seeking to develop as much as 250 km² of the seabed. The coastal exclusion zones also tend to push these projects further offshore and into deeper water. To date three Round 2 projects* have secured consents and are now planning for construction. Figure 2.1 provides an overview map of Round 1 and Round 2 sites around the UK.

Note: * At the time of publication:

1. London Array
2. Greater Gabbard
3. Thanet

Figure 2.1 *Map of Round 1 and Round 2 offshore wind projects (courtesy The Crown Estate)*

In Scotland, the Beatrice wind farm demonstrator project has taken the installation of offshore wind projects into the deepest water so far. Construction started in 2006 for two turbines adjacent to the Beatrice Oilfield in the Moray Firth, a site which is around 25 km offshore, in 45 m water and is exposed to high waves from the North Sea.

In summary, the offshore wind industry has achieved a position where the development of commercial scale projects is now being advanced by major utilities and targeting areas further offshore where the wind resource improves away from the coast. The total installed capacity from currently planned offshore wind projects amounts to nearly 9 GW and from over 2500 turbines. Experience is developing rapidly for the industry in areas of project planning, environmental assessment, design, construction and operation. Projects remain too new for decommissioning to be considered, although some early met mast structures may soon be removed.

The industry has been assisted with various forms of guidance for consenting and design that are anticipated to be readily transferable to support wave and tidal developments in due course. These include:

- *Design of offshore wind turbine structures* (DNV, 2004)
- *Offshore wind farm consents process* (DTI, 2004)
- *Decommissioning of offshore renewable energy installations under the Energy Act 2004, guidance notes for industry* (DTI, 2006)
- *Guidelines for the certification of offshore wind turbines. IV – Part 2* (GL Wind, 2004)
- *Proposed UK Offshore Renewable Energy Installations (OREI) – guidance note on navigational safety issues* (MCA, 2004)
- *Offshore wind farms. Guidance for Environmental Impact Assessment in respect of FEPA and CPA requirements* (MCEU, 2004).

2.4 WAVE AND TIDAL STREAM

Unlike offshore wind there is presently no convergence in technology type for either wave energy converters (WEC) or tidal stream energy converters (TEC), and it remains probable that more than one type of WEC or TEC will emerge as market leader. This is partly due to the nature of the resource and the variety of technology designs needed to harness the resource from different locations.

Wave and tidal stream devices are presently entering the demonstration phase of their respective technologies. This phase in technology proving is assisted by a number of initiatives such as the European Marine Energy Centre (EMEC), based in Orkney, which provide testing bays for prototype WEC and TEC designs, and the recently consented WaveHub project, off Hayle in Cornwall, for demonstrating WEC technology.

Table 2.1 identifies the range of planned deployments around the UK for WEC and TEC devices which presently amounts to around 120 MW of installed capacity from around 64 units and nine device types.

Table 2.1 ***Schedule of known WEC and TEC UK developments (correct at date of publication)***

Developer	Installed capacity	Location	Status
Marine current turbines	1.2 MW SeaGen	Strangford Lough, Northern Ireland	Consented, construction expected to commence in 2007
SWRDA (WaveHub + wave energy converters)	20 MW to connect up to 30 WECs	20 km north-west of Hayle, North Cornwall	Consented in September 2007
Wave Dragon	7 MW Wave Dragon	1.7 km west off St Ann's Head at Long Point, Pembrokeshire	Application under consideration
Marine current turbines	10 MW SeaGen Array	Lynmouth, Bristol Channel, 2–4 km off the North Devon Coast	Application awaited
Tidal electric	60 MW Tidal Lagoon	Swansea Bay	Application awaited
Marine current turbines	10 MW SeaGen Array	South Stack, Irish Sea, 2–3 km from the West Anglesey Coast	Application awaited
Marine current turbines	10 MW SeaGen Array	Skerries, Irish Sea, between the Skerries and Carmel Head off Anglesey	Application awaited
Pulse generation	100 kW	Tidal power generation device, 1 km from the south bank of the Humber	Application awaited
npower renewables and Wavegen	3 MW	Active breakwater at Siadar, on the north coast of Lewis	Application awaited

The Carbon Trust has previously completed an initiative called the Marine Energy Challenge (MEC) to support development and increase understanding of wave and tidal stream energy technologies by means of engineering analysis and design activities. Various publications are available from their website related to UK tidal stream resource, the application of engineering standards to marine energy devices and the variability of wave and tidal stream energy <http://www.carbontrust.co.uk>.

In comparison to offshore wind, wave and tidal stream is yet to announce major commercial scale projects and it is anticipated that a marine renewable SEA will need to be completed first to enable this process for sites in England and Wales. In comparison, the Scottish Government has completed a renewables SEA for the west coast of Scotland <http://www.seaenergyscotland.co.uk>.

The emerging information resource to assist wave and tidal stream projects presently includes:

- *UK tidal stream energy resource assessment* (Black & Veatch, 2005)
- *Tidal stream resource and technology summary* (Black & Veatch, 2005)
- *Guidelines on design and operation of wave energy converters. A guide to assessment and application of engineering standards and recommended practices for wave energy conversion devices* (DNV, 2005)
- *Atlas of UK marine renewable energy resources: technical report. A strategic environmental assessment report* (DTI, 2004)

- *Planning and consents for marine renewables. Guidance on consenting arrangements in England and Wales for a pre-commercial demonstration phase for wave and tidal stream energy devices (marine renewables)* (DTI, 2005)
- *Preliminary wave energy device performance protocol* (DTI, 2007)
- *Preliminary wave energy device performance protocol. Supporting commentary* (DTI, 2007)
- *Preliminary tidal current energy: Device performance protocol* (DTI, 2007)
- *Performance assessment for wave energy conversion systems in open sea test facilities* (EMEC, 2004)
- *Variability of UK marine resources. An assessment of the variability of the UK's wave and tidal power and their implications for large-scale development scenarios* (Environmental Change Institute, 2005)
- *Guidelines for the certification of ocean energy converters. Part 1: Ocean current turbines. IV. Industrial services* (GL Wind, 2005)
- *Strategic Environmental Assessment (SEA) environmental report* (Scottish Marine Renewables, 2007)
- *UK tidal resource review (*Sustainable Development Commission (2007)

It is also helpful to note that an ad hoc working group (AHWG) on marine renewable standards has recently been formed to co-ordinate the development of further standards.

2.5 SUMMARY

Round 1 offshore wind projects are providing valuable experience to the marine renewable industry, but the industry will also confront new challenges associated with the increased scale of Round 2 projects. In comparison, wave and tidal projects are confronting an even greater set of uncertainties, but can draw on the experience from offshore wind. However, there will always remain key differences between the technologies in terms of resource interests and associated deployment conditions. Despite these differences, a sufficient understanding of metocean conditions remains fundamental to all offshore developments and through all stages in a project life cycle.

3 Metocean data

3.1 TERMINOLOGIES

Metocean data has become an accepted industry abbreviation for meteorological and oceanographic data, terminologies that embrace the subject of marine climatology.

In the present context, metocean data is used as a group name for the following types of data:

- descriptions of water movements (eg water levels and flows)
- description of offshore wind conditions
- description of sea states (eg wave conditions).

These metocean conditions are generated from two independent physical mechanisms:

1 Astronomical forcing.
2 Meteorological forcing.

Metocean conditions generated by these separate mechanisms will remain independent of each other unless there is some form of interaction. For example, in offshore locations, water depth is usually sufficient for waves to be effectively independent of tidal influence. In shallow water, waves may become dependent on changes in depth due to the tide once they start to feel the seabed. Further dependency may also exist in areas of strong current.

The variation of these processes over time and for different locations is directly relevant to engineering design, construction and operational planning, and to determine issues such as trends, cycles and extremes. The exercise that determines the importance of each process to overall conditions at a project site is commonly referred to as a metocean study.

3.1.1 Water movements

The predictable rise and fall of the sea in open water is primarily a function of gravitational effects from the sun and moon (astronomical forcing). These gravitational effects are at their strongest when the sun and moon are in alignment leading to the higher spring tidal range. Conversely, when the sun and moon are out of phase the result is a neap tide with a lower range. The pattern of spring and neap tides repeats over a regular frequency of around 28 days (full moon to full moon).

The earth's daily rotation through the tide creates a sequence of high and low waters (diurnal period). On the UK Continental Shelf this process is further enhanced by resonance of the main tidal harmonics into sub-harmonics which characteristically leads to two sets of high and low waters each day (semi-diurnal period).

At times, water levels can be further modified during storm periods by strong winds and rapid changes in atmospheric pressure. This non-tidal influence is termed a *surge* and can act to elevate or depress water levels by a few metres.

Large volumes of water are exchanged during each tide. From low water the rising flood tide generates flows into an area up to high water, after which flows ebb away towards the next low water. In shallow water the pattern of tidal flows is greatly influenced by the local bathymetry and coastline orientation, with channels and headlands characteristically providing locations with strongest flows.

The common parameters used to describe water movements are as follows:

- *sea-surface elevation*, the vertical rise and fall of the tide expressed in metres and referenced to some agreed datum eg mean sea level, lowest astronomic tide (chart datum) or ordnance datum (Newlyn)
- *current speed,* U_c , the rate of horizontal flow of water (m/s) averaged over a sample interval and representative of a point in the water column. Current speed can be further resolved into zonal (u, west to east), meridional (v, south to north) and vertical (w) components. Currents continually interact with the seabed through friction which creates drag forces in a boundary layer, the consequence of which is a variable velocity profile over the water column and one which diminishes rapidly towards the seabed (Figure 3.1). The shape of this vertical profile is of primary interest to any TEC developer, as the ideal position for energy capture is likely to be at mid-depths to avoid velocity shear towards the seabed and increased turbulence likely towards the sea surface.

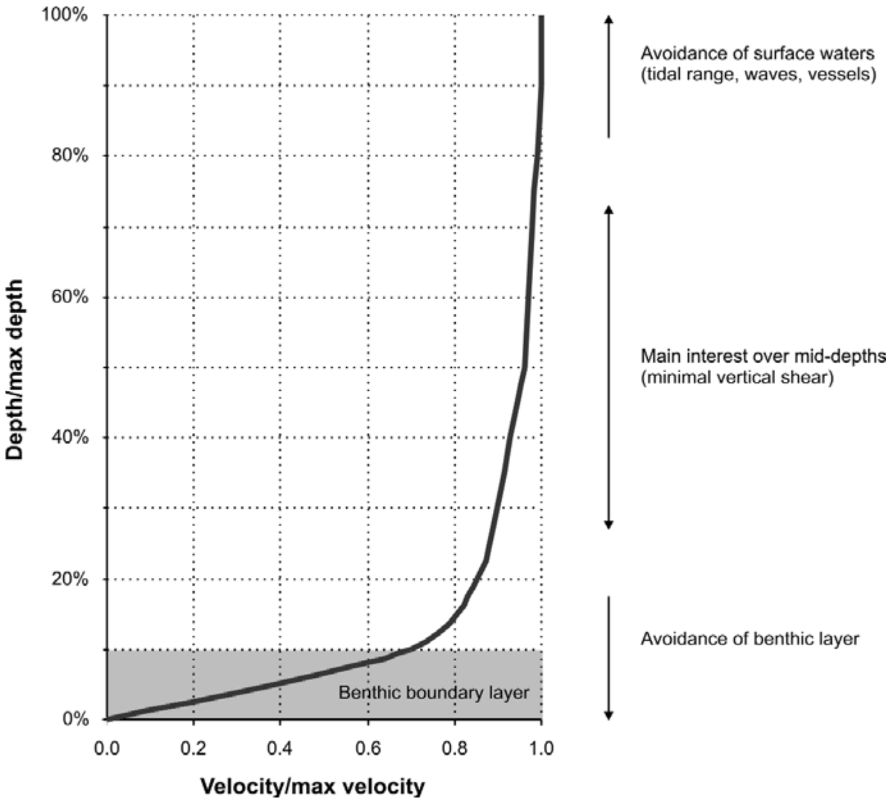


Figure 3.1 ***Theoretical velocity profile over depth (after ABPmer, 2006)***

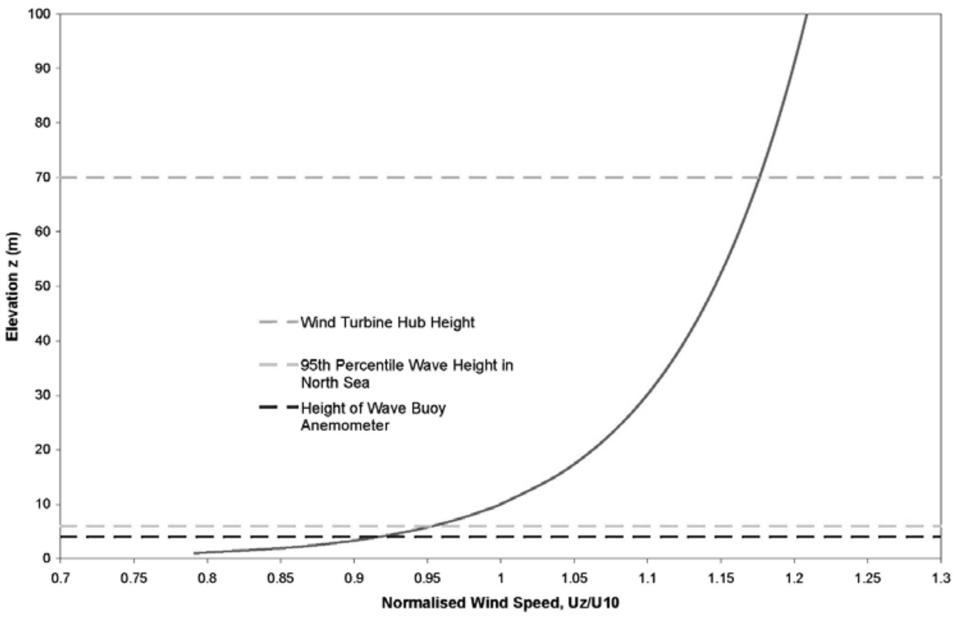
- *current direction*, $Ø_c$, the direction in which horizontal current flows are heading toward (referenced as degrees north), the resultant of the u and v vectors.

It is preferred to obtain water level and current measurements which have been recorded using a sampling rate of 15 minutes, or less, so that key features of the tide, such as peak flows and times of high and low water, can be fully resolved.

The inherent regularity of the tidal component of water movements can also be expressed in terms of harmonic constituents for sea-surface elevation (an equivalent of the one dimensional wave spectrum), or for currents as the semi-major and semi-minor axes of a *tidal ellipse*. Further details on these descriptors are available in *Manual on sea level measurements and interpretation* (UNESCO, 2006) or in Pugh (1987).

3.1.2 Offshore wind

Offshore winds tend to fluctuate rapidly in speed and direction. As a result of boundary layer effects, caused by the drag associated with wind flowing over the sea, the strength of the wind is generally assumed to decrease through the vertical toward still water level (Figure 3.2). Wind may be subject to further vertical variability depending on the stability of the atmosphere (ie the potential for air to rise), which is usually determined as a function of sea temperature, and the temperature of the overlying air mass. As a consequence of these vertical variations offshore wind farms require definition of the wind climate at the hub height as the vertical reference.



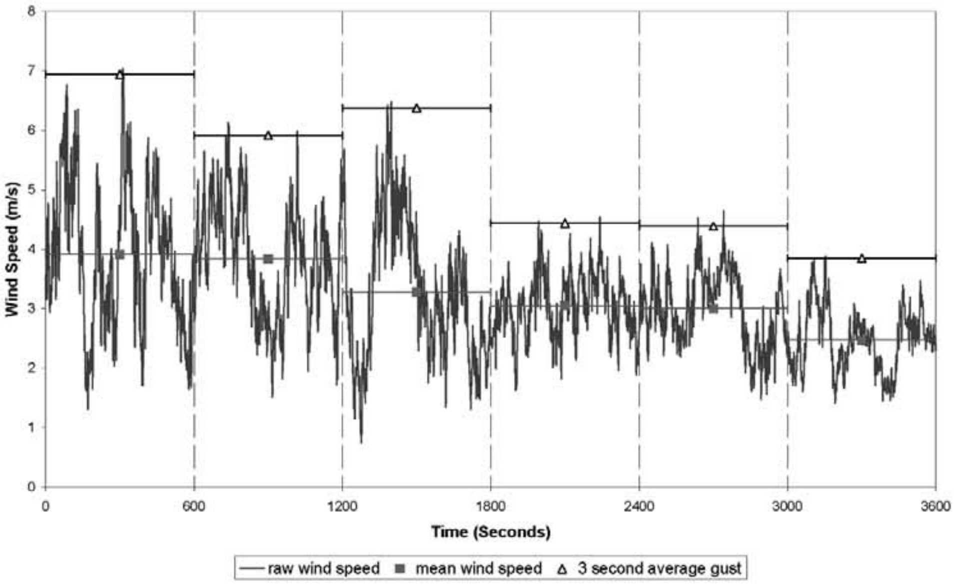
Note: Dashed lines marked on the diagram indicate representative heights for the measurement of wind speed from an *in situ* meteorological buoy (approximate) 95th percentile significant wave height for the North Sea, and an assumed wind turbine hub height. The increase in wind speed between the near surface wind experienced by a wave buoy and that at hub height is significant, and the 95th percentile significant wave height relative to buoy anemometer height indicates that in high sea states, waves will potentially have an adverse effect on wind measurements at this level due to shadowing

Figure 3.2 ***Illustration of an idealised logarithmic wind profile through the boundary layer (courtesy Met Office)***

At the sea surface the wind field will interact with the water surface through friction to create waves. Since wave height will increase in line with increased forcing by the wind, a major component of the wave climate will be linked to wind conditions blowing across the sea surface (see also Section 3.1.3). The wave field will also have a feedback effect on surface winds, since changing wave conditions imply a change in surface roughness and the level of friction affecting the wind boundary layer.

The behaviour of winds is commonly defined by the following terms:

- *mean wind speed* (U_{10}), expressed in m/s and referenced to a given elevation, where the mean is taken over a standard measurement period, such as 10 minutes (Figure 3.3)
- *standard deviation* (δU), measure of variability of wind speed around the mean (m/s)
- *gust wind speed*, referenced to a given elevation, as an indicator of the maximum fluctuations about the mean, for example taken as the maximum three seconds mean of wind speed (m/s) (the three second gust is a recent standard adopted by the WMO, succeeding the maximum wind value from the observed wind record)
- *turbulent intensity*, defined as the ratio of $\delta U/U_{10}$ (dimensionless)
- *mean wind direction*, the direction that the wind is coming from, referenced to a given elevation, where the mean is derived over a standard measurement period, such as 10 minutes (degrees north).



Note: The blue trace shows variability in raw wind speed and indicates strong short-term fluctuations. This is compared with standard measures of 10 minute average wind speed, U10 (red squares), and the maximum three second average gust value for the 10 minute sample (yellow triangles)

Figure 3.3 ***Example wind speed time series (courtesy Met Office)***

For cases where a more detailed consideration is required of the wind conditions (eg for engineering design) the wind spectrum can be described in terms of a power spectral density function of the wind speed process, S(f), which is a function of U_{10} and δU, and expresses how the energy of the wind speed is distributed between different frequencies. This method of describing wind is analogous to the wave spectrum. Further details relating to deriving wind spectrum are given in Appendix A of ISO-19901-1 (2006) and Section 3 of DNV-OS-J101 (2004).

3.1.3 Sea state

Sea state describes the wave field resulting from combined contributions of *wind-sea* and *swell* components. *Wind-sea* waves are generated by local winds blowing over the surface of the ocean. *Swell* represents wind waves that have either travelled out of the area in which they were generated, or can no longer be sustained by the winds in the generating area. It is possible that for a given sea state, swell may come from more than one direction.

The properties of individual waves within a given sea state can be defined according to:

- *wave height*, vertical difference in elevation between wave crest and trough (m)
- *wave period*, time between successive wave crests (s)
- *wave direction*, direction that waves arrive from (°N).

During the period in which wave observations are made, the sea state will comprise groups of waves with varying height, period and direction. Statistical analysis of these variations provides standard summary parameters which are commonly related for design purposes to properties of a particular wave spectrum and statistical distribution.

When discussing statistical wave distributions it is necessary to distinguish between distributions used to represent the variability of individual waves in a sea state persisting over the order of hours (short-term distribution) and distributions used to represent the variability of a statistical parameter, such as significant wave height over a period of years (climate or long-term distribution). For either time scale, a number of distributions are used in engineering practice, and an expert consultant will choose which to use according to the time scale on which waves are to be analysed, and whether the waves are in deep or shallow water. For example, a short-term distribution of waves is likely to be derived following a form such as the Rayleigh distribution (see Figure 3.4) in deep water (Longuet-Higgins, 1952), or a modified form for shallow water (eg where wave breaking constrains higher waves) such as proposed by Groenendijk and Battjes (1999) or Thornton and Guza (1983). When considering a distribution that represents the upper tail of a long-term sample of significant wave heights to calculate an extreme significant wave height value (eg with a return period of 100 years), commonly used probability density functions (PDF) include the Weibull and Fisher-Tippett distributions, among others (see Section 7.4.1).

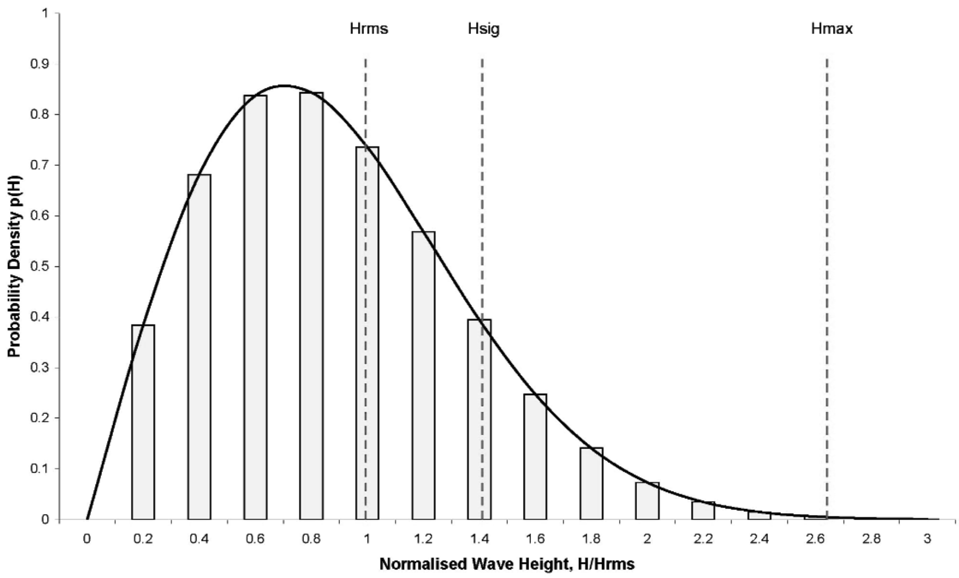
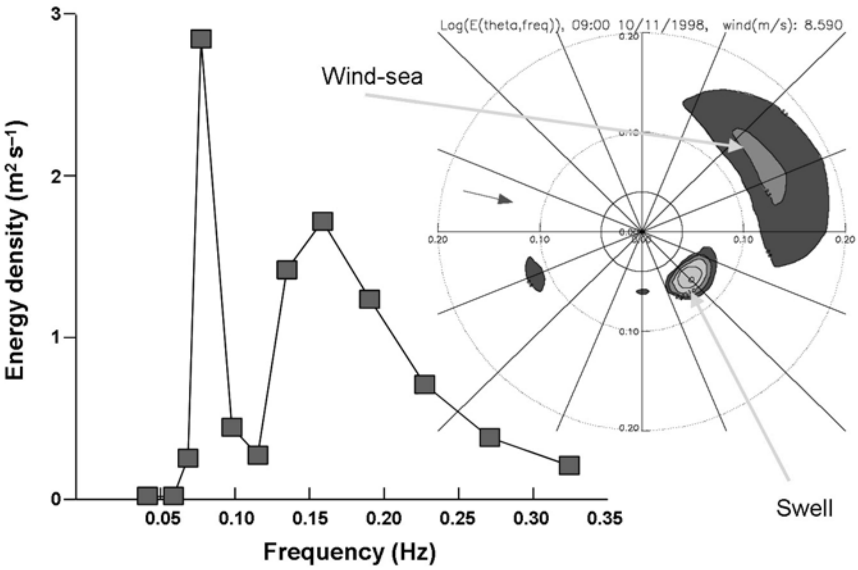


Figure 3.4 ***Normalised Rayleigh distribution of individual wave heights (Longuet-Higgins, 1952) and showing positions in the distribution of the root mean square wave height (H_{rms}), significant wave height (H_{sig}) and maximum wave height (H_{max} based on a sample of 1000 waves) following Abramowitz and Stegun (1965)***

The wave spectrum is defined on the assumption that a given wave field can be described as a summation of a pre-defined number of sinusoidal waves, each with a given amplitude (energy), period (or frequency) and direction. Two forms of the wave spectrum are commonly used by oceanographers (Figure 3.5). The two dimensional spectrum defines energy for sinusoids in frequency-direction space; the one dimensional spectrum generally refers to energy for sinusoids defined in frequency space only (ie no directional information is available).



Note: The sea state shown comprises a south westerly wind-sea with a peak period of approximately six seconds, and an oblique north westerly swell with a period of approximately 13 seconds. On the one dimensional spectrum (left hand plot) the two components are represented in frequency space (the inverse of period) as two distinct peaks in energy. The two dimensional spectrum (right hand plot) provides further information on direction (toward which the waves travel) and directional spread of energy, and shows the typically high directional spread of wind-sea energy compared to the more narrow directional spread of swell energy

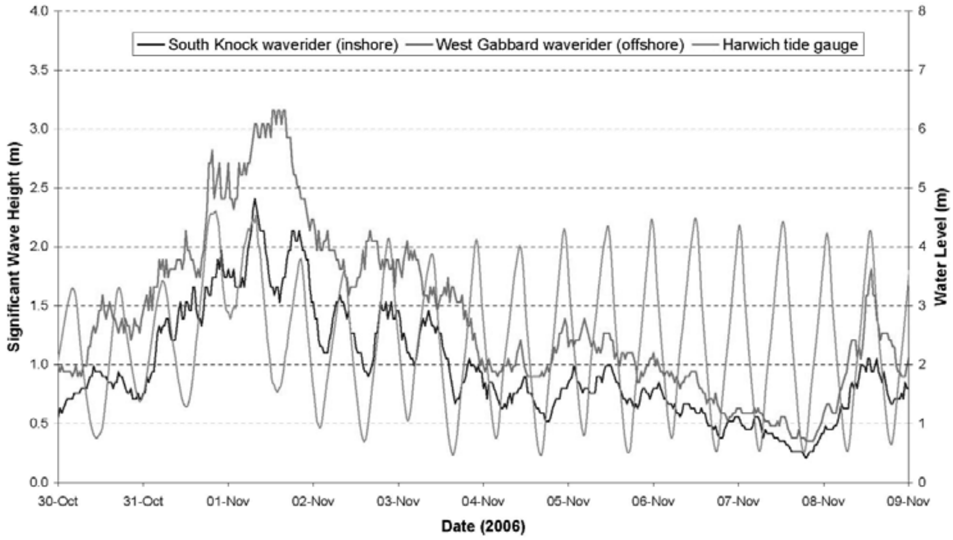
Figure 3.5 ***Representation of a wave field using the one and two dimensional wave spectra***

In deep water it is fairly common to sample wave conditions at intervals of three hours and over a duration (burst period) of several minutes (theoretically 30 minutes or longer) to capture and resolve sufficient detail in the moving wave form. Over the measurement interval it is presumed that the mean still water level remains constant and that waves oscillate around this fixed level. In strongly tidal locations and areas of shallow water these intervals may no longer be suitable since tidal variations may begin to modulate the wave regime and a sample interval of 30 or 60 minutes may be more suited to resolve such effects. This pattern of wave modulation can be demonstrated by examining larger waves measured within the Outer Thames and where the shallow profile of large sandbanks creates additional sheltering around times of low water (see Figure 3.6).

When waves are not being affected by the seabed they are described as deep water waves, and in general the water depth (d) can be considered large in comparison to the wavelength (λ), ie $d/\lambda > 0.5$.

Wave conditions heavily influenced by the seabed are described as shallow water waves, and in general the water depth (d) can be considered small in comparison to the wavelength (λ), ie $d/\lambda < 0.05$.

Intermediate waves are those that are beginning to feel the seabed and here the relationship between water depth (d) and wavelength (λ) falls in the range $0.05 < d/\lambda < 0.5$.



Note: Deep water offshore waves (measured at West Gabbard) are reduced as they pass over shallow sandbanks in the Outer Thames to reach a shallow inshore site (measured at South Knock). Further reductions in larger waves correlate to periods of low water (measured at Harwich). Wave data from WaveNet with measurements every 30 minutes. Tide data from UK Tide Gauge Network with measurements every 15 minutes

Figure 3.6 ***Example of wave modulation effects due to shallow water influences***

It is standard practice for wave parameters to be referenced from a wave spectrum measured over a standard interval of time (ie the duration of the sea state under consideration) based on moments (m_n) of the spectrum calculated as:

$$m_n = \int_0^\infty f^n S(f) df \quad , \qquad n = 0, 1, 2, \ldots$$

where S(f) represents the spectrum in frequency (f) space.

Commonly used wave height parameters include:

Root mean square wave height (H_{rms} , see Figure 3.3), a statistical mean of a sea state derived over an averaging period (m).

$$H_{rms} = \sqrt{(8\ m_0)}$$

where m_0 is the variance of the wave displacement time series acquired during the wave acquisition period.

Significant wave height (H_s , H_{sig} , H_{m0} or $H_{1/3}$) approximately equal to the average of the highest one-third of the waves (m), see Figure 3.3. Also referred to as the modal wave height. H_s is calculated from spectral moments as follows:

$$H_s = 4 \sqrt{m_0}$$

Maximum wave height (H_{max}), a statistical value of the sea state derived over an averaging period and representing the most probable highest wave height in the record (m), see Figure 3.4. The maximum probable deep water wave height can be estimated from:

$$H_{max} = H_s \sqrt{(0.5 \ln N)}$$

where N is the number of wave records during the measurement period.

When referencing large waves it is important that maximum wave height in a series is not confused with the *maximum significant wave height* determined from a probability distribution, these are fundamentally different parameters.

In shallow water, larger waves may be subject to depth-induced breaking, resulting in a profound change in the shape of the wave height distribution compared to those in deep water. Alternate methods of deriving maximum wave height may be required for this case, such as that proposed by Battjes and Groenendijk (2000).

Commonly used wave duration parameters include:

Duration of the sea state (T_s) (s)

Zero up-crossing period (T_z), the mean wave period through the spectral record (s)

$$T_z = \sqrt{(m_0/m_2)}$$

Peak period (T_p), the peak period in the spectral record (s)

$$T_p = m_{-2}\, m_1/m_0^2$$

Energy period (T_e), commonly used in the calculation of wave power (s)

$$T_e = m_{-1}/m_0$$

Commonly used wave direction parameters include:

Wave direction (θ), mean direction (degree).

Wave directional spreading (s), provides information as to the directional distribution of wave energy (degrees).

Further derived wave parameters are also of consequence to metocean studies and include:

Wavelength (λ), the horizontal distance between two identical points on two successive wave crests or two successive wave troughs (m), and is a function of wave period and water depth.

Wave steepness, the ratio of wave height divided by wavelength (non dimensional). For (regular) periodic waves the concept is as straightforward as:

$$H/\lambda$$

For random waves the definition is used with the significant wave height (H_s) and the wavelength (λ_p) that corresponds with the peak period (T_p) of the wave spectrum in deep water. The significant wave steepness is then defined as:

$H_s/\lambda_p = H_s/((g/2\pi)T_p^2)$ and is typically in the range of 1/16 to 1/20 for severe deep water sea states.

It is important to note that these and other derived parameters will be sensitive to the original statistics from which they are derived. For example, for a given wave field the wave steepness derived from root mean square wave height and peak period will be lower than the steepness calculated using significant wave height and zero up-crossing period. The latter approach is most common, but the potential for confusion when using such data highlights the importance of explicitly stating the method of calculation in project documents.

An in-depth review of waves is available in Tucker and Pitt (2001).

3.2 DATA PROVENANCE

Along with understanding the various types of metocean data it is also important to identify data origins and the process by which the data has been created so that suitable consideration can be given to such issues in any further application of the data. Standard practice is to describe these attributes using metadata, a term which provides information about the data. Present standards on compiling *metadata* include:

- ISO 19115:2003 *Geographic information – metadata*

The choice of which data are selected to aid decision making for a given project and task may be influenced by availability in programme and budget, and tested against what might be considered as sufficient (ie fit-for-purpose) for addressing each specific phase of the project. As such, there may be limited consideration of how front-end investment in comprehensive data may benefit later stages of the project. In addition, each dataset will ultimately have its own limitations (eg availability, cost, quality) which need to be understood in the selection process and tested as part of a risk-based decision. Metadata information providing indication of costs and limitations can often be provided to decision makers by specialist contractors prior to a dataset, product or service being contracted.

Well-specified metadata has a key role in delivering increased access to, and interoperability between, oceanographic datasets. The Marine Metadata Interoperability <http://marinemetadata.org>, Gigateway <http://www.gigateway.org.uk> and MarineXML <http://www.marineXML.net> initiatives aim to provide methods for increasing data exchange and interoperability.

The following publications provide additional information on metadata and data exchange:

- ISO/TS 19139:2007 *Geographic information – Metadata – XML schema implementation*
- *A geo-spatial metadata interoperability initiative* (AGI and e-Government Unit, 2004)
- *Metadata guidelines for geospatial datasets in the UK. Part 1 Introduction. Part 2 Creating metadata using UK Gemini. Part 3 Metadata quality* (DCLG, 2006)
- *GETADE formatting guidelines for oceanographic data exchange* (ICES, 2005).

Primary metadata fields discussed in the following sections include:

Ownership:	Data provider's details, copyright, cost and licence.
Quality:	Instrumentation type(s), quoted accuracy and (where possible) calibration/servicing information, suppliers assessment of data quality (eg level of quality control/data processing applied).
Temporal:	Deployment period, frequency of measurement and details of any changes in instrument type during deployment.
Spatial:	Location, and coverage, of observations (eg latitude, longitude, elevation).
Origin:	Description of data type: *in situ* measurement, model prediction, satellite observation etc.

In the UK, the Marine Data and Information Partnership (MDIP) is leading on the application of marine data standards and metadata, including those related to metocean data. Further details on the function of MDIP are available at <http://www.oceannet.org>.

3.2.1 Ownership

Invariably all metocean data has some form of ownership which may influence choice about its use in a project. Ownership will normally be protected by permitting use of the data under a licence agreement, with the licence stating any special requirements such as distribution and copyright.

Data obtained from third parties will normally incur a cost. Depending on the budgetary constraints on a metocean study, these costs may influence the choice in selecting such data or adopting a less expensive alternative.

3.2.2 Quality

Metocean studies are driven by the available data. The confidence and robustness in the results of a metocean study are intrinsically linked to the quality of the data which is used. An experienced metocean contractor will be familiar with data quality issues and be able to relate this through to a measure of uncertainty (or reliability) in any assessment.

It is good practice to conduct a process of data review for any inputs into a study and to document data quality issues. This review should consider, as a minimum:

- data spikes – determining if the data remains within expected upper and lower bounds and is representative of anticipated conditions
- data gaps – identifying missing data and the means of handling a data gap
- data accuracy – clearly verifying the accuracy in geo-referencing, timestamp, and individual metocean parameter units, noting that advances in technology may yield improved accuracies over time.

Graphical presentation of the data is often the most effective way to reveal quality issues. Where data are identified to have quality issues then careful notation is required to flag the data, and any action taken to moderate the data should be explicitly stated to subsequent users of the data to ensure it is possible to recover the original data values if subsequent users do not accept the editing procedures applied.

Established practices in data validation and quality control include:

⇨ *Metocean data – validation and documentation* (UKOOA, 1993)

- ⇨ *Recommended procedures for validation and documentation of oil company metocean data* (UKOOA, 1987)
- ⇨ *Manual of quality control procedures for validation of oceanographic data* (UNESCO, 1993).

3.2.3 Temporal reference

In some form or other metocean data will always represent the temporal behaviour for a particular area and location. This may be as a summary statistic (eg a single statement of a long-term average), or as a time-series ie the high frequency variation in a parameter measured over a given period.

The source data may also represent one of the following types:

1. **Past** data is the archived data which may originate from either model or measurement. Hind-casting is the common term for models that attempt to replicate measured data. Extreme analysis statistics depend on past data, with the length of the data archive being the prime interest for robust statistical analysis. Long-term datasets also provide the means of establishing climatic behaviour in metocean conditions and inherently this requires data spanning decadal periods.
2. **Present** data relates to real time observations and are desirable to support operational decisions (preferably based upon on-site measurements). When such real time data are used to make a short-term (order of a few hours) prediction of conditions the resulting data product is known as a nowcast.
3. **Future** data provide some form of prediction, commonly based on a suitable atmospheric or ocean model. Forecasting is a skill which considers these predictions and offers an informed view on conditions in the near future. This type of data has value in planning on-site operations.

A further temporal reference is the frequency of the observation. To be useful the variability in observation over time needs to be resolved by sampling at a sufficiently high frequency. For example, the rate of change in tidal processes means that a minimum of hourly values is needed to describe the change in value through a tidal cycle, with a higher frequency of observation preferable.

The choice of which data is selected may be influenced by availability in programme and budget, tested against what might be considered as sufficient (ie fit-for-purpose) for addressing each specific phase of the project. As such, there may be limited consideration of how front-end investment in comprehensive data may benefit later stages of the project. In addition, each dataset will ultimately have its own limitations (eg availability, cost, quality) which need to be understood in the selection process and tested as part of a risk-based decision.

3.2.4 Spatial reference

As with the temporal reference, metocean data will have an associated geographic reference to identify its representation of a general sea area, a specific location (x and y) or an exact position (x, y and z). If the characteristics of a large offshore area are required then the amount of spatial coverage in metocean data becomes especially relevant. This issue is important for sites where seabed profiles or shorelines might exert an influence sufficient to modify the metocean conditions over relatively small length scales.

3.2.5 Origin

Metocean data will originate from one of the following sources:

1 ***In situ* measurements** generally regarded as the most accurate and reliable description of metocean conditions. Data may be available from real time (present) deployments or archives of previous measurements (past). Coverage of existing data is likely to be sparse, so the distance to the development site will play a factor in suitability and application in a project. Whenever possible, project development should consider acquisition of sufficient *in situ* measurements across the site with the aim of providing improved analysis, forecasts and nowcasts. Costs for such an exercise (eg installation of a met mast, ongoing servicing of an offshore measurement platform or buoy) are high compared with other data sources. Nonetheless as a ground truth the data obtained should be considered essential in mitigating risk involved when using other data sources – particularly for elements of the project where financial exposure is high. The specification for a measurement program should be carefully drawn up with a full understanding of what the acquired data should achieve (eg through gap analysis, see Section 6.2). In addition, careful stewardship of new *in situ* measurements and effective integration of these data with other sources should be planned in order to make project specific measurement data as cost effective and useful as possible.

2 **Remote sensing** for the purpose of these guidelines, refers to measurements made from a location other than *in situ*. Remotely sensed data commonly refers to satellite earth observation (EO), although recent developments in ground based radar means that these techniques also have marine applications eg wave radar systems. Over past decades satellite remote sensing of the sea surface utilising microwave based systems has led to the generation of substantial datasets relating to marine winds and sea state. However, repeat coverage and resolution of satellite orbits remain a limiting issue, as does the coarseness in intervals between track lines. Data archives offer the potential to support design and planning, provided that data quality is assured for sites where downscaling issues may arise.

3 **Re-analysis/hind-cast modelling** datasets are available from a number of providers and have the advantage of covering both a wide spatial area (eg UK wide, global) and for reasonably long periods. The compromise is that spatial resolution may remain on a broadscale.

4 **Forecast products** are available from specialist providers at varying levels of sophistication and cost, with the trade-off being accuracy and/or applicability to a specific site or operation. Forecasts relevant to marine operations are available for a variety of timescales, from short range (next few days) to seasonal. However, to obtain a precise quantitative prediction of a given parameter (eg wind speed, wave height), the range of forecast may be restricted to several days at the most.

These data types each have different strengths, limitations and range of application which are summarised in Table 3.1.

Table 3.1 ***Generic strengths and limitations of data sources classified as: in situ measurements, remote sensing, re-analysis/hind-cast modelling, forecasts***

Data source	Strengths	Limitations
In situ measurements	Most accurate representation of metocean conditions Data provided as a time series should fit all analysis types Can supply real time data for nowcast	Site-specific, may not represent whole area of interest Need to carefully plan deployment and servicing to avoid data gaps Expensive to deploy and maintain, particularly with real time communications
Remote sensing	Measured data with wide spatial coverage Specialist providers ensure a level of quality control and provide pre-processed data Errors expected due to high level of processing applied to raw instrument data	Poor temporal sampling makes data inappropriate for some analysis types Subject to errors where complex sites are represented by broader scale spatial grid points
Re-analysis/ hind-cast modelling	Good coverage both in time and spatial area Data provided as a time-series should fit all analysis types	Errors expected due to model representation of complex physical processes Subject to errors where complex sites are represented by broader spatial scale grid points
Forecasts	Allow planning for future events Numerous products can be tailored to specific operations	Risk of higher level of error with increasing forecast horizon Spatial detail may be coarse Need to ensure forecast delivers benefit (eg through validation)

A metocean study may combine a number of these data types leading to interpreted values which are a derivative of the source data. The selection of any particular dataset should also consider the project requirements at each stage so that data remains fit-for-purpose and suitable for the task. For example, initial site appraisals may only require broadscale data.

Recognised data limitations and in-built errors/accuracies should also be acknowledged throughout the process of data analysis and interpretation so that some form of confidence limit can be taken into consideration when decisions are being based on study outputs.

The case of the European Wave Model is used here to illustrate pertinent issues related to data provenance (Box 3.1).

Box 3.1 *Case study: European Wave Model*

Ownership:	The Met Office own and operate the European Wave Model and can supply data under licence for forecast and hind-cast.
Quality:	The model has a history of development and improvements since its initial formulation in 1986. Model predictions are continually validated by comparison with wave parameters measured from a network of buoys. The physical description of wave processes included in the model determines the major part of quality and accuracy.
Temporal reference:	The model is operated in forecast model to T+48 hours. A three hourly data hind-cast archive started in June 1988, which now provides access to over 18 years of data.
Spatial reference:	Predictions are offered on a grid scheme based on 1/4° latitude and 2/5° longitude (approximately 35 km). Features that are smaller than 35 km are not resolved.
Origin:	Data products are based on model output (hind-cast).
Limitations:	The model is best suited to describing a deep water wave condition that is also remote from the coast. The model resolution and treatment of shallow water influences limit the value and accuracy of the model in nearshore locations.

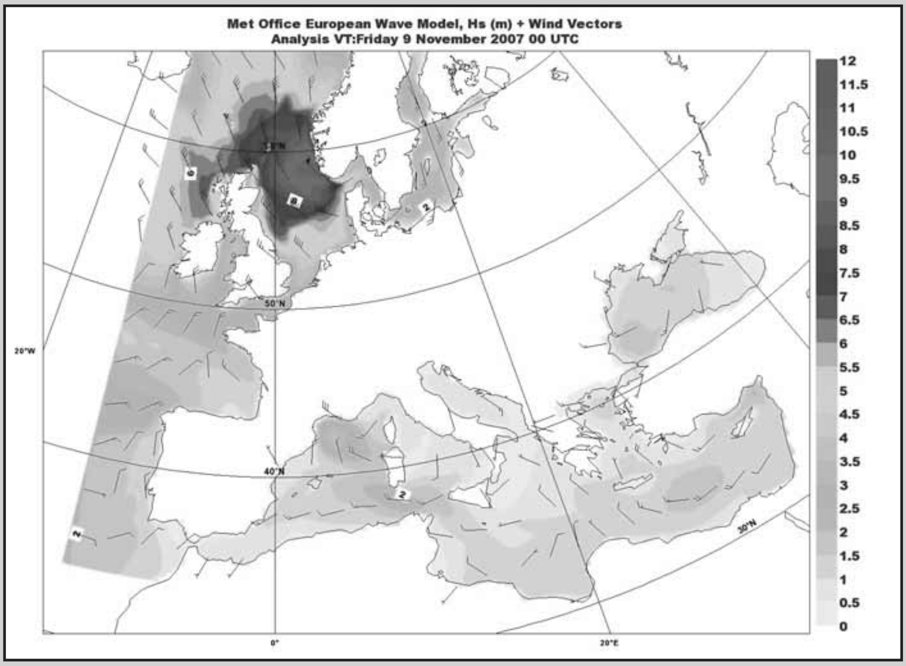


Figure 3.7 *European Wave Model (courtesy Met Office)*

3.3 DATA SOURCES

Traditionally, metocean data has been gathered and applied by disparate groups, and for disparate purposes such as national meteorological services, offshore oil and gas operators, coastal monitoring programs and academic research groups. The UK has identified a need to make more cost effective use of these resources, leading to the formation of a number of programs aimed at standardising, cataloguing, exchanging and raising the general profile of marine data. At present, full co-ordination of the variety of metocean and other oceanographic data sources remains a work in progress with data accessibility, cost and support all variable and dependent on the organisations responsible. However, the state-of-the-art is such that a large amount of metocean data for UK seas can now be identified, and in some cases accessed, from a variety of online services (eg metadata discovery websites which include EDMED, SeaDataNet, SIMORC) and other standard data sources. Some of these services represent established data archive centres (DAC) that exist with a remit to maintain and develop their archives for further scientific interest (see Table 3.2). Data from such sources may be held in a preferred format which may not always be immediately suitable for a specific project requirement.

Table 3.2 ***UK data archive centres for metocean data***

Data archive centre	Data type	Web address
British Atmospheric Data Centre (BADC)	Wind and other atmospheric parameters	<http://badc.nerc.ac.uk>
British Oceanographic Data Centre (BODC)	Wave, water levels, currents and other oceanographic parameters	<http://www.bodc.ac.uk>

A vast amount of metocean observations, including winds and waves, are also gathered by ships transiting the oceans under the Voluntary Observing Ships (VOS) programme <http://www.vos.noaa.gov>. The main aim of VOS is to provide metocean data for incorporation into meteorological forecast models. For some parameters, VOS data can be fairly qualitative and mainly applicable to sites further offshore than is of interest to present marine renewable developers. Where VOS measurements are gathered close to the coast more consistent monitoring platforms are often available.

A direct initiative for the marine renewables industry to co-ordinate data management and make data resources more widely available has been instigated by The Crown Estate under the COWRIE initiative (see Section 3.6). Data holdings collated through this initiative from Round 2 offshore wind projects are available from <http://data.offshorewind.co.uk/catalogue>.

The following sections give a brief description of commonly used UK data sources in water movements, winds and waves. In assessing the suitability of any dataset the following generic categories should be considered:

- *geographic location* – to ensure that this is representative for the project site
- *vertical location* – relative to device height
- *sensor type and accuracy* – to ensure the sensor is appropriate for the measurements required and location in which they are made
- *sampling length and frequency* – to ensure the data is appropriate for design and/or planning analyses
- *data processing* – to ensure the data is appropriate to design and planning analyses (eg effects of averaging are understood).

3.3.1 Water movements

Water levels

Water levels are typically measured around the coastline where they can be levelled to a consistent land datum, such as Ordnance Datum Newlyn, and maintained as operational devices in the long-term. It is fairly uncommon to find any long-term deployments in the offshore due to practicalities of levelling to any benchmark and cost-effective maintenance of the gauge. For cases where information is required away from the coast careful reference can be made to co-tidal charts (published by UKHO) or direct analysis of modelled data (where available).

The primary data repository for *in situ* measured water level data is the UK Tide Gauge Network (Figure 3.8), which forms part of the National Tidal and Sea Level Facility (NTSLF). This network includes 44 tide gauges distributed around the UK and with data archives which can be freely accessed via the BODC website. The network of tide gauges was established after violent storms in the North Sea in 1953 resulted in serious flooding in the Thames Estuary. Various port authorities and the Environment Agency also operate a number of tide gauges which remain independent of the UK Tide Gauge Network, and whose information is not always as readily available.

Where data has been collected on a consistent basis for several decades then it becomes possible to analyse the record for extreme events, secular trends (such as variation in mean sea level) and the behaviour of non-tidal influences (such as surge-tide interactions).

When water level data is being screened for application in a project, it is advantageous to select a dataset that spans a period of at least 28 days (the period of the full moon). This gives the opportunity to perform tidal analysis which can be used to establish resolution of the primary lunar and solar harmonic constituents. A set of constituents provides the means to re-compute the astronomical tide and predict future tidal conditions. A number of desktop applications are readily available from suppliers, such as Proudman Oceanographic Laboratory and the UK Hydrographic Office, to offer this service for selected locations.

Figure 3.8 ***The UK Tide Gauge Network (courtesy POL)***

Water levels during storms may also be affected in the significant meteorologically forced surge component, which can only be predicted in the short-term using forecast models and trained forecasters. The use of real time display alongside predicted water level values provides a means to determine any non-tidal deviation which may indicate surge influences (note that such deviations can be positive or negative). Forecasters in the Met Office Emergency Monitoring and Response Centre (EMARC) employ this methodology in support of the Environment Agency Storm Tide Forecasting Service, which provides emergency response measures for flood defence.

The Channel Coastal Observatory (CCO) links to various available tide gauges and gives near real time display for tides at sites from Portland to Herne Bay. Similarly, the Liverpool Bay Coastal Observatory replicates this from Holyhead to Heysham.

Key sources for water level data are detailed by parameter type and listed in Table 3.3.

Table 3.3 ***Summary of water level data sources***

Type	Example	Source	Link from
In situ	Tide gauges	UK Tide Gauge Network	<http://www.bodc.ac.uk>
		Channel Coastal Observatory	<http://www.channelcoast.org>
		Liverpool Bay Coastal Observatory	<http://cobs.pol.ac.uk>
Remotely sensed	Satellite altimeter	ARGOSS (Tidal Info)	<http://www.tidalinfo.com>
Forecast		UKHO (Easy Tide)	<http://easytide.ukho.gov.uk>
		POL	<http://www.pol.ac.uk>
Synoptic maps	DTI Atlas	DTI	<http://www.offshore-sea.org.uk>
Co-tidal charts	UKHO		<http://www.ukho.gov.uk/amd/standardNavigationalCharts.asp>

Currents

BODC maintains the UK inventory of moored current meter data, a comprehensive archive which includes detailed metadata records about each deployment. In comparison to tide gauge records these data tend to be shorter-term deployments lasting from several days up to months. As with water level records, data which spans a period of 28 days or longer can be considered for harmonic analysis. In most cases the data will represent a measure of flows at a fixed depth in the water column. When selecting such data from an archive, it is beneficial to consider both the length of the data record and its relative position in the water column.

A further online metadata database is the CEFAS iSEA website, although some older records may be replicated in the BODC archive.

No UK-wide real time data source for current data exists at present, but results from an ongoing HF Radar deployment at the Liverpool Bay Coastal Observatory provide an example of what can be achieved using state-of-the-art equipment and communications.

Table 3.4 summarises the primary data sources for current data.

Table 3.4 ***Summary of current data sources***

Type	Example	Source	Link from
In situ	Current meters	BODC (UK Inventory of Moored Current Meter Data) CEFAS iSEA	<http://www.bodc.ac.uk> <http://www.cefas.co.uk>
Forecast	Numerical Model	POL Met Office	<http://www.pol.ac.uk> <http://www.metoffice.gov.uk>
Synoptic maps	DTI Atlas	DTI	<http://www.offshore-sea.org.uk>
Tidal streams	Admiralty Charts TotalTide	UKHO	<http://www.ukho.gov.uk/amd/standardnavigationalcharts.asp> <http://www.ukho.gov.uk/amd/TotalTideSDK.asp>

3.3.2 Offshore wind

Offshore wind data (wind speed and direction) is of primary interest to offshore wind farm development, since project siting will be based on determining a location where the wind resource is favourable for power generation, and also in terms of micro-siting for the array layout itself in relation to knowledge of the prevailing up-wind direction. Ideally these data will be in the form of long-term site-specific observations and related to the appropriate height above sea level. Offshore wind data will also remain relevant to all marine renewable developments in terms of planning any marine operations for which the high winds or larger sea states may provide a safety constraint (ie weather downtime).

Major land and marine observation networks (such as the Marine Automatic Weather Station (MAWS) network, Figure 3.9), supplemented by ship borne and satellite remote sensing measurements, provide large volumes of surface wind data daily to national meteorological services for use in establishing initial conditions for atmospheric forecast models. However, there is a key difference in the data requirement for wind farms in that resource estimates need to apply to the equivalent hub height which is notionally at least 70 m above mean sea level. The general scarcity of *in situ* offshore measurements, and absence of any data at equivalent hub heights, has led project developers to install met masts so that resource validation can occur, however, this represents a major expense to a project. At present met mast data remains under the ownership of the project developer and is generally not accessible to third parties.

A useful summary on the availability of offshore wind data is provided by Grainger *et al* (1999). The British Atmospheric Data Centre (BADC) is the designated DAC for atmospheric data, including winds. The Met Office is also a primary source for offshore wind data and is responsible for maintaining the UK MAWS network. MAWS is designed as part of an early warning system to help reduce the effects of natural disasters, such as flooding due to storms. The network of buoys is stationed out on the continental shelf and facing the Atlantic, with locations not always suitable to support the direct interests of marine renewable projects. Similarly the oil and gas sector has significant data holdings, but these sites are often at a greater distance offshore.

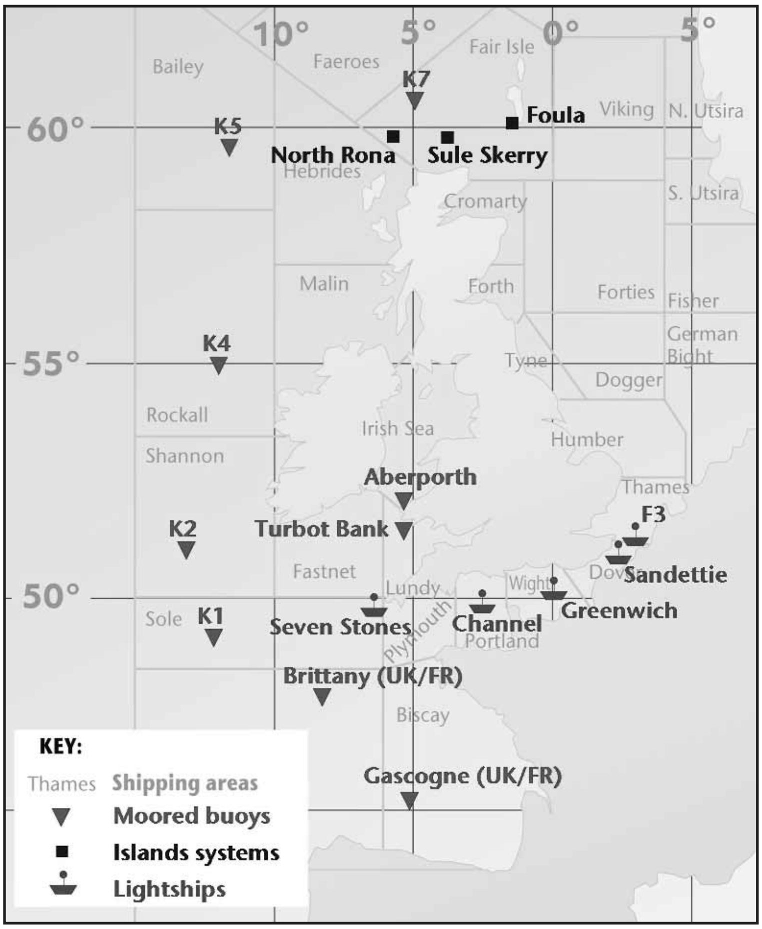


Figure 3.9 ***Marine Automatic Marine Weather Station (MAWS) network (courtesy Met Office)***

Operational atmospheric forecast models, often termed numerical weather prediction (NWP) models, provide a source of predicted winds and at various levels through the vertical. Such models form the basis for long-term re-analysis or operational hind-cast datasets, for example the European Centre for Medium Range Weather Forecasting (ECMWF) ERA-40 dataset and the Met Office Global, European and UK Waters wave model archives.

Processing of satellite remote sensing signals allow a derivation of sea-surface wind parameters, and data or products based upon archives from various satellite missions are available both freely (eg QuickSCAT winds from Remote Sensing Systems in the United States) and from commercial companies (eg Satellite Observing Systems in the UK, ARGOSS in the Netherlands).

Apart from these offshore data sources, long-term wind measurements are available from a network of land based weather stations. By convention these sites normally record winds at heights of 10 m above land. Importantly, land based data should be treated with caution as local topography and diurnal temperature effects will lead to bias in comparison to measurements at sea. Despite these restrictions, some coastal sites may remain useful. Access to any long-term archive is likely to incur some form of data charge. Real time data is generally accessible from harbour authorities (Vessel Traffic Services, VTS) and online data from the emerging suite of coastal observatories (eg Channel Coastal Observatory and Liverpool Bay Coastal Observatory).

Table 3.5 gives a summary of the primary sources for wind information.

Table 3.5 ***Summary of offshore wind data sources***

Type	Example	Source	Link from:
In situ (offshore)	Met buoys	MAWS	<http://www.metoffice.gov.uk>
	Met masts	Offshore wind developers	–
	Offshore Platforms	SIMORC	<http://www.simorc.org>
In situ (coastal)	Met stations	Channel Coastal Observatory	<http://www.channelcoast.org>
		Liverpool Bay Coastal Observatory	<http://cobs.pol.ac.uk>
		Harbour authorities	–
		Met Office	<http://www.metoffice.gov.uk>
		BADC	<http://badc.nerc.ac.uk>
Modelled/forecast	NWP	The Met Office	<www.metoffice.gov.uk>
Remote sensing	SAR	ESA	<http://www.esa.int>
Synoptic maps	DTI Atlas	DTI	<http://www.offshore-sea.org.uk>

3.3.3 Waves

Wave data (wave height, period and direction) is relevant to all marine renewable projects for design (survivability), construction, and operational and maintenance (access) issues, and is especially relevant to wave farm developers as this is the primary resource variable. As with offshore wind data, the ideal situation is for long-term site-specific observations, but as with other metocean data there is typically sparse coverage from existing field measurements. A review of presently available baseline data for future use in the prediction of energy yield from commercial scale wave energy forms is in preparation (natural power, 2007)

A primary portal for UK wave data (real time and past measurements) is WaveNet (Figure 3.10). Presently funded by Defra and the Environment Agency, this facility provides a wave monitoring network for England and Wales, with the main objective to improve the management of flood and coastal erosion risk. WaveNet includes direct access to the data archive for any publicly funded measurements and also integrates relevant parts of MAWS, the data from which are held by the Met Office.

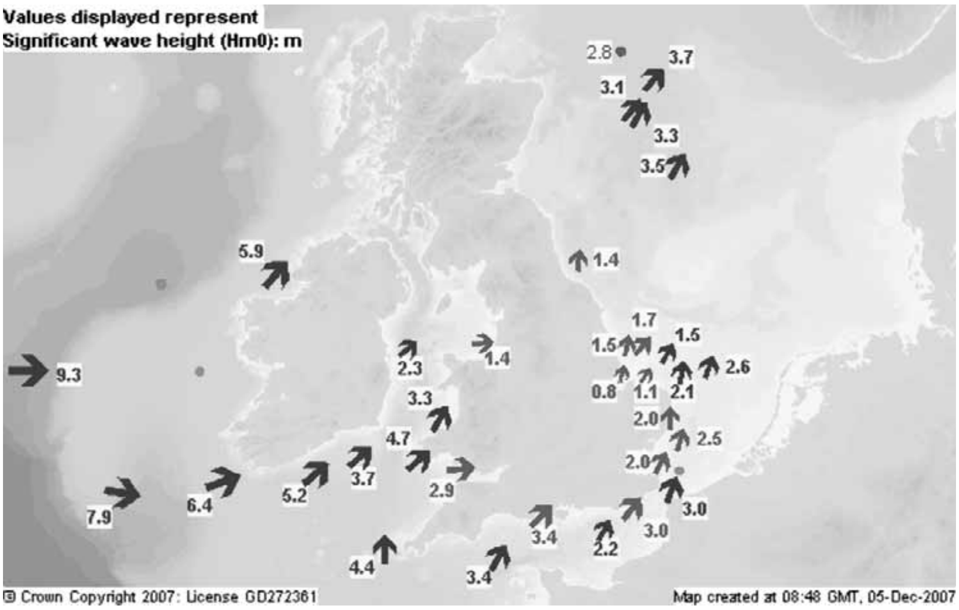


Figure 3.10 ***WaveNet measurement sites (courtesy CEFAS)***

The primary DAC for past deployments of wave data is the British Oceanographic Data Centre (BODC). In addition, operational ocean forecasting models give a source of predicted wave conditions, including the Global, European and UK Waters wave models from the Met Office. At the time of publication the Global Wave Model has a data archive spanning a 10-year period with data at six hourly intervals from a grid with a 60 km resolution. The European Wave Model has over an 18-year data archive and holds values at three hourly intervals, based on a grid resolution of around 35 km. Finally, the UK Waters Wave Model has over a 7-year data archive and holds data at a three hourly interval based on a grid of around 12 km resolution.

Table 3.6 provides a summary of the main sources for wave data.

Table 3.6 ***Summary of wave data sources***

Type	Example	Source	Link from
In situ	Met buoys	MAWS	<http://www.metoffice.gov.uk>
	Wave buoys	WaveNet	<http://www.cefas.co.uk>
		Channel Coastal Observatory	<http://www.channelcoast.org>
		Liverpool Bay Coastal Observatory	<http://cobs.pol.ac.uk>
		UK wave data catalogue	<http://www.oceannet.org>
Forecast/ modelled	European and UK Waters Wave Model	Met Office	<http://www.metoffice.gov.uk>
	NESS, NEXT and NEXTRA Wave models	Ness User Group	
Remote sensing	SAR	ESA	<http://www.esa.int>
		ARGOSS	<http://www.waveclimate.com>
Synoptic maps	DTI Atlas	DTI	<http://www.offshore-sea.org.uk>
	Extreme waves	HSE	<http://www.hse.gov.uk>

3.4 DATA PRODUCTS

3.4.1 Definition

In the majority of marine renewable projects, decision makers will not deal directly with raw metocean data, but will often reference some form of post-processed or analysed data product.

Within these guidelines, data products are identified under four headings:

1. Site specific post-processing.
2. Design and planning analyses.
3. Metocean atlases.
4. Forecast products.

Each data product is summarised briefly within this section.

3.4.2 Site specific post-processing

In situ measured, remote sensed or modelled data sources will have often been developed with a broader remit than supply of information for the site-specific coastal user. As a result it will be the exception rather than the rule that pre-existing and/or regional scale data products can be confidently used by a renewables project without explicit validation and enhancement. This is particularly the case when operating in a shallow water environment with complex bathymetry (wave, tide) and/or close to the shoreline (wind).

Risks associated with data obtained at project inception will be identified through gap analysis (see Section 6.2). Mitigation of any identified risks can be achieved through the use of (often newly gathered) site-specific measurements, and statistical methods or models that provide better simulation of physical effects at a scale appropriate to the project site. The application of such techniques is often called downscaling.

In particular, downscaling techniques can be used to create long-term site specific datasets required for design and planning analyses, based upon the combination of short-term site measurements and other long-term past data (eg from an offshore measurement source or numerical model). Since committing to a project (site) specific measurement program presents a financial risk, and gaining maximum cost benefit and risk reduction through use of data in this manner should be an objective.

Techniques developed to perform site specific post-processing and downscaling include:

- a straightforward validation of pre-existing data using concurrent new measurements
- assessment of a (simple) statistical relationship between pre-existing data and new measurements
- deriving a black box model to relate pre-existing data and new measurements (eg multivariate statistics, artificial neural network)
- validation of a process based downscaling model using pre-existing data as boundary conditions and new measurements as validating data; the process model may also be coupled with simple and black box statistical models.

The validation, statistical and black box modelling techniques provide the basic tools of measure correlate predict (MCP) methodologies.

The techniques may also be applicable in future data usage (eg modification or value add to forecasts) and as a result should be well documented in order not only to validate any data analysis product from specialist contractors, but with a view to re-use the technique at a later project stage.

At present, no single source of standards for site specific metocean data post-processing exists, so it is recommended that appropriate information be sought from specialist contractors regarding the application and limitations of their chosen post-processing method.

3.4.3 Design and planning analyses

Design and planning analyses provide the main decision making tools for assessing the opportunities and risks to a project or operations presented by the project site's metocean climate.

The four most common analysis procedures required by a marine renewables project are:

1. Resource (what can be commercially exploited).
2. Extremes (risk of low probability high impact events).
3. Fatigue (risk due to general metocean climate).
4. Downtime (risk of weather preventing safe access to site).

Resource analysis will, in the first instance, examine a candidate site's raw resource potential (usually given as a headline average figure) and, on more detailed inspection, the ability for a given energy converter to extract power. While standards for making resource estimates remain under development, the underlying methods are relatively simple and robust enough to exist as *de facto* standards. In general a frequency distribution representing the climate of a given resource parameter (wind, wave, current) will be sufficient for initial assessments, allowing the source dataset to be drawn from *in situ* measured, remote sensed or modelled datasets (see Section 3.2.5).

Extreme events have, by definition, a low probability, but potentially a high impact on marine structures. In the context of design, an assessment of extreme metocean conditions (usually at a return period of 50 or 100 years) is applied as input for engineering load calculations. In order to assess extreme wind or wave loads, procedures either adopt an approach that ascertains the extreme mean condition (ie mean wind speed, significant wave height at a one in N year return period) from which the highest event (ie highest wind gust, maximum wave height) can be determined, or determine an extreme event directly from a probability distribution representing the total distribution of individual events (eg population of individual waves). Further details are discussed in Section 7.4.1.

Design for fatigue limits is required to assess the cyclical loading on structures by considering the loads caused by various combinations of metocean factors during operational conditions, and taking into account issues such as wake effects. In contrast to extreme loads, the cyclical loads operate at a much higher frequency of seconds to minutes rather than years, see Section 7.4.2.

Downtime analysis aims to describe the metocean risks to given operations on site, ie a description of workability. Each downtime analysis uses a specific operating threshold determined relative to one or more environmental parameters. For example, personnel transport operations may be permitted in relatively high sea states, whereas heavy lift operations will be extremely sensitive to both sea state and wind effects on the crane. The approach for downtime analysis, as described in Section 7.4.3, is relatively straightforward, although attention should be paid to confidence in the available environmental data when setting thresholds, and the interpretation of the analysis results. The most effective form of downtime analysis requires high frequency time series data as input, ruling out the use of satellite remote sensed data for which the sample interval is sparse.

3.4.4 Metocean atlases

A number of metocean studies of seas immediately surrounding the UK (in particular the North Sea) have led to the creation of atlas style products that provide broadscale mapping of wind, waves and water movements.

Early studies (eg DOE, 1991) were conceived on the basis of informing design and operations of offshore oil and gas facilities. The studies were based on measured data, with interpolation used to contour between the most reliable (data dense) locations.

Recent advances in high resolution numerical modelling allowed the production of the DTI *Atlas of UK marine renewable energy resources* (Cooper *et al*, 2006). This atlas provides GIS enabled maps of marine wind, waves and current resource, is freely available from the DTI and has been designed to support their SEA plan for commercial scale marine renewable developments. Further details on the DTI Atlas are available from <http://www.offshore-sea.org.uk>. Note that this atlas is currently being updated with a further version due for release in 2008.

3.4.5 Forecast products

A forecast will provide future data to inform marine operations. The product selected should be based upon the importance of the operation being conducted, the level of detail required from the forecasts, the consequence of a poor forecast being issued and how much support (eg from a forecaster) might be required. For example, routine crew transit operations to and from site conducted by an experienced master are likely to require minimal information. Working alongside and deploying personnel to an unmanned platform may need more specific information (eg winds, sea state, currents, daylight hours) and to be interpreted in terms of the operating vessel's available power and likelihood of a rapid change in conditions that might affect platform access. Towing and large plant operations, with potentially expensive downtime costs, may have their cost effectiveness improved by an even more focused forecast, and can be made more robust through support by an expert forecaster. For further detailed discussion on the use of marine forecasts see Section 8.3.

Forecast products will be used to inform operational planning for the majority of on-site (and transit to site) activities. Typical forecast products that are readily available for marine operations are summarised in Table 3.7.

Table 3.7 ***Forecast products relevant to marine renewables applications***

	Forecast product	Parameters	Timescales	Format
1	Automated deterministic forecast (raw model data)	Pressure Temperature Wind Sea state (waves) Currents (surface and sub-surface)	Short-range (0–3 days) Medium-range (3–7 days)	Map Graph/Table
2	Forecaster intervened deterministic forecast	Pressure Temperature Wind Sea state (waves) Visibility	Short-range (0–3 days)	Text Map Graph/Table
3	Forecaster probabilistic forecast eg probability of threshold exceedance	Temperature Wind speed Sea state (wave height) Visibility	Short-range (0–3 days)	Text Table
4	Ensemble probabilistic forecast (model data) eg probability of threshold exceedance	Pressure Temperature Wind speed Sea state (wave height) Visibility	Short-range (0–3 days) Medium range (3–7 days) Long-range* (7 days to 1 month)	Map Graph
5	Towing operations (threshold based using any of methodologies 1 to 4)	Wind Sea state Currents	Short-range (0–3 days) Medium-range (3–7 days)	Map Graph/Table Text warnings
6	Subsea operations (threshold based using method 1 for currents and any of 1 to 4 for sea state)	Sea state Currents	Short-range (0–3 days) Medium-range (3–7 days)	Map Graph/Table
7	Vessel response for heavy lift (calculated from the wave spectrum, usually method 1 or 2)	Sea state (wave spectrum)	Short-range (0–3 days)	User specific

Note: * Forecasts anomalies with respect to climatology eg likelihood of being windier/less windy than usual for a given month.

Box 3.2 provides an example of a typical marine forecast schedule and includes an explanation of the key features of the forecast along with considerations of how confidence in such forecasting can vary over time.

Box 3.2 ***Case study: Example of a typical marine forecast***

Project:	Construction operations at Barrow Offshore Wind Farm
Requirement:	Provision of a five day forecast of metocean conditions at the Barrow site.
Forecast example:	The forecast example is an extract from a typical tabulated section of a tab and graph forecast issued by the Met Office marine forecasting centre. The forecast is generated by a human forecaster who provides quality control and intervention on the NWP data. In addition to the text items in this example, accompanying graphs of forecast parameters are provided. Further parameters can be added to the forecast on request, for example wind speeds at 100 m above sea level (hub height).
Forecast features:	The forecast contains the following features: ● forecast issue time should be given so that users are assured of using the latest information ● designated site name should be provided to identify forecast location ● headline statements give information regarding general warnings that might affect operations health and safety on-site (eg gale warnings, lightning risk) ● general situation provides information as to the evolving meteorological forecast affecting the site's sea area ● confidence rating judges the reliability of the forecast for the days ahead. As confidence diminishes further up-to-date forecasts will be required ● at a glance data allows the potential for weather effects on operations in the first 36 hours of the forecast to be identified before making detailed inspection of later tables ● visibility and cloud base are forecast for the first 36 hours after issue. ● tables give a quantitative five day forecast of wind and wave parameters for detailed planning work.
Forecast confidence:	Confidence in this type of forecast is based upon two factors: 1 The raw NWP forecast will be expected to diminish in quality over the five day forecast period as the forecast moves away from the initial analysis state. In this case, the first 36 hours are forecast using a model with higher resolution than is used for successive days. 2 The second factor is the ability of the expert forecaster to successfully quality control and intervene the NWP forecast. For parameters such as visibility and cloud base this combination leads to 36 hours as a maximum time for which the forecast is issued with confidence. Wind speed and wave height are forecast to the longer five day period, but the forecaster will generally only apply their expertise to improve the quantitative forecast during the first three days (shaded dark blue). In the following two days the NWP data is expected to offer a good qualitative guide as to changes in conditions, but with a higher quantitative error expected.
Long-range forecasts:	Two types of forecast are available beyond the five day range. Over subsequent days (plus day 5 to day 10) an ensemble probabilistic forecast can be provided for areas where the coarse resolution model grid is deemed to behave appropriately (eg presently for waves this will mostly restrict the 5 to 10 day ensemble forecast to open sea basin sites). Monthly and seasonal forecasts are a more recent development and offer a probabilistic forecast of conditions relative to a background climatology, for example will weather be warmer or colder than average? Application for wind and wave parameters has been limited to date.

Case study: Example of a typical marine forecast (contd)

Forecast issued on Wednesday 1 August 2007 at 22.02 UTC (i)

Barrow (ii)

Headline (iii)

Gale warning in force	No	Lightning risk: 4 (low)
Sea temp (Celsius)	14	

General situation (iv): Area of low pressure will remain slow moving in the Norwegian Sea during Thursday while a ride of high pressured extends east across England and the North Sea before sinking south into the near continent on Friday. A deep Atlantic low will become established south-west of Iceland by Friday this pushing associated frontal systems across the UK and North Sea during Friday and the weekend. High pressure will build over Denmark by Sunday.

Confidence (v): High becoming medium Saturday then low on Monday.

At a glance – valid until 0600 Fri 3 August 2007 (vi)

Phase	Wind (mean)	Time (UTC)	Sea (Sig)	Time (UTC)
Max	11	02/1100	1.0	03/0400
Min	04	02/0000	0.3	02/0900

(vii) Cloud height (FT) above sea level = 3/8 coverage or more below 5000 ft

	Thur 02 August 2007								Fri 03
	00	03	06	09	12	15	18	21	00
Weather	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
Visibility	10 KM+	10 KM+	10 KM+	10 KM+	10 KM+	10 KM+	10 KM+	10 KM+	10 KM+
Temp	15	15	15	15	15	15	15	6	16
Cloud	NIL SIG	4400	2700	4200	NIL SIG	NIL SIG	NIL SIG	NIL SIG	NIL SIG

(viii) Wind speed in knots, waves and swell heights in metres, wave and swell periods in seconds

	Thur 02 August 2007								Fri 03 August 2007				
	00	03	06	09	12	15	18	21	00	03	06	09	12
Wind dir	NW	NNW	NNW	WNW	W	W	W	WSW	SSW	SSW	SSW	SSW	SSW
10 m Wnd spd	4	5	4	6	11	10	9	7	9	10	11	14	15
10 m gus	6	6	6	9	15	14	12	10	13	14	16	20	20
50 m wnd spd	5	5	5	8	12	12	10	9	12	13	15	18	19
50 m gust	7	7	7	11	17	17	14	13	16	19	20	25	26
Sig wav hgt	0.6	0.6	0.5	0.3	0.5	0.7	0.8	0.6	0.7	0.9	1.0	1.1	1.2
Max wav hgt	1.0	0.9	0.7	0.5	0.8	1.2	1.3	1.0	1.2	1.5	1.6	1.7	2.0
Sig wav prd	4	4	4	4	4	4	4	4	4	4	4	4	4
Swell dirn	WSW	SWS	W	W	W	W	W	W	W	WSW	WSW	WSW	WSW
Swell hgt	0.6	0.5	0.4	0.3	0.2	0.3	0.4	0.3	0.2	0.3	0.3	0.1	0.1
Swell prd	4	4	4	5	7	6	6	6	7	7	6	7	7

			Sat 4 August 2007				Sun 5 August 2007				Mon 6 August 2007			
	15	18	00	06	12	18	00	06	12	18	00	06	12	18
Wind dir	SSW	SSW	SSW	SSW	SSW	SSW	SW	WNW	NNE	NNE	N	NNW	NNW	WNW
10 m Wnd spd	15	15	16	17	15	14	9	2	1	2	4	4	6	7
10 m gus	22	21	22	23	21	19	13	3	1	3	5	5	8	10
50 m wnd spd	20	20	23	24	22	20	13	3	1	3	5	5	8	10
50 m gust	28	27	32	34	30	28	18	4	1	5	8	7	12	15
Sig wav hgt	1.3	1.3	1.8	1.9	1.7	1.5	1.3	0.9	0.6	0.5	0.4	0.5	0.5	0.6
Max wav hgt	2.1	2.1	2.9	3.0	2.7	2.5	2.1	1.4	0.9	0.8	0.7	0.7	0.8	0.9
Sig wav prd	5	5	5	5	5	5	4	4	5	5	5	4	4	4
Swell dirn	WSW	WSW	WSW	WSW	WSW	WSW	WSW	WSW	WSW	SW	SW	SW	SW	W
Swell hgt	0.1	0.2	0.2	0.2	0.4	0.3	0.9	0.8	0.6	0.4	0.4	0.4	0.4	0.2
Swell prd	8	8	8	8	9	8	6	5	5	5	6	7	6	8

The levels at which forecasts can be deemed representative for a given site or operation, and the support available (eg through use of a specialist forecaster) are highly variable, usually on a cost basis. It is recommended that services are obtained on the basis of consultation that assess service cost and support against the risk to operations associated with receiving a poor forecast.

As guidance the Offshore Weather Panel TD-850 *Handbook of offshore forecasting services* (WMO, 1997) gives details of services and good practice for specialists offering marine forecasts to the offshore oil and gas industry.

Observations made on-site can also potentially be integrated with forecasts to further improve risk management, with short-term (few hours ahead) nowcasts and verification of forecast performance used as a basis for decision making.

Forecast formats generally fall into one of four categories:

1 General text forecasts and warnings for a designated area.

2 Map-based formats.

3 Site specific graphical/tabular product (eg time-series plots).

4 Operation specific product (eg wave spectra for heavy lift).

Formats and products are also discussed in more detail in WMO/TD-850 (1997).

The actual format in which data is given depends on both provider, and the ability for the data to be received and disseminated by a shore and/or site based controller. The ability to receive forecast data offshore is often a limiting factor, and for a project involving a high number of extremely weather sensitive and expensive operations, methods for receiving the widest product suite (eg through the internet) should be investigated.

One of the important benefits of employing an on-site forecaster or marine operations expert is their experience in dealing with complex forecast data. These personnel fulfil an interpretive role, providing explicit information to key decision makers (eg site co-ordinator, vessel masters) in instances when changing or marginal metocean conditions may affect operations over the short-term.

3.5 Climate variability

With commercial scale projects securing lease periods of between 25 and 50 years, and in exploiting what are fluctuating resources, marine renewable projects need to be aware of timescales and effects of climate change. This requirement will be most important for sites where re-powering may be considered, extending the lifetime of the site.

The scales upon which climate will vary and impact on a marine renewables project are:

- seasonal – fluctuations in performance and accessibility due to storm frequency
- annual – sustained periods of storm and calm affecting site performance, and operations and maintenance (O&M) access on a year-on-year basis
- decadal – general variation in storm tracks impacting frequency of high energy or difficult access periods. These variations are known to occur in decadal cycles as, for example, represented by indices such as the North Atlantic Oscillation (NAO)
- multi-decadal – scenarios associated with broadscale climate change, for example net sea level rise.

An indication of present trends and cycles in climate variability at a site on a seasonal and annual basis can be assessed based on past data (for example year-on-year variability of storms and calms). It is important that the site selection process recognises these variations as much as a headline long-term mean resource figure, since highly variable climates may be detrimental to both power conversion and operations (eg site access), and such sites could be more sensitive to longer-term climate change.

Understanding broadscale processes and impacts relating to climate change scenarios in the future is the subject of significant research, and has led to an improved appreciation of future risk in aspects that affect engineering design. For example, estimates of change in temperature and mean sea level rise are predicted with high confidence, and may affect structural lifetime and description of splash zone areas.

However, at a site-specific scale, and in terms of complex metocean processes (eg wind, waves, tide and storm surge at the coasts), quantitative predictions of future change and impacts have not yet been realised. This is since for most climate prediction models future scenarios are subject to significant levels of uncertainty, and in any instance such models need to be run at a coarse scale in order to be practicable. The science is evolving rapidly however, and the advice is to check with expert providers as to the level of practically useful information available. For example, while quantitative data on future wave regime may not be readily available, an approach that might be adopted with useful qualitative outcomes is to understand how regional climate variability (ie statistics of storms and calms on seasonal and annual timescales) may impact sites in a given area under future climate scenarios.

Climate change scenarios for the United Kingdom: the UKCIP02 scientific report (Hulme *et al*, 2002) gives helpful information and a review of state-of-the-art climate science for the UK <http://www.ukcip.org.uk/>.

3.6 Data management

Metocean data will be one of many data types in use during a project.

It is good practice to develop a data management plan for a project to identify what investment needs to be made in obtaining all data, requirements for quality checking all inputs, what use such data will have to support the project, what further analysis and understanding will need to be developed from the data and any onward intent to offer data collected by the project to a public domain DAC. The data management plan should include the use of a project database to catalogue the data and associated metadata with the intention to maintain this data and knowledge base throughout a project life cycle.

The Marine Data and Information Partnership (MDIP) has a priority interest to provide guidance on standards and protocols for data management, and to build adherence to common standards across the UK. At present the following standards remain under development:

- acquisition and quality control of data
- data management standards and best practice
- standards for interoperability and metadata.

The Crown Estate lease arrangements for Round 2 wind farms oblige each developer to submit their data holdings at key stages during their project (The Crown Estate, 2003). In the tender documentation Clause 5.1 stated that:

> *It is The Crown Estate's intention to improve the availability and dissemination of marine data and information collected during all stages of windfarm development including site assessment and selection, development, construction, operation and decommissioning, subject to agreed constraints of commercial confidentiality. The Tenderer is obliged to make available to The Crown Estate, all Data as a result of investigations and monitoring linked to the development as set out in the Lease Documentation. Data submission will be required from site investigation to decommissioning.*

A definition for data is also provided in the lease, which states the following:

> *"Data" means primary data observations and metadata gathered and stored by or on behalf of the Tenant in relation to meteorological (including, without limitation, wind resource), geotechnical, geophysical, bathymetric, oceanographic, sedimentological, environmental, cultural and heritage investigations modelling and monitoring on the Site the Designated Area or surrounding areas.*

It is fully anticipated that a similar requirement will be extended to wave and tidal developers in due course.

The Crown Estate utilises the interest from Round 1 deposits, and also uses the option fees for the Round 2 sites to fund research under the Collaborative Offshore Wind Research into Environment (COWRIE) forum. Within COWRIE the Data Management Technical Working Group (DMTWG) is responsible for establishing a data and information management plan (DIMP) and data and information stewardship plan (DISP) to assist developers in meeting their lease responsibilities (Hill and Sadler, 2005, 2006).

COWRIE envisage data to consist of:

- raw data
- processed data
- visualisation of the data
- data reports
- environmental impact assessment (EIA), statements, technical and non-technical summaries
- future operational and monitoring data.

Further information on the work of COWRIE and details of the DIMP are available from <http://www.offshorewind.co.uk>, and information on data management issues available from <http://data.offshorewind.co.uk/>. Access to the environmental data presently available through COWRIE is by user registration from <http://data.offshorewind.co.uk/catalogue/>.

4 Project life cycle

4.1 TECHNICAL ELEMENTS

The structure of these guidelines describes a chronological flow of metocean issues through the life cycle of a marine renewables development according to three primary elements of the process:

1. Financial – commercial measures to determine the whole project costs and the viability of the site to deliver adequate energy resource to meet financial returns.
2. Engineering – design and engineering measures to ensure safe and successful construction and operational phases that deliver optimal outputs.
3. Environment – environmental measures to characterise the site and minimise potential impacts, leading to consent.

While presented and discussed separately, all three elements are interrelated and should be considered as having an important influence on each other. Invariably these issues will require a specialist to be involved in co-ordinating the specific information requirements of each element.

4.2 PHASE OF DEVELOPMENT

The life cycle of a marine renewable project can be generalised into a sequence of six development phases:

1. Pre-lease.
2. Pre-consent.
3. Pre-construction.
4. Construction.
5. Post-construction.
6. Decommissioning.

The duration of each phase may well be a project specific issue, but in general a project will incur cost throughout its life cycle and will only be in a position to generate revenue during the post-construction phase when the development is operational; the longest phase of the project can be expected at this point. A developer will want to secure a lease which provides development rights on the seabed for periods typically in the range 25 to 50 years to maximise the potential revenue opportunity. Within this period, projects may also consider the opportunity to re-power to take advantage of technological developments.

A conceptual development path for metocean data through an idealised marine renewables project is shown in Figure 4.1. The flow chart adopts the six phases through project development and arranges activities under financial, engineering and environmental themes in a project at the point where they may be run by different specialists. Green shaded tasks relate to environmental elements, grey relates to engineering activities and blue for financial interests. Some items may have dual roles and these are shaded accordingly. The linkage between tasks identifies the typical pathway for metocean data through the project life cycle.

Figure 4.1 also includes an indication of a project timeline along the development path for each phase, noting that different types and sizes of development will take different amounts of time. Furthermore, significant lags may occur in the timeline at points when lease award and consents are awaited.

It is stressed that adequate consideration to the marine environment and metocean related issues is fundamental to the success of each phase, along with effective and continued management of the information and knowledge base being developed throughout the project.

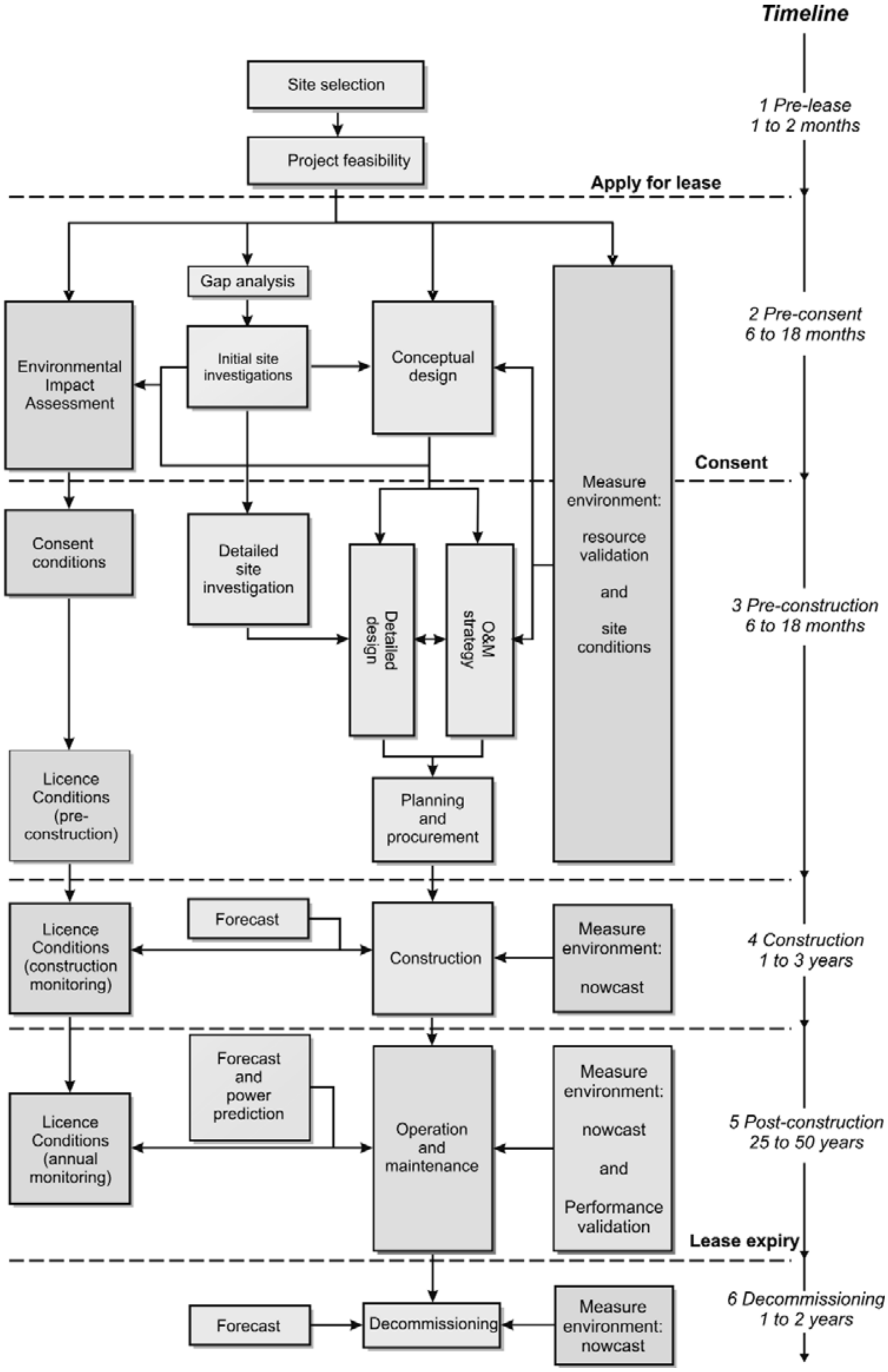


Figure 4.1 ***Schematic of work programme and knowledge transfer through the life cycle of an idealised marine renewables project***

4.3 PROJECT RISKS

The subject of risk management is relevant to any offshore development and careful consideration of a multitude of issues beyond those related to metocean conditions is needed. However, metocean issues present significant challenges to marine renewable projects that, if underestimated, may lead to increased project risk.

The areas of risk where metocean issues are relevant extend to health and safety, engineering, financial and environmental.

For health and safety, all on-site operations should be carefully planned and documented using risk assessment practices. These should include vessel audits and toolbox talks prior to mobilisation.

Risk of failure in design under metocean loads may be catastrophic for a project. Certification of engineering represents good practice and should help secure better terms for insurance cover.

Weather risk is a major factor in all offshore operations. Knowledge of the site and its approaches through thorough appraisal of downtime and weather limits on vessels and associated planned O&M should be undertaken to minimise costs (Section 7.4.3).

When any such decision is being based on metocean data it is necessary to consider the accuracy and limitations remaining with the data along with any analysis which has been performed on that data. For example, while historical data and hind-cast modelling may be of sufficient quality to support site selection, its further use for consent purposes or design, construction and operation and maintenance phases could add an unacceptable financial risk to the project.

Construction activities should be completed in a safe and environmentally sensitive manner, so the over-arching requirements for metocean data are driven by health and safety guidelines. Risk assessment is a key activity in the management of health and safety, and it is a legal requirement for every employer under the Management of Health and Safety at Work Regulations 1999 as well as a requirement of the Construction (Design & Management) Regulations 2007. Emergency arrangements should also be in place, and procedures should be established based on suitable and sufficient risk assessments.

Project risks can be mitigated and managed by following good practice. Risk mitigation measures include:

- scheduling of critical construction in the summer months
- maximising use of onshore construction so that offshore construction activity is minimised
- construction planning methodology that builds in flexibility allowing for appropriate activities to take place according to the conditions and vessel capabilities, and to maximise the efficient use of specialist and expensive construction vessels and equipment
- accurate forecasting to direct activities appropriate to the conditions.

The most obvious mitigation of metocean risk is to schedule as many critical construction activities as possible during the summer months. This will usually fall between April and October in UK waters, but there are likely to be refinements within this window according to the site location. It is important that all weather factors are considered, including likelihood of number of days when visibility is reduced due to fog.

Key references related to risk management are:

- ⇨ *Marine risk assessment* (DNV, 2001)
- ⇨ *Risk management in marine and subsea operations* (DNV, 2003).

5 Pre-lease issues

5.1 OVERVIEW

In the context of the present guidelines pre-lease issues cover the initial stage in project development which includes:

- site selection
- project feasibility.

It is anticipated that a period of between one and two months would be required to conduct initial analysis of metocean data to support these activities and enable the project to be sufficiently informed to apply for a lease (Figure 5.1). It is recommended that any information collated from this stage of project development should be managed using a data management plan (see Section 3.2). This should be available to feed into subsequent stages of development, especially in the pre-consent stage to contribute to EIA, gap analysis, conceptual design and resource validation exercises.

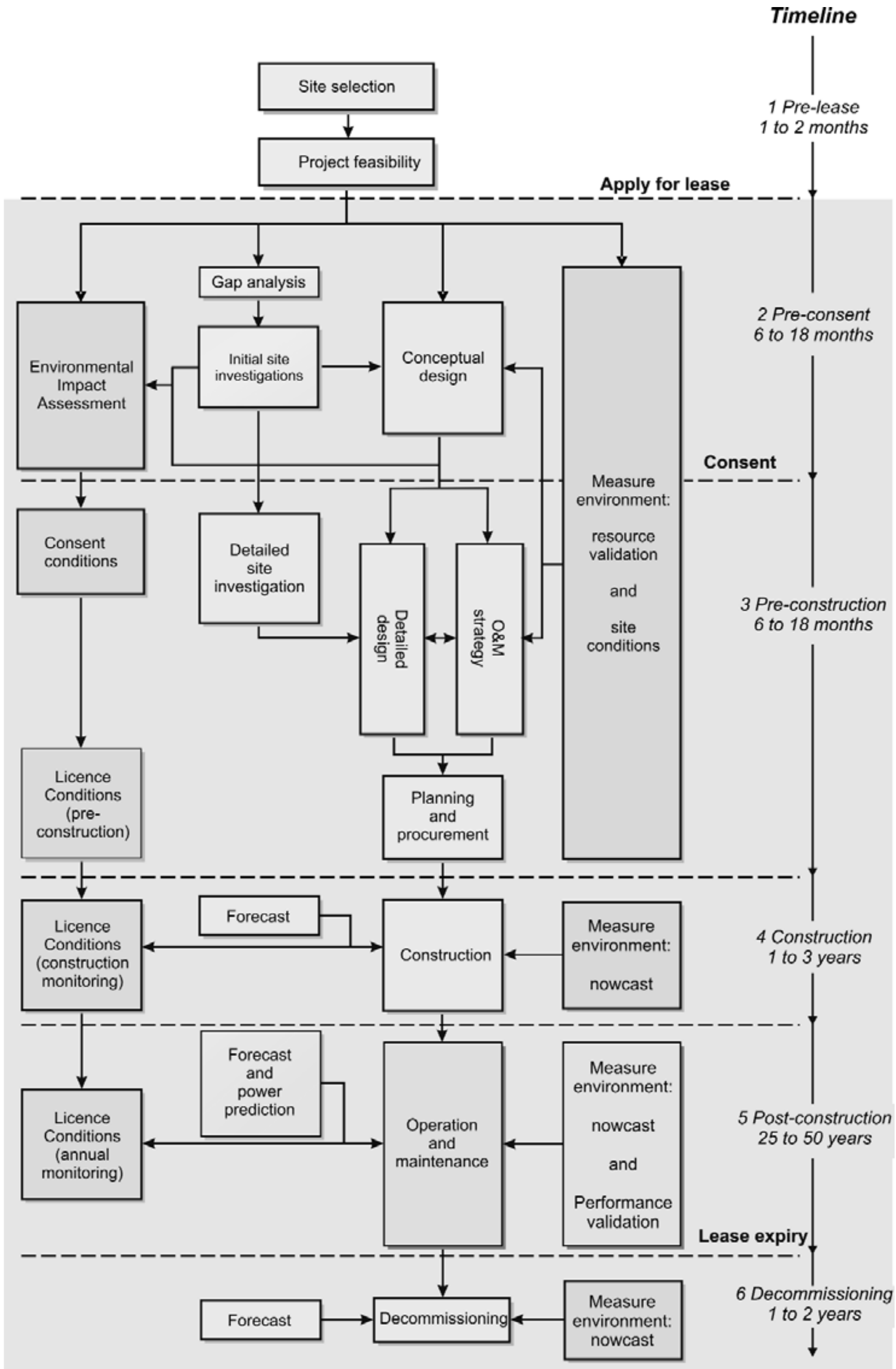


Figure 5.1 ***Pre-lease activities and linkages***

The Crown Estate owns virtually the entire seabed out to the 12 nautical mile (nm) territorial limit, including the rights to explore and utilise the natural resources of the UK Continental Shelf (excluding oil, gas and coal). More recently the Energy Act 2004 vested rights to The Crown Estate to licence the generation of renewable energy on the continental shelf within a renewable energy zone (REZ) which extends out to 200 nm, the extent of the UK Continental Shelf. However, The Crown Estate does not own the rights to exploit resources in the water column. In most cases marine renewable developments in UK waters will require a lease from The Crown Estate to install structures on the seabed, including cables.

The first milestone for a project is to secure an agreement for lease with exclusive development rights from the respective owner of the seabed. So the initial stage in the project life cycle relates to pre-lease issues that are largely based on desk-based reviews to determine options for favourable sites for development that can then be screened to determine outline project feasibility.

At this initial stage of project development it is anticipated that a relatively low-cost exercise, lasting about one to two months, is adequate to develop sufficient detail to support an application to the owner of the seabed.

Decisions on awarding a lease will involve a number of criteria, including technical and financial considerations, and a regard as to whether the development presents the most sustainable use of the seabed. For cases where multiple interests are targeting a single area then the decision to provide a lease may extend to the amount of installed capacity per unit area to ensure the best use of the seabed for power output.

5.2 SITE SELECTION

The first activity for any marine renewable energy project is the initial site selection. A developer may consider one or more sites at this stage, with the prospect of identifying a preferred site based on project feasibility.

For full-scale commercial developments this activity is normally prompted by the completion of a strategic environmental assessment (SEA). This has been the case for Round 2 offshore wind farm projects and it is anticipated to be the case again ahead of any further commercial round which invites interest in marine renewable development. The responsibility of developing a SEA presently rests with DTI. Note that the present phase of wave and tidal demonstration scale projects are not the subject of SEA (DTI, 2005).

The process of site selection is essentially desk-based and will draw from existing published data and reports to establish criteria for potential resource and constraints on development. Subsequent phases are likely to need refinement of this base information and move to site investigation, but at the site selection stage these more detailed activities are likely to be prohibitive in time and cost.

The primary criterion in site selection is a minimum level of potential resource most suited to the specific device characteristics. Inherently, this will be based on metocean data archives of wind, wave or tidal stream that are of sufficient duration to characterise the synoptic variation in resource over the long-term.

High-level screening using data providing broadscale synoptic coverage is helpful for comparative assessment, but by itself may not reveal sufficient detail of seasonal and inter-annual variations. A primary tool designed to assist the site selection process is the *Atlas of UK marine renewable energy resources* (DTI, 2004), and the accompanying freeview

GIS. Figure 5.2 illustrates some of the primary resource maps for tidal stream, wave and offshore wind available from the atlas.

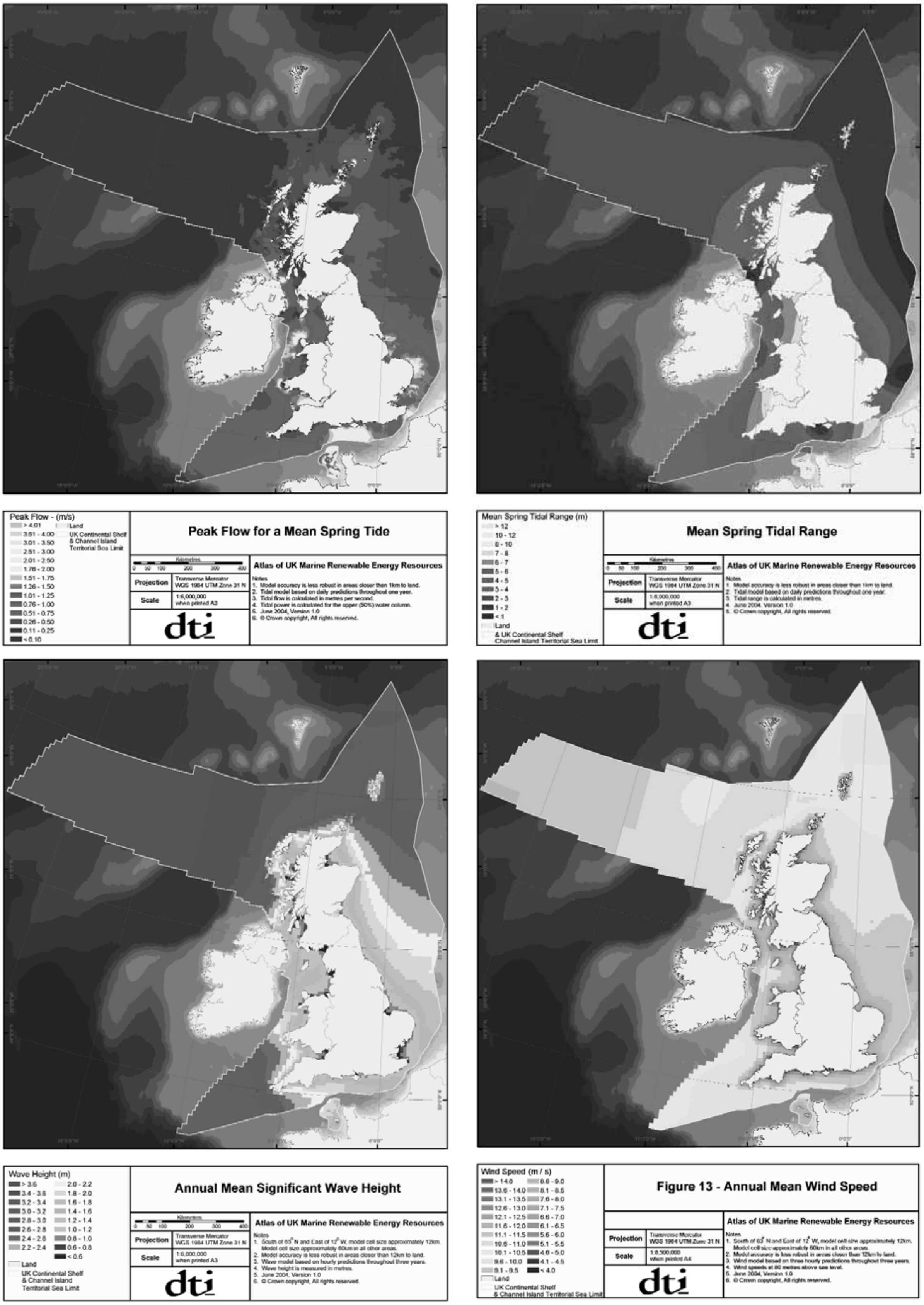


Figure 5.2 *Example resource maps from the Atlas of UK marine renewable energy resources. Top left: Peak mean spring flow. Top right: Mean spring tide range. Bottom left: Annual mean wave height. Bottom right: Annual mean wind speed (courtesy DTI)*

Existing field measurements may provide improved levels of detail in temporal patterns, but data coverage may be sparse, highly site-specific and difficult or costly to obtain. It is also likely that the majority of existing metocean measurements will have fulfilled a specific data requirement that is separate to any marine renewable interest. For example, offshore wind measurements from MAWS may be relatively close to the sea surface and will not provide a direct indicator of wind speeds at hub heights. It is prudent to understand any such limitations if used to validate the broadscale data.

The combination of broadscale and site-specific measurements should provide for a more robust examination of the potential resource. Table 5.1 summarises examples of broadscale metocean data and Table 5.2 site-specific metocean measurements, along with suggested sources for such information.

Table 5.1 ***Broadscale metocean data to inform site selection***

Broadscale metocean data	Suggested source
Potential resource	Atlas of UK marine renewable energy resource1
Water depth	Admiralty Chart/DTI Atlas
Tide level	Admiralty Tide Tables/DTI Atlas/OTH 89 293
Tidal flows	Admiralty Chart/DTI Atlas/OTH 89 293
Waves	DTI Atlas/HSE RR392/OTH 89 303
Offshore wind	DTI Atlas

Notes: The *Atlas of UK marine renewable energy resource* (DTI, 2004) provides a range of primary maps for wind, wave, tidal elevation and tidal stream to identify potential resource areas across the UK Continental Shelf. The Atlas is designed to assist DTI in strategic planning decisions related to further rounds of marine renewable development. Study reports and GIS based data are available from <http://www.offshore-sea.org.uk>.

Table 5.2 ***Sources of metocean measurements***

Metocean measurement	Suggested source
Tide level	UK National Tide Gauge Network
Tidal flows	UK Inventory of Moored Current Meter Data
Waves	UK Wave Data Catalogue
Offshore wind	Marine Automatic Weather Station Network

Other useful references for site selection include:

- *UK tidal stream energy resource assessment* (Black & Veatch, 2005)
- *Tidal stream resource and technology summary* (Black & Veatch, 2005)
- *Variability of UK marine resources – an assessment of the variability of the UK's wave and tidal power and their implications for large-scale development scenarios* (Environmental Change Institute, 2005)
- *Quantification of exploitable tidal energy resources in UK waters* (ABPmer, 2007).

It is good practice to record the combination of metocean data and reports assembled to support site selection and document these details in the form of a metocean database. It would be the intention to maintain this data and knowledge base throughout a project life cycle. This information can then be used to answer some typical questions relevant to the site selection phase:

1 Which areas provide for the minimum level of resource?
   a With required depths for deployment.
   b Within reach of a grid connection.
2 What is the temporal variation in resource at the site?
   a To estimate the power outputs.
   b To evaluate the accessibility.
3 What is the accuracy/reliability of the data?
   a To specify further validation, as required.

The outcome of the site selection process needs to carry through known limitations in any metocean data considered at this point, and any assumptions made in applying such data, so that these issues can be addressed in subsequent stages of the project (eg resource validation).

5.3 PROJECT FEASIBILITY

From site selection, refinement towards identifying a preferred site (or multiple sites) can be made according to further constraint-based evaluations with consideration of logistic, economic and environment based criteria to judge the commercial feasibility of project development.

Further consideration of metocean issues at this point should include a high level review of site accessibility during both construction and post-construction periods, and to assist in the development of an outline O&M strategy. A site which appears to offer good resource potential may prove to be inaccessible for long periods of time which will ultimately render it unsuitable for commercial development. Similarly a site which experiences extreme peaks in metocean conditions may also be unsuitable, since the costs of engineering to meet these conditions and the low predictability of power generation may make the project uneconomic.

Site-specific metocean data is unlikely to be collected at this stage since the cost of collecting such data at a number of potential sites would not be justified and would be considered a high-risk investment at this early point in project development.

Ideally, the site selection process will also wish to understand impacts of climatic change occurring over the lifetime of the project (see Section 3.5). Climate variability at a site may also be assessed based on past data (for example year-on-year variability of storms and calms). It is important that the site selection process recognises these variations as much as a headline long-term mean resource figure, as highly variable climates may be detrimental to both power conversion and operations.

Sites deemed suitable from the project feasibility stage and awarded a lease agreement can be progressed through to consent application, noting carefully the limitation of any metocean data and rigour of analysis used to develop the project to this point.

6 Pre-consent issues

6.1 OVERVIEW

Projects that achieve a lease agreement can progress to the next milestone of gaining consent. At this stage of project development the improved viability in taking the project forward unlocks further investment to conduct more detailed studies.

Data collated from the pre-lease stage of project development will provide an immediate input to various pre-consent activities (Figure 6.1) which are likely to include:

- gap analysis
- initial site investigations
- environmental impact assessment
- conceptual design
- resource validation.

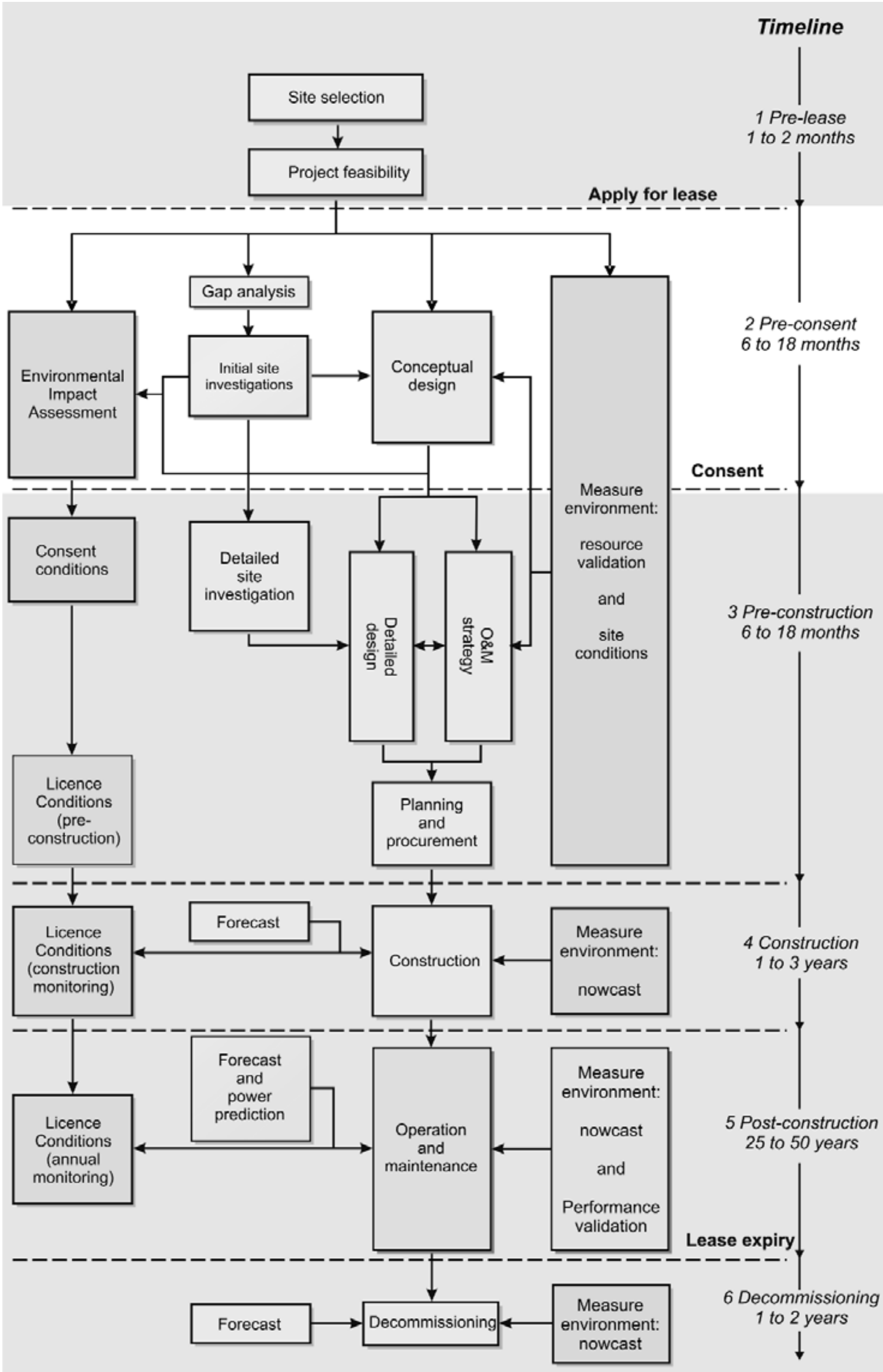


Figure 6.1 ***Pre-consent activities and linkages***

These more detailed activities inherently represent a greater cost and are likely to require a substantial investment in further data which exceeds the requirements in the pre-lease stage. In addition, the nature of such tasks may also require specialist input. As an outline estimate, the timescale required to undertake pre-consent metocean activities may be between 6 and 18 months, and be linked to completing any initial site investigations targeted on securing sufficient knowledge of seasonal variability in key parameters, such as winds and waves. Other environmental studies, such as those required for birds, may take up to two years. Overall the timescale for completing an EIA and achieving consent is likely to exceed a period of two years.

6.2 GAP ANALYSIS

It is most likely that only a limited amount of metocean data will be available to the project at the start of the pre-consent activities and will have been assembled to meet the immediate requirements of site selection and project feasibility activities. This information needs to be managed and maintained in the form of a project database, initiated during the pre-lease stage (see Section 5.1).

A gap analysis is required to understand the continued sufficiency of using this data to support subsequent stages of the project life cycle, especially EIA, conceptual design and resource validation, but also other activities such as development of an O&M strategy. It is recommended as good practice to involve all specialists in the process of gap analysis to enable a better understanding of respective data requirements, and to identify and plan for opportunities of data and information exchange between such specialists.

Note that the EIA scoping phase and consultation process may raise a number of environmental issues which require further data. Where risk profiling has identified a significant issue associated with a dataset, a gap analysis will determine what is needed to mitigate or remove that risk.

The gap analysis process will seek to confirm the overall information requirements for the project life cycle, confirm on sufficiency of present data holdings and identify what further data might be required to fill any gaps. The gap analysis will also need to consider issues such as:

- data quality (accuracy and error)
- data quantity (coverage/resolution across a development site and in duration/frequency).

From the gap analysis, specifications for additional data acquisition will be established to meet the requirements of further project activities. Such data acquisition may be in the form of additional data purchase (where data is available) or site investigations (to collect new data).

6.3 INITIAL SITE INVESTIGATIONS

Both EIA and engineering design require robust metocean data to underpin their respective activities. These activities are phases of work that are closely linked, are likely to overlap in programme and at times may require iteration (eg a design modification is required to mitigate a significant environmental impact). In the context of metocean issues, the design process will typically consider how the scheme needs to be engineered to withstand severe conditions (extreme events with a low probability of occurrence), whereas the EIA aims to assess how typical metocean conditions may be affected by the development during its deployment period (construction, operation and decommissioning stages). Site investigations will be required if there is insufficient data available to support either activity, as determined from gap analysis.

Initial site investigations may include a range of field investigations among which is a specific metocean survey. The scope of the metocean survey needs to consider all further project requirements reliant on good metocean data. The survey also requires a stated objective to determine fulfilment of these further data requirements. Although not practical in every case, the opportunity to combine initial and detailed site investigations (see Section 7.3) may give a net benefit to a project and optimise the data collection effort in both time and cost. The main issues that might inhibit such a combined site investigation strategy at the pre-consent stage are the greater investment and timescale which might be required to conduct a more comprehensive survey, and the risk that not all of the data requirements are known at this point.

The specification of the metocean survey should be validated between the EIA contractor, design team and developer, and in certain cases it may also be beneficial to offer the scope to the regulatory bodies to gain their endorsement, especially where this may respond to stakeholder concerns. The survey specification needs to consider issues such as what, where, when, how long:

- suite of metocean parameters required to enable selection of appropriate measurement device(s)
- number of deployment locations considered against the proportional scale of the development and the amount of variation in seabed characteristics anticipated across the general area which may influence metocean behaviour
- siting of equipment with avoidance of areas which may compromise good data returns (eg shallow areas prone to wave breaking, high use areas where equipment may present an obstruction)
- duration of deployment verses longevity of equipment in data storage/battery life to plan for service intervals
- timing of survey with consideration to any need to capture storm events
- water depths and seabed characteristics to decide on mooring arrangements
- frequency between measurement intervals to ensure sufficient temporal resolution of variations in key metocean parameters versus longevity of equipment in data storage/battery life to plan for service intervals
- vessel selection for safe operations, and vessel audit
- notifications to mariners to avoid conflicts with other users in the area
- post-processing, quality checking and reporting requirements

The EIA process may identify the need for further metocean parameters and use the process of initial site investigations to capture sufficient data to describe a representative baseline condition, and one which might be considered sufficient from a relatively short-term deployment period of one month or more. In comparison, detailed design and O&M planning may need a longer period of data spanning periods of one year or more. A recommendation of good practice would be to consider combining these requirements within a single survey campaign.

The specification of metocean surveys will be finalised according to logistical and budgetary considerations, along with an evaluation of risks to minimise data loss. The ICES Working Group on Marine Data Management (WGMDM) has developed various guidelines (available from <http://www.ices.dk>) to assist those involved in the collection, processing, quality control and exchange of various types of (mainly) physical oceanographic data, including:

⇨ WGMDM *Guidelines for water level data* (ICES, 2000)

⇨ WGMDM *Guidelines for moored current meter data* (ICES, 2000)

⇨ WGMDM *Guidelines for moored ADCP data* (ICES, 2006).

Other guidance includes:

- HS&E *Guidelines for metocean surveys* (OGP, 2003)
- *Manual on sea level measurements and interpretation* (UNESCO, 1985).

Metocean surveys can be a relatively expensive exercise involving costly instruments that are left unattended at sea for long periods. This places a high value on the data returns. The risk of data loss is very real and can be due to a combination of factors (eg failure in equipment or moorings, accidental or malicious interference, poor weather delaying service intervals), and may not be discovered until attempts are made to recover the equipment possibly several months after deployment. Good survey planning and selection of a competent survey contractor can assist in mitigating these risks. In addition, the option for telemetry of data to a shore station provides an immediate indication of data loss which can then be attended to and minimise the period of potential loss. Adjacent platforms, such as a met mast, may provide opportunities for using existing telemetry links and improve security of deployments.

The output of the metocean survey needs to include a comprehensive document and data report to summarise the activity, including statements related to:

- equipment selection, calibration certificates and configuration
- mooring arrangement
- mobilisation, deployment, service schedules and de-mobilisation activities
- local observations, down-time events affecting access to site
- data return summary, quality checking, processing and presentation
- health and safety.

Note that this volume of information is a key deliverable which responds to The Crown Estate lease requirements relating to data.

Alongside completion of a metocean survey, site investigations, in general, need to make adequate consideration to any vessel selection, as the threshold limits for safe operations will vary from vessel to vessel. A thorough selection process will not only mitigate safety issues but will also reduce weather risks on downtime.

Those vessels conducting non-intrusive site investigation work, such as seismic and other towed array or ROV deployed techniques, are generally free-floating and are less sensitive to extreme metocean conditions than vessels conducting intrusive site investigation work, such as geotechnical sampling. However, seismic surveys, particularly hi-resolution surveys can themselves be highly weather dependant due to both swell noise and its adverse effect on cable control. Vessels conducting intrusive site investigation work will normally be operating in dynamic positioning, anchored or jacked up modes. Table 6.1 summarise typical operating limits for survey vessels, noting that these limits will vary depending on vessel size, power and displacement, and are intended as a guide only.

Table 6.1 ***Typical metocean operating limits for site investigation vessels***

Site investigation	Vessel type	Typical operating limits	
Non-intrusive eg seismic survey	Conventional powered mono-hull or multi-hull displacement vessel	10 m wind	20–30 knots
		H_s	2.5 m
		Current	2 knots (dependant on operation and proximity to navigation hazards)
Intrusive site investigation eg geotechnical	Dynamically operated mono-hull	10 m wind	20 knots beam, 50 knots, head to
		H_s	2.5 m
		Current	1.5 knots beam, 3 knots head to
	Anchored barge, anchored	10 m wind	30 knots
		H_s	2.0 m
		Current	3.0 knots
	Anchored barge, anchoring or towing	10 m wind	25 knots
		H_s	2.0 m
		Current	1.5 knots
	Jack-up barge, jacking or towing	10 m wind	20 knots
		H_s	1.5 m
		Current	1.5 knots
	Jack-up barge, jacked up (survival)	10 m wind	70 knots
		H_s	3.7 m
		Current	higher risk of scour

Equipment deployed on survey vessels will also be subject to operational limits for use, particularly when being deployed from floating vessels and barges. Examples include:

- heave compensated drilling from floating barges DP vessels, where the operations are constrained by the limits of the heave compensation, typically H_s of 3.0 m
- cone penetration test rigs deployed from floating vessels or barges are typically subject to maximum working limits of H_s at around 2.5 m.

It remains prudent to make use of opportunities to capture metocean data during any period of site investigation. Comparisons of forecast and actual conditions from any vessels on site will assist in validation of forecast accuracy, determining site exposure threshold conditions for future installation and O&M work, as well as recommendations for vessel specifications and site access equipment. The incremental cost of additional measurements taken may be considered appropriate against the cost of further investigations at a later stage of the project.

6.4 ENVIRONMENTAL IMPACT ASSESSMENT

The EIA process is initiated with project scoping and stakeholder consultation. The combination of generic guidance for consenting and stakeholder views determines the full range of issues for consideration which in turn assists finalising the overall data requirements for EIA. These data requirements provide a direct feed into gap analysis (see Section 6.2).

Present guidance for offshore wind (MCEU, 2004) assumes that the characterisation of potential impacts needs to include for site-specific assessment of:

- high frequency low energy events (eg normal tidal conditions)
- low frequency high energy events (eg storm conditions).

It is assumed that this guidance will remain applicable for both wave and tidal stream projects, and the metocean data available to the EIA will need to include for both types of events. The initial task is to determine if suitable information already exists from accessible data sources as part of the gap analysis (see Section 3.3). If such data is to be obtained from a metocean survey then the phasing of the EIA will need to be considerate to the completion of this activity, along with the timing and duration of any surveys required to capture suitable data describing such high and low energy events.

EMEC has provided their own EIA guidance for developers wishing to deploy wave or tidal devices at their test sites (EMEC, 2004). This document has broader application than just for EMEC and helpfully outlines current key issues of interest to statutory bodies.

⇨ *Environmental impact assessment (EIA) guidance for developers at the European Marine Energy Centre* (EMEC, 2005) <http://www.emec.org.uk/>.

The purpose of the EIA is to investigate the scale of potential changes to the baseline environment resulting from the planned development (eg placement of structures in the marine environment) and to determine if these changes might lead to significant impacts on sensitive receptors which may be of concern to regulatory bodies. At the present time there is an expanding evidence base on the impacts arising from offshore wind projects but very little information available relating to WEC and TEC devices. To address this knowledge gap and to provide an improved understanding of the likely issues The Crown Estate and Countryside Council for Wales (CCW) funded the following study (available from <http://www.ccw.gov.uk>):

⇨ *The potential nature conservation impacts of wave and tidal energy extraction by marine renewable developments* (ABPmer, 2006).

The EIA process is reported in an environmental statement (ES), which is the primary technical reference that accompanies the application process to gain consent(s). The EIA process generally includes descriptions of the physical, biological and built environment. The physical environment is commonly investigated as a coastal process study to determine changes in physical processes (eg waves, tides and sediment transport). It will make use of appropriate numerical modelling tools that extend the use of metocean data enabling predictions over wider areas and for a broader set of events. Cooper and Beiboer (2002) give a useful review of applicable coastal process models in common use.

Process models also offer convenient methods of downscaling that attempt to explicitly represent physical processes on the scale of high-resolution bathymetry not fully represented from the coarser-scale information that might be used as boundary conditions. For example, wave transformation models offer a useful method to downscale available wave data that is typically located further offshore and in deeper water (eg long-term data from the European Wave Model). They are also effective where a nearshore equivalent is required, particularly if the area of interest is subject to shallow water influences, such as sandbanks, and features and processes not included in the original larger-scale model (see example in Box 6.1).

Box 6.1 *Case study: Example of downscaling using wave transformation modelling*

Requirement:	To develop a description of shallow water inshore wave conditions across a development site.
Available data:	Deep water wave predictions exist in the UK Waters Wave Model which provides a coarse scale (12 km), and is generally only suitable further offshore. This scale of offshore wave data is illustrated as the larger box in Figure 6.2.
Downscaling method:	The deep water wave data is used as a boundary condition to drive a wave transformation model which is equipped with higher resolution bathymetry, and accounts for shallow water processes of refraction, shoaling and wave breaking.
Fit-for-purpose:	The performance of the model is compared with wave data measured in the nearshore. Nearshore results (measured and modelled) demonstrate a close agreement and both illustrate a small reduction in wave heights from offshore due to frictional energy losses due to shallow interactions.

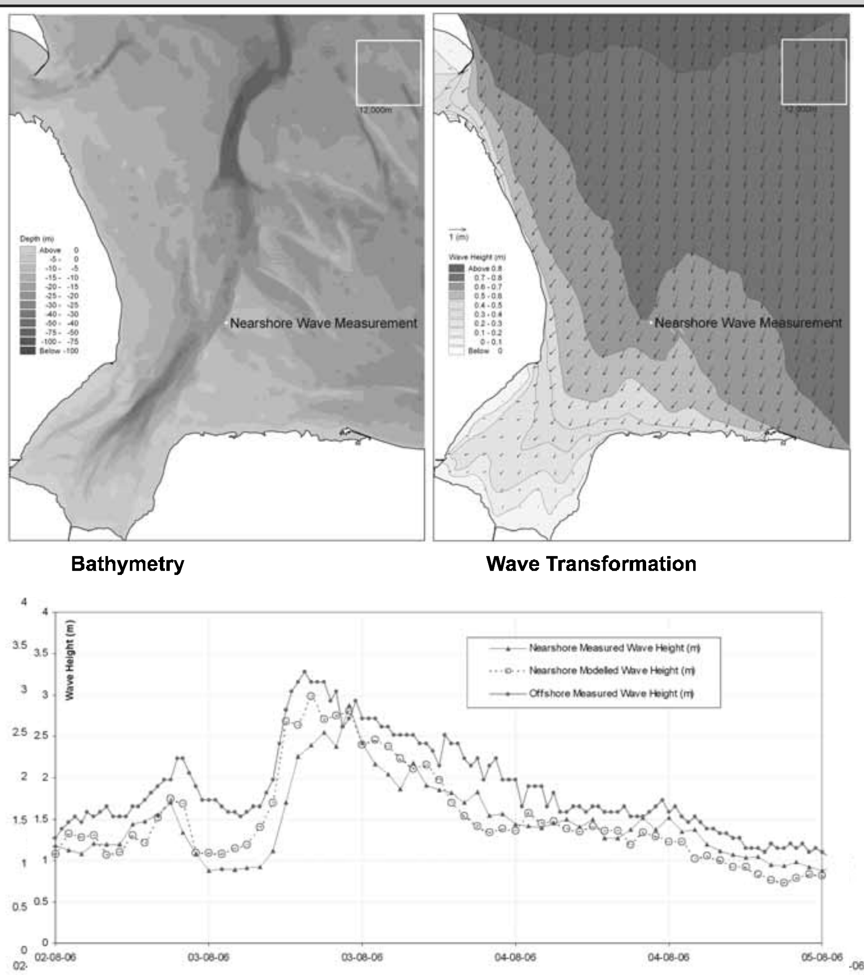


Figure 6.2 *Downscaling results from wave transformation modelling*

It is common for the EIA and coastal process study to be outsourced to a specialist contractor, and consequently a different team may be involved in this exercise to those that have developed the project through to the pre-consent stage. If this is the case, then earlier knowledge gained in metocean issues needs to be offered to the contractor for consistency. The metocean database will assist this knowledge transfer.

As a minimum, the base metocean data and analytical methods used in the EIA process also need to remain consistent with those used in the conceptual design. If the EIA contractor can offer any improved understanding by acquiring additional data or using more refined methods then it is prudent to allow for exchange between the EIA contractor and design engineers if this improves the design, or mitigates any apparent significant environmental impacts.

6.5 CONCEPTUAL DESIGN

The developer's engineering team will wish to understand the offshore conditions (air, sea and seabed) to a sufficient level of detail to develop an outline (conceptual) design for the project. At this stage the design process needs to be supported by a range of metocean parameters that represent the statistically probable extreme conditions that may occur across a time period that is considerably longer than the operational life of the installation. In offshore developments this is typically a 50-year return period extreme event, but since the period of the site lease for most marine renewable developments may be equivalent to this timescale, then a higher return period event may be needed (eg designs that can survive a 100-year event).

Key variables of interest are extreme conditions of:

- winds, including gusts
- water levels, including surge
- currents, including wind induced currents and surges
- waves, wind-sea and swell
- potential wake effects across an array of devices.

For conceptual design, basic design environmental values relevant to UK waters can be estimated from a range of standard texts, including:

⇨ *Environmental considerations* (HSE, 2001)

⇨ *Wave mapping in UK waters* (HSE, 2005).

However, it would also be anticipated that more local information would be developed as part of the EIA process.

With guidance on WEC design provided in:

⇨ *Guidelines on design and operation of wave energy converters* (DNV, 2005)
A guide to assessment and application of engineering standards, and recommended practices for wave energy conversion devices.

For TEC design in:

- no present guidance.

And for offshore wind design in:

⇨ *Design of offshore wind turbine structures* (DNV, 2004)

⇨ *Wind turbines – Part 3: design requirements for offshore wind turbines* (IEC, 2005a).

The outputs from conceptual design will state the broad description of the component parts of the marine renewables development and the means of construction. Good practice is to capture and maintain up-to-date information in the form of a project design statement (PDS). This document is likely to contain a number of design options which remain dependent on further site investigations, detailed design and build contractor inputs. The developer will wish to retain sufficient flexibility in design through the further EIA evaluation and consenting stage of the project, thereafter a process of detailed design will draw out final design statements before taking the project into construction.

6.6 RESOURCE VALIDATION

On the basis of securing development rights for an area of seabed it is recommended that the developer validate the resource potential by investing in further on-site data, especially if the area of interest had not been previously monitored or large uncertainties remain from the data considered at the site selection stage (see Section 5.2).

The scale, location and type of the development will determine the approach to resource validation. Larger projects or those where strong variability is expected across the development site may need to utilise multiple validation sites, whereas it may be adequate for single point validation for smaller sites.

As a guide winds are likely to be more spatially consistent than waves, and waves more spatially consistent than tidal stream.

The duration of the measurement campaign to develop site data for resource validation is also likely to be different for offshore wind, wave and tidal stream projects. As a minimum, the measurement period needs to allow for at least one full cycle in the anticipated variability in the resource parameter. For offshore wind and wave this will equate to a minimum of one annual cycle of measurements to consider seasonal variability, and for tidal stream a lunar cycle to consider spring to neap variations.

Year-on-year variations in wind and waves may be linked to larger scale global climatology (eg North Atlantic Oscillation) and trends (eg effects of climate change), so reliance on only 12 months of measurement is unlikely to be representative of the long-term average (see Boxes 6.2 and 6.3).

In order to mitigate issues arising from perceived discrepancies between initial resource estimates and short-term validation data then measure correlate predict (MCP) analysis can be used to assess further the reliability of the local resource measurement when there is long-term data available from sites near to the proposed development. In its simplest form MCP will be a test of the linear correlation between target data and concurrent reference data, with a 1:1 relationship and zero bias being the ideal measure of a perfect match. For omni-directional data (commonly winds and waves) it can also be helpful to break the data down into discrete directional sectors, as required (eg 30 or 45°). In projects where the MCP techniques are applied to numerical model data and prove robust, the method might also be re-used at later stages to enable a simple downscaling approach to improve the accuracy of broadscale forecasts with respect to the project site.

6.6.1 Offshore wind

The standard resource validation approach for offshore wind projects is to deploy a meteorological mast (met mast), or number of masts, within the development site as early as possible. By convention, the met mast is configured with an array of anemometers at levels through the vertical comparable to the hub height and points along the blade sweep, with telemetry transmitting data to a shore station. A minimum of 12 consecutive months of measurements is required for resource validation.

The mast is also likely to be equipped to monitor a standard suite of met parameters, including atmospheric pressure, temperature, humidity etc. Such an installation represents a major cost to the project, but the value of the validation exercise remains as a fundamental stage in demonstrating the commercial viability of the project and to secure investment in project construction. The met mast may remain on site for several years and through construction to deliver additional data to support design, construction, and O&M strategies and activities. Depending on the location relative to the final wind array, an up-wind met mast may be installed to enable incident wind conditions to be monitored that can assist in performance validation of the installed turbines though the post-construction period.

Standard resource measurements would include 10 minute average wind speed and direction and three second gusts (Figure 3.3). Useful references for wind resource assessment include:

- *Wind resource assessment handbook. Fundamentals for conducting a successful monitoring programme* (AWS Scientific Inc, 1997)
- *Wind turbines Part 12-1: power performance measurements of electricity producing wind turbines* (IEC, 2005).

Box 6.2 ***Case study: Installation of a met mast***

Project:	Greater Gabbard Offshore Wind Farm, Thames Estuary
Justification:	Installation of the met mast was primarily justified for resource validation purposes, with the data also benefiting detailed design and engineering decisions, and live feed information likely to inform operational decision making during the construction and post-construction phases. A single met mast was installed since site variations were considered unlikely to be significant in the context of resource validation requirements.
Location:	Greater Gabbard Offshore Wind Limited (GGOWL) compiled an extensive GIS database of data through the execution of the EIA process. A metocean campaign was carried out to inform both the environmental and engineering analyses and decisions, including the location of the met mast.
Instruments:	The met mast includes a total of nine anemometers placed at 40 m to 85 m above mean sea level. In addition the met suite logs temperature, atmospheric pressure and fog. GPRS telemetry for data transfer.
Mitigation:	The detailed metocean and geophysical surveys informed a wide range of decisions including design, access and installation methodology for the met mast. These included the location itself, as well as the orientation of access ladders and boat landing sites. Knowledge of the metocean conditions local to the installation site also allowed for definition of installation and service vessel operating thresholds and optimisation of installation schedules to minimise downtime.
Installation:	Specialist services were employed to provide site-specific forecasts for wind, weather and significant wave height for the duration of the installation. The jack-up barge Excalibur was selected for the operations as being suitable for the water depths and having the deck space, loading and lift capacity. With a carefully selected weather window the operation was successfully completed in less than 20 hours.

Figure 6.3 *Met mast installation (courtesy GGOWL)*

6.6.2 Waves

Given the present status of WEC projects there have been very few cases of wave resource validation studies in the UK to date apart from efforts at EMEC and WaveHub.

Duration and location

Validation of the wave resource requires *in situ* monitoring for a minimum period of 12 months and for a sufficient number of sites to describe major variability which might be expected over the footprint of the development site. Extensions to the deployment period may be required if significant data loss is experienced.

Measurement device

Directional wave buoys equipped with telemetry links are likely to be the most practical option, with WaveNet being an example of an effective approach.

Pitt (2006) reviewed a number of wave measurement devices for resource validation studies at WaveHub, including HF Radar, acoustic current doppler profiler (ADCP), satellite observations and the more traditional wave buoy. The conclusion from this work was that the wave buoys remain the most reliable and well-proven technology of those considered, especially for deep water sites.

Sampling regime

For areas prone to shallow water influences and strong tidal variation a suitable measurement interval is required to resolve effects which may modulate the wave regime. For these sites an interval of 30 minutes is recommended (comparable to WaveNet), whereas for deeper water sites where tidal effects are minimal, the sampling regime can be relaxed to three hourly intervals, which is a more standard interval for oil and gas applications.

In a separate study for EMEC, the issue of sampling intervals was given detailed consideration. Pitt (2005) reported that a sampling regime based on 30 minutes duration could result in an error (95 per cent confidence) of about 10 per cent in the determination of wave power. Increasing the sampling period to 60 minutes reduces this potential for under-prediction to around seven per cent.

The data provider should be able to capture these issues in statements regarding data quality.

Standards

At present there is no standard in place for resource validation methodologies, although comment on conducting wave resource measurements is included in the draft WEC device performance protocol:

- *Preliminary wave energy: device performance protocol* (DTI, 2007)
- *Preliminary wave energy device performance protocol supporting commentary* (DTI, 2007).

The WaveHub project provides a good example of pre-consent issues, including the process of wave resource validation (see Box 6.3). A full set of project reports is available from <http://www.wavehub.co.uk>.

Box 6.3 ***Case study: WaveHub***

Project: WaveHub

Site selection: In 2004 SWRDA commissioned a regional study to review wave and tidal stream opportunities around the south-west of England in a project called *Seapower south west* (Metoc, 2004). This work relied on existing modelled data for waves and tides, including long-term wave data from the Met Office European Wave Model. The site selection process identified suitable resource locations and grid options and then screened out unsuitable areas on the basis of various constraint issues. From the site selection process a favoured area for wave farms was selected off Hayle, Cornwall.

Resource validation: In January 2005 a waverider buoy was deployed to collect local measurements off Hayle and used to compare with initial wave resource estimates. A further resource comparison was undertaken using data from the UK Waters Wave Model, noting that only a short data record was available from this model (Table 6.2). Variations in annual average wave power indicate a significantly higher resource estimated from the long-term dataset versus the short-term observation and model records. While some of this differential could be attributed to the model schemes used, further investigation indicated that the main differences were attributed to year-on-year variations in number and severity of storms, which were captured in the long-term record. This exercise indicated the importance of understanding the limitations inherent in all of the available datasets, ie wave models should be validated by observations, but a single year sample of data may show significant variation from long-term climatic averages.

Table 6.2 *Wave resource estimates derived for WaveHub*

Source of wave data	Length of record	Annual wave power resource estimate (kW/m)
European Wave Model	12 years (1988 to 2000)	31
UK Waters Model	6 years (2000 to 2006)	19
Measured data	1 year (2005)	18

EIA: The EIA scope included a coastal process study to evaluate the likely effects that deployment of multiple WECs would have on local waves and effects on the coast. This work included the use of wave transformation models to both downscale deep water waves and consider the potential effects of the development on local waves.

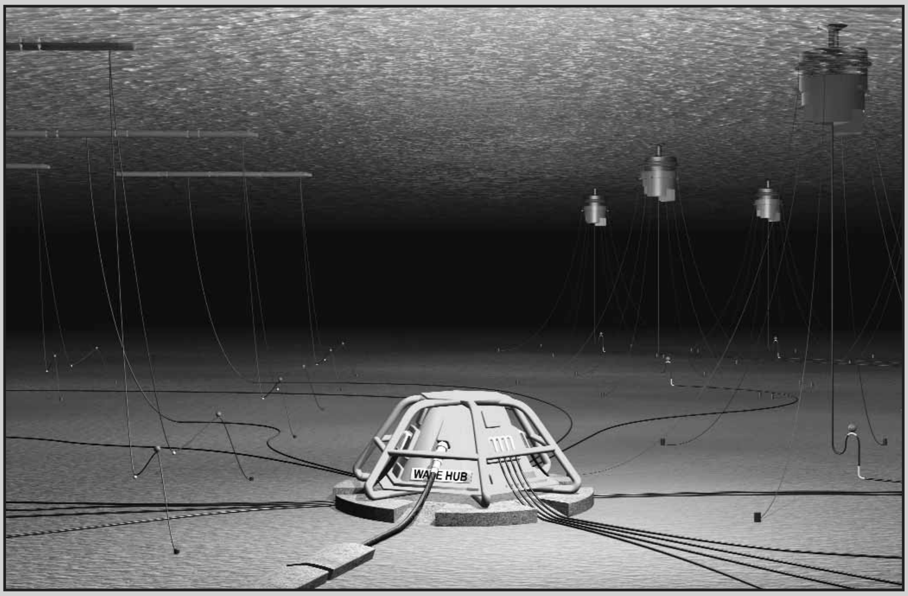


Figure 6.4 *Illustration of WaveHub concept (courtesy SWRDA)*

6.6.3 Tidal stream

Given the present status of TEC development there have been very few cases of resource validation to date.

Duration and location

Validation of the tidal stream resource requires *in situ* monitoring for a minimum period of 30 days (ie sufficient period to span a lunar cycle) and for a sufficient number of sites to describe major variability which might be expected over the footprint of the development site. The capture radius of a TEC device and the relative position of the device in the water column require that flow measurements are sampled over the full depth to resolve the vertical flow structure. If a tidal stream resource is located within a channel, then the lateral (across channel) variability of flow also needs to be carefully resolved by using a vessel mounted ADCP and conducting monitoring over the relevant part of the channel cross-section. The practicalities of using vessel mounted ADCP is likely to limit the period of such monitoring to key phases of the tide, such as a diurnal cycle repeated for spring and neap conditions.

Measurement device

The most practical means of measuring the tidal stream resource through the water column is by deployment of a bed mounted ADCP device. Since the equipment is likely to be bed mounted then the opportunity for telemetry becomes more restricted. However, given the short duration (ie minimum of 30 days) required to develop sufficient resource validation, on-board data logging would be sufficient. For longer deployment periods suitable service intervals would be required to maintain the instrument(s), download the data and replace batteries.

Sampling regime

Two issues will be of interest in the flow structure (horizontal velocity and the turbulent intensity) and measured at regular intervals over depth, at a minimum spacing of 2 m. The sampling regime also needs to resolve the high frequency variations due to turbulence and tide. A minimum sampling interval of 10 minutes is desirable and averaging over a 20 second measurement burst. To determine the turbulent intensity the averaging algorithm also needs to provide the standard deviation in velocity over the burst period.

Standards

At the present time there is no formal standard or guideline in place to describe a methodology for tidal resource validation, although it is noted that the AHWG is preparing a draft standard and a procedure to characterise the local tidal resource, included in the draft TEC device performance protocol:

⇨ *Preliminary tidal current energy: device performance protocol* (DTI, 2007).

A further document which discusses performance testing of a TEC device and the derivation of a power capture coefficient is:

⇨ *Development, installation and testing of a large-scale tidal turbine* (DTI, 2005).

7 Pre-construction issues

7.1 OVERVIEW

Projects that achieve consent can move forwards to the next milestone of preparing for construction. Activities that are likely to be advanced during this stage of project development include (Figure 7.1):

- consent conditions
- detailed site investigations
- detailed design
- O&M strategy
- planning and procurement.

During this stage of the project the resource validation is likely to continue, especially in relation to offshore wind and wave projects.

As an estimate, the period required to undertake pre-construction metocean activities may last between 6 and 18 months.

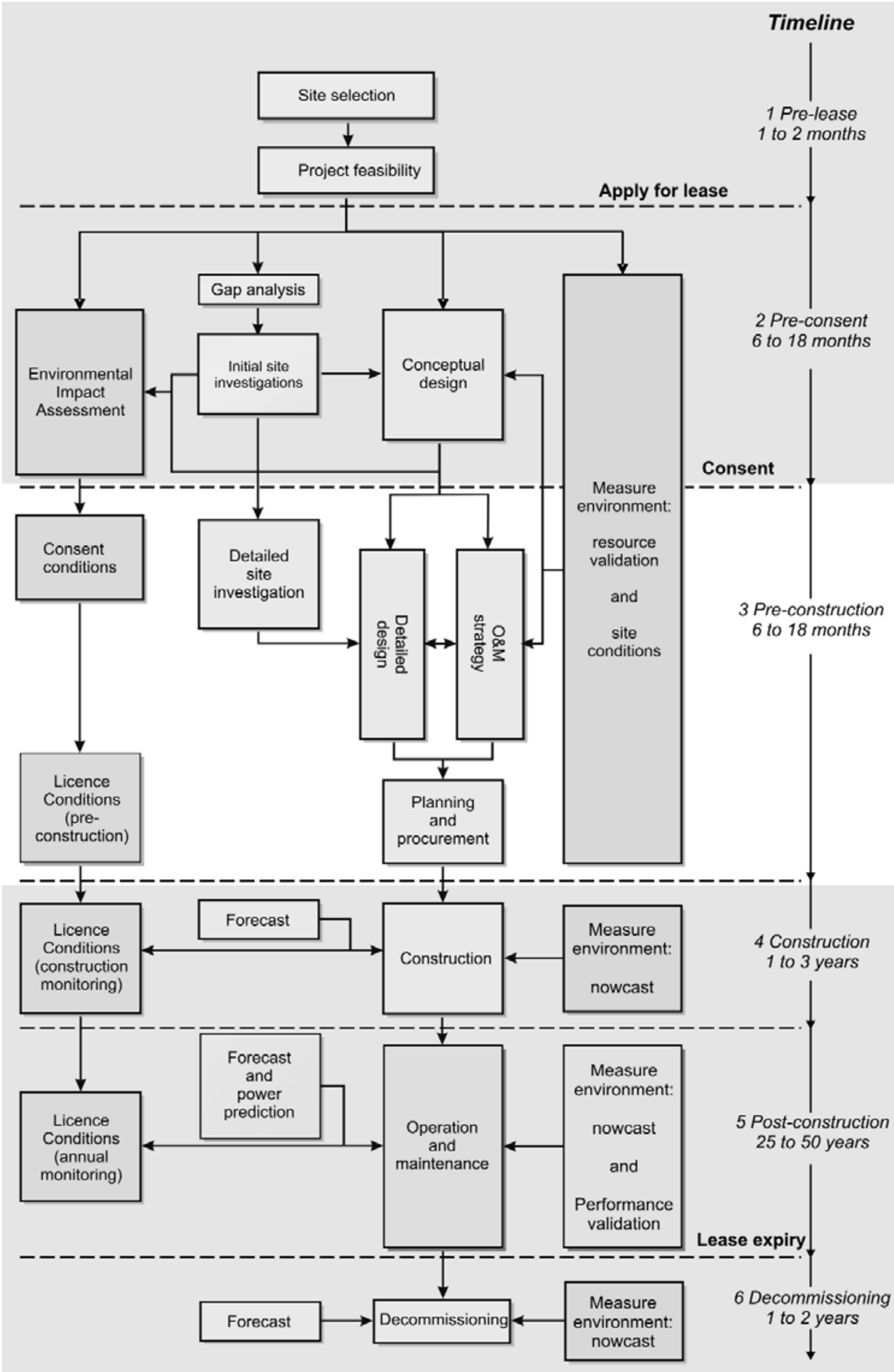


Figure 7.1 ***Pre-construction activities and linkages***

7.2 CONSENT CONDITIONS

Consent conditions normally relate to the degree of uncertainty remaining with the regulator at the point of granting consent. Such conditions are generally framed as a response to the EIA process and the level of understanding available (ie the status of the evidence base). Consent conditions will be developed on a case-by-case basis and will have particular regard to the technology type, any remaining design options retained for the consent and any site specific issues. It is common for the FEPA licence to be used as the primary tool for adding such conditions.

At the present time the regulator is developing a good understanding and drawing from an expanding evidence base related to offshore wind projects, especially those adopting mono-pile foundations. To date metocean related consent conditions for offshore wind have tended to be grouped into three headings:

1 Scour.

2 Suspended sediment.

3 Morphology.

Monitoring related to these issues has generally been required for periods at pre-construction, construction and post-construction, the latter being repeated on an annual basis over a period of a few years with annual review. Monitoring reports are required to be submitted to the consenting body at the end of each year. It is anticipated that new projects will also be required to submit these data and reports to The Crown Estate as part of the lease requirement, once the consenting body has approved the information.

For WEC and TEC devices it is generally antiquated that the effects of energy reduction will be added to the list of monitoring requirements and remain as the projects increase in scale from single demonstrators through to commercial projects adopting arrays of devices. The topic of energy extraction is reviewed in a recent research report published for CCW and The Crown Estate (ABPmer, 2006) and provides recommendations for *in situ* monitoring around devices. It is understood that this recommendation has been accepted as a research priority by the pan-government research advisory group (RAG) with further progress awaiting initial device deployment.

The FEPA license granted to Marine Current Turbines to operate the SeaGen device in Strangford Lough provides the only recent example of consent conditions for a TEC.

7.3 DETAILED SITE INVESTIGATIONS

If significant data gaps remain at the pre-construction stage required to support detailed design, and following initial site investigations, then further and more detailed site investigation work may be necessary to confirm the project design. Such site investigation work will be specifically targeted to assist moving the project from conceptual design, where several solutions for different aspects of the project may be considered, to detailed design where final choices are made.

As with initial site investigations, any survey methodology will need to consider local metocean conditions for safe marine operations (eg vessel selection, survey planning, downtime, forecasts) (Section 6.3). At this point the existing metocean knowledge base should be sufficient to characterise the likely working conditions, supplemented by regular forecasts for daily planning.

Typically, detailed site investigations are likely to focus on more intensive:

- geophysical surveys (eg bathymetry, near surface soil conditions and surface debris or obstructions)
- geotechnical surveys (seabed soil profile).

The results of these detailed investigations will be used to finalise the foundation design requirements and determine exact positioning for the structures or moorings and cable routes and with regard to other constraints, such as wake effects and navigational issues. While there is likely to be ongoing data collected from resource measuring devices (such as met masts, wave buoys or ADCP), it is unlikely that there will be further justification for additional metocean data collection effort at this stage.

7.4 DETAILED DESIGN

Design should be in accordance with the Construction, (Design and Management) (CDM) Regulations (2007).

The main inputs to detailed design will include the initial conceptual design (used as the basis for consenting the project) along with additional detailed site investigation data and further on-site resource monitoring. The O&M strategy will also influence final design, especially in relation to access onto structures or means for recovering devices for onshore maintenance.

For commercial scale projects it is likely that the responsibility for detailed design will fall to a build contractor selected through competitive tendering. The supply and quality of site-specific metocean information reaching these contractors to assist their considerations of project design risks has not always been consistent between projects and at times resulted in increased areas of uncertainty. With this approach it is inevitable that there will be different front-end considerations developed by each contractor which will vary according to the level of effort (including independent investment in data and analysis) put into developing the cost of construction. The outcome of this approach may also produce very different solutions to design as well as overall build costs. This can make bid comparison and subsequent contractor selection an inefficient and possibly arbitrary process.

In cases where the developer has chosen to provide a relevant set of design parameters themselves by commissioning a metocean design study, it has been found that substantial savings can be achieved. This route to procurement of construction helps to develop a consistent knowledge base for each contractor. It is anticipated that such a metocean design study will include details such as:

1 FMECA (failure modes and effects and criticality analysis) for:
   a Extreme and joint probability extreme conditions.
   b Fatigue considerations.
2 Operational thresholds.
3 Site access downtime analysis for construction and O&M.

This approach is consistent with the CDM Regulations 2007 and is recommended as good practice for consideration at an early stage in the project methodology.

In all cases, the general philosophy behind design should be that offshore activities are kept to an absolute minimum and what can be constructed or economically maintained onshore should be. DNV offshore standards (OS series) and recommended practices (RP series) give guidance to the design of offshore installations as well as the appropriate ISO and IEC standards where relevant. In the case of wave and tidal power, the choice of standards will be made according to the most applicable for the installation.

The output from this activity is a finalised detailed project design which will be certified by an independent certification body.

DNV is in the process of drafting certification standards for WEC and TEC devices:

⇨ *Certification of tidal and wave energy converters* (DNV, 2007).

GL has published a certification guide for TEC and offshore wind devices:

⇨ *Guidelines for the certification of ocean energy converters. Part 1: Ocean current turbines* (GL Wind, 2005)

⇨ *Guidelines for the certification of offshore wind turbines* (GL Wind, 2004).

HSE has published a general discussion on loads in an Offshore Technology Report, which includes details on environmental loads, extremes and fatigue issues:

⇨ *Loads* (HSE, 2001).

The following text outlines the principle metocean issues for consideration in offshore wind, wave and tidal stream projects. In each case the analysis process should consider the potential for spatial variability of metocean conditions across the footprint of any development area, an issue which will guide decisions on the amount and location of sites chosen to characterise design conditions. For example, it may be possible for a large open water site extending over a relatively flat seabed to be characterised by a single location, whereas a smaller site extending over a complex seabed formed of banks and channels may need several sites to characterise each of these environments.

Offshore wind

Table 7.1 is a summary of the design issues which require some consideration of metocean conditions.

Table 7.1 ***Design choices that will be influenced by metocean considerations***

Design	Major metocean consideration	Data required
Site layout	Wind-wake effects for the range of prevailing conditions	Turbulence effects of turbines in normal operating range
Cable route and burial depth	Erosion and sediment transport due to water movement	Analysis of water movement and sediment transport, especially in areas of steep depth changes and breaking waves in the nearshore
Foundation: selection and design	Environmental load effects of current, tide, wind, waves and marine growth Severely aggressive environment in splash zone *Instability* given site specific conditions and vessel/crane limitations	Extreme analysis and joint effects of wind, wave and current loads, fatigue analysis Upper and lower limits of splash zone Downtime analysis against vessel operating thresholds
Transition piece design	Height and orientation of access ladders and platforms for prevailing conditions Height of ladder platforms in relation to extreme sea levels J-tube design – external tubes increase environmental dynamic forces on the structure	Tidal range, waves and currents direction Extreme and joint probability analysis of water levels and wave height
Foundation and tower interaction	Natural frequency Wake effects of adjacent turbines	Wind loads Turbulence effects of turbines in normal operating range

Design of offshore wind turbine foundations and structures is comprehensively discussed in:

⇨ *Design of offshore wind turbine structures* (DNV, 2004).

A further document providing details on offshore wind design is:

⇨ *Wind turbines – Part 3: design requirements for offshore wind turbines* (IEC, 2005a).

Wave (WEC)

WEC device design will need to be optimised for maximum power delivery under the prevailing site conditions, and for survival under extreme conditions. It is likely that the device design will be optimised for power output during the winter months when the available wave energy is at its highest and coinciding with peak energy demand.

The dominating metocean issues for WEC design are:

- wave spectrum
- current
- variation about mean water depth.

Wind itself will not significantly influence design, since devices are generally low lying to the sea surface and are likely to present little windage. However, the effect of wind conditions on the wave spectrum and currents will need to be modelled for design considerations.

Further guidance for WEC design is found in:

⇨ *Guidelines on design and operation of wave energy converters. A guide to assessment and application of engineering standards and recommended practices for wave energy conversion devices* (DNV, 2005).

In all cases, moorings and umbilical design needs to withstand the predicted extreme wave conditions for the site. Mooring design needs to take into account the combined forces of wave and tidal current as a load factor on the anchor chains, but also in terms of the risk in mobilising the local seabed. In addition, consideration needs to be made of the risk of marine growth on the device, umbilicals and mooring components.

Layout of wave energy converters around the site will need to be made with reference to any wake effects and to the orientation of the devices to any current flows (apart from point absorbers).

Tidal stream (TEC)

Designs for TEC devices will be influenced by:

- bi-directionality of flow between flood and ebb tides
- variation of the flow through the water column and height of boundary layer
- extremes of flow for definition of survival conditions
- surface conditions for access
- extreme analysis of surface layer load effects
- wake effects of adjacent units or local land masses.

Most designs mimic the windmill concept of a horizontal axis rotor secured to face the tidal stream and fixed to the seabed either by piled foundations or dynamic moorings. Not all devices are designed to rotate with the tidal stream and preferred sites are normally selected for their uniformity of direction of flow through periods of ebb and flood tides, and generally favouring those sites which have a strongly rectilinear axis.

Due to the nature of the sites selected for tidal devices, inter array and export cable protection will require careful consideration. Cable armour may be sufficient at sites where cables are laid in parallel with the tidal flow and the rock stratum is relatively benign. However, rock dumping, matting and/or cable protectors need to be employed where more erosive environments exist, or where there is a requirement to lay the cables perpendicular to the tidal flow. Cable burial is unlikely to be employed since in areas of fast flowing water the seabed may be scoured to the rock level in many places.

7.4.1 Extreme conditions

Extreme conditions represent rare events (nominally storm conditions) that deliver peak values of metocean conditions or combinations of conditions that may need to be accounted for in any offshore design, ensuring the development is sufficiently robust to survive such conditions (ie withstand peak loads). The extreme conditions are likely to repeat in their occurrence at very low frequencies ie once every 50 years, and consequently are unlikely to fall within any set of measured data.

Uni-variate parameters

For offshore structures the main interest is likely to be with extreme wave conditions, commonly referred to as the design wave. The design wave is an individual wave (event) with a height that is only exceeded on average once over a specified time period, referred to as a return period. The choice of return period needs consideration to the service life of the scheme, which for offshore wind may be between 25 to 50 years for foundation units, noting that opportunities for re-powering the project with upgraded turbine units may happen on shorter timescales. Over this timescale the design process needs to consider an upper return period that is longer than the service life, ie 50 or 100 years to ensure survival of the installation under extreme sea conditions.

In full, the extreme value statistics are required for:

- winds (including gusts)
- water levels (including surge contribution)
- wave heights
- currents (including surge contribution).

The standard methodology for quantifying extreme conditions is to analyse a long-term record that contains an adequate sample of extreme (storm) events, and extrapolate the marginal extreme events to lower frequency return periods based on a fitted probability distribution.

If the long-term record is not immediately coincident with the site of interest then suitable methods need to be employed to develop the data to that site. This may rely on MCP methods or numerical models, such as wave transformation models that modify deep water wave conditions into shallow water sites (see Box 6.1).

The means of extrapolation relies on fitting a probability distribution function (PDF) to the marginal extremes, using techniques such as Weibull, Fisher-Tippett, Generalised Extreme Variate, Generalised Parteo Distribution etc. The first task is to prepare the data and filter out any secular trend to ensure there is no bias in the distribution of the data around a long-term mean value. For water levels, this normally filters out issues that may relate to non-random trends such as sea level rise. Other climate change effects may similarly influence other metocean parameters. Furthermore, it remains prudent to revisit extreme analysis on occasions when key events may modify the signature of the extremes distribution.

It is generally regarded that the statistical confidence in the extrapolation of the probability distribution reduces for return periods greater than two or three times the length of the input record. For example, a 10-year time series should be able to provide a reliable statistical distribution which can be extrapolated to derive an estimate of extreme events up to return periods of around 1 in 30-years. Consequently, the standard error in the extrapolation may increase for longer return periods.

For omni-directional metocean parameters, such as wind and wave, a sector analysis becomes relevant, with the number of sectors commonly being either 8 or 12 (with increments of 45° and 30°, respectively). When eight sectors are adopted then convention is to centre on standard compass bearings as follows:

North	centred on 000°N, spanning 337.5 to 022.5°N
North-West	centred on 045°N, spanning 022.5 to 067.5°N
West	centred on 090°N, spanning 067.5 to 122.5°N
South-West	centred on 135°N, spanning 112.5 to 157.5°N
South	centred on 180°N, spanning 157.5 to 202.5°N
South-East	centred on 225°N, spanning 202.5 to 247.5°N
East	centred on 270°N, spanning 247.5 to 292.5°N
North-East	centred on 315°N, spanning 292.5 to 337.5°N

In some cases it may also be appropriate to provide a sector analysis for current speeds, although here it is more probable that only directions of peak flood and peak ebb become relevant.

The choice of PDF is a fairly arbitrary process, and with consideration of issues including standard error, the final decision can be based on what fits the data best. Using the best-fit PDF, the extreme value predictions can be readily derived for a set of return periods, commonly: 1, 2, 5, 10, 20, 50 and 100-year. It is also informative to report the standard error values alongside these predictions.

As the PDF is purely a method of statistical extrapolation there should be judgement on the extreme values predicted at this point, in relation to the derived metocean condition remaining physically realistic and not exceeding any limiting condition. For large waves the limiting conditions would be wave steepness and water depth beyond which waves may break. A detailed discussion on deriving various extreme metocean parameters is given in:

⇨ *Environmental considerations* (HSE, 2001b).

It is good practice for the extreme analysis results to be presented in both graphical and tabular form. The graphical presentation will include both the marginal extreme values and the best-fit PDF extrapolated to the required higher return periods.

Table 7.2 provides an example tabular presentation for a uni-variate extreme estimate of wave heights, broken down into directional sectors, and including a non-directional prediction.

Table 7.2 ***Example of tabular presentation for directional wave extreme values. Based on 30° sectors***

	Directional sector (°N)												
Return period (yrs)	**000 to 029**	**030 to 059**	**060 to 089**	**090 to 119**	**120 to 149**	**150 to 179**	**180 to 209**	**210 to 239**	**240 to 269**	**270 to 299**	**300 to 329**	**330 to 359**	**All**
1	3.36	3.69	3.58	2.87	2.70	3.85	4.14	3.70	3.22	2.87	2.79	3.26	4.41
2	3.56	3.93	3.74	3.15	2.93	3.99	4.35	3.94	3.51	3.14	3.00	3.47	4.64
5	3.83	4.22	3.91	3.51	3.21	4.15	4.59	4.24	3.91	3.52	3.26	3.72	4.92
10	4.02	4.44	4.01	3.79	3.41	4.25	4.76	4.46	4.24	3.82	3.45	3.89	5.12
20	4.22	4.64	4.10	4.06	3.60	4.34	4.91	4.67	4.59	4.13	3.62	4.05	5.31
50	4.48	4.90	4.20	4.42	3.84	4.43	5.10	4.95	5.07	4.57	3.85	4.23	5.55
100	4.68	5.09	4.26	4.69	4.01	4.49	5.22	5.15	5.47	4.91	4.01	4.36	5.73

Figure 7.2 presents the extract of data for the 30° sector between 180 and 209°N to show the level of agreement between the marginal extreme wave events and the predicted extreme wave events after fitting a generalised Pareto distribution PDF to the data.

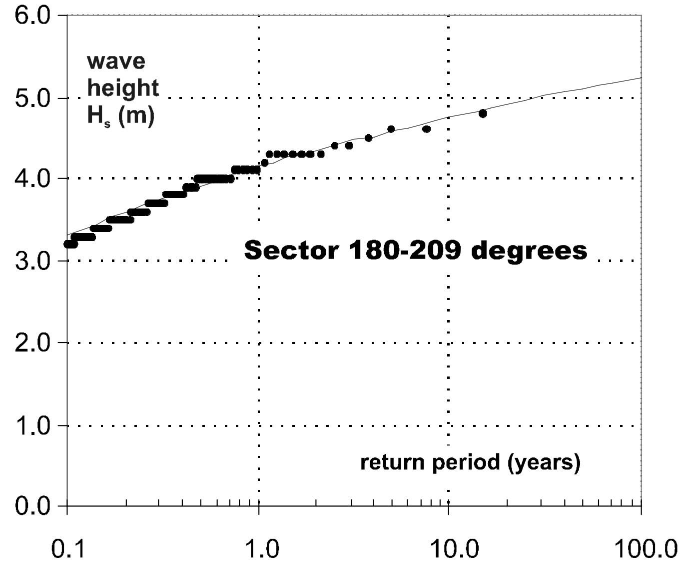


Figure 7.2 ***Predicted extreme return period significant wave heights compared with the underlying data for the direction sector 180 to 209 °N***

Multi-variate extremes

It is unlikely that all extreme conditions (winds, waves, water levels and currents) will occur simultaneously, ie there is a reduced probability. Allowances can be made in design, with care, by considering combined probabilities of two or more variables, and by establishing the degree of correlation (dependency) of these extreme conditions occurring together.

Typically, the analysis of the joint distribution of metocean variables assumes the following relationships:

- surges, strong winds and large waves are likely to show some dependency (being generated from the same storm conditions)
- wave height, period and direction are dependent (representing properties of the same physical process)
- tides and surges are partially dependent (due to interactions between the two processes)
- water levels and waves are independent in deep water with increasing dependency in shallow water
- waves and currents are independent in deep water with increasing dependency in shallow water
- water levels and currents are dependent (representing properties of the same driving physical process).

These metocean conditions are generated from two independent physical mechanisms:

1 Astronomical forcing.

2 Meteorological forcing.

Metocean conditions generated by these separate mechanisms will remain independent of each other unless there is some form of interaction. For example, in offshore locations, water depth is usually sufficient for waves to be effectively independent of tides. In shallow water, waves become dependent on the changes in depth due to the tide once they start to feel the seabed (see Section 3.1.3). Further dependency may exist in areas of strong current.

As with uni-variate analysis, the directional variation of winds and waves requires these extreme conditions to be assessed on the basis of directional sectors.

The form of any dependence can be considered in relation to how well the joint behaviour of extremes is statistically correlated.

In 1998, DEFRA published a joint probability methodology for coastal engineering called JOIN-SEA (HRW). The methodology is transferable to the present application and is not solely limited to waves and water levels.

⇨ *The joint probability of waves and water levels: JOIN-SEA, a rigorous but practical approach* (HR, 1998).

The method considers the degree of dependency between two sets of variables, which may range from fully independent, partially dependent to fully dependent. This document also provides a useful review of extreme value methods to determine uni-variate distributions.

7.4.2 Fatigue loads

Design for fatigue limits is required to assess the cyclical loading on structures by considering the loads caused by various combinations of metocean factors which occur during operational conditions, and taking into account issues such as wake effects. In contrast to extreme loads, the cyclical loads operate at much higher frequencies from seconds rather than years.

A metocean study to support engineering design will commonly include a series of data summaries based around frequency analysis of a long-term time series of metocean parameters with consistent increments between records, and developed into a series of tables and graphs. The principle of grouping data into directional bins also applies, so good practice is to standardise on either 8 or 12 directional sectors in both extremes analysis and frequency analysis.

The following set of frequency analysis is generally required:

- wave scatter diagram and tables (wave height, H_s , versus wave period, T_p), all directions and by direction sector
- wave frequency tables (wave height, H_s , versus wave direction, and also wave period, T_p), and presented as wave roses
- wind frequency tables (wind speed versus wind direction) and presented as wind roses
- wave height versus wind speed, all directions and by direction sector
- current speed versus current direction and presented as current roses.

Inter-annual (seasonal) variability in winds and waves will also be of interest, leading to a further sub-division of these data to enable frequency analysis on a month-by-month basis.

Note that for offshore wind installations the conditions at the equivalent hub height are required, not measurements close to the sea surface.

The construction of frequency analysis tables also relies on pre-selected bin sizes for each parameter and to increment over the full range of the measured data, ie spanning the minimum to maximum recorded values. Table 7.3 offers recommended increments for use in frequency analysis, noting that the use of a very small increment in shorter records may lead to unnecessary gaps in the resulting tables, especially where the probability density values might be expected to be low.

Table 7.3 **Recommended increments for use in frequency analysis**

Parameter	Symbol	Unit	Increment
Significant wave height	H_s	(m)	0.5 to 1
Wave period	T_p	(s)	1 to 2
Wave direction	Ø	(°)	30 or 45
Wind speed	U_{10}	(m/s)	1 to 5
Wind direction	Ø	(°)	30 or 45
Current speed	U_c	(m/s)	0.1 to 0.5
Current direction	$Ø_c$	(°)	30 or 45

The reported unit for frequency analysis represents a dimensionless count of the number of events falling within each bin which can also be normalised into a percentage value. It is helpful to report the amount of data used in creating each table to provide an indication of statistical reliability, especially when fractions of months or years are used as input.

A worked example of a wave scatter diagram and frequency table is given in Box 7.1, followed by an example of a wave rose in Box 7.2.

Box 7.1 ***Example of wave scatter diagram and frequency tables***

Task: To develop a wave scatter diagram and frequency table.

Input: Quality checked time series of long-term wave measurements containing wave height (H_s) and wave period (T_p).

Scatter diagram: The raw data is initially plotted out as H_s versus T_p (Figure 7.3) to present the full distribution of the dataset and to establish upper and lower limits of each parameter. From Figure 7.3 the swell component can be interpreted as the lower amplitude and longer period waves (ie H_s <0.5 and T_p >10 s), whereas the wind-sea component is likely to be the larger grouping of waves where wave periods are marginally lower.

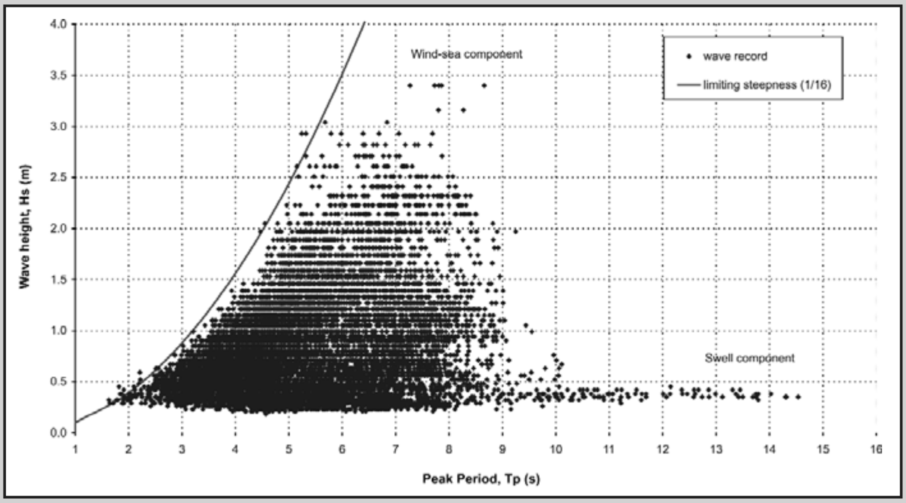


Figure 7.3 *Example wave scatter diagram*

Wave steepness: The wave scatter diagram allows for a limiting wave steepness to be estimated, which in this example is 1/16. On this basis, further extrapolation of sea states might be expected to follow a similar limiting steepness.

Wave frequency table: On its own the wave scatter diagram does not easily quantify the probability density of combinations of H_s and T_p unless contouring is applied. A wave frequency table is used to compliment the wave scatter diagram and determine the absolute contribution of waves falling into pre-defined bins. Table 7.4 offers a frequency table to quantify the probability density (expressed in per cent occurrence) adopting 0.5 m bins for H_s and 1 s bins for T_p and to span the range of data (note: blanks are used when no values are recorded to aid interpretation). From Table 7.4 waves between 0.5–1 m and 4–5 s are most frequent at over 14 per cent of the events.

Table 7.4 *Example wave frequency table (wave height versus period) – all directions, all months*

Wave height, H_s (m)			Wave period, T_p (s)															
		>=	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Total**
		<	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	
>=	<																	
3.5	**4.0**																	0.00
3.0	**3.5**						0.01	0.01	0.04	0.02								0.80
2.5	**3.0**						0.15	0.32	0.21	0.01								0.69
2.0	**2.5**					0.04	0.42	1.06	0.72	0.27								2.52
1.5	**2.0**					0.62	2.94	2.14	0.90	0.26	0.01							6.87
1.0	**1.5**				0.50	6.69	6.16	3.46	2.42	0.85	0.04							20.11
0.5	**1.0**			0.79	11.66	14.06	6.16	5.04	3.52	0.89	0.11	0.04						42.26
0.0	**0.5**		0.16	1.97	6.52	6.25	5.14	3.96	1.86	0.61	0.34	0.27	0.14	0.13	0.10	0.04		27.47
Total			0.16	2.76	18.67	27.66	20.98	15.98	9.68	2.91	0.49	0.30	0.14	0.13	0.10	0.04	0.00	100

Box 7.2 ***Example of wave rose and frequency tables***

Task: To develop a wave rose and frequency table (wave height versus direction, wave period versus direction).

Input: Quality checked time series of long-term wave measurements containing wave height (H_s), wave direction (Ø) and wave period (T_p).

Wave rose: The raw data is initially plotted out as H_s versus direction (Figure 7.4) in twelve direction sectors of 30° and using the 0.5 m bins for wave height. Two prominent wave directions are revealed, north to north-east and south to south-west.

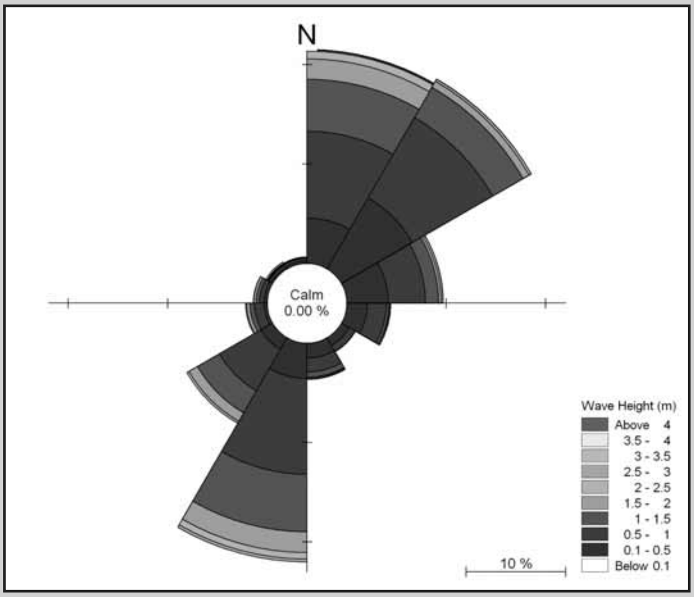


Figure 7.4 *Example wave rose*

Wave frequency table: A wave frequency table using the same divisions in wave height and direction complements the wave rose by establishing the probability density of events. Table 7.5 presents wave heights versus direction. Waves from 30 to 059°N are most common (over 22 per cent), with the majority of waves grouped between 0.5 to 1 m in wave height (over 42 per cent).

Table 7.5 *Wave frequency table (wave height versus direction)*

				Wave direction, θ (°N)												
			>=	**0**	**030**	**060**	**090**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
			<	**029**	**059**	**089**	**119**	**149**	**179**	**209**	**239**	**269**	**299**	**329**	**359**	
Wave height, H_s (m)	>=	<														
	3.5	**4.0**														0.00
	3.0	**3.5**		0.07										0.01		0.80
	2.5	**3.0**		0.11	0.01	0.04			0.10	0.24	0.01			0.15	0.04	0.69
	2.0	**2.5**		0.78	0.25	0.20	0.02		0.13	0.67	0.23	0.11	0.03	0.06	0.04	2.52
	1.5	**2.0**		2.05	0.68	0.34	0.05		0.19	1.92	0.99	0.34	0.22	0.07	0.02	6.87
	1.0	**1.5**		5.26	3.52	1.43	0.12	0.03	0.91	5.41	2.54	0.51	0.27	0.08	0.04	20.11
	0.5	**1.0**		8.70	9.34	4.18	01.44	0.69	2.02	9.01	4.84	1.03	0.43	0.28	0.28	42.26
	0.0	**0.5**		4.58	8.23	4.59	1.68	0.91	2.08	3.01	1.33	0.36	0.28	0.16	0.25	27.47
	Total			21.55	22.03	10.79	3.32	1.63	5.43	20.26	9.95	2.36	1.23	0.81	0.65	100

Wave frequency table: A similar approach can be taken when considering wave period versus direction. Table 7.6 summaries the same data in terms of wave period binned at 1 s intervals versus wave direction. This grouping of data can assist in confirming which direction the longer period swell component has arrived from. In this example, waves between 0 to 060°N account for the majority of the longer period data (events where T_p > 10 s).

Box 7.2 — *Example of wave rose and frequency tables (contd)*

Table 7.6 — *Wave frequency table (wave period versus direction)*

Wave period, T_p (m)		Wave direction, θ (°N)												
	>=	0	030	060	090	120	150	180	210	240	270	300	330	Total
	<	029	059	089	119	149	179	209	239	269	299	329	359	
>=	<													
14	15	0.02	0.02											0.04
13	14	0.03	0.06	0.01										0.10
12	13	0.11			0.01						0.01		0.01	0.13
11	12	0.11	0.01						0.01				0.02	0.15
10	11	0.26	0.04						0.02					0.31
9	10	0.38	0.05					0.01		0.01	0.01		0.02	0.48
8	9	2.14	0.70	0.07			0.01	0.03				0.01	0.03	2.98
7	8	5.85	2.85	0.50	0.08	0.01	0.15	0.27	0.04		0.02	0.01	0.04	9.80
6	7	6.29	4.77	1.43	0.25	0.09	0.43	1.96	0.34	0.10	0.15	0.04	0.10	15.95
5	6	3.59	6.14	1.88	0.41	0.21	0.95	5.15	1.75	0.50	0.17	0.25	0.11	21.10
4	5	1.61	5.14	3.84	1.05	0.54	2.02	7.85	4.21	0.60	0.39	0.19	0.16	27.60
3	4	1.05	2.06	2.69	1.42	0.68	1.46	4.30	3.19	0.90	0.42	0.21	0.12	18.50
2	3	0.11	0.19	0.34	0.10	0.10	0.38	0.67	0.40	0.22	0.07	0.10	0.04	2.71
1	2	0.01	0.02	0.02			0.02	0.04		0.03			0.02	0.14
Total		21.55	22.03	10.79	3.32	1.63	5.43	20.26	9.95	2.36	1.23	0.81	0.65	100

7.4.3 Downtime analysis

Downtime analysis provides a means to evaluate the accessibility of a site against limiting weather conditions, to assist in vessel selection (operability) and to plan for suitable construction periods. The analysis is also integral to O&M planning and to establish suitable allowances for numbers of weather days when agreeing contractual conditions with build contractors (see Section 7.6).

Downtime analysis involves the assessment of a metocean parameter (commonly wind speed, U_{10} and wave height, H_s) to establish when conditions remain above (exceedance) or below (non-exceedance) a specified operational threshold. For tidal stream sites current speed thresholds are likely to be an additional requirement to determine durations of slack water.

Figure 7.5 provides an example for a short extract of wave conditions considered against a threshold condition of significant wave height (H_s) set at 1 m, with periods in red representing exceedance and green non-exceedance. In this example there are four periods when the threshold is exceeded for periods longer than 24 hours.

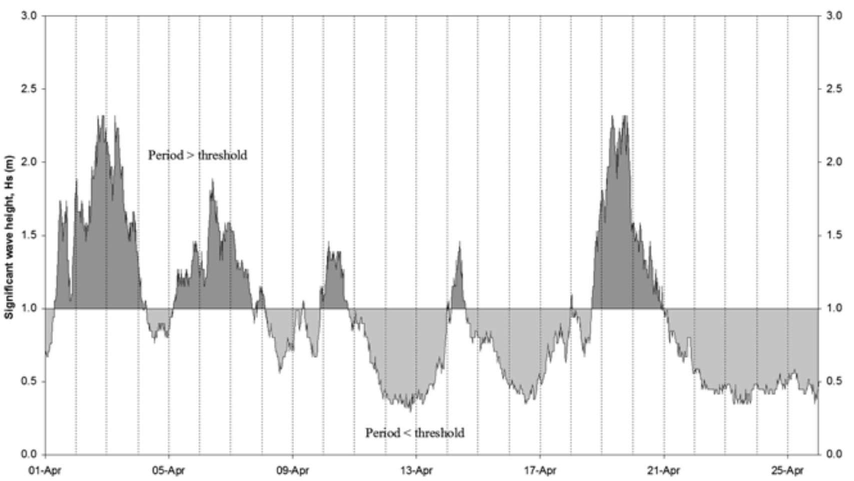


Figure 7.5 — ***Example of assessing threshold conditions from wave data***

Two forms of assessment commonly used in downtime analysis are:

1 Percentage exceedance – to determine the proportion of events above a threshold (non-exceedance for events below a threshold).

2 Persistence analysis – a measure of likelihood for consecutive durations of discrete time intervals, when the threshold is either exceeded or not.

Good practice is to develop downtime analysis for the required metocean parameter(s) from a long-term time series of events recorded on a site located in the area of interest. It is most useful to obtain an uninterrupted data stream recorded with a regular interval of about one hour. To understand variations of downtime through the year, the time series data needs to be grouped into individual monthly blocks to establish periods when conditions are likely to be favourable for a selected activity. Where a long-term time series spans several years it may also be instructive to provide this analysis for each year and month separately to assess inter-annual variations as well as providing the generalised monthly statistics. Special care needs to be taken if gaps in the dataset have been filled as this may distort the statistics.

Threshold values need to be selected with consideration of pre-established operational limits for various activities, with values selected both towards and at the notional operational limit. For waves this is likely to be H_s values from 0.5 m up to the largest recorded wave height (to establish the full range of conditions) for the site in question and at a suitable increment, notionally from 0.1 m. For wind speeds, this is likely to be from 5 m/s up to the maximum wind speed and at a similar suitable increment, notionally from 2 m/s. It is good practice to adopt the same thresholds for both exceedance and persistence analysis, for consistency.

For exceedance analysis, the likelihood of exceedance is expressed as the percentage of events which are greater than the threshold value.

For persistence analysis, the likelihood for consecutive periods of time to remain above (exceedance) or below (non-exceedance) a threshold value is established for a series of time intervals, commonly 6, 12, 24, 48 and 72 hours, and expressed as a percentage.

Note that the percentage exceedance value is equivalent to the persistence percentage value determined at the interval of the source data.

Table 7.7 provides an example of persistence analysis for a month period, with year-on-year variation and an all-year summary value for the monthly variation included. In this example the probability to remain below the threshold for periods longer than 72 hours is assessed as 36.4 per cent of the month for all years. For a shorter duration of six hours this probability increases to 69.8 per cent of the month.

Table 7.7 ***Example table of persistence statistics***

Month events < Threshold			Probability of non-exceedance (%)			
Durations	2002	2003	2004	2005	2006	All years
≥ 6 hours	68	72	75	65	69	69.8
≥ 12 hours	64	67	69	63	66	65.8
≥ 24 hours	58	59	59	56	57	57.8
≥ 48 hours	44	47	48	43	44	45.2
≥ 72 hours	37	39	40	33	33	36.4

For offshore wind projects the percentage of time when the combined wind and wave conditions remain below respective threshold conditions is likely to be of additional interest to planning heavy lift operations for turbines and blades.

Graham (1982) provides a useful reference describing the theory of downtime analysis.

7.5 OPERATION AND MAINTENANCE STRATEGY

An initial high-level consideration of a project's O&M strategy is likely to have been developed as part of the project feasibility stage. During pre-construction activities this O&M strategy will need to be refined and finalised by absorbing and iterating the design activities.

The environments in which offshore projects are situated are, by definition, hostile to humans. The O&M strategy needs to be considered in conjunction with the detailed design, in order to define safe methods of access to the offshore site (and in particular to the structures), and appropriate to the sea state and climate conditions on-site. The limits of access, both getting in and getting out, to the site structures should also be clearly defined and written into the O&M contracts, to vessel charter parties and form part of the project health and safety plan, in accordance with CDM Regulations 2007. These access limits, or operational thresholds, will need to have an agreed, defined method of measurement and recording. The downtime analysis will inform the project as to what measures need to be taken to maximise operating efficiency, which may include design compromises for reduction in maintenance requirements, and vessel selection for improved access.

7.5.1 Operations

A system of continuous operations management will need to be in place, although not necessarily manned on a 24-hour basis. Operational co-ordination of site activities will include:

- ensuring site safety
- forecasting site output for grid management as a function of resource forecast and plant availability
- liaising with and directing maintenance management
- liaising with other sea users in the vicinity of the site and its access routes
- providing emergency response for the site
- logging of site operational data, including met ocean conditions.

In order to co-ordinate site activity, an operations manager will need:

- real time information (nowcasts) describing present conditions on-site
- short-range site-specific forecast
- medium-range site-specific forecast
- long-range site-specific forecast.

And for each of the following:

- wind speed and direction
- wave height, period and direction

- tidal direction and flow velocity
- visibility
- temperature
- lightning risk.

An operations manager will need confidence that the forecast data accurately predicts the site-specific conditions to ensure site safety, predict power output and optimise maintenance activities. As site experience is gained, the forecast model can be reviewed to improve data prediction. Accurate predictions of power output for the site, particularly for very large installations, can have significant impact on grid integration and will reduce grid balancing costs.

7.5.2 Maintenance

Maintenance requirements will vary depending on the technology employed and the scale of the project. A large wind farm installation may have permanent accommodation facilities for maintenance crew, while for a wave or tidal stream installation it may be preferable to have devices towed ashore for routine maintenance.

Again, the maintenance strategy should be considered in conjunction with detailed design because it will have significant influence on design selection for maximising equipment availability. If metocean conditions prevent site access for significant periods of time during winter months, when for wind and wave installations the resource is likely to be at its greatest, then design options may well include some redundancy or enhanced reliability in order to maximise plant availability.

Maintenance involving specialist activities such as towing operations, heavy lifts or subsea operations, where expensive equipment is involved, downtime risks are high, and safety risks are increased, may benefit from specialist forecasts for their duration. All such operations will benefit from guidance from the *Rules for planning and execution of marine operations* (DNV, 1996).

Ports selected to service maintenance operations will need to provide suitable access for maintenance vessels and draft. Tidal and weather restrictions should be considered as well as appropriate storage facilities for spares and equipment. If there are access restrictions to the port(s) selected, then suitable shelter should be defined for vessels unable to access the port in bad weather.

Offshore wind

Maintenance intervals for wind turbines are suggested to be about one visit per year. However, experience has shown that there may be other malfunctions, failures or breakages on the whole range of installed equipment. General and preventative maintenance will also be required which will combine to significantly increase site access requirements beyond this level. Indeed on a large wind farm (50 or more turbines) it is likely that an almost constant requirement for site access will exist for:

- post-commissioning visits
- in service inspections
- reliability centred maintenance (RCM)
- scheduled repairs of duplicate parts

- unscheduled repairs of critical parts
- third party testing and inspections
- survey monitoring requirements (as stipulated within consent conditions)
- decommissioning.

It is anticipated that most of the maintenance effort will be focused on the turbines themselves and in particular within the nacelle and hub as it is here that most of the equipment is concentrated. The turbine SCADA system will provide diagnostics for equipment malfunctions.

Transformer platforms and met masts will also require maintenance visits and the inter-array and export cables will require regular inspection with reburial and remedial cable protection work carried out when necessary.

Added to this should be the necessary general maintenance, which will also be required on the structures including boat landings, navigational lights, fog signals and safety lighting. There will also be a through life cleaning and painting workload.

Site access will be also be required for third party testing and inspections, for example for warranty or safety purposes.

Routine maintenance activities will usually be concentrated into summer campaigns which can be planned in advance to a high degree, and winter activities should be confined to unplanned events wherever possible.

Operations management will co-ordinate site activities, forecast site output, liaise with the maintenance management to ensure cost effective programmes, be responsible for site safety and provide emergency response for the site.

Wave

During uninterrupted operation of moored devices there is minimum requirement for personnel access to the unit. Larger devices are likely to be disconnected and towed to a local maintenance facility for almost all planned or breakdown maintenance. This facility will need to be sheltered from the prevailing weather to allow access and motion sensitive work to be completed. Devices will need to be designed so that personnel access to the device, once moored at the maintenance facility, is straightforward and safe. Appropriate weather windows (as determined by downtime analysis) can be selected for the towage operation, as discussed in Section 8.2.

Offshore site inspection of moorings and dynamic umbilicals may be required annually and is likely to be carried out with ROVs or divers. Similarly, annual surveys of cable burial depths and condition of scour protections will be needed.

As with wind installations, third party inspections and environmental consent conditions will be required.

Tidal stream

The tidal stream sites around the UK which offer the greatest potential for resource are generally located out with estuaries, for example Pentland Firth, the west coast of Scotland, Channel Islands, Anglesey and Bristol Channel. The majority of these areas are exposed to often challenging wind and wave conditions, and very high tidal flow rates (typically in the range 4 to 10 knots). It is anticipated that there will be little or no safe access possible to some of these sites during autumn and winter months.

In general, maintenance operations would benefit from being planned during neap tide periods and some operations, for example jacking, will need to be timed to coincide with slack water periods. Specialist vessels will be required in areas where the tidal flow exceeds safe levels for jacked up barges.

Most tidal devices are designed to be raised, in whole or part, to the surface for maintenance of the turbines. Some devices will be lifted aboard the maintenance vessel or barge for repair either on-site, or to be taken ashore. For minor repairs and maintenance cycles, personnel access to the structures may be planned.

For moored devices, offshore site inspection of moorings and dynamic umbilicals is likely to be required at least annually and these are likely to be carried out with ROVs or divers. Similarly, annual surveys of cable burial depths and scour protection conditions will be required.

7.5.3 Site accessibility

Offshore wind

Metocean parameters for site accessibility to offshore wind farms will be defined in terms of:

- maximum significant wave height (H_s) for boat/ladder
- maximum wind strength (figures vary greatly dependant upon site location, wind direction and access method) for boat/ladder, sea bridge or helicopter access
- visibility, icing and temperature
- state of tide, speed and direction of tidal flow, with positioning of ladders and access platforms a consideration in design
- lightning risk.

These parameters are interdependent and a matrix of threshold conditions is likely to be derived, based on site-specific metocean data which include validated historical datasets. These conditions, their definition and measurement will form part of the O&M contract between developer and contractor and, during warranty periods, between the developer and the turbine supplier.

In order to finalise detailed design of foundations, transition pieces and also nacelle design (if in the case of some offshore wind turbines helicopter access is required), then the access strategy should be determined. The transition piece will have access ladders and platforms orientated in relation to tidal flow and prevailing wind and wave directions to maximise accessibility to the structure. They will also include fenders for vessel docking. The height of the lower access platform is critical for both safe access and the structural integrity of the platform. It will be calculated from the lowest astronomical tide height (LAT) at the site, with an allowance made for extreme wave heights.

At the point of detailed design, it is important that there is a high degree of confidence in the analyses of site-specific conditions over both an annual cycle and in establishing the design wave conditions with respect to site access equipment.

Again, sampling locations for wave data are key in sites where there is a high degree of variation in the bathymetry, since shoaling, wave breaking and non-linear effects can have a profound effect on significant wave height at a localised level. In particular, data should be collected and analysed around points of significant changes in depth, while areas of consistent depth may be treated in a more generalised fashion. If turbines are placed in areas where conditions prevent safe access for long periods, then these turbines may need to include more robust design options to attempt to limit the requirement for unplanned access.

Access systems

It is not yet clear which access systems will prove the best or the most acceptable with respect to health and safety risks. At present different government departments, countries and even key individuals hold different views and restrictions. For example the Irish authorities will not allow rigid inflatables for personnel transfer offshore, while it is acceptable in UK waters. It is likely that access strategies to larger offshore installations will use a combination of access methods to suit different types of maintenance requirements under different conditions.

A number of innovative access solutions are currently in use in the offshore oil and gas industry, including concepts such as heave compensated gangways deployed from dynamically positioned vessels. In time, such solutions may be deployed in the offshore renewable industry, but they are not currently in use and are not considered here.

Personnel access to structures

Ladder access from small vessels has so far been the preferred method of access for Round 1 wind farm sites. *In situ* analysis of prevailing conditions at different parts of the site will define the most appropriate orientation for the ladders. Ladders are susceptible to slippery marine growth in the splash zone, due to wave action, and need to be regularly cleaned to prevent slipping and crush injuries or man overboard occurrences.

Vessel design for ladder access is a compromise between boat size and landing strength, and speed in transit versus heave response during transfer.

A vessel will move with six degrees of freedom – it will pitch and roll, yaw and heave, surge and sway. The heave and pitch of the vessel are of particular concern during personnel transfer operations and it is these characteristics which will be considered in relation to the prevailing site conditions when selecting a suitable vessel or vessels. The vessel and boat landing contact points should be designed such that the vessel is to power ahead while in contact with the boat landing, effectively increasing the friction between the two, largely reducing the vertical motion of the vessel at the contact point. This method increases the maximum significant wave height threshold for safe personnel transfers.

Figure 7.6 shows a typical arrangement of vessel access to a fixed platform with the bow pushed onto the access ladder. Typical limiting conditions for such access may be:

- significant wave height less than 2 to 2.5 m (depending on vessel and platform)
- wind speeds (at 10 m) less than 20 to 25 knots
- surface currents (depending on boat landing orientation)

Figure 7.6 ***Illustration of the challenge of vessel access to a fixed platform (courtesy WindCat Workboats Ltd)***

Presently there remain differing views as to whether vessel access is best achieved with mono-hull or catamaran designs, and examples of both are currently in use. The choice is dictated to a degree by the wave climate at the site and for the transit route from the shore base. Passenger comfort and safety during both transit and transfer will be enhanced by careful selection of the vessel hull design with respect to the dominant wave conditions.

These small vessels are particularly weather sensitive and ultimately use is limited to conditions where ladder access to structures is possible. In general, they do not provide a comfortable travel environment for technicians in moderate and bad weather; in bad weather the operating speed drops significantly. In deteriorating weather they may be forced to quickly leave the site and seek shelter. So they will have small weather operating windows for sites further offshore and are likely to experience considerable weather downtime. These reduced operating windows become of particular concern if they impact on the planned maintenance programme for the site.

Other access methods

Offshore maintenance bases have not been justified for the small nearshore Round 1 wind farm projects. However, they may offer an efficient and cost effective solution to some of the larger and more remote Round 2 projects which experience more limiting metocean conditions and offer a means to avoid transit from a distant shore station. Options for such bases could include:

- a mother vessel capable of remaining on station in all but the most extreme conditions with living accommodation for maintenance teams to remain offshore for a predetermined maintenance campaign of multiple working shifts
- a jack-up barge operating on-site in the self elevated mode with accommodation and endurance similar to the mother vessel
- a moored barge with accommodation and endurance as above
- a dedicated offshore accommodation and maintenance base designed and installed as an integral part of the project.

Large campaign based maintenance projects involving heavy lifts will require the use of specialist vessels, which are discussed in Section 8.2. These operations may require vessels to be jacked up adjacent to the turbine structures, in which case personnel can be transferred directly to the turbine structures via gangways.

Helicopter access

Site access via helicopter is considered a very expensive option. Personnel will need to be lowered onto the hub: a procedure which requires specialist training for both technician and helicopter crew. This method of access is typically only used on sites that are ice bound for periods or in an emergency where personnel are stranded or injured on the tower. Access conditions will be defined according to the capabilities of the helicopter and its crew.

Helicopter transport of personnel is an essential part of offshore oil and gas operations, and standards for metocean data observation and forecasting specific to these and other aviation activities are well established. The requirements will not be dealt with in great detail in this document, but introductory text and example forecasts may be found in *Weather-sensitive offshore operations and metocean data* (HSE, 2001) and in the Offshore Weather Panel *Handbook of offshore forecasting services* (WMO, 1997).

Wave farms

Site accessibility to wave energy sites requires assessment of metocean conditions to develop strategies for:

- maintenance of the wave energy converter
- site access for inspection, and maintenance of moorings and the subsea electrical infrastructure.

It is anticipated that most wave energy devices will be removed from site and towed or transported to an onshore facility for maintenance, so the limiting metocean conditions for service maintenance are those defined by the operating limits of the vessels used. The disconnection and towing operation would typically be carried out by a small multi-purpose support vessel (about 30 to 50 m). These vessels would be capable of deploying an observation class ROV and be equipped with dedicated anchor handling and towing equipment. Typical limiting conditions for a wave farm tow vessel may be:

- significant wave height less than 2 m (depending on vessel)
- wind speeds (at 10 m) less than 20 knots.

Inspection and maintenance of moorings, umbilicals and export cables will be carried out using a multi-purpose vessel or barge capable of holding station while deploying an observation class ROV. Operating limits will depend on whether the vessel is using dynamic positioning, anchoring or manual propulsion control. Typical limiting conditions for a wave farm subsea inspection and maintenance vessel may be:

- significant wave height less than 2.5 m (depending on vessel)
- wind speeds (at 10 m) less than 25 knots.

Note that WEC technologies are typically surface floating devices which have a relatively low profile in the water column. In raised seas the line of sight from the bridge of a service vessel may become severely limited and provide an added risk to approaching such devices (Figure 7.7).

Figure 7.7 ***Restricted line of sight for small service vessels in raised sea conditions***

Tidal stream sites

Site access to tidal energy sites, by the nature of the resource being exploited, will be governed by the strong tidal conditions as well as the wave profile. Tidal devices are generally designed for maintenance by:

- raising the device above sea level for surface access
- removing the device from the deployment structure or mooring for remote maintenance.

In the first scenario, metocean limits will be determined for safe personnel access to the maintenance platforms on the structure. For boat landing access, the constraints will be similar to those with access to a wind turbine structure, with the additional complication of strong tidal conditions. The tidal conditions, particularly for devices located in tidal races, may limit safe personnel access to short periods around slack water.

In the second scenario, the removal of the device may involve crane operations either from a jack-up barge or a vessel holding position with anchors or DP. Whichever vessel type is used, tidal stream conditions will significantly influence the operating windows for the work in addition to the wind and wave influences previously discussed.

Inspection and maintenance of moorings, umbilicals and export cables will be carried out using a multi-purpose vessel or barge capable of holding station while deploying an observation class ROV. Operating limits will depend on whether the vessel is using dynamic positioning, anchoring or manual propulsion control. Typical limiting conditions for a tidal device subsea inspection and maintenance vessel are likely to be:

- significant wave height less than 2.5 m (depending on vessel)
- wind speeds (at 10 m) less than 25 knots
- surface current less than 1.5 knots.

7.6 PLANNING AND PROCUREMENT

The principal contractor will carry out construction planning. Planning should take into account the likely metocean conditions during the construction window (typically April to October in UK waters). Agreement should be reached between contractor and developer as to the threshold limits for safe working and the thresholds and amount of downtime waiting on weather that is likely to be encountered (commonly referred to as weather days). These safe limits will be defined by the construction activity and vessel specifications. Depending on the amount of downtime anticipated and the amount of construction activity planned for each window, then the number and type of vessels required can be identified. This is an iterative process, which will depend not least on vessel availability (Figure 7.8). It is advisable that where the use of specialist vessels is anticipated, particularly in construction of offshore wind farms, vessel availability is established and they are procured as early as possible to avoid schedule delays. At the time of writing there are very few purpose built or converted specialist jack-up vessels for turbine installation that have both the ability to carry the significant payloads involved, piling and drilling equipment and have suitable cranes installed.

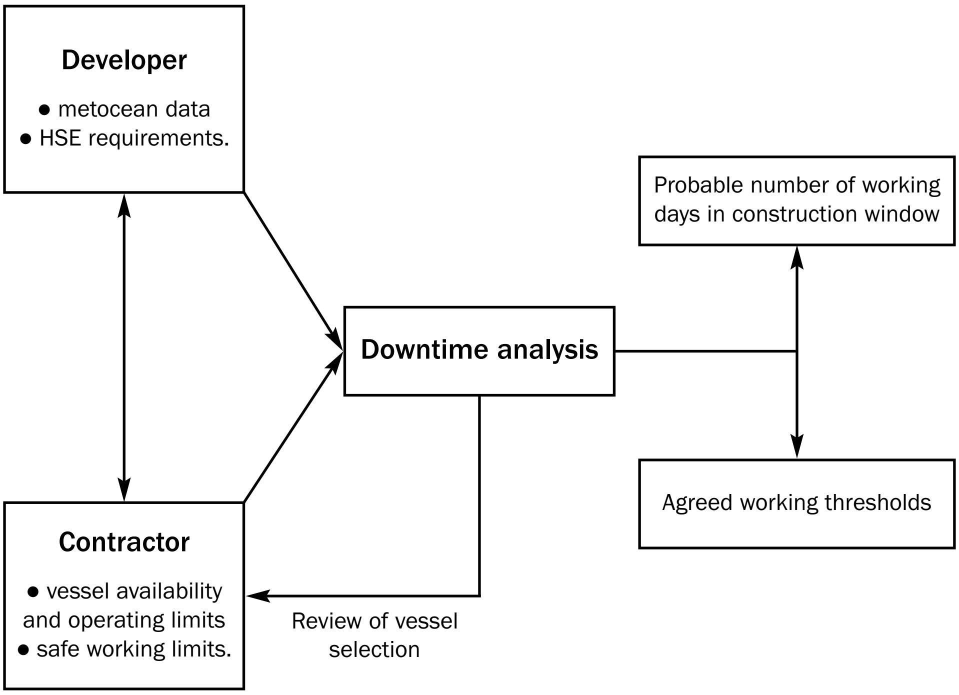


Figure 7.8 ***Vessel operations planning process***

It is particularly important when defining the downtime and threshold limits for contractual purposes, that the definitions of each parameter are agreed (for example, definitions of wave height and significant wave height, or for wind strength and direction, the height of measurement is stated) and equally importantly, that the method of measurement, time of measurement, and in the case of forecast data, time of forecast with relation to planned activities are agreed. This will avoid the potential for disagreement during the construction period in downtime claims.

Further, it should always be noted that the captain of a vessel is ultimately responsible for the safety of the vessel and crew and has final decision on all operations. HSE OTR 2001/022 on offshore operations specifically mentions that metocean data should not be used to apply pressure on vessel masters to work in conditions that are, in their judgement, marginal.

7.7 PRE-CONSTRUCTION MONITORING

Pre-construction monitoring activities are defined here as the set of further environmental surveys that have been agreed between the developer and regulator to respond to any remaining uncertainties in presumed environmental effects as described by the ES. Such requirements normally arise from the consenting of the project and are placed as a condition of the licence. For the purpose of the present guidelines these issues are taken as distinct from any detailed site investigation work required to fill data gaps to support detailed design, although opportunities to combine the two should not be ignored.

Pre-construction monitoring should also be seen to be part of the overall environmental monitoring programme which will extend to construction (Section 8.4) and post-construction phases (Section 9.4). It is good practice for the overall monitoring programme to be developed and agreed with the licensing authority.

The purpose of monitoring at the pre-construction phase is to provide additional evidence of the baseline environmental conditions ahead of any marine development activities.

In terms of metocean issues, vessel selection remains a primary issue for consideration, as described in Section 6.3. At this stage in the project life cycle the metocean database is likely to be fairly extensive and with detailed analysis developed to support both engineering design and O&M planning. This data and knowledge should be considered to assist in planning any further surveys.

8 Construction issues

8.1 OVERVIEW

From completing all pre-construction requirements a project will move into its construction phase. Activities that will be advanced during this stage of project development include (Figure 8.1):

- construction
- forecasting
- construction monitoring.

On-site monitoring is likely to continue, especially in relation to offshore wind and wave projects.

As an estimate, the timescale required to undertake construction activities may be between one to three years, depending on the scale of project and accessibility of the site.

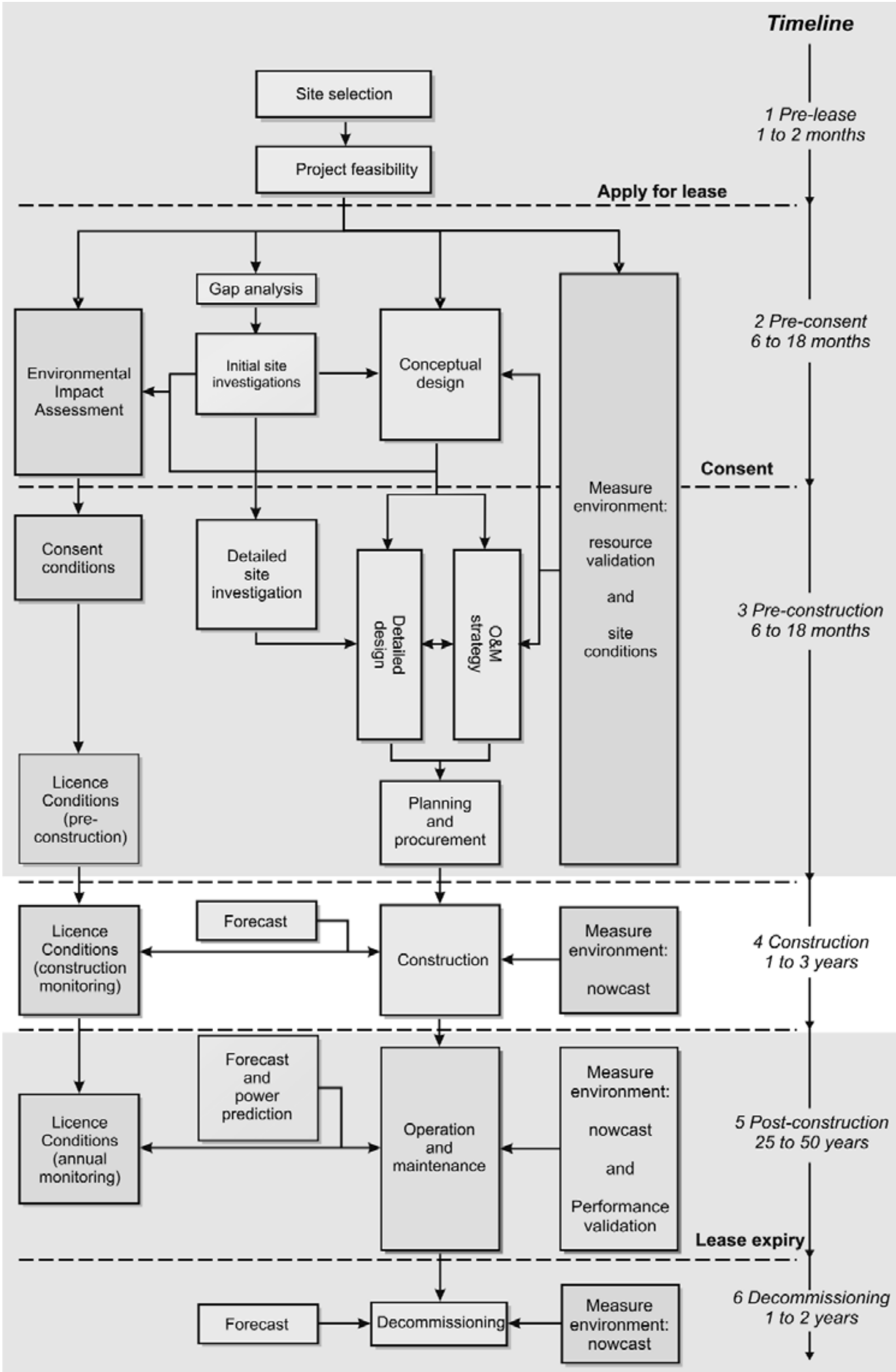


Figure 8.1 ***Construction activities and linkages***

8.2 CONSTRUCTION

Metocean conditions can have a significant influence on construction activities and adverse conditions can lead to cost escalation at a critical time in the project life cycle. At this point in the project, there will be a good understanding of the seasonal variation in prevailing conditions and site specific data collected will enable developers to have additional confidence in the accuracy or validity of historical datasets. This will also add confidence to the accuracy of predicting conditions at the site for a given forecast dataset. This information will allow the developer or principal contractor to define the construction window and with special reference to the probability of favourable weather windows assessed as part of downtime analysis (Section 7.4.3).

The project developer has responsibility for all activities contracted under them, so metocean data needs to be effectively communicated to all sub-contractors. Each type of renewable energy development (wind, waves and tide) will require bespoke engineering solutions to complete the construction phase. There will be common activities to all, as well as some marked differences requiring specific metocean information.

For example, metocean considerations for a wind farm installation should support the five main construction phases:

1. Foundation installation.
2. Tower and turbine installation, including blades.
3. Sub-station installation.
4. Cable laying.
5. Commissioning.

Construction activities will involve some or all of the following:

- loading of parts and equipment onto vessels
- transport or tow to the site
- positioning of construction vessels on-site
- drilling, piling or seabed levelling operations for foundations
- placement of scour protection
- crane operations
- diving operations, including ROV
- cable laying, including burial and scour protection
- personnel transfers
- commissioning and testing.

Wave device construction will be completed onshore, so offshore considerations for the construction are confined to installation of moorings and umbilicals, towage of device to the site, connection and commissioning. These operations are typically restricted to a maximum significant wave height of 2 to 2.5 m. Anchor handling with dynamic positioning (DP) capability and high load pull capability are required to pretension the moorings while on station using main engine power. The working limits of the tugs are defined by the safe working limits of personnel on the anchor handling decks, with significant wave height of 2.5 to 3.0 m.

The limiting environmental conditions for the tow route will dictate the availability of weather windows for completing the tow. A pre-requisite for the tow is the availability of sheltered havens at the departure and destination points for the tow. A typical procedure for getting a device from an onshore construction facility to the offshore site might be:

- major component assembly either onshore or afloat in sheltered harbour
- pre tow-out commissioning work and tow warranty survey (detailing maximum environmental limits for the tow, and the tow route)
- await weather window within limiting environmental conditions for the tow (tide height, tidal strength, wave height and period, wind strength and direction)
- conduct tow either directly to the offshore site or to the local port facility
- tow device to offshore site when metocean conditions are within limits for connection (Figure 8.2)
- connect and commission the device.

Specialist ocean tow forecast products are becoming available and should be investigated for their suitability to the specific project. The *Rules for planning and execution of marine operations* DNV (1996) is useful for single event operations such as tows.

Figure 8.2 ***Wave energy device under tow (courtesy Ocean Power Delivery Ltd)***

Metocean considerations for offshore construction of commercial scale tidal devices will largely mirror those of wind and wave devices with the significant complication that many activities may not be possible during times of peak flow. DP vessels may not be able to hold station for construction activities in these conditions and anchored vessels will be required.

All of these activities will be affected by the wind, tidal height, water flow rates, sea state and visibility. Timing of all transportation operations will be decided by weather forecasts, including wind and sea state and visibility for the duration of the passage. Medium and long-range forecasts will also need to be studied to ensure that, upon arrival, conditions on-site will be favourable for the start of installation. If this is not the case, then there is little point in risking vessel and equipment leaving port. Another unwanted cost that accurate metocean data management can assist in avoiding is demurrage. Finally, developments requiring specific heavy lift forecasts should be explored for their potential in maximising the use of weather windows, by increasing confidence in the forecast accuracy.

Construction planning should take into account the likely conditions that will prevail during the construction period and ensure personnel and equipment are safe when conditions deteriorate. In addition, downtime costs of specialist vessels used at this project stage are such that poorly informed decision making with regard to having such vessels on-site and operating could potentially increase the overall project costs substantially. As a result, understanding the accuracy of the forecasts for on-site and route-to-site conditions, and their influence on the decision making process is of high importance. The more confidence that the construction team have in the ability to understand and predict the metocean conditions on-site, the better site safety controls will be determined. For example, certain wind directions may be known to cause unsafe working conditions when combined with strong counter directional tides or large swells. This knowledge can be used with site-specific forecasts to plan operations around the tidal flows, potentially saving many hours of waiting time for vessels. Understanding the time available in which such a matrix of threshold conditions will not be exceeded may be critical to certain operations. For example, construction tasks that have very strict minimum completion durations, such as export (site to shore) cables installation, which is usually completed in one piece. Round 2 offshore wind projects may need up to 30 km of cable to be laid in a single operation.

Each construction activity and its associated equipment will have safe limits of sea state and weather pre-determined. Metocean considerations will have an important bearing on safety. The vessel owners and operators will define vessel safe working limits and hazard risk assessments will be completed for each operation. These limits will be written into construction contracts and vessel charter parties. It is important that agreement is reached on precise definitions of measurement for both real time and forecast conditions, remembering that vessel captains have ultimate responsibility for the safety of their vessel and crew.

Wind farm tower and turbine installation is an example of the extreme engineering challenges that need to be managed as towers are now generally in excess of 80 m in length. Tower, nacelle and blade installations (Figure 8.3) are carried out using jack-up vessels, with the deck raised to provide a stable platform for the crane operations. In addition to the metocean factors affecting foundation installation, the wind speed at maximum crane operating heights is an important influence on the installation timing. Nowcast data from the met mast should be used to assist in evaluating wind conditions at the equivalent lifting height.

Figure 8.3 ***Installation of turbine blades (left) aborted operations during high winds, (right) favourable conditions (courtesy Centrica Renewable Energy Limited)***

Vessel selection is a critical component of construction planning. To illustrate this some examples of wave and wind operating limits for foundation installation are presented. Foundation and transition pieces are normally installed using jack-up barges or specialist jack-up vessels which are self-propelled.

Figure 8.4 ***Typical jack-up barge (left) and jack-up vessel (right) (courtesy Centrica Renewable Energy Limited)***

Typical maximum operating conditions for a jack-up barge are shown in Table 8.1.

Table 8.1 ***Typical maximum operating conditions for a jack-up barge***

Operation	Wave height H_s (m)	Wave period T_p (s)	Wind speed at 10 m (knots)	Surface current (knots)
Under tow	1.5	–	20	Dependant on vessel power
Jacking operations	1.5	–	20	1.5
Jacked survival (non-operational)	10.0	9	70	2.5
Crane operations	3.7	6	25	–

Note: Figures based on 7.5 m air gap

Typical maximum operating conditions for a jack-up vessel are shown in Table 8.2.

Table 8.2 ***Typical maximum operating conditions for a jack-up vessel***

Operation	Wave height H_s (m)	Wave period T_p (s)	Wind speed at 10 m (knots)
Jacking operations	3.0	–	30
Jacked survival (non-operational)	10.0	9	70
Crane operations	–	–	30

Construction activities should be completed in a safe and environmentally sensitive manner, so the over-arching requirements for metocean data are driven by health and safety guidelines. Risk assessment is a key activity in the management of health and safety, and it is a legal requirement for every employer under the Management of Health and Safety at Work Regulations 1999. Emergency arrangements should also be in place, and procedures should be established based on suitable and sufficient risk assessments (Section 4.3).

For the purposes of this document the *Guidelines for health and safety in the wind energy industry* (BWEA, 2005) provide information that is common to the other resource types, also *Weather-sensitive offshore operations and metocean data* (HSE, 2001).

Risk mitigation measures include:

- scheduling of critical construction in the summer months
- maximising use of onshore construction so that offshore construction activity is minimised
- construction planning methodology that builds in flexibility to allow for appropriate activities to take place according to the conditions and vessel capabilities, and to maximise the efficiency of using specialist and expensive construction vessels and equipment
- accurate forecasting to direct activities appropriate to the conditions.

The most obvious mitigation of metocean risk is to schedule as many construction activities as possible during the summer months (usually between April and October in UK waters). Note there may be refinements within this window according to the site location. It is important that all weather factors are considered, including likelihood of electrical activity (lightning strikes) or number of days when visibility is reduced to unsafe levels due to fog in a given period.

Construction co-ordination, particularly of wind and tidal projects, is an extremely complex task and requires experienced personnel and well-defined procedures. The developer can add much to the project construction phase by providing contractors with a framework of comprehensive site metocean data for these decision processes.

Wherever possible, metocean data gathering should continue throughout the construction phase. This data will add to the site-specific experience and will be of particular use in further defining threshold limits for O&M activities, especially in relation to vessel performance and personnel access.

All offshore operations will need to comply with the International Convention for the Safety of Life at Sea (SOLAS) 1974 and amendments, and to take note of, and co-ordinate with, the Maritime and Coastguard Agency responsible for implementing maritime safety policy in UK coastal waters. In general, exclusion zones will be established around works with boundaries designated by navigational marks whose configuration will be agreed with Trinity House (England, Wales and the Channel Islands) or the Northern Lighthouse Board (Scotland and the Isle of Man), while IALA codes give international guidance. Notices to Mariners will be issued advising of construction activity, to notify other sea traffic. A safety boat will be on standby to protect against persons falling into the water, and to warn away approaching vessels from the boundary. As the construction works are carried out in summer months, there are likely to be yachts and other pleasure craft trying to get a closer look.

Operations need to be designed so they can be terminated or made reversible wherever possible, should weather conditions deteriorate. This will include definition of the threshold conditions under which search and rescue operations can be carried out that will influence the site exposure limits for activities where man overboard is a potential risk. *Rules for planning and execution of marine operations* (DNV, 1996) will assist for specific events and compliance with the CDM Regulations 2007. Operational worst-case scenarios include abandonment of all construction activities in the case of a *force majeure*. This may apply when, due to stress of weather or any other cause, the master of a vessel determines that it is necessary to deposit the substances or articles because the safety of human life and/or of the vessel is threatened. A robust metocean information management system in conjunction with the safe system of work should ensure that this eventuality does not occur.

Plans should also be made for evacuation and return to safe waters, should forecasts change so that conditions are expected to deteriorate to the point where it becomes untenable for the vessel(s) to remain on-site.

On completion of construction, CDM Regulations 2007 dictate a safety file is passed onto the owners. There will be a test phase before the renewable development is handed over, followed by a snagging phase.

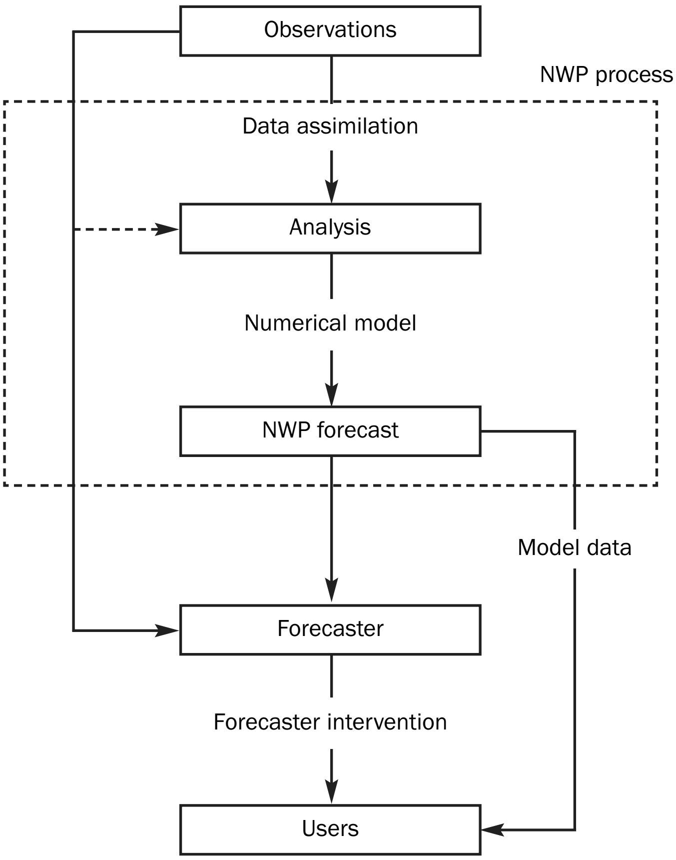
8.3 MARINE FORECASTS

During construction, post-construction and decommissioning phases marine forecasts will become essential when making decisions for all offshore activities.

Forecasts build on the capability to run numerical weather prediction (NWP) models forward in time (the model forecast). NWP models aim to provide an accurate description of environmental variables over a high density global or regional grid of locations. The NWP process can be thought of as having two stages:

1. To combine available observations with a background of high density model data in order to achieve a best representation of near past or present conditions over the whole model grid (the analysis), a process known as data assimilation.
2. To propagate the model forward in time to produce the forecast.

For all the recent advances in computing power and NWP model sophistication, the human forecaster retains a key role in assessing model performance, referring to up-to-the-minute observations and adjusting the forecast as necessary. This role can be particularly important when and where the model does not sufficiently resolve complex topography or small-scale weather effects. As a result the idealised forecast process follows the schematic presented in Figure 8.5.



Note: Real time observations sourced worldwide are combined with model fields through the process of data assimilation in order to produce an analysis. NWP models propagate the analysis conditions forward in time to produce the model forecast. Model data may be released straight to users, but in major meteorological agencies the forecaster remains a critical part of the system, providing quality assurance and where necessary intervention to improve both analysis and forecasts over the short to medium-range

Figure 8.5 ***Schematic of the weather forecast process (courtesy Met Office)***

The source models from which forecast data are acquired will differ. Three source model types provide the basic parameters for metocean forecasting:

1. Atmospheric models simulate winds, weather and cloud details (which can be used to deduce other parameters, such as lightning risk). Incorporating observations of the current state of the atmosphere into a previous model forecast, and then running the model forward in time using mathematical equations (often known as the primitive equations) to produce predictions of future atmospheric conditions.
2. Wave models are driven by forcing from an atmospheric model and provide sea state characteristics, including significant wave height, period, direction and swell details based on evolution of the wave spectrum. Two model schemes are in common operational usage and are described as second or third generation depending on the amount of explicit calculation used by the model to describe wind-sea growth.
3. Ocean models use either two dimension depth averaged or full three dimension schemes, and, based on tidal harmonics and atmospheric model forcing, simulate sea surface elevation and current (flows), plus other physical properties of seawater such as temperature and salinity. Two dimension depth averaged models do not make consideration of the vertical density effects (due to variation of seawater temperature and salinity over depth) that are explicitly represented in three dimension models, but are nonetheless considered adequate for a number of shallow water applications.

A number of providers (both National Met Services and commercial companies) already service the offshore oil and gas industry (Table 8.3), leading to a range of highly developed forecast product types being available. Each product will have its own level of quality assurance, which is often directly linked to cost. When commissioning a service it is important to consider the requirement and importance of the operation being conducted, the consequence of a poor forecast being issued, and how much support (eg by a forecaster) might be required.

Table 8.3 ***Example providers of forecast services to the UK sector of the North Sea oil and gas industry***

Company name	Web address
Aerospace & Marine International (UK)	<http://www.amiwx.com/>
MeteoGroup UK	<http://www.meteogroup.co.uk/>
Met Office	<http://www.metoffice.gov.uk/>
Wilkens Weather Technologies (partners Nowcasting International)	<http://www.wilkinsweather.com/> (<http://www.nowcasting.ie/>)
WNI Weathernews (UK)	<http://www.weathernews.com/>

The Offshore Weather Panel *Handbook of offshore forecasting services* (WMO/TD-850, 1997) offers a number of guidance principles that should be applied to the quality control system presented by a service provider to potential forecast users. The majority of forecast providers apply WMO standards as the basis for quality control, and in addition the modern specifics of professional weather/ocean forecasting (ie compilation of observations, running NWP models in an operationally robust fashion, robust and up-to-date dissemination methods) act strongly to distinguish between good and bad forecasting agencies. Application of WMO standards does have a limitation however, in that its validity for atmospheric forecasting does not yet extend into oceanographic forecasting.

WMO/TD-850 proposes the basic requirements for a provider of marine/coastal forecasts should be that:

- the service shall be based on a coherent production line, connecting:
  - a collected observational data
  - b numerical prognostic and hind-cast models
  - c a system for information distribution and warnings
  - d a dynamic feedback system connected to the customers
- observational data should flow continuously into the service on a 24 hourly basis, both from the WMO conducted global network, as well as from national and locally dedicated networks. Networks and sensors should be adequately documented
- numerical model tools embrace atmosphere, waves, sea level, ocean circulation and stratification, sea ice and transport of substances and objects. All numerical models shall be documented in open literature. Expertise of staff shall follow WMO recommendations and be documented
- systems of warnings and bulletins should follow WMO standard requirements, to avoid misinterpretations. Included should be a requirement for 24 hour services all year round, and arrangements for emergency situations. Recommended emergency response should be within 30 minutes any time of day or night
- the contact with the end user should be interactive and dynamic, with arrangements for swift follow-up of user requirements

- the service should follow a framework for quality management in close compliance with WMO recommendations.

A variety of forecast types and products (Section 3.4.5) are available to decision makers, and should allow a cost effective source of information to be available throughout the course of operations.

In a number of cases, generic and area forecasts (ie non site-specific) can be used when decision making, subject to the operations tolerating a lower degree of certainty in prediction of conditions on-site and acknowledging the possibility of a greater number of downtime days waiting on weather as a result. For many operations however, the cost of acting on incorrect forecast information (in safety and/or financial terms) will be such that it is most effective to bear the overhead of employing specialist forecasters and forecasting products.

Beyond the simple rule of thumb that weather forecasts are likely to diminish in accuracy with increasing lead time (ie a five day forecast should perform worse than a two day forecast), general quantitative statements regarding forecast performance versus lead-time are hard to make. This is for a variety of reasons, including:

- the parameter to be forecast (some parameter types are dealt with better than others in NWP, and/or vary less rapidly in the real world, ie are more predictable)
- the complexity of the location to be forecast for, and need for downscaling required
- the degree to which observations and/or known uncertainties in the NWP model are accounted for during the early part of the forecast (ie has a nowcast or forecaster been used to improve the first one to two days of the forecast)
- the NWP model from which data in the early and latter stages of the forecast is sourced (for example in early 2007 the Met Office sourced from model data with approximately 12 km and hourly resolution for the first 36 hours of a forecast, but from approximately 60 km and three hourly resolution model data thereafter).

Quantification of forecast performance will be service dependent and, with this in mind, obtaining some suitable forecast verification statistics when engaging a forecast service should be considered. Metocean forecast suppliers should hold some examples of these data.

The Beatrice Wind Farm demonstrator provides an example of an extremely precise wind and wave forecasting requirement experienced during the construction of the project (see Box 8.1). The operation being undertaken (transit and heavy lift) had a significant financial risk attached due to the use of specialist plant and fully constructed turbine component. The successful outcome was the result of recognising potential pitfalls associated with model forecast data and choosing to augment the service with an on-site forecaster and the deployment of a waverider buoy at the installation location.

Box 8.1 ***Case study: Forecast services for Beatrice wind turbine installation***

Project: Beatrice Wind Farm demonstrator (Talisman Energy UK Ltd/Scottish and Southern Energy)

Characteristics: This project presents a glimpse into a potential future for marine renewable developments by deploying wind turbines around existing offshore oil and gas infrastructure. Generally such deployments would be in deeper water than the present raft of wind farm schemes, but should benefit from established construction and operations technologies and practices for offshore oil and gas installations.

Installation issues: An example of this use of existing technology was in the choice of a familiar jacket and topsides design for the wind turbine installation. Further details of this process are provided in the DTI document *Deepwater offshore windfarm – design fabrication and installation study* (Talisman Energy Ltd, 2004). Installation of the wind turbine required a transport and lifting operation for both the jacket structure and topsides comprising a fully assembled turbine (ie tower, nacelle and blades). The jacket was towed onto the site using a tug, but otherwise lifting and transportation of the turbine were performed using the heavy lift barge Rambiz (Figure 8.6). For these operations the threshold for sea state was relatively low (less than 0.5 m significant wave height and no swell of period longer than five seconds), with a window of three to five days required for transport and lift of the topsides. Wind conditions were also required to be relatively benign with a maximum of 8 m/s (approximately 16 knots) gust speed constraining crane operations.

Mitigation: From a forecast provider's perspective, provision of a forecast based on model data only with respect to such low thresholds will incur a level of risk, since known model errors for both wind and wave prediction (eg for wave models due to misrepresentation of early stage wind-sea growth, or arrival time of long distance swell) are potentially significant with respect to the threshold value. In recognising this, the Beatrice project adopted the mitigating strategy of employing a Met Office specialist marine forecaster that could identify uncertainties in model forecast performance and adjust the prediction accordingly. For offshore site deployments, the experiences of the forecast staff on-site are also logged in order to inform future service provision at the same site.

The on-site forecaster is significantly aided by good on-site metocean observations, and for this project a waverider buoy was deployed (although some issues were noted with regard to data communication and format from this instrument). The forecaster also requested and used spectral wave data (in addition to the usual wave height forecast) due to the sensitivity of the lifting barge to low long period waves in sea states comprising multiple components.

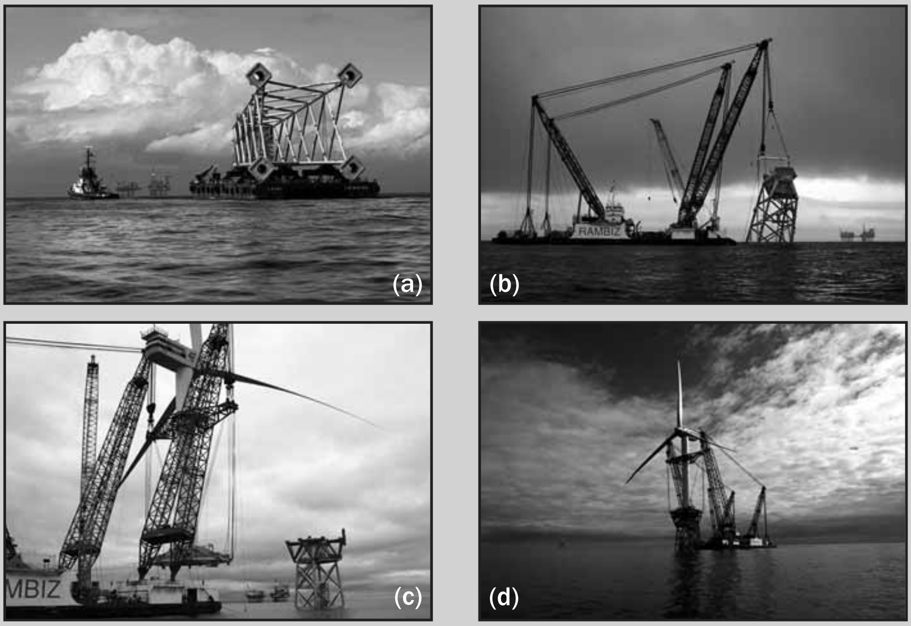


Figure 8.6 *Installation operations at the Beatrice wind farm demonstrator site: (a) towing the jacket onto site, (b) the jacket lift operation, (c) approaching the jacket with the topsides (fully assembled wind turbine tower, nacelle and blades), (d) topsides installed atop the jacket (courtesy Beatrice Wind Farm demonstrator project website at <http://www.beatricewind.co.uk>)*

8.4 CONSTRUCTION MONITORING

During the construction phase of a marine renewable development it is anticipated that further metocean information is required to support the construction process. In addition, construction monitoring may be needed to respond to any licence condition for environmental issues.

Depending on the construction process further metocean information will be vital to support operational decisions, including real time forecast verification and as input to nowcast products (ie short-term predictions that combine both real time observations and forecast). These data can also be available for longer range forecast verification, as well as other future data analysis (eg for plant selection in the operations and maintenance phase). Unless there are periods when no construction is occurring, such as during winter months, it can be expected that continuous observation is required.

The purpose of construction monitoring is to provide additional evidence of the effects on the environment by the construction process such as piling noise, disturbance to seabed etc. At this point there may be no direct requirement to monitoring impacts on metocean conditions, but more interest in indirect effects resulting from changes to metocean conditions, such as potential for scouring.

As with pre-construction monitoring, vessel selection remains as a primary issue for consideration, as described in Section 6.3. At this stage in the project life cycle the metocean database is likely to be fairly extensive and with detailed analysis developed to support both engineering design and O&M planning. This data and knowledge should be considered for further survey planning.

9 Post-construction issues

9.1 OVERVIEW

From completing all construction requirements a project will move into a phase of operation (revenue generation period). Activities that will be advanced during this stage of project development include (Figure 9.1):

- operation and maintenance
- forecasting and power prediction
- post-construction monitoring.

On-site monitoring is likely to continue, especially in relation to offshore wind and wave projects.

As an estimate, the timescale for the post-construction phase will equate to the lease conditions and is likely to be 25 to 50 years for the commercial scale projects.

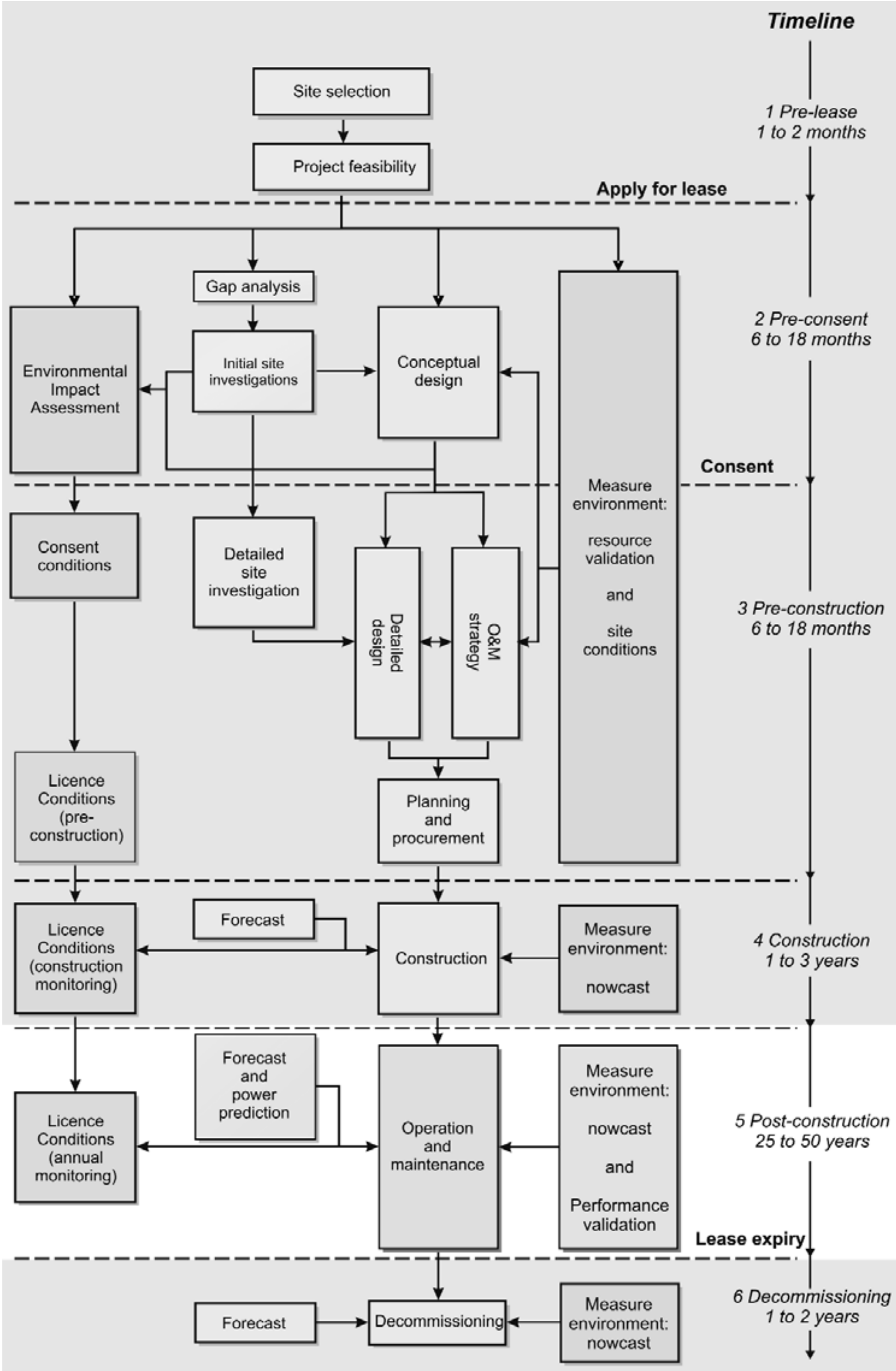


Figure 9.1 ***Construction activities and linkages***

9.2 OPERATION AND MAINTENANCE

The O&M phase of the project feeds from the strategy developed as part of the pre-construction activities (Section 7.5). At present all marine renewable technology remains relatively young in its development which leads to higher than normal maintenance cycles when compared to established technology. Where possible, measuring devices placed on-site for previous phases of a project should be left in place and maintained to assist in providing continuous data to support O&M.

During the post-construction phase there should be a significant amount of metocean data available to increase confidence in being able to accurately predict conditions at the site. O&M activities should be completed in a safe and environmentally sensitive manner, so the over-arching requirements for metocean data are driven by health and safety guidelines. Risk assessment is a key activity in the management of health and safety and it is a legal requirement for every employer under the Management of Health and Safety at Work Regulations 1999. Emergency arrangements should also be in place, and procedures should be established based on suitable and sufficient risk assessments.

For the purposes of this document the *Guidelines for health and safety in the wind energy industry* (BWEA, 2005) and W*eather-sensitive offshore operations and metocean data* (HSE, 2001) provide information which is applicable to all resource types.

Maintenance planning can split into two areas:

1 Strategic maintenance (anticipated).

2 Immediate maintenance (reactive).

Strategic maintenance includes all forms of maintenance that can be anticipated, or that involve equipment ordering or specific lead times that allow for selection of favourable seasonal conditions. For example, a painting programme for a wind farm installation will need to be planned and this will naturally be timetabled for the summer months when more stable conditions prevail.

Downtime analysis will help to identify the most appropriate times in which to plan this work and provide an estimate of risk due to unfavourable weather conditions. Long-range forecast products may allow a degree of scheduling for specific activities, and vessel and personnel arrangements. Forecasts at a shorter range (up to seven days ahead) can be used to confidentially confirm the start date, taking into account sea state, wind speed and direction, tidal range and visibility. Short-range forecasts and nowcasts will be used for schedule refinement according to the likely conditions met on the day. However, the actual measurement of sea conditions and wind strength on-site versus the threshold limits set, together with the experience of the vessel and maintenance crews, will dictate the level of access possible.

For Scroby Sands a 2 m significant wave height (H_s) limit is set for transfers, and during 2005 this incurred 143 weather days when the threshold criteria was exceeded. In comparison Kentish Flats works, with a lower threshold of H_s = 1.5 m, incurred only 31 weather days during 2006. The greater number of weather days incurred at Scroby Sands (albeit in the previous years) is a clear indication of the greater exposure of the site to waves.

As site experience is gained, licence holders have found that the analysis of site recorded metocean data can help to predict the degree of maintenance likely to be needed. This information can be fed into the maintenance programme.

Immediate maintenance is reactive. It will be necessitated from:

- equipment failure
- site emergency
- emergency within the vicinity of the site requiring assistance of site vessels and personnel
- deterioration of weather conditions on the site, requiring immediate review of planned activities
- deterioration of forecast conditions for the site, requiring review of planned activities.

Site operations managers will need to know the threshold limits of all vessels on site so that they are able to direct activities appropriate to the vessels abilities given the conditions. The types of vessels likely to be used for O&M are anticipated to be small mono-hulls and catamarans drawing from existing supply boats, diving support vessels and emergency rescue and recovery vessels (ERRVs).

It is good practice for operations managers to be supplied with nowcast and forecast data on a 24-hour basis and this information will play a large part in the day-to-day decision making. It is important that opportunities are taken throughout the project development to both gather and analyse site specific data so that there is a high degree of confidence in the models used to make site forecasts at this stage in the project and also in understanding the nowcast data in terms of its influence on site activities. This is particularly important for installations further offshore where access to the equipment is very sensitive to the sea states. The need for key operational decision makers to appreciate and correctly interpret the metocean information available may dictate that some level of training is provided to these staff by a metocean specialist.

Definition of appropriate maximum exposure conditions will be both site-specific and vessel specific and are likely to be adjusted as experience of operating and maintaining the development is gained. In general, access to marine renewable platforms is not recommended in conditions with significant wave heights of greater than 2 to 2.5 m. Factors that affect wave steepness and boat handling, such as wind strength, wave period, tidal conditions and their combined local effects, should be taken into consideration. Data received from real time on-site monitoring of metocean conditions is likely to be referenced in contractual arrangements between the installation operators and vessel owner/operators.

Experience has shown that some operations and maintenance personnel, who are expert in their fields onshore, are unable to operate effectively in the marine environment due to seasickness or extreme discomfort with the environment. This should be taken into account at an early stage when resource planning for the site. Consideration should also be given to ensuring that sufficient comfort is provided in access vessels so that maintenance personnel arrive at the site and are able to work safely and efficiently.

Accurate modelling and recording of site-specific metocean conditions will certainly lead to improved maintenance vessel selection for the site which will maximise its accessibility. This is likely to be an iterative process through the life cycle of the project.

Diving operations

For certain tasks divers might be required for O&M activities, particularly in the case of tidal stream devices, when it is not possible to raise the parts requiring attention above sea level. Dive times are limited by current flow rates that dictate the ability to complete underwater tasks. TEC devices will be placed in fast flowing waters, and accurate information on currents will enable these operations to be planned and carried out more safely and efficiently. Diving related maintenance will need to be completed around periods of slack water and preferably during neap tides. Quantifying the time available around slack water will be crucial for planning such maintenance. It might be considered that real time flow data throughout the water column (using ADCP devices) should be permanently installed to verify conditions for divers, with a further value in supporting resource validation and energy extraction efficiency calculations (Section 9.3).

Diver operations are also highly sensitive to sea state conditions and accurate information on this will be required. The wave height when recovering a diver is critical, as poor conditions will increase levels of risk. Equally, rough seas can make surfaced diver location very difficult. Real time wave data will enable operations to be completed within agreed safe systems of work and risk assessments.

An ideal project at this stage of the project life cycle will have benefit of:

- validated forecast model which can be used to:
  - select operating windows for vessels working on-site that can be written into maintenance charter parties
  - plan seasonal maintenance windows
  - optimise maintenance schedules within a window
  - improve site safety by minimising exposure to extreme conditions
  - accurately predict output for national grid balancing.

- nowcast site data which can be used to:
  - direct operations real time
  - improve site safety
  - accurately predict output for national grid balancing
  - evaluate production efficiency allowing identification of areas for improvement.

9.3 PERFORMANCE VALIDATION

Offshore generating equipment will always need to incorporate a remote monitoring and shutdown facility. In the case of wind turbine generators this will be provided through fibre optic data communications, transmitting real time SCADA feeds (supervisory control and data acquisition), monitoring every aspect of the equipment's status (including wind speed and wind direction taken from the turbine's anemometers).

An offshore wind site will still maintain several met masts from which data will be continuously gathered throughout the life cycle of the project. It is good practice for at least one met mast to be placed immediately adjacent (within 100 m) of a turbine to provide validation of the power curve, noting that turbine anemometers are influenced by blade passing shadow and local turbulence effects. The data from the met mast would be considered as the definitive record of energy yield at the site. Local turbine anemometer readings give a means to analyse possible wake deficit effects which could influence projected energy yields from individual turbines.

The same principles apply for any wave or tidal scheme. Independent site measurements (from site buoys or other measuring devices) need to be taken in addition to any monitoring equipment built into generating devices.

Guidance for performance validation of wind turbines is available from:

⇨ *Wind turbines* (ASME, 1988).

For tidal stream devices a preliminary guide has recently been produced:

⇨ *Preliminary wave energy device performance protocol* (DTI, 2007).

And similarly for waves:

⇨ *Preliminary tidal current energy: device performance protocol* (DTI, 2007)

⇨ *Performance assessment for wave energy conversion systems in open sea test facilities* (EMEC, 2004).

9.4 POST-CONSTRUCTION MONITORING

Post-construction monitoring activities are defined here as the set of further environmental surveys that have been agreed between the developer and regulator to respond to any remaining uncertainties in presumed environmental effects as described by the ES. This monitoring is a continuation of activities required at various phases through project development, from pre-construction (Section 7.7) and construction monitoring (Section 8.4).

It becomes important that the suite of monitoring remains consistent to pre-construction activities as this initial set of data will form a basis of comparison to results collected after construction. Annual monitoring reports will require submission to the licensing authority for review. This review process will provide the basis for decisions to continue with further environmental monitoring.

As with pre-construction and construction monitoring, vessel selection remains as a primary issue for consideration, described in Section 6.3. At this stage in the project life cycle the metocean database should be fairly extensive. This data and knowledge should be considered for further survey planning.

10 Decommissioning issues

10.1 OVERVIEW

When the scheme has expired its lease or there is a previously agreed point when the development is no longer required, a process of decommissioning will be required. Activities that will be necessary at this stage of project development include (Figure 10.1):

- decommissioning
- forecasting.

On-site monitoring will also cease as the scheme is decommissioned with any measurement platforms quickly removed.

The timescale for the decommissioning phase depends partly on the scale of the project, and for larger developments this may require a period of up to two years.

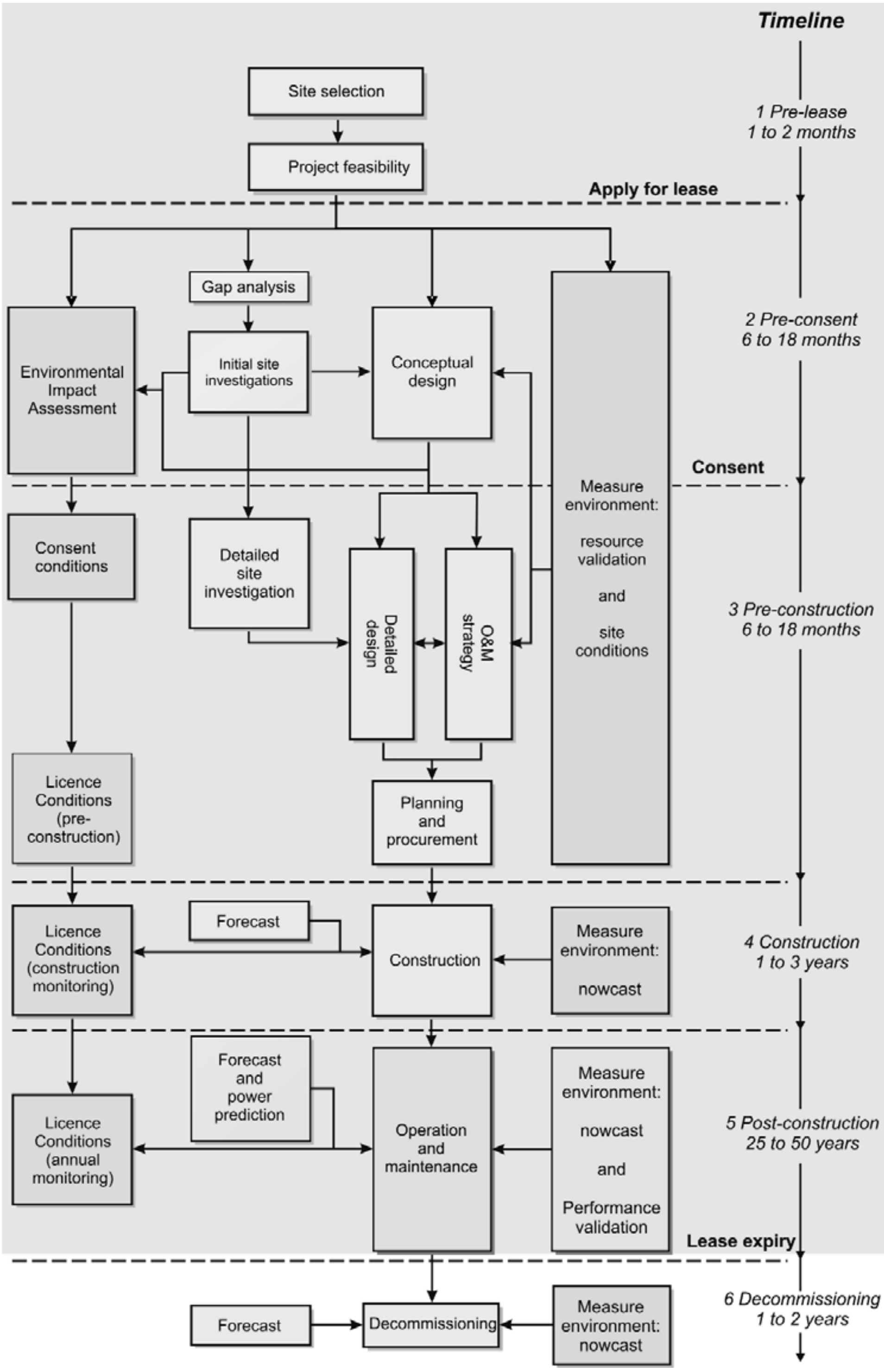


Figure 10.1 ***Decommissioning activities and linkages***

10.2 DECOMMISSIONING

The removal of structures in seas around Europe is governed by both the Oslo-Paris Agreement (OSPAR) 1998 and the Energy Act 2004, which states that structures should be removed to seabed level unless it can be shown to be environmentally worse to do so.

Metocean considerations for decommissioning are similar to those for general construction works with a requirement for suitable vessel selection and use of forecast data for operations. Post-decommissioning surveys may also be needed to ensure scouring around residual structures or buried cables are not significant.

Present guidance on decommissioning issues includes:

⇨ *Decommissioning of offshore renewable energy installations under the Energy Act 2004, guidance notes for industry* (DTI, 2006).

Alongside the presumption in favour of full removal the guidance considers five situations where other solutions may be considered:

1 Alternate use of the structures.
2 Entire removal would incur extreme cost.
3 Entire removal would involve unacceptable risk to personnel.
4 Entire removal would involve unacceptable risk to the marine environment.
5 The installation weighs more than 4000 tonnes or is standing in over 100 m of water without causing unjustifiable interference to other uses of the sea.

In cases where only partial removal of any installation or structure is considered, the coastal state should be satisfied that any remaining materials will stay on location on the seabed and not move under the influence of waves, tides, currents, storms or other foreseeable natural causes so as to cause a hazard to navigation. Such considerations will need to draw on the available metocean data and assess if future extreme conditions provide any remaining risk sufficient to move structures from their charted positions.

It is also likely that climate change and improvements in climate change predictions may lead to a greater understanding in future metocean conditions to the extent that, for example, estimates of downtime devised for the construction phase no longer hold. These risks to the original dataset substantiate the potential benefit for ongoing monitoring and maintenance of the project metocean database through the project O&M phase.

Different engineering solutions will probably be available when decommissioning is required and could be 25 to 50 years after the construction phase. Additionally, bespoke metocean data requirements might arise due to the nature of the decommissioning process and use of specialist equipment such as a decommissioning rig, which necessitates the re-evaluation of risks and metocean data use. This will include issues common to the construction phase such as rig movements, operations and downtime analysis.

11 Summary remarks

This document has sought to highlight that a successful marine renewable development requires an adequate consideration of metocean issues throughout all stages of project development.

Metocean parameters have a primary influence on the feasibility of a project since sites offering high resource potential are also likely to lead to increased challenges for design and access.

The preferred means of determining metocean criteria is by making use of long-term site-specific field measurements. A range of data sources and data providers exist, but the general scarcity of long-term marine observational data means that other types of data may be taken into a study at the outset (ie from broadscale models).

Early phases of project development, through to pre-construction activities, are likely to draw on available archives of metocean data to support economic, environmental and engineering related activities. Care needs to be taken when selecting such data into a study to support these activities, as this information will frequently need to be developed further to become fit-for-purpose for the area of interest and the type of application.

Many existing publications provide comprehensive descriptions of metocean conditions more immediately relevant to deep water and offshore installations. Adopting such data, to infer conditions at an adjacent shallow water site, may lead to both over- and underestimation of certain parameters. Waves, for example, may be overestimated when shoaling effects begin to dissipate some of the deep water wave energy.

Importantly, as the project moves through its life cycle, a more refined understanding of metocean issues will be required which will extend beyond available data. Initial datasets may no longer be fit-for-purpose for subsequent tasks, leading to a requirement for further and other types of data, such as *in situ* monitoring and forecasts.

The amount of data and understanding of metocean issues will naturally increase through the project life cycle and over time, as will knowledge and experience of site conditions. To ensure that this knowledge is used and shared effectively throughout a project team requires the use of a good data management system and regular maintenance of a metocean database.

It is also prudent to comment that ongoing research and development is likely to introduce new methods, improved products and services, as well as developing a greater understanding of issues such as climate change. Over time these advances may assist in reducing some of the remaining risks and uncertainty related to metocean information.

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