Sustainable Development Commission

Tidal Power in the UK

Research Report 1 - UK tidal resource assessment

An evidence-based report by Metoc for the Sustainable Development Commission

October 2007

SUSTAINABLE DEVELOPMENT COMMISSION

UK TIDAL RESOURCE REVIEW

CONTRACT 1

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SUMMARY

INTRODUCTION

This review covers the tidal energy resource in the UK, and also considers grid connection issues, policy related to tidal energy development and issues associated with sea level rise and coastline types.

Tides are caused by the gravitational attraction of the moon and the sun acting upon the oceans of the rotating earth. The rise and fall of the tides gives rise to horizontal water movements, known as tidal currents (or streams), and vertical water movements, known as tidal range. Both tidal range and tidal currents can be used to generate energy, typically in the form of electricity.

In the UK high and low tides occur approximately twice daily, and the time of high water advances by approximately 50 minutes per day. The height of the tides change on a world-wide 14 day cycle due to the degree of alignment between the moon and the sun. This gives rise to spring, and seven days later, neap tides. The tides are also affected by a half-year cycle, due to the inclination of the moon's orbit to that of the earth, giving rise to the largest spring tides around the time of the March and September equinoxes, and the smallest spring tides approximately coincident with the summer and spring solstices.

REVIEW OF TIDAL ENERGY RESOURCE

A range of studies, data and information were reviewed to give an overview of the spatial distribution and temporal variation of resource around the UK and the potential electricity generation contribution to UK demand.

The spatial distribution of sites of good **tidal current** resource, identified in the various studies reviewed, are illustrated in Figure A.

Sustainable Development Commission - Review of UK Tidal Resource

Summary of tidal stream resource locations

Legend

Tidal stream resource sites

Date	26 April 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	Black & Veatch, ABPMer et al, DETI et al, Metoc	
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The various studies and data sources revealed the following with regards to tidal current resource:

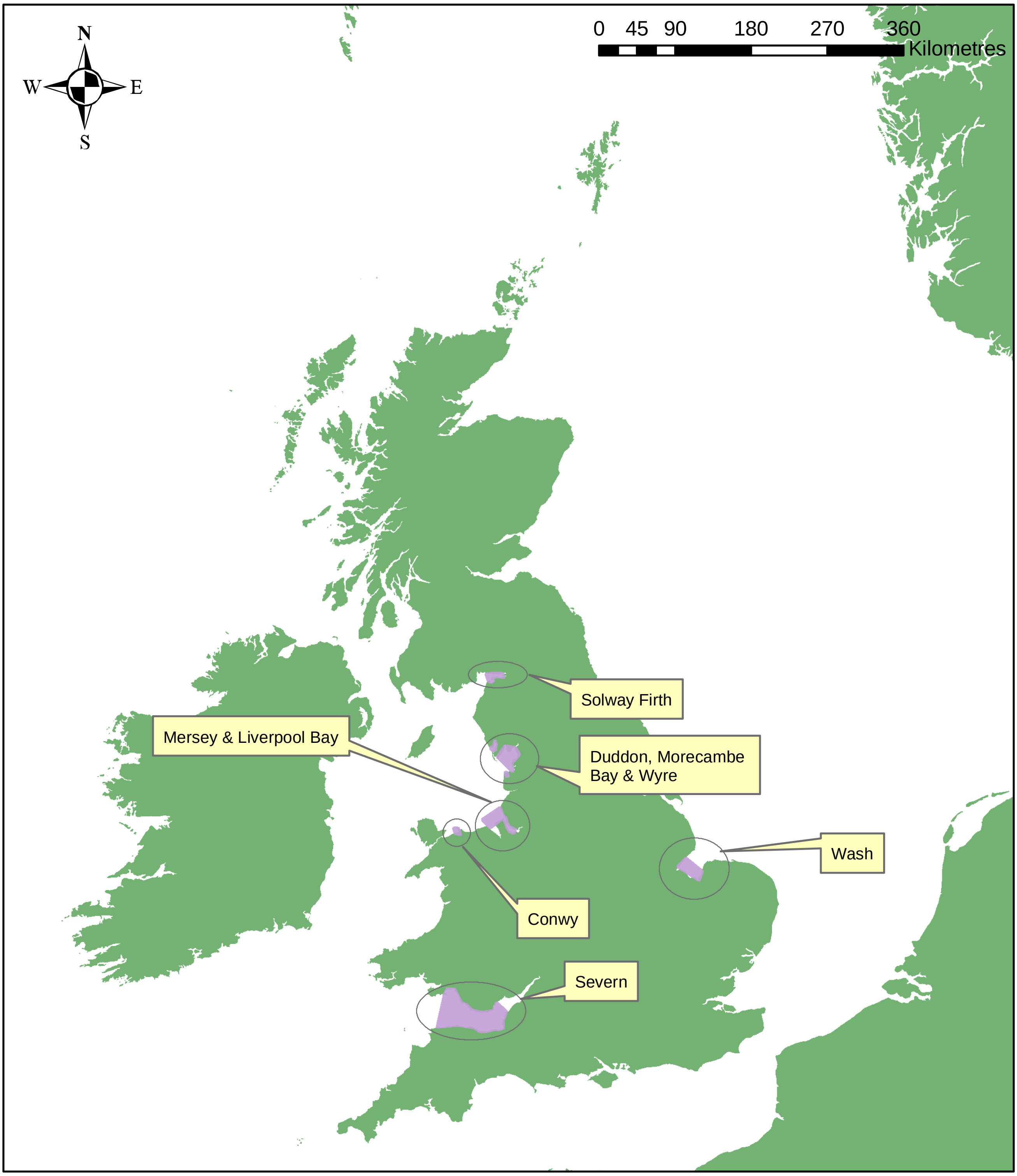
- Several studies have been undertaken that quantatively estimate tidal resource on UK wide, regional and individual project scales. However each study uses different methods of resource assessment and therefore the results are not directly comparable.
- Typically, the tidal current sites with sufficient energy to be of interest are focused in constricted channels and around headlands.
- Much of the UK tidal current raw resource is concentrated in a limited number of sites (particularly the Pentland Firth and Channel Islands) and predominantly at a depth of greater than 40 m (Black and Veatch, 2005).
- The scale of input data and models that predict tidal current resource can have a significant effect on resource estimates and therefore although the large scale, UK wide and regional studies give a good overview of the location of tidal current resource, they are not sufficient for detailed estimates of potential power generation or project specific planning.
- The studies undertaken do not take into account the effects of tidal energy generation on the environment. However, a suite of studies undertaken for the Carbon Trust used significant impact factors (which take into account the fact that extracting energy from tidal stream impacts the characteristics of the flow) to reduce resource calculations.
- Although the timing of power output from tidal current energy generation is highly predictable, the daily tidal cycle and spring to neap tidal cycle, by their very nature, do not necessarily coincide with peak demand periods, or provide a constant level of generated power. This is exacerbated by the fact the energy is focused in a small number of locations.

The majority of studies reviewed in this study are based on the currently accepted method of calculating tidal stream resource (the “Flux Method”). However methods of calculating resource and the energy that can be extracted from it are still being developed. There is work ongoing by both S.H. Salter (Salter, 2005) and D. MacKay (MacKay, 2007) that suggests that this standard method may be an under-estimate by a factor of between 10 and 20, but this information is not yet in the peer reviewed literature.

Tidal range resource is power that may be extracted from potential energy released from water at a high level relative to a low water level: for example, water released from a barrage after high water flows to lower levels around low tide, releasing exploitable potential energy as it falls. The spatial distribution of sites of good tidal range resource, identified in the various studies reviewed, are illustrated in Figure B.

The review of tidal range resource indicated the following:

- There are standard methods for calculating the energy available from tidal range sites. Generation is proportional to the square of the tidal range. Therefore a site with an 11 m range for example, will have approximately twice the generation potential of a site with 8 m range.
- Tidal range resource can be extracted by barrage or lagoon type developments.
- The tidal range resource in the UK is significant in terms of its potential contribution to meeting UK electricity demand.
- Tidal range resource is focused in a limited number of locations which include the Bristol Channel (including the Wales and Devon coasts), Liverpool and Morecambe bays, the Solway Firth, The Wash, The Duddon, The Wyre and the Conway.
- The most significant resource is located in the Bristol Channel area.
- On a daily scale, variability in the resource is reduced because peak tidal flow at key areas is not synchronised. However the dominance of the resource in the Bristol Channel area would remain a significant peak in tidal energy production. There is also opportunity to vary the period of generation slightly by varying the timing of the release of water from the lagoon or barrage.



Sustainable Development Commission - Review of UK Tidal Resource

Summary of tidal range resource

Legend

Tidal range resource sites

Date	26 January 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	World Energy Council, ABPMer, Metoc	
File Reference	P936/gis/mxd/report	
Checked	RM	GIS Specialist
	DW	Project Manager

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SUMMARY OF GRID CONSTRAINT IN RELATION TO RESOURCE LOCATIONS

There is a significant amount of information available on the status of the UK electricity distribution grids, and the requirements and plans for upgrading of the grid network to accept increasing electricity generating capacity.

Figure C below summarises the geographical distribution of tidal resource and issues of connecting energy generated from the tides to the grid. It also indicates that the tidal resource assessments considered predict that the likely exploitable tidal resource locations are focused along the north and west coasts of Scotland, the west coasts of England and Wales, the Channel Islands and the east coast of Northern Ireland. Additionally, the resource assessments suggest that the Pentland Firth and the Severn areas are the most significant sites for the potential capture of tidal energy. However, this assessment does not take into account physical and environmental constraints.

Figure C also shows how the present constraints of connecting to the electricity transmission system vary for each site of tidal resource identified. It indicates that the grid is currently most able to accept electricity generated by tidal energy in locations in the Severn, the Wash, and the Mersey, with the grid in the north of Scotland most constrained.

In the Highland and Islands of Scotland, there are a significant number of developers waiting to connect to the grid. Under the current connection arrangements, they have been arranged into a 'queue' on a first come first served basis. The first of a number of planned reinforcements to enable the connection of these projects is an overhead line from Beauly to Denny. This line is currently the subject of a public enquiry and so could face significant delays. Studies of the potential for subsea interconnector cables are being carried out, but no firm plans have yet emerged. A recent proposal by National Grid intends to offer any available transmission capacity to the 'most suitable' project. So, if a tidal project in Scotland was able to get planning permission and show that it was technically and commercially in a position to connect, the next available capacity gap made available by an existing developer relinquishing or reducing its required capacity could be made available to the tidal generator.

In the rest of the U.K., there are number of significant transmission reinforcements that will be required to enable further generation to connection north of the Midlands. The only generation that will be able to connect north of this boundary in the short-term is embedded generation, connected into the distribution network and supplying local demand.

There is capacity for the connection of generation in the south and south west but as the distribution networks in these areas are quite weak, reinforcements will be required to connect the generation into the backbone of the transmission network rather than the local distribution lines.

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Summary of grid constraints

Key

- Green - Areas where it should be possible to connect additional generation into the transmission and distribution network close to the shore without significant reinforcement.
- Amber - Areas where the connection of additional generation into the transmission and distribution network should be possible with some reinforcement back to substations a little way inshore, longer subsea links to more secure parts of the network or the completion of planned reinforcements to the transmission network.
- Purple - Areas where connection into the nearest network will allow a limited amount of export (up to about 20MW) but to allow larger amounts of generation to connect a long subsea cable and significant onshore reinforcements would be required.
- Red - Areas where the connection of additional generation into the transmission and distribution network would require significant reinforcements with long development times.

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COASTLINE TYPES AND SEA LEVEL CHANGE

The effect of offshore tidal power extraction is to change currents and water levels and is, in general, to reduce the erosive energy or power reaching adjacent coastlines. It may be possible for some coastal areas to receive more incident energy because of the effects of channelling and local intensification of currents. There may also be secondary effects on the waves. Most waves seen on the sea are generated by local or distant winds and are known as wind waves. The local pattern of wind-waves is often referred to as the field of wind-waves. If tidal power extraction changes wave diffraction or refraction, there will be associated secondary changes to the wind-wave field.

Coastal areas sensitive to these influences are likely to be characterised by locally high flow associated with straits, channels, restrictive headlands or estuaries, by the availability of mobile sediment, and by the presence of eroding coastline.

Coastal areas insensitive to these influences are characterized by open sea, paucity of mobile sediment and by resistant coastline.

Local changes to sea level induced by tidal energy extraction schemes are only likely to be significant relative to local and sea level global change if they are of order of tenths of a metre or more.

In addition to the effects of tidal energy devices on potential sea-level rise issues, the potential influence of global sea-level rise on siting of onshore infrastructure associated with bringing energy onshore should be considered. Relatively low-lying areas may be at risk of flooding for some distance inland, with infrastructure requiring to be sited appropriately.

STRATEGIC POLICY FRAMEWORK

The strategic policy and planning framework in relation to the exploitation of tidal energy has also been reviewed and outlined. In summary:

- Government policy statements (including the Energy White Paper and the recent Energy Review) across the UK express support for the development of a mix of renewable energy technologies which will help meet the targets of the Kyoto Protocol.
- Government policy is supported by initiatives such as the Renewables Obligation and funding initiatives such as that led by the DTI which can be drawn upon for developments across England, Wales, Scotland and Northern Ireland.

- The devolved responsibilities for renewable energy provide a flexible approach, allowing focus on areas of potential benefit.
- Strategic environmental assessment (SEA) for tidal energy development is currently under way in Scotland. There are no currently no publicised plans for SEA to be undertaken in England, Wales or Northern Ireland, but CCW have undertaken a high level assessment on the nature conservation impacts of marine renewable energy development and the Welsh Assembly Government are currently considering a Marine Renewable Energy Strategic Framework.
- Consent regimes are in place across the UK for tidal energy developments, however the regimes are currently only being used for pre commercial scale developments and no formal consenting guidance exists for full commercial scale development. The consenting process is complex with a number of different bodies required to provide different elements of consents.
- The European Directives on the Water Framework, EIA, Habitats and Birds are transposed into UK legislation and requirements of the relevant regulations will have to be met by any tidal energy development. This may be challenging for tidal energy developments where there is currently very little information and understanding on the environmental effects of such developments.
- The UK is currently developing a Marine Bill and a Planning White Paper which are likely to have some effects on the planning and consenting of tidal energy developments, however, the specific impacts of these initiatives can not predicted at this stage.
- The European Commission is currently developing a marine strategy that will be translated into a marine directive, but it is currently too early to accurately assess any impacts of this directive on tidal energy development.

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GLOSSARY

Amplitude – The maximum extent or magnitude of a vibration or other oscillating phenomenon, measured from the equilibrium position or average value

ARODG - Access Reform Options Development Group

BETTA - British Electrical Trading and Transmission Arrangements

BSP - Bulk Supply Point

CAP - CUSC Amendment Proposal

CCGT - Combined Cycle Gas Turbine

CUSC - Connection and Use of System Code

DNO - Distribution Network Operator

DGUoS - Distributed Generation Use of System

DTI - Department of Trade & Industry

Embedded Generation - Electrical generation which is connected to the distribution network rather than to the extra high voltage National Grid

GB - Great Britain

GBSO - Great Britain System Operator

GSP - Grid Supply Point

Grid – A network of inter connected cables for the supply/distribution of electricty

GW - GigaWatt (1,000,000 kW)

Kinetic energy - Kinetic energy is the energy of motion, observable as the movement of an object, particle, or set of particles. Any object in motion is using kinetic energy.

km - kilometer

kV - KiloVolt (1,000 V)

LAT – Lowest Astronomical Tide

LTDS - Long Term Development Statement

MVA - MegaVoltAmpere (1,000 kVA)

MW - MegaWatt (1,000 kW)

NGT - National Grid Transco

NGET - National Grid Electrical Transmission Limited

NIE - Northern Ireland Electricity

Ofgem - The Office of Gas and Electricity Markets

Potential energy - Objects that are not in motion possess potential energy (the other main type of energy), which is converted to kinetic energy when some force, such as gravity, acts upon the object to set it in motion.

Re- conductoring - Replacing conductor on an existing transmission line to enable more current/power to flow in the line

RETS - Renewable Energy Transmission Study

Resonance – Am increase in the oscillatory energy absorbed by a system when the frequency of the oscillations matches the system's natural frequency of vibration

RPZ - Registered Power Zone

RO - Renewables Obligation

s185 - Section 185 of the Energy Act 2004

Semidiurnal – Occurring approximately once every 12 hours

SHETL - Scottish Hydro Electric Transmission Limited

SONI - System Operator Northern Ireland

SP - Scottish Power

SP Manweb - Scottish Power Merseyside and North Wales Electricity Board

SPTL - Scottish Power Transmission Limited

SYS - Seven Year Statement

TNUoS - Transmission Network Use of System

UK - United Kingdom

1 INTRODUCTION

1.1 BACKGROUND

Metoc were contracted by the Sustainable Development Commission (SDC) to undertake a review of the available information on tidal energy resource in the UK.

This report is one of a set of five linked evidence-based research reports forming the research strand of the SDC's "Tidal Power in the UK" Project, considering tidal power from a sustainable development perspective. This review covers the tidal energy resource in the UK and also considers grid connection issues, policy related to tidal energy development and issues associated with sea level change.

The first deliverable under this contract was a Scoping Report that identified available information sources and literature and set out the proposed structure of this report. The Scoping Report was submitted in December 2006.

This subsequent report is the main deliverable of the contract on the "Review of the UK Tidal Resource".

It should be noted that this study is a review of available information. Metoc have not undertaken any new development or analysis, but have simply drawn together, summarised and, where relevant, compared and contrasted the available information and opinions.

TNEI have supported Metoc on electrical grid issues in this study.

1.2 STUDY OBJECTIVES

The specific objectives for this study (as specified by the SDC) are as follows:

Resource mapping -

- Research and analyse existing data, information and evidence sources to assess the nature and extent of the UK tidal resource and based on this research, present an up-to-date, reliable and comprehensive overview addressing the following matters:
    - Resource mapping (with visual materials) of geographical and temporal distribution of UK tidal resource including characterisation of the tidal current resource e.g. spatial and temporal variation at a local site level and the implications for energy extraction.
    - Potential electricity generation contribution to UK demand based on this resource – including consideration of peak output (total as well as 'hour to hour' availability of the tidal resource) and variability and relationship with consumption/demand and grid.
    - Grid constraints and implications for utilisation of tidal resource (including visual materials).

- Mapping (with visual materials) of coastline types (hard and soft) and effect of predicted sea level rises due to climate change (in general terms)

The resource mapping exercise should draw together information sources and present the information effectively using a combination of visual and graphic materials, tables, matrices and text so that the information is accessible and provides a comprehensive but high level overview of current understanding of the tidal resource and how this fits with the UK's electricity system. The exercise should consider a range of scales from the UK resource to regional and site specific.

Strategic policy framework

- Review and provide an up-to-date, reliable and comprehensive overview of the strategic policy and planning frameworks (current and under development) for consenting, planning and environmental impact assessment in relation to tidal power and resources in the UK.

Report

- Draw together referenced information and analysis into a report to the SDC with a clear Executive Summary of the key issues.

2 INTRODUCTION TO TIDAL RESOURCE

Tides are caused by the gravitational attraction of the moon and the sun acting upon the oceans of the rotating earth. The tide raising force exerted by the moon is approximately twice that of the sun. The relative motions of these bodies cause the surface of the oceans to be raised and lowered periodically, according to a number of interacting cycles. These include:

- A daily or half day cycle, due to the rotation of the earth within the gravitational field of the moon. This leads to the familiar occurrence of high water and low water. In UK waters, high water occurs approximately twice daily, and the time of high water advances by approximately 50 minutes per day.
- A world-wide 14 day cycle, resulting from the degree of alignment between the moon and sun gives spring and, seven days later, neap, tides. Spring tides are those with the largest range (i.e. highest high water and lowest low water) while neap tides have the smallest range. Spring tides are found to occur shortly after full moon and new moon, with neaps occurring shortly after first and last quarters. For any given location, the spring tide high water will always occur at the same time of day.
- A half year cycle, due to the inclination of the moon's orbit to that of the earth, giving rise to the largest spring tides around the time of the March and September equinoxes, and the smallest spring tides approximately coincident with the summer and winter solstices.

The range of a spring tide is commonly about twice that of a neap tide, whereas the longer period cycles impose smaller perturbations. In the open ocean, the maximum amplitude of the tides is about one metre. Conservation of energy means that tidal amplitudes are increased substantially towards the coast, particularly in estuaries. This is mainly caused by shelving of the sea bed and funnelling of the water by estuaries. In some cases the tidal range can be further amplified by reflection of the tidal wave by the coastline or resonance.

In combination with the effects of Coriolis and friction effects, these factors mean that the tidal range and times of high and low water can vary substantially between different points on a coastline.

The rise and fall of the tides gives rise to horizontal water movements known as tidal streams. In most locations the tidal stream approaches zero ("slack water") around high water and again at low water, with peak tidal stream velocities occurring between these times at mid ebb (when the tide is falling) and mid flood (when the tide is rising). The notable exception to this is the English Channel where the synchronisation between the state of the tide and the tidal stream velocity shifts, but remains largely straightforward.

The amount of energy obtainable from a tidal energy scheme therefore varies with location and time. Output changes dramatically as the tide rises and falls, and as the tidal stream ebbs and floods each day; it also varies significantly over a spring-neap cycle. Tidal energy is, however, highly predictable in both amount and timing.

The general principles of the tidal system can be found in numerous oceanographic textbooks such as the Open University's Series of Volumes on

Oceanography (Open University, 1999), or on the world wide web at a number of renewable energy and oceanographic websites such as the British Wind Energy Association, http://www.bwea.com/marine/tides.html, and Proudman Oceanographic Laboratory, http://www.pol.ac.uk/home/insight/tidefaq.html.

3 TIDAL CURRENT RESOURCE

3.1 AVAILABLE INFORMATION

A large amount of work has been undertaken, across a number of studies, in order to determine the scale and availability of the UK tidal current resource. Much of this work naturally presents site by site estimates or predictions of power which may be generated, making certain assumptions about the number and efficiency of generation units in place.

The following key current sources of information have been identified to give a geographical overview of tidal resource across the UK.

- ABPmer, The Met Office, Garrard Hassan and Proudman Oceanographic Laboratory (2004). Atlas of UK Marine Renewable Energy Resources: Technical report. A report to the Department of Trade and Industry.
- Black & Veatch (2004). Tidal Stream Energy Resource and Technology Summary Report. A report to the Carbon Trust's Marine Energy Challenge.
- Black & Veatch (2005). Tidal Stream – Phase II UK Tidal Stream Energy Resource Assessment. A report to the Carbon Trust's Marine Energy Challenge.
- Environmental Change Institute (2005). Variability of UK Marine Resources, commissioned by The Carbon Trust.
- Metoc plc (2004). Seapower SW review – Resources, Constraints and Development Scenarios for Wave & Tidal Stream Power, commissioned by the South West Regional Development Agency.
- PMSS (2006). Wales Marine Energy Site Selection, commissioned by the Welsh Development Agency.
- Department of Trade and Industry, Department of Enterprise Trade and Investment, Northern Ireland Electricity, 2003, The Potential for the Use of Marine Current Energy in Northern Ireland

Additionally, in order to give an indication of how the scale of the assessment undertaken can influence resource estimates two refined scale assessments of potential tidal energy are presented in example areas for comparison against the original strategic scale assessments (see Section 3.1.7 and 3.1.8).

Sections 3.1.1 – 3.1.8 below give an overview of the assumptions made in, and outputs of, each of the studies noted above.

Temporal factors are also considered, including the effects of the phasing of tides around the UK on daily and spring-neap timescales.

It should be noted that each of the assessments reviewed use the currently accepted standard method of calculating the energy available from tidal streams, which relates available power to the cube of the tidal stream velocity.

The studies also have significantly different output objectives. Attempts have been made to examine:

- The raw resource available

- The technically retrievable resource (the quantity of raw resource that can be harvested by technology)
- The constrained technically retrievable resource (the quantity of raw resource that can be harvested by considering technological, economic and environmental constraints – e.g. the 'significant impact factor' as discussed in Section 3.1.3)

3.1.1 Marine Energy Atlas

The Atlas of UK Marine Renewable Energy Resources (ABPmer, et al., 2004), compiled on behalf of the DTI, presents charts of peak flows for mean spring and neap tides, and tidal current power density around the UK coast as an annual mean. Tidal power has been calculated from predictions of current velocity made by the POL CS3 and HRCS models, of approximate resolution 12 km and 1.8 km respectively.

It should be noted that the atlas, in presenting power density, does not take account of the depth of water over which a resource exists. It may therefore be the case that while a significant power density is observed at a given location, shallow water depths may mean that the power resource is more limited.

The peak flow for a mean spring tide and mean annual tidal power density, as given the atlas, are presented in Figures 3.1a and 3.1b respectively.

Figure 3-1a: Marine Energy Atlas – Peak Flow at Mean Spring Tide

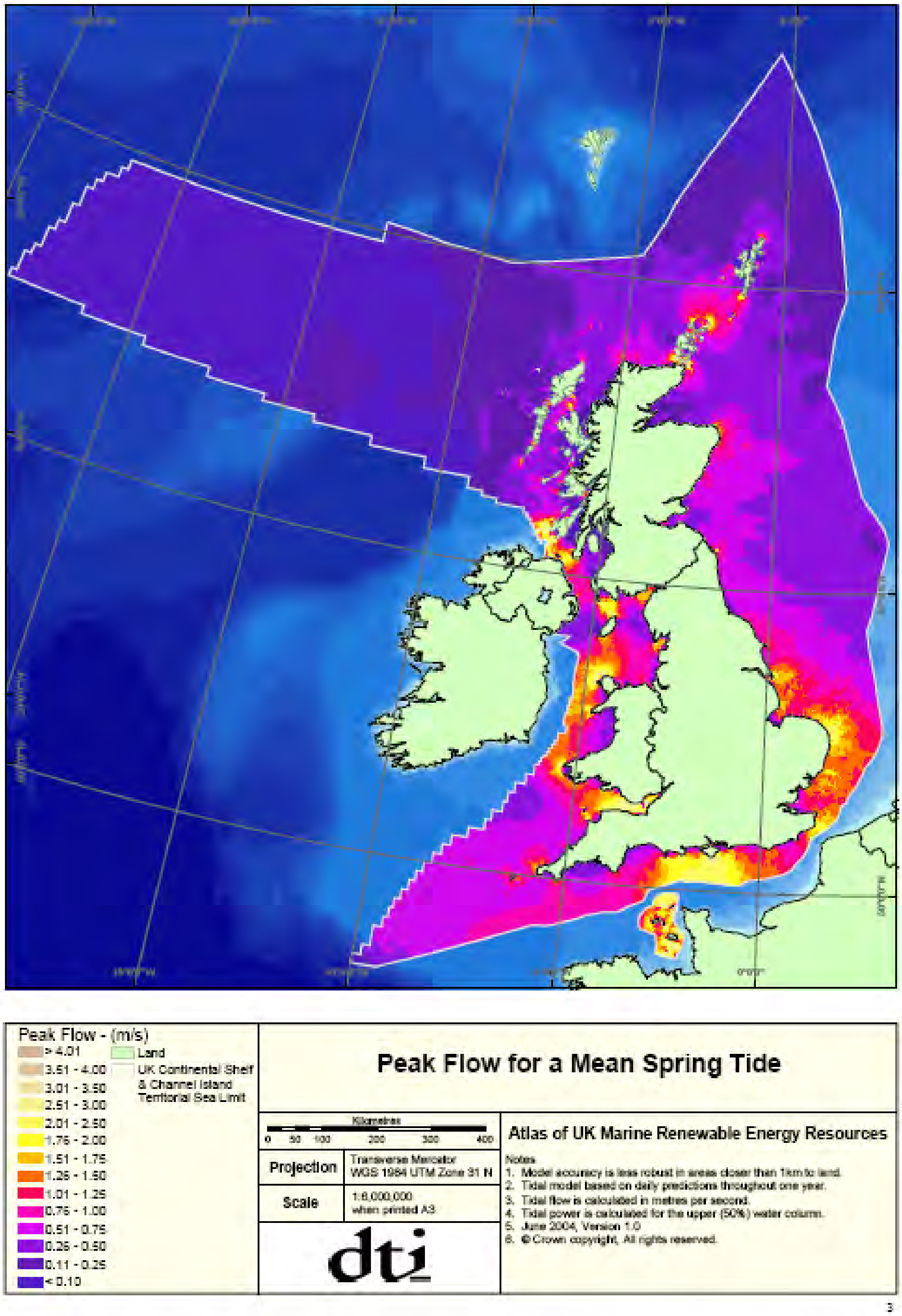
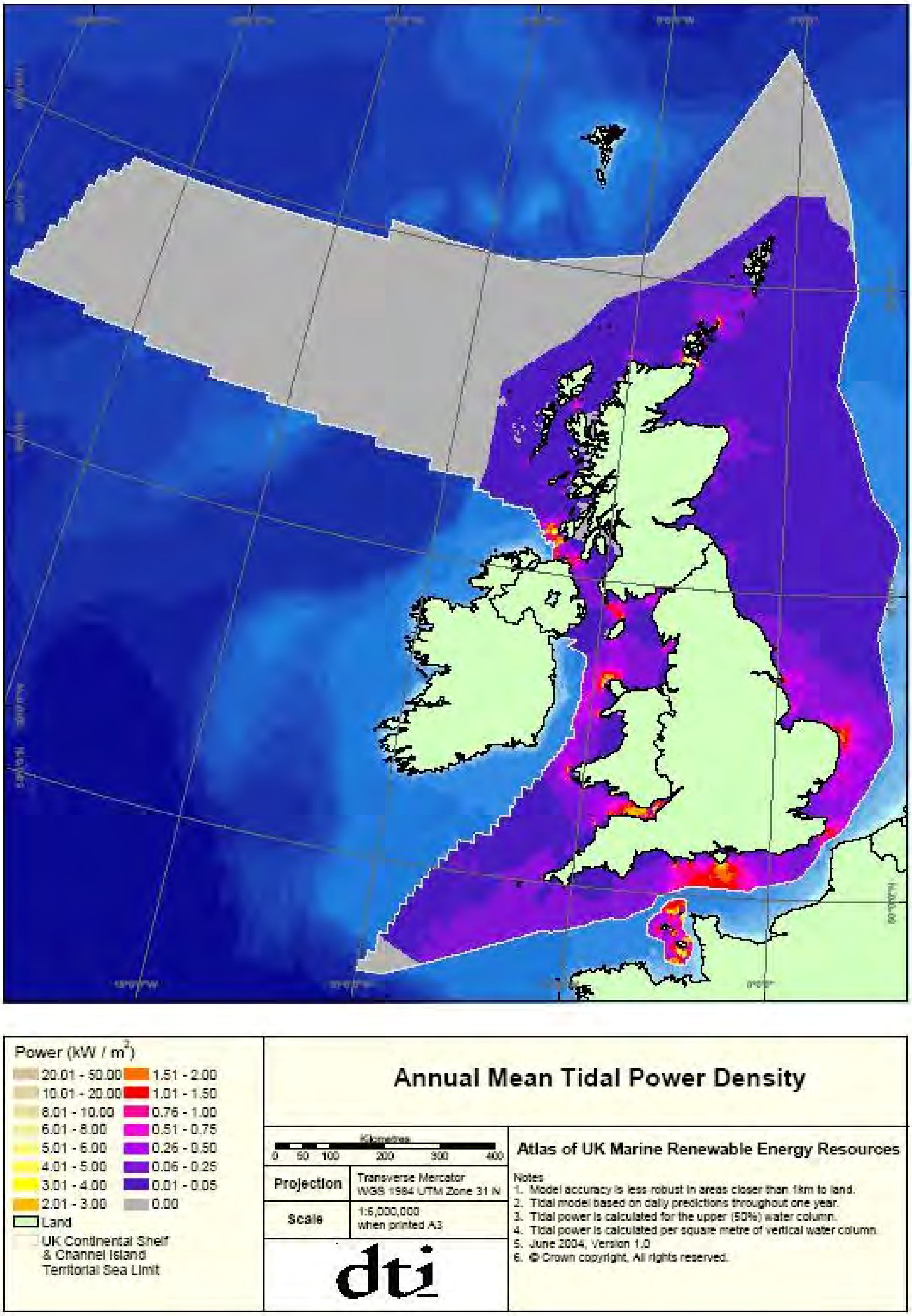


Figure 3-1b: Marine Energy Atlas - Mean Annual Tidal Power Density



The following areas are readily identified from the chart as being of interest in terms of annual mean power density:

- Pentland Firth
- Isle of Wight (St Catherine's Point)
- The Channel Islands
- Bill of Portland
- The Bristol Channel
- Pembrokeshire (St David's Head, Ramsey Island)
- Lleyn peninsula
- Anglesey (Carmel Head)
- Islay

Of these sites, the Pentland Firth and The Bristol Channel appear to offer significant areas where annual mean density exceeds 10 kW/m².

3.1.2 Carbon Trust Phase I

In 2004, as part of the Marine Energy Challenge, the Carbon Trust commissioned an assessment of the UK tidal stream resource (Black and Veatch, 2005). The conclusions of this "Phase I" study are summarised below.

- A "Flux Method" was developed as a method for calculating the amount of energy available for extraction at a site.
- The Flux Method includes a Significant Impact Factor (SIF) which represents the fraction of the total energy resource which is available for extraction. The SIF is essentially a method by which it is possible to account for the fact that extracting energy from a tidal stream affects its characteristics, and therefore there must come a point where further energy extraction is neither economically or environmentally viable. This may be as a result of a large number of factors examples of which may include – depending on the specifics of the site – changes in marine habitat, and increased mechanical wear on installed generation plant due to increased turbulence.
- For the purposes of the Phase I study, the authors assumed a SIF of 20% for all sites assessed, while highlighting the site to site variability of the SIF. This assumption, significantly refined in the Phase II study, was applied to an estimated UK Total Resource of 110 TWh/y to give an estimate of the UK Technically Extractable Resource of 22 TWh/y (6% of UK demand) which was contrasted with previous estimates of 58 TWh/y and 31 TWh/y.
- The report concluded that much of the UK resource is concentrated in the Pentland Firth and the Channel Islands, and predominantly at depth greater than 40 m. Recommendations were also made that the Phase II study should focus on the development of more robust "SIFs" for the most important sites.

3.1.3 Carbon Trust Phase II

Following the Phase I report discussed above, a Phase II report was commissioned. The Phase II report focussed on the ten most important sites identified during Phase I. Site widths and depths were confirmed, and associated velocities extracted from the Marine Energy Atlas and published Admiralty data.

The ten most important sites identified, representing an estimated 80% of the total UK Technically Extractable Resource, are detailed in Table 3 1 below.

Table 3-1: Marine Energy Challenge Phase II - UK Technically Extractable Resource

Stage 1 Ranking	Site	Contribution (%) to UK tidal stream resource	Cumulative Contribution (%) to UK tidal stream resource
1	Pentland Skerries	17.9	17.9
2	Stroma, Pentland Firth	12.7	30.6
3	Duncansby Head, Pentland Firth	9.3	39.9
4	Casquets, Channel Islands	7.6	47.5
5	South Ronaldsay, Pentland Firth	7.0	54.4
6	Hoy, Pentland Firth	6.3	60.8
7	Alderney Race, Channel Islands	6.3	67.0
8	South Ronaldsay, Pentland Skerries	5.3	72.3
9	Rathlin Island, N. Ireland	4.0	76.2
10	Mull of Galloway	3.7	79.9

Figure 3-2 below indicates the locations of the sites in the Pentland Firth which are noted in the table above.

Figure 3-2: Location of Pentland Sites

The updated "Technically Extractable Resource" was then reduced by the removal of two Pentland Firth Sites (Pentland Skerries and Stroma), which it was considered had been "double counted" in terms of flux streamlines to other sites. The result was a drop of 20% in the estimated Technically Extractable Resource from the Phase 1 work, to 5% of UK demand.

Further consideration was also given to the determination of site –specific SIFs. While the report states that the industry's understanding of SIF is still developing, the following five types of site were identified:

1) Inter-island channels with fixed head differences caused by tidal phase lag at either end of the channel. Flow through the channel does not, therefore, affect the water level at either end. Examples include the Pentland Firth, with SIFs considered to lie in the range 10-20%.

2) Open sea sites with fixed head differences. Head differences are not likely to be significantly affected by energy extraction. Casquets is given as an example with a SIF range estimated at 10-20%.

3) Headlands with fixed head differences. These sites – for example the Bill of Portland – experience complex flow patterns, but were considered to experience similar effects to open sea sites, with a SIF range estimated at 10-20%.

4) Sea lochs with head difference determined by energy extraction. These sites could, the report considered, have SIFs of up to 50% but only represent a small fraction of the UK resource.

5) Resonant estuaries with the head difference the result of complex resonant effects. The environmental sensitivity often associated with such sites, and the expected sensitivity of such sites to energy extraction, led to the report suggesting SIFs of < 10%.

Updating the SIFs in the calculation of Technically Extractable Resource at each of the top ten sites identified during Phase 1 gave new production figures, presented in Table 3-2.

Table 3-2: Tidal Current Generation

Stage 1 Ranking	Site	GWh/y
1	Pentland Skerries	4526
2	Stroma, Pentland Firth	2114 (eliminated)
3	Duncansby Head, Pentland Firth	1699
4	Casquets, Channel Islands	418
5	South Ronaldsay, Pentland Firth	1030
6	Hoy, Pentland Firth	714
7	Alderney Race, Channel Islands	365
8	South Ronaldsay, Pentland Skerries	964 (eliminated)
9	Rathlin Island, N. Ireland	408
10	Mull of Galloway	383

(note: In addition to the 'top ten' sites noted above the following sites were also assessed:- Guernsey Big Russel, Guernsey North West, North East Jersey, Shetland Yell Sound West, Shetland Yell Sound East, Shetland Bluemull, Orkney Westray Fers Ness,, Orkney Papa Westray, Orkney North Ronaldsay Firth, Westray Falls of Warness, Orkney Eday Sound, Kyle Rhea, Mull of Kintyre, Mull of Oa, Sanda Sound, Pentland Inner Sound, Bristol Channel North Lundy, Bristol Channel South Lundy, Bristol Channel Barry, Bristol Channel Foreland point, Cornwall Cape Cornwall, Cornwall lands end, Cornwall the Lizard, Isle of Wight, Portland Bill)

These results give a much reduced Technically Extractable Resource at the original top ten sites of 11.3 TWh/y, and applying an assumed SIF of 20% to the remaining UK sites allows the report to suggest a UK Technically Extractable Resource of 13.1 TWh/y.

A number of additional sites were then identified for further consideration, of which Islay, Carmel Head (Anglesey) and The Isle of Wight were put forward for analysis. A number of assumptions were made regarding tidal stream velocities at these sites (note that available power is proportional to the current speed cubed[1]) in order to derive an additional Technically Extractable Resource of 2,500 GWh/y, bringing the UK Technically Extractable Resource to 18 TWh/y.

Breaking the above analyses down further, the report considers that 63% of the UK Technically Extractable Resource is found in deep sites > 40 m and approximately 20% is at 30 – 40 m with maximum velocities on a mean spring

[1] The kinetic energy of a moving body is proportional to the product of its mass and the square of its speed. The kinetic energy carried by a given volume of moving fluid is therefore proportional to its density and to the square of its speed. The rate at which the fluid arrives at a generator is proportional to its speed. The rate at which energy is delivered to the generator (the power) is therefore proportional both to the rate at which fluid arrives, and to the kinetic energy in each arriving volume of the fluid, giving a cubic dependence on speed. For example, twice the flow delivers twice the amount of fluid; twice the flow contains four times as much kinetic energy per unit volume; so twice the flow delivers eight times as much power.

tide in the range 2.5 to 4.5 m/s, i.e. those sites which are considered to be most economically attractive.

3.1.4 Variability of UK Marine Resources

The Carbon Trust report Variability of UK Marine Resources (Environmental Change Institute, 2005) examines the regional characteristics of the wave and tidal power energy resources around the UK. It focuses in particular on temporal variability.

The report considers the tidal stream characteristics of 36 potential sites which together represent an estimated 99.5% of the UK tidal current resource. Hourly output at each site was determined from current velocity data, in combination with the total annual yield as calculated in the Carbon Trust Phase II report discussed above.

A number of assumptions were made regarding the operational characteristics of the generation plant:

1) Power is only generated at current speeds above 1 m/s.

2) The operational power output is calculated using 70% of mean spring maximum current speed (rated speed)

3) Each turbine is 45% efficient at the rated speed

These calculations were carried out on a regional basis to provide an assessment of the variability in the aggregate power supplied to each region. Assuming all identified sites within each region to be operational, the report provided ranges of power output under spring and neap tides, as presented in Table 3-3. Analysis and discussion of variability at various stages of development were also considered.

Table 3-3: Regional Tidal Current Resources

Region	Spring Tide Power Output Range (%)	Neap Tide Power Output Range (%)
Pentland	10 - 100	10 – 30
Channel Islands	10 to 20 - 100	0 – 30 to 50
South West	40 - 100	5 – 30
North West	< 10 – 100	0 – 20 to 50
Northern Isles	0 - 100	0 – 30

The report stressed that 61% of the UK potential tidal generation was focussed in the Pentland region. This dominance leads to a significant daily variation of output for current power generated across the whole of the UK. The pattern of spring and neap tides takes place over a 14 day cycle and, as it is driven by the changing positions of the sun and moon, occurs at the same time across the UK and worldwide. The report considered that during springs the average UK output levels can reach a peak of 70% of maximum, dropping to 6% during neaps.

The figures presented in the Carbon Trust Phase II were also further analysed in this study in order to provide a table showing the distribution of tidal stream power yield across the tidal sites and regions, assuming development to full capacity limit. This information is summarised in Table 3-4.

Table 3-4: UK Tidal Current Resource – Potential Outputs by Region

Region	Site	GWh/y	% of Total Output	Installed Capacity, MW
Channel Islands	Casquets	416	3.12	110
	Guernsey Big Russel	380	2.85	106
	Guernsey NW	492	3.69	165
	NE Jersey	164	1.23	55
	Race of Alderney	365	2.74	97
Total		1817	14	533
Northern Isles	All sites	1045	8	318
Total		1045	8	318
North West	Mull of Galloway	383	2.87	109
	Rathlin Coast	408	3.06	122
	Other sites	328	2.07	94
Total		1119	8	325
Pentland	S Ronaldsay to Swona	1030	7.73	294
	Pentland Inner Sound	151	1.13	40
	Pentland Duncansby Head	1699	12.75	440
	Pentland Hoy	714	5.36	194
	Pentland Skerries South	4526	33.95	1324
Total		8120	61	2292
South West	Bristol Channel Foreland point	548	4.11	156
	Portland Bill	438	3.29	116
	Other sites	243	1.6	96
Total		1229	9	368
UK Total		13330	100	3836

The report considers a range of development scenarios other than full exploitation which allow the daily variability of tidal current power production to be minimised. It finds that this is best achieved when tidal stream power is developed in conjunction with wave power, which is potentially a much larger, if less predictable, resource.

3.1.5 Seapower SW Review

In January 2006, a high level study (Metoc, 2004) was undertaken on behalf of the South West Regional Development Agency. Part of the scope of this study was the consideration of the tidal stream energy resources of the south west region.

The report primarily draws data from the UK Shelf Model (5 km resolution) and output from 2 km resolution models of the Isles of Scilly, Start Point and Portland Bill nested within it. The report states that at these resolutions some areas of increased tidal stream velocity – caused by topographic and bathymetric detail – will not be identified.

Identifying "promising" areas as being Portland Bill, Start point, Lizard Point, the North Cornwall and Devon coast, and the Isles of Scilly, the primary conclusion of the tidal stream aspect of the report highlights the Bristol Channel as the major tidal stream resource in the region. The study found that, within the Bristol Channel, an area of 275 km^2 achieved mean spring tidal stream velocities in excess of 2.25 m/s in water depths of around 20 m.

Results of previous studies were also presented which indicate that the south west available resource is 9.2 or 3.2 TWh/y, representing 16% or 10% of UK demand respectively.

A new analysis of the extractable resource was not presented, but rather the report considered generation in the context of development scenarios and is therefore outside the scope of the present study.

3.1.6 Wales Marine Energy Site Selection

PMSS undertook a study for the Welsh Development Agency to assess the practicable marine energy resource around the Welsh coastline. The study considered opportunities for offshore, wind, wave and tidal energy development drawing upon resource data from the DTI Marine Energy Atlas, information on the resource and water depth requirements of a number of renewable energy technologies, and data on environmental constraints to give an indication of potential areas for future development. Areas in Pembrokeshire, Anglesey, and the Bristol Channel were identified has having potential for tidal energy development.

3.1.7 Northern Ireland Potential

"The Potential for the Use of Marine Current Energy in Northern Ireland" (DETI et al., 2003) made use of a DHI Mike 21 model (450 m and 45 m resolutions) of the coastal waters of Northern Ireland to assess the potential for electricity generation from marine currents.

A techno-economic model was applied to promising locations, in order to determine future energy capture. The following locations and potential outputs were presented as being potentially useful:

- Strangford Narrows - up to 31.5 MW (144 GWh/h)
- Copland Islands – up to 45 MW (138 GWh/y)
- Fair Head to Runabay Head (up to 40 m depth) – 67 MW (303 GWh/y)
- Fair Head to Runabay Head (40 to 80 m depth) – 650 MW (3123 GWh/y)

The total potential resource was therefore found to be a rated power of 784 MW, or 3.7 TWh/y.

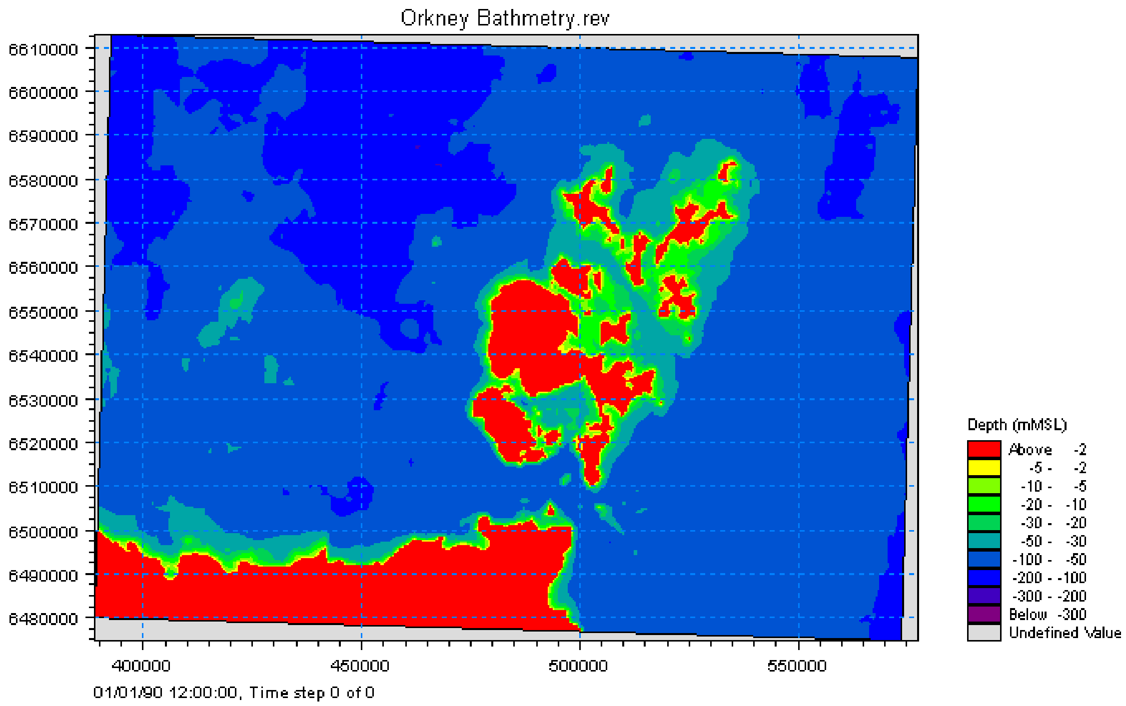
3.1.8 Metoc Orkneys Hydrodynamic Models

The Carbon Trust Phase I and II data presented above was based on tidal current velocities obtained from the POL HRCS hydrodynamic model, of resolution 1 nautical mile (approximately 1800 m), or from published tidal stream data.

While water level predictions are largely unaffected by grid resolution, current velocity is significantly influenced by the details of the local bathymetry. Increased model resolution is therefore key to increasing the accuracy of model predictions of current velocity and therefore tidal power density. For comparative purposes a fully calibrated Orkney model held by Metoc plc, which is nested within the regional IMDS modelling system, has been applied to derive a more robust dataset for the Pentland area. This model operates within the industry standard DHI Mike 21 modelling suite.

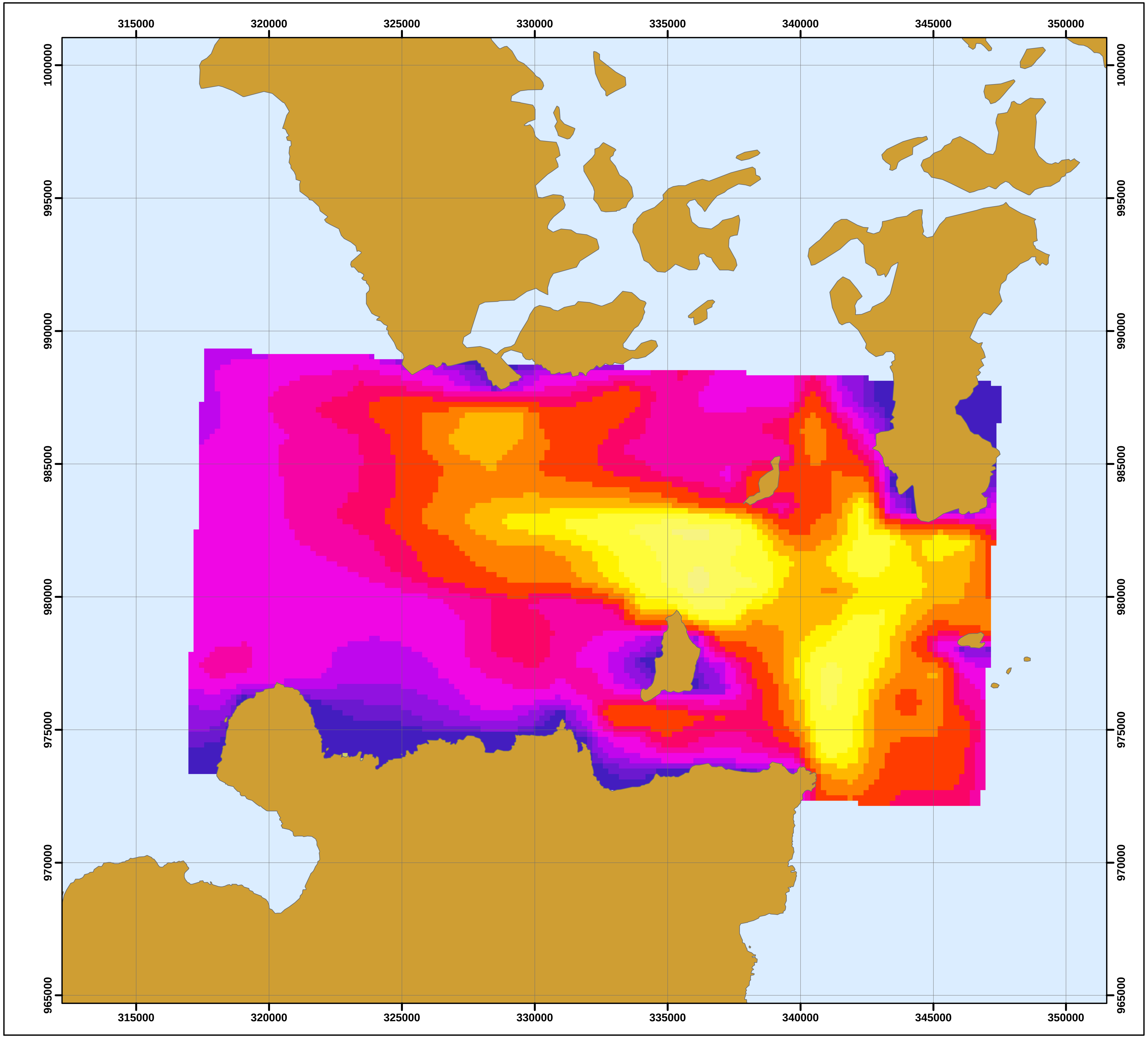
The Orkney model, shown in Figure 3-3, is of grid resolution 1000 m.

Figure 3-3: The IMDS 1000 m Orkney Model



Model predictions of tidal power density for a mean spring tide are presented in Figure 3-4. For comparison, a detail of the equivalent POL output is presented in Figure 3-5.

Note that these figures, in presenting power density, do not take account of the depth of water over which a resource exists. It may therefore be the case that while a significant power density is observed at a given location, shallow water depths may mean that the power resource is more limited.



Pentland Spring Regional Power

Legend

Land

Regional Power

kW / m^2

- 0 - 0
- 0.01 - 0.050
- 0.051 - 0.1
- 0.11 - 0.25
- 0.251 - 0.5
- 0.51 - 1
- 1.01 - 1.5
- 1.51 - 2.0
- 2.01 - 3.0
- 3.01 - 4.0
- 4.01 - 5.0
- 5.01 - 6.0
- 6.01 - 8.0
- 8.01 - 10.0
- 10.01 - 20.0
- 20.01 - 50

Date	22 January 2007	
Projection	British National Grid	
Spheroid	Airy	
Datum	OSGB36	
Data Source	Model Results	
File Reference	I:\...\P936Q -...\GIS\mxd\Pnt_Spring_reg_Power.mxd	
Checked	F Hashemi	GIS Specialist
	R McCall	Project Manager

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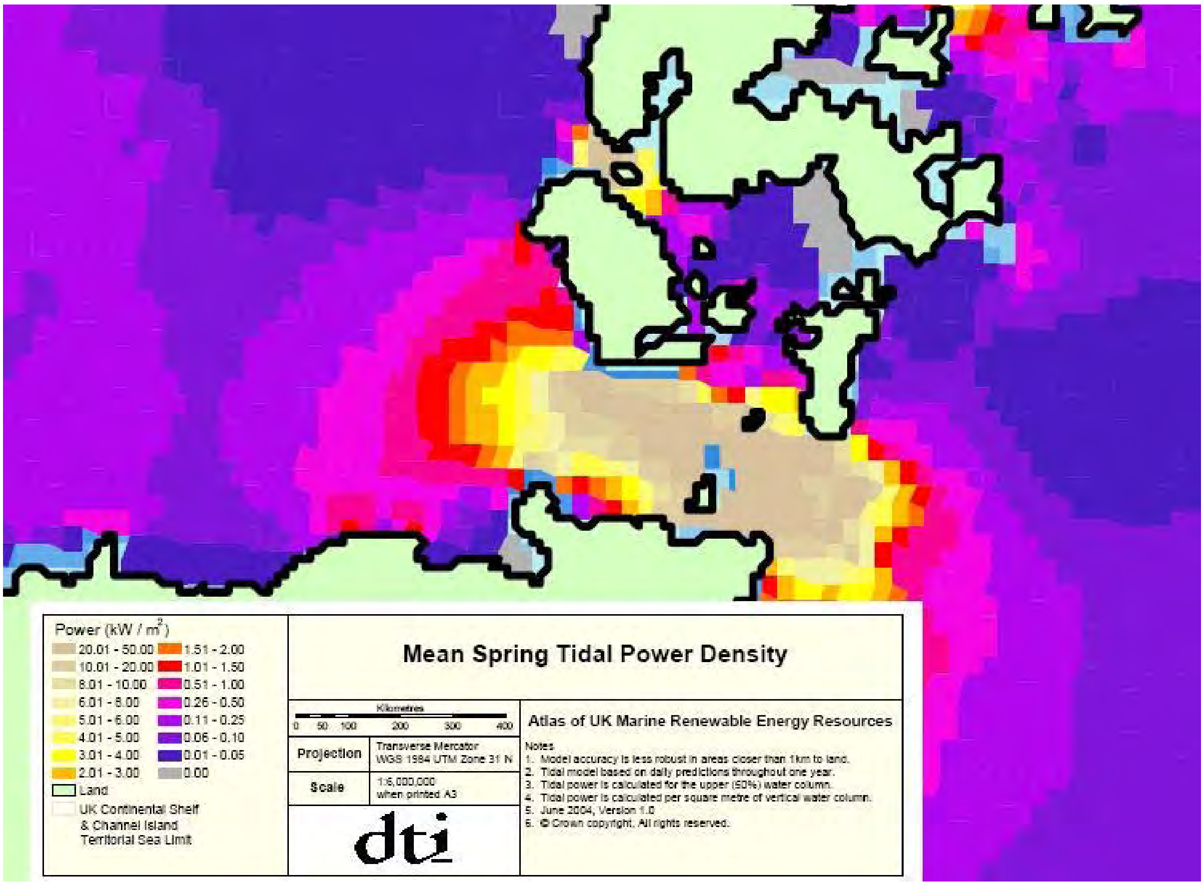
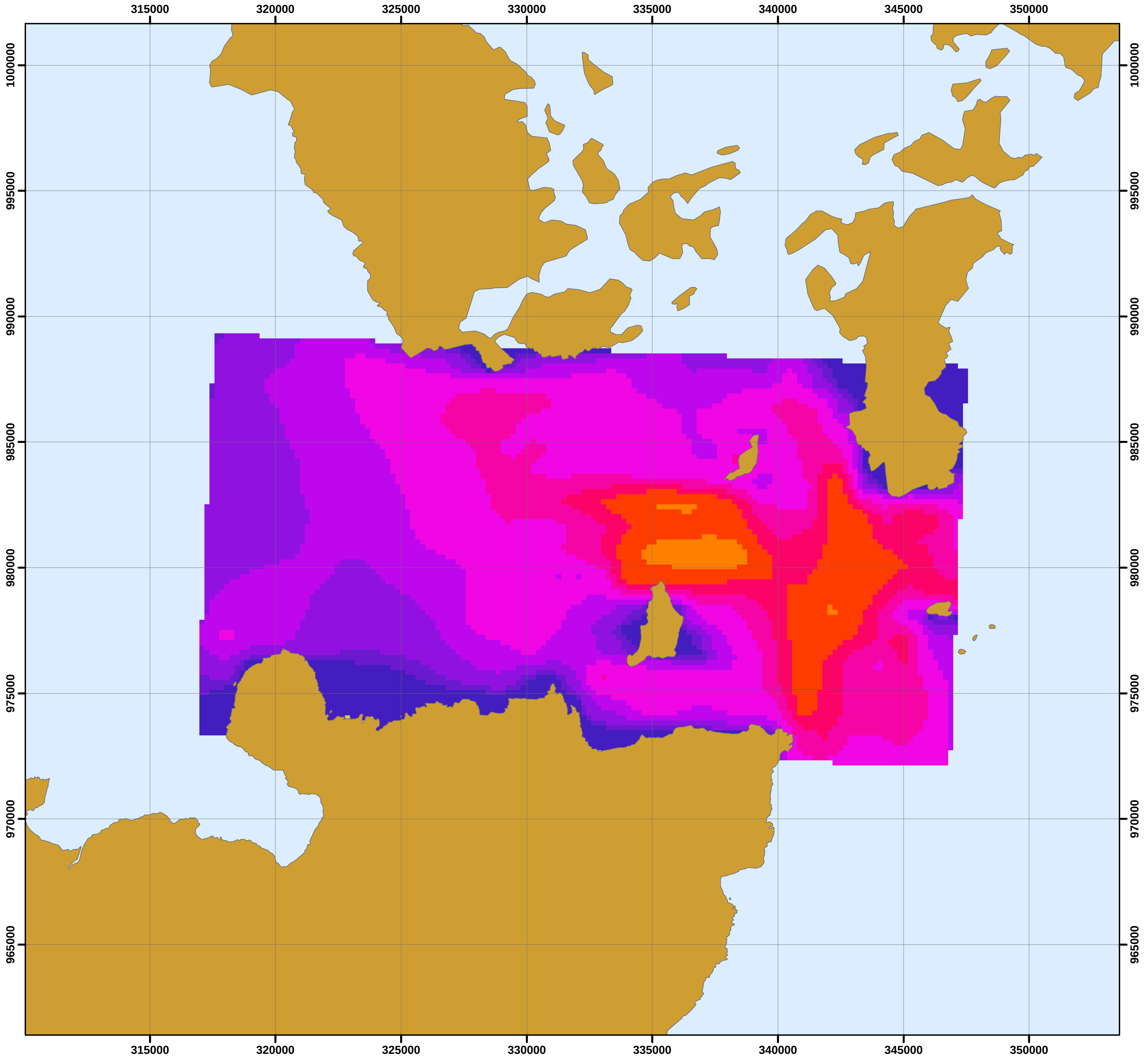
Figure 3-5: Marine Energy Atlas Mean Spring Tidal Power – Pentland





Pentland Neap Regional Power

Legend

Land	

Regional Power

kW/m^2

- 0 - 0
- 0.01 - 0.050
- 0.051 - 0.1
- 0.11 - 0.25
- 0.251 - 0.5
- 0.51 - 1
- 1.01 - 1.5
- 1.51 - 2.0
- 2.01 - 3.0
- 3.01 - 4.0
- 4.01 - 5.0
- 5.01 - 6.0
- 6.01 - 8.0
- 8.01 - 10.0
- 10.01 - 20.0
- 20.01 - 50

Date	22 January 2007	
Projection	British National Grid	
Spheroid	Airy	
Datum	OSGB36	
Data Source	Model Results	
File Reference	I:\...\P936Q -...\GIS\mxd\Pnt_Neap_reg_Power.mxd	
Checked	F Hashemi	GIS Specialist
	R McCall	Project Manager

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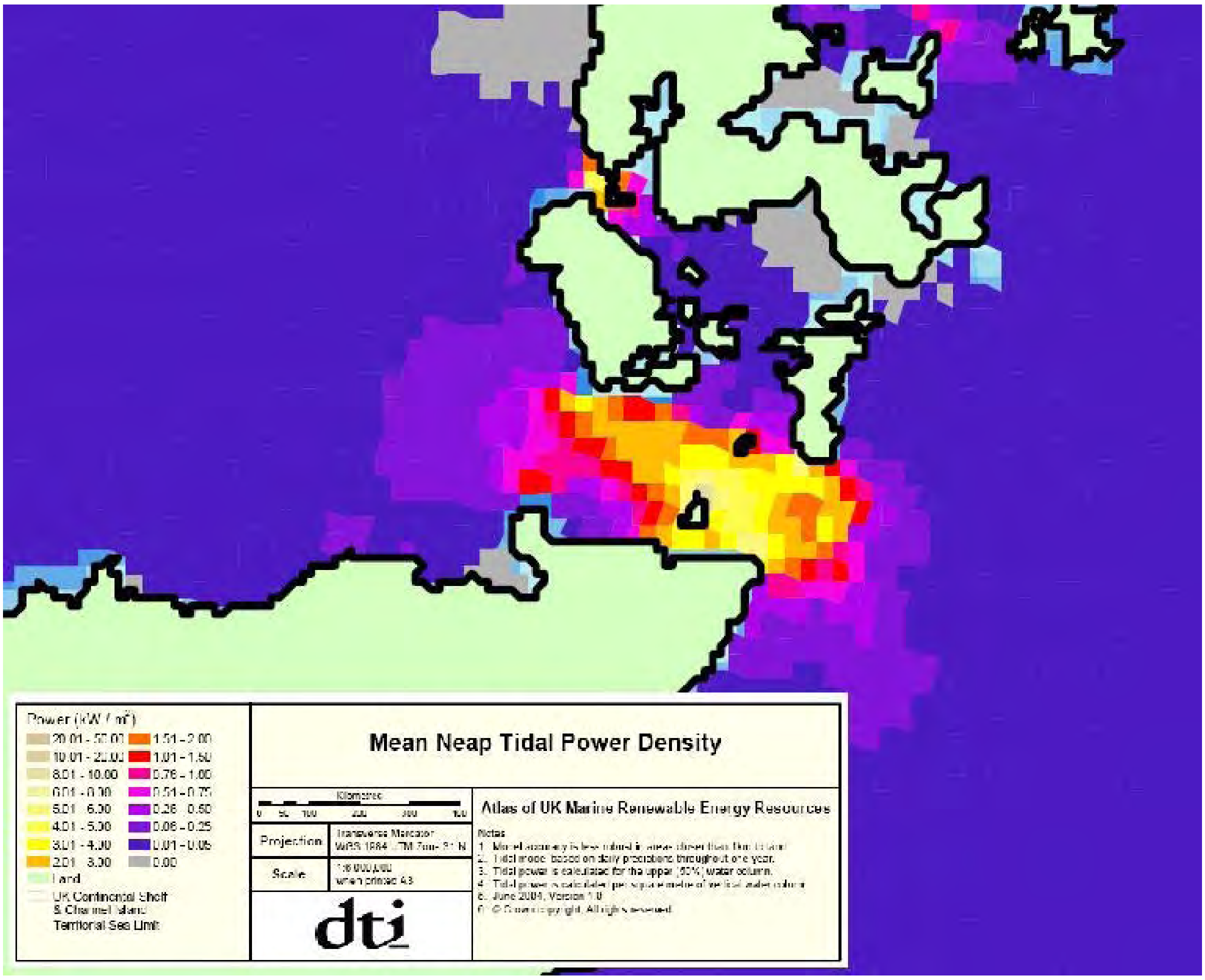
Figure 3-7: Marine Energy Atlas Mean Neap Tidal Power – Pentland



The output from the existing Orkney model, at 1000 m resolution, is in broad agreement with the data presented in the Atlas, derived from the HRCS model at 1 nautical mile resolution, although the existing model tends to predict lower power density. Note that, since power density is a function of speed cubed, small changes in predicted velocity will lead to large changes in predicted power density.

The 1000 m model output is also significantly more refined, such that the localised details of the tidal stream resource will differ between the two data sets. Predictions made regarding the power available at any given site would be expected to be significantly more robust when derived from the finer resolution model output. This expectation is reinforced since the latter model is calibrated and validated specifically for application in the Orkneys region.

The purpose of this comparison is to illustrate the differences in resolution that may be achieved when using strategic, regional or local scale models to assess tidal power.

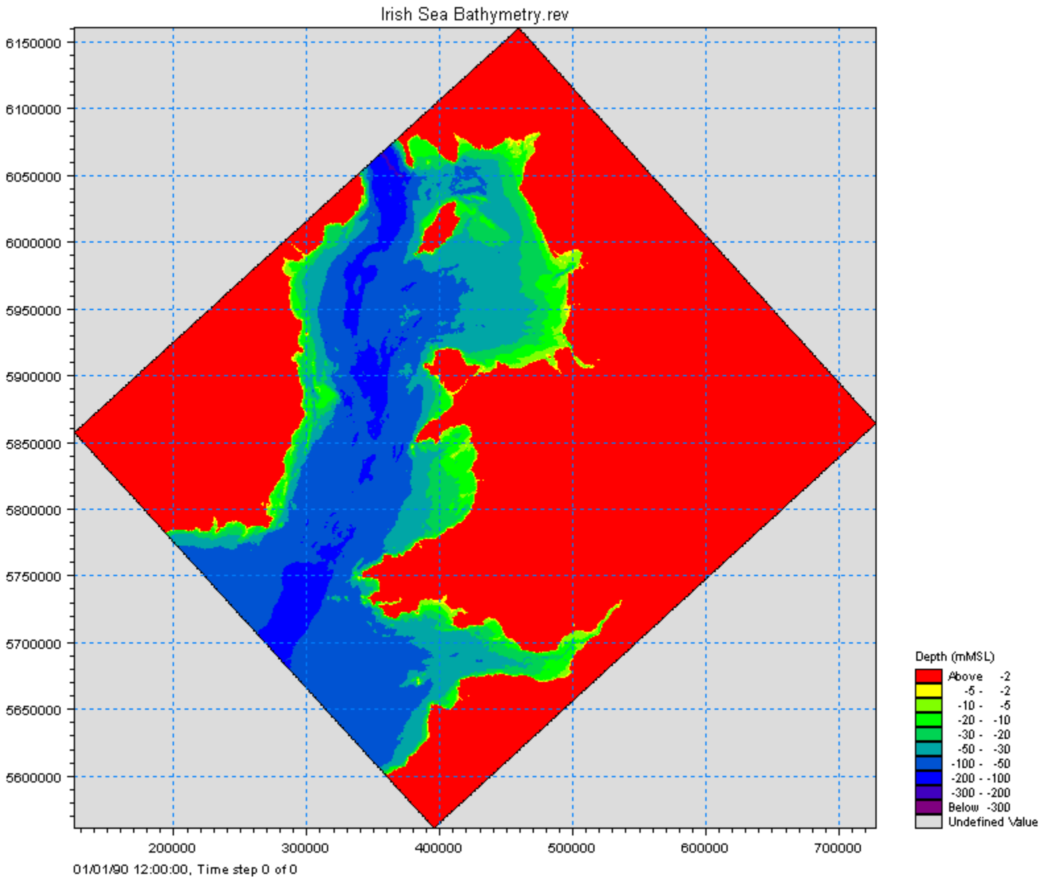
3.1.9 Coastal Modelling System for Wales

The Carbon Trust Phase I and II data presented above was based on tidal current velocities obtained from the POL HRCS hydrodynamic model, of resolution 1 nautical mile (approximately 1800 m), or from published tidal stream data.

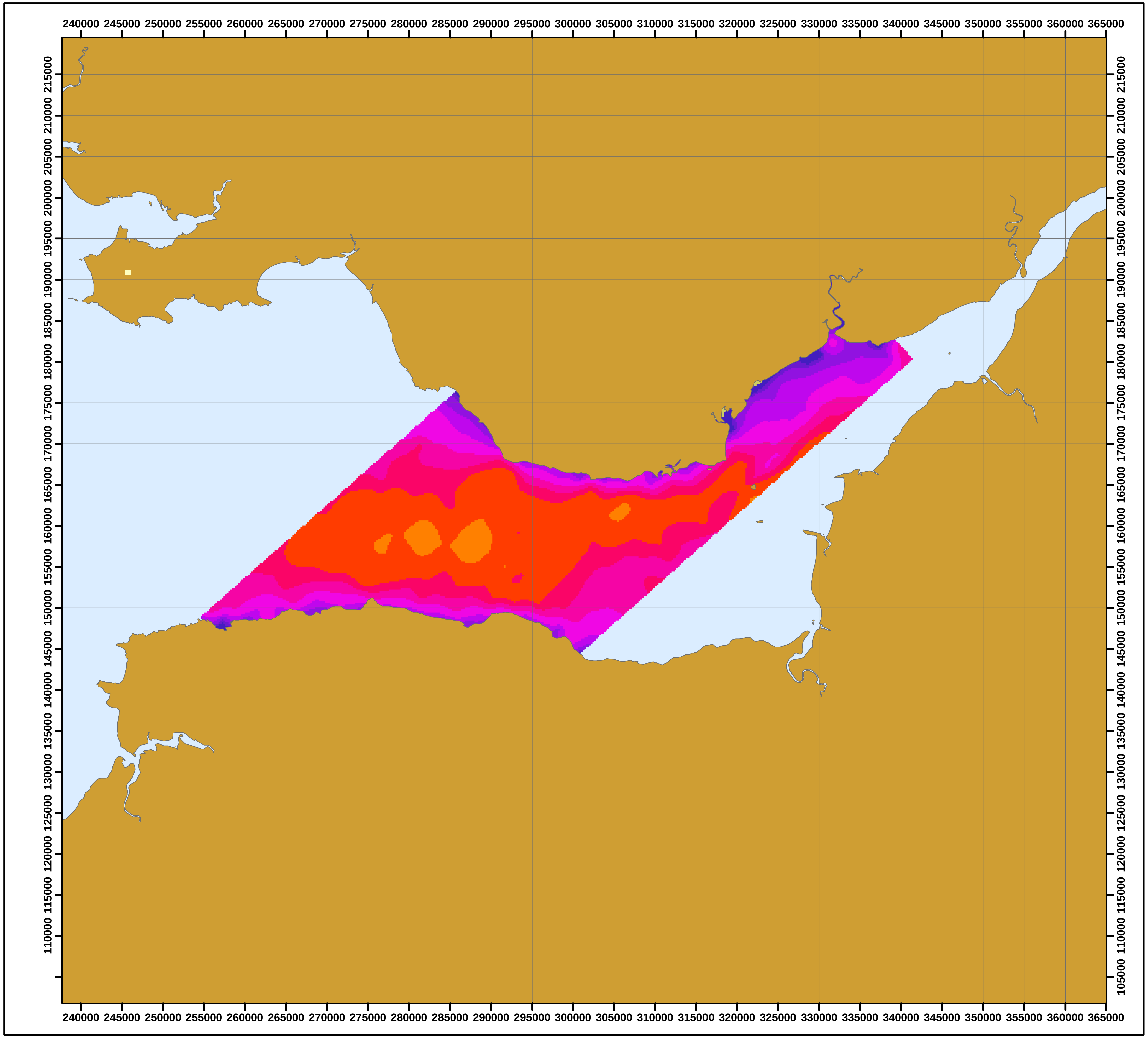
As stated above, current velocity is significantly influenced by the details of the local bathymetry. Increased model resolution is therefore key to increasing the accuracy of model predictions of current velocity and therefore tidal power density. Again, for comparative purposes, a fully calibrated Coastal Modelling System for Wales (CMSW), which has a resolution of 1000 m, has been appliedto derive tidal current power density datasets for part of the Bristol Channel. The purpose of this exercise is purely comparative, to provide an indication of the effects of more highly resolved data.

The CMSW operates within the industry standard DHI Mike 21 modelling suite and is shown in Figure 3-8.

Figure 3-8: The CMSW Model Domain



Spring and neap tide output from the CMSW for part of the Bristol Channel is presented in Figure 3-9 and Figure 3-11, for comparison with Atlas data presented in Figure 3-10 and Figure 3-12.



Bristol Channel Spring Regional Power

Legend

Land

Regional Power

kW/m^2

- 0 - 0
- 0.01 - 0.050
- 0.051 - 0.1
- 0.11 - 0.25
- 0.251 - 0.5
- 0.51 - 1
- 1.01 - 1.5
- 1.51 - 2.0
- 2.01 - 3.0
- 3.01 - 4.0
- 4.01 - 5.0
- 5.01 - 6.0
- 6.01 - 8.0
- 8.01 - 10.0
- 10.01 - 20.0
- 20.01 - 50

Date	22 January 2007	
Projection	British National Grid	
Spheroid	Airy	
Datum	OSGB36	
Data Source	Model Results	
File Reference	I:\...\P936Q -...\GIS\mxd\BC_Spring_reg_Power.mxd	
Checked	F Hashemi	GIS Specialist
	R McCall	Project Manager

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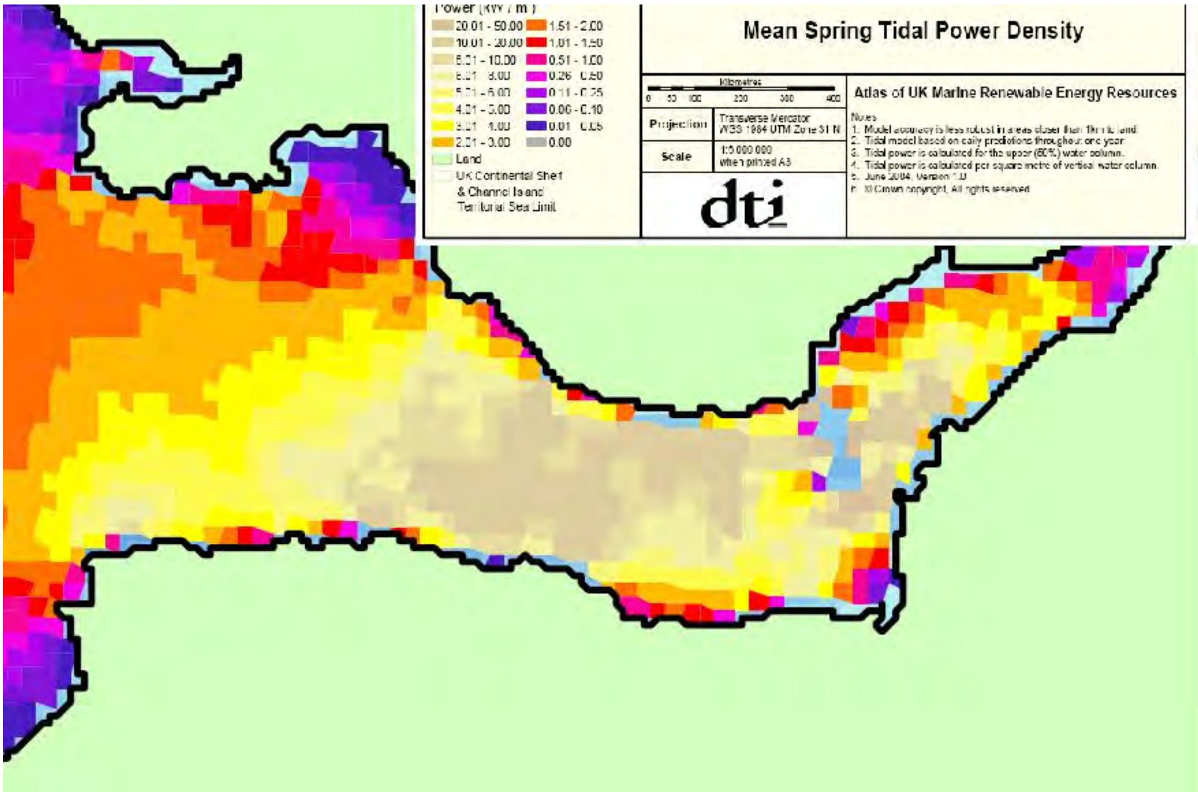
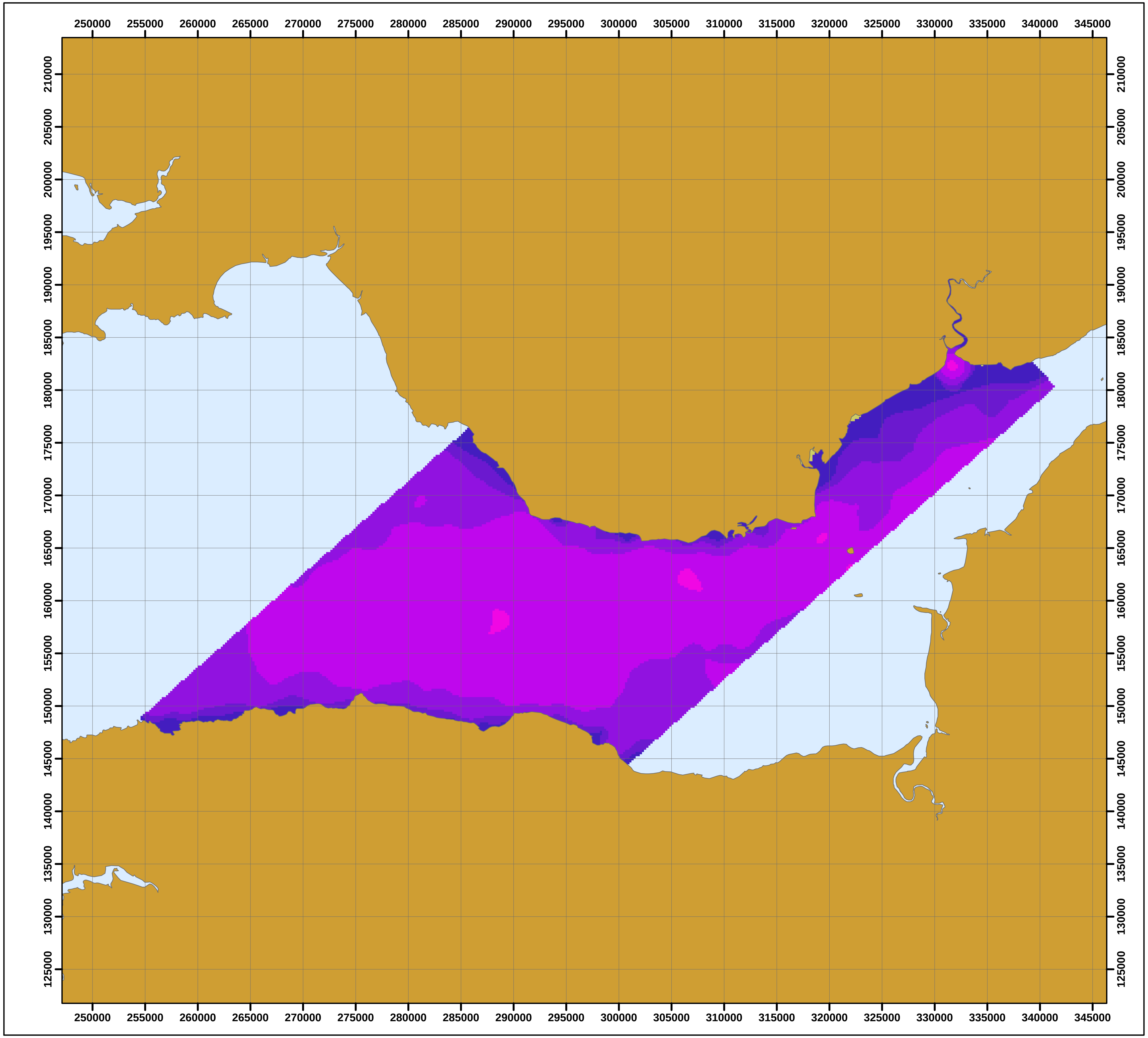
Figure 3-10: Marine Energy Atlas Mean Spring Tidal Power – Bristol Channel





Bristol Channel Neap Regional Power

Legend

Land

Regional Power

kW/m^2

- 0 - 0
- 0.01 - 0.050
- 0.051 - 0.1
- 0.11 - 0.25
- 0.251 - 0.5
- 0.51 - 1
- 1.01 - 1.5
- 1.51 - 2.0
- 2.01 - 3.0
- 3.01 - 4.0
- 4.01 - 5.0
- 5.01 - 6.0
- 6.01 - 8.0
- 8.01 - 10.0
- 10.01 - 20.0
- 20.01 - 50

Date	22 January 2007	
Projection	British National Grid	
Spheroid	Airy	
Datum	OSGB36	
Data Source	Model Results	
File Reference	I:\...\P936Q -...\GIS\mxd\BC_Spring_reg_pwr.mxd	
Checked	F Hashemi	GIS Specialist
	R McCall	Project Manager

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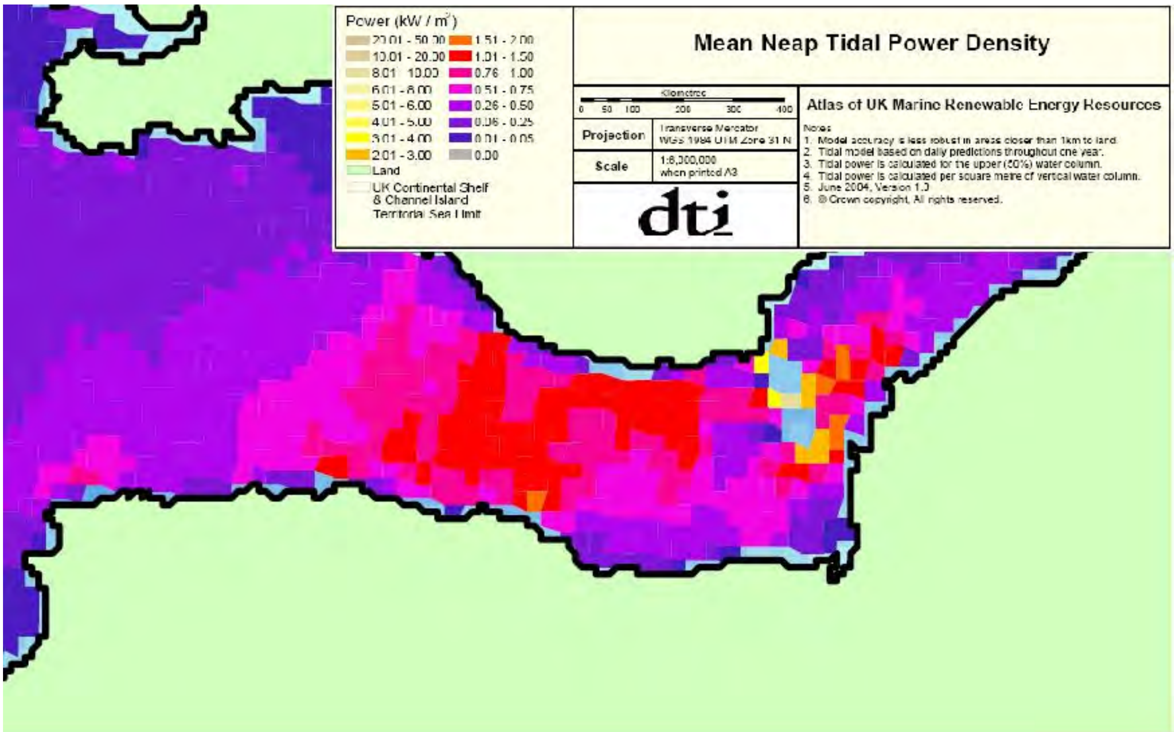
Figure 3-12: Marine Energy Atlas Mean Neap Tidal Power – Bristol Channel



The two datasets produce markedly different predictions of tidal stream power density on the spring tide. As previously mentioned, this is due to the cubed relationship between speed and power density, and highlights the fact that predictions of tidal resource vary depending on the level of detail of the assessment undertaken.

3.2 GEOGRAPHICAL LOCATIONS

From the information sources described above, it is clear that the dominant tidal current resource in the UK is found at sites in the Pentland Firth. This site has been estimated to represent over 60% of the UK resource.

Other key sites include:

- Casquets (Channel Islands)
- Rathlin Island and other sites in Northern Ireland
- Mull of Galloway
- Islay
- Carmel Head (Anglesey)
- Bill of Portland
- The Bristol Channel
- Pembrokeshire (St David's Head, Ramsey Island)
- Lleyn peninsula

Figure 3-13 below gives an overview of geographical extent of tidal resource across the UK based in the resource assessments discussed above.

The amount of energy that can be extracted at these sites will depend on the Significant Impact Factor and on the local details of the site in terms of the construction and operation of generation technology. Therefore, although the available information gives a good indication of the tidal stream resources across the UK it would be necessary to undertake further detailed local feasibility assessments to more accurately quantify the resource.

Sustainable Development Commission - Review of UK Tidal Resource

Figure 3-13: Summary of tidal stream resource locations

Legend

Tidal stream resource sites

Date	26 April 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	Black & Veatch, ABPMer et al, DETI et al, Metoc	
File Reference	P936/gis/mxd/report	
Checked	RM	GIS Specialist
	DW	Project Manager

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3.3 TEMPORAL FACTORS

Temporal variability has been discussed above in Section 3.1.4. In addition, the following comments can be made:

The power that can be extracted from marine currents (by turbine generators) is dependant on the speed of the water flow, and the area and efficiency of the turbine, as follows:

Power = 0.5 ρ A v3 Cp (1)

… where:

ρ is the density of seawater (approximately 1025 kg/m³)

A is the area swept by the rotors (m²)

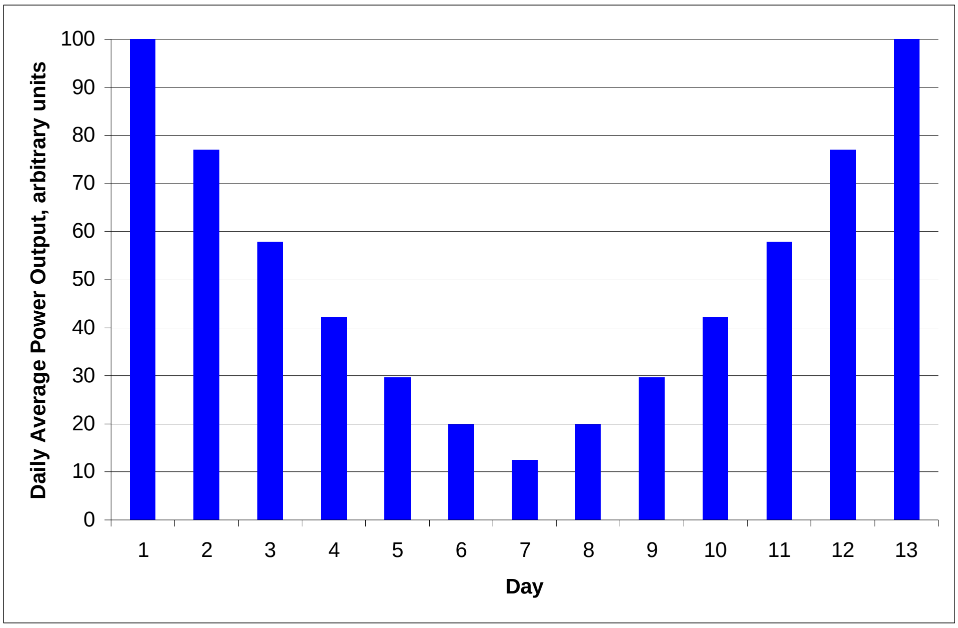
V is the current speed (m/s)

Cp is the efficiency factor of the turbine.

The density of seawater means that marine turbines are significantly smaller than wind turbines of similar generation capacity, and rotate at approximately 20 to 30 rates per minute.

It is clear from (1) that the current speed is the most important factor in determining power output from any given plant. Tidal stream velocities are highly predictable in nature. Generally speaking, tidal stream (which combines with wind effects to produce currents) magnitude varies sinusoidally, with the highest speeds occurring at mid ebb or mid flood, and speeds approaching zero at the turn of the tide. The turn of the tide happens, in most cases at high and low water. However, in some areas, for example the English Channel, the turn of the tide does not coincide with high and low water. Further, the 14 day spring-neap cycle is common to all UK sites, and power output during the neap phase will be significantly lower than that during the spring phase, as demonstrated by Figure 3-14 (assuming spring tidal stream speeds to be twice those on neaps and the variation to be linear).

Figure 3-14: Variation in Available Tidal Stream Power over a typical Spring – Neap Cycle



The temporal variability in power output will be site specific, with a perhaps extreme example being the Pentland area. Due to the high velocities in this area, turbine rated velocities (generally set to 70% of mean spring maximum velocity) frequently exceed 4 m/s. This would mean that, while peak generation would be high, the temporal variability in power output would be increased.

The Variability of UK Marine Energy Resources report, discussed above, shows that in addition to the variations in power output over the spring-neap cycle, the fully developed UK tidal current resource would show strong daily variations. During spring tides, peak output was found to be 90 to 100% of installed capacity, dropping to a 15 to 30% minimum. During neap tides, peak output was found to be 15 to 40% of installed capacity, dropping to a minimum of less than 10%.

Spring tide peak generation at the Pentland sites, occurring at mid flood and mid ebb, will occur at around 0900 and 1500 and then on the subsequent tide at around 2130 and 0330. The cyclical changes in the timing of mid flood and mid ebb mean that the periods of peak generation change by approximately an hour each day through the spring-neap cycle. Daily surges in electricity demand commence at approximately 0600 and again, during the winter, at 1600. Thus, peak spring tide generation at the Pentland sites does not synchronise well with peak energy demand. However, the changing nature of periods of peak current speed means that peak generation will go in and out of phase with peak demand through the spring-neap cycle. From Figure 3-14 it can be seen that, on the day before or after the spring tide, available power at a given site is reduced to approximately 77% of its spring tide value (assuming spring tidal stream speeds to be twice those on neaps and the variation to be linear). This continues until the neap tide when the peak available power is approximately 12.5% of the spring tide peak. Therefore, as the time of high water shifts through the spring-neap cycle, the time of the peak energy production will a) shift accordingly and b) be significantly reduced when compared with the spring tide peak.

3.4 SUMMARY & DISCUSSION

The review of available information indicates that tidal current resource in UK waters is significant in terms of its potential contribution to meeting the UK electricity demand. On a national scale, by far the greater part of the extractable UK tidal stream energy is located in a small number of locations, of which the Pentland Firth is by far the most significant. Other sites are nonetheless important, in part because of the temporal variability of the resource. Smaller sites may also be important in terms of local scale generation, even if their contribution on a national scale is small.

The tidal current resource in the UK is highly variable. Because of the cubed relationship between current speed and extracted power, there is approximately eight times more tidal stream power during spring tides than at neaps. Since spring tides occur at the same time around the UK coast, geographical diversification of the tidal stream generating capacity does not present a solution to this aspect of tidal power. However, the timescale of this variation (14 days) may fit well with load-following operations by coal or CCGT power stations. A solution to temporal variability may be to use a mix of wave and tidal current generation or to limit transmission capacity to 70% of peak capacity which both reduces costs and removes considerable variability from the site.

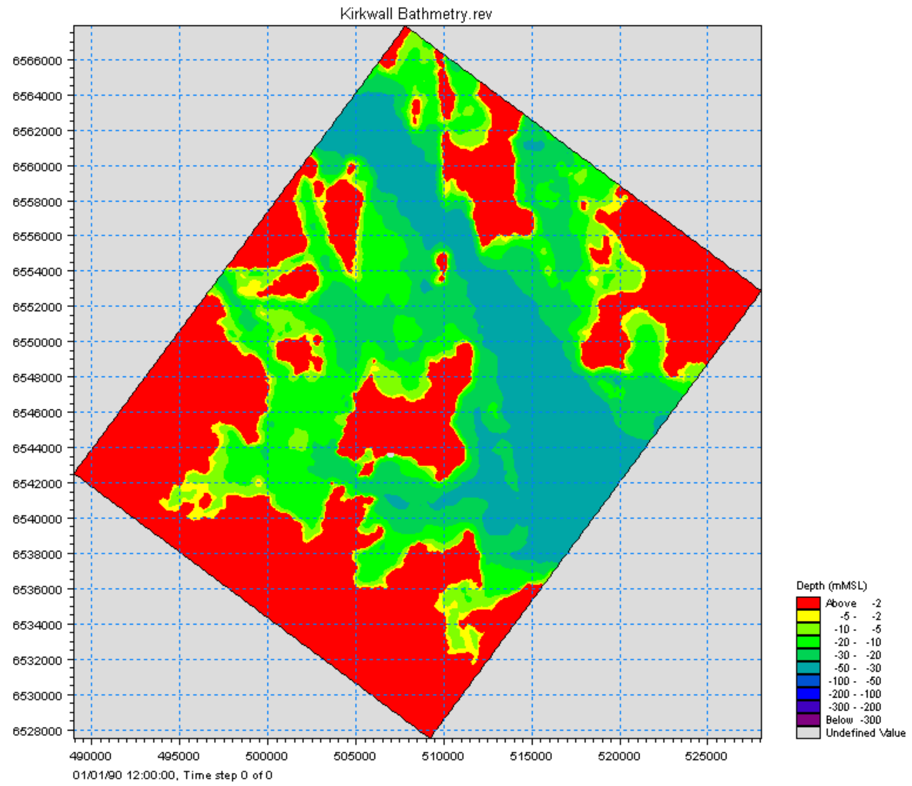
On a daily scale, variability in the tidal current resource is reduced because peak tidal flow at key areas across the UK do not occur at the same time. However, because of the dominance of the Pentland area, production peaks from that area are inevitably synchronized. Mid flood and mid ebb peak power production will occur approximately every three hours.

3.4.1 Data Resolution

3.4.1.1 The Importance of Resolution

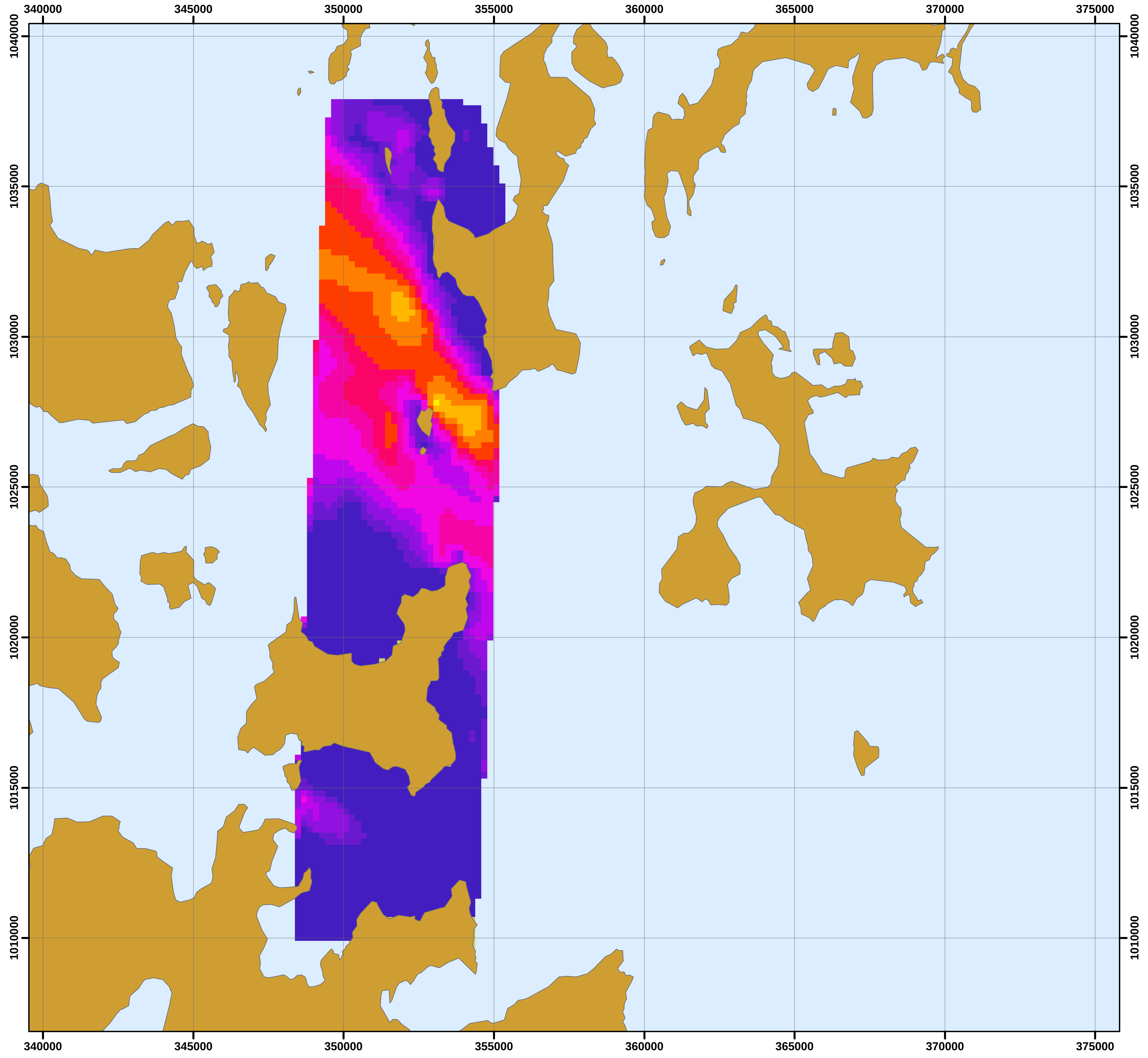
In order to further explore the effect of model resolution on the quality of tidal stream data, an existing 200 m resolution model of the Kirkwall area has been applied. This model domain is presented in Figure 3-15.

Figure 3-15: 200 m Kirkwall model domain



Predictions of the tidal stream resource derived from the Kirkwall 200 m model spring tide output is compared with output from the previous Orkney 1000 m model below, in Figure 3-16 and Figure 3-17. Note that this Kirkwall model does not extend to the Pentland Firth, and the comparison is therefore made for that section of the models including Fall of Warness and Stronsay Firth.

Orkney Spring Medium Grid Power



Legend

Land

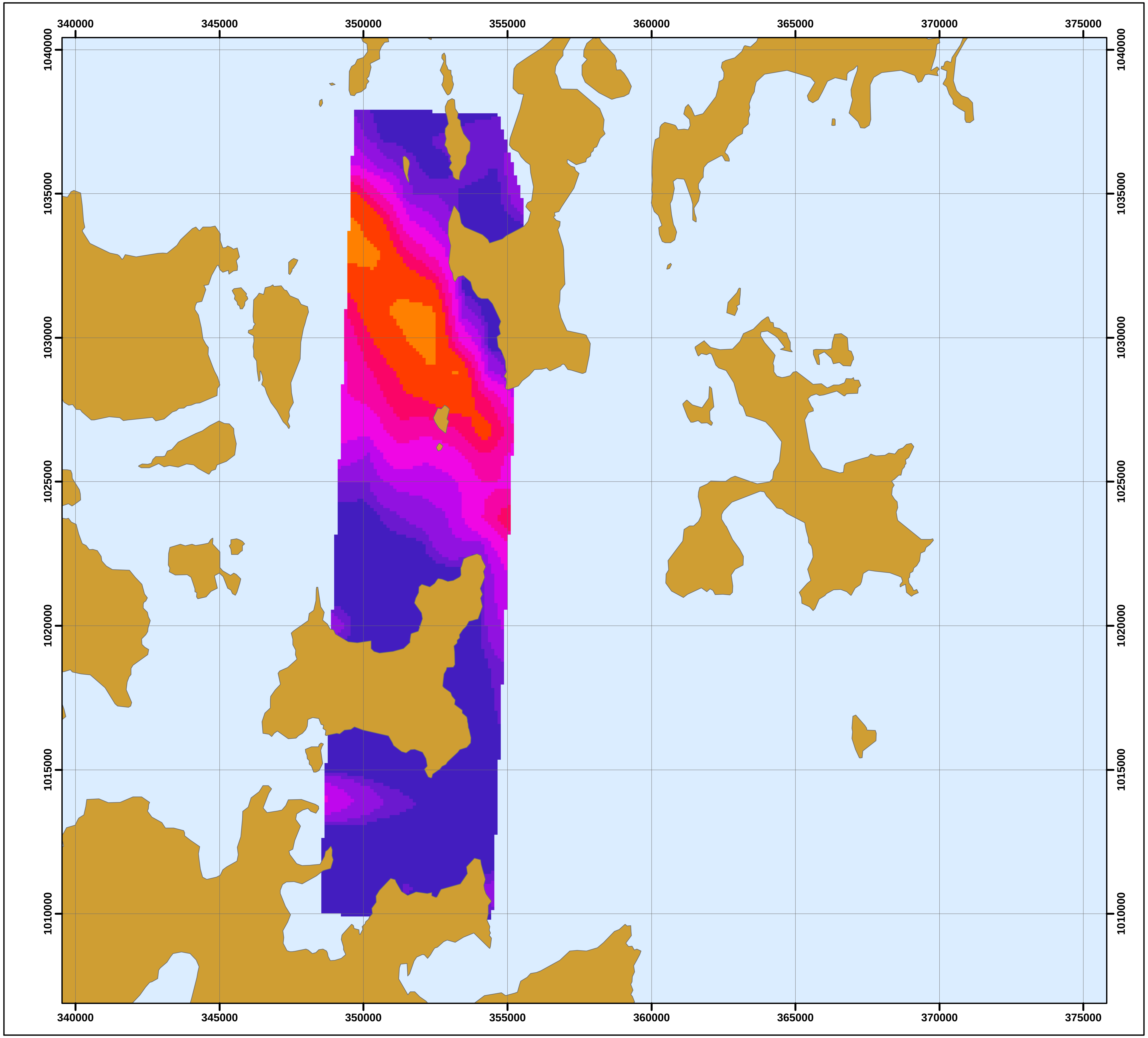
Medium Grid Power

kW / m^2

0 - 0
0.01 - 0.050
0.051 - 0.1
0.11 - 0.25
0.251 - 0.5
0.51 - 1
1.01 - 1.5
1.51 - 2.0
2.01 - 3.0
3.01 - 4.0
4.01 - 5.0
5.01 - 6.0
6.01 - 8.0
8.01 - 10.0
10.01 - 20.0
20.01 - 50

Date	22 January 2007	
Projection	British National Grid	
Spheroid	Airy	
Datum	OSGB36	
Data Source	Model Results	
File Reference	I:\...\P936Q -...\GIS\mxd\BC_Neap_reg_Power.mxd	
Checked	F Hashemi	GIS Specialist
	R McCall	Project Manager

METOC



Orkney Spring Regional Power

Legend

Land

Regional Power

kW / m^2

- 0 - 0
- 0.01 - 0.050
- 0.051 - 0.1
- 0.11 - 0.25
- 0.251 - 0.5
- 0.51 - 1
- 1.01 - 1.5
- 1.51 - 2.0
- 2.01 - 3.0
- 3.01 - 4.0
- 4.01 - 5.0
- 5.01 - 6.0
- 6.01 - 8.0
- 8.01 - 10.0
- 10.01 - 20.0
- 20.01 - 50

Date	22 January 2007	
Projection	British National Grid	
Spheroid	Airy	
Datum	OSGB36	
Data Source	Model Results	
File Reference	I:\...\P936Q -...\GIS\mxd\BC_Neap_reg_Power.mxd	
Checked	F Hashemi	GIS Specialist
	R McCall	Project Manager

METOC

It is apparent that the 1000 m and 200 m models are in broad agreement, but it is clear that identification of the localised details of the flow pattern is significantly improved by the application of the more highly resolved model.

Comparison of power density charts derived from datasets of differing resolutions highlights the requirement for tidal current data of a significantly higher resolution than currently exists or has been made available, in order to undertake site selection for tidal energy developments.

If the key areas of tidal stream resource were to be assessed by the application of higher resolution modelling the following would be possible:

- Previously identified sites could be confirmed in terms of their location, geographical size and output potential
- Where necessary sites could be relocated and reassessed.
- New potential sites could be identified and assessed.

For more detailed assessments, the review of information presented above suggests that model resolution should be better than 250 m, given the limited spatial scales of the resource in key areas.

3.4.2 A Note on Calculation of Energy Resource

The estimates of the practical UK tidal resource reviewed in this report and the calculations carried out to provide the estimates of available power in the Pentland Firth, Bristol Channel and Wide Firth (Orkney Islands) are all based on the ‘Flux Method’ (Black and Veatch, 2005). However, both S.H. Salter (Salter, 2005) and D. MacKay (MacKay, 2007) have suggested that this standard figure may be an under-estimate by a factor of between 10 and 20.

The ‘Flux Method’ addresses the extraction of power from only the kinetic energy of tidal currents. Both Salter and MacKay have suggested that the total power in tidal waves is not equal to the kinetic energy flux across a plane but is related to the work done by the weight of water as a tidal peak exerts pressure on the neighbouring water. In the Pentland Firth, Salter has calculated the peak energy dissipation to the seabed due to friction to be of the order of 100 GW, which is 6.6 times the total calculated kinetic energy flux for the entire UK.

At the time of writing, both the Salter and MacKay documents are yet to be published in the scientific literature, where they will be subject to peer review. It is recommended that the outcome of this process is monitored closely by interested parties.

S.H. Salter’s work has been published on the DTI website (Salter 2005). In this analysis, the energy losses due to bed friction through a channel, such as the Pentland Firth, are considered. Initial estimates of energy dissipated to the channel bed through the Pentland Firth were found to be of the order of 100 GW, many times more than the Carbon Trust estimate for the whole of the UK. The author proposes that the installation of plant to remove energy from the tidal flow will slow the flow velocity and so reduce frictional losses, thus making available the energy previously lost to friction. Extraction of energy from the tidal stream is expected to tend to divert water round the north of the islands and place an upper limit to the gain. However, this diversion is also expected to improve the economics of tidal current plant sited further north. Work is ongoing by Ian Bryden to replace the current crude constant-velocity rectangular model with a model using a matrix of small areas and including island resistance and flow diversion though the northerly bypass passages. Prof. Bryden and his colleagues (Bryden 2005) have prepared a paper on the modelling of energy extraction from tidal currents.

Prof. David MacKay (MacKay 2007) has provided an analysis which largely concurs with Prof. Salter's work. Prof. MacKay demonstrates that tidal resource is not limited to the kinetic energy flux across a plane, except in very specialised circumstances such as at the Straits of Gibraltar. Prof. MacKay has calculated the true total incident power both by considering the total energy present in one tidal wavelength and by calculating the average work done by the tidal wave, when considered as a piston. Both calculations show that the tidal stream power available is not equal to and is far in excess of the kinetic energy flux across a plane. These calculations also show that the available power is proportional to the amplitude of the current speed squared, while the kinetic energy flux method suggests that the total power varies with the amplitude cubed. This analysis has far reaching consequences for continuity of supply as the potential available power under neap tidal conditions is predicted to be 25% of the available spring tidal conditions power, rather than the 12.5% predicted by the kinetic flux method.

Additionally, it should be noted that a further tidal resource assessment is currently underway. This study is being undertaken by ABPMer, funded by the NPower Juice Fund. It is expected that the report of the study will present findings of exploitable resource and schedule output for technology types, categorised by water depth (shallow water technologies - 5 to 25 m depth Lowest Astronomical Tide (LAT); intermediate depth technologies - 25 to 40 m LAT; and deep water site technologies - >40 m LAT). This study will therefore build on the currently available work and present more refined descriptions of tidal resource especially in larger estuaries and around headland features (pers. comm. Bill Cooper, ABPMer). This work is expected to be published in April 2007.

4 TIDAL RANGE RESOURCE

As was found to be the case for the tidal current sector, a large amount of work has already been undertaken in order to determine the scale and availability of the UK tidal range resource.

The tidal range resource is power that may be extracted from potential energy release from water at high level relative to low level: for example, water released from a barrage after high water flows to lower levels around low tide, releasing exploitable potential energy as it falls (by potential energy we mean energy stored by raising material against the force of gravity: “potential” is not synonymous with “possible” or “conceivably available”).

The resource is proportional to the square of the tidal range. The potential energy stored in a column of fluid is proportional both to the height of the column above some reference level (such as tidal low water) and to the mass of fluid in the column. The mass in the column is itself proportional to the height of the column, so the stored energy becomes proportional to the square of height. As an example, twice the column contains twice the mass at twice the height, so stores four times the potential energy. Potential energy may be released by the falling of the column to the level of low water. Tidal range is the difference between high and low waters, so the potential energy available by the falling of the high column to low water level is proportional to the square of tidal range. Operational factors and procedures mean that technically extractable power is approximately proportional to the square of the tidal range.

Because the frequency of tidal phenomena is fixed (for example, about two tides per day in semidiurnal areas), the number of occasions per day on which the potential energy may be extracted is fixed, and the power to be derived from tidal potential thus only depends on the stored potential energy on each occasion – on the square of the tidal range. Areas of large tidal range therefore play a disproportionately important role in potential supplies.

The assessment of tidal range resource consists of a summary and assessment of the key reports and information sources (listed below), and discussion of key temporal and other factors.

- ABPmer, The Met Office, Garrard Hassan and Proudman Oceanographic Laboratory (2004). Atlas of UK Marine Renewable Energy Resources: Technical report. A report to the Department of Trade and Industry.
- World Energy Council (2004). Survey of Energy Resources 2004
- Royal Commission on Environmental Pollution (2000). 22nd Report – Energy – The Changing Climate, presented to parliament June 2000

In assessing the tidal range resource, it must be borne in mind that since the generation capacity is approximately proportional to the square of the tidal range, a site with an 11 m range, for example, will have approximately twice the generation potential of a site with an 8 m range.

4.1 AVAILABLE INFORMATION

4.1.1 Marine Energy Atlas

The Atlas of UK Marine Renewable Energy Resources includes charts that show spring and neap tidal ranges around the UK coast. Much of the information contained in this atlas is derived from the POL hydrodynamic model of resolution 1 nautical mile. In the case of predicted water level (as opposed to the details of tidal stream velocity) resolution is not important and the predictions presented here are considered to be robust.

Areas of note, in terms of spring tidal range exceeding an arbitrary 7 m, apparent from examination of the presented charts, are:

- The Bristol Channel including the South Wales and North Devon coasts
- Liverpool and Morecambe Bays including parts of the North Wales coast.
- Solway Firth
- East Sussex Coast / Strait of Dover
- Channel Islands
- The Wash

It should be noted that although the tidal range information indicates sites in the Channel Islands and the East Sussex coast have sufficient tidal range to potentially be of relevance for a barrage development, they are not ideal locations for a barrage development due to the fact that they are not located in embayments (an embayment is an inlet in whose length is significantly greater than its width at the mouth, or whose area relative to its width at the mouth is significantly greater than the width of the mouth. In practical terms it is an area whose mouth may be profitably closed or partly closed in order to extract the potential energy stored within it).

4.1.2 Survey of Energy Resources

The World Energy Council (WEC) Survey of Energy Resources (World Energy Council, 2004) lists a number of UK sites where the tidal range is sufficient to make the generation of power - with a barrage type scheme - a prospect. These prospective sites are presented in Table 4-1.

Table 4-1: Principal Prospective Barrage Sites

Site	Mean Tidal Range (m)	Installed Capacity (MW)	Annual Output (TWh/y)	Annual Plant Load Factor (%)
Severn	7.0	8,640	17	23
Mersey	6.5	700	1.4	23
Duddon	5.6	100	0.212	22
Wyre	6.0	64	0.131	24
Conwy	5.2	33	0.06	21

The survey mentions that the Severn and Mersey barrages were considered in detail from the mid-1980s to 1992, but did not progress because tidal energy was considered to be less economic than other renewables at that time. In general, the survey considers tidal barrage projects to be capital intensive with relatively high costs per installed kilowatt.

Environmental effects of barrages were also considered, with the potential loss of intertidal areas, siltation and changes to the sediment transport characteristics of the enclosed water body – due to reduced velocities – highlighted as areas which would require particular attention. Similar effects might also be associated with the construction of bunded reservoirs for generation purposes.

The survey does not include a consideration of the energy available for extraction by means of tidal lagoons.

4.1.3 Royal Commission on Environmental Pollution 22nd Report – Energy – The Changing Climate

The Royal Commission on Environmental Pollution's 22nd report Energy – The Changing Climate (RCEP, 2000) is a wide-ranging document concerned with the impact of pollution and energy use on the global climate. Chapter 7 contains a detailed assessment of alternatives to fossil fuels.

In relation to tidal barrages, it notes that the Government at that time declined to provide further funding for appraisals of the Severn Barrage on economic grounds (price per kW generated). The report highlights the radical effects of barrages on the appearance and ecology of the bunded (enclosed) area, together with disruption to fisheries and navigation. However the report also reiterates that the primary reason for such schemes not having proceeded to date is economic, and in the case of the Severn Barrage issues with the national grid accommodating such a large source of electricity operating intermittently (based on a potential installed capacity 8,640 MW for a Severn Barrage compared to less than 1,500 MW for a conventional power station).

The report refers to the Renewable Energy Advisory Group's 1992 Report to the President of the Board of Trade that (REAG, 1992) estimated the technically feasible resource from tidal barrages in the UK could represent 20% of UK demand, with 30% of this coming from the Severn Barrage, and most other schemes being considered "less attractive in financial terms because conditions at the sites are less favourable".

No specific consideration was made of the energy available for extraction by means of tidal lagoons.

4.1.4 Tapping the Tidal Power Potential of the Eastern Irish Sea

A study is currently underway (due to complete in September 2008) looking at the potential for tidal energy generation (tidal range and tidal current) in the Irish Sea (Burrows et al, 2006). The study will use a three dimensional hydro-dynamic model designed to take into account tidal and other oceanographic data, meteorological data and ecological issues.

The preliminary results of this study appear to indicate that there are 17TWh/year of tidal energy potential (from tidal range and tidal currents) in the

Irish Sea area, which equates to 6 % of UK demand. However, it should be noted that this study is not yet completed and therefore has not been taken into account in the assessment of temporal factors presented in Section 4.3.

4.2 GEOGRAPHICAL DISTRIBUTION

As discussed above, the key areas in terms of tidal range resource are:

- The Bristol Channel including the South Wales and North Devon coasts
- Liverpool and Morecambe Bays including parts of the North Wales coast.
- Solway Firth
- The Wash

The vast majority of the tidal range resource is therefore centred around two regions, namely the Bristol Channel, and the North-West of England, as is clear from an examination of the Mean Spring Range chart, from the DTI Atlas of UK Marine Renewable Energy Resources presented as Figure 4-1.

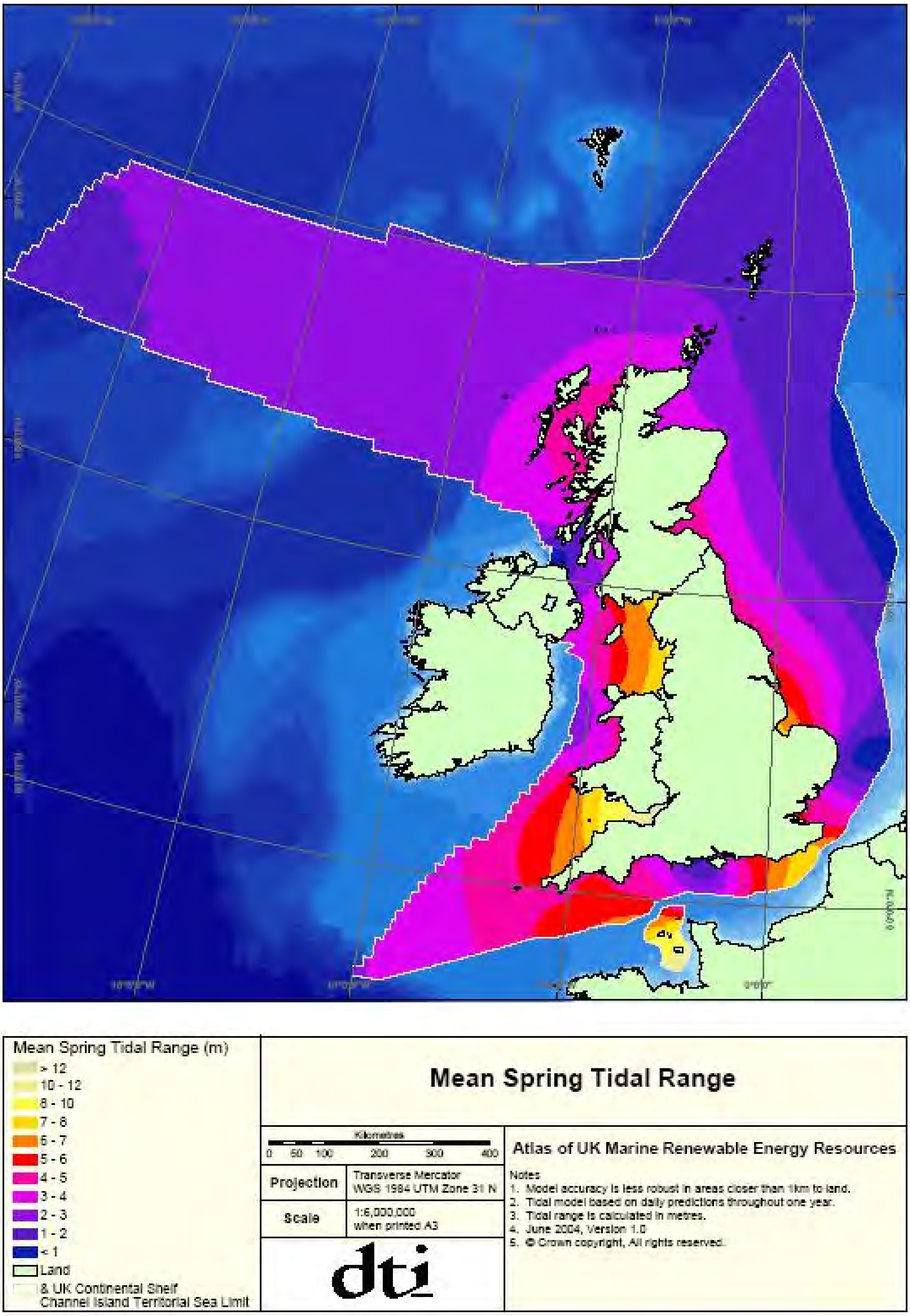
In addition to this there may be opportunities for resource extraction in other areas, examples of which may include:

- The Atlantic coast of North Cornwall
- Milford Haven
- The Irish Sea to the East of the Isle of Man
- The Humber
- The Thames Estuary

However, no resource assessments have been undertaken for these sites to date.

Geographical distribution is important in terms of timing of the supply, as discussed below.

Figure 4-1: Mean Spring Tidal Range (DTI Atlas of UK Marine Renewable Energy Resources)

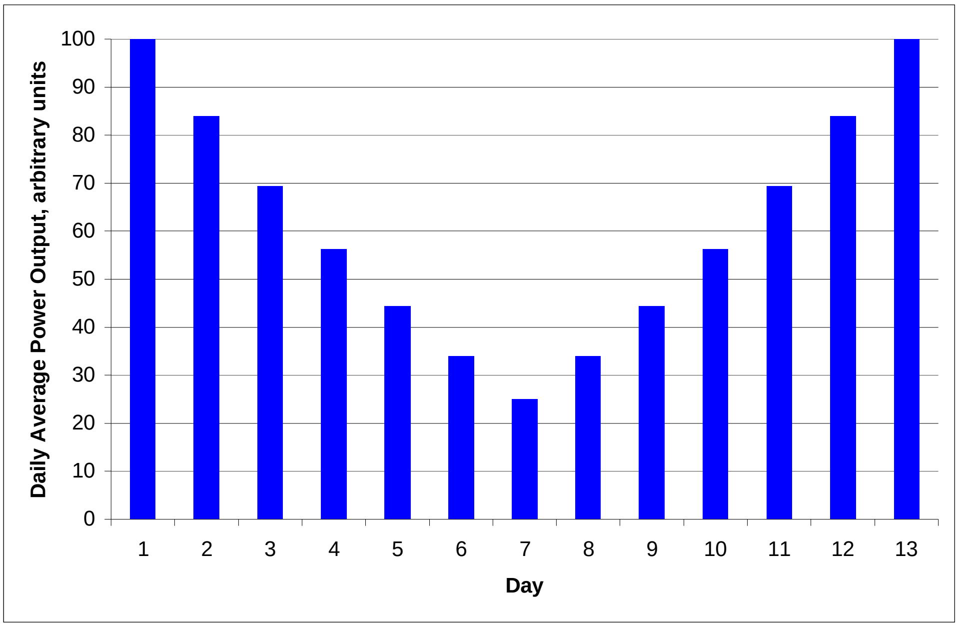


4.3 TEMPORAL FACTORS

4.3.1 Spring - Neap Cycle Variation

Taking the available energy to be proportional to the square of the tidal range, it is apparent that the amount of power which may be generated by any given tidal range resource during neaps would be approximately 25% of that generated during springs, as shown on Figure 4-2 (assuming spring tidal range to be twice that on neaps and the variation to be linear).

Figure 4-2: Variation in Available Tidal Range Power over a typical Spring – Neap Cycle



Spring and neap tides occur at approximately the same time worldwide. Therefore the variability in power production due to the spring – neap cycle cannot be reduced by the geographical distribution of tidal range generation plant around the coast.

4.3.2 Daily Variation

The operational regime of tidal range power plant for a barrage scheme is found to be most efficient when ebb tide generation is employed, consisting of four stages:

1) Fill the basin during the rising tide. Possible pumping of additional head into the basin during this stage.

2) Hold the water in the basin until the falling tide creates sufficient head for generation.

3) Empty the basin through turbines (generation stage) until minimum operating head is reached.

4) Hold the lagoon until the tide has risen sufficiently to repeat 1.

Pumping during the flood stage allows for some degree of flexibility in terms of generation timing and can increase overall power output.

Generation times would vary on a case by case basis, but typically would be expected to commence approximately 3 hours after high water, and continue for approximately 4 hours. Peak power generation would be expected to occur at different times of the day depending on the location of the barrage. The timing of the spring peak power generation is detailed in Table 4-2. This example illustrates the variability of peak power production across the proposed UK tidal range generation sites.

Table 4-2: Spring Tide Tidal Range Generation

Location	Approximate Time of High Water Springs	Approximate Times of Generation
Bristol Channel	0800 & 2000	1100 to 1500 & 2300 to 0300
Liverpool Bay	1300 & 0100	1600 to 2000 & 0400 to 0800
Solway Firth	1300 & 0100	1600 to 2000 & 0400 to 0800
Dover Strait	1230 & 0030	1530 & 0330
Channel Islands	0800 & 2000	1100 to 1500 & 2300 to 0300
The Wash	0800 & 2030	1100 to 1500 & 2300 to 0300

In practice, high spring tides will occur approximately 1 hour either side of the times given in Table 4-2. It might also be possible for the operators to advance generation by approximately 1 hour or delay it by approximately 2 hours on spring tides (or advance by 2 hours or delay by 1 hour on neaps), although this will lead to a significant reduction in power generated, of the order of 25%.

From Figure 4-2 it can be seen that, on the day before or after the mean spring tide, available power at a given site is reduced to 84% of its spring tide value (assuming spring tidal range to be twice that on neaps and the variation to be linear). This continues until the neap tide when the peak available power is approximately 25% of the spring tide peak. Therefore, as the time of high water shifts through the spring-neap cycle, the time of the peak energy production will a) shift accordingly and b) be significantly reduced when compared with the spring tide peak.

The following observations can be made regarding the information presented in Table 4-2:

- Peak generation associated with spring tides, in the Bristol Channel, The Channel Islands and The Wash does not tie in well with daily increases in grid demand which occur from approximately 0600 and again (winter only) from approximately 1600. This may be of limited significance since demand does not drop away during the daytime following the 0600 increase.
- There is a potentially useful range of generation windows at the various sites, with the ability to advance or delay generation enhancing this further.

The operating regime for a tidal lagoon is somewhat different, in that the option for multiple lagoons provides higher load factors and greater flexibility over the timing of generation.

4.4 THE BRISTOL CHANNEL

Of particular interest in any consideration of the tidal range potential of the UK waters is the Bristol Channel/Severn Estuary which, with mean spring tidal ranges of more than 6 m in the west and exceeding 12 m upstream of Avonmouth, experiences the second largest tidal range in the world after Canada's Bay of Fundy. The option of constructing a tidal barrage across the Bristol Channel has historically been the subject of much interest. The principal alternative is the option of constructing one or more tidal lagoons at locations within the Bristol Channel.

Barrage options are discuused in detail in SDC Research Report 3.

4.4.1 The Cardiff-Weston Barrage Option

The Cardiff-Weston barrage, developed and promoted by the Severn Tidal Power Group (STPG), would be located between Cardiff and Weston-super-Mare. Studies (Black and Veach, 2006) have shown ebb generation with flood pumping optimises energy output at Cardiff-Weston.

4.4.1.1 Description & Available Power

The Cardiff-Weston Barrage scheme, as currently proposed by the Severn Tidal Power Group (STPG, 2006), would run from Lavernock Point to Brean Down, be 16 km long and enclose approximately 480 km² of the Bristol Channel/Severn Estuary.

The mean spring tidal range at this location is 10.5 m, increasing to 14 m upstream (this would reduce to 7 m post construction). Its installed generation capacity would come from 216 x 40 MW turbines, giving a total installed capacity of 8,640 MW on a spring tide. Operating at a capacity factor of 23%[1], the barrage could produce 17 TWh/y (equivalent to a continuous output of approximately 2,000 MW), which is approximately 5% of UK electricity demand.

4.4.1.2 Timing of Power Output

The proposed barrage would operate a system of ebb generation, with pumping to increase the head of water at high tide. Some degree of generation flexibility would be technically possible, although this would lead to reduced overall output. A second lagoon would increase flexibility of production while maintaining or increasing power output.

For an 11 m tide, daytime generation would commence at the earliest at 0900 (Shawater Ltd, 2006) - delaying the commencement of generation until around 1230 would increase instantaneous power output but reduce the generation window. Maximum energy yield of 40 GWh (up to 25% more than the 0900 and 1230 scenarios) is achieved if generation commences at 1030, three hours after high water.

As the tidal range decreases, the power output is better maximised by delaying the start of generation. For neaps, the maximum output of approximately 15

[1] 23% capacity - when averaged over time the power output of the barrage would be equivalent to 23% of it's maximum installed capacity, because a) generation would not take place continuously, and b) generation would frequently take place at reduced output.

GWh is achieved by starting generation at 5 hours after high water, i.e. approximately 0630 and 1830. This can be advanced by up to 1 hour or retarded up to 2 hours, with a drop in total power production of up to 25%.

4.4.2 The Shoots Barrage Option

The Shoots barrage (formerly the English Stones barrage), proposed by Parsons Brinkerhoff (PB), would be located just downstream of the second Severn crossing. Studies (Black and Veach, 2006) have shown that ebb generation is the preferred mode of operation at the Shoots barrage sites.

4.4.2.1 Description & Available Power

As an alternative to the Cardiff-Weston barrage scheme discussed above, the option of a smaller barrage, located close to the second Severn Crossing, has been put forward. This barrage would extend approximately 4 km across the estuary, and enclose approximately 90 km^2 of the Severn Estuary.

The mean spring tidal range at this location is approximately 11.5 m. Its total installed capacity of 1,050 MW could produce 2.75 TWh/y (equivalent to a continuous output of approximately 313 MW).

4.4.2.2 Timing of Power Output

The Shoots Barrage would operate a system of ebb generation, with pumping to increase the head of water at high tide. Some degree of generation flexibility would be technically possible, although this would lead to reduced overall output.

For a mean spring tide, daytime generation would be expected to commence at the earliest at approximately 0900. Maximum energy yield would be expected to be achieved if generation were to commence at approximately 1100, three hours after high water.

4.4.3 Other barrage options

Several other barrage schemes in the Severn/Bristol Channel area have been explored over recent decades. Further details of these schemes can be found in Research Report 3 – Review of Severn Barrage Proposals (Black and Veatch et al, 2007)

4.4.4 Tidal Lagoon Options

The generation of energy from tidal barrages relies on complete closure of the estuary. However, energy can also be generated by impounding water within a bunded lagoon (AEA, 2007). Tidal lagoons, an alternative approach to barrages, would be self-contained impoundment structures constructed in the shallow nearshore area, but not extending to the shoreline and not extending across the full estuary width.

The option of tidal lagoons as an alternative to the Severn Barrage has a number of perceived advantages, both environmentally (tidal range at the coast is not significantly affected) and in terms of flexibility of generation (see Research Report 4 – Severn Estuary Tidal Energy Case Study Non-Barrage

Options (AEA, 2007) for further details). The key difference in terms of energy resource, however, is that the tidal lagoon option could be developed incrementally, and possibly in conjunction with other forms of tidal generation such as marine current generation.

A large impounded basin can be created at relatively low cost by building embankments with dredged material, in comparatively shallow water on intertidal areas. The construction of more than one lagoon makes it possible to generate on both the ebb and flood tide which provides continuity of supply over a greater proportion of the day. The Russell lagoons scheme proposes that lagoons could be built out from the shore to limit the amount of material used, one from the south side of the estuary in an area known as English Grounds and on the Welsh Grounds from the opposite shore (AEA, 2007). A study in the Russell lagoons concluded that a lagoon built on the English Grounds could generate 2.16 TWh/year. If two bunded enclosures were to be built on the Welsh grounds phased generation could be possible with one basin operated on the ebb tide and the other on the flood. It has been assumed (AEA, 2007) that the energy output from the two Welsh Lagoons would be similar to the energy output from the lagoon built on the English Grounds.

In addition to the above project Tidal Electric Ltd are proposing a tidal lagoon project in Swansea Bay.

TEL believe that the lagoons approach can provide an annual output equivalent to the Barrage (17 TWh/y) from a much smaller enclosed area (130 km^2 c.f. 480 km^2) because the lagoon system would a) have a higher load factor (TEL claim that generation can be prolonged by the management of water levels within the individual lagoons), and b) enclose only selected areas which would not include the large inter-tidal and shallow areas which are of little value in terms of energy production. A 3-lagoon system would, TEL claim, allow generation to continue for 81% of the time (Pers. Comm., Peter Ullman, TEL). The Swansea Bay component of such a project is predicted to have a generating capacity of approximately 60 MW (AEA, 2007).

The Swansea Bay project was assessed by consultants contracted by the DTI and WDA in 2006 (AEA, 2006). The objective of this review was to provide these Government Departments with an authoritative independent review of the scheme by experience civil engineers. This case study considers both designs and compares the costs, energy output and unit cost of generation. Because of the difference of opinion, Professor Mike Forde, Carillion Professor of the Institute for Infrastructure and Environment, at the University of Edinburgh was consulted for his opinion of the assumptions used in the construction of the embankment (AEA, 2007).

Since publication of the DTI/WDA review, the developers TEL have published a rebuttal refuting many of the conclusions drawn by the DTI/WDA review (TEL, 2007). TEL commissioned a report by Atkins which forms the basis of the design and cost estimate of the proposed lagoon. This report has not been published and it is not therefore possible to discuss its contents (AEA, 2007).

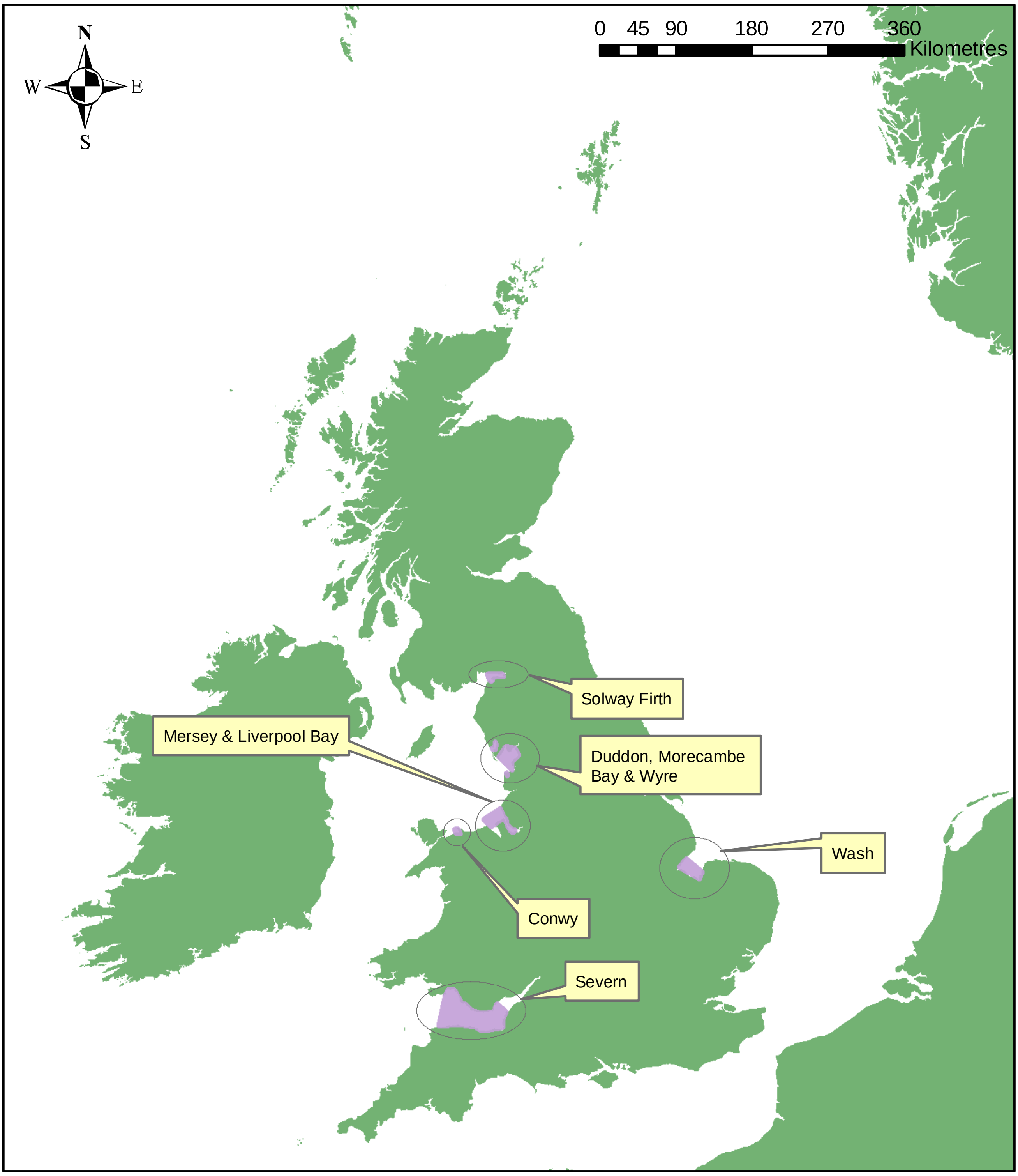
Tidal Lagoon options are discussed in detail in SDC Research Report 4 (AEA, 2007).

4.5 SUMMARY AND DISCUSSION

The tidal range resource in UK waters is significant in terms of its potential contribution to meeting the UK electricity demand. On a national scale, by far the greater part of the extractable UK tidal range resource is located in a small number of locations, of which the Bristol Channel is by far the most significant. Other sites are nonetheless important, in part because of the temporal variability of the resource. Smaller sites may also be important in terms of local scale generation, even if their contribution on a national scale is small. The geographical extent of identfied tidal range resource across the UK is illustrated in Figure 4.3 below.

The tidal range resource in the UK is highly variable. Because of the approximately squared relationship between tidal range and extracted power, there is approximately four times more power produced during spring tides than at neaps. Since spring tides are synchronised around the UK coast, geographical diversification of the generating capacity does not present a solution to this aspect of tidal power. However, the timescale of this variation (14 days) may well fit well with load-following operations by coal or CCGT power stations.

On a daily scale, variability in the resource is reduced because peak tidal flow at key areas is not synchronised. Because of the dominance of the Bristol Channel area, and the synchronisation of production peaks there, there would remain a significant peak in tidal energy production. However, the nature of the resource lends itself well to geographical diversification as a means of reducing variability on a daily scale. Technological advances - for example multi-lagoon plant – will also be a possible solution. Additionally, the UK daily demand schedule may change in the future due to advances in technologies such as plug-in hybrid vehicles or electrically driven hydrogen production, and greater use may be made of demand management and smoothing technologies.



Sustainable Development Commission - Review of UK Tidal Resource

Figure 4-3: Summary of tidal range resource

Legend

Tidal range resource sites

Date	26 January 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	World Energy Council, ABPMer, Metoc	
File Reference	P936/gis/mxd/report	
Checked	RM	GIS Specialist
	DW	Project Manager

METOC

5 GRID CONSTRAINTS

5.1 APPROACH TO ASSESSMENT OF GRID CONSTRAINTS

Electrical grid constraints have been assessed for each of the locations identified in the review of tidal resource presented above with the aim of identifying the potential grid connection opportunities at each site.

In Section 5.2, there is a brief discussion of the current generation opportunities in Scotland, England, Wales and Northern Ireland considering the network connection issues within the National Grid Electricity Transmission (NGET), Scottish Power Transmission Limited (SPTL), Scottish Hydro Electric Transmission Limited (SHETL) and Northern Ireland Electricity (NIE) transmission networks and local distribution networks, as well as the deeper system impact issues that may exist.

Section 5.3 discusses the annual use of system charges for the transmission and distribution systems and how that varies across the UK.

Section 5.4 discusses each of the sites individually and describes the connection opportunities and limitations at each site.

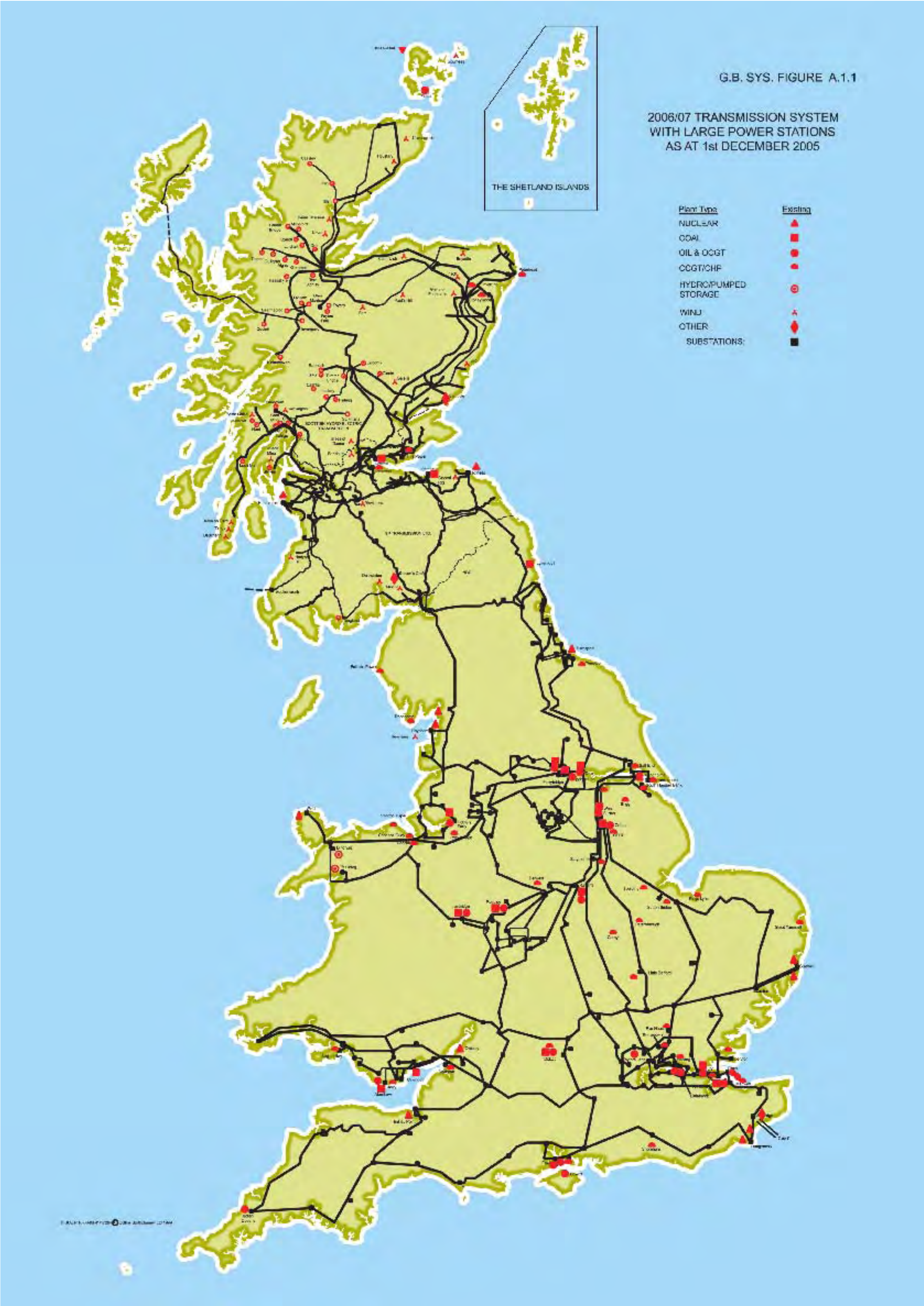
5.2 GRID CONNECTION OPPORTUNITIES FOR TIDAL POWER - BACKGROUND

In the generation context, opportunities are interpreted as the ability to connect new generation without an associated need for major transmission reinforcement which could in turn lead to delays, including those which may be incurred due to the consenting process.

Great Britain (GB) generation agreements are conditional on the completion of the required reinforcements to maintain compliance with the Licence Standard.

The map in Figure 5—1 shows the Transmission network in Scotland, England and Wales. A similar map for the Northern Ireland system is not available for security reasons.

Figure 5-1: GB Transmission System



5.2.1 The GB Queue and BETTA – the Current Situation in Scotland

The British Electricity Trading and Transmission Arrangements (BETTA) were implemented on 1 April 2005. They created a fully competitive British-wide wholesale electricity market for the first time by integrating the England and Wales network with the Scottish network.

As part of the transition from previous arrangements, a cut-off date was established whereby, if a generator accepted commercial terms for connection before the 1st January 2005, then the constraints in the England and Wales network and in the Scotland/England interconnector would not be contractually limiting.

Essentially, if such a generator had to be subsequently constrained due to lack of network capacity outside of Scotland then it would be commercially compensated under the standard market mechanisms. This means that such generators have a commercially 'firm' connection even if they do not have a physically firm connection.

Post 1st January 2005, all generation connection agreements received by the Great Britain System Operator (GBSO) are placed in a queue (The GB Queue) in strict order by date on which the developer formally accepted the connection offer. Those offers accepted earliest are typically contingent on fewer reinforcements than those accepted later.

This is a matter of on-going discussion, in particular within the Access Reforms Options Development Group (ARODG, 2006) who were set up by Ofgem to develop a range of options for amending the existing arrangements for securing transmission capacity. This is because there are some generation projects in the queue that may find it difficult to get planning consent thereby indirectly blocking connection of other generation projects further down the queue that may be more straight-forward to consent. The worst case would be a project in a position to start construction, network capacity still being available, but it is unable to connect due to the commercial terms of its connection offer.

The above paragraphs describe the current situation. However, there are proposals that could change this. One of these, the Connection and Use of System Code (CUSC) Amendment Proposal (CAP) 131, proposes that new generators should provide a stronger user commitment signal, which could have implications for the composition of the GB queue. This user commitment would be in the form of an upfront payment of up to £3/kW prior to the reinforcements being approved in planning. Once approval is given then they will be required to provide security of up to 6 times their annual use of system charge. For projects in northern Scotland, this will amount to more than £120/kW (see section 5.3 for further information on use of system charges).

Another proposed change to this situation, brought forward by National Grid recently, is that any 'gaps' created in the queue by developers relinquishing or reducing their required capacity, would be offered to any project that is in a position to proceed. Therefore, is a tidal generator was able to gain planning permission and was technically and commercially able to connect, then they may be offered the available capacity when it occurred.

Currently there are a total of 12 GW of accepted connection offers for connection in Scotland under the pre-BETTA regulations. The vast majority of these applications are for wind power generation[1].

Of these, Scottish Hydro Electric Transmission Limited (SHETL) has a total of 7.7 GW and Scottish Power Transmission Limited (SPTL) has the remaining 4.4 GW. The existing SHETL transmission network can only accommodate approximately 1.5 GW of new renewable generation without reinforcements being triggered[2]. New generation has previously been defined as post-privatisation in 1990 and as of November 2006, approximately 830 MW has been built or is currently under construction.

In 2003, the Department of Trade and Industry (DTI) initiated some preliminary studies into the scope of work required to upgrade the transmission system to accept increasing amounts of renewable generation. The Renewable Energy Transmission Study (RETS) identified the transmission system reinforcement costs associated with installation of up to 6 GW of renewable energy generation in Scotland. It was clearly recognised that the provision of this infrastructure was crucial in ensuring that the generators are able to make a contribution to meeting the Government 2010 targets for renewable energy generation.

The RETS report, produced for the DTI by the three transmission licensees (SHETL, SPT, NG) assessed the connection of 2 GW, 4 GW and 6 GW of additional renewable generation in Scotland and then recommended the staged reinforcements required to accommodate this (DTI, 2003).

SHETL studies have indicated that the most effective, economic and efficient way of increasing the network capacity in its system is to upgrade the existing Beauly-Denny corridor from 132 kV to 400/275 kV (400 kV on one side and 275 kV on the other to facilitate interconnection with the rest of the system at Errochty and Braco). The application for consent under Section 37 of the Electricity Act 1989 for this upgrade was submitted and has been referred to a Public Inquiry that was scheduled to start on 1st February 2007. Were permission to be granted in 2008 the works will then take approximately three years to build, so completion will not be achieved until at least 2011. As there have been a number of objections to the proposal, there may be significant delays in implementing this reinforcement. This reinforcement will allow up to a total of 3000 MW of generation to be connected in the northern SHETL region. All of this capacity has been allocated to projects already in the queue and if all these projects go ahead then SHETL would have to consider further reinforcements to accommodate additional generation connection applications.

In addition to the Beauly-Denny option, the next reinforcements that have been identified by SHETL as the most effective way of increasing the network capacity in line with the accepted generation connection offers are shown in

Table 5-1. The column on the right-hand side shows the cumulative capacity for the connection of renewable generation in the SHETL area.

[1] Consultation with SHETL
[2] Consultation with SHETL & SPTL

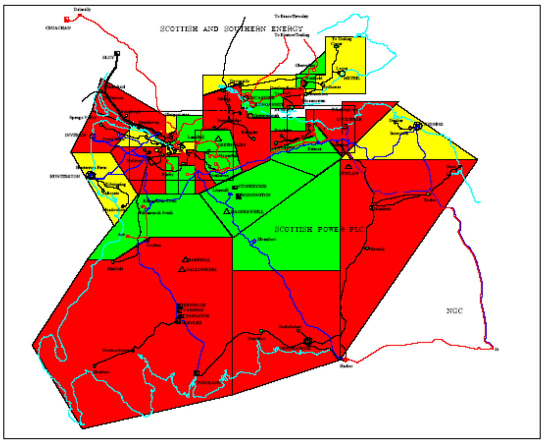
Table 5-1: Anticipated Reinforcements Required in the SHETL Region[3]

Order	Line	Upgrade required	Anticipated date of completion	SHETL capacity for new renewable generation after completion
1	Beauly - Dounreay	Second Circuit on existing towers	2010	Additional connection capacity for the North of Scotland as far as Beauly
2	Beauly – Denny	New 400/275 kV route replacing existing 132 kV route	2011	2.5 GW
3	Beauly – Blackhillock	Re-conductoring	2013	3.0 GW
4	Beauly - Keith	Rebuild at 400 kV one of the three existing routes between Beauly and Keith/Blackhillock	2015	4.2 GW
5	Keith – Kintore - Tealing	Creation of 400 kV ring by operating existing routes at 400 kV	2015	5.2 GW

Scottish Power Transmission indicated that in addition to planned changes to the substation at Sloy near Loch Lomond and the part of the Beauly-Denny upgrade that is located in their area, fewer reinforcements are required in their transmission area to accommodate these connections. Re-conductoring of some of the existing lines and some reactive power compensation may be required dependent upon where the generation chooses to connect[4].

The summary of results is displayed graphically on a geographic representation of the SP Transmission system in Figure 5—2.

Figure 5-2: Opportunities for the Connection of Generation



The graphic notation is a traffic signal convention i.e. green denoting no significant problems, amber potential difficulties, while red indicates area of difficulty for the connection of additional generation.

This figure indicates that in the area where some of the proposed tidal generation (Mull of Kintyre, Mull of Oa, Mull of Galloway and Solway Firth) could connect it is currently difficult to connect additional generation.

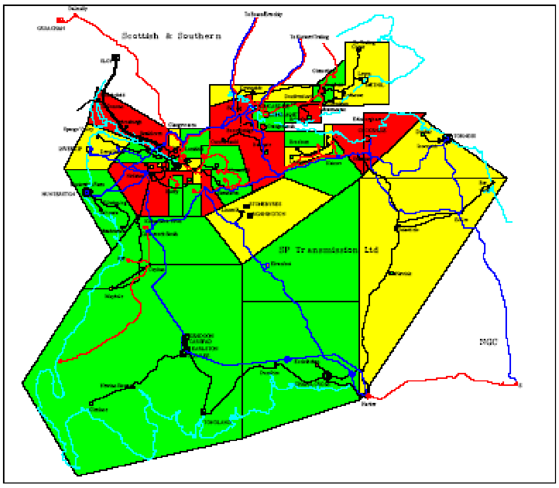
[3] Consultation with SHETL
[4] Consultation with SPTL

The RETS study in 2003 highlighted the need for a 400 kV system between Kilmarnock South and Harker, via Dumfries and Kendoon, with the existing 132 kV line from Kendoon to Kilmarnock South being upgraded to 400 kV. The RETS revisited report published by the DTI in November 2005 suggested the most likely timescale for this reinforcement was 2009.

In the event that the system improvements proposed are implemented, the transmission system infrastructure would facilitate the transmission of significant quantities of renewable generation.

A revised diagram of the Opportunities for the Connection of Generation is shown in Figure 5—3 below and shows that in the area where the proposed tidal generation connection is located the opportunities for connection are significantly improved.

Figure 5-3: Revised Opportunities for Connection of Generation



There is also a significant requirement for reinforcement of the Scottish Power network where it interconnects with England. This is because the Scotland/England interconnector currently only has a firm capacity of 2.2 GW. With the additional 12 GW of connection agreements in Scotland, there will be significant constraints on these lines from Gretna to Harker and then on to Hutton, and from Eccles to Stella West[5].

The next reinforcements that have been identified by SPTL and NGET as the most effective way of increasing the network capacity are shown in Table 5-2.

[5] Consultation with SPTL and NGET

Table 5-2: Anticipated Reinforcements Required in the Scotland-England Inter-connector[6]

Line	Upgrade required	Anticipated date of completion	Interconnector capacity after completion
Eccles – Stella West Strathaven – Harker Blyth – Stella West	Re-conductoring Upgrade to 400 kV Upgrade to 400 kV	2010	2.8 GW
Strathaven - Harker Northeast Ring Heysham Ring	Reactive Compensation Upgrade to 400 kV Upgrade to 400 kV	2012	3.3 GW

No further reinforcements to increase the capacity beyond 3.3 GW have yet been detailed or approved by Ofgem. However, if and when additional capacity is required, then it is likely that an additional interconnector will need to be built, either onshore or offshore. With the requirement to secure wayleaves and planning permission for this additional route it is possible that this third interconnector could take 5 or more years to realise.

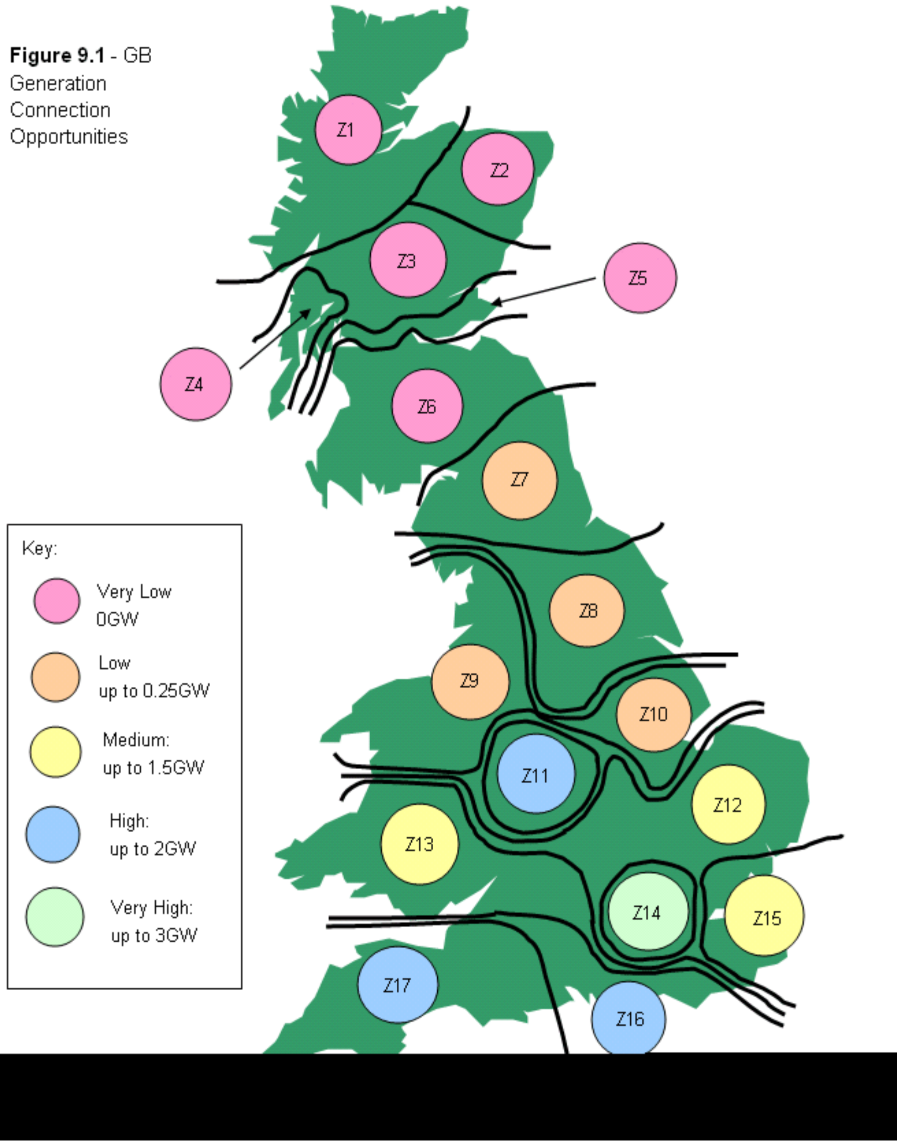
5.2.2 Current Situation in England and Wales

The GBSO Seven Year Study provides an overview of the generation opportunities in the GB network.

Figure 5—4, below taken from the Seven Year Study provides a summary of the opportunities available in the 17 SYS Study Zones. The 17 zones have been grouped into five opportunity groups, namely: VERY LOW, LOW, MEDIUM, HIGH AND VERY HIGH. These categorisations are intended to provide a broad indication of the relative level of possible opportunities for connection within individual zones, or groups of zones, without the need for further major inter-zonal transmission reinforcement, which would be likely to incur significant delays in the proposed project.

[6] Consultation with SPTL and NGET

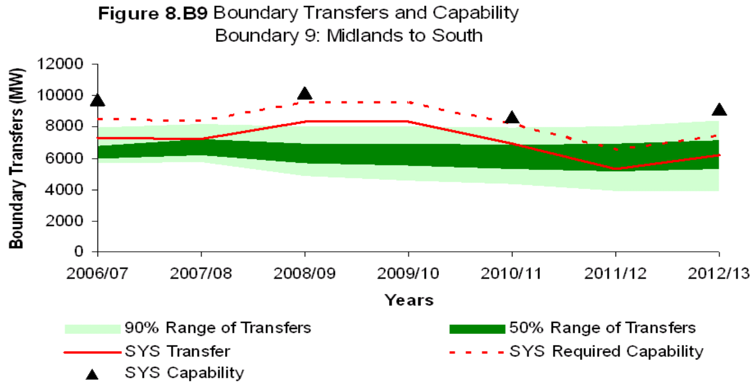
Figure 5-4: GB Generation Connection Opportunities



This figure indicates that the best opportunities for the connection of generation are in the south of England and Wales. In these areas, subject to the local network configurations it should be relatively straightforward to connect new generation.

In the north of England, Midlands, and north Wales there are more constraints on the network and reinforcements may be required to enable generation to connect. The most difficult areas for connection are those north of the Midlands to South Boundary (B9) and the boundary transfer capability for this boundary are shown in Figure 5—5.

Figure 5-5: Boundary Transfers and Capability Boundary 9: Midlands to South



The boundary capabilities give an indication of the maximum boundary transfer that can be supported without contravening any of the unacceptable conditions following a secured event. A boundary capability that is less than the required capability indicates a need for transmission reinforcement. A boundary capability that is greater than the required capability shows only that the security criteria are satisfied for the particular transfer conditions and background studied.

The amount by which a boundary capability exceeds the required capability gives an indication of the approximate extent of 'spare' transfer capacity on that boundary. However, this does not necessarily mean that an equivalent volume of additional generation on the exporting side of the boundary (or an equivalent volume of additional demand on the importing side) can be readily accommodated (National Grid, 2006).

Therefore, this figure indicates that over the next 7 years, the capability of this boundary will remain just above the required capability but that there is very little capacity for additional generation.

Additional generation that wishes to connect into the England and Wales transmission system (more than 100 MW) will be entered into the GB queue and may be subject to major reinforcements within the transmission system. Generation of less than 100 MW can be embedded into the local distribution system and as long as it does not affect the Distributions Networks Operators (DNO) connection with the Transmission Network will not need to join the GB queue. This is an important point when considering the capacity of generation that is being proposed because embedded generation connections supplying local loads usually find it much easier to connect than large amounts of generation in remote areas with no significant loads.

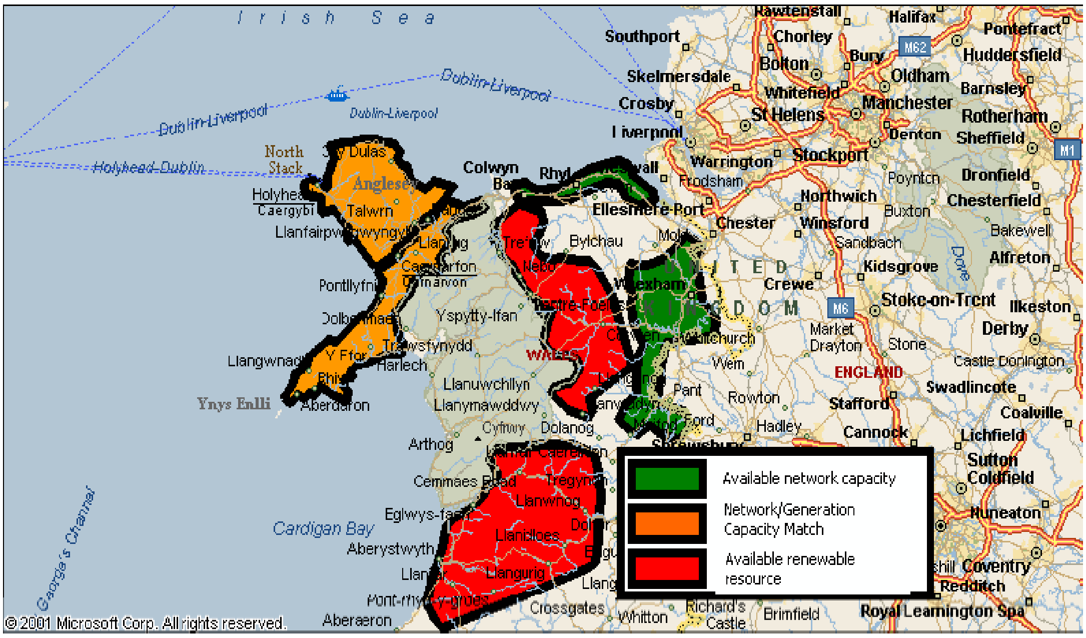
The situation in north Wales is summarised by SP-Manweb (the DNO for that area), in their long-term development statement:

“Significant amounts of generation cannot readily be accepted at, or near to, many 132/33 kV bulk supply points because of fault level limitations. The connection of additional rotating plant, resulting in increased fault infeed at such locations, may provoke system reinforcement or modifications.

Some areas of the network will be more favourable for the connection of additional generation capability than others. In order to provide guidance on the development opportunities available, an assessment of the 132 kV and 33 kV networks has been carried out for power flow (thermal capacity) and fault levels in the Wales region of the SP-Manweb area.

A summary of the results is displayed graphically on a geographic representation of the SP-Manweb system in Figure 5—6. The green areas show the areas where some network capability exists for the connection of generation, whilst the amber areas show where there is some limited capacity for the connection of generation. The red areas show where the connection of generation is difficult" (SP-Manweb, 2006)."

Figure 5-6: Opportunities for the Connection of Generation



The tidal generation projects under consideration in North Wales are in areas of the network that have been identified as having some capacity for connection of generation.

This type of analysis has not been published by the other DNOs in England and Wales and there are not such significant amounts of renewable generation trying to connect into a very rural and weak network.

5.2.3 Current Situation in Northern Ireland

In the SONI Seven Year Transmission Statement, the following discussion on the best locations for the addition of new generation is given:

"With respect to thermal considerations, significant new generation can be accepted at any of the 275 kV nodes except those on Island Magee and around Coolkeeragh.

The power flow diagrams give an indication of the predominant flows and ratings on the 110 kV system. Using these, it is possible to identify whether *new generation connected to the 110 kV system will add to or subtract from the existing system loadings.*

It may be important also to consider the impact of possible displacement of generation. Power station location has a significant impact on voltage support both in relation to local networks and to the overall post-fault voltage profile. Generation at Kilroot is particularly beneficial in maintaining post-fault network voltage profiles, since the station has direct connection to Kells, Castlereagh and Tandragee.

In summary, the bias of the existing generation is to the east of the system, particularly when the Moyle Interconnector is operating. New generation is most easily accommodated near the 275 kV system. There is a continuing role for generation in the north of the province and some scope in Belfast, although the need for the latter is lessened by Belfast Central Main substation. There is also some scope for generation in the west. The new plant at Coolkeeragh saturates the present capacity at the node.

The existing 275 kV transmission system is relatively robust with the exception that the increased in-feed requirement at Island Magee can give rise to heavy post-fault loading on this and parallel 110 kV networks. The 110 kV network towards the west and around Coolkeeragh remains heavily loaded. The introduction of the new Tyrone 275/110 kV node at Dungannon will reduce the loading between Tandragee and Dungannon, improve resupply to Creagh, and this will generally stabilise system voltage in the area. New generation at Coolkeeragh creates a generation saturation condition at Coolkeeragh node."

This indicates that the connection of tidal generation from the North Channel, near port Patrick and the North of the Isle of Man may be possible but that connection into the Island Magee area (around Ballylumford) should be avoided.

5.3 GENERATION CONNECTION CHARGES

For generation connecting into the transmission system (>10 MW in Northern Scotland, >50 MW in southern Scotland and >100 MW in England, Wales and anything connecting at 110 kV or 275 kV in Northern Ireland) generators are expected to pay a generation Transmission Use of System Charge. This charge is based on their geographical location and aims to be cost reflective – charging generators a long way from the load centres more than those that are close and generation located in areas of the country where they are able to provide support and increase stability of the system are allocated very low if not negative TNUoS charges.

Under Section 185 of the Energy Act 2004 the Secretary of State has the power to adjust transmission charges for renewable generators in an area of GB with high potential for renewable development, where that development would be deterred by the high level of transmission charges that would otherwise apply.

Section 25 of the Climate Change and Sustainable Energy Act 2006 extended the potential life of any scheme from 10 years to 20 years.

Currently, this adjustment is being considered for the Scottish islands of Orkney, Shetland and the Western Isles as renewable generation in these areas will not only have to pay the TNUoS charges for northern Scotland, they will need to pay a proportion of the costs associated with the subsea cables required to provide their connection to the mainland.

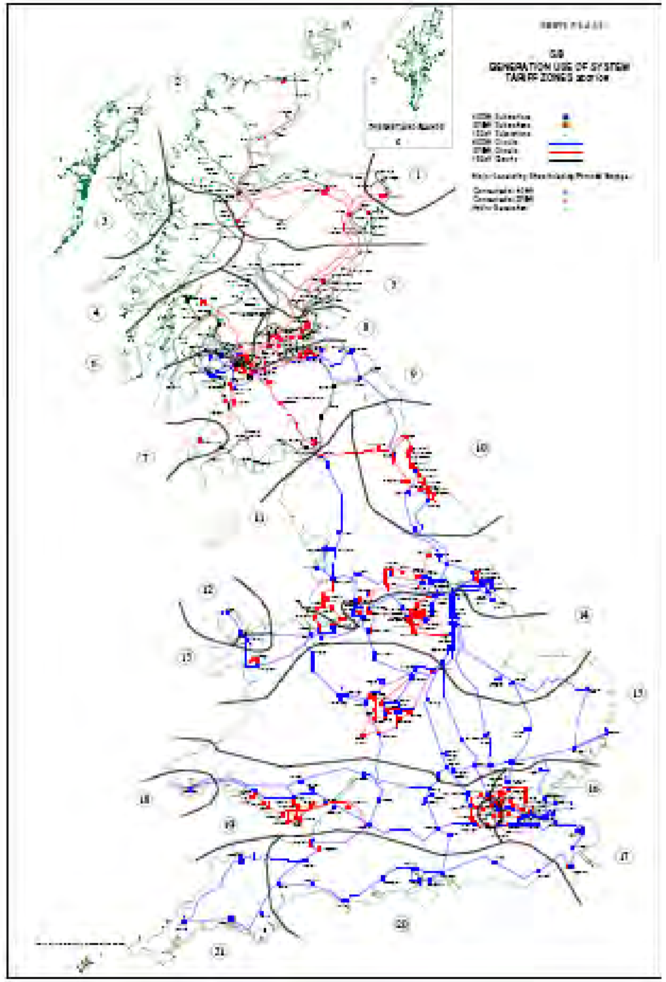
The adjustment is only expected to affect the "additional" portion of their TNUoS charges (those over an above the existing mainland charges) so they would still be expected to pay at least £21.81/kW/year. Some estimates for the TNUoS charges anticipated for connection in Shetland are up £60/kW/year even after the adjustment.

These charges will have a significant effect on the viability of projects in Northern Scotland as the connection charges could easily account for up to 16% of the income received from generation each year.

Large projects in the south, south west and south Wales would be favourably placed as the TNUoS charges in these areas are very low.

Figure 5-7, taken from the NGET website, shows the Draft TNUoS charging zones in England, Scotland and Wales for 2007/8.

Figure 5-7: Draft TNUoS Charging Zones for 2007/8



Zone	Name	£/kW/year
1	Peterhead	19.36
2	North Scotland	21.81
3	Skye	14.69
4	Western Highland	20.27
5	Central Highlands	18.15
6	Argyll	14.82
7	Auchencrosh	10.02
8	Stirlingshire	13.89
9	South Scotland	12.90
10	North East England	9.11
11	Humber, Lancashire	5.75
12	Anglesey	6.38
13	Dinorwig	9.25
14	South Yorks & North Wales	3.88
15	Midlands	1.87
16	Central London	-6.09
17	South East	0.54
18	Pembroke	0.86
19	South Wales & Thames Valley	-0.49
20	South Coast	-2.87
21	Peninsula	-5.49

For connections into the Northern Ireland transmission network the use of system costs are currently unknown. As part of the All Island Project, a new methodology for Transmission Use of System charging is being developed. The system will be similar to the GB system discussed above with cost reflective charges that will vary based on the distance the generation is from the load centres and the congestion that there already is in the system. This new methodology is expected to be published in quarter 3, 2007.

For connections into local distribution systems, generators are charged a distributed generator use of system (DGUoS) charge by the local DNO. These vary considerably from region to region but are also expected to be cost reflective so in areas where distributed generation can easily be accommodated in the system, the charges should be lower than in areas where generation triggers significant reinforcement.

Generation connection and use of system charges differ as follows:

- Embedded generation are expected to pay their full connection costs and a proportion of the reinforcement charges up front (deep charges).
- Directly connected generators (generators connected to the transmission network) pay only for their dedicated connection assets up to the grid transformer and from there on the costs are included in the TNUoS charges (shallow charging).

5.4 REVIEW OF CONNECTION OPPORTUNITIES BY LOCATION

This section discusses each of the areas that have been identified as having potential tidal resource. It provides an indication of the likely size of installation that can be connected at this time, without significant transmission and distribution reinforcements and also provides an indication of the likely reinforcements that will be required to enable larger quantities of tidal power generation to connect in that area in the future. The review of tidal resource in Sections 3 and 4 above have been used to give an indication of potential generating capacity at each of the locations of interest for tidal resource development but it is acknowledged that these tidal generation developments may not take place on a large scale for many years so this analysis aims to convey the current situation, which could change over time, especially if existing generation is decommissioned.

It should be noted that the assessment of grid constraints and potential opportunities for connection into the grid has not taken into account environmental effects associated with these connections and any upgrade to the grid system. It cannot be assumed that upgrades to grid infrastructure or the most direct connection from an offshore installation to the grid will be environmentally benign. Environmental appraisal and assessment would be required to determine the most feasible options.

5.4.1 Orkney North

Based on the resource information the estimated opportunity for tidal generation in this area has a total installed capacity of up to 318 MW.

If tidal generation in this area were to connect to the existing Orkney distribution system then there is only capacity for up to 15 MW of additional generation (SSE, 2006).

The connection to the mainland is already the subject of a registered power zone which allows the active management of the existing 2 x 20 MW links to the mainland. If more than 15 MW of generation is to be installed and connected, then an additional subsea cable to the mainland would be required and the level of generation connecting will determine whether this is a 132 kV or 33 kV connection.

SHETL are currently planning an additional connection from the islands to the mainland for a wind farm project with an installed capacity of about 126 MW. For this connection they are proposing two 132 kV subsea cables with a secure capacity of 180 MW and an unsecure capacity of 360 MW. To allow the transmission of this power into the network, they would also have to reinforce the existing lines from Dounreay to Beauly.From the GBSO Seven Year Study, and as discussed in Section 5.2.1 above, it can be shown that there is insufficient transmission capacity to accommodate the existing level of contracted generation in Scotland. Additional generation that wishes to connect into the transmission system (more than 10 MW) will be entered into the queue and will be subject to major reinforcements within the transmission system. The reinforcements that have currently been planned are those shown in Section 5.2.1 and show that the generation would probably have to wait until at least 2015 for a firm connection. There may be some opportunities before this stage to arrange non-firm access but the methodologies involved in this arrangement are still under discussion within National Grid.

Therefore, for generation with a total capacity of 10 MW or less there may be some opportunity for connection in this area but for generation of more than 10 MW there is very little opportunity for connection and the reinforcements required for the connection of up to 318 MW would involve new subsea cables from Orkney to the mainland, the reinforcement of an existing 132 kV transmission line from Dounraey to Beauly to 275 kV and additional reinforcements within the transmission network extending as far as the North of England. These reinforcements could take up to 10 years to complete depending on the outcomes from planning committees.

5.4.2 Orkney South

The estimated opportunity for tidal generation in this area has a total installed capacity of up to 2,292 MW.

Tidal generation in this area would have to connect to the Scottish mainland rather than into the existing Orkney distribution system as there is very limited capacity for generation on the islands.

The same issues that are discussed for Orkney North apply here and so, for generation with a total capacity of 10 MW or less there may be some opportunity for connection in this area but for generation of more than 10 MW there is very little opportunity for connection and the reinforcements required for the connection of up to 2,292 MW would involve a new 400 kV double circuit line from Dounraey at least as far as North Yorkshire unless significant amounts of existing generation in Scotland are decommissioned. The timescale involved in this reinforcement is impossible to estimate as transmission lines of this length are not currently being built and the time spent in public enquiry could be extensive.

5.4.3 Shetland

The estimated opportunity for tidal generation in this area is unknown but is expected to be located in small discrete sites.

If tidal generation in this area were to connect to the existing Shetland distribution system then it would need very careful design and planning as the current system is an 'islanded system' with one old generating station providing the energy required by the islanders. The capacity for additional generation without causing instability is unknown.

There is no connection between Shetland and the Scottish mainland but SHETL are currently planning a new connection from the islands to the mainland for a couple of wind farm projects with a total installed capacity of about 600 MW. For this connection they are proposing a HVDC subsea cable link, operating at 500 kV, and connecting near Cullen in Moray.

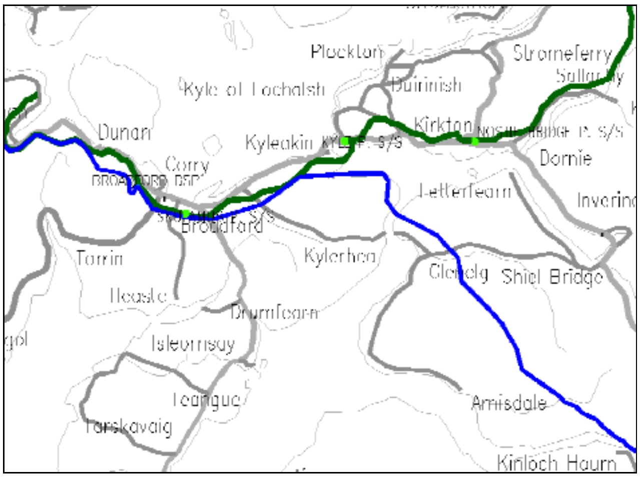
Once this link is installed, the Shetland Isles will become part of the GB Transmission System and connection applications will be subject to the same rules as the rest of GB.

Therefore, for the same reasons discussed in the Orkney North analysis, for generation with a total capacity of 10 MW or less there may be some opportunity for connection in this area but for generation of more than 10 MW there is very little opportunity for connection and the reinforcements required for the connection of larger amounts of generation could involve new HVDC subsea cables from Shetland to the mainland and additional reinforcements within the transmission network extending as far as the north of England. These reinforcements could take up to 10 years to complete depending on the outcomes from planning committees and the connection costs would be significant.

5.4.4 Kyle Rhea

There is a 33 kV network in this area connected into the 132 kV transmission network at Broadford. As the 132 kV transmission back into the mainland has a summer rating of 79 MVA (Scottish Hydro-Electric Distribution, 2006) then a subject to any other additional generation connections in this area then up to about 60 MW of tidal power may be able to connect here without local reinforcements. Figure 5—8 shows the local distribution network in the area

Figure 5-8: Scottish Hydro Distribution Network around Kyle Rhea



As discussed in Section 5.2.1 and the Orkney North analysis, there is very little capacity for connection in the SHETL region and generation with a capacity of more than 10 MW will need to wait unitl all the planned reinforcements are completed before connection is possible.

Therefore, for generation with a total capacity of 10 MW or less there may be some opportunity for connection in this area but for generation of more than 10 MW there is very little opportunity for connection. A connection of up 60 MW would not trigger local reinforcements but may be subject to deeper reinforcements as far as the North of England which could take up to 10 years to complete depending on the outcomes from planning committees. A connection of more than 60 MW would require local transmission reinforcements as well.

5.4.5 North Channel

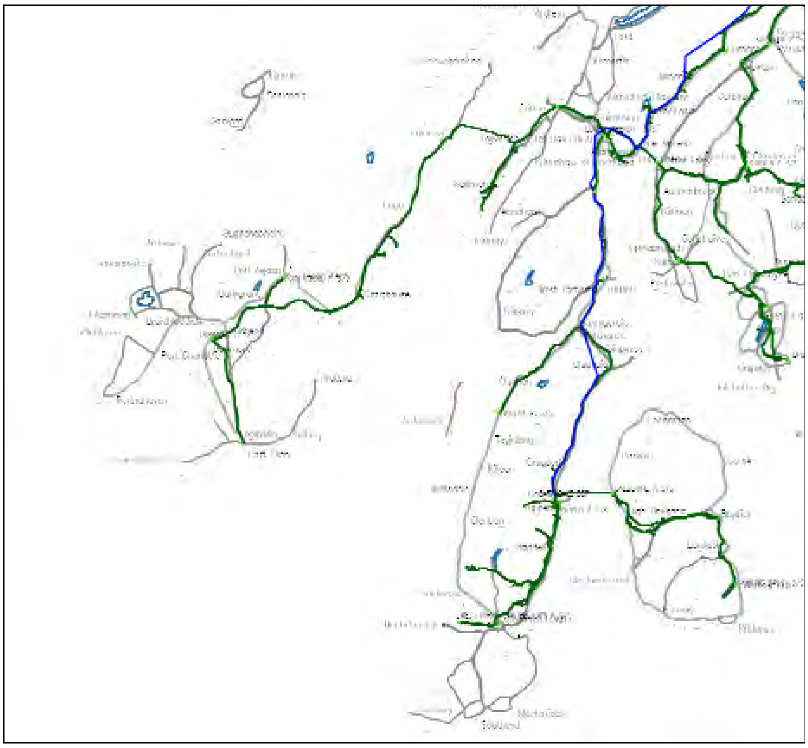
Tidal generation in this area could connect into either the Scotland or Northern Ireland networks.

5.4.5.1 Scotland - Mull of Kintyre and Mull of Oa

The estimated opportunity for tidal generation in this area has a total installed capacity of up to 21 MW.

As there is only a very weak 33 kV network on the nearby Scottish islands the amount of generation that would be able to connect here (at Port Ellen or West Park Fergus) would be limited to about 8 MW as that is the rating of the connection back to the mainland (Scottish Hydro-Electric Distribution, 2006) . If a connection of more than 8 MW was required then either the 33 kV circuits back to Port Ann or Carradale could be reinforced (a distance of approximately 90 km or 35 km respectively) or a subsea connection could be made into the Scottish mainland at Maybole or Auchencrosh (a distance of approximately 120 km). Figure 5—9 shows the local distribution network on the nearby Scottish Islands.

Figure 5-9: SPTL Distribution Network on South West Scottish Islands



As there is insufficient transmission capacity in Scotland, additional generation that wishes to connect into the transmission system (more than 10 MW in the SHETL area and more than 50 MW in the SPTL area) will be subject to major reinforcements within the transmission system. These reinforcements are discussed in Section 5.2.1 and the main reinforcements that this generation would have to wait for are the reinforcements to the Scotland / England interconnector. As there is currently only capacity for up to 2.2 GW of generation to be exported from Scotland and there are 12 GW of generation projects in the queue, it is anticipated that any generation would have to wait until a third interconnector is built which could take at least five years to achieve as planning permission could prove extremely difficult.

Therefore, for generation with a total capacity of 8 MW or less there may be some opportunity for connection into the nearby 33 kV network on the Scottish islands. For generation of more than 8 MW but less than 50 MW there may be some opportunity for connection into the 132 kV or 275 kV network in Dumfries and Galloway although, it would involve a very expensive subsea connection and may require further onshore reinforcements. There is very little opportunity for the connection of more than 50 MW as significant reinforcements would be required. For connections totalling up to around 20 MW, the best option would probably be to connect the proposed installations on the Mull of Kintyre and the Mull of Oa directly into the local Scottish 33 kV networks with local reinforcements as required.

5.4.5.2 Northern Ireland - Rathlin Island

From the SONI Seven Year Transmission Statement, and as discussed in Section 5.2.3 above, there is capacity for the connection of generation into the NIE network at Loguestown. The two 110 kV circuits from Loguestown to

Coleraine and onwards are rated for 82 MVA in the summer so a connection of up to 75 MW may be possible subject to fault levels and other thermal constraints during outage conditions.

Therefore, for generation with a total capacity of 75 MW or less there may be some opportunity for connection into NIE transmission network at Loguestown but there is very little opportunity for the connection of more than about 75 MW. For larger capacity connections, it would be necessary to substantially extend the 110 kV or 275 kV networks along the north coast or a long subsea cable landing near Kilroot. Both of these options would be extremely expensive and would delay any project substantially.

5.4.6 Mull of Galloway

The estimated opportunity for tidal generation in this area has a total installed capacity of up to 109 MW.

Tidal generation in this area could connect to either the Scottish mainland near Port Patrick or the Northern Ireland network near Carrick Fergus.

From the SONI Seven Year Transmission Statement, and as discussed in Section 5.2.3 , there is no capacity for the connection of generation into the NIE network around Ballylumford. A connection into Kilroot at 275 kV or Belfast at 110 kV may be possible subject to fault levels and other thermal constraints during outage conditions.

The issues associated with a connection into Port Patrick would be similar to those discussed for Mull of Kintyre and Mull of Oa above. Connection of up to 50 MW in this area can be counted as embedded generation and so will not have to wait for the reinforcements on the Interconnector. As there is no extra high voltage (EHV) network in the Port Patrick area for connection, extensions to the network will be required.

Therefore, for generation with a total capacity of 50 MW or less there may be some opportunity for connection into the area around Port Patrick with connection possible from 2009 onwards. For generation of more than 50 MW there is very little opportunity for connection into the GB network due to the reinforcements required but there are opportunities for a connection of more than 50 MW into the NIE network around Kilroot although this would require a long subsea cable, which would be extremely expensive.

5.4.7 Solway Firth

The estimated opportunity for tidal generation in this area is unknown.

Tidal generation in this area could connect into either the Scottish Power network near Gretna or the United Utilities network near Carlisle. There is a relatively strong 33 kV network in the Carlisle area fed from the Harker GSP (United Utilities, 2006). For connections of more than about 20 MW, a connection into the 132 kV system at Harker or Carlisle should be considered and for a connection of more than about 100 MW then the options are reduced to the Harker GSP.

The issues associated with a connection into Harker or Carlisle would be similar to those discussed for Mull of Galloway Oa above. Connection of up to 50 MW in the SPTL area is counted as embedded generation whereas up to 100 MW of generation can connect into the United Utilities area before it is automatically categorised as a Transmission connection.

Therefore, for generation with a total capacity of 50 MW or less there may be some opportunity for connection into the area but for generation of more than 50 MW there is very little opportunity for connection into the GB network at this time (even in England as the impact on the interconnector would still be significant). Once the planned upgrades to the interconnector are complete, including the building of a third interconnector, then there will capacity for the connection of generation in this area.

5.4.8 Isle of Man North

The estimated opportunity for tidal generation in this area is not known.

Tidal generation in this area could connect to the Scottish mainland near Tongland or the Northern Ireland network near Carrick Fergus as discussed above and if either of these connection options were chosen then the limitations would be the same as those discussed for Mull of Galloway above.

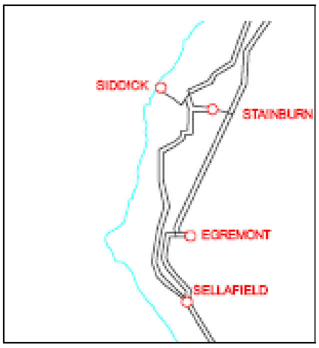
Figure 5-10: The Manx Interconnector

There are two alternative connection options; connection into the Isle of Man network or connection into the England mainland network at Sellafield.

If a connection into the Manx Electricity Authority network option was chosen then the maximum generation that could be connected would be limited to less than 40 MW, which is the capacity of the connection to the English mainland.

If a connection into the English mainland network near Sellafield Nuclear Power Station was considered then up to 100 MW of generation could be connected. However, the connection may be subject to a non-firm connection so that if one of the lines to Sellafield has an outage the generation is tripped. Furthermore, some reinforcement of the transmission network may be required as the network in this area may become severely constrained if a significant amount of generation connects in Scotland. These reinforcements are expected to be complete by 2010.

Figure 5-11: United Utilities 132 kV Distribution Network near Sellafield



From the SONI Seven Year Transmission Statement, and as discussed in Section 5.2.3 above, there is some capacity for the connection of generation into the NIE network around Rathgael and Castlereagh. The two 110 kV circuits from Rathgael to Castlereagh are rated for 82 MVA in the summer so a connection of up to 75 MW may be possible subject to fault levels and other thermal constraints during outage conditions.

The following options for connection are available at this time:

- For 40 MW or less there may be some opportunity for connection into the network on the Isle of Man,
- For generation of 50 MW or less there may be some opportunity for connection into the 132 kV network in Dumfries and Galloway,
- For generation of more than 50 MW there may be some opportunity for connection into the NIE 110 kV network at Rathgael. This would be limited to about 75 MW unless reinforcements back to Castlereagh are undertaken. This connection to NIE would involve longer subsea cables than the other options to the Isle of Man and Scotland.

An alternative connection option for more than 50 MW is via an even longer subsea cable to England but as there is already a nuclear power station connection into the grid at this point this connection would probably be non-firm and may be subjected to reinforcements of the transmission network meaning the connection would not be possible until 2010.

5.4.9 Duddon

The estimated opportunity for tidal generation in this area has a total installed capacity of up to 100 MW.

Tidal generation in this area could connect into the local United Utilities distribution system. There may be sufficient capacity for a connection of up to 80 MW without significant reinforcements in the network as long as the local load demands are sufficient to avoid this generated power creating an export condition at the Hutton GSP. If a connection is required for more than 100 MW then it will be subject to a bilateral agreement with the transmission system operator and may need to connect directly into the transmission network at 400 kV.

From the GBSO Seven Year Study it can be shown that there is sufficient transmission capacity to accommodate up to 250 MW of additional generation in this area. But as the reinforcement of the Heysham Ring is part of the planned reinforcements discussed in Section 5.2.2, this capacity may not be available until after 2012.

Generation that wishes to connect into the distribution systems (less than 100 MW) will need to apply to the local DNO, United Utilities, for a connection agreement and the connection offer they receive will be dependant on the local network arrangements including thermal and fault level constraints.

Near Duddon it should be possible to connect up to 20 MW of generation into the 33 kV network at Askam or up to 80 MW of generation into the 132 kV network at Barrow (United Utilities, 2006). Some reinforcement of the transmission network may be required as the network in this area may become severely constrained if a significant amount of generation connects in Scotland.

5.4.10 Wyre

The estimated opportunity for tidal generation in this area has a total installed capacity of up to 64 MW with a tidal barrage and possibly more with other tidal array schemes.

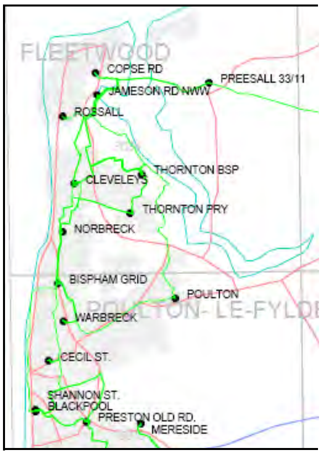
Tidal generation in this area could connect into the local United Utilities distribution system and there may be sufficient capacity for a connection of up to 100 MW without significant reinforcements in the network as long as the local load demands are sufficient to avoid this generated power creating an export condition at the Stanah GSP. If a connection is required for more than 100 MW then it will be subject to a bilateral agreement with the transmission system operator and may need to connect directly into the transmission network at 400 kV.

From the GBSO Seven Year Study, and as discussed in Section 5.2.2 above, it can be shown that there is sufficient transmission capacity to accommodate up to 250 MW of additional generation in this area. But as the reinforcement of the Heysham Ring is part of the planned reinforcements discussed in Section 5.2.2, this capacity may not be available until after 2012.

Generation that wishes to connect into the distribution systems (less than 100 MW) will need to apply to the local DNO, United Utilities, for a connection agreement and the connection offer they receive will be dependant on the local network arrangements including thermal and fault level constraints.

Near The Wyre it should be possible to connect up to 100 MW of generation into the 132 kV network at either Bispham or Thornton (United Utilities, 2006). As there are expected to be offshore wind farms connecting in this area then this will be subject to other generation connections. Furthermore, some reinforcement of the transmission network may be required as the network in this area may become severely constrained if a significant amount of generation connects in Scotland.

Figure 5-12: United Utilities Distribution Network



5.4.11 Anglesey

The estimated opportunity for tidal generation in this area is not known.

Tidal generation in this area should connect into the local distribution system and there should be sufficient capacity for a connection of up to 100 MW without significant reinforcements in the network. If a connection is required for more than 100 MW then it will be subject to a bilateral agreement with the transmission system operator and may need to connect directly into the transmission network at 400 kV.

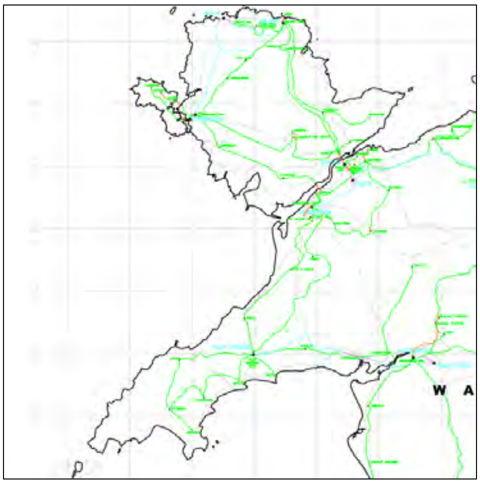
From the GBSO Seven Year Study, and as discussed in Section 5.2.2 above, it is apparent that there is sufficient transmission capacity to accommodate up to 250 MW of additional generation in this area. But as there is expected to be additional offshore wind generation connecting into the north Wales coast, some reinforcements may be required on the Legacy to Ironbridge and the Macclesfield to Cellarhead lines to enable the generation to cross the boundary from north Wales to the Midlands. This capacity may not be available until after 2012.

Generation that wishes to connect into the distribution systems (less than 100 MW) will need to apply to the local DNO, Scottish Power Manweb, for a connection agreement and the connection offer they receive will be dependant on the local network arrangements including thermal and fault level constraints.

On Anglesey it should be possible to connect into the 132 kV or 400 kV networks at Wylfa without reinforcements but the connection may be subject to a non-firm connection so that if one of the lines to Wylfa Nuclear Power Station has an outage the generation is tripped (SP-Manweb, 2006).

The nuclear power station at Wylfa is scheduled for closure in 2010 and once this occurs, the capacity for the connection of generation on Anglesey will increase. The constraints at the North / Midlands boundary discussed above will not be removed though as this closure will not significantly affect the flow of power over this boundary.

Figure 5-13: SP Manweb Distribution Network in North Wales



5.4.12 Conwy

The estimated opportunity for tidal generation in this area has a total installed capacity of up to 33 MW.

Tidal generation in this area should connect into the local Scottish Power Manweb distribution system and there should be sufficient capacity for a connection of up to 100 MW without significant reinforcements in the network. If a connection is required for more than 100 MW then it will be subject to a bilateral agreement with the transmission system operator and may need to connect directly into the transmission network at 400 kV.

From the GBSO Seven Year Study, and as discussed in Section 5.2.2 above, it can be shown that there is sufficient transmission capacity to accommodate up to 250 MW of additional generation in this area. But as there is expected to be additional offshore wind generation connecting into the north Wales coast, some reinforcements may be required on the Legacy to Ironbridge and the Macclesfield to Cellarhead lines to enable the generation to cross the boundary from north Wales to the Midlands. This capacity may not be available until after 2012.

Generation that wishes to connect into the distribution systems (less than 100 MW) will need to apply to the local DNO, Scottish Power Manweb, for a connection agreement and the connection offer they receive will be dependant on the local network arrangements including thermal and fault level constraints.

Near Conwy, it should be possible to connect up to 10 MW of generation into the 33 kV network at Llanfairfechan without reinforcements and for more than 10 MW, reinforcements back to Dolgarrog 132 kV will be required. For very large amounts of generation, a connection into the 400 kV transmission network along the coast would be required.

5.4.13 Mersey

The estimated opportunity for tidal generation in this area has a total installed capacity of up to 700 MW.

Tidal generation of this size will probably need to connect into the transmission network at 275 kV although multiple connects into the distribution network may be possible as there is significant load in this area.

From the GBSO Seven Year Study, and as discussed in Section 5.2.2 above, it can be shown that there is sufficient transmission capacity to accommodate up to 250 MW of additional generation in this area. But as the 275 kV network in this area connects into the rest of the grid at Penwortham on the Heysham ring and as the reinforcement of the Heysham Ring is part of the planned reinforcements discussed in Section 5.2.2, this capacity may not be available until after 2012.

Generation that wishes to connect into the distribution systems (less than 100 MW) will need to apply to the local DNO, Scottish Power Manweb, for a connection agreement and the connection offer they receive will be dependant on the local network arrangements including thermal and fault level constraints.

Around the Mersey, there are multiple 33 kV and 132 kV substations where connection should be feasible. For large generation connections (more than about 150 MW) a connection into one of the Supergrid substations may be necessary at Frodsham, Birkenhead or Capenhurst (SP-Manweb, 2006).

5.4.14 Lleyn Peninsula

The estimated opportunity for tidal generation in this area is not known.

Tidal generation in this area should connect into the local distribution system and there should be sufficient capacity for a connection of up to 100 MW without significant reinforcements in the network.

From the GBSO Seven Year Study, and as discussed in Section 5.2.2 above, it can be shown that there is sufficient transmission capacity to accommodate up to 250 MW of additional generation in this area.

Generation that wishes to connect into the distribution systems (less than 100 MW) will need to apply to the local DNO, Scottish Power Manweb, for a connection agreement and the connection offer they receive will be dependant on the local network arrangements including thermal and fault level constraints.

On The Lleyn Peninsula it should be possible to connect up to 18 MW of generation into the 33 kV network at Edern without reinforcements and for more than 18 MW, reinforcements back to Trawsfynydd or Caernarfon will be required either by subsea cable or overhead lines on land (SP Manweb, 2006).

5.4.15 The Wash

The estimated opportunity for tidal generation in this area is not known but as it is anticipated to be a barrage scheme then it could be quite large.

Tidal generation in this area could connect into the local distribution system. There are a number of suitable connection locations around the coast and there should be sufficient capacity for a connection of up to 60 MW without significant reinforcements in the network.

If more than 60 MW of generation is planned then a connection into the National Grid at Walpole would be possible and this should allow up to 1 GW of generation to connect.

From the GBSO Seven Year Study, and as discussed in Section 5.2.2 above, it can be shown that there is sufficient transmission capacity to accommodate up to 1500 MW of additional generation in this area.

As there is a considerable amount of offshore wind generation planned for this area in the next few years, this capacity may no longer be available when this tidal project is in a position to connect.

Generation that wishes to connect into the distribution systems (less than 100 MW) will need to apply to the local DNO, EDF or Central Networks, for a connection agreement and the connection offer they receive will be dependant on the local network arrangements including thermal and fault level constraints.

Near the Wash it should be possible to connect up to 60 MW of generation into the 132 kV network at Boston, Skegness or Kings Lynn without reinforcements and for more than 60 MW a connection to Walpole will be required (Central Networks, 2006 and EDF, 2006a).

5.4.16 The South, South West and South Wales (Pembroke, Lundy, Lands End, Lizard Point, Start Point, Portland and Isle of Wight)

Small tidal generation schemes in these areas could connect into the local distribution system and there should be sufficient capacity for a connection of up to 100 MW without significant reinforcements in the network.

Generation that wishes to connect into the distribution systems (less than 100 MW) will need to apply to the local DNO for a connection agreement and the connection offer they receive will be dependant on the local network arrangements including thermal and fault level constraints.

Larger tidal generation schemes will need to connect into the transmission network and from the GBSO Seven Year Study, and as discussed in Section 5.2.2 above, it can be shown that there is sufficient transmission capacity to accommodate between 1.5 and 3 GW of additional generation in these areas subject to system stability and local network issues.

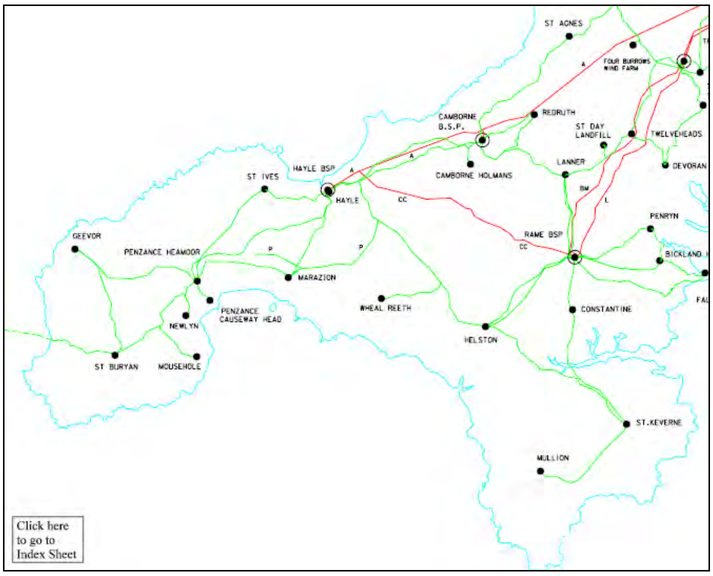
Near Pembroke it should be possible to connect up to 100 MW of generation into the network at either Pembroke Power Station BSP or Waterston BSP without reinforcements, subject to other generation connections in the area (Western Power Distribution, 2006). For connection of more than 100 MW a connection directly into Pembroke would be required and as 4 GW of generation is planning to connect in this area, capacity on the lines may be limited and the generation may be subject to a non-firm connection so that if one of the lines to Pembroke has an outage the generation is tripped.

Near Lundy it should be possible to connect up to 10 MW of generation into the 33 kV network at Clovelly without reinforcements. For a connection of 100 MW, a connection into East Yelland BSP would be more suitable (Western Power Distrubution, 2006) and for more than 100 MW a connection into the transmission system at Alverdiscott would be required.

Near Lands End it should be possible to connect up to 20 MW of generation into the local 33 kV network at Mousehole. For a connection of more than 20 MW, reinforcements back to Hayle or Rame will be required (Western Power Distrubution, 2006). As there is no transmission network in this area, large quantities of generation would require reinforcements back to Indian Queens (approx 75 km).

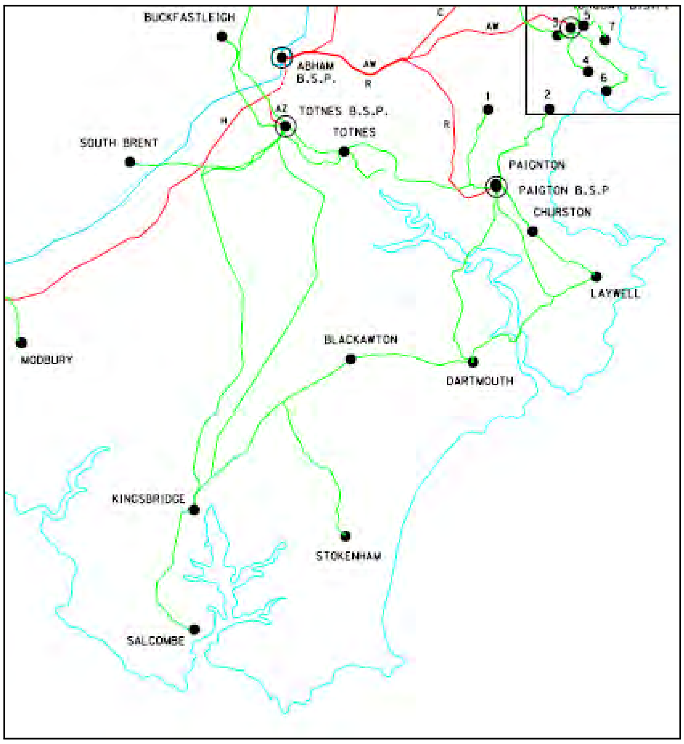
Near Lizard Point it should be possible to connect up to 20 MW of generation into the local 33 kV network at St Keverne. For a connection of more than 20 MW, reinforcements back to Rame will be required (Western Power Distrubution, 2006). As noted above, as there is no transmission network in this area, large quantities of generation would require reinforcements back to Indian Queens.

Figure 5-14: WPD Distribution Network Near Lands End



Near Start Point it should be possible to connect up to 20 MW of generation into the 33 kV network at Stokenham without reinforcements. For a connection of more than 20 MW, reinforcements back to Paigton, Totnes or Abham will be required (Western Power Distribution, 2006).

Figure 5-15: WPD Distribution Network Near Start Point



Near Portland it should be possible to connect up to 16 MW of generation into the 33 kV network at Portland without reinforcements. For a connection of more than 16 MW, reinforcements back to Chickerell will be required (Southern Electric, 2006).

Near the Isle of Wight it should be possible to connect up to 16 MW of generation into the 33 kV network at Ventnor on the island without reinforcements and up to 80 MW (possibly 100 MW with active network management) of generation with reinforcements back to Cowes (Southern Electric, 2006). For a connection larger than 80 MW, a subsea cable connection to Fawley would be necessary.

5.4.17 Severn

There are a number of different tidal projects being considered for the Severn area:

- A Tidal Barrage that goes from Lavernock point to Brean Down and would have an installed capacity of 8640 MW
- A smaller Tidal Barrage, called Shoots Barrage, located near the 2nd Severn Crossing and with an installed capacity of 1050 MW.
- A Three Tidal Lagoon system as detailed in Section 4.4.4 each lagoon having an estimated installed capacity of 1200 MW.
- A tidal lagoon option in Swansea Bay with an initial capacity of 60 MW
- Two Tidal Current potential areas, one near Barry and one near Foreland Point.

- As each of these options will have very different connection requirements they will be discussed here separately.

5.4.17.1 Large Tidal Barrage

The connection of this capacity (8.6 GW) of generation into the national transmission system would have very wide consequences and a thorough study would need to be undertaken to determine the reinforcements that would be required in the system and to ensure that system stability can be maintained.

5.4.17.2 Shoots Barrage

Near the 2nd Severn Crossing there are two 400 kV National Grid substations, one at Seabank and one at Whitson. The connection of 1050 MW of generation should be possible at these substations as the GBSO Seven Year Study shows that there is sufficient transmission capacity to accommodate about 1.5 GW of additional generation in this area. This would still be subject to system stability and local network issues.

5.4.17.3 Tidal Lagoon Schemes

The 3 - site system is discussed site by site below:

At site 1 (on the South coast of the Severn near Clevedon) it should be possible to connect into the National Grid substations either at Hinckley Point or Seabank without triggering significant reinforcements in the network.

At site 2 (on the North coast of the Severn between Newport and Caldicot) it should be possible to connect into the National Grid substation at Whitson but the 275 kV and 400 kV transmission lines across the Severn may need some reinforcement.

At site 3 (on the North coast of the Severn between Cardiff and Newport) it should be possible to connect into the National Grid substations at either Tremorfa or Uskmouth but the 275 kV and 400 kV transmission lines across the Severn may need some reinforcement.

For the Swansea Bay scheme, there should be sufficient capacity for the connection of this generation into the distribution network but if, due to large amounts of wind energy connecting in this area, this capacity is unavailable, connections at Margam or Baglan Bay should be possible. As noted above, any further generation connecting in South Wales may mean that the 275kV and 400kV transmission lines across the Severn need reinforcement.

5.4.17.4 Tidal Current Schemes

Near Barry it should be possible to connect some generation into the distribution system at Sully but as there is a 240 MVA CCGT generator in this area, the export capacity may be limited, especially under outage conditions. An alternative would be a connection into the transmission system at Aberthaw but the connection may be subject to a non-firm connection so that if one of the lines to Aberthaw Power Station has an outage the generation is tripped (Western Power Distribution, 2006).

Near Foreland Point it should be possible to connect up to 100 MW of generation into the distribution system at Bowhayes Cross, or more than 100 MW into the transmission system at Hinkley Point or Alverdiscott, without reinforcements (Western Power Distribution, 2006).

5.5 PREVIOUS GRID CONSTRAINT ASSESSMENTS

5.5.1 BWEA – Npower Juice "Path to Power" Project

The BWEA – Npower Juice "Path to Power" Project (Econnect,2006) studied marine power issues (wave and tidal) and included an assessment of the GB electricity grid in terms of the transfer capability between defined zones based on the existing generation in the specific zones and the demand of electricity in these zones. The network was also assessed in three time periods to give an overview of how the network capacity would change up to 2020 if planned reinforcements and generation commissioning and decommissioning took place.

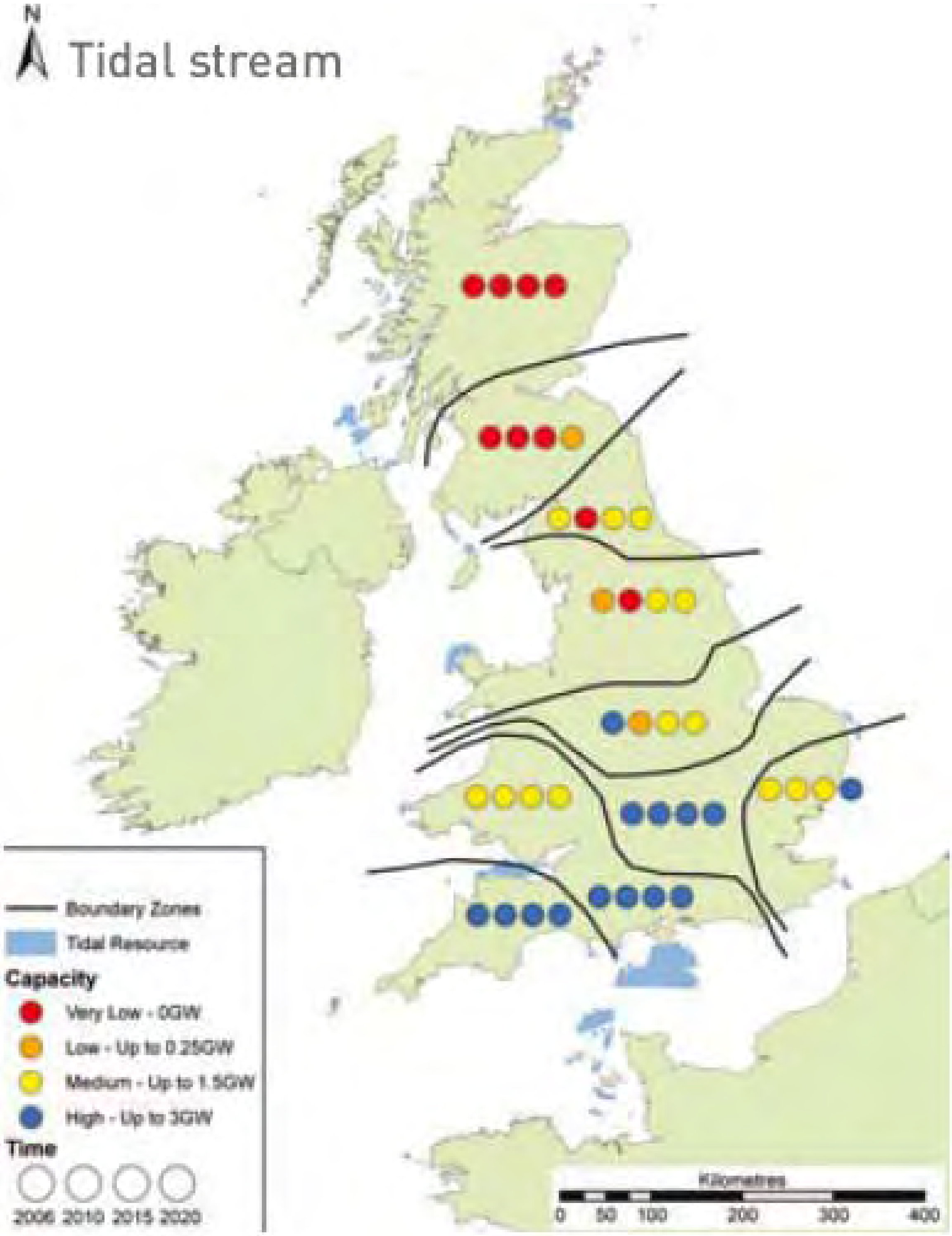
Figure 5-16 summarises the constraints on a geographical basis over time for potential development scenarios from the BWEA-Npower Juice study.

For the time period from 2006 to 2010, the study expected to see the integration of marine projects in the range of prototype to small array. The regions with the lowest number of network capacity 'bottlenecks' were thought to be in the south of England. Connections for prototype devices to small arrays were thought to be possible throughout England and Scotland at a distribution network level without the requirement for significant network reinforcements, although in Scotland any connection offers that were issued may be dependant upon transmission reinforcements and therefore delays to connection of these projects could be expected. In Wales, due to the penetration of wind generation and severely restricted distribution network capacity, prototype to small arrays would need to seek connections to the key network nodes.

From 2010 to 2015, the study expected to see the integration of marine projects in the range of small arrays to large arrays. It considered that connections, without the requirement for significant network reinforcements, in Scotland, at both the transmission and distribution network level, and in Wales, at a distribution network level, may still be severely restricted. In developing the assessment, the study also considered that decommissioning of existing generation facilities in the north of England and southern Scotland would reduce power flows through the GB transmission network. This was considered to allow some capacity in the north of England to be released. The south of England was still considered to have more opportunities for the connection of large arrays and significant projects.

From 2015 to 2020, the study expected to see the wider deployment of projects in the range of large arrays to significant projects and a greater utilisation of the transmission network. On the assumption that there was no rationalisation of the BETTA queue and no further extensive network reinforcements in the north of England and Scotland, it considered that the integration of significant projects may continue to be restricted by the existing transmission network 'bottle-necks'. Decommissioning of existing generating facilities could release further capacity in the north of England and the Midlands although any new build of alternative ‘Low Carbon’ generation to replace the decommissioned facilities plants could absorb any network transfer capacity that this may produce.

Figure 5-16: BWEA - Npower Juice Grid Assessment



5.5.2 Edinburgh University "Matching renewable energy generation with demand" report

Edinburgh University undertook an academic appraisal of the extent to which Scotland could meet forty-percent of its demand for electricity in the year 2020 from renewable resources (University of Edinburgh, 2006, Matching Renewable Electricity Generation with Demand). The study considered a range of renewable resources, not just tidal, and was to provide a detailed exploration of the temporal and spatial factors that govern the match between renewable electricity generation and demand for electricity.

However, the study concentrated on analysis of the location and availability of the renewable resources relative to the location and timing of demand, as if the network would impose no restriction. This study therefore provides no further information on the specifics of grid constraint issues.

The study indicated that Scotland could, in 2020, meet on average 40% of its demand for electricity from renewable resources with a total renewable capacity of around 6 GW (1 GW of which would come from wave and tide). This does not mean that the aspirational demand target is reached during each hour of a year. There will be periods of shortfall and periods of excess.

The conclusions of the report were that diversification of energy sources and their geographical dispersion improves the hour-by-hour matching with demand. Nevertheless, there will be many hours in a year when renewable output from wind, waves and tidal currents falls below demand targets and balancing plant would be needed. A strong interconnected transmission system would reduce the need for local balancing plant and increase security of supply. Full development of the more remote onshore and most of the offshore resource would require completion of planned network upgrades in northern and western Scotland.

5.6 SUMMARY

The following table summarises the discussions in Sections 5.2 to 5.4. The table below shows the tidal generation that would be able to connect without reinforcement of the system. It also indicates the level of reinforcement that would be required to allow a larger generation connection at each location and the potential TNUoS charges that the connection would attract.

Table 5-3: Summary of Generation Connection Opportunities

Location	Approximate Connection without Reinforcements	Reinforcements Required for larger connections	Annual Connection Charge
Orkney North	10 MW to Orkney	To Orkney with additional Subsea Cable to the Islands, Beauly to Dounreay Second Circuit, SHETL 400 kV Ring, Third Scotland / England Interconnector	£21.81 / kW + costs of subsea cable
Orkney South	10 MW to Thurso	To Thurso with Beauly to Dounreay Second Circuit, SHETL 400 kV Ring, Third Scotland / England Interconnector	£21.81/kW
Shetland	Small amount into island system	To Cullen with planned HVDC link, SHETL 400 kV Ring , Third Scotland / England Interconnector	£21.81 / kW + costs of subsea cable
Kyle Rhea	10 MW to Broadford	To Broadford with SHETL 400 kV Ring and Third Scotland / England Interconnector	£14.69/kW
North Channel -			
Mulls			
Rathlin	8 MW to Port Ellen and/or West Park Fergus	To Dumfries and Galloway with Third Scotland / England Interconnector	£14.82/kW or £12.90/kW
	75 MW to Loguestown	Substantial Extensions to the 110 kV or 275 kV network in Northern Ireland	Not Available
Mull of Galloway	50 MW to Tongland	Subsea Connection to Kilroot or To Tongland with Third Scotland / England Interconnector	£12.90/kW or
Solway Firth	50 MW to Harker	To Harker with Third Scotland / England Interconnector and Heysham Ring	£12.90/kW
Isle of Man North	40 MW to Isle of Man or 50 MW to Tongland	Connection to Castlereagh or Sellafield with Subsea cables. The connection at Sellafield may only be possible for a non-firm connection.	£12.90/kW(Tongland) or £5.75/kW (Sellafield) others not available.
Duddon	20 MW to Askam	Connection to Barrow or Hutton with 400 kV Heysham Ring Reinforcement if the generation causes an export condition at Hutton GSP	£5.75/kW
Wyre	100 MW Bispham or Thornton	To Bispham, Thornton or Stanah with 400 kV Heysham Ring Reinforcement if the generation causes an export condition at Stanah GSP	£5.75/kW
Mersey	150 MW to local 132 kV substations	To 275 kV network at Frodsham, Birkenhead or Capenhurst	£3.88/kW
Anglesey	More than 100 MW at Wylfa	Connection at Wylfa may only be possible for a non-firm connection	£6.38/kW
Conwy	10 MW to Llanfairfechan	To Dolgarrog or into 400 kV network	£3.88/kW
Lleyn Peninsula	18 MW to Edern	Subsea Connection to Trawsfynydd or Caernarfon	£3.88/kW
Pembroke	100 MW to Pembroke or Waterston	Connection at Pembroke may only be possible for a non-firm connection	£0.86/kW
Orkney North	10 MW to Orkney	To Orkney with additional Subsea Cable to the Islands, Beauly to Dounreay Second Circuit, SHETL 400 kV Ring, Third Scotland / England Interconnector	£21.81 / kW + costs of subsea cable
Orkney South	10 MW to Thurso	To Thurso with Beauly to Dounreay Second Circuit, SHETL 400 kV Ring, Third Scotland / England Interconnector	£21.81/kW
Shetland	Small amount into island system	To Cullen with planned HVDC link, SHETL 400 kV Ring , Third Scotland / England Interconnector	£21.81 / kW + costs of subsea cable
Kyle Rhea	10 MW to Broadford	To Broadford with SHETL 400 kV Ring and Third Scotland / England Interconnector	£14.69/kW

North Channel -			
Mulls			
Rathlin	8 MW to Port Ellen and/or West Park Fergus	To Dumfries and Galloway with Third Scotland / England Interconnector	£14.82/kW or £12.90/kW
	75 MW to Loguestown	Substantial Extensions to the 110 kV or 275 kV network in Northern Ireland	Not Available
Mull of Galloway	50 MW to Tongland	Subsea Connection to Kilroot or To Tongland with Third Scotland / England Interconnector	£12.90/kW or
Solway Firth	50 MW to Harker	To Harker with Third Scotland / England Interconnector and Heysham Ring	£12.90/kW
Isle of Man North	40 MW to Isle of Man or 50 MW to Tongland	Connection to Castlereagh or Sellafield with Subsea cables. The connection at Sellafield may only be possible for a non-firm connection.	£12.90/kW(Tongland) or £5.75/kW (Sellafield) others not available.
Duddon	20 MW to Askam	Connection to Barrow or Hutton with 400 kV Heysham Ring Reinforcement if the generation causes an export condition at Hutton GSP	£5.75/kW
Wyre	100 MW Bispham or Thornton	To Bispham, Thornton or Stanah with 400 kV Heysham Ring Reinforcement if the generation causes an export condition at Stanah GSP	£5.75/kW
Mersey	150 MW to local 132 kV substations	To 275 kV network at Frodsham, Birkenhead or Capenhurst	£3.88/kW
Anglesey	More than 100 MW at Wylfa	Connection at Wylfa may only be possible for a non-firm connection	£6.38/kW
Conwy	10 MW to Llanfairfechan	To Dolgarrog or into 400 kV network	£3.88/kW
Lleyn Peninsula	18 MW to Edern	Subsea Connection to Trawsfynydd or Caernarfon	£3.88/kW
Pembroke	100 MW to Pembroke or Waterston	Connection at Pembroke may only be possible for a non-firm connection	£0.86/kW

Location	Approximate Connection without Reinforcements	Reinforcements Required for larger connections	Annual Connection Charge
The Severn -			
Large Tidal Barrage	Thorough grid connection study required to determine connection options	-£0.49/kW	
Shoots Barrage	Seabank or Whitson		-£0.49/kW
Tidal Lagoons - 1	Seabank or Hinckley Point		-£0.49/kW or -£5.49/kW
- 2	Whitson	Transmission lines crossing the Severn Estuary.	-£0.49/kW
- 3	Uskmouth or Tremorfa	Transmission lines crossing the Severn Estuary.	-£0.49/kW
Barry			
	Up to 100 MW to Sully		
	Connection at Aberthaw which may only be possible for a non-firm connection	-£0.49/kW	
F Point	100 MW to Bowhayes Cross	To Hinckley Point or Alverdiscott	-£5.49/kW or -£2.87/kW
Lundy	10 MW to Clovelly	Subsea Connection to East Yelland or Connection direct to Alverdiscott	-£5.49/kW
Lands End	20 MW to Mousehole	To Hayle or Rame or possibly to Indian Queens	-£5.49/kW
Lizard Point	20 MW to St Keverne	To Rame or possibly to Indian Queens	-£5.49/kW
Start Point	20 MW to Stokenham	To Paigton, Totnes or Abham	-£5.49/kW
Portland	16 MW to Portland	To Chickerell	-£2.87/kW
Isle of Wight	16 MW to Ventnor	80 MW to Ventnor with new 132 kV transmission line back to Cowes or subsea cable to Fawley	-£2.87/kW
The Broads	100 MW to Great Yarmouth	To Norwich Main	£1.87/kW
The Wash	60 MW to Boston, Skegness or King Lynn	To Walpole	£3.88/kW

Figure 5—17 below has been coloured to give an indication of how opportunity for grid connection for the various tidal resources sites identified in Sections 3 and 4 varies across the UK.

This is broadly consistent with Figure 5—16 and the assessment of the BWEA-Npower Juice study.

The findings of the various grid studies may vary in terms of timing and scale of development scenarios and interaction with other potential generation sources, but are broadly consistent that grid constraints are one of the key issues facing the development of the UK tidal energy resource.

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Figure 5-17: Summary of grid constraints

Key

Green - Areas where it should be possible to connect additional generation into the transmission and distribution network close to the shore without significant reinforcement.

Amber - Areas where the connection of additional generation into the transmission and distribution network should be possible with some reinforcement back to substations a little way inshore, longer subsea links to more secure parts of the network or the completion of planned reinforcements to the transmission network.

Purple - Areas where connection into the nearest network will allow a limited amount of export (up to about 20MW) but to allow larger amounts of generation to connect a long subsea cable and significant onshore reinforcements would be required.

Red - Areas where the connection of additional generation into the transmission and distribution network would require significant reinforcements with long development times.

Date	26 January 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	TNEI	
File Reference	P936/gis/mxd/report	
Checked	RM	GIS Specialist
	DW	Project Manager

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6 COASTLINE TYPES AND SEA LEVEL RISE

6.1 INTRODUCTION

The effect of offshore tidal power extraction is to change currents and water levels and is, in general, to reduce the erosive energy or power reaching adjacent coastlines. It may be possible for some coastal areas to receive more incident energy because of the effects of channelling and local intensification of currents. There may also be secondary effects on the waves. Most waves seen on the sea are generated by local or distant winds and are known as wind waves. The local pattern of wind-waves is often referred to as the field of wind-waves. If tidal power extraction changes wave diffraction or refraction, there will be associated secondary changes to the wind-wave field.

These hydromorphologic effects raise questions to do with changing patterns of erosion and deposition around the coast. Such changes may affect all the usual themes of use and protection of the coast: navigation; shoreline stability; conservation; exploitative and extractive industries; marine archaeology; fishing; leisure; defence activities and others.

To discuss these issues it is useful to distinguish various pairs of complementary concepts: estuaries and coasts; natural and extractive effects; global and local effects; enclosing and non-enclosing extraction schemes; sea level and wave spectrum. Some of these concepts are discussed in the following sections as a context to the maps which show the general nature of the UK coastline.

In addition, the location and development of the cabling and shore-based infrastructure associated with bringing the generated power onshore may require consideration of the long term general effects of sea level rise, flooding and coastal erosion to protect these assets adequately. These are issues of constraint rather than a fundamental resource issue and are not developed further in this report.

6.2 SEA LEVEL

Local sea level varies because of: global sea level change (eustatic change); local movement of the land associated with post-glacial uplift or tectonic movements (isostatic change); and anthropogenic effects associated with local engineering, in this present case for the purposes of exploiting the tidal resource.

6.2.1 Global Change in Mean Sea Level

Eustatic change may be natural or anthropogenic – the latter often associated with large-scale effects such as global climate change rather than with any particular local causes.

A recent assessment (IPPC, 2007) from the Intergovernmental Panel on Climate Change, Working Group 1, updated the physical science basis for climate change previously reported in 2001. As judged by new in situ and satellite data, global sea levels rose from 1993 to 2003 by 3.1±0.7 mm (limit of 90% confidence) per year. This exceeds a previous estimate of 1.8±0.5 mm per year during 1961-2003. The increased rate of rise stems from greater losses from the Greenland and Antarctic ice sheets. The total rise in the 20th century is judged to be 0.17±0.05 m.

These estimates are qualified by the IPCC's warning that they do not incorporate the effects of increased ice flow from Greenland and Antarctica. If these flows continue as observed during 1993-2003, the above rise in level could be increased by 0.1 to 0.2 m over the century. In the long-term extreme case of disappearance of the Greenland ice sheet rise of about 7 m would ensue.

6.2.2 Change in Extreme Sea Levels

There is an additional aspect to sea level change: not only mean level changes, but the likelihood of extreme levels may also change. For example, the 2007 IPCC report indicates that westerly winds in both northern and southern hemispheres increased after the 1960s. Extreme sea levels in British latitudes, defined as the highest 1% of hourly sea levels, have therefore probably increased since that time. This is not a trivial phenomenon: it may for example lead to an increase in rates of erosion or, in some cases, deposition at land levels lying above mean sea level.

6.2.3 Local Change in Mean Sea Level

Isostatic change is usually natural and caused by depression of landmasses under weight of ice or by uplift as the weight of ice is removed in postglacial times.

The sum of these global and local effects has in recent Holocene times been a sea level rising in the south of Britain by about 1 mm per year, and a rise in the north of England and the Scottish mainland relative to mean sea level by about 1 mm per year (Shennan and Horton, 2002). DEFRA general guideline rates (DEFRA, 2006) of rise are 4 mm per year to 2025, 8.5 mm per year 2026 to 2055, 12 mm per year 2056 to 2085 and 15 mm per year to 2115: this results in a possible rise of about 1 metre over the next century, somewhat exceeding the IPCC figures.

6.2.4 Engineered Change in Mean Sea Level

In general, non-enclosing energy extraction schemes have no effect on local sea level because there is no mechanism to counter the hydrostatic equilibrium of a flat sea surface. In more restricted estuarine or inlet sites, tidal energy extraction schemes of an enclosing nature characterized by barrages, dams, lagoons, reservoirs or significant throttling of flow are very likely to change enclosed sea levels significantly.

6.2.5 Significance of the Local Engineered Changes in Mean Sea Level

Possible engineered rises should be looked at in relation to the above global and local rises of several decimetres and in the context of the present Environment Agency and Scottish Environment Protection Agency flood risk maps which are generally based around analysis of the 0 to 5 metre contours on land. From this viewpoint, local changes induced by tidal energy extraction schemes are likely to be significant relative to local and global change only if they are of order of tenths of a metre or more.

6.3 SEA LEVEL AND WAVE SPECTRUM

It is convenient and physically meaningful to distinguish three influences on coastal erosion: changing mean sea level; changing extreme sea level; and changes in the wave spectrum. These may act separately or together to affect coastal erosion. The first and second have been discussed above.

The third influence is waves. Tidal extraction schemes may alter the wave field, altering the local wave spectrum, and changing the frequency, amplitude and power of waves reaching the coast. Changes in the wave spectrum affect the erosive power of the waves at any height and may therefore change the focus of the erosion within the coastal height profile. This is part of a wider contemporary concern that changes in storminess may both deliver more wave power and deliver it to greater heights on the land.

As a secondary effect, extraction of energy from the tides affects the local wave spectrum by changing the local waves' propagation, refraction and diffraction. In restricted sites particularly, extraction of tidal energy via dams, barrages or flow throttling will alter these wave characteristics. Dams, lagoons and barrages will reflect waves and shadow them, substantially redistributing and modifying wave action. Similarly, tidal flow throttling of any sort may increase or reduce wave action at nearby sites, depending on the local hydrographic details. In this way the patterns of erosion or deposition may alter significantly.

6.4 ESTUARIES AND COASTS

6.4.1 Estuaries and Tidal Power

Estuaries and other semi-enclosed inlets of sea offer the possibility of extracting tidal power from the potential energy stored in such regions during high tides, as at La Rance in France and as considered for the Severn estuary. The extraction of this energy has the potential to alter greatly the tidal sea level regime in such areas, considerably altering the erosion patterns. The associated structures will modify the local wave field by reflection, diffraction, refraction and damping, leading to associated changes in erosion patterns.

Estuarine areas whose erosion and deposition patterns are most likely to be sensitive to tidal power extraction of this nature are likely to be characterized by: low lying estuarial regions (Figure 6-6: estuaries); weak relief (figure 6-1: the non-cliff areas); nearby mobile landforms (Figure 6-3: the dunes); softer offshore formations (Figure 6-4: the non-hard formations); leading to some of the higher risk areas of Figure 6-5.

6.4.2 Coastal Sites and Tidal Power

Energy may be extracted from the tides by trapping potential energy and releasing it through generators, or by direct capture of kinetic energy as, for example, with turbines in strong tidal streams such as the Pentland Firth.

The trapping and release of potential energy presupposes some form of enclosure such as dams, barrages or throttles. In principle, areas of open sea might be enclosed for this purpose but - in economic engineering practice - it is only in semi-enclosed seas, embayments or coastal inlets such as La Rance and the Severn that such schemes receive serious attention. Wherever an enclosed or semi-enclosed scheme is built, the local sea level regime will be changed. In particular, the extraction of potential energy is bound to reduce the tidal range within the enclosed region. It may, but not necessarily, also alter the mean sea level within the enclosed region.

To capture kinetic energy directly via turbines is to introduce artificial obstacles and friction into otherwise natural systems. Flows therefore alter, as do local water levels. The extent of these changes depends critically on the rate of energy extraction relative to the natural energy flow through the region, on the scale of the site relative to local topography, and on the regional hydrodynamics. With the limited scale of present engineering, the effects on regional flow and water levels in many open offshore sites will be undetectable outside the immediate vicinity of the turbines.

In more enclosed sites (straits, channels), substantial tidal energy extraction will modify flows and levels. In such sites the effects of locally modified sea levels will be to move the focus of wave erosion up or down the coastal height profile. The effect of modified flow fields will be to change erosion and deposition patterns. It will also have the secondary effect of altering wave trajectories through the flow field, thereby altering the coastal erosion associated with wave action.

Coastal areas whose erosion and deposition patterns are most likely to be sensitive to tidal power extraction of this nature are likely to be characterised by: low lying ground with weak relief (Figure 6-1: the non-cliff areas); unstable and eroding cliffs (note that Figure 6-1 does not distinguish stable cliffs from unstable cliffs such as are found along the Yorkshire and East Anglian coasts); nearby mobile landforms (Figure 6-3: dunes); softer offshore formations (Figure 6-4: the non-hard formations). These characteristics lead to recognition of some of the higher risk areas shown in Figure 6-5. In most cases any changes to coastal erosion caused by tidal energy development would be considered to have a negative effect on the marine environment by the consenting agencies.

6.4.3 Water Framework Directive

The Water Framework Directive makes explicit mention of hydromorphology in coastal and transitional (estuarine) waters (further details of the Water Framework Directive can be found in Section 7.4.4.3). It requires all water bodies to reach and remain in “Good Ecological Status” which is partly related to the “hydromorphological status” of the water body. At our present level of discrimination it is not necessary to map all UK water bodies, but it is clear from the directive and its implementation that the regulatory force of the directive will be most keenly felt in estuaries and in restricted coastal waters affected by barrages, dams and similar structures.

6.5 SUMMARY

The following table summarises the above points.

Table 6-1: Summary of issues associated with sea level rise and coastline types

Open Coast or Estuary	Natural or Extractive Change	Enclosed (e.g. estuaries or semi enclosed inlets) or non-enclosed water body	Main Effects
Open Coast	Natural	-	Sea level - isostatic & eustatic changes - rising in the South, stationary or falling in the North. Possible general rise of about 1 metre over the next century.
Open Coast	Extraction	Enclosed	Not economically practicable in engineering terms: no effects on sea level or flows presently expected. WFD regulation would have weak influence.
Open Coast	Extraction	Straits and channels	Sea level - local changes are possible. Flow rates - general reduction - possible localised intensification. Secondary modification of wave field near sites. WFD regulation would have influence.
Open Coast	Extraction	Non-enclosed	Sea level - no change at sites - no regional change Flow rates - general reduction - possible localised intensification. Secondary modification of wave field near sites WFD regulation would have weak influence.
Estuary	Natural	-	Sea level - isostatic & eustatic changes - rising in the South, stationary or falling in the North. Possible rise of up to 1 metre over the next century.
Estuary	Extraction	Enclosed	Sea level - changed within site – some regional changes. Tidal range - significant change within site - regional changes outside site. Wave Field - changed within site - secondary modification outside site. WFD regulation would have strong influence.
Estuary	Extraction	Non-enclosed	Sea level – small regional changes. Tidal range – small regional changes. Wave field – changed within site - secondary modification outside site. WFD regulation would have influence.

These are the general characteristics of the processes that underlie erosion or deposition and of the way they may be modified by foreseeable energy tidal extraction schemes.

Coastal areas sensitive to these influences are likely to be characterized by locally high flow associated with straits, channels, restrictive headlands or estuaries, by the availability of mobile sediment, and by the presence of eroding coastline.

Coastal areas insensitive to these influences are characterized by open sea, paucity of mobile sediment and by resistant coastline.

To compose a high level overview of the British Coast in the light of these characteristics requires indicators or surrogates. The associated maps therefore show:

- coastal cliffs (source: MAGIC) as an indicator of resistive shore insensitive to tidal energy extraction. However, this indicator is not completely correlated with resistive coast: for example, cliffs on the North Yorkshire coast offer some resistance to erosion but are particularly fragile within the UK context;
- dunes (source: MAGIC) as an indicator of weak mobile shore and hinterland whose characteristics may be sensitive to tidal energy extraction;
- sand and mud (source: MAGIC) as an indicator of coastal areas whose erosional and depositional character is particularly sensitive to tidal energy extraction;
- offshore shingle, gravel and rock platform (source: MAGIC) as an indicator of harder offshore sea bed whose characteristics may be relatively insensitive to tidal energy extraction;
- the Foresight programme's indicative map of erosion risk in the face of climate change (source: Foresight) in 2080;
- estuaries: most estuaries lie outside likely energy extraction areas. The two important exceptions are the Humber and the Severn, both of which are clearly associated with high sand and mud concentrations and with areas of low relief. These estuaries may therefore be expected to be particularly sensitive to the effects of local tidal power extraction.

The maps showing coastal cliffs, dunes, offshore sand and mud, and offshore shingle gravel and rock platforms drew on the Magic data resource (www.magic.gov.uk) which brings together geographical information on various environmental topics. The source data presented in Magic relating to coastline types is supplied by Scottish Natural Heritage, Natural England and the Countryside Council for Wales. This data was summarised to create the following maps. Although this data gives a good overview of coastline types across the UK, further, more detailed, data such as the Mapping European Seabed Habitats (http://www.searchmesh.net/) project and the UKSeaMap (http://www.jncc.gov.uk/page-2117) is available and would be expected to give more refined maps. This data could be used to give a more detailed indication of coastline types for regional investigations or specific project developments.

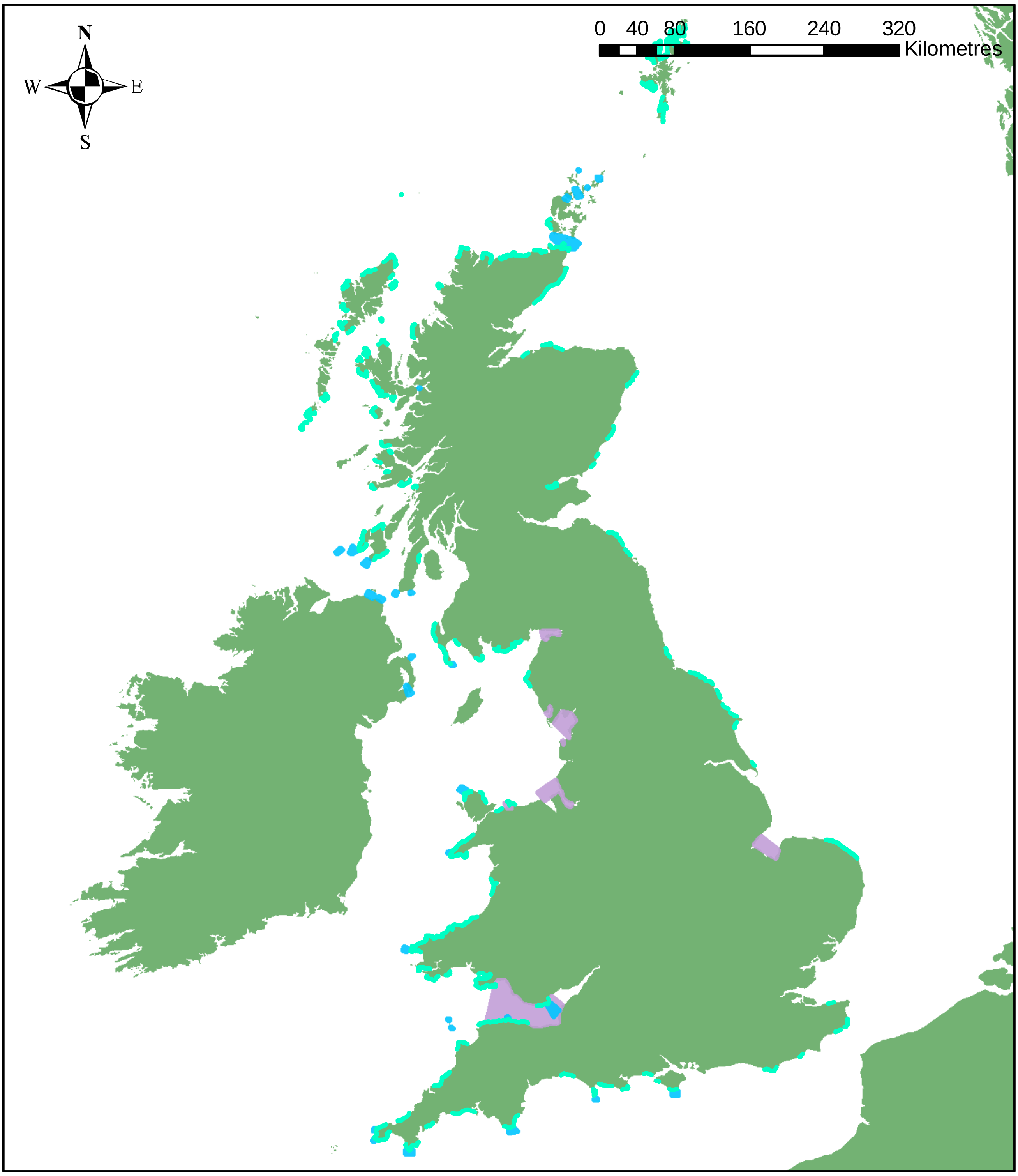

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Figure 6-1: Overview of cliff coastline types

Legend

Coastline type: cliff

Tidal stream resource sites

Tidal range resource sites

Date	1 February 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	Black & Veatch, ABPMer et al, DETI et al, Metoc; Magic	
File Reference	P936/gis/mxd/report	
Checked	RM	GIS Specialist
	DW	Project Manager

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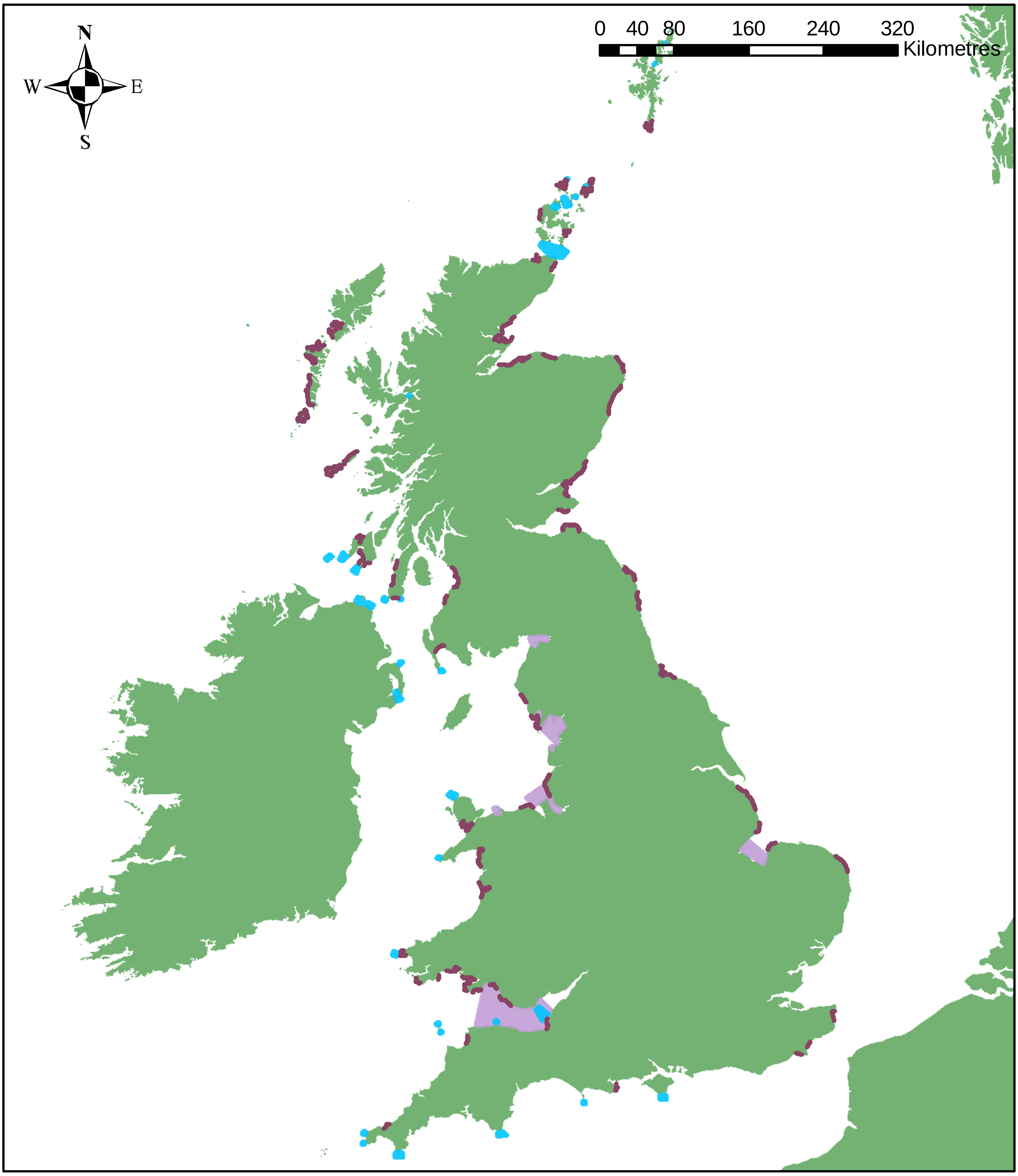

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Figure 6-2: Overview of dune coastline types

Legend

Coastline type: dune

Tidal stream resource sites

Tidal range resource sites

Date	1 February 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	Black & Veatch, ABPMer et al, DETI et al, Metoc; Magic	
File Reference	P936/gis/mxd/report	
Checked	RM	GIS Specialist
	DW	Project Manager

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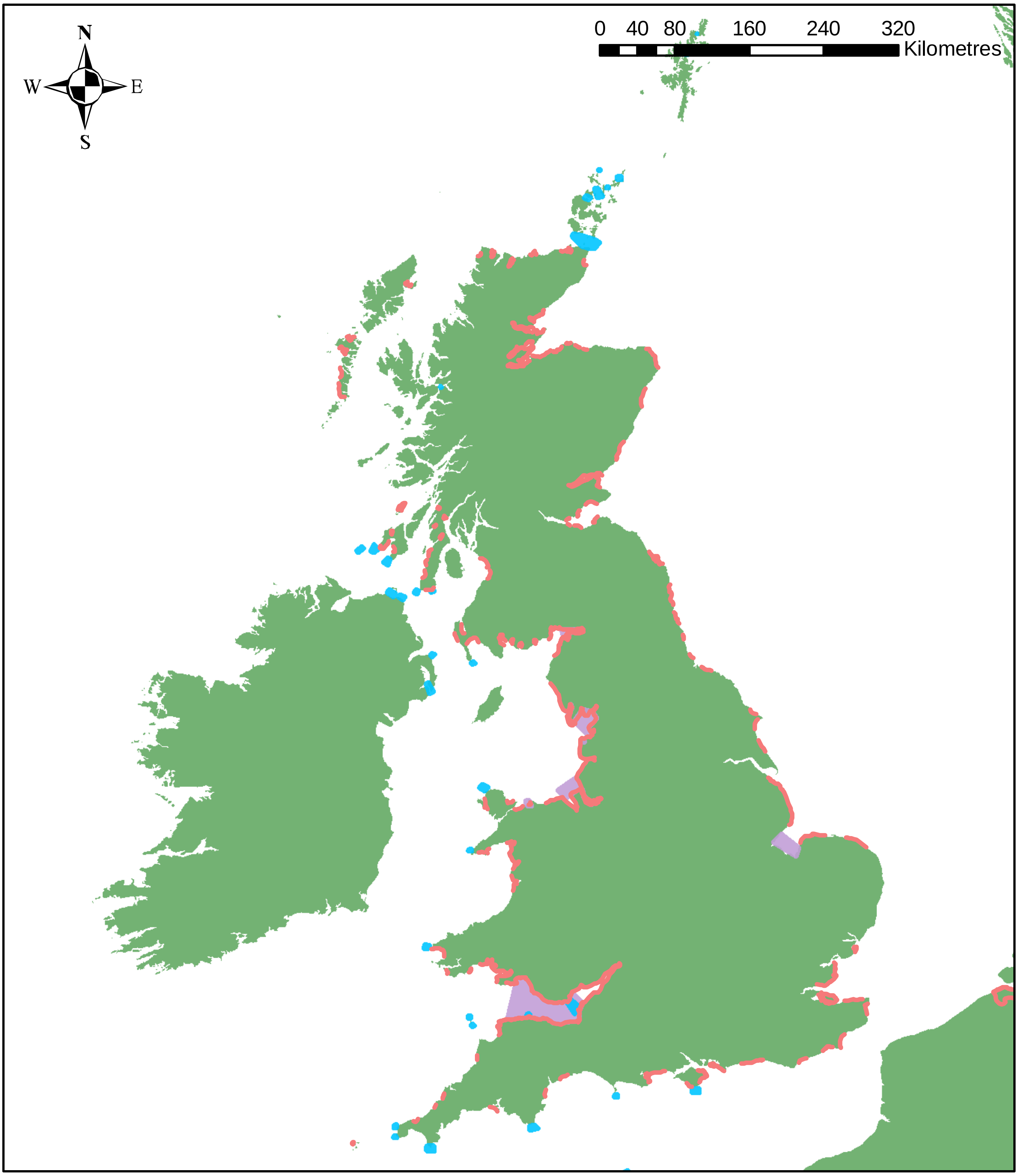

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Figure 6-3: Overview of offshore sand and mud

Legend

Overview of offshore sand and mud

Tidal stream resource sites

Tidal range resource sites

Date	1 February 2007
Projection	Transverse Mercator
Spheroid	Airy
Datum	OSGB36
Data Source	Black & Veatch, ABPMer et al, DETI et al, Metoc; Magic
File Reference	P936/gis/mxd/report
Checked	RM GIS Specialist
	DW Project Manager

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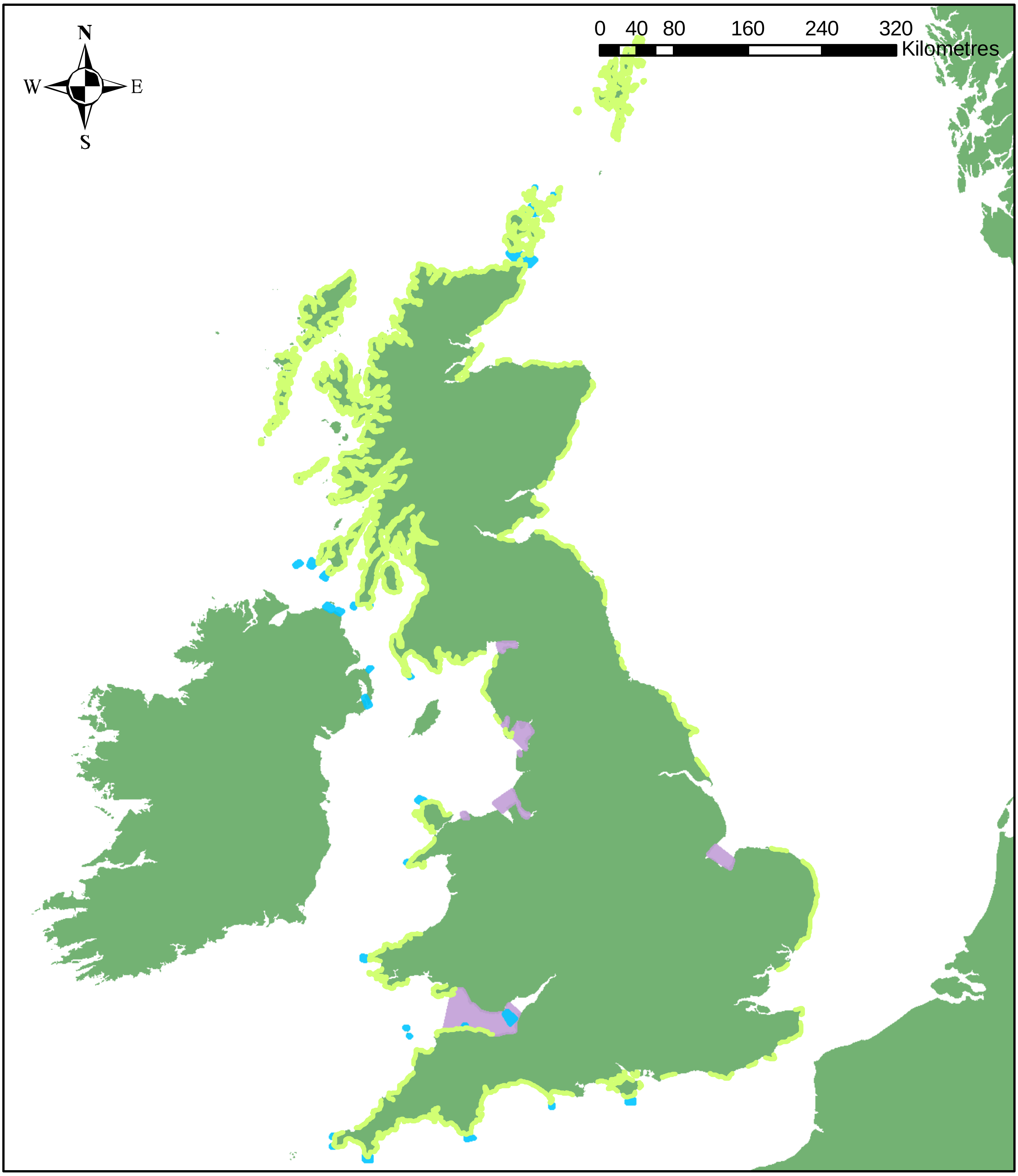

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Figure 6-4: Overview of offshore shingle, gravel and rock platforms

Legend

- Overview of offshore shingle, gravel and rock platforms
- Tidal stream resource sites
- Tidal range resource sites

Date	1 February 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	Black & Veatch, ABPMer et al, DETI et al, Metoc; Magic	
File Reference	P936/gis/mxd/report	
Checked	RM	GIS Specialist
	DW	Project Manager

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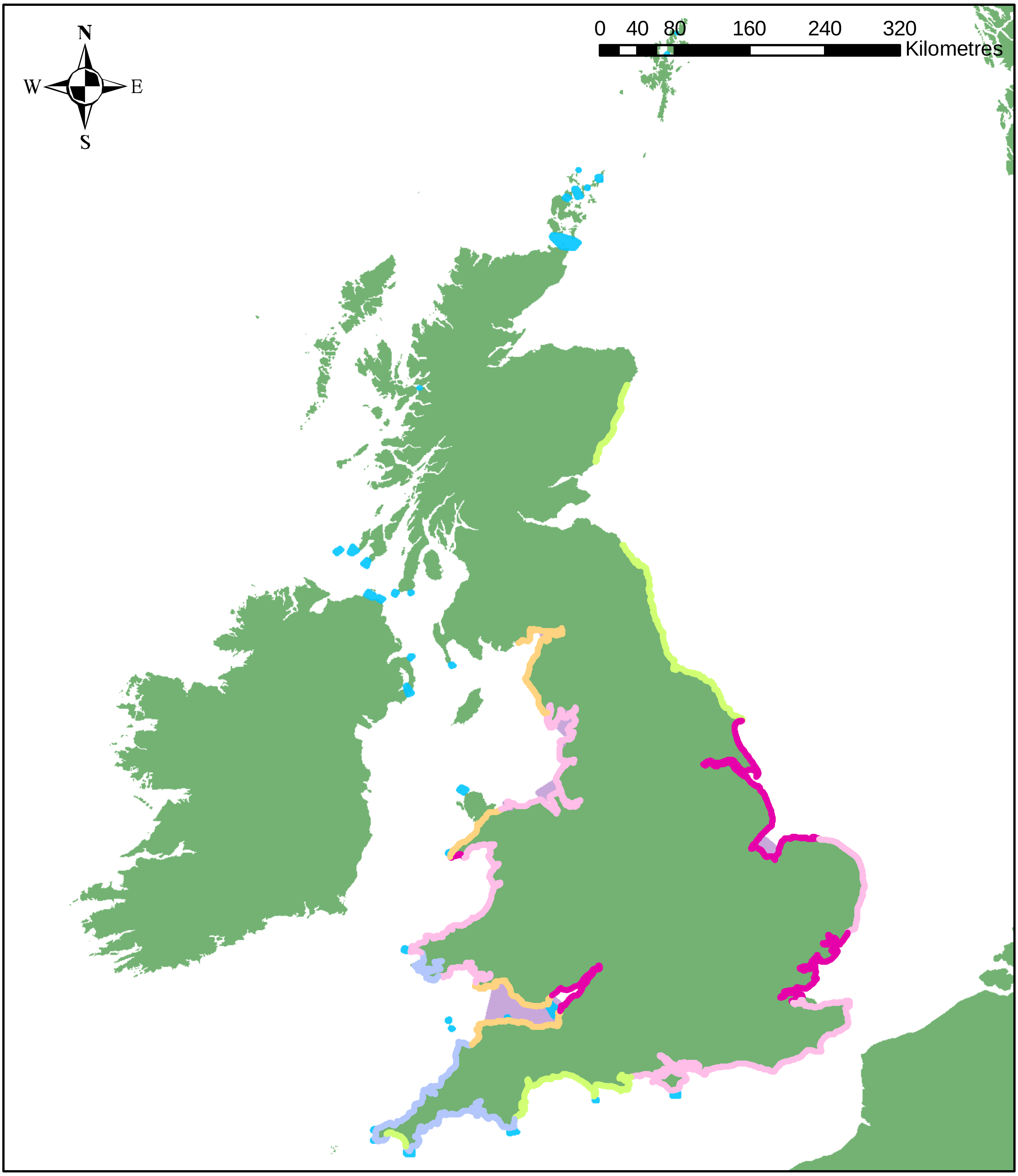

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Figure 6-5: Erosion risk due to climate change

Legend

Erosion (high emission scenario 2080)

- Extreme
- Very high
- High
- Moderate
- Low
- Tidal stream resource sites
- Tidal range resource sites

Date	1 February 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	Black & Veatch, ABPMer et al, DETI et al, Metoc; Foresight Floodrisk Report	
File Reference	P936/gis/mxd/report	
Checked	RM	GIS Specialist
	DW	Project Manager

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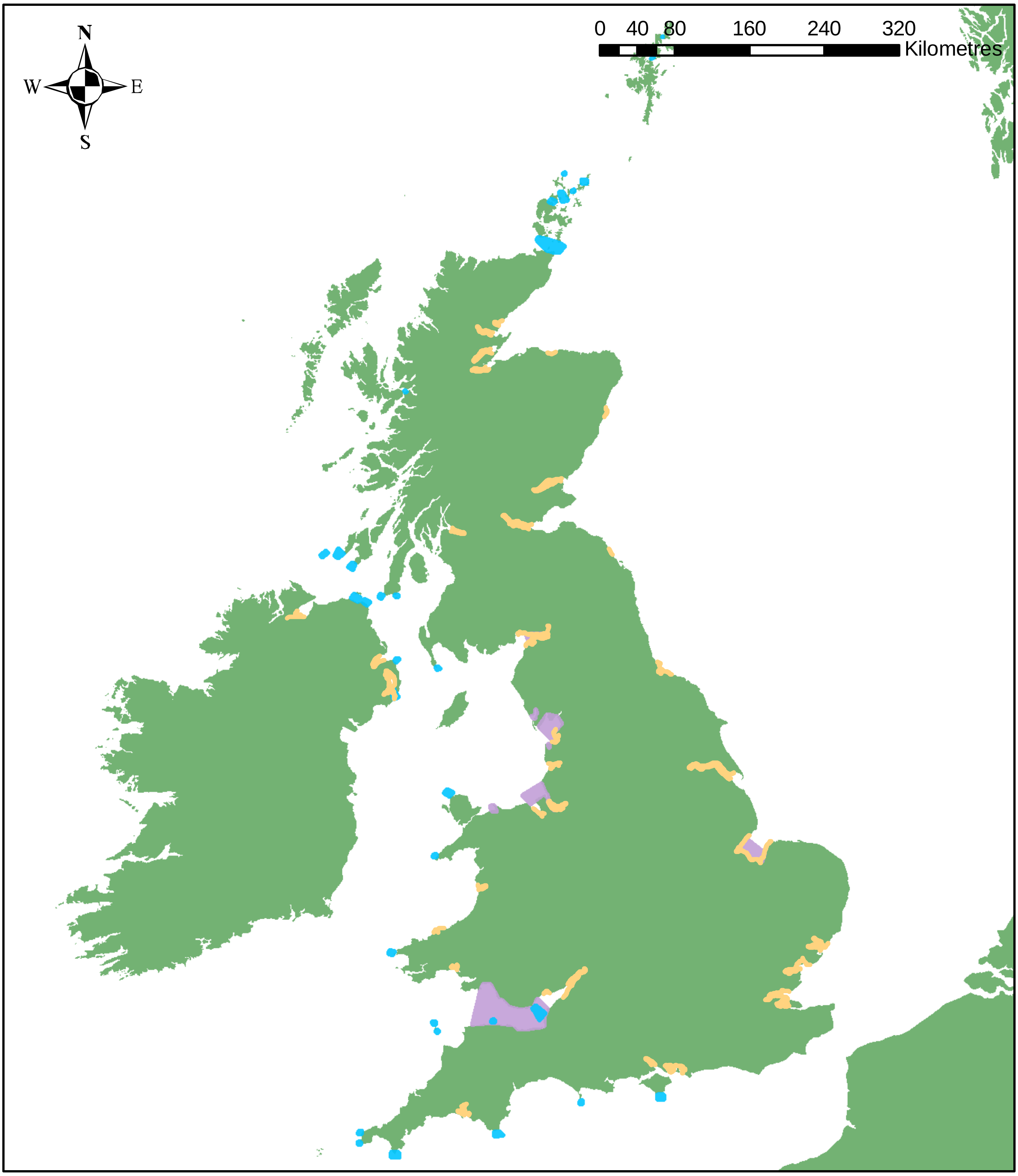

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Figure 6-6: Overview of estuary coastline types

Legend

Coastline type: estuary

Tidal stream resource sites

Tidal range resource sites

Date	1 February 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	Black & Veatch, ABPMer et al, DETI et al, Metoc; Magic	
File Reference	P936/gis/mxd/report	
Checked	RM	GIS Specialist
	DW	Project Manager

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7 STRATEGIC POLICY FRAMEWORK

7.1 APPROACH

This section of the study gives an overview of the strategic policy and planning framework (current and under development) for consenting, planning and environmental impact assessment (EIA) in relation to tidal power and resources in the UK. It begins by looking at strategic renewable energy policy across the UK before giving an overview of planning and permitting (including EIA) requirements for tidal energy development. Policy statements by statutory bodies and non-government organisations with regards to renewable energy development are also outlined. Finally, an overview of future policy developments that may impact the planning and permitting of tidal energy developments is given.

Where appropriate the roles and responsibilities of the Devolved Administrations are also discussed. Energy policy is a reserved matter, dealt with by UK Government, for England, Wales and Scotland (although Scotland have devolved responsibilities for renewable energy policy and planning). The Northern Ireland Government have responsibility for their own energy and planning policy.

7.2 POLICY IN THE UK WITH REGARDS TO TIDAL ENERGY GENERATION

7.2.1 Background

As set out in the European Commission's Green Paper on security of energy supply (2000), key priorities for European Union (EU) energy policy are to address the Union's growing dependence on energy imports from a few areas of the world, and to tackle climate change, notably as regards European commitments in the Kyoto Protocol (European Commission, 2001). The promotion of renewable energy has an important part to play in both tasks. Since 1997, the EU has been working towards the target of a 12% share of renewable energy in gross inland consumption by 2010 (European Commission, 2004).

In the 2003 Energy White Paper (DTI, 2003) the UK Government set a target of achieving 10% of electricity supply from renewable energy by 2010 (subject to the costs being acceptable to the consumer) with a further aspiration to derive 20% of electricity from renewable sources by 2020. The Scottish Executive (who have devolved responsibility for renewable energy policy) have set a target of achieving 18% of electricity generation in Scotland from renewable energy resources by 2010, rising to 40% by 2020. This is in recognition of the extensive hydro, wind, wave and tidal resources located in and around Scotland (FREDS, 2005). The Northern Ireland target is to obtain at least 12% (at least 15% of which must be from non-wind technologies) of energy from indigenous renewable energy sources by 2012 (DETI, 2004).

7.2.2 The Renewables Obligation

The Renewables Obligation (RO) is the main policy mechanism aimed at increasing the proportion of electricity generated from renewable sources in the UK. The Utilities Act 2000 gives the Secretary of State the power to require electricity suppliers to supply an annually increasing amount of their electricity from eligible renewable sources. From this came the three Orders which were subject to review in 2005/06; the new Orders coming into effect on 1 April 2006 (see Table 3 1). The current target, as a percentage of total supplies, is 6.7% for 2006/07, rising to 15.4% by 2015/16 in Great Britain (England, Wales and Scotland) and 2.6% and 6.3% respectively in Northern Ireland (Ofgem, 2006_a).

Table 7-1: Renewables Obligation

Order	Statutory Department	Statutory Instrument (SI)
Renewables Obligation (England and Wales)	Department of Trade and Industry (DTI)	The Renewables Obligation Order 2006 (SI 2006 No. 1004)
Renewables Obligation (Scotland) (ROS)	Scottish Executive	The Renewables Obligation (Scotland) Order 2006 (SI 2006 No. 173)
Northern Ireland Renewables Obligation (NIRO)	Department of Enterprise Trade and Investment (DETI)	The Renewables Obligation Order (Northern Ireland) 2006 (SI 2006 No. 56)

Electricity suppliers meet their obligations by presenting Renewables Obligation Certificates (ROCs); a tradable certificate issued for each megawatt hour of renewable energy generated and supplied to customers within the UK. ROCs are issued by Ofgem, Britain's gas and electricity regulator, who also administers the Northern Ireland Renewables Obligation (NIRO) on behalf of the Northern Ireland Authority for Energy Regulation (NIAER) (previously Ofreg) (Ofgem, 2006_b).

7.2.2.1 Future Changes to the Renewables Obligation

Following the UK Government's 2006 Energy Review (DTI, 2006_a), in which a package of proposals were announced to help address the issues of climate change and the need to deliver secure, clean energy at affordable prices, the Government announced a number of changes to the Renewables Obligation, including policy recommendations. Subsequently, a consultation document on the Reform of the Renewables Obligation and the Renewables Obligation Order 2007 was published on 9 October 2006, by the DTI, and closed on 5 January 2007 (DTI, 2006_b).

The consultation contained two parts:

1) Part 1 consulted on the proposals in the Government's Energy Review Report to introduce from 2009 or 2010 "banding" of the RO to "differentiate levels of support to different renewable technologies to give more support to emerging technologies such as offshore wind, wave and tidal" and give additional certainty on long-term ROC prices. These changes to the RO would be subject to the passage of primary legislation; any changes coming into force on 1 April 2009 at the earliest.

2) Part 2 was a statutory consultation on a small number of more limited and detailed changes to the Renewables Obligation legislation (via secondary legislation) that it is proposed to come into force for 1 April 2007. These changes are in the area of the administration of the Obligation, including: changes to allow easier access to the Renewables Obligation for small generators and the removal of the requirement for sale and buyback agreements for certain renewable generators.

The amendments proposed under part two of the DTI paper are fully supported by the Scottish Executive, and therefore, subject to the outcome of the consultation, would also be made to the ROS (Scottish Executive, 2006_b). The outcome of this consultation will feed into the Energy White Paper due to be published in 2007.

The Scottish Executive also intends to introduce a Marine Supply Obligation under the Renewables Obligation (Scotland) (ROS), which will stipulate that suppliers purchase a specified amount of electricity from tidal and wave generation, or pay a buy-out price. Following statutory consultation, the revised ROS was laid before the Scottish Parliament in February 2007 and is expected to come into force in April 2007.

At the time of the consultation on the reform of the Renewables Obligation, although there was general support for the intention to increase the volume and diversity of energy in the UK, there was some concern from the renewables industry that the amendments could affect investor confidence and that there could be more approriate instruments to deliver targeted support to emerging technologies (BWEA, 2007).

7.2.3 Finance and Research Support

Financial support for tidal energy projects is currently available under the DTI's Technology Programme and the Marine Renewables Deployment Fund (DTI, 2007_a). The DTI Technology Programme has already committed in excess of £20m to single device projects and on 2 August 2004, the Government announced a £50 million Marine Renewables Deployment Fund at the core of which lies the DTI's 'Wave & Tidal Stream Energy Demonstration Scheme' for multiple device (i.e. arrays of two or more devices) projects (DTI, 2007_a). The key features of this scheme are summarised in Table 7-4. Revenue support for individual projects under the scheme will be available for up to 7 years from commissioning. The maximum amount available per project will be £9 million and is available throughout the UK (DTI, 2005_b).

In Scotland, the Scottish Executive's £8 million Wave and Tidal Energy Support Scheme (the Scheme) has recently been increased to £13 million (Scottish Executive, 2007_a). The aim of the scheme is to provide grants to businesses to support the installation and commissioning/ deployment of pre-commercial wave and tidal electricity generating devices and supporting the EMEC (European Marine Energy Centre) test centre in Orkney.

The Secretary of State for Northern Ireland announced a £15.2 million Research and Demonstration Programme in February 2006 led by DETI to encourage and facilitate the demonstration of innovative renewable energy solutions over the next two years (DETI, 2006).

In Wales funding is also available via the Wales EU Structural Fund. The Structural Fund Programmes last from 2000 to 2006, although expenditure can continue until mid 2008 (Welsh European Funding Office, 2007).

Table 7-2: Summary table of the key features of DTI's 'Wave & Tidal Stream Energy Demonstration Scheme'

Total amount allocated	£42 million
Length of scheme	3 years
Maximum funding for any one technology/ project	£9 million
Revenue Support Payment	£100/ MWh, ROCs, electricity for 7 years from commissioning
Project support	2 years for commissioning and 7 years for operation

There are various groups that currently provide advice, support and discussion forums for those with an interest in renewable energy, some of which are listed in Table 7-5 (note this list is not exhaustive but gives a good overview of support for marine renewable energy development). Advice is provided to the UK Government through the Renewables Advisory Board (RAB) on a wide range of renewable energy issues. The board is an independent, non-departmental public body sponsored by the DTI that brings together government departments, the renewables industry and the unions. Its aim is to address the key issues and barriers to the Government's target of providing 10% of electricity from renewable sources by 2010 (DTI, 2007_b). The Scottish Executive established their own group in October 2003, The Forum for Renewable Energy Development in Scotland (FREDS), to consider how best to exploit Scotland's renewable energy potential. It has a key role to play in helping the Executive achieve its 2020 target of 40% of electricity generated from renewable sources (Scottish Executive, 2007_b).

Table 7-3: Organisations involved in providing advice and support to parties in involved with renewable energy (note - this list is not exhaustive)

Organisation	Aim
Renewables Advisory Board (RAB)	The Renewables Advisory Board (RAB) is sponsored by the DTI and provides advice to Government on a wide range of renewable energy issues. It brings together government departments, the renewables industry and trade union representatives to improve government understanding of the obstacles and opportunities for the development and deployment of renewable energy technologies in the UK.
Renewable Energy Association	The REA's main objective is to secure the best legislative and regulatory framework for expanding renewable energy production in the UK. They undertake policy development and provide input to government departments, agencies, regulators, NGOs and others. They have also set up a number of 'Resource Groups', looking at individual technologies and sub-sectors of the industry.
British Wind Energy Association (BWEA)	The British Wind Energy Association is the trade and professional body for the UK wind and marine renewables industries. They act as a central point for information for members and as a lobbying group to promote wind energy and marine renewables to government.
National Assembly Sustainable Energy Group (NASEG)	The National Assembly Sustainable Energy Group raise awareness of sustainable and renewable energy issues, opportunities and innovations, and assist in the development of sustainable energy policy and strategy across Wales.
npower Juice Fund	npower renewables, in partnership with its sister company npower, is investing in marine renewables through the npower juice fund. The npower Juice Fund concentrates on wave and tidal technologies as they have the ability to supply a significant proportion of the UK power market. The Juice Fund has already supported a number of projects.
Regen SW	Regen SW is responsible for driving forward the Regional Renewable Energy Strategy in the South West of England. They help develop all aspects of the renewable energy industry in the South West.
Scottish Parliament Renewable Energy Group (SPREG)	SPREG aims to bring together Members of the Scottish Parliament and others with an interest in renewable energy and energy efficiency in Scotland. The group meets to ensure an exchange of information between Members of the Parliament, industry, NGOs and other interested parties.
Forum for Renewable Energy Development in Scotland (FREDS)	FREDS endeavours to build a partnership between industry, academia and Government to enable Scotland to capitalise on its huge renewable energy resource and secure significant economic development opportunities for Scotland through bringing together key stakeholders.
Scottish Renewables	Scottish Renewables works with Government organisations, NGOs and other interested parties to formulate effective strategies, deliver agreed targets, and integrate renewables into the broader agenda for sustainable development in Scotland.
Orkney Renewable Energy Forum (OREF)	Members of the Forum include representatives of the local authority, renewable energy generators, energy experts, civil engineers, environmental consultants and electrical engineering companies, amongst others. The main purpose of the forum is to promote renewable energy projects within Orkney.
Shetland Renewable Energy Forum (SREF)	SREF aims to ensure that Shetland maximises the economic and community benefit of developing its renewable energy resources while minimising the impact on the environmental, social and visual amenity of the islands. It provides support on supply chain and infrastructure and planning.

7.3 STRATEGIC ENVIRONMENTAL ASSESSMENT (SEA) DIRECTIVE

The SEA Directive (2001/42/EC) came into force on 21 July 2001 and regulations to implement it into UK law were put in place on 20 July 2004. Its purpose is to ensure that the likely significant environmental effects of certain plans and programmes are identified and taken into account during their preparation and before their adoption. Under the directive an environmental assessment, including public consultation, is compulsory for plans and programmes in specific sectors, including energy, which set frameworks for development consents for projects listed in the EIA Directive and for those requiring an Appropriate Assessment under the Habitats Directive. Any Strategic Environmental Assessment will be undertaken by or for Government. This directive enables the integration of environmental considerations into decision-making on plans and programmes, and is therefore intended to help promote sustainable development.

Currently, it is not proposed that an SEA would be required for a demonstration phase tidal energy project in UK waters; although the undertaking of an SEA is already a requirement for all offshore commercial projects e.g. offshore wind farms (DTI, 2006_a).

There is currently a range of views across the Devolved Administrations as to whether the marine renewable energy industry is at a sufficiently advanced stage for an SEA to be meaningfully carried out. Currently there is limited information available on the potential scale of tidal energy developments and their environmental effects, as there are currently no commercial developments deployed in the UK and a very limited number of proto-type or pre-commercial developments. Completion of an SEA would be a pre-condition for the start of any formal commercial development phase and would be subject to full public consultation.

The Scottish Executive began an SEA in 2005 to examine the potential environmental impacts of harnessing energy from Scotland's marine environment, including tidal energy, and are also carrying out an SEA on SPP6 which relates to land planning policy with regards to all renewable energy development in Scotland (Scottish Executive, 2005).

The marine SEA is due to report in summer 2007 and looks at environmental issues associated with commercial development of wave and tidal energy.

The DTI have taken the view that there is currently a lack of knowledge with regards to marine renewables and that there have been insufficient projects to date to provide the data required to test different scenarios required under an SEA. However, completion of an SEA will be a pre-condition for the start of any commercial phase and will be subject to full public consultation. In the meantime the DTI view is that the "EIA process will ensure that site decisions are made in a way that recognises and avoids any serious potential adverse impact of projects in relation to other users of the sea or on the marine environment" (DTI, 2005).

In Wales a high level assessment of the potential nature conservation impacts of marine renewable energy development has been undertaken (ABPmer, 2006) but this does not qualify as an SEA under the SEA Directive.

There is no published evidence that an SEA is planned in Northern Ireland at this time.

7.4 PLANNING AND PERMITTING

7.4.1 Renewable energy planning policy across the UK

In accordance with Directive 2001/77/EC - Directive on Electricity Production from Renewable Energy Sources, all European Member States have adopted national targets for the share of electricity production from renewable energy sources. The United Kingdom (UK) Government has proposed that 10% of the UK's electricity requirements should be met from renewable sources by 2010, with an aspiration to reach 20% by 2020 (the UK currently generates about 3% of its electricity in this way) (note that the targets in Scotland are higher at 18% and 40% respectively). UK Government policy on renewables was set out in the 2003 Energy White Paper 'Our energy future – creating a low carbon economy' (DTI, 2003), and Planning Policy Statement 22 (PPS22) was issued in England in 2004 to reflect the importance of renewables to local planning, setting out the Government's policies for renewable energy, which planning authorities should have regard to when preparing local development documents and when taking planning decisions (ODPM, 2004).

The United Kingdom is a unitary state with a devolved system of government in Scotland, Wales, and sometimes Northern Ireland (currently under suspension).

Although overall energy policy is a reserved matter, renewable energy policy is a devolved matter in Scotland, and Northern have full responsibility for their energy policy and planning system (energy policy relating to renewables is not devolved in Wales). Most aspects of planning policy have also been devolved, and in Scotland the planning system as a whole is devolved, governed by the Planning etc. (Scotland) Act 2006 (rather than the Town and Country Planning Act 1990), and a National Planning Framework which controls spatial planning through until 2025. In Wales, the planning system related to offshore power stations greater than 1 MW has not been devolved, therefore the responisibilities lie with the Secretary of State for Trade and Industry.

As a devolved administration, the Scottish Executive have set their own 2010 renewable energy target, that 18% of electricity generated in Scotland should come from renewable sources. In their strategy document, 'Securing a Renewable Future: Scotland's Renewable Energy', published on 25 March 2003 they set an additional target: 40% of Scotland's electricity to be generated from renewable sources by 2020 (Scottish Executive, 2003). Within the document the potential benefits of setting a new longer-term target were acknowledged as a means of stimulating further renewables development and to help deliver their Programme for Government commitment to make an equitable contribution to the UK's obligation under the Kyoto Protocol (SNH, 2004).

A consultation on Draft Scottish Planning Policy (SPP) SPP6: Renewable Energy was published in July 2006 with the intention of facilitating successful achievement of the 2020 target and superseding the existing NPPG6 (National Planning Policy Guidelines) (Scottish Executive, 2006_a). A report on the consultation was published early 2007 and the SPP6: Renewable energy has now been published. Equivalent planning guidance has been issued in Wales through the Technical Advice Note 8: Renewable Energy (TAN8). In Wales, the planning system is partially devolved and is governed by the Town and Country Planning Act 1990 (England and Wales) (DTI, 2006_a).

In Northern Ireland, regional renewable energy planning policy is currently expressed in the Planning Strategy for Rural Northern Ireland Policy (Public Services and Utilities) PSU12. It is intended that this will eventually be replaced by a planning policy statement. Northern Ireland has its own primary planning legislation, the Planning (Northern Ireland) Order 1991[1], which relates to development control, enforcement and development plan preparation functions. Currently, over 3% of electricity consumed in Northern Ireland is generated from indigenous renewable sources. Northern Ireland's existing target of 12% (at least 15% of which must be generated by non-wind technologies) by 2012 contained in the 2004 Department of Enterprise, Trade and Investment's (DETI) 'Strategic Energy Framework' is in line with the indicative 2010 target for the UK as a whole.

7.4.2 Consenting requirements in Great Britain

The planning and consenting system for marine energy projects in the UK is complex, with projects falling under a number of different consenting regimes.

This section sets out the application of existing lease and consenting procedures for all small-scale marine renewable energy generation demonstration devices in the waters around Great Britain.

Before a developer can deploy marine energy devices in the sea it must also acquire permission from the Crown Estate to a site licence or lease. At present, The Crown Estate grants leases to demonstration-scale wave and tidal projects in the UK on the basis of a business plan (DTI, 2005_a). The Crown Estate owns the seabed out to the 12 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 the Renewable Energy Zone out to 200nm[2] (see Figure 7-1). The designation of the Renewable Energy Zone was necessary so that renewable energy resources could be exploited for the generation of electricity, permitting the Government to extend regulation of offshore renewable energy activities beyond territorial waters and thus make a contribution to meeting the Government's renewable energy targets for 2010 and beyond. Scottish Ministers have responsibility for the REZ beyond Scottish territorial waters[3] (see Figure 7-2) to provide for a consistency of approach with regard to reserved and devolved competencies in the waters off Scotland as far as the development of renewable energy resources are concerned.

[1] extended by the Planning (Amendment) (Northern Ireland) Order 2003
[2] as defined by The Renewable Energy Zone (Designation of Area) Order 2004
[3] as defined by The Renewable Energy Zone (Designation of Area) (Scottish Ministers) Order 2005

Figure 7-1: UK Renewable Energy Zone

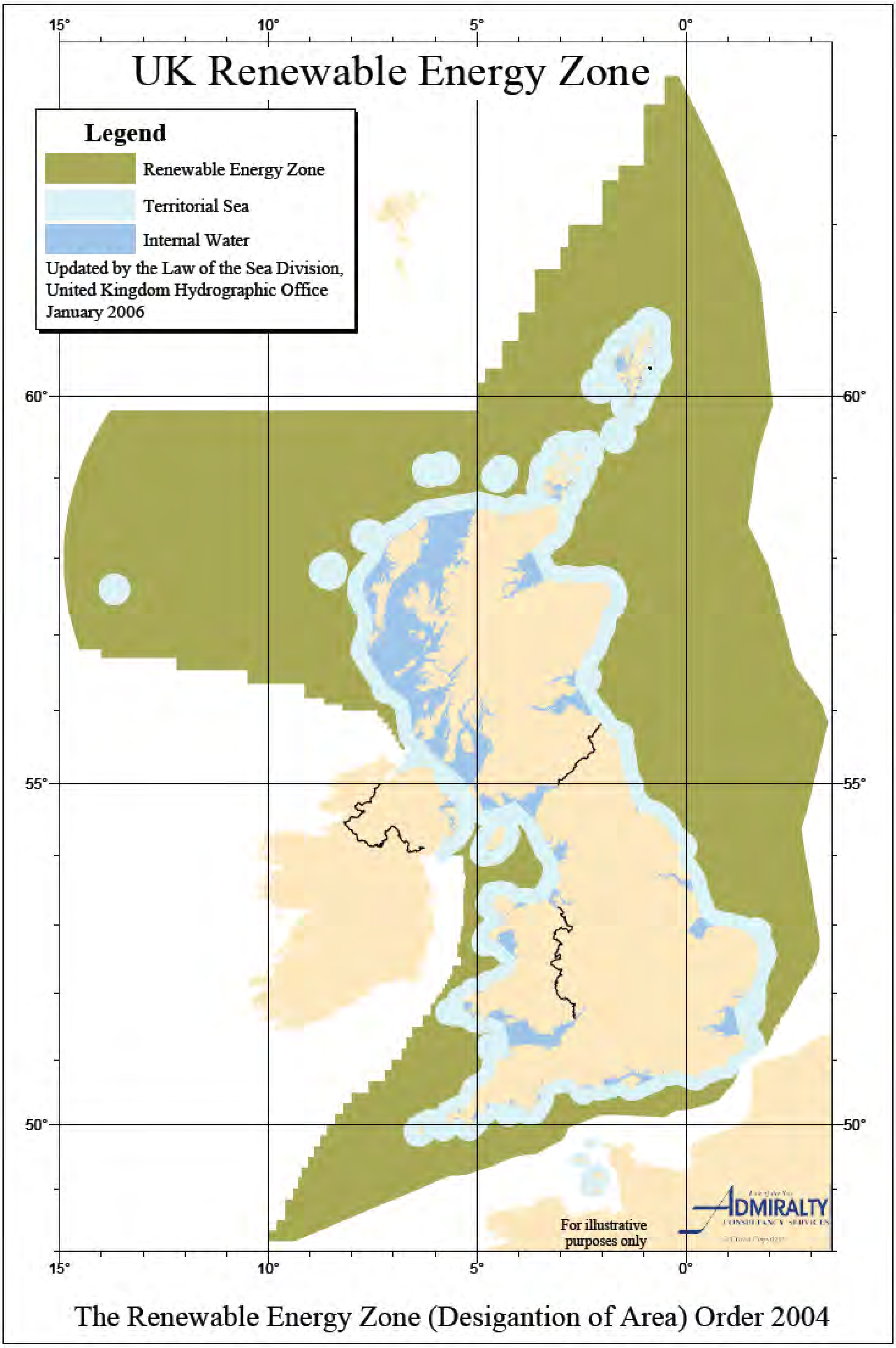


Figure 7-2: Scotland Renewable Energy Zone

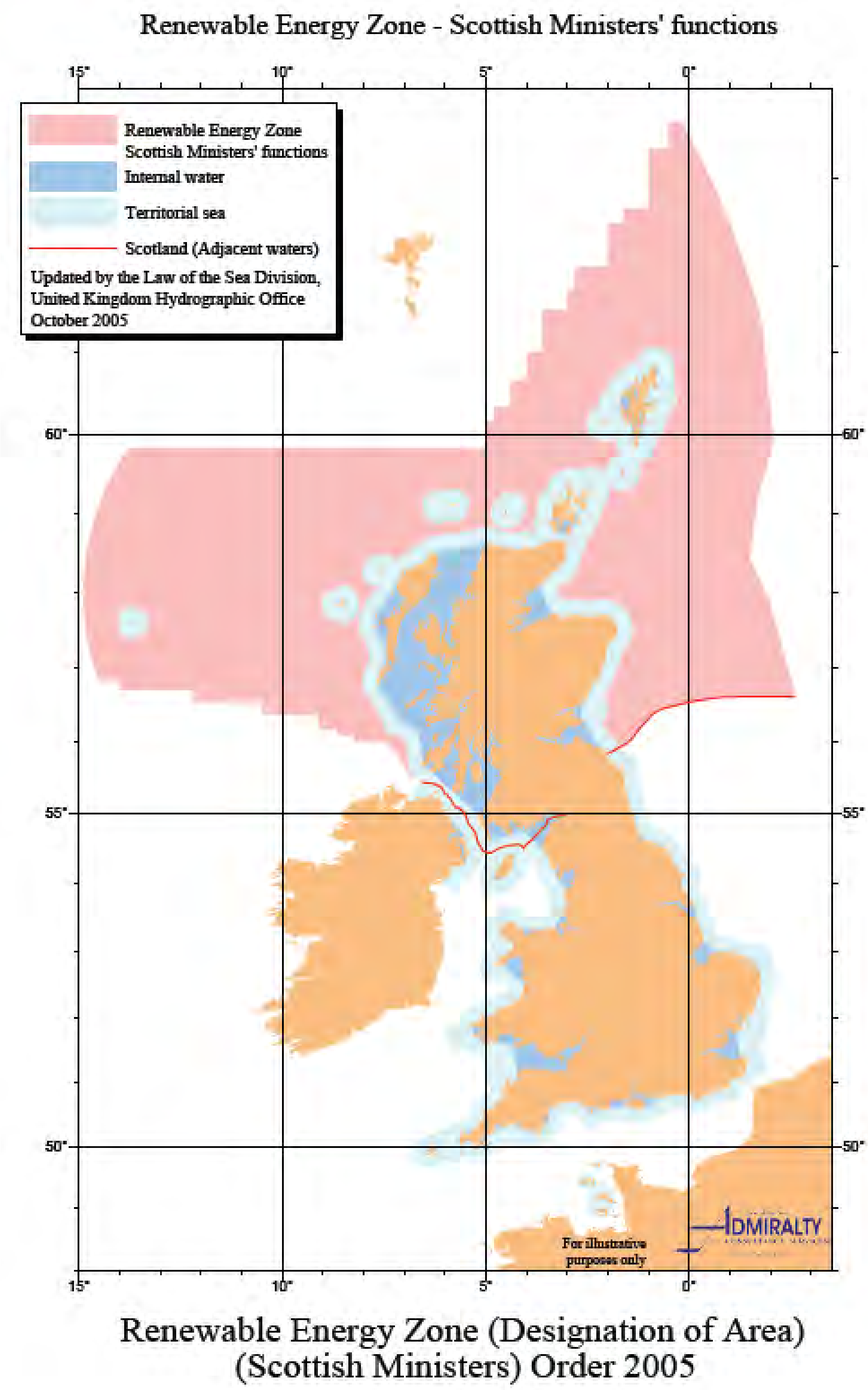


Table 7-4: Key consent requirements for tidal projects in the UK

Description	Legislation	Authority			
		England	Wales	Scotland	Northern Ireland
For offshore generating stations under 1 MW capacity within territorial waters adjacent to England, Wales and Scotland	Town and Country Planning Act 1990 (TCPA) and equivalent legislation Coast Protection Act 1949 (CPA) - Section 34 Food and Environment Protection Act 1985 (FEPA) - Section 5	Local Planning Authority Secretary of State for Environment, Food & Rural Affairs Secretary of State for Environment, Food & Rural Affairs	Local Planning Authority Secretary of State for Environment, Food & Rural Affairs National Assembly[5a]	Local Planning Authority Scottish Ministers Scottish Ministers	Department of the Environment
For offshore generating stations over 1 MW capacity within territorial waters adjacent to England, Wales and Scotland and any developments in the Renewable Energy Zone[4]	Electricity Act 1989 Section 36	Secretary of State for Trade and Industry	Secretary of State for Trade and Industry	Scottish Ministers	N/A
For electricity generating stations over 2 MW capacity in Northern Ireland	Electricity Consents (Planning) (Northern Ireland) Order 2006 - Article 39	N/A	N/A	N/A	Department of Enterprise, Trade and Investment
Planning consent for certain onshore elements of an offshore project.	Town and Country Planning Act 1990 (TCPA) and equivalent legislation[5]	Initial applications by local authorities. Appeals and call-ins by Secretary of State for Communities and Local Government.	Initial applications by local authorities. Appeals and call-ins by National Assembly.	Initial applications by local authorities. Appeals and call-ins by Scottish Ministers.	Department of the Environment
Construction of works under or over the seashore lying below the level of MHWS around the UK	Coast Protection Act 1949 (CPA) - Section 34	Secretary of State for Environment, Food & Rural Affairs	Secretary of State for Environment, Food & Rural Affairs	Scottish Ministers	Department of the Environment

[5a] With Government of Wales Act 2006 these powers will now be conferred on Welsh Assembly Government

[4] Now designated outside territorial waters under the Energy Act 2004

[5] Town and Country Planning (Scotland) Act 1997, Planning (Northern Ireland) Order 1991

For depositing articles or materials in the sea/ tidal waters below mean high water springs around England, Wales, Scotland and Northern Ireland.	Food and Environment Protection Act 1985 (FEPA) - Section 5	The Secretary of State for Environment, Food & Rural Affairs	National Assembly[5a]	Scottish Ministers	Department of the Environment
An alternative route (with FEPA 1985) to obtain certain statutory rights necessary for development of offshore projects in England and Wales, displacing the need for EA 1989 and CPA 1949 consents.	Transport and Works Act 1992 (TWA)	Secretary of State for Transport	National Assembly[5a]	N/A	N/A

Note: In addition to the above, a licence from the Crown Estate will also be required and for developments that encroach on areas under the jurisdiction of ports and harbours additional consents will also be required

[5a] With Government of Wales Act 2006 these powers will now be conferred on Welsh Assembly Government

Table 7-4 summarises the current key consenting requirements across the UK that would apply to tidal energy developments.

It should be noted that decisions on site leases and grant funding are entirely separate from decisions on individual consents applications submitted to the regulatory bodies. Separate approvals as regards the laying of electricity export cables may also be required from Port Authorities and the Environment Agency.

The situation across Great Britain is further discussed below.

7.4.2.1 England and Wales

Existing planning and permitting arrangements for demonstration phase projects in England and Wales (as noted in Table 7-2 above) are described in the DTI's recently published guidance on consenting arrangements (DTI, 2005_a). The guidance does not cover the procedures for larger commercial scale wave and tidal stream projects which will only go ahead on the basis of a full Strategic Environmental Assessment (SEA) and a Crown Estate site lease competitive round. This is not expected to happen for several years (DTI, 2005_a).

A consent under the Electricity Act 1989 must be obtained if the generating station has a capacity above 1 MW and, in all cases, a licence under the Food and Environmental Protection Act (FEPA) 1985 and the Coastal Protection Act 1949 are required. Where an Electricity Act or Transport and Works Act consent is required, a generating station does not require a separate license under the Coast Protection Act (CPA) (DTI, 2005_a). Consent under the Town and Country Planning Act 1990 (or section 57 of the Town and Country Planning (Scotland) Regulations 1997) either from DTI (via "deemed planning permission" under the Electricity Act 1989) or the relevant local authority will also be required for the associated onshore works (Bond Pearce, 2005).

7.4.2.2 Scotland

The Scottish Executive were due to consult on similar consenting arrangements to those for England and Wales for offshore renewables in late 2006, but this is yet to take place (Bond Pearce, 2005). However current understanding with regards to consenting requirements in Scotland is summarised below.

Coast Protection Act 1949 — Section 34 (Provisions for Safety of Navigation)

The Scottish Ministers have devolved responsibility for issuing consents required for the safety of navigation within UK territorial waters adjacent to Scotland. Consents are issued on behalf of the Scottish Ministers by the Ports and Harbours Branch of the Scottish Executive Enterprise, Transport and Lifelong Learning Department. Works within the Scottish sector of UK controlled waters (designated under section 1(7) of the Continental Shelf Act 1964) beyond the territorial sea are reserved. The Department for Transport handles all CPA cases that do not fall within devolved responsibilities.

Food and Environment Protection Act 1985 — Part II (FEPA) (Deposits in the Sea)

FEPA applies throughout UK controlled waters from the tidal limit of Mean High Water Spring tides out to the limit of areas designated under section 1(7) of the Continental Shelf Act 1964. The Scottish Ministers have devolved responsibility as licensing authority for issuing licences for deposits in the sea throughout the Scottish portion of this area. In practice applications are assessed and licences are issued on behalf of the Scottish Ministers by the Fisheries Research Services, an Executive Agency of the Scottish Executive Environment and Rural Affairs Department. Policy responsibility however rests with the Water Environment Division.

Electricity Act 1989 — Section 36 (Consents for offshore electricity generation)

Under section 36 of the Electricity Act 1989 (EA), a consent is required from the Scottish Ministers for the construction, extension or operation of a generating station of over 50 MW (megawatts) in capacity, unless otherwise exempted. This covers offshore generating stations above 50 MW within UK territorial waters adjacent to Scotland, except for those offshore installations used solely for supplying power for use offshore. To bring smaller wind and water driven developments within the ambit of the EA, and thus subject to the Electricity Works (Environmental Impact Assessment) (Scotland) Regulations 2000 (SI 2000/320) the Scottish Ministers powers under the Act were extended in 2002 by means of The Electricity Act 1989 (Requirement of Consent for Offshore Generating Stations (Scotland) Order 2002 (SI 2002/407) to cover all offshore wind and water driven developments above 1 MW capacity. The Consents Unit of the Scottish Executive Enterprise, Transport and Lifelong Learning Department is responsible for considering applications and issuing consents. They also act as a focal point for the receipt of other offshore renewable energy related applications under the Coast Protection Act 1949 and the Food and Environment Protection Act 1985.

The Scottish Executive are currently proposing to exempt developers from making a consent application under section 36 of the Electricity Act 1989 when testing devices greater than 1 MW at the European Marine Energy Centre (EMEC) based off the coast of Stromness, Orkney. The aim is to create a procedure which allows marine devices to be tested at EMEC without undergoing a potentially lengthy consents procedure. However, to ensure that potential environmental impacts are still fully considered before installation, EMEC have created Environmental Impact Assessment guidelines which developers must adhere to before a licence to operate is granted (Scottish Executive, 2006_c).

7.4.2.3 Consenting requirements in Northern Ireland

Responsibility for the consent process for marine energy devices off the coast of Northern Ireland lies with the Department of Enterprise, Trade and Investment (DETI) under Article 39 of The Electricity Consents (Planning) (Northern Ireland) Order 2006. In common with the rest of the UK, additional consent is required under the provisions of Section 5 of the Food and Environmental Protection Act (FEPA) 1985 for any activities that result in the deposition of any material in the marine environment below the mean high water springs (MHWS) (EHS, 2006). FEPA licences are granted by the

Department of the Environment (DoE) through the Environment and Heritage Service (EHS). Leases for the use of the sea bed, off the coast of Northern Ireland, out to the 12 nautical limit are still subject to a formal legal agreement with the Crown Estate.

Additional consent may also be required under the provisions of the Coast Protection Act 1949, for construction on or under the seashore below the level of mean high water spring tides.

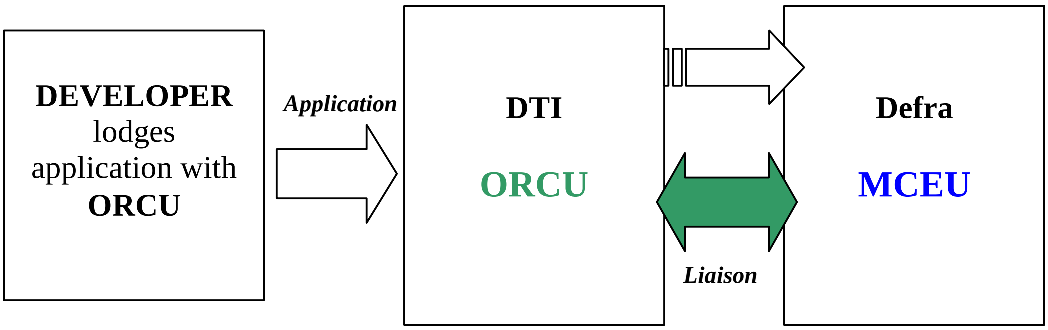
7.4.3 Handling of consent applications

7.4.3.1 England and Wales

Typically all marine consent applications in England are processed and licences issued by the Marine and Fisheries Agency (MFA) on behalf of the licensing authority (see Figure 7-3). The MFA is responsible, on behalf of the Secretary of State for Environment, Food & Rural Affairs, for the administration of a range of applications for statutory licences and consents to undertake works in tidal waters and at sea in UK waters and beyond; including marine developments, offshore energy, coast defences, dredging and waste disposal. Although responsibility for statutory controls in respect of activities within Welsh territorial waters is devolved to the National Assembly for Wales, the administration of such applications on behalf of the Assembly is also undertaken by the MFA.

The MFA works in close partnership with the Offshore Renewables Consents Unit of the DTI with regard to the consenting of offshore renewable energy generation schemes.

Figure 7-3: Application process for tidal energy projects (adapted from DTI 2004)



7.4.3.2 Scotland and Northern Ireland

Licences for developments in Scottish waters are the responsibility of the Scottish Executive (administered on behalf of the Environment and Rural Affairs Department by the Marine Laboratory, Aberdeen), those around the coast of Northern Ireland being the responsibility of the Northern Ireland Assembly (DoE Environment and Heritage Service).

7.4.4 Environmental Requirements

There are several EU Directives which are of notable importance in the granting of consents for tidal projects, which have been put into practice through UK legislation (see Table 7-3). These are discussed in greater detail in Sections 9.4.5.1 and 9.4.5.2 below.

Table 7-5: Environmental Regulations relevant to tidal energy projects in the UK

EU Legislation	Relevant UK Legislation
EIA Directive (85/337/EEC as amended)	Electricity Works (Environmental Impact Assessment) (England and Wales) Regulations 2000 Electricity Works (Environmental Impact Assessment) (Scotland) Regulations 2000. There is no equivalent provision in Northern Ireland requiring EIA for generating stations which require Article 39 consent.
Water Framework Directive (2000/60/EC)	The Water Environment (Water Framework Directive) (England and Wales) Regulations 2003 Water Environment and Water Services (Scotland) Act 2003 Water Framework Directive (Implementation) Regulations (Northern Ireland) 2003
Birds Directive (79/409/EEC),	Wildlife & Countryside Act 1981 (as amended) applies to England Wales and Scotland. The Conservation (Natural Habitats, &c.) Regulations 1994 (as amended) apply to England, Wales and Scotland Conservation (Natural Habitats, &c.) Amendment (Scotland) Regulations 2004 Nature Conservation (Scotland) Act 2004 The Wildlife (Northern Ireland) Order 1985 The Nature Conservation and Amenity Lands (Northern Ireland) Order 1985 The Conservation (Natural Habitats, &C.) (Northern Ireland) Regulations 1995 (as amended)
Habitats Directive (92/43/EEC)	The Conservation (Natural Habitats &c.) Regulations 1994 (as amended) (known as the Habitats Regulations). Apply to England, Wales and Scotland and their territorial seas up to 12 nautical miles (nm) from baseline. The Conservation (Natural Habitat, etc.) Regulations (Northern Ireland) 1995 (as amended). Apply to Northern Ireland and its territorial seas up to 12 nautical miles (nm) from baseline.

In addition to the key environmental legislation that is noted above there are also several pieces of domestic legislation that would apply to tidal energy that relate to issues such as archaeology, effects on water resources and flood defences and effects on protected species . Examples of legislation that may apply to such issues are given in Table 7-6 below.

Table 7-6: Examples of Domestic Legislation

Legislation	Country	Description
Water Resources Act 1991	England and Wales	Covers requirements for consent to discharge to water or carry out works to drainage schemes
Water Northern Ireland Order 1999	Northern Ireland	Covers requirements for consent to discharge to water
The Water Environment (Controlled Activities) Scotland Regulations 2005	Scotland	Covers requirements for consent to discharge to water or carry out engineering works in inland waters
The Merchant Shipping Act 1995	UK	All wreck material which comes UK territorial waters must by law be declared to the Receiver of Wreck
Protection of Wrecks Act 1973	UK	A licence is required to carry out any activities in a protected wreck area
Protection of Military Remains Act 1986	UK	Provides protection to military wrecks
The Ancient Monuments and Archaeological Areas Act 1979	UK	Provides for the scheduling of 'monuments' and scheduled monument consent is required to demolish, destroy, alter or repair a scheduled ancient monument (SAM)
The National Heritage Act 2002	England	Enables English Heritage to assume responsibilities for maritime archaeology (out to 12 nautical miles) in English coastal waters, modifying the agency's functions to include securing the preservation of ancient monuments in, on, or under the seabed, and promoting the public's enjoyment of, and advancing their knowledge of ancient monuments, in, on, or under seabed

7.4.4.1 Environmental Impact Assessment (EIA) Directive (97/11/EC)

Marine renewable energy demonstration projects are subject to the requirements of EIA regulations and habitat regulations where applicable (see Table 7-2 for a summary of relevant UK regulations). The EIA Directive requires that an environmental impact assessment (EIA) is carried out in support of an application for development consent for certain types of major projects listed in Annex 1 of the Directive and for other projects listed in Annex 2 where they are likely to give rise to significant effects. Energy Industry projects come under Annex 2, which under Article 4(2) of the Directive, are subject to assessment on a case-by-case examination determined by the Member State.

The EIA Directive has been transposed into UK law, for electricity works producing over 1 MW of electricity, by the Electricity Works (Environmental Impact Assessment) (England and Wales) Regulations 2000 and the Electricity Works (Environmental Impact Assessment) (Scotland) Regulations 2000.

These regulations do not apply in Northern Ireland; however, the impact on the environment is normally assessed when consent is being sought to carry out an activity under the Electricity Consents (Planning) (Northern Ireland) Order 2006 and the Food & Environment Protection Act 1985 (FEPA) Part II.

The Department for Environment Food and Rural Affairs (Defra) has recently published a consultation document entitled 'The Marine Works (Environmental Impact Assessment) Regulations 2007' (Defra, 2006). The Marine Works (Environmental Impact Assessment) Regulations 2007 will transpose the Environmental Impact Assessment Directive for the purpose of the removal or disposal of substances or articles, and the construction, alteration or improvement of certain works within the UK marine area. It is proposed that this will be achieved by making Regulations covering activities under Part II of the Food and Environment Protection Act 1985 and, for Great Britain only, activities under Part II of the Coast Protection Act 1949.

7.4.4.2 Birds and Habitats Directives

Under the EU Habitats Directive (European Commission Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora) Member States are required to nominate sites to be designated as Special Areas of Conservation (SACs). Similarly under the Birds Directive (Council Directive 79/409/EEC) Member States are required to nominate sites as Special Protection Areas (SPAs) for the conservation of wild birds. SPAs and SACs are collectively called Natura Sites.

These sites are subject to the protection measures provided by the Directive to ensure that they will not be adversely affected by activities taking place. One key measure that relates to development in or close to SAC or SPA protected sites is the requirement for appropriate assessment. A competent authority, before deciding to undertake or give any consent, permission or other authorisation for, a plan or project which -

a) is likely to have a significant effect on a European site in Great Britain (either alone or in combination with other plans or projects), and

b) is not directly connected with or necessary to the management of the site,

is required to make an appropriate assessment of the implications for the site in view of that site's conservation objectives (SNH, 2007). The need for "appropriate assessment" extends to plans or projects outwith the boundary of the site in order to determine their implications for the interest(s) protected within the site. Therefore, if a tidal energy project sited outside of a Natura Site were to potentially have an adverse effect on the conservation objectives of a Natura Site an appropriate assessment would be required.

In the Waddenzee judgment (European Court of Justice, 2004), the European Court of Justice ruled that a plan or project may be authorised only if a competent authority has made certain that the plan or project will not adversely affect the integrity of the site. An appropriate assessment must be informed by the best scientific information and the competent authority must be certain that "no reasonable scientific doubt" remains that the conservation objectives of the site will be compromised (EJC, 2004). Competent national authorities must be "convinced" that there will not be an adverse affect and where doubt remains as to the absence of adverse affects, the plan or project must not be authorised, subject to the procedure outlined in Article 6(4) of the EC Habitats Directive regarding imperative reasons of overriding public interest.

The Habitats Directive introduces for the first time for protected areas, the precautionary principle; that is that projects can only be permitted having ascertained no adverse effect on the integrity of the site. Projects may still be permitted if there are no alternatives, and there are imperative reasons of overriding public interest. In such cases compensation measures will be necessary to ensure the overall integrity of the network of sites (EJC, 2004).

It should be noted that such protected sites are located throughout the UK coastline and if development were to be proposed in, or close to such areas detailed and rigorous environmental survey and assessment would be required to determine the significance of effects upon the qualifying features or species. It should also be noted that certain species and features are likely to be more sensitive to the effects of installation and operation of tidal energy devices or barrage developments. If significant adverse effects are predicted, that could not be mitigated or compensated for then a development would be prevented from proceeding.

7.4.4.3 Water Framework Directive

The Water Framework Directive requires all coastal and transitional waters to be typed within an exhaustive water typology scheme, to be split into water bodies, each to be characterised by the pressures on them and to be classified for their ecological status as it is defined in the directive and in subsequent guidance. All identified water bodies within each defined type are required to reach and remain in "Good Ecological Status". Part of the definition of "Good Ecological Status" depends on the "hydromorphological status" of the water body. Energy extraction thus relates to this key legislative objective. Some aspects of classification will be affected by energy extraction, others will not. This is an emerging issue and discussions would need take to take place the relevant authorities (e.g. The Environment Agency in England and Wales, and the Scottish Environmental Protection Agency (SEPA) in Scotland) on a development by development basis.

7.4.5 Decommisioning

Decommissioning of any marine installation (including tidal energy installations) can have adverse effects on the marine environment.

A legal requirement for decommissioning was introduced under the Energy Act 2004. This Act was introduced to respond to the UK's international obligations for decommissioning as set out under the United Nations Convention on the Law of Sea (UNCLOS). This requires disused installations or structures to be removed to ensure safety of navigation, taking into account generally accepted International Maritime Organisation (IMO) standards that were adopted in 1989 (DTI, 2006_c)

Work was also undertaken under the OSPAR Convention, which guides international cooperation on the protection of the marine environment of the North-East Atlantic. OSPAR Decision 98/3 sets out binding requirements for the disposal of disused offshore oil and gas installations. Whilst there is no equivalent Decision for offshore renewable energy installations, OSPAR has produced guidance documents on offshore wind farms, incorporating ideas on their decommissioning.

Prior the introduction of the Energy Act 2004, developer decommissioning liabilities were met through compliance with The Crown Estates consenting process whereby provisions for decommissioning had to be set out in seabed lease applications. Developers were also expected to comply with decommissioning provisions set out under consents given under Section 36 of the Electricity Act. However, provisions to ensure that decommissioning was undertaken to the required standards were limited.

The Energy Act, places a legal obligation on developers to carry out decommissioning to the required standards and set out their financial provisions to ensure that decommissioning can be carried out appropriately. The Secretary of State can approve, modify or reject a programme, including any financial security provisions which the responsible person proposes to provide.

The Secretary of State is required to review the programme from time to time (DTI, 2006_c). The requirements of the new decommissioning scheme in Sections 105 to 114 of the Energy Act 2004, have to date, not been applied to any new installations. The Department for Trade and Industry (DTI) has recently produced guidance on the application of the Energy Act decommissioning scheme. This guidance document 'Decommissioning Offshore Renewable Energy Installations' sets out the scope of the decommissioning scheme, decommissioning standards, information on financial security, the process for submitting a decommissioning programme and what they should contain, residual liability and industry corporation and collaboration.

With regard to tidal energy devices, the decommissioning scheme applies to all energy installations in territorial waters (whatever their generating capacity) that are not yet consented or operational (Faber Maunsell and Metoc, 2007).

7.5 POLICY POSITION STATEMENTS

In recognition of the growing interest towards marine renewable energy, policy position statements (PPS) have been published by statutory and non statutory bodies. A PPS is a specific policy option recommended by a particular organisation.

In Scotland, Scottish Natural Heritage (SNH) have published a policy statement on marine renewable energy (SNH, 2004), strongly encouraging the exploration of marine renewable energy developments, subject to sensitive design and siting of such developments. However, it should be noted that their PPS also states that "SNH is likely to oppose tidal barrage development unless a tidal barrage forms a component of a structure required for other purposes".

English Nature also published a more general renewable energy position statement that includes their stance towards wave and tidal projects (English Nature, 2003). In summary their PPS recognises the importance on renewable energy development, but stresses the point that such developments should be sensitively designed and environmental effects and the appropriateness of the development will have to be considered for individual projects. More recently English Nature has become part of Natural England and a new policy statement has not yet been developed. However, Natural England did make a submission to the Energy Review and this submission outlines their current policy submission (Natural England, 2006) which is broadly in line with the PPS noted above provided by English Nature and advocates a process of strategic planning (e.g. use of SEA) for marine renewable energy development.

In February 2005, the Countryside Council for Wales (CCW) commissioned ABP Marine Environmental Research Ltd (ABPmer) to undertake a study on the development of marine renewable technologies and the possible impacts that these may have upon the environment to enable CCW to develop its policy positions in relation to these developments (ABPmer, 2005). CCW's current policy position is reflected in their submission in response to the Energy Review and the Welsh Assembly Government's Energy Route Map. Their policy advocates a process of strategic planning to give an indication of the most appropriate technologies and potentially suitable locations, and is generally supportive of tidal energy development as long as precautionary approach to development is taken (CCW, 2006). However, it should also be noted that CCW are generally opposed to barrage developments because of their "serious and irreversible effects on the ecology and landscape of such areas" (CCW, 1992).

The Environment Agency also have a policy position on tidal energy that is generally supportive of tidal energy developments, providing the appropriate strategic planning and environmental assessment is undertaken. However it should be noted that Environment Agency is not supportive of a Severn Tidal Power Barrage due to its impacts on wildlife and habitats (Environment Agency, 2007).

A marine renewable energy policy position document was produced by WWF in 2005 (WWF, 2005) advocating renewable energy technologies. It also highlighted the need for careful planning of our seas to ensure the right technology is developed appropriately, in the right place, with full consideration of the benefits as well as the potential adverse impacts on the marine environment. WWF strongly supports the use of marine spatial planning as a tool to achieve this.

7.6 FUTURE POLICY AND PLANNING DEVELOPMENTS

7.6.1 Energy White Paper

As referred to in the above sections, a UK Government policy on renewables was set out in the 2003 Energy White Paper 'Our energy future – creating a low carbon economy' (DTI, 2003). The Energy White Paper looked forward to 2050 and considered how to reduce the UK's carbon dioxide emissions, maintain the reliability of energy supplies, promote competitive markets and ensure every home is adequately and affordably heated.

In 2006 an Energy Review was announced to assess the developments and progress since the 2003 White Paper. The Government's report on the Energy Review - "The Energy Challenge" was released on 11 July 2006 and an extensive consultation programme ensued on the proposals included in the review. The consultation on the Energy Review has now closed and the proposals are being progressed. The key proposals of relevance to tidal energy are those on the reform of the Renewables Obligation (see Section 7.2.2 for further details) and the establishment of a new fund to support renewable energy and other non-nuclear low carbon technologies.

7.6.2 The Planning White Paper

In spring 2007 the government plan to publish a White Paper setting out proposals for reform of major infrastructure planning, mainly as a result of the Barker and Eddington reviews which were carried out in 2006 and related to housing and transport respectively. Electricity generating plant and their connections into the national grid can be considered major infrastructure and therefore this White Paper may affect the planning of such developments.

7.6.3 Marine Bill

Calls for a Marine Bill stemmed from a number of studies from a variety of government and non government organisations into the status and management of the marine environment over a number of years. In 2006 consultation on the potential remit and content of a "Marine Bill" began, led by DEFRA.

The consultation focused on:

- Planning in the marine area
- Licensing marine activities
- Improving nature conservation
- The potential for a marine management organisation

Additionally, potential changes to the management of marine fisheries were outlined, but these aspects were consulted on separately to the main marine bill consultation.

Although a Marine Bill did not feature in the recent Queen's speech, DEFRA are working to provide a White Paper on a Marine Bill in early 2007. This will set out more detailed policy proposals in relation to the main areas outlined in the previous consultation. The Scottish Executive is working with DEFRA in the development of these proposals. The White Paper will offer a further opportunity for stakeholders to shape the proposals in the consultation period that follows.

It is anticipated that Marine Planning will be tiered to include a national level policy statement at the highest level, agreed jointly by all UK administrations. Underneath this, plans for UK waters would be produced for specific areas. These plans would be consistent with the high level policy statement.

The underlying principle of a Marine Bill is to achieve improved management of the marine environment - taking into account the need for sustainable development, the value of marine ecosystems and the need to maintain them, and the need for better regulation of activities in the marine environment that is efficient, effective, transparent, consistent, and proportional.

Each of the four bullet points noted above have potential to impact upon the development and consenting of tidal energy developments. A summary of some of the key proposals mooted for each of these topics are summarised below.

7.6.3.1 Planning in the marine area

In contrast to the terrestrial situation there is no coherent planning system in the marine environment. Instead the management of marine areas has developed over time, based on a range of unconnected legislative measures which are managed by a range of government departments and statutory agencies. The proposals in the Marine Bill consultation in 2006 considered the current framework for managing the marine area, recent studies identifying a need for reform of the way the marine environment is managed, issues of geographical jurisdiction, strategic marine policy planning, and spatial planning.

A key proposal in the consultation on the content of a Marine Bill is the introduction of marine spatial planning to provide a framework for the marine licensing system. Various pilot projects have been undertaken on marine spatial planning, with one for the Irish Sea area specifically commissioned by DEFRA to help inform the consultation on spatial planning in the marine bill.

No firm indication of how marine spatial planning will look or how it would work were given during the consultation but several options were outlined including whether a marine planning system should be statutory or whether other methods should be considered, what the geographical jurisdiction of the plan should be, which marine activities should be covered by the plan, what sort of data marine spatial planning should draw upon, how it could interact with other plans and who would be responsible for plan making and implementation.

Depending on the range and detail of data that is put in, marine spatial planning could reasonably be expected to provide an indication of the areas best suited (e.g. areas of least constraint) to tidal energy development. However it should be noted that under current plans it is intended that a system of marine spatial planning would run along side consenting arrangements and the Crown Estate's role of "seabed owner" in most waters within the 12 nautical mile limit of territorial waters in the UK.

7.6.3.2 Licensing of marine activities

One of the key objectives of a Marine Bill is to streamline the marine consents process which has developed in a piecemeal fashion over several decades. The consultation set out a range of options for streamlining the marine consents process (see Section 7.4 for details of the current consent regime for tidal energy developments) for marine development and activities. Options proposed were as follows:

- Do nothing
- Merging of environmental and navigational consents regimes (i.e. the Food and Environment Protection Act 1985 and the Coast Protection Act 1949)
- A simplified sectoral regime – this would involve a single licensing system for each marine industry, run by appropriate government sponsors

- An integrated regime incorporating FEPA, CPA and other sectoral licensing systems, run by a single regulatory body.

The principal of providing better regulation would suggest that a Marine Bill will improve any inefficiency in the current consenting regime for tidal energy.

7.6.3.3 Improving nature conservation

The consultation also considered measures that could improve nature conservation including marine ecosystem objectives, marine protected areas, controls on currently unlicensed activities, species conservation and enforcement.

7.6.3.4 The potential for a marine management organisation

The potential for the requirement of a marine management organisation to manage certain products of the marine bill (e.g. marine spatial planning and/or consenting) was also outlined and options for the responsibilities and nature of such an organisation were also given but at present it is unclear what the role and remit of any marine management organisation will be.

7.6.3.5 Issues of Devolved Administrations

Many aspects of management of the marine environment are the responsibility of the devolved administrations and talks are currently underway to try and work out how buy-in to a Marine Bill by the devolved administrations can be achieved.

7.6.3.6 Timescales for a Marine Bill

A White Paper on the Marine Bill is due to be published on 15th March 2007. The consultation on the Marine Bill White Paper is programmed to take place between 15th March and 8th June 2007 and it is expected that the proposals will reach parliament in Spring 2008.

7.6.4 European Marine Strategy Directive

The European Commission has proposed and is currently developing a Marine Strategy Directive on the Protection and Conservation of Marine Environment. It is proposed that the strategy is developed to be consistent with the Water Framework Directive that requires that surface freshwater and ground water bodies (lakes, streams, rivers, estuaries, coastal waters) achieve a good ecological status by 2015.

The information below is taken from the Marine Strategy website and gives a good overview of how it likely to progress.

"The Marine Strategy will constitute the environmental pillar of the future maritime policy the European Commission is working on, designed to achieve the full economic potential of oceans and seas in harmony with the marine environment.

A Marine Strategy Directive will establish European Marine Regions on the basis of geographical and environmental criteria. Each Member State, in close cooperation with the relevant other Member States and third countries within a

Marine Region, will be required to develop Marine Strategies for its marine waters.

The Marine Strategies will contain a detailed assessment of the state of the environment, a definition of "good environmental status" at regional level and the establishment of clear environmental targets and monitoring programmes.

Each Member State will draw up a programme of cost-effective measures. Impact assessments, including detailed cost-benefit analysis of the measures proposed, will be required prior to the introduction of any new measure.

Where it would be impossible for a Member State to achieve the level of ambition of the environmental targets set, special areas and situations will be identified in order to devise specific measures tailored to their particular contexts."

(European Commission, 2006)

In terms of the Marine Directive and associated Maritime Policy it is very difficult to predict how it will effect the planning and development of tidal energy developments in the UK at this time. However DEFRA who are working on the Marine Bill are aware of the development in Europe and it likely that as far as possible at the time a Marine Bill will try and anticipate such requirements.

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