SCOTTISH EXECUTIVE

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Note: This document is only a section of the Final Environmental Report

Scottish Marine Renewables SEA
Environmental Report Section C SEA Assessment: Chapter C3: Marine and Coastal Processes

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Glossary & Abbreviations

Anthropogenic	Caused or produced by humans
Attenuation	Reduction in energy per unit area with distance from the source as a result of absorption, dispersion, scattering, etc
Betz' Law	Albert Betz' theory regarding the maximum amount of energy that may possibly be extracted (by means of a rotor) from a fluid flowing at a certain speed.
Diffraction	A change in direction and/or intensities of waves as they pass an obstacle or through an aperture of similar size to the wavelength of the wave
Eddies	A current with a circular movement sense
EMEC	European Marine Energy Centre
Eustatic Change	Sea-level change on a global scale
Fetch	The area of the surface of a water body over which a wind has blown in order to generate a wave
Holocene	The geological term for the present epoch (from approximately 10,000 years ago to the present day)
Hydrodynamics	The dynamics of fluids in motion
Hydrostatic Equilibrium	When compressional force (due to gravity) on a fluid body is balanced by an opposite force produced by a pressure gradient in the body.
Isostatic change	Change in sea-level due to change in the relative position of the land e.g. because of tectonic activity or post-glacial uplift.
Km	Kilometres
kW.m	Kilowatts per metre
Lee	The area downwind from a point of reference
mm	Millimetre
Refraction	The change in direction of a wave as it moves towards regions of slower velocity in shallow water depths relative to its wavelength.
Semidiurnal	Every twelve hours
SEPA	Scottish Environmental Protection Agency
Shoaling	The conditions in which refraction of a wave is likely to occur i.e. in shallow waters where wavelengths are long relative to water depth and wave velocity becomes strongly depth dependant.
WaveHub	A renewable energy project in the South West of England that aims to create the UK's first offshore facility for the demonstration and proving of the operation of arrays of wave energy generation devices.

C3 Marine and Coastal Processes

C3.1 Introduction

This chapter considers the impacts of energy removal from the sea by wave and tidal energy developments acting on relevant marine and coastal processes. This includes the natural hydrodynamic processes directly influenced by energy extraction - currents, tides and waves. These processes can be changed by the introduction of extraction devices that modify the natural motion of the sea, by the extraction of energy from the sea's motion, or by both.

The physical mechanisms by which wave hydrodynamics can be affected include:

- diffraction around the device array, changed refraction in modified topography;
- reflection from structures;
- attenuation and spectral modification by the selective extraction of energy at some wavelengths and not at others.

The physical mechanisms by which currents and flows can be affected include:

- physical obstruction leading to flow intensification and tidal range reduction;
- non-linear combinative interaction between individual extraction devices;
- changes to the local hydrodynamics, including the field of turbulence;
- regional hydrodynamic changes.

Hydrodynamic processes, mechanisms and devices operate on many spatial and temporal scales. This chapter highlights some of the key scales on which effects may be expected. Some of these scales are determined by fundamentals such as the physics of waves and tides or the feasibilities of contemporary engineering. Others are determined by the peculiar coastal topography of shorelines, straits, islands, inlets, sea-lochs and estuaries which comprise the Scottish coast.

The consequent and direct changes to the coastal hydrodynamics may, in their turn, change sediment deposition, sediment suspension and re-suspension, sediment transport, erosion rates from hard or consolidated sediments or from rock. The potential consequences are, therefore, changes to the coastal patterns of sediment distribution, movement and erosion.

This chapter informs the assessment of effects on various receptors considered in other chapters (particularly Section C, Chapter C2 – Geology and sediment transport and Chapter C6 – Benthic Ecology). As such, it is not structured in the same format as the majority of other chapters in the Level 1 assessment. Instead, the following structure has been adopted:

- Overview of the baseline environment in terms of wave and tidal regimes and types of coastline that are found in the SEA study area.
- A review of existing knowledge and understanding with regards to removal of energy from the environment by wave and tidal devices.
- An assessment of the potential effects of removal of energy upon marine and coastal processes
- Recommendations for further work

Figures C3.1 to C3.4 accompany this chapter.

C3.2 Baseline Environment

C3.2.1 Wave Regimes

C3.2.1.1 General Features

Wind waves arrive in this region from a broad band of directions centred to the west of the study area. These waves are usually fully developed, having travelled over long fetches under some of the windiest waters in the northern hemisphere. The wave regime in the study area has a rather even distribution along the north – south lie of the coast because of almost uniform exposure to the west, south-west and north-west. There is a strong west – east variation in power potential associated with the attenuation of these long-wavelength wind waves as they meet frictional resistance in shallow water closer to the coast.

Much of the study area is characterized by an annual mean wave significant height of around 3 m, associated with an annual mean wave power of about 30 kW.m^{-1}. This value doubles in the oceanic waters to the west of the Western Isles, and halves towards the land in the east. By comparison, the wave resource is weak (annual mean significant height around 1 to 2 metres) in sheltered zones such as the North Channel, the Inner Isles, the North coast and the waters between Orkney and mainland Scotland.

Few areas with potential for wave energy development coincide with identified areas of tidal potential: the exceptions are the area to the south-west of Islay and at the extremities of the Western Isles. Elsewhere, areas of low wave power resource may be attractive for the engineering of tidal developments because of their sheltered nature.

C3.2.1.2 North Channel Assessment Area

The North Channel assessment area covers sea areas to the south of the Mull of Galloway, and the southern part of the North Channel proper. It is sheltered from oceanic waves and offers only weak wave power potential. The low wave action relative to other parts of the Scottish coast may be an attraction from the tidal extraction engineering point of view.

C3.2.1.3 Argyll and Bute Assessment Area

This area includes the Clyde Sea and the northern parts of the North Channel proper on the west side of Kintyre. The Clyde Sea offers only weak tidal currents and a sheltered wave field: it therefore has little energy potential.

In the southern part of the Argyll and Bute assessment area, there is limited potential for both wave and tidal power to be extracted from the area to the south-west of Islay. Here, annual average significant wave height is around 2 m. Annual average wave power reaches around 20 kW.m^{-1} and coincides with tidal power densities of 2 to 3 kW.m^{-2}.

C3.2.1.4 Western Isles and Outer Isles

On the western side of the Western Isles is a large zone of high wave energy, with annual significant wave heights of about 3 m, reaching annual averages of 30 kW.m^{-1} or more. On the sheltered eastern side of the islands there is relatively little wave energy.

C3.2.1.5 Inner Isles

The Inner isles are sheltered from westerly waves and winds by the Western Isles and receive no significant wave energy, although a weak peak of activity reaches in from the south-west near the island of Canna.

C3.2.1.6 North Coast

Offshore of the North Coast, with average annual significant wave height around 2 m, wave energy reaches about 20 kW.m^{-1}. Levels are lowest close to the north-facing shore and on the western side of south Orkney.

C3.2.1.7 Pentland Firth

In the sheltered Pentland Firth, wave exposure is low and wave energy is therefore at a local minimum. However, when extracting tidal power, it may be an engineering advantage that the wave exposure is low.

C3.2.1.8 Northern Isles

To the west of Shetland and north of Orkney, with average annual significant wave height around 2 m, wave energy reaches about 20 kW.m^{-1}.

C3.2.2 Tidal Regimes and Currents

C3.2.2.1 General Features

The Scottish continental shelf is dominated by strong semidiurnal tides of ranges generally reaching 5 m (but up to 7 m in the Solway Firth; down to 2 m off Kintyre). Flows tend to run parallel to the shore but further offshore they may assume some rotatory nature, where there may also be long-lived eddies associated with residual and wind-driven circulations. On the continental shelf, peak spring currents are typically about 1 m.s^{-1}. West of Islay, to the north of the Scottish mainland, and in the Minch are relatively small regions where peak spring currents attain about 2 m.s^{-1} or more.

The tidal wave propagates clockwise around Scotland, producing semidiurnal differences in water level between different places that drive strong flows and that may be exploited for power generation. These flow effects are most marked in channels such as the Pentland Firth, the Minch between Skye and Harris, the North Channel, various straits between islands, and the entrances to some sea-lochs. In these places currents may reach maximum spring speeds of up to about 4 m.s^{-1}. There is also relatively minor flow intensification around various headlands such as the latitudinal extremities of the Western Isles, Cape Wrath and others.

Tidal power has significant and prominent regional maxima in the fastest flowing regions, of 5 kW.m^{-2} or more to the south-west of Islay in the northern part of the North Channel proper, between Skye and Harris, around Cape Wrath, in the Pentland Firth and in north Orkney. Of these, the Pentland Firth and the North Channel offer the greatest geographic spread of potential tidal energy.

C3.2.2.2 North Channel Assessment Area

The North Channel assessment area covers the southern part of the North Channel proper and sea areas to the South of the Mull of Galloway: there is variable tidal power potential, some of which is attractive to developers because of strong and reversing currents – particularly south of Galloway. Low wave action relative to other parts of the Scottish coast may also be an attraction from the tidal extraction engineering point of view.

C3.2.2.3 Argyll and Bute Assessment Area

This area includes the Clyde Sea and the northern parts of the North Channel proper to the west of Kintyre. The Clyde Sea offers only weak tidal currents and a sheltered wave field: it therefore has little tidal energy potential. The North Channel proper to the west of Kintyre offers particularly strong reversing tidal currents augmented by less predictable residual flows in and out of the Irish Sea: it has therefore been identified as an attractive area for tidal energy extraction.

In the southern part of the Argyll and Bute assessment area, in the region to the south-west of Islay, there is some overlap of areas of potential for both wave and tidal power. Annual average wave power reaches around 20 $kW.m^{-1}$ and coincides with tidal power densities of 2 to 3 $kW.m^{-2}$.

C3.2.2.4 Western Isles

The likely tidal resource areas are at the northern and southern extremities, and at straits connecting the Minch to the Atlantic, as in the Harris-Uist area.

C3.2.2.5 Inner and Outer Isles

Tidal currents are generally weak except between Skye and Harris, where flow restriction near Scalpay creates strong tidal flows and the possibility of energy extraction from a zone whose annual average approaches 2 $kW.m^{-2}$.

C3.2.2.6 North Coast

Other than round exposed headlands such as Cape Wrath or Duncansby Head, there is little recognised potential for tidal power extraction.

C3.2.2.7 Pentland Firth

The Pentland Firth is a fairly sheltered area with strong tidal currents. The clockwise propagation of the semidiurnal tide around the Scottish continental shelf creates substantial height differences either side of Orkney that drive strong flows through the Firth and some Orkney straits. Tidal energy densities of about 10 $kW.m^{-2}$ or more are widespread in the Pentland Firth area, which offers some of the greatest potential for tidal energy generation in Scotland. When extracting tidal power, it may be an added engineering advantage that the wave exposure is low.

C3.2.2.8 Northern Isles

There are pockets of high tidal energy density around headlands and within some Orkney straits, all of which offer potential for power generation.

C3.3 Review of Existing Knowledge Regarding Removal of Energy from the Environment

C3.3.1 Introduction

By their very nature, sites chosen for the exploitation of their wave or tidal current resource are host to high energy densities. Removal of energy from these sites changes, in some way, the nature of the environment.

Wave and tidal resources are of quite different natures. Waves are generated by wind blowing over a fetch of free ocean surface, transferring energy into progressive disturbances of the free surface between the sea and the atmosphere. The propagation of energy as a wave travels across the surface involves continual interchange of energy between potential and kinetic forms. In principle, at least, it is possible to extract almost 100% of the energy in a sea wave by devices that may variously be seen as extracting the potential or the kinetic energy or both.

The tides of UK seas are also waves, but of such a long period and wavelength that a useful distinction may be made between their kinetic energy – that stored in the motion of the water - and their potential energy – that stored in the raised height of the water. Tidal energy may therefore be extracted by the conversion of potential energy of water held temporarily behind dams and barrages into electrical energy (a form of hydroelectric power as at La Rance in France or as contemplated in a Severn Barrage), or by the harnessing of the kinetic energy of the flow by the use of turbines. In Scottish waters the latter is the likely method of extraction (as discussed in Section A of this SEA, barrage projects are not within the scope of this SEA).

The levels of energy removed from tide or wave energy extraction are governed by the scale of interception of the incident energy flux, the position of the device in the water column relative to neighbouring devices, local topographic effects such as channelling, and the efficiency of the technology. In the case of tidal energy, the removal of all kinetic energy would bring the fluid to a halt, preventing its removal from the turbine region. It is therefore impossible, even in principle, to extract all the kinetic energy. A more sophisticated formulation of this aspect is Betz' Law. In practice, efficiency of energy capture appears to be less than 60% for tidal devices and, probably less for wave devices (ABPmer, 2006).

The geographic extent of energy removal from the sea cannot be predicted reliably: it depends strongly on the future economic balance between engineering and distribution costs in relation to the sources, the demand and the economic incentives. Nevertheless, primary themes that cover the possible effects of many or possible marine projects may be identified and are described below.

The local geographical zone of influence of energy extraction effects is likely to be both device-specific and site-specific, with different cumulative 'farm' effects possible for different array layouts. The significance of any particular effect then depends on the site-specific circumstances in terms of the sensitivity of receptors such as local erosion and deposition processes, habitats, species and other marine features.

C3.3.2 Wave Energy

C3.3.2.1 Existing Knowledge

The current level of understanding of potential energy extraction impacts is less for waves than for tides. In part this reflects the deterministic predictability of tidal phenomena compared with the more weather-dependent random nature of wave activity. Waves of many directions, frequencies, amplitudes and stages of development under the variable wind fields give a variable character to the wave field that makes it inherently difficult either to specify or to model representative wave conditions and energy extraction effects.

Numerous site-specific assessments are currently underway on the likely effects of energy loss, including studies for WaveHub in the south-west of England. As a conservative assumption, most modelling for this project assumed a structure that absorbs 100% of incident wave energy, with a footprint of 10 km^2, whereas a more realistic value for wave absorption is likely to be in the order of 30%. The model did not include refraction or diffraction effects but indicated the scale of impacts from wave devices.

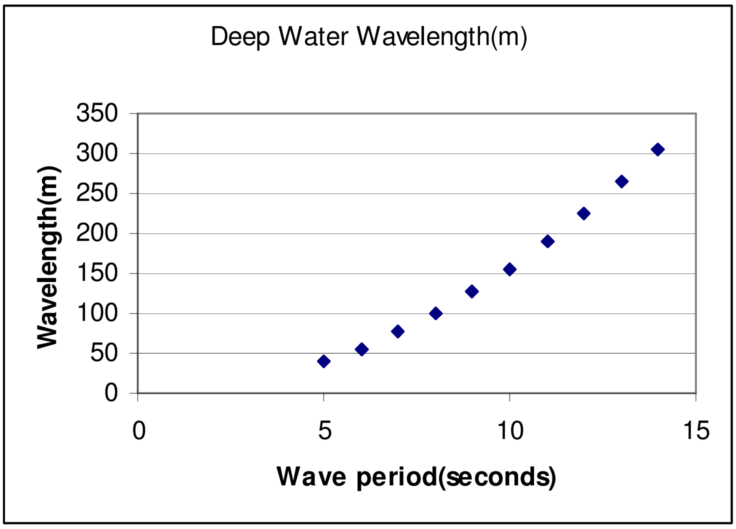
There appears to be no available field evidence to assess and quantify the energy removal effects of wave devices. As with tidal stream technology, present development remains focused on devices that are efficient in energy capture, durable, and are economical to produce, install and service.

C3.3.2.2 Information from Modelling Studies

The following factors need to be taken into account when modelling the impacts of wave energy extraction.

- Diffraction - Any complete or partial obstacle placed in a wave field produces a diffraction pattern of constructive and destructive wave interference: a shadow zone beyond the obstacle is to some extent filled with waves diffracted from the obstacle. This effect varies with the wavelength of the waves compared to the size of the obstacle – the longer the wave relative to the size of the obstacle, the more diffuse is the shadowing. Simple diffraction analysis modelling for a 10 m capture width device which extracts 25% of the energy from an incoming wave field has been undertaken for mono-frequency unidirectional waves, multi-frequency unidirectional waves, and multi-frequency multi-directional waves (Bryden, unpublished data). These parameters could be representative of a commercial wave energy device.
- Refraction and shoaling - Diffraction is not the only modifier of wave fields. Refraction is also a factor, as waves follow paths determined by their velocity, curving towards regions of slower velocity. This does not happen in deep water - where the velocity is constant for any particular wavelength - but in shallow water, where waves become long relative to the water depth, wave velocity depends strongly on water depth and decreases into the shallows. In these shoaling conditions, refraction thus turns waves towards shallower ground, focussing or defocusing the wave energy onto different parts of the coast. Refractive effects also vary crucially with the wavelength and direction of the incoming waves. In consequence, refraction is an important influence on the coastal energy field. As the wave shoals, so the amplitude of the wave increases. Refraction and shoaling become significant when the water depth is less than half the wave length. As can be seen from Figure C3.5 below, this depends on wave period. Short high frequency waves of period 5 s have a wavelength in deep water of only 40 m, so shoaling and refraction only become significant for depths of less than 20 m. Longer waves, with a period of 10 s have a length of 160 m, so shoaling and refraction are significant for depths of less than 80 m.

Figure C3.5: Deep Water Wavelength



The models MIKE 21 and MIKE3 have been used within the Supergen (marine) research consortium to predict the distortion of wave fields resulting from energy extraction. Distortion of the wave field resulting from energy extraction by an array of wave devices off the south-west coast of the Orkney Mainland was modelled. The software allows for growth of wave spectra under changing wind, for energy loss to wave breaking and even for ecological modelling and littoral processes. The model predictions are based purely upon energy extraction properties and are representative of any floating system. Indeed, even bed-mounted devices would show the same influence on the non-local wave patterns, because device type only has immediate influence on local distortions.

The results suggest than there would be only slight measurable distortion for developments up to the limits presently set for the test sites at the European Marine Energy Centre (EMEC), even with all wave berths occupied fully. Future deployment of commercial scale arrays will require case-specific analysis. At present, any large development may be considered a special case because of the inherently complex nature of the interactions between sediment, waves and energy.

C3.3.3 Tidal Energy

C3.3.3.1 Existing Knowledge

Current understanding of potential extraction impacts is better for tidal energy than it is for wave energy. Waves are rather random and lack deterministic predictability. In contrast, tides are driven by astronomic phenomena that are largely deterministic and therefore predictable. The prediction of tidal phenomena has a long history, from the initial empirical efforts of Galileo, Kepler and Descartes through the analytical physics of Newton and others, culminating in the present-day large scale computational models used for example at the Proudman Oceanographic Laboratory and elsewhere. These models may in principle be modified to incorporate conjectured changes to the physical environment such as might ensue from tidal energy extraction.

No specific modelling has been undertaken to assess the large-scale impacts of energy extraction by tidal stream devices. Although some inferences have previously been drawn from wind energy modelling, there is limited value to comparing these two technologies, for reasons described below.

The Supergen Consortium is currently undertaking a "Marine Energy Research Programme" to increase understanding of these effects. Supergen's work package entitled "Appraisal of marine energy resource and interaction between converters and fluid environment" has the objective of establishing and calibrating methodologies that allow a greater understanding of the nature and magnitude of the recoverable, sustainable and deliverable marine energy resource. This research project will develop and test models to predict the fluid and other environmental modifications resulting from tidal energy extraction, and deliver a software package capable of predicting the influence of large-scale tidal current energy extraction on flow distributions and identifying the resulting limitations to exploitation potential.

Site-specific modelling of the impacts of tidal energy extraction has been undertaken for the MCT Seagen project in Strangford Lough, Northern Ireland. This used the MIKE 21 HD module to model the effects of energy extraction on the hydrodynamic regime.

To date, the only technology exposed to prolonged field trials is the MCT Seaflow device which has been deployed in 20 m of water off Lynmouth in Devon since summer 2003. This device is a 2-bladed horizontal axis single turbine unit rated at 300 kV on peak spring tides. The unit is in a fixed orientation to the ebb flows and mounted on a 2.1 m diameter pile. Variable pitch blades with a rotor diameter of 11 m allow energy capture from both flood and ebb flow directions. During the deployment, MCT measured flow upstream and downstream of the device, to describe flows modified by both the 2.1 m vertical pile, and the single 11 m diameter rotor. The results of these field trials in terms of estimating geographical extents of the effects on tidal streams are summarised in sub-section C3.4.2.1.

C3.3.3.2 Analogy with Wind Farm Models

The wind farm industry has modelled extensively the effects of offshore wind farms on wave and tidal regimes and coastal processes. Although outputs do not apply directly to impacts of wave and tidal devices for the reasons listed below, they do provide some valuable reference information.

Wave and tidal devices and the environments in which they operate are quite different offshore wind energy devices, despite some superficial similarities. The piles of wind turbines distort locally the waves, currents and sediments but do not extract energy from the sea. Marine energy systems present similar passive obstacles but also remove energy from the environment itself and so require different analysis.

Wind farm models cannot, therefore, be used to extrapolate impacts from extraction of energy by tidal devices. Tidal stream devices are more comparable with wind turbines than wave energy, in that both tidal and wind technologies capture from a fluid which characteristically flows horizontally. Numerous key differences mean that wind models do not apply directly to assess impacts of tidal energy extraction. These include the following.

- **Fluid properties of air and water**: water is about 800 times denser than air.
- **Boundaries**: Wind energy is captured from a region quite close to the land surface, from a fluid which is essentially unbounded above. The ocean, however, is a fluid of finite depth bounded between the air-sea and sea-bed interfaces.
- **Scale of interception – blade diameters**: Tidal stream rotor diameter is limited by water depth and blades are typically designed in the range 10 – 20 m, whereas wind turbine blades for some of the new planned offshore wind farms exceed 100 m diameter.
- **Directional properties**: Wind is largely omni-directional and somewhat random, with a tendency to reveal "prevailing" conditions when averaged over long periods. Tidal streams are regulated by deterministic gravitational and astronomic forces operating on regional scales, and by local bathymetry and topography, leading to distinct and predictable flows often of a rotary nature but which in constrained channels may adopt a marked to-and-fro character along on ebbs and floods. Present tidal stream technology ideally is deployed in such locations where the flow axis is bi-directional and 180° out of phase between ebb and flood tides (i.e. rectilinear). These conditions are most marked in narrow straits, channels and estuaries but also pertain to many sites on the continental shelf where astronomic tides dominate.

- **Array design**. Array design for tidal stream devices is likely to be a single row of devices perpendicular to the axis of peak flows, whilst wind farms can be spaced over much wider areas. For example, a large offshore wind farm project may extend over distances of several tens of kilometres, whereas a tidal stream array may have a width of less than one km.

C3.4 Potential Effects

Tidal or wind energy extraction effects are likely across three spatial scales with progressively reducing intensity:

- device scale - localised to the immediate vicinity of devices – such as lee effects and local scour;
- near-field scale - on the scale of an array of devices or a licence area - device effects acting in combination;
- far-field - effects extending beyond the project area.

Alongside effects attributable to the energy extraction itself, is the added interference of the devices and moorings with waves and tidal streams.

C3.4.1 Wave Energy Devices

Whilst recognising that the potential effect of wave energy extraction on the wave climate is currently not well understood, the main areas of potential effects may be identified as the following:

- Wave climate;
- Sediment processes;
- Coastal processes.

C3.4.1.1 Wave Climate

The area affected by wave energy extraction devices - their geographical footprint - is more uncertain than for tidal stream devices. It is most likely that effects will increase in relation to the amount of extracted energy, itself related to device efficiency and the capture width of extraction. Where both are large, a more developed energy shadow is likely.

For WaveHub, modelling based on conservative assumptions suggests that an array of devices absorbing 100% of wave energy across a 10 km^2 offshore area would lead to around 5-10% reduction in wave height at the lee coast 20 km away. This estimate does not allow for any recovery of wave heights in this lee distance to shore through further wind-wave generation, and is therefore considered to be a conservative estimate in the case of this particular project. However, whilst this project can provide an indication of the scale of impacts from wave energy devices, this data should be viewed with caution, as it is not possible to extrapolate these results to other projects due to the wide range of variability both in device and environmental characteristics.

A very basic analysis of these circumstances suggests that the Wavehub results may however be more generally applicable. We consider two extremes: a unidirectional wave field; and one of variable direction.

For example, an extractive array 3 km x 3 km with unidirectional incident waves 150 m long would create a diffraction shadow zone extending about 30 km downwind. For such a shadow zone to be a persistent and discernible feature at 30 km in the lee, the incident wave direction would have to be constant to about 3 km/30 km or about 5 degrees. To create a persistent and discernible wave shadow at a coast 20 km in the lee, the incident wave direction would have be constant to about 3 km/20 km or about 9 degrees. Such unidirectionality will be short lived off the west coast of Scotland, so intense shadow zones of this size will only rarely pertain.

More realistically, it is illuminating to imagine a more variable wave field with direction varying 30 degrees either side of a constant direction. In this case, ignoring any refraction, the shadow zone would move up and down a coast 20 km in the lee on a length scale approaching 30 km. The 30 km of affected coast will therefore receive its usual energy flux, less that extracted along the 3 km device front. This corresponds to about 10% reduction in energy (or 5% in height), in agreement with the more detailed calculations of Wavehub.

Lacking any further quantified studies on the geographical extent of wave device impact, it is therefore assumed for the purposes of the SEA that wave devices affect a zone 20 km around the device or device array. This is a conservative estimate for all but the largest conceivable development, particularly in view of the assumption of 100% energy extraction and the lack of detail in diffraction or refraction effects. It is therefore likely that for most device arrays, effects would be felt over a smaller area.

Useful generalities may emerge in future that reduce the need for detailed site specific models, but at this stage in development it is assumed that the use of site-specific modelling studies on a project by project basis.

C3.4.1.2 Sediment Processes

To consider the impact on the sediment processes, wave devices may be classified into floating systems, bed-mounted devices and coastal-mounted systems. It is believed that immediate effects on sediment processes from single devices will be restricted to a few tens of metres from the devices and be confined effectively to the flow shadow and accelerative flow regions. It is possible that the insertion of fixed devices into large fields of mobile sediment may stimulate the formation of some fixed patterns into the sediment field in the lee. Nevertheless, cumulative impacts are expected usually to be low in the region out to 20 km, depending on the nature of the local sediment dynamics.

- Floating systems - Floating devices will be located in water depths sufficient for effective mooring, and are therefore expected to have the least influence on the physical environment. In water that is deep relative to the wavelength, no effect of the surface equipment is expected on the sea bed: in shallower water there will be some changes to the wave currents at the sea bed. In both shallow and deeper cases the associated bottom moorings and anchors are expected have the main effect on sediment *via* flow perturbation and scour. The floating systems themselves will only distort slightly the local sediment pattern with small scour effects. The floating devices may however exert long-term influences on the sediment dynamics. The effect of devices in arrays will be additive, although without significant effects of scour unless the mooring systems are such that they result in major sediment disturbance.

In any case, the influence of energy extraction on the local sediment dynamics may be less the further the devices are placed from the coastline, although this might pose difficulties in device survival and mooring.

- Bed-mounted devices - Bed-mounted systems will need to sit on a firm or rock bed, perhaps under mobile sediment. They disturb flow patterns across and through the sediment itself, and may seriously disturb the local sediment equilibrium, in addition to the larger scale issues discussed earlier. Localised scour around their bases may be enhanced in device arrays, where consequences will be cumulative, especially if the devices are sufficiently close that their regions of influence overlap.

  In a cluster or array of piles, the entire cluster may effectively be treated as one pile, with scour associated with the entire array. Aside from this group scour, there is also scour at each individual pile in the array. The scour interaction of groups of piles can be estimated in many cases from published literature.

Experiments in the early seventies and eighties showed that the scour depths around individual piles in a cross-flow array were unaffected by neighbouring piles when separated by more than 6 pile diameters. This critical spacing changes if the piles are not circular. For example, it reduces to 5 diameters if the piles are square. If the pile separation is reduced from 6 to 2 diameters, the depth of the scour increases by as much as 40%.

The scour ratio (the ratio of scoured area to area of the array) depends on the distance between adjacent piles within the array. It should be noted that the scour ratio relates to the scour around the whole array and that scour around individual piles still takes place (Whitehouse, 1998). For example, in a 3 × 3 array with piles separated by a distance of 3 diameters the scour ratio is 1.8. This decreases to 0.3 if the piles are separated by 9 diameters.

In general, significant distortion to sediment dynamics is expected for a distance of up to 50 m from the device.

- Coastal-mounted systems - The structures of coastal-mounted systems are attached to a hard coastline and alter it substantially but locally. Systems are likely to be installed on coastlines that would otherwise be hard and reflective of incoming wave energy. The removal of this reflected energy may therefore alter local sediment equilibrium, perhaps with a tendency to more local deposition. The medium or far field effects will be related to the size of the extraction zone relative to the medium and far field, so may be relatively small.

  Further understanding of these effects will be forthcoming during the timescale of the Supergen (marine) research consortium (2003 to 2011).

C3.4.1.3 Coastal Processes

- Soft coastlines - Soft coastlines are often characterised by ready supplies of unconsolidated erodible material, offshore sand and mud, mobile shingle, sandy or muddy beaches, a hinterland of dunes, and low physiographic relief. They may often offer good supplies of local mobile sediment of various grades which moves and redistributes freely under the influence of waves and tides. Large-scale wave energy extraction offshore of a soft coastline distorts the wave field pattern and has the potential to affect these dynamic coastal sediment zones.

  In general, energy extraction rate depends on wavelength in relation to the size and design of the system, and systems tend to extract energy preferentially from small rather than large waves. This alteration of the spectrum may alter dynamic equilibria between deposition and erosion of soft sediments. As a rule of thumb, large waves tend to disturb and remove sediment offshore, whereas smaller waves tend to deposit material. It is therefore expected that large-scale wave energy extraction may increase offshore movement of the sediment.

  Furthermore, wave action causes longshore drifts as well as on-offshore movement. Modification of the wave field may in some circumstances change sediment deposition or erosion affected by the longshore drift, perhaps countering any on-offshore tendency, but changing erosion downstream of the development. Therefore, wave energy extraction offshore of soft coastlines may affect coastal erosion either inshore of the development, or along the coast, depending on local conditions.

- Hard coastlines - In many cases, hard coastlines are associated with small supplies of finer sediments. This may owe to smaller indigenous supplies in such areas, or to the winnowing effects of currents and waves on what are often exposed coasts. In either case, the potential for significant change to already weak deposition patterns is small when compared to soft coastlines. Nevertheless, wherever hard coasts have significant soft fringes, those fringes are at the same risk as soft coasts.

Hard coastlines are, like soft coastlines, dynamic - albeit over longer timescales. Cliffs are eroded by waves and soften over time. Large-scale wave power extraction may offer some degree of protection to hard coastlines threatened by erosion but influence would generally be felt over long timescales and would normally only be significant in those environments in danger of critical or immediate change. Even in these cases, the preferential absorption of shorter rather than longer waves and changes to the device efficiency with wave amplitude may limit the protection afforded from longer or higher waves.

Wave energy extraction therefore has greater potential for impact - some of it adverse - on soft coastlines than on hard coastlines, which may be expected to experience positive or no effects on erosion.

C3.4.2 Tidal Energy Devices

C3.4.2.1 Tidal Regime – Geographical Footprint

Wind turbine models often assume that the wake influence extends to 10 rotor diameters behind the turbine. However, the models used to predict these effects pertain to persistence of the central pressure zone in the wake and take no account of the cyclic pressure fluctuations derived from the blade tips. Preliminary studies have shown that, for tidal energy devices, the wake core persistence is less than in the wind. The presence of the free air-sea surface results in more rapid collapse. This means that the wake of the tidal turbine is present over a smaller area per blade diameter than for a wind turbine but that the local disturbance is more intense. The flow enhancement under the device is of particular concern because it increases scour. Investigation of this phenomenon continues but it is anticipated that the phenomenon will extend up to 4 rotor diameters behind devices, with greater intensity of impact within this smaller zone of influence.

Turbines across the flow will add local friction within regional flows rather than adding asymmetric deflections (as in a rudder or keel across a flow). Because most flows are driven and influenced by regional tidally varying pressure gradients rather than by relatively small increases in local friction, it is unlikely that any significant directional effect will be felt even from large arrays. No gross alteration in the direction of the tidal stream is therefore expected.

Field studies undertaken by MCT around their Seaflow device off Lynmouth show that 167 m downstream the flow is very little disturbed from the ambient conditions. The Seaflow blade diameter is 11 m, so this equates to a geographical zone of influence of up to 15 x blade diameter.

The modelling studies undertaken for the MCT tidal devices “Seagen” in Strangford Loch found that there would be no measurable change in the tidal currents beyond 500 m from the device. This device has two 16 m diameter rotors, so this equates to a geographical zone of influence of less than 30 x blade diameter.

Based on information obtained from developers, turbine diameters for commercial horizontal axis turbines are typically some 10 to 16 m but may be varied according to site characteristics. For the purposes of the SEA, a precautionary and conservative estimate of up to 30 diameters - a zone of influence up to 500 m around tidal devices or arrays may be used. From the above review of limited field measurements and by inference from available wind model data, it is likely that the zone of influence is substantially less than this.

It is not presently possible to extrapolate these considerations to the impacts of multiple devices in an array. If flow effects are undetectable at 10 to 15 diameters it is unlikely that devices at similar spacings would interact significantly. Nevertheless there remains the possibility of interaction between downstream structures and eddies shed from upstream structures at some to-date unmeasured spatial scale. For the purposes of the SEA it is assumed that tidal devices in arrays would be spaced and staggered so as to separate wakes. This would mitigate the interactions of devices within an array.

C3.4.2.2 Tidal Regime – Device-Related Issues

The position of the device in the water column influences substantially the distortion of local tidal flow near the sea bed. In addition, the dynamic influence of vortex tubes shed by lifting surfaces is expected to produce localised cyclic changes in the water column and near the sea bed. These and other localised effects might influence the significance of effects of the various technology types in some sites, especially when associated with substantial hardware, or if involving major site preparation.

It is likely that shallow water sites will be exploited by bed-mounted systems, with significant local influence on the bed flow. Deep water sites are more likely to be exploited by a moorings based technology held well away from the bed. Most developers would rather their devices were well away from the bed in order to minimize flow shear effects.

Even tethered systems must be attached to the sea bed by some form of mooring, with concomitant disruption during installation. The bulk flow disruption associated with tethered systems is, however, not expected to be significant in its impacts.

C3.4.2.3 Water Levels

Local sea level varies because of global sea level change (eustatic change) or local movement of the land (isostatic change) associated with post-glacial uplift or tectonic movements. The isostatic change is usually natural. The eustatic change may be natural or anthropogenic – the latter often associated with large-scale effects such as global warming rather than with any local effects. The sum of these effects has in recent Holocene times been raising sea level in the South of Britain by about 1 mm per year, but has been raising the North of England and the Scottish mainland relative to mean sea level by about 1 mm per year (effectively a 1 mm decrease in sea level relative to the land) (Shennan, 2002). Changes in sea level move the focus of the sea's erosive power up and down the coastal height profile. This is of more concern in peripheral parts of Scotland such as the Western and Northern Isles than on the mainland because isostatic uplift from the last glaciation is still raising the mainland.

This potential rise should be seen against the background of the present SEPA flood risk maps which are based on analysis of the 0 to 5 metre contours. From this viewpoint, local changes induced by energy extraction schemes are likely to be significant only if they are of order of 10 cm or greater. In general, the non-enclosing tidal energy extraction schemes being considered by this SEA project will have no effect on local sea level because there is no mechanism to counter the hydrostatic equilibrium of a flat sea surface.

To capture kinetic energy directly *via* turbines is to introduce artificial obstacles and friction into 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 associated coastal wave erosion.

C3.4.2.4 Sediment Transport and Coastal Processes

In many ways the issues associated with sediment movements are simpler for tidal than for wave extraction. The modifications and general reductions to flow speed suggested by our understanding of the tidal processes will alter sediment suspension and deposition. Energy extraction also introduces turbulence into the flows which may have a local counter-influence on sediment, resuspending sediment in the region of the wakes. The most noticeable influences would be experienced in estuarine conditions, such as the Solway, rather than in energetic channels such as the North Channel and Pentland Firth. In such sites, sediment is dynamic and influenced by waves as well as tidal currents.

It may be that the Solway would be precluded from tidal current development by the highly unstable nature of the tidal channels, which would pose the risk of devices being buried. Whilst it is interesting to observe that no negative influence from energy extraction on sediment dynamics has been reported for the MCT Seaflow site off Lynmouth in the Bristol Channel, only limited modelling has been undertaken at this site.

Impacts on sediment processes depend on the size of the rotors compared to the water depth and height of the device above the seabed. These factors bear on the likelihood of seabed interactions. However, in cases where these effects reverse between the flood and ebb tide, the potential for net change in the deposition signature is small and the same sediment regime is expected to remain stable.

For tidal energy devices there is a dearth of necessary baseline understanding of sediment behaviour in high tidal energy zones, particularly where unnatural turbulence is to be introduced by moorings, piles and the operation of the devices. Such studies may be necessary in areas thought to be at particular risk from sediment redistribution.

C3.5 Sensitivity

C3.5.1 Sensitivity of Different Receiving Waters to Tidal Energy Extraction

Inter-island channel The sensitivity of inter-island sites depends on their length, width, depth and roughness and flow alteration in such channel flow may generally be predicted with some confidence. The longer, shallower and rougher the site is, the less the extracted energy will be relative to the energy lost within the strait to natural friction. In this sense such a site is less sensitive.

Other relativities are possible: that between the rate of extraction of energy and the kinetic energy flowing naturally through the strait is also important. Case by case calculations may be the most appropriate tool, particularly if flow changes interact with local sediment so as to change to erosion and deposition patterns.

Non-resonant sea lochs In these environments, an inlet (or sea loch) links to the sea, often by a recognisable channel. The dimensions of all Scottish sea-lochs are such that none resonates with the tides so as to amplify them (as happens for example in the Bay of Fundy in Canada, where tidal ranges reach 16 metres). All the small potential tidal sites in the West of Scotland fall into this category.

The general environmental effects of interference with the natural flows of lochs include: reduction of tidal range within the loch; reduction of net inflows and outflows; the general reduction of flows within the loch; reduction of baroclinic (layered) flows in the entrance region; a greater chance of bottom water deoxygenation in such restricted systems; and increases in the salinity and temperature ranges within the loch.

It has also been shown (Bryden, 2004) that the sea-loch environment may be modelled in respect of some of these effects so as to estimate the upper limits to energy extraction.

Open water environments Some sites (which are rare in Scottish waters) are sufficiently large that they cannot be regarded as channels. To gauge accurately the effect of tidal energy extraction for such areas, 3-dimensional analysis would be needed, or at least a vertically parameterised 2-dimensional analysis. However, because of the regional scale of tidal forcing, any site sufficiently large to fall into this class is very insensitive to energy extraction beyond the immediate vicinity of the extraction site.

Headland sites There are some sites where flows are enhanced by geographic features such as headlands. Flow around these sites tends to excite local topographic eddies. This makes for strong spatial variability, horizontal shear flows, associated time-varying eddies, unstable directionality and consequent unsuitability for energy extraction.

C3.5.2 Sensitivity of Coastline to Tidal Energy Extraction

Coastline types in the study area have been identified bearing in mind their relative sensitivity to changes induced by wave and tidal energy extraction. 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. In what follows we deal mainly with shoreline stability and aspects of erosion and deposition.

Coastal sensitivity

Power extraction changes to currents, waves and water levels can potentially reduce the erosive power reaching adjacent coastlines. In addition, some coastal areas may receive more incident energy because of local effects of channelling and intensification of currents. There may also be secondary changes to local erosion associated with modification of the wind wave field by changed diffraction and refraction.

Coastal types

Coastal sensitivities relate to the processes that underlie erosion or deposition and to 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.

Figures showing the types of coastline likely to be sensitive and insensitive to changes in hydrodynamic processes are included as Figures C3.1 – C3.4, and described below (MAGIC, 2007).

- coastal cliffs are considered as being insensitive to tidal energy extraction. However, this is not always the case: for example, cliffs on the North Yorkshire coast offer some resistance to erosion but are particularly fragile within the UK context;
- dune habitats indicate weak mobile shore and hinterland whose characteristics may be sensitive to tidal energy extraction;
- sand and mud coastline indicate areas whose erosional and depositional character is particularly sensitive to tidal energy extraction;
- offshore shingle, gravel and rock platform coasts, indicate harder offshore sea bed whose characteristics may be relatively insensitive to tidal energy extraction.

C3.6 Confidence and Knowledge Gaps

The fundamental physics of energy extraction and its influence on wave and tidal fields is largely known. Computational fluid dynamics modelling and shelf sea modelling are in general sufficiently advanced that we may predict the influence of tidal energy extraction on the local and regional flow patterns. The detailed prediction of the effects of wave energy extraction is more difficult: the inherent variability of wave fields and the short term dynamics of wave-sediment interactions are sufficiently complex that generalizing is difficult, and case by case study of particular proposals seems the most productive route forward.

A larger body of empirical knowledge or increased theoretical understanding is needed to predict more accurately the influence of tidal or wave energy extraction on soft mobile coastlines or to estimate thresholds for extraction below which no measurable or significant changes are to be expected.

There are substantial gaps in our understanding of the behaviour of different sizes of sediment: from cohesive clays and silts through to large shingle beds we lack universal or even particular models appropriate to all size fractions.

As for the hydrodynamic extraction models, the erosion/deposition models have not been subjected to full scale validation studies in the context of marine energy extraction.

C3.6.1 Modelling Issues

In many wave or tidal cases, case by case specific modelling remains essential for the prediction of effects.

With waves coming predominantly from the west or south-west, the most appropriate wave system to model with regard to the real ocean waves expected off the west coast of Scotland may be multi-frequency quasi-unidirectional waves.

Refraction and shoaling depend critically on incident wavelength, wave direction and water depth: refraction and wave height calculations must be done with correspondingly detailed specification of these variables. Such detailed calculations are essential if the wave field in any particular site and circumstance is to be analysed as it propagates towards the coast into areas where it may influence sediment motion, coastal erosion and deposition. It is possible in principle to model the refraction and shoaling of waves propagating from deep water to the coast. Many numerical computational models have been developed to simulate these processes.

Coupled refraction and diffraction models may be used effectively to predict the changes to wave patterns resulting from the presence of wave energy devices in a coastal regime. There are commercial packages which offer opportunities for such analysis. The best known include MIKE21, MIKE3 and Swan.

Site-specific modelling of impacts of wave energy extraction may be required for development of wave farms, using models such as Mike21 or Mike3 that include explicitly time and space-dependent wave propagation, diffraction, shoaling and refraction. Necessary inputs to the models include wave specification, detailed bathymetry, and parametric representations of device performance such as effective absorption width and absorption properties related to wave periods & directions. Device performance is related to wave amplitude as well as period and direction and, as such, the effects are related to wave conditions in non-linear ways.

Models such as MIKE3 include sedimentation in their operation and it is suggested that they could be used to identify sensitivity, even if they are do not predict in detail the redistribution in sensitive areas. It is anticipated, however, that most potential development areas will have relatively little sensitivity, in terms of sediment stability, to energy extraction.

Numerical modelling readily allows predictions of the changing hydrodynamic environment in particular cases. These models have not yet been compared with full-scale deployments of wave and tidal energy technology. Their verification is therefore in doubt. Even in the absence of such direct comparisons, we recommend a review of alternative software methodologies and commercial packages modified and parameterized to incorporate the processes of wave and tidal energy extraction.

Nevertheless, looking to the future, it may be that general patterns will emerge from modelling and analysis of a number of particular cases: these may well form the basis of the development of general binding rules or other generic regulatory mechanisms.

C3.7 Recommendations for Further Work

C3.7.1 General

In the case of both waves and tides, as has been argued here, much may be achieved by considering relativities: those of energy extraction rate to natural energy supply rates; of site size relative to regional tidal forcing; of site size and wave shadows relative to local topography; of the extracted part of the wave spectrum relative to the whole spectrum; of the size of the local sediment bank; of mobile material relative to immobile material. Such initial comparisons are essential if the effects are not to be over-stated and environmental assessment is not to be over-expensive.

Where consideration of these simple relativities shows a reasonable probability of measurable or significant effect, further case by case research assesses the impacts of tidal and wave energy extraction on wave and tidal regimes.

Looking to the future - regulation, decision-making, lobbying and discussion are likely to focus on the following:

- baselines from which future change may be predicted or monitored;
- the prediction of that change;
- monitoring the change.

This report has dealt earlier with aspects of prediction; we now focus on the concepts of the baseline and the monitoring.

If much survey effort is not to be wasted, and if a regulatory “level playing field” is to be created, it is essential that any baseline is defined by criteria similar or identical to those used to perceive or monitor subsequent changes. As a trivial example, it is pointless to define a baseline on a “hot / warm / cold” scale and then monitor on a degrees Celsius scale. The baseline is often the first point on the monitoring graph.

This raises the question of what variables are to be measured in the baseline that will be later monitored. As examples, candidate variables at key sites might include: mean sea level; beach profile; sediment size composition; algal cover; mean wave height; hard rock erosion rate; mean current.

Most of these exemplary variables, and others, are variable in space and time. That variability should be taken into account most carefully in the construction of both the baseline and the monitoring programme.

Our key recommendations are therefore that:

- key variables should be reviewed and identified at an early stage;
- guidance should be developed on the sound measurement and proper statistical description of the inherent variability in each variable;
- those variables and statistics chosen for the baseline should also be applied as far as possible to the monitoring programme.

C3.7.2 Baseline Surveys

Baseline surveys have some special functions over and above that of being the first point on the monitoring graphs.

In view of our uncertain knowledge of future management and development it may be acceptable to measure some variables and features in a baseline that are not immediately carried forward into a monitoring programme. As an example, we might chose to include some sediment stratigraphy in a baseline even though we doubt that it will change significantly over short or medium time scales: it may prove useful in the longer term.

In specific cases or sites, a baseline survey may usefully also have a research function, in quantifying the parameters by which the site is to be modelled.

C3.7.3 Baseline Prediction and Modelling

Areas to target research have been highlighted here and in a number of papers and include the following. They have been categorized roughly according to their application to the requirement to improve our understanding of baseline, prediction or monitoring.

Table C3.1: Data Gaps – Marine and Coastal Processes

Identified data gap	Potential to fill the data gap	Purpose: baseline/ prediction monitoring	Priority
Uncertainty in methods of assessing change in wave climate in the lee of wave devices	▪ Review survey techniques to resolve energy reduction effects. ▪ Review the approaches to data analysis.	Baseline, Prediction & Monitoring	High
No standardisation of type or quality of methods, nor of the quantity of data needed.	▪ Guidance for *in situ* assessment of energy reduction so as to provide a standard approach to field measurement for wave and tidal devices. ▪ Guidance for data collection, methods of analysis and interpretation. ▪ Development of useful data-based indicators.	Baseline, Prediction & Monitoring	High
In specific sites, limited data for understanding and quantifying the processes and geographic footprint of change	▪ Modelling predicted change at specific sites, with field survey where feasible, to increase understanding of the potential geographic extent of change.	Baseline, Prediction & Monitoring	High
Limited understanding of the potential for energy extraction to affect the seabed, through changes in the substrate type, energy flow or turbulence characteristics.	▪ Modelling to determine the extent of change within the water column	Baseline & Prediction	Medium
Little research to date into identifying thresholds for energy extraction which might make measurable or significant changes in the dynamic equilibria of coastlines	▪ Identification of such thresholds should be a matter for academic and regulatory cooperation. ▪ Research should link to the development of the baseline. ▪ One problem here is that information on the dynamics of beaches prior to wave energy exploitation may necessitate long periods of observation for confidence in model predictions.	Baseline & Prediction	Medium
	▪ There may not be time for this, so from a regulatory or coastal management point of view, it may be necessary to develop simple surrogates for likely thresholds.	Baseline, Prediction & Monitoring	High

Identified data gap	Potential to fill the data gap	Purpose: baseline/ prediction monitoring	Priority
Ensure that site-specific data gathered for individual devices is used to further the overall knowledge base, to inform future data collection requirements in advance of commercial deployment	Review of data collected from demonstration phase projects	Baseline & Prediction	Currently Medium, but likely to increase to High as more data become available
Limited understanding of the significance of scaling up from single to multiple devices	As greater understanding of the significance of single devices becomes available, modelling to assess potential in-combination effects will be required	Prediction & Monitoring	High
Wave and tidal energy devices are likely to be associated with well mixed water bodies, but an improved understanding of changes to mixing and stratification would be valuable in the analysis of wake suppression dynamics and may have slight significance for local plankton growth regimes	Modelling of area of disturbance within the water column together with associated turbulence and the extent of such disturbance and turbulence. The influence of stratification – including the plankton - is amenable to a first and simple analytic/theoretical fluid dynamical approach rather than any high level computational one.	Prediction & Monitoring	Medium Low

Source: Adapted from ABPmer, 2006

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Figures

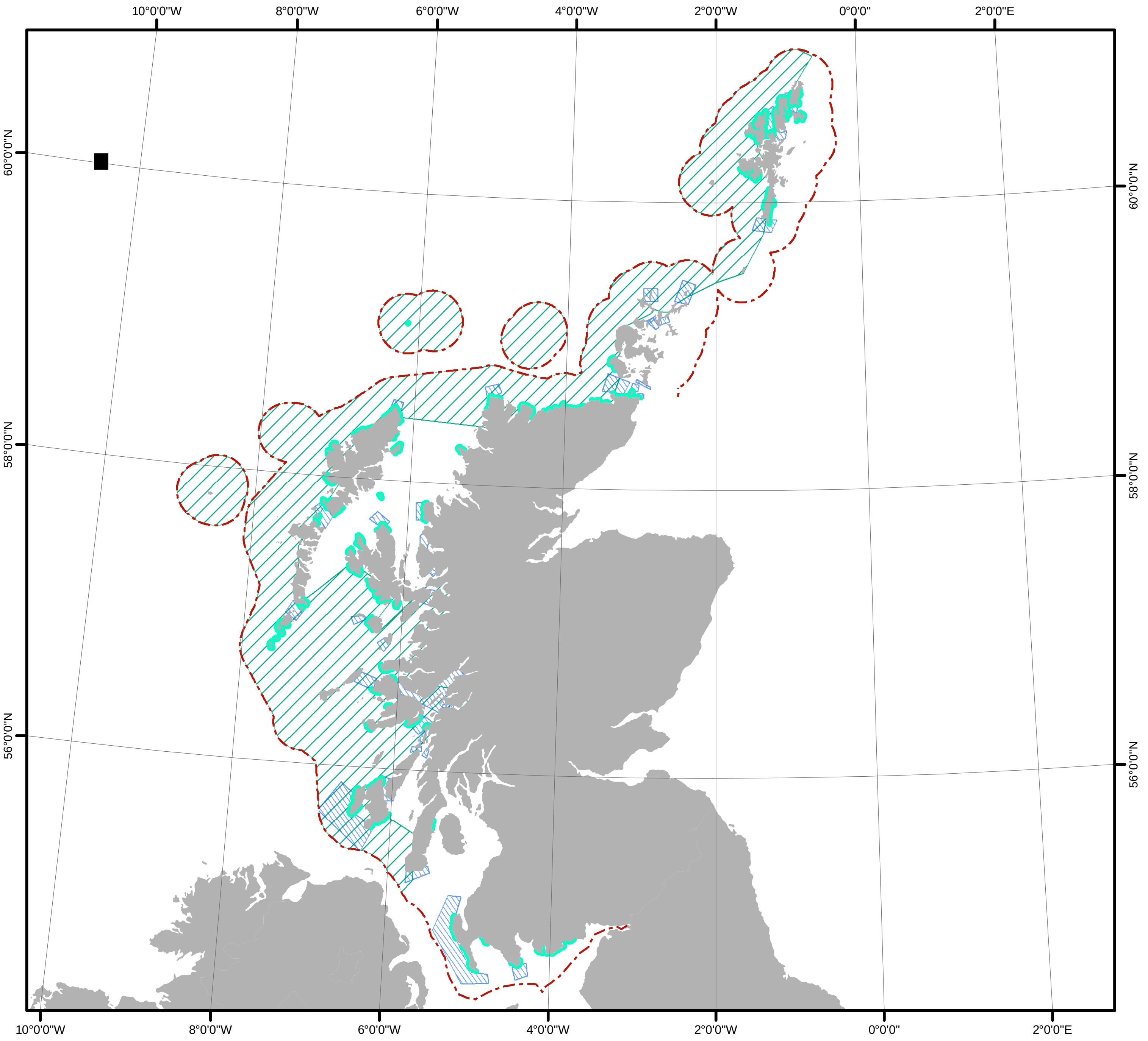

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Figure C3.1: Cliff coastline types

Legend

- ▬ Coastline type: cliff
- –·– 12 Nautical mile limit (study area only)

Potential development area

- ▨ Tidal resource
- ▨ Wave resource

0 25 50 100 150 200 Kilometres

Date	21 February 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	SeaZone Solutions Ltd; Magic	
File Reference	P736\GIS\Mxd\SEA\baseline	
Checked	RM	GIS Specialist
	FLB	Project Manager

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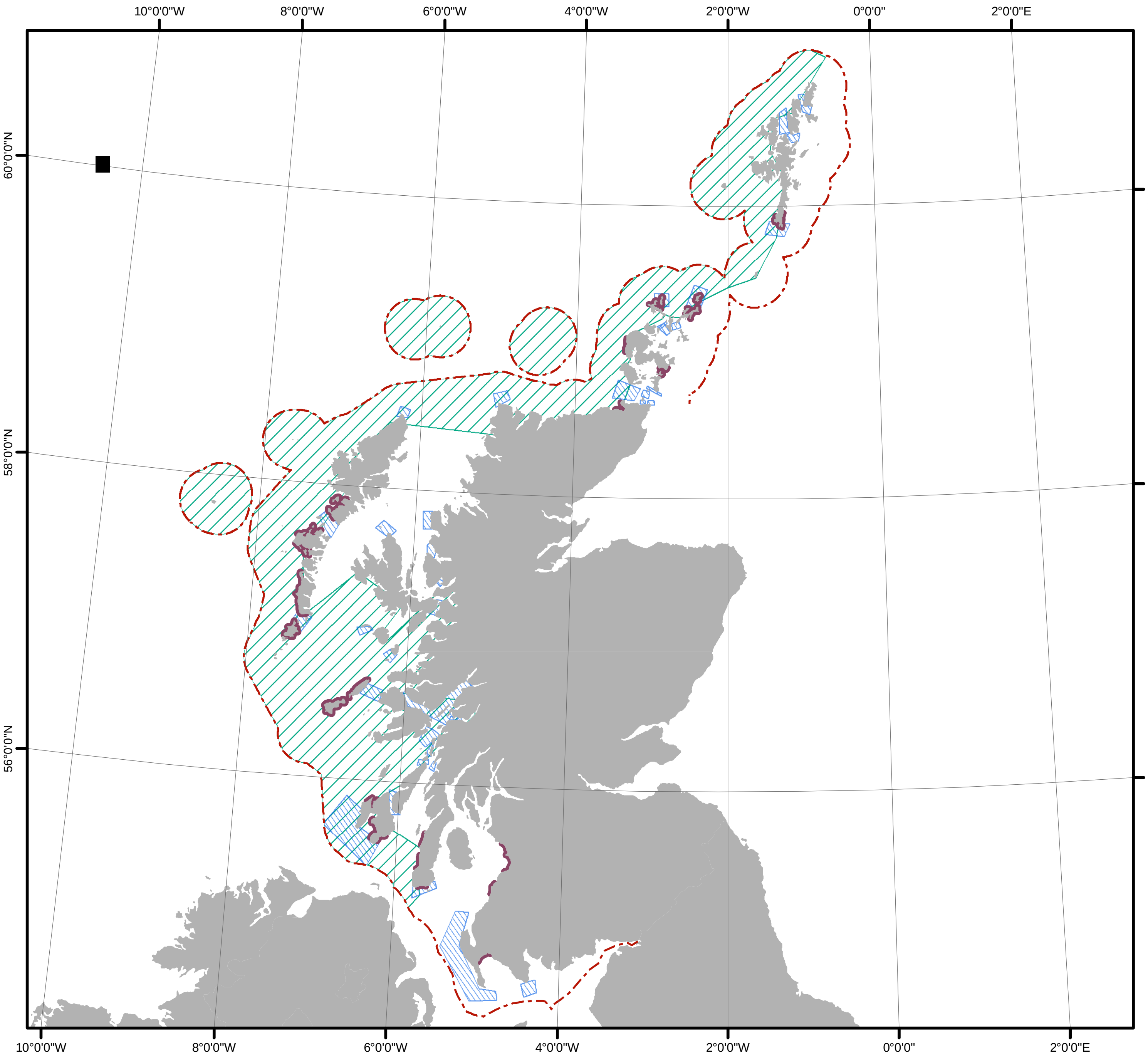
Figure C3.2: Overview dune coastline types



Legend

- Coastline type: dune
- 12 Nautical mile limit (study area only)

Potential development area

- ▨ Tidal resource
- ▨ Wave resource

Date	21 February 2007
Projection	Transverse Mercator
Spheroid	Airy
Datum	OSGB36
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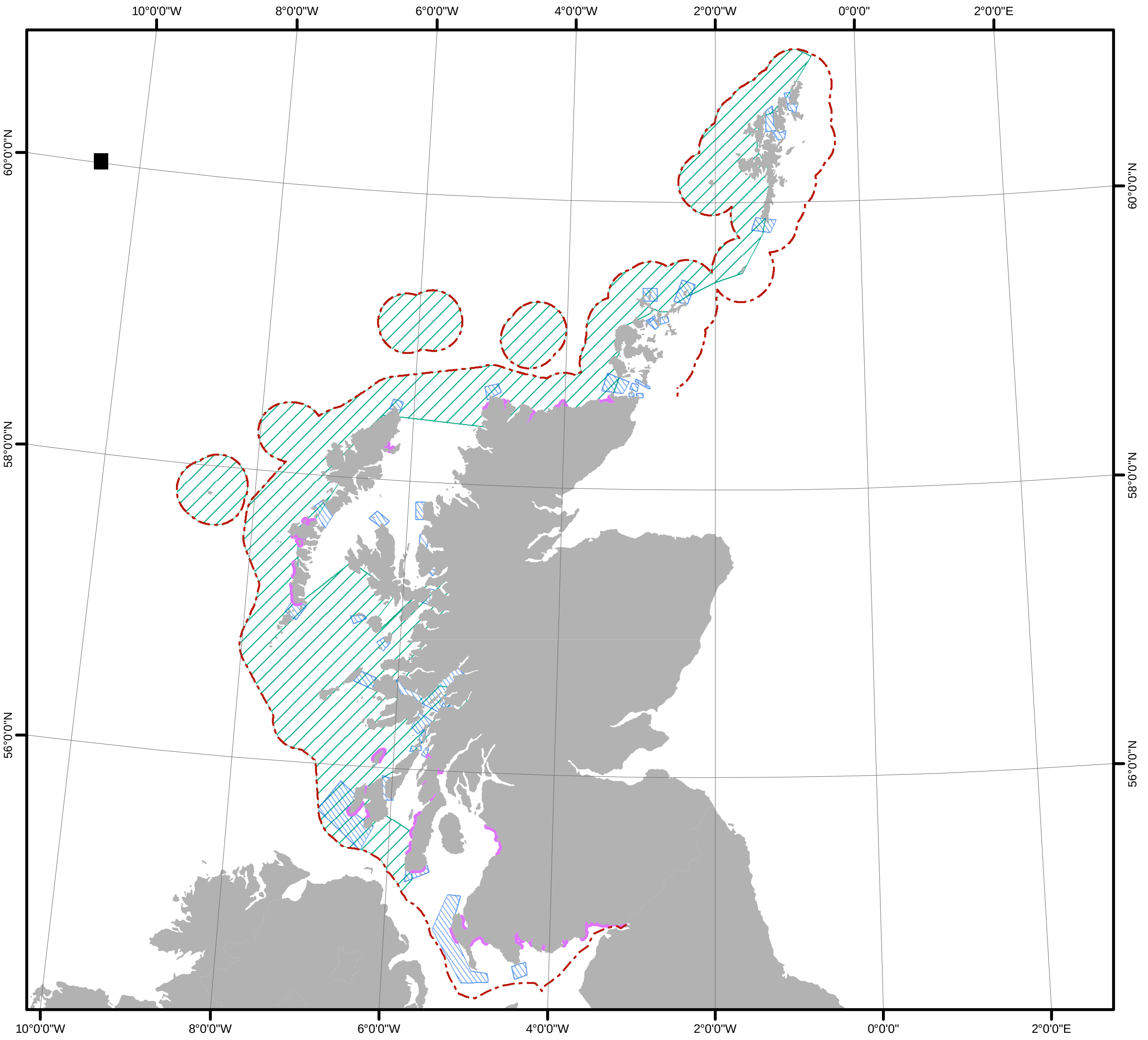

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Figure C3.3: Overview of coastal offshore sand and mud areas

Legend

━	Overview of offshore sand and mud
-·-	12 Nautical mile limit (study area only)

Potential development area

▧	Tidal resource
▨	Wave resource

0 25 50 100 150 200 Kilometres

Date	21 February 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	SeaZone Solutions Ltd; Magic	
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	FLB	Project Manager

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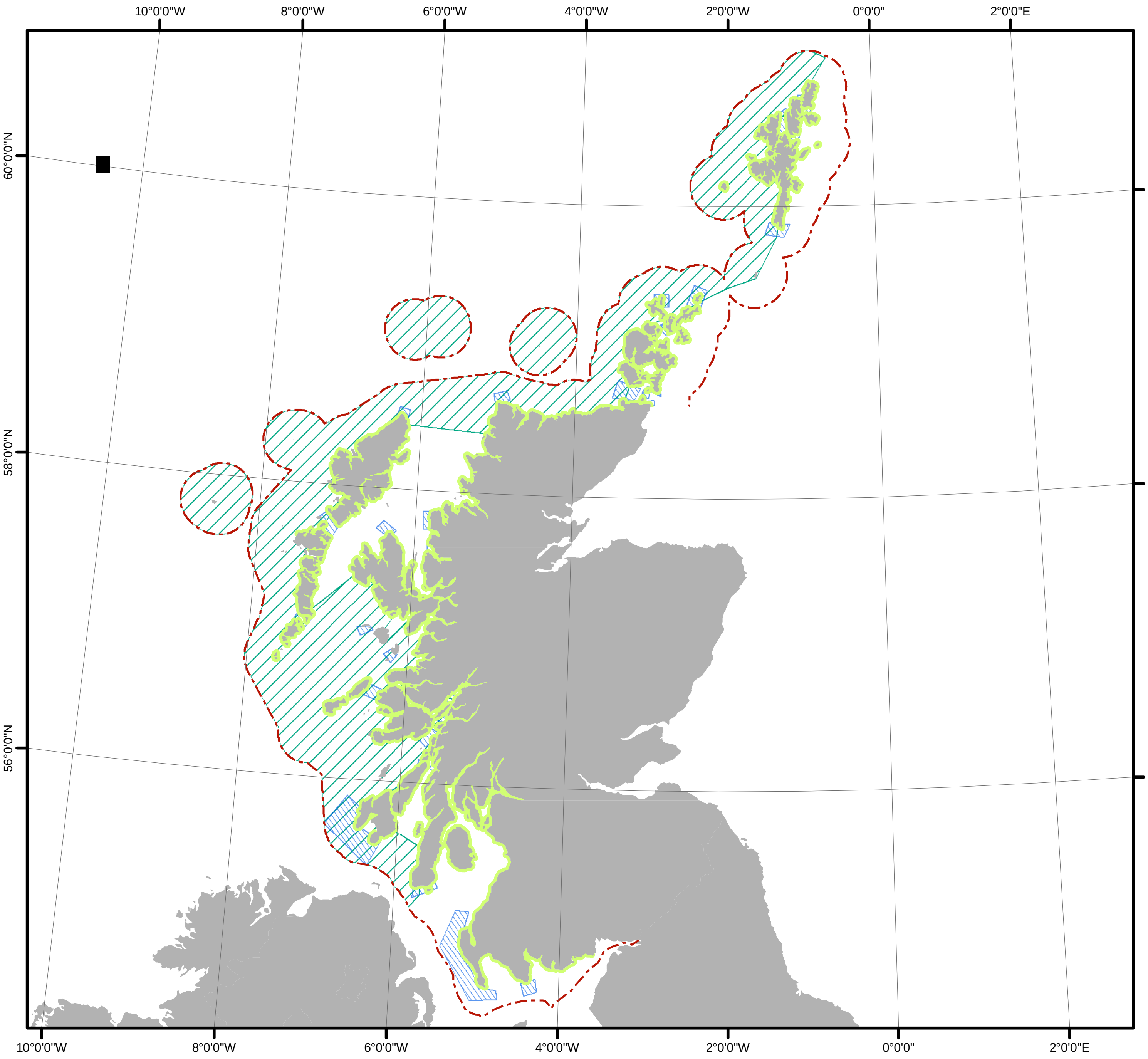

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Figure C3.4: Overview of coastal offshore shingle, gravel and rock platform areas

Legend

- 🟩 Overview of offshore shingle, gravel and rock platforms
- ─ · ─ 12 Nautical mile limit (study area only)

Potential development area

- ▨ Tidal resource
- ▨ Wave resource

0 25 50 100 150 200 Kilometres

Date	21 February 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	SeaZone Solutions Ltd; Magic	
File Reference	P736\GIS\Mxd\SEA\baseline	
Checked	RM	GIS Specialist
	FLB	Project Manager

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