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Coastal Cells in Scotland: Cell 10 – Orkney

D L Ramsay & A H Brampton

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REPORT

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THE SCOTTISH OFFICE HISTORIC SCOTLAND SCOTTISH NATURAL HERITAGE

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CONTENTS

Summary

This report reviews the coastline of Cell 10 which encompasses the Orkney Islands. It describes the various coastal characteristics and processes which affect the regime of this particular stretch of shoreline. The report includes a description of the major coastal features, processes, and defences along with other aspects of beach development. The stretches of coastline which, for coastal management purposes, can be treated as independent or semi-dependent cells are also identified.

The study was carried out for Scottish Natural Heritage, Scottish Office Agriculture, Environment and Fisheries Department and Historic Scotland by the Coastal Group at HR Wallingford. The contract was administered by Dr George Lees of Scottish Natural Heritage. For further details of the study please contact Mr Douglas Ramsay or Dr Alan Brampton of the Coastal Group at HR Wallingford.

Note

This contract was undertaken prior to the establishment of The Scottish Executive. The report therefore contains references to The Scottish Office and The Secretary of State for Scotland. The following changes therefore apply and should be borne in mind when reading the report.

Previous terminology	*Present*
The Secretary of State for Scotland	The First Minister
The Scottish Office Agriculture, Environment and Fisheries Department	The Scottish Executive Rural Affairs Department

1 *Introduction*

1.1 General

In January 1996, HR Wallingford was commissioned by Scottish Natural Heritage (SNH), the Scottish Office Agriculture, Environment and Fisheries Department (SOAEFD) and Historic Scotland (HS) to extend an existing study (HR Wallingford, 1997) to define Coastal Cells and Sub-cells around the coastline of Scotland. This report, which reviews the coastline of Cell 10 defined as the coastline of the Orkney Islands, is one of a series of 11 reports covering the entire coastline of mainland Scotland, the Western Isles, Orkney and Shetland. The study concentrates on identifying and describing the various natural and man-made characteristics and processes which affect the behaviour of this particular stretch of coastline. The report includes a description of the dominant hydraulic processes, areas of erosion and accretion, coastal defences and various other aspects of the coastal regime. The aim of the report is to provide an overall understanding of the character and processes occurring within each sub-cell to allow as full an appreciation as is presently possible of the coastal regime on a macro scale.

1.2 Terms of reference

The terms of reference for this study were detailed by Scottish Natural Heritage in Annex A of their Project Specification. The aims are to provide:

(i) a basic description of coastal cells and their significance,

(ii) maps of each cell showing the location and boundaries of all sub-cells contained therein and the nature of the cell boundaries,

(iii) a map of each sub-cell showing the general direction(s) of littoral drift therein and known areas of erosion and accretion,

(iv) a map of each sub-cell showing the location of all sites designated for their nature conservation interest,

(v) a map of each sub-cell showing the location of sites designated for their historical or archaeological interest,

(vi) a map of each sub-cell showing the location of all principal coastal protection works and beach monitoring schemes,

(vii) descriptions for each sub-cell of the following characteristics and processes:

- geology and geomorphology
- wave and tidal regime
- areas of erosion and accretion and, where information exists, details of any rates of change
- assessment of existing erosion problems
- a summary of the relevance or implications of the littoral processes identified to sites of nature conservation interest
- a summary of the susceptibility of historical and archaeological sites to coastal erosion

- existing coastal protection and management measures (including dredging and spoil disposal)
- present monitoring arrangements
- assessment of sensitivities of sites to climatic change and sea level rise.

1.3 Outline of report

A general introduction to the concept of coastal cells, and how the concept has been applied to the coastline of Scotland is provided in Chapter 2. Chapter 3 provides general background information on the coastal environment of Scotland in the context of coastal cells. Chapter 4 provides reference to data sources of relevance to coastal management in Cell 10. Chapter 5 forms the main body of the report. A brief description of Cell 10 detailing the cell boundaries, a description of its character and the processes occurring there is given. An assessment of climatic change, sea level rise, and the likely effects on the coastline of Cell 10 is given in Chapter 6, with Chapter 7 listing the references used. A listing of Sites of Special Scientific Interest (SSSI), the locations of noted historical and archaeological sites, useful addresses and glossary are contained within the appendices of this report.

2 Coastal Cells

2.1 Coastal Cells

The concept of Coastal Cells was introduced in an initial document identifying the main cells around the coastline of Scotland, (HR Wallingford, 1997), and in a similar document for the coastline of England and Wales, (HR Wallingford, 1993). The description below summarises the significance and importance of such cells in managing the coastline with regard to the naturally occurring processes acting upon it.

The processes which shape and alter a coastline show no respect for administrative boundaries. Coastal defences installed by one local authority have, at some sites in the UK, contributed to erosion along frontages under the care of an adjacent authority. These difficulties can be avoided by recognising the natural divisions of a coastline, often called coastal "cells". Where the main concern in managing a shoreline is to defend against erosion or flooding, then the most useful definition of a cell is based on a consideration of the longshore drift of beach material (sand and shingle). This is because most cases of severe coastal erosion are caused by interruptions to the natural longshore transport of sediment.

A recent study of the coastline of England and Wales, (HR Wallingford, 1993), resulted in its suggested division into 11 main cells, each of which was further divided into sub-cells. An ideal cell would be entirely self-contained from a sediment transport viewpoint, i.e. there would be no nett import or export of beach material. Then, although coastal defence works could affect the whole cell by interrupting the longshore drift, they cannot affect beaches in other cells. Once established, these cells (and sub-cells) have proved to be a useful basis for shoreline management purposes. In England, the Ministry of Agriculture, Fisheries and Food (MAFF) have introduced Shoreline Management Plans; these are drawn up to provide a strategic basis for planning future coastal defences. Apart from considering aspects such as waves, tidal levels and coastal erosion/accretion, these Plans consider wider issues. Typically these include land use, ecological and geological conservation, tourism and recreation etc. As a consequence, in England and Wales, these plans provide a useful input into wider Coastal Zone Management initiatives. Each Plan is normally carried out for one or more sub-cells as defined above. An initial study has just been completed into defining coastal cells around the coastline of mainland Scotland, Orkney, Shetland and the Western Isles, (HR Wallingford, 1997).

On rocky coastlines like most of those on Orkney, where sediment is sparse, and beaches are often confined to deeply indented bays, then "cells" are often small and numerous. It becomes impractical in such areas to draw up a management plan for each cell; as a result it is sensible to group a number of these small bays together, to form a more convenient "cell" for management purposes. Considerations other than just the longshore transport of beach material are used to define cells in these situations. These include general orientation of the coastline and its hydraulic environment. Cell 10 has been defined in this manner.

Bearing the above description of cell boundaries in mind, the coast of Scotland has been divided up into 11 main "cells" as shown in Figure 1. These major cells not only reflect beach sediment units, but also divide the coast into regions where the geology, physical character and orientation are similar.

Where appropriate, those cells are sub-divided into "sub-cells" based upon the same general criteria. At many sites, the sediment transport around a headland or a large harbour only moves in one direction, and is often of small volume. Engineering works on the updrift side of such a feature may therefore have some impact on the downdrift coast, but such impacts may be small or totally insignificant. Interference with the beaches downdrift of such a "one-way" valve will not affect beaches updrift. We can regard such sub-cells as being "partly dependent", with the understanding that the cell boundary between them is not totally "sediment-tight". An idealised cell is shown in Figure 2.

The definitions of cells and sub-cells in this report are principally derived from the viewpoint of movement of sand and shingle along the beaches, and taking into account the likely consequences of interfering with that movement, i.e. sediment movement in the littoral zone, Figure 3. A particular difficulty arises, however, in estuaries, which are often 'sediment sinks' and hence suitable cell boundaries. For those interested in the biological aspects of an estuary, or the movements of cohesive sediments, this separation of the estuary into two cells is inconvenient. To avoid this, we have preferred to define cell, (and sub-cell) boundaries, around Scotland on the basis of 'drift divide' points (e.g. headlands). The inner portions of several major firths have then been defined as sub-cells.

Identification of such coastal cells is intended to help planners determine the length of coastline likely to be affected by coastal works in a particular area. It is hoped that this type of 'overview' will assist in the understanding of the coastal system as a whole and may lead to a more unified approach to the planning of coastal defences, and hence assist in wider Coastal Zone Management.

2.2 Coastal planning and development

In England and Wales, Shoreline Management Plans co-ordinated with other initiatives can provide useful information in informing decisions on Statutory policies, for example in areas which face particular pressures such as in estuaries where competing usage is often experienced. An example, from England and Wales, of the interrelationship between some of these initiatives is shown in Figure 4. Local authorities are required to produce a structure and local plan which together provide the Development Plan for an area. The Development Plan provides the statutory framework within which development control decisions are made.

Shoreline Management Plans should be integrated within the work of the local authority and can have an important role in informing development plan policy.

There are several documents available which highlight the Government policy on key issues affecting the coastal zone. Of most relevance to the coastline of Scotland is the recently published discussion document from the Scottish Office on *Scotland's Coast* (Scottish Office, 1996) and *National Planning Policy Guidelines (NPPG)13: Coastal Planning* (Scottish Office, 1997). Similar publications in England and Wales, despite being geared to the legislative framework in these countries, are also of use in highlighting the key issues affecting the Scottish coastline. Of particular note, in the context of this report, is the Department of Environment (DoE) publication on *Policy guidelines for the coast* (DoE, 1995) and the MAFF publication, *Shoreline Management Plans - A guide for coastal authorities* (MAFF, 1995).

2.3 Coast protection legislation in Scotland

The new Unitary Authorities with a coastal frontage are known as coast protection authorities under the Coast Protection Act 1949 and have powers under the Act to undertake such coast protection works as they consider necessary to protect any land in their area. Where coast protection work proposed is not maintenance and repair, the coast protection authority is required to follow the procedures defined in the Act. This may lead to approval by the Secretary of State. Once a scheme is approved by the Secretary of State, government grants are available towards the eligible cost of the works at a rate dependant on the authority promoting the scheme. The grant level can vary from between 20% to 80% at present.

The seabed below the Mean Low Water Mark of Ordinary Spring Tides is owned by the Crown Estate *prima facie* in law. The Crown Estate also owns much of the foreshore between Mean High and Mean Low Water Springs but does not hold a title to the foreshore and ownership can be displaced by anyone who can show a title derived from a Crown Grant. As part of the process required to enable consideration of schemes for approval under the Coast Protection Act 1949, consultation with the Crown Estate Commissioners is required. Approval must be obtained from the Commissioners before any coastal defence works, or any works on Crown Estate property is carried out.

Planning permission will be required for all new coastal defence works above Mean Low Water Mark of Ordinary Spring Tides and for any associated works such as borrow pits. In addition, building warrants are normally required for the construction of all walls and structures over a certain height. The exceptions to this are where work is being conducted within harbour limits and are covered by the Harbour Act 1964; for maintenance work; and for emergency works. There are a number of other consents which may be required before coastal defence work can be undertaken. Some of these are detailed in the table below:

Table 1 Required consents for proposed coast protection works

Consent	Application
Planning Permission (TCPSA 1997)	• All new works above MLWS • Associated works such as borrow pits above MLWS
Coast Protection Authority (CPAu) consent (CPA 1949)	• All coast protection works other than those carried out by a CPAu in its own area • New works carried out by a CPAu in its own area require consent of SoS (Scotland)
FEPA Licence (FEPA 1985, part II)	• Licence required for all operations entailing construction or deposition on seabed below MHWS
Environmental Statement (ES) (EA 1988/1994)	• If Planning Authority considers significant environmental effects to a "sensitive location" [1] will result from proposed works, it can require an ES with planning application
Notice of Intent (WCA 1981 Sn28)	• If works are permitted development on an SSSI

Notes

[1] Indicative criteria for assessing the significance of such impacts are contained within the Environmental Assessment legislation referred to.

Abbreviations used:

- CPA 1949: Coast Protection Act 1949
- CPAu: Coast Protection Authority
- EA 1988/1994: Environmental Assessment (Scotland) Regulations as amended
- ES: Environmental Statement
- FEPA 1985: Food and Environment Protection Act 1985
- SoS: Secretary of State
- TCPSA 1997: Town and Countryside Planning (Scotland) Act 1997
- WCA: Wildlife and Countryside Act 1981

Details of the statutory designations, and consultees, of conservation, historical and archaeological sites are described in Section 3.6.

3 *The marine environment*

3.1 Introduction

This chapter provides a brief general introduction to the coastal environment of Scotland in the context of this report. For more detailed information the reader is referred to the recently published CIRIA manuals *The use of rock in coastal engineering* (CIRIA, 1991) and the *Beach management manual* (CIRIA, 1996).

3.2 Geology and geomorphology

Scotland is composed of a particularly wide range of different rock types, representing most periods of geological time. Sedimentary rocks (those formed by the consolidation and lithification of sediments deposited in different marine and non-marine environments), igneous rocks (those formed by the solidification of lava erupted on the surface of the land or of magma which consolidated within the earth's curst) and metamorphic rocks (those formed by the alteration or deformation of other rock types) are all well-represented around the coastline.

In geological terms, Scotland can be considered as being formed of 5 distinct units or divisions, each separated by a major fault or fracture in the Earth's crust:

- the north-west Highlands and Islands west of the Moine Thrust, composed of "ancient" Lewisian gneiss;
- the Northern Highlands between the Moine Thrust and the Great Glen Fault, composed of the eroded roots of the Caledonian Mountain Belt, consisting primarily of 1,000 Ma old metamorphosed sediments of the Moine;
- the Central Highlands between the Great Glen Fault and the Highland Boundary Fault, composed of 800 Ma old Dalradian sediments and intruded with granites now forming the Cairngorms and other mountains and hills;
- the Midland Valley, composed of sediments deposited in tropical seas 300 Ma ago, extensive lava fields of the Ochils and Clyde plateau and the volcanic rocks of Edinburgh and the Laws of Fife and East Lothian; and
- the Southern Uplands, composed of sediments deposited in the former lapetus Ocean which, for over 100 Ma, separated Scotland and England.

The geological structure and the lithological variability exert a strong influence on the morphology of the coastline. However, it is the processes which have occurred over the last ca. 2 Ma (during the period known as the Quaternary) that have left a major impact on the coastline, in particular those during the last (Late Devensian) glaciation (ca. 26,000-10,000 years) and in the postglacial period or Holocene.

The last ice sheet, which reached a thickness of 1500 metres in places, advanced from the Highlands over the entire Scottish mainland and most of the islands. Ice extended off-shore and local ice-caps may have existed on the more remote island groups such as Shetland and the Western Isles. Sea level, world-wide, was up to 140 metres lower than it is today. This, and earlier ice sheets, extensively scoured and eroded the bedrock, particularly in the west where it carved out the fjords and sea lochs along lines of pre-existing geological weakness. By 13,000 years ago the ice sheet had melted, depositing a variable cover of drift off-shore in the process. On-shore the ice deposited a thick cover of till in the more eastern areas. Meltwater from the retreating ice also deposited glaciofluvial deposits in the major eastern valleys and coastal lowlands. As sea level rose during deglaciation, some of the glacial sediments in the off-shore zone were reworked and moved into the present coastal zone, and fresh material was eroded from the glacial deposits on the coast. It is the material derived from these glacial deposits which supplied the majority of the sediment for the sand and shingle beaches of the present coastline.

As the ice sheet melted, the loading it applied on the Earth's crust was removed, resulting in the land recovering, or rising, typically at rates of a few millimetres per year (known as isostatic uplift). Rates varied, however, being greater where the ice was formerly thickest and less where the ice had been thinner, as was the case, for instance, around the Northern and Western Isles. At the same time, melting of the ice sheets caused global sea level to rise (known as eustatic rise). Accordingly, the patterns of relative sea level change during and since the Ice Age have varied around the country depending upon each location's proximity to the centre of the former ice sheet.

When the ice first began to melt, between approximately 17,000 and 15,000 years ago, global or eustatic sea level rose, flooding over the continental shelf and engulfing many coastal areas. In some western areas, such as Jura and Arran, "raised" beaches were deposited on the coast at heights of up to 40m above present day high water mark. Thereafter, isostatic uplift gradually overtook eustatic rise causing a relative fall in sea levels around most of the country. This trend continued, with local variations, until around 8,000-9,000 years ago, bringing sea level down to around or below present day levels in most areas. At that time, eustatic rise once more overtook isostatic uplift and relative sea level rose again (known as the Postglacial Transgression) to attain a maximum height relative to the land, in most areas, around 5-6,000 years ago.

Since that time eustatic rise has tailed off and so isostatic uplift has caused, in general, a gradual fall in relative sea level of around 1-2 millimetres per year in Scotland, though recent studies suggest that changes in sea level related to global climate change may now be counteracting this. Moreover, in areas remote from the centre of the main Scottish ice cap, such as the Northern and Western Isles, eustatic rise in sea level has continued to outpace isostatic uplift and so gradual submergence has dominated in these areas in recent millennia, rather than emergence.

3.3 Hydraulic processes

In understanding the recent (and past) evolution of the coastline a knowledge of the prevailing tidal levels, currents, wave and swell conditions is necessary.

Tidal levels

Tidal levels experienced around the Scottish coastline are generally made up of two components, an astronomical component and a residual component due to weather effects. The main tidal driving forces are the "astronomical forces"'- the major contribution being due to the relative motions of the Earth, Moon and Sun. The differential gravitational effects over the surface of the oceans cause tides with well defined "semi-diurnal" and "diurnal" periods (actually about 12.38 and 24.76 hours respectively).

In addition to the contribution to the tides which results from the earth's rotation, other periods are apparent in the fluctuation of tidal levels, for example the fortnightly spring-neap cycle, corresponding to the half period of the lunar cycle. Due to the slight ellipticity of the earth's orbit around the sun, there is also an annual variation of tidal effects. The solar tidal components are increased due to declinational effects giving rise to the equinoctal tides in September and March. Even longer variations can also be identified, such as that of approximately 18.6 years which corresponds to the changing angle between the axis of the earth and the plane of the moon's orbit.

Analysis of tidal measurements takes advantage of the knowledge of these precisely known periods, and uses a "harmonic" analysis of the measured data to derive information on the phase and magnitude of each tidal constituent, i.e. a component with a defined period. By analysis of the range (i.e. the vertical difference between high and low water levels), and the timing of the arrival of high/low waters, considerable light can be shed on the propagation of tides around the coast. All the tidal energy experienced around the coastline of Scotland stems from the Atlantic and were it not for the openings to the Atlantic, there would be no noticeable tide in the North Sea. Once the tidal energy reaches the shallow waters of the north-west European continental shelf, however, it becomes concentrated by both the reducing water depth and the converging land-masses. A large number of complex processes then occur, including reflections and complicated swirling motions around areas of little or no tidal range (so called *amphidromic points)*.

Sufficient information to predict tides with reasonable accuracy can be gathered in as little as four weeks (a Spring-Neap tidal cycle) in most locations. However, longer periods of recording are necessary to accurately determine all the components. Some of the most influential components, or "harmonics", are normally presented in Tide Tables. It is possible to purchase software (a) to analyse tidal measurements, and/or (b) to use the resulting (or published) harmonics to make your own predictions of water levels. Yearly <u>predictions</u> of water levels are published in the Admiralty Tide Tables. The tide tables also tend to give levels relative to "Chart Datum" and the relationship between the particular "Chart Datum" and a more "universal" vertical datum, e.g. Ordnance Datum Newlyn (ODN) in the UK, must <u>always</u> be carefully established. **For the design of coastal works, it is better to use information derived from analysis of <u>recorded</u> water levels (see below), related to a land-based vertical datum, e.g. ODN.**

Actual water levels experienced around the coastline will vary from those predicted in the Admiralty Tide Tables. Generally speaking the differences between the levels of highest astronomical tide and, say, the largest predicted tide in any year is rather small (i.e. a few centimetres). In practice, this difference is unimportant, at least in Scotland, when compared with the difference between predicted and observed tidal levels due to weather effects. As a very simple example, a static depression with a pressure 38 millibars lower than average can produce an increase of 0.3m in tidal level above that predicted. Such static barometric effects, however, are usually less important than dynamic ones.

A rapidly changing weather pattern will often produce short period fluctuations in atmospheric pressure, which in turn produce fluctuations of a similar timescale in the tidal curve. A good example is provided by the passage of a series of squalls. As a result, undulations in tidal level are caused, with a typical period of a few minutes. These undulations are usually called 'seiches', and on the open coast they normally present no great problems, since the associated changes in water levels, velocities and accelerations are small. However, in enclosed or partly enclosed bodies of water such as harbours, bays or sea lochs the periodicity of the seiches can cause a resonance which amplifies their effect. This rarely occasions any distress to coastal defences but can cause problems to moored ships.

The most important meteorological effects which alter water levels are generally known as 'storm surges'. Such surges result from the effects of wind stress on the surface of the sea. In shallow seas, such as the North Sea, a strong wind can cause a noticeable rise in sea level within a few hours. As one result, tidal levels at the coast can be increased (at both high and low water) until the wind abates. If the wind suddenly drops and then reverses in direction, the excess water held in an area by the wind can then be released, usually as one or more long waves. If such waves are amplified by a narrowing estuary, they can attain a significant amplitude and if the resulting surge arrives at a coast at the same time as the high water of an astronomical tide, the nett result can be devastating.

In the North Sea, such effects can regularly produce a "residual", i.e. a difference between predicted and actual water levels of a metre or so. In severe events, a "surge" can be produced, i.e. a long wave-like disturbance which can add several metres to the tidal level, although fortunately not often at high tide. "Negative surges" can also occur, for example under an anti-cyclone, producing much lower levels than expected.

It is often the combination of a surge and a predicted high tide which causes flooding or damage along a coast. Both the height of surges, and the time of their arrival relative to (predicted) high water are very variable. A considerable amount of research into such events has been carried out, with the main objective of predicting extreme tidal levels. Such predictions are usually expressed in a probabilistic manner, using the idea of "return periods". For example the 100-year (return period) tidal level is that level expected to occur or be exceeded only once, on average, in each century.

For sites where there is insufficient measured data, it is necessary to use numerical modelling to predict such extreme levels (by interpolation from nearby sites), or to "hindcast" tidal levels that have occurred in the past. This latter task is important if information on a particular severe event is required, for example to analyse the causes of flooding or of damage to coastal structures.

Tidal currents

The tides occurring around the coastline of Scotland also result in significant tidal currents, even in areas where the tidal range is small, e.g. off the coast of Islay. Where the shape of the coast allows the tide to fill and empty a large area during each cycle (e.g. estuaries, tidal inlets), the effects of the currents often dominate the hydraulic and sedimentary regime of the area. Even on an open, wave dominated coastline, such currents have a variety of effects. They act together with the waves to transport sediment more efficiently, both on beaches and over the nearshore seabed. As a result of this capacity to transport sediment, the tide can produce shifting banks of sediment which affect coastal processes. The currents also interact with the waves, altering their character, especially where they are similar to the wave propagation speeds. Finally, although the currents tend to be roughly equal on flood and ebb in most places, the small asymmetries can be fundamentally important in a large number of ways, particularly in the transport of fine-grained sediments (muds and clays), together with any adsorbed pollutants, for example heavy metals. In terms of sediment transport in the nearshore zone, the direction and velocity of currents acting at High Water Level may be more important than higher current velocities acting at mid tide. Similarly the tidal residual (vectorial displacement over the period of one tidal cycle) may also be important in the transport of nearshore sediments, particularly in estuaries.

While tidal levels vary slowly in space, and can be represented by a single value for each location at a specified time, tidal currents are much more complex. Very substantial changes in speed and direction can occur over a few tens of metres. Also, currents can change significantly with depth. In the open sea, such changes are often modest, i.e. a gradual reduction in speed below the water surface, but maintaining a consistent direction. However, in shallow water close to a coast, in estuaries, and in the vicinity of structures, the situation is often much more complex. Indeed flows can be in very different, sometimes entirely opposing, directions at the surface and near the seabed.

Waves and swell

The action of waves on the coastline is normally the dominating process influencing the littoral regime. The main wave influence on much of the Scottish coastline is from wind generated waves. Such waves have periods in the range 1-25 seconds, but in Scottish coastal waters the important range is usually between 4 and 20 seconds. The size and period of waves which strike a coast depend on the wind speed, its duration and the 'fetch', that is the unobstructed distance over the sea surface that the wind has travelled. On open coasts where the fetch is very large but the wind blows for only a short period, the wave height is limited by the duration of the storm. Beyond a certain limit, the total fetch length becomes unimportant. Where fetch lengths are restricted, e.g. by offshore islands, a short storm may produce the largest potential waves and any increase in the duration will not cause extra wave growth. Such waves are described as "fetch limited".

On oceanic shorelines, including some of the Scottish coastline (especially the exposed west and north coast), the situation is usually more complicated. Where both the fetch and durations are extremely large waves then become 'fully developed' and their height depends solely on the wind speed. In such situations the wave period usually becomes quite large, and long period waves are able to travel great distances without suffering serious diminution. The arrival of "swell', defined as waves not generated by local and/or recent wind conditions, presents a difficulty in wave forecasting which it is only now becoming possible to overcome, using for example a global wave forecasting model.

Swell waves are of nearly constant period and direction (although the height of successive waves does vary). Swell can be measured easily and accurately gauged "by eye", but is difficult to predict numerically. In contrast, waves generated locally (i.e. over a few hundred kilometres, during a day or so) are much more variable in direction and period. These waves are more difficult to measure, or gauge accurately by eye, but much easier to forecast numerically.

As waves approach the shoreline they are altered as shallow water processes become important. Around much of the UK this starts to affect waves in water depths of around 20m (more off the north and west coasts of Scotland, where larger wave conditions are experienced). In shallow water the main processes in the transformation of waves are shoaling, depth-refraction, current refraction, seabed friction, wave breaking, diffraction and reflection. In general terms this results in a decrease in wave heights as they travel into shallow water but little change in wave period. Whereas offshore wave conditions vary gradually in space, inshore wave conditions are normally site-specific with considerable variation often experienced over relatively short distances. Similarly, around the coastline of the UK, offshore wave conditions are experienced from every directional sector. However, the range of wave directions experienced in shallow water will be much smaller and some offshore wave directions may be unimportant.

For coastal engineering purposes, both offshore and inshore wave conditions are normally defined in terms of the significant wave height, H_s (which is the average height of the highest one third of the waves in a given sea state), the wave period, T_m (which is the time taken for two successive wave crests to pass the same point), and the wave direction, θ.

3.4 Littoral processes

The concept of coastal cells is concerned with sediment movements in the littoral zone (see Figure 3). The rate and direction of such movements are influenced not only by the prevailing hydraulic processes, such as swell and wind waves and tidal, wind and wave induced currents, but also by the bathymetry and the physical characteristics of the beach and seabed (e.g. sediment size).

On a sand or shingle beach, the influence of the natural processes, particularly the wave action, will result in the beach attempting to attain an equilibrium profile. This profile will normally vary depending on the incident conditions. For example there is often a distinct summer/winter cycle where storm wave action in winter months draws beach material further down the beach to below the low water mark resulting in a flatter beach slope. This material is then transported back up the beach during the summer (resulting in a steeper beach slope) during milder wave conditions. Where there is little long term change in the beach morphology the beach system is said to be in dynamic equilibrium. In general, drawdown of the beach occurs at a much quicker rate, e.g. over the period of a single storm, than beach build-up, which may take a number of months. Hence, beach material may appear to have been eroded when it may simply be removed due to a recent storm with there being insufficient time for the material to be moved back onto the upper beach.

Where waves break obliquely to the coast, a longshore current will be created in the surf zone which, when acting with the stirring action of the waves, will result in the longshore transport of material. Littoral drift is a dominant influence in shaping the coastline and is the major cause of coastal erosion (or accretion) particularly where the dynamic equilibrium of the drift regime is altered in any way (either due to natural changes or due to other external influences, e.g. human). On most of Scotland's beaches, sediment will move in both directions along a beach due to waves from different directions. However, it is normally the nett sediment transport rate and direction which is of greatest importance. A nett transport of material may be evident at the coastline, e.g. where there is a build up against a harbour breakwater, or a groyne over a length of time (years). However, it is often difficult to determine the direction and magnitude of any littoral transport confidently, particularly around the coastline of Scotland where the magnitude and direction of wave conditions are variable. To do so normally requires the use of numerical models which predict longshore transport using a time series of wave data. In certain situations, other hydrodynamic processes can cause littoral drift, either adding to or opposing the drift caused by waves breaking obliquely to the beach contours. These processes include tidal currents and longshore variations in breaking wave height. The former can be important when currents are still strong at high (and low) water, especially on straight coastlines (e.g. north of Aberdeen). The latter process is well demonstrated by the shelter provided by an offshore island. This provides substantial spatial variations in wave height, leading to a strong drift from the more active areas into the sheltered water.

In addition to an understanding of sediment movements, a knowledge of the inputs and outputs of sediment into the littoral regime is required. This is known as the sediment budget. It is important to know whether there is any fresh source of beach material being input to the system, e.g. from fluvial sources, cliff erosion or offshore deposits, or whether existing material is being reworked by coastal erosion. Similarly knowledge of whether material is being lost completely from the beach system, e.g. offshore, or if it is moved by wind action into a dune system, or whether it is accreting on the beach, is also important.

To assess the possible impacts and requirements of future coastal protection works, and to understand the likely future evolution of the shoreline, a quantitative understanding of these littoral processes is required.

3.5 Coastal defence, monitoring and management

There are two main types of coastal defence - "Coast Protection" where engineering works are used to protect an eroding coastline from further erosion, and "Sea Defence" where works are provided to prevent flooding of the coastal hinterland due to extreme wave and/or tidal conditions. In assessing existing defences along a frontage there are three main criteria which need to be examined:

- the structural condition of the defence,
- its capacity to prevent overtopping or flooding,
- the impact of the defence on the surrounding littoral regime.

The standard of protection provided by a section of coastal defence depends on the margin of safety it provides against structural collapse or unacceptable high overtopping discharge, for example, both of which are highly influenced by the level and condition of the beach in front of the defence. Each of these criteria are interrelated with structural failure a consequence of the hydraulic forces as well as structural and geotechnical aspects. Overtopping and flooding, as well as depending on the severity of storm conditions, is also a function of the crest level of the structure and its cross-sectional profile. Similarly the condition of the beach in the locality of the defence is a function of the sediment supply, hydraulic conditions and also of the type and design of the structure.

Construction of coastal defences, either to prevent flooding or to control coastal erosion, can have a variety of effects on the coastline and the development of beaches. Linear structures built along a frontage can have various detrimental effects on a beach. For instance, structures constructed in front of eroding cliffs or links areas can prevent the contribution of fresh material to the beaches, with resulting sediment starvation of the coast downdrift, known as downdrift erosion. Where wave action interacts with a linear defence, wave reflections from the structure can lower the level of the beach in front of it, and hence allow greater wave attack on the structure itself.

Of greater impact on the littoral regime is the effect of interrupting or altering the longshore transport of beach material, e.g. by the construction of a harbour breakwater or groyne system. The long-term effects of either reducing or stopping all drift along a coastline can be an increase in erosion at beaches along the coast due to sediment starvation.

3.6 Natural and cultural heritage

There are a number of statutory and non-statutory designations which are used to protect terrestrial sites with natural and cultural heritage value. Statutory designations, or areas which have some form of 'custodial' ownership, have mechanisms which protect them, to a limited extent, from certain development or harmful activities. There is also a wide range of conservation legislation protecting individual habitats and species which may affect future shoreline management. Further information on natural heritage sites can be obtained from Scottish Natural Heritage with information on cultural heritage sites from Historic Scotland.

The range of national and international designations afforded to the coastal areas of Scotland of direct relevance to shoreline management, the designating organisations, and a short description of each taken from the Scottish Office discussion paper, *Scotland's Coasts* (Scottish Office, 1996), are detailed below:

<u>Sites of Special Scientific Interest (SSSI)</u> <u>Scottish Natural Heritage</u>
Designated by SNH under the Wildlife and Countryside Act 1981 Section 28 to protect areas of important flora, fauna, geological or physiological features. Extensive parts of the coast are included within the SSSI network but the legislation only applies to land above MLWS.

SSSIs provide the basis for other national and international designations e.g.. NNRs and SACs. SNH requires to be consulted on developments, or notified of potentially damaging operations, which may affect the SSSI interest.

National Nature Reserves (NNR) — Scottish Natural Heritage

Declared by SNH under the National Parks and Access to the Countryside Act 1949 Section 16. NNRs are owned or leased by SNH or managed under agreement to protect and enhance their outstanding nature conservation interest. Public access may be controlled through bylaws. NNRs are also SSSIs, and some have coastal frontage or are offshore islands.

Marine Nature Reserves (MNR) — Scottish Natural Heritage

Provision is made in the Wildlife and Countryside Act 1981 Sections 36 and 37 to designate marine areas to conserve their marine flora and fauna. This is the only statutory designation which specifically relates to marine areas below the low water mark. Designation procedures involve extensive consultation and protection is by byelaws. There are currently no MNRs in Scotland but a voluntary Reserve operates at St Abb's Head in Berwickshire.

Local Nature Reserves (LNR) — Local Authorities/Scottish Natural Heritage

Section 21 of the National Parks and Access to the Countryside Act 1949, and Section 10 of the Local Government (Scotland) Planning Act 1982, give powers to local authorities in conjunction with SNH to establish Local Nature Reserves for their conservation and amenity value and for the public enjoyment of the countryside. They are controlled by byelaws. To date three coastal LNRs have been established in Scotland.

Special Areas of Conservation (SAC) — Scottish Office

SACs are to be designated under the 1992 EC Directive on the Conservation of Habitats and Species. The special interest of SACs must be strictly protected. SACs, together with SPAs classified under the EC Wild Birds Directive (see below) will form a European-wide network of sites known as Natura 2000. The main aim of the network is to maintain the relevant species and habitats in a favourable conservation status. Coastal and marine sites are among the areas which, following consultations, are being proposed to the European Commission for SAC designation.

Special Protection Areas (SPA) — Scottish Office

The 1979 EC Directive on the Conservation of Wild Birds requires special measures to be taken to protect wild birds and their habitats, including the designation by the Secretary of State of Special Protection Areas to safeguard vulnerable species and regularly occurring migratory birds. Scotland is particularly important for cliff-nesting seabirds, waders and wildfowl. SPAs are subject to the same strict protection of their special interest as SACs.

Ramsar sites — Scottish Office

The Ramsar Convention requires wetlands of international importance to be protected to safeguard wetland habitats and species including those which contain large numbers of wildfowl. Several coastal or marine areas are designated or proposed Ramsar sites. The Secretary of State, on the advice of SNH, designates Ramsar sites and the Government has decided that as a matter of policy these sites should be accorded the same strict protection as for SPAs and SACs.

National Scenic Areas (NSA) Scottish Natural Heritage

National Scenic Areas were introduced by circular in 1980 (amended in 1985) to safeguard areas of outstanding landscape importance as identified by SNH (formerly CCS). Policies for protecting NSAs are set out in development plans and planning authorities are required to consult with SNH on specific categories of development. A number of NSAs incorporate part of the coast.

Natural Heritage Areas (NHA) Scottish Natural Heritage

The Natural Heritage (Scotland) Act 1981 Section 6 makes provision for the designation of NHAs, although none have been introduced to date. These will cover extensive areas including the coast within which nature conservation, landscapes and cultural issues will be managed under a single integrated management plan which will be approved by the Secretary of State.

Areas of Great Landscape Value (AGLV) Local Authorities

Under the provisions of Circular 2/1962, AGLVs are identified by local authorities in development plans with appropriate policies to protect areas of regional or local landscape importance. AGLVs may include parts of the coast.

Environmentally Sensitive Areas (ESA) Scottish Office (SOAEFD)

These are designated by the Secretary of State under the 1986 Agriculture Act to encourage landowners to manage their land to safeguard and enhance the nature conservation, landscape and cultural interest of the land for which a grant is available.

Marine Consultation Areas (MCA) Scottish Natural Heritage

These are non-statutory areas introduced in 1986 where SNH wish to be consulted on developments, in particular fish farms, which are likely to have an impact on the marine environment. There are 29 sites within Scotland, most of which are on the West Coast or the Islands.

Regional Parks and Country Parks Local Authorities

These are promoted by local authorities under the provision of Section 48 of the Countryside (Scotland) Act 1967 to provide informal outdoor recreation and to protect local landscape and amenity for the enjoyment of the public. Country parks are relatively small areas used intensively for informal recreation. Regional parks are extensive areas where existing land use continues but also accommodates recreational activities. Some of these parks incorporate coastal areas.

RSPB Reserves Royal Society for the Protection of Birds

Private reserves owned by the Royal Society for the Protection of Birds where the main interest is ornithology but where there are often other important conservation interests.

Scheduled Monuments Historic Scotland

Ancient monuments surviving in both town and country are tangible reminders of Scotland's long history. Because of the evidence they can provide about Scotland's past, many ancient monuments are given legal protection against deliberate or accidental damage or destruction by being "scheduled". A scheduled monument is one which the Secretary of State considers to be of national importance and is included in a set of records (known as the Schedule) maintained by him under the Ancient Monuments and Archaeological Areas Act 1979.

4 *Cell 10 - Information sources*

4.1 General

Information on the physical characteristics and coastal regime is available from a variety of sources and organisations. The purpose of this section is to provide general details on the availability of such information and of any data sources of relevance to shoreline management. Further, site specific information, particularly on littoral processes and coastal defences, is contained within each of the sub-cell sections.

The UK Digital Marine Atlas (UKDMAP) which was developed by the British Oceanographic Data Centre, Birkenhead provides a reference database of the marine environment for the whole of the UK (BODC, 1991). It provides general information on a wide range of subjects including geology, hydrography, conservation and ecology. A review of information relating to the natural environment, the current protected status of coastal and marine habitats, communities and species and activities is contained in, *Coasts and Seas of the United Kingdom: Region 2:* Orkney (Barne et al, 1996).

Details of physical oceanographic and meteorological (metocean) data collected around the British Isles on behalf of the UK energy industry is summarised in a report by Metocean (1994). This includes details on organisations who have collected information on winds, waves, currents, water levels and other associated parameters. Further information sources of physical data are detailed in the following sections.

4.2 Geology and geomorphology

The geology of the Orkney Islands is reviewed in detail in several studies, the most comprehensive being *British Regional Geology: Orkney and Shetland* (Mykura, 1976). This report references a large number of more detailed localised studies conducted within the north of Scotland. The British Geological Survey have also produced a series of solid and drift geology maps the availability of which is detailed in Table 2.

The Geological Conservation Review was a 12 year research programme initiated by the Nature Conservancy Council in 1977 to identify the key onshore earth science sites in Great Britain using available survey and research information. Site classification was completed in 1989 and the review is currently being published through a series of approximately 40 volumes, 14 of which are now available.

Table 2 Available geological maps

Map No.	Map Name	Solid/Drift Geology	Scale
117	Hoy	Drift	1:63,360
118	Copinsay	Drift	1:63,360
119	Kirkwall	Drift	1:63,360
120	Stronsay	Drift	1:63,360
121	Westray	Drift	1:63,360
122	Sanday	Drift	1:63,360

The geomorphology of the Orkney coast is described in several reports, the main texts being *The Coastline of Scotland* (Steers, 1973) and *The Beaches of Orkney* (Mather, Smith

& Ritchie, 1974). Information on the geomorphology of estuaries within Cell 10 can be found in the Estuaries Review carried out by the Joint Nature Conservation Committee (Buck, 1993).

4.3 Bathymetry

The bathymetry around Orkney is illustrated in detail on the following Admiralty Charts:

Table 3 Available Admiralty Charts

Chart No.	Location	Scale
35	Scapa Flow and approaches	1:30,000
1234	North west approaches to the Orkney Islands	1:200,000
1553	Bay of Kirkwall	1:12,500
1942	Fair Isle to Wick	1:200,000
1954	Cape Wrath to the Pentland Firth and Orkney Islands	1:200,000
2162	Pentland Firth and approaches	1:50,000
2249	Orkney Islands western sheet	1:75,000
2250	Orkney Islands - eastern sheet	1:75,000
2568	Plans in the Orkney Islands	Various
2584	Approaches to Kirkwall	1:25,000
2622	Plans in the Orkney and Shetland Islands	Various

The charts are produced by the Hydrographic Office, Taunton, and also include information on tidal streams, tidal levels and other information of use to the navigation of sea vessels.

4.4 Wind data

There are a number of anemometer stations where winds have been recorded and the information passed to the Met Office which could be useful in estimating wave conditions around Orkney. The only anemometer station on the islands is at Kirkwall which is equipped with Digital Anemograph Logging Equipment (DALE), which logs wind data onto magnetic tape, and which is sent to Bracknell for incorporation into the Climatological Data Bank. The recorder at Wick will also be fairly representative of conditions around Orkney, particularly on the east coast. This station is equipped with Semi-Automatic Meteorological Observing Systems (SAMOS) which produce wind statistics continuously for immediate archiving.

Table 4 Cell 10 - Availability of wind data

Location	Period covered	Anemometer Type
Kirkwall	01/70 - Present	Digital anemograph logging equipment (DALE)
Wick	01/70 - Present	Analysed anemograph from SAWS/SAMOS/CDL station

4.5 Tidal data

There are no A-class tidal gauges in the Orkney Islands. The closest gauges are situated at Lerwick, in Shetland, and at Scrabster and Wick on mainland Scotland. A-class gauges are installed and maintained as part of a national network of tide-gauges organised by the Proudman Oceanographic Laboratory (POL) situated at Bidston, Merseyside. Long term measurements from these gauges have been analysed to produce "harmonic constants" from which predictions of tidal levels can be made for any desired time. Harmonic constants can be used to provide local tide predictions, either by POL, or other organisations who have obtained the relevant computer programs to make such predictions. It should be realised, however, that the harmonic constants derived for these sites may not be as reliable as those from an A-class gauge. Tidal gauges, which are not part of the A-class network, are located at Kirkwall and Stromness, Figure 6.

Information on mean sea level can be obtained from the Permanent Service for Mean Sea Level (PSMSL) which is located at the Bidston Observatory in Birkenhead. This was set up in 1933 and is responsible for collecting monthly and annual mean values of sea level from approximately 1450 tide gauge stations around the world. The contents of the PSMSL data set are described in the report *Data holdings of the PSMSL* (Spencer & Woodworth, 1993) which can be obtained from the Bidston Observatory. Within Cell 10 there are no locations where mean sea level is recorded.

Actual tidal levels, however, can and often do vary significantly from those predicted using harmonic analysis due to the influence of meteorological effects (surges) see Section 3.2.2. The UK Met Office Storm Warning Service operate a surge prediction model provided by POL. This has a 12km spatial resolution around the coast of the UK, and can provide information on surge conditions offshore of the Orkney Islands. To provide predictions at the coastline a more detailed numerical model would be required.

A number of studies have been conducted into extreme (surge) water level predictions (e.g. Graff, 1981; Woodworth, 1987; Coles & Tawn, 1990). The latest research into trends of extreme sea levels (Dixon & Tawn, 1994) provides a site by site analysis, from the A-class tide gauge network, of extremes around the coast of the UK. This research has been extended to produce a spatial analysis of extreme water levels every 20km around the coast of mainland Britain (Dixon & Tawn, 1997) and therefore does not include Orkney.

The Admiralty have always provided information on tidal currents to assist in navigation. The Admiralty Charts usually have a selection of "Diamonds", i.e. locations indicated on the chart by a diamond symbol, with accompanying lists of current speeds at that point throughout the tide. In UK waters, this information is given for both Spring and Neap tides. The currents are usually "depth-averaged", i.e. an average value of the speed throughout the water column.

In addition the Admiralty also produce "Tidal stream atlases" with the offshore zone of Cell 10 covered in the Orkney and Shetland Islands (Hydrographer of the Navy, 1986). These show the currents over a wide area at various states of the tide. The flows are represented by arrows, annotated with the approximate speeds (again for Spring and Neap tides). However, this information is aimed at those navigating ships; it is rarely of much use in very shallow coastal waters or away from the main channels in estuaries.

Tidal current measurements are normally made over relatively short periods of time, (usually less than 1 year), often in connection with a particular study. There are two main sources of such data. Firstly the British Oceanographic Data Centre have a digital inventory of current meter data around the British Isles collected from a large number of both national and international organisations. The directory contains information up to 1991 and is available directly from BODC. The other source is from commercial survey companies carrying out site-specific studies.

4.6 Wave data

Information on offshore wave conditions can be obtained from measured or recorded wave data, or from synthetic wave data generated using numerical models. The only detailed records of instrumentally recorded wave data in Scotland is a catalogue compiled by Metocean (1994) and the MIAS catalogue (MIAS, 1982) which was compiled in 1982. An updated digital version of the MIAS catalogue is presently being developed. Wave recording occasionally is conducted by commercial organisations, normally in connection with marine construction projects, e.g. harbour development. There is no known recorded wave information around the Orkney Islands

Information on wave conditions can also be obtained from the VOS (Voluntary Observations from Ships) archives. The majority of ships of passage make regular observations of wind and wave conditions as part of their routine duties. This information is collected worldwide and collated by the UK Meteorological Office. The records include date, time, location, wind speed and direction, significant wave height (H_s), zero-crossing period (T_m) and wave direction. Although not scientifically measured, VOS records have been found to be a useful source of data where there has been a large number of records spanning over many years, e.g. major shipping lanes. VOS data is available in the form of monthly, seasonal and annual frequency tables of wave height and period in 30° sectors for sea areas specified in 1° latitude and longitude squares. Details of the density of VOS data can be obtained from the Met Office.

When using VOS data it is important to ensure that the selected area is large enough to contain sufficient data in each sector for a reliable analysis of extreme conditions, but small enough to ensure that conditions are representative of the region of interest. In addition, for an analysis based on VOS observations to be valid, it is necessary to ensure that the exposure of the location of interest is the same as that of the VOS area used.

In many locations offshore wave prediction using numerical modelling techniques is difficult. Around much of the UK coast it is necessary, as a minimum, to have a model which can predict the generation of waves over a substantial part of the sea or ocean, and then to "follow" those waves as they develop into swell. A number of such numerical models exist, all run by national meteorological offices, or other governmental departments. In the UK, the most appropriate model to use is the Meteorological Office European Wave Forecasting Model.

Two surface wave models are run at present on an operational (daily) basis at the UK Meteorological Office. These are the result of an evolving series of such models, in use since 1976. They were designed primarily for offshore application, for example in ship routing and operation of offshore structures. The model calculations are carried out on a polar stereographic grid, whose exact spacing varies from one latitude to another. The European Wave Model (grid spacing about 30km) is nested within the Global Model (grid spacing about 150km) from which it takes its boundary wave conditions. The 30km grid size means that shallow water effects are not well represented in the model, and grid points closest to the land are not used for prediction purposes. Before use, the model predictions therefore need to be transformed from 20-50km offshore to the shoreline (see below).

Both models are run twice daily, driven by wind fields extracted from operational global weather forecasting models. They produce wave forecasts from 12 hours prior to the run-time ("T") up to 36 hours ahead, at 3 hourly intervals. As well as noting the time, date, latitude and longitude, each forecast gives the wind speed and direction, and the significant wave height, mean wave period and wave direction for the separate wind-sea and swell components and overall. The data from T-12 hours to T+0 hours is permanently stored in an archive, whilst the data from T+0 hours to T+36 hours is immediately disseminated for forecasting purposes. Sea state observations from fixed buoys, oil platforms, Ocean Weather Ships, and more recently satellite wave measurements, are used for real-time "calibration" of the models, and also for periodic validation.

The archived information provides a very useful "synthetic" offshore wave climate. Figure 6 shows the grid point locations offshore of the coast of the Orkney Islands.

Table 5 Cell 10 - Sources of numerically modelled wave conditions

Location	Offshore/Inshore Position	Period	Mean water depth (m)	Wave data	Contact
On a regular grid 0.25°lat. by 0.4°long.	Offshore: First point is normally less than 20km from the coast	1986 onwards	Variable	Wind, swell and total sea climate and extremes	UK Met Office or HR Wallingford
Rapness, Westray	Inshore: NE of Rapness Sound Rapness Sound North of Eday	-	34m 14m 54m	Wave distribution & 1, 10 & 50 year extreme conditions	HR Wallingford
Kettletoft	Inshore: 250m seawards of pier Tip of pier	-	9.68m	0.01, 0.05, 0.1,1,5,20 & 50 year extreme conditions	HR Wallingford
Kirkwall	Inshore: 59°N 2°57.5'W West of pier	-	6.9m	0.1, 1, 5, 10, 20, 50 year extreme conditions	HR Wallingford
Churchill Barrier No 2	East of Barrier on -10m CD contour	-	13.3m & 13.8m	0.1, 0.2, 0.5, 1.0, 10, 50 year extreme conditions	HR Wallingford
Burwick Bay, South Ronaldsay	Offshore: SW of Lother Rock Inshore: 50m SW of ferry terminal	-	-	Wave distribution & 0.1, 1, 10 & 50 year extreme conditions.	HR Wallingford

Modern numerical methods are capable of accurate predictions of "wind-sea" for offshore areas, especially if there is good quality, sequential wind data available to provide the basic input conditions. The final stage in numerical wave prediction is to transform such offshore wave information into corresponding nearshore conditions. This may be carried out just for a few offshore conditions (e.g. waves expected to occur only in exceptional storms), or for a whole wave "climate". For further details of the range of numerical techniques available, the reader is referred to a recent report by Dodd and Brampton (1995). However, in outline, all such models start from a digital representation of the water depths between the offshore point at which waves are predicted, and the stretch of coastline under consideration. A number of alternative techniques are available that calculate the way the wave energy propagates shoreward; they all include the processes of refraction and shoaling, and many can include other effects such as frictional dissipation, the shelter provided by offshore islands or headlands, the effects of tidal currents or the continuing growth of waves as they travel across the area being modelled. The accuracy of such transformation methods is generally good, provided an appropriate model has been chosen. The inshore wave climate has been derived at a number of locations along the coastline of this cell. These locations are detailed in Table 5 and are shown on Figure 6.

4.7 Natural and cultural heritage

Information on statutory designations and protected sites of natural heritage importance, and on certain non-statutory sites, is provided by Scottish Natural Heritage. A description of the various designations is given in Section 3.6.

Within Cell 10 the number of designated natural heritage sites is given in Table 6. The locations of SSSI is provided in Figure 7 with further information detailed in Appendix 1. Other natural heritage designations are shown in Figure 8. These data are accurate to September 1996.

Table 6 Cell 10 - Natural heritage designations

Designation	Number	Designation	Number
SSSI	19	NSA	1
NNR	-	NHA	-
MNR	-	AGLV	-
LNR	1	ESA	-
SAC	2	MCA	-
SPA	5	RSPB	9
RAMSAR	-	LWT	-

Note: Data correct to September 1996. Supplied by Scottish Natural Heritage.
The distribution of designated SACs and SPAs has changed significantly since these data were compiled.

Details of recent additions to this network can be obtained from Scottish Natural Heritage.

The Royal Commission on the Ancient and Historical Monuments in Scotland (RCAHMS) maintain a GIS database (National Monuments Records of Scotland, NMRS) with the locations of scheduled Archaeological and historical sites. Only the location of sites within 50m of the coastline was requested from RCAHMS in this study. However, the RCAHMS advised that to locate all coastal sites would require a resolution of 500m from the coastline.

Table 7 Cell 10 - Information sources for sites of cultural heritage

Advice or information on:	**Contact**
Scheduled monuments	Historic Scotland
Designated wrecks	Historic Scotland
The protection & management of sites and monuments	Historic Scotland or Regional Archaeologist
Sites or monuments already known	Historic Scotland/Regional Archaeologist/RCAHMS
Archaeological remains discovered during development	Historic Scotland/Regional Archaeologist
The discovery of a site	Regional Archaeologist/RCAHMS
An isolated artefact find	Regional Archaeologist/National Museums of Scotland/Local Museum
Damage to a scheduled monument	Historic Scotland
Damage to an unscheduled monument	Regional Archaeologist

Adapted from *Archaeological and Historical advice in Scotland* available from Historic Scotland.

Figure 9 shows the location of scheduled archaeological and historical sites within 500m wide by 10km long strips along the coastline of Cell 10. Because of the low resolution these will include a large number of sites which are not truly coastal. Only where more detailed surveying has been conducted can an assessment of the number of coastal sites be determined. There are also a large number of sites, e.g. Listed Buildings, which do not appear in the NMRS database. Appendix 2 shows the actual locations of scheduled sites within 500m of the coastline obtained from the RCAHMS GIS database.

5 *Cell 10: Orkney*

5.1 General

Cell 10 is defined as the Orkney coastline. The concept of coastal cells, as defined in Section 2.1, is not really applicable to Orkney as there are few areas of continuous, or semi-continuous, "soft" coastline. Beach areas tend to be pocket beach types which, at present sea levels, tend to have little longshore continuity.

The cell has been split into four sub-cells based on the exposure to the wave climate and the grouping together of coastlines with similar characteristics. Sub-cell 10a encompasses much of the high energy outer coastline of The Mainland and Hoy. Sub-cell 10b covers the relatively more sheltered Scapa Flow coastline. The sheltered north eastern coastline of the Mainland is defined as Sub-cell 10c with the remaining islands to the north east covered in Sub-cell 10d.

Within each sub-cell relatively self contained beach units can also be identified. For example there is unlikely to be significant interchange of beach material between the individual beach areas in sub-cell 10a. The locations of these "semi-independent beach units" are shown on the relevant littoral process maps.

Sections 5.2 to 5.6 describes the coastal regime occurring within Cell 10.

5.2 Cell 10: Physical characteristics

5.2.1 General

The characteristics of Cell 10 and processes occurring within it are described under the headings of Geology and geomorphology, Hydraulic processes, Littoral processes and Coastal defences and monitoring.

The geology and geomorphology of the coastline of Scotland is an extremely complex topic with few detailed texts on the subject. Only a brief description is provided within this report in the context of the influence of the solid geology on present day coastal processes, and the geomorphological features evident around the coastline. The drift deposits occurring within each sub-cell are shown in Figure 10.

Details of the dominant hydraulic processes, i.e. the tides, currents and waves are described. Tidal elevations within each sub-cell are described and, where known, details of any surge information. The direction of the main tidal currents and magnitude of tidal velocities is also detailed. Any areas where significant tidal flooding occurs are noted. The offshore wave climate (both total sea and swell) has been predicted from the Met Office Wave Model along with a range of extreme offshore wave conditions. The dominant nearshore processes which affect the transformation of offshore to inshore wave conditions are also described.

The next section within each sub-cell describes the main littoral processes. The dominant beach sediment sources and sinks are described. Where possible the main nett longshore transport directions are detailed with an indication of the dominant forces causing this drift. Known areas of long term nett erosion and accretion are also described. Where more detailed engineering studies have been conducted, these are referred to for any indication of erosion or accretion rates. Any known locations where man-made development in the coastal zone has altered the littoral regime are also described. Details of the foreshore and hinterland characteristics are shown in the relevant figures for each sub-cell along with the dominant littoral processes. Locations where maintenance dredging is conducted are mentioned and, where possible, any known dredging rates and sources of siltation.

The final section details the location, type and influences of coastal protection work. Where possible the length of coastline protected has been given along with a brief indication of the present state of the defences and any significant impacts on the coast due to these works. Locations where beach monitoring or coastal surveys have been conducted are mentioned and, where possible, details of the length of such records and monitoring authorities given. Details of existing coastal defences and locations where regular monitoring is conducted are shown in the relevant figures for each sub-cell.

5.3 Sub - cell 10a: Cost Head to Mull Head

5.3.1 Geology

The solid geology of the Orkney Islands is composed almost entirely of sedimentary rocks of Middle and Upper Old Red Sandstone Age (i.e. formed between 387Ma and 360Ma). Within this sub-cell the western coastline of the mainland, and the islands of Burray and South Ronaldsay, are dominated by Middle Old Red Sandstone (ORS) deposits. These fall into two major groups, the lower group, which comprises the Stromness Flags and Rousay Flags, and the upper group, the Eday Bed. The Stromness Flags outcrop as high sea cliffs along the entire western seaboard of the Orkney Mainland. These outcrops consist mainly of flagstones, with sequences of marine deposits of siltstones, mudstones and sandstones.

The Middle ORS of the east facing coastline of this sub-cell comprises the Rousay Flags and the Eday Beds. The Rousay Flags are similar in lithology to the Stromness Flags, with the Eday Beds composed of yellow and red sandstones with pebbly lenses. The region is heavily faulted and has resulted in the variability in the ORS outcrops occurring at the coast. Much of the ORS deposits outcrop as cliffs along the eastern coast, but the elevation is not as high and much more variable than occurs on the west coast.

Upper Old Red Sandstone deposits are principally confined to the island of Hoy. The strata consist of layers of various sandstones and bands of marl. These outcrop as spectacular high cliffs along the western coastline.

Volcanic activity has had some influence upon these islands with intrusive dykes and sills occurring within the ORS deposits, particularly around the south and west coastlines. The ORS cliffs are generally still actively eroding due to the severity of the wave conditions and the relatively soft nature of this rock type. However, the influence of variable erosion rates, due not only to these thin outcrops of igneous rocks but also due to differences in rock hardness within the ORS, can be seen in the range of wave cut features evident around this coastline. Cliff erosion has input a considerable amount of sediment into the nearshore zone around the high energy coastline of the Orkney Islands but it is doubtful whether much of this material finds its way onto the few beaches within this sub-cell.

The solid geology does have considerable influence on the character of the beaches in the Orkney Islands. Many beaches are constrained between cliffs or rock platforms, particularly in this sub-cell, which influence the nearshore wave conditions and the resulting beach planshapes. Other outcrops act as hinge points for the many tombolo, salient and spit features which characterise the Orkney coast. This is more evident on the lower energy coastlines around the islands to the north east of the Mainland than in this sub-cell.

Glaciation had a considerable effect on the Orkney Islands with ice scouring smoothing out the original relief to produce the present day rounded landscape. Glacial deposits are limited to boulder clay which caps the bedrock, mainly on the lower ground. Such deposits range in thickness from 3m to 10m and are exposed at the coastline at a number of very localised sites. Boulder clay deposits cap much of the ORS along the eastern coastline of this sub-cell, but there is little evidence of any glacial deposits along the western coastline of Hoy and the Mainland. Marine erosion of this till material will have provided a high percentage of the siliceous material on many of the beach areas. There is little evidence of fluvio-glacial deposits either onshore or around the immediate nearshore zone with such deposits restricted to the valley behind Rackwick Bay. Hence, offshore or fluvial deposits is unlikely to have provided any significant source of beach material in these islands.

Unlike the majority of mainland Scotland there is little evidence of previous higher sea levels in Orkney. There are no raised beaches or well defined shore platforms above present sea levels. Instead, since the end of the last Ice Age Orkney appears to have been experiencing continuous submergence of the land (there is evidence of submerged peat beds at a number of locations e.g. Bay of Skaill). It is thought that the isostatic depression which occurred due to the Ice Sheet over mainland Scotland caused uplift of the land mass in the Orkney region; submergence of the landmass of Orkney appears to have been occurring ever since. Postglacial sediments found in the coastal hinterland are limited to blown sand deposits. These deposits can be extensive, for instance about a third of Sanday is covered with blown sand, but are less so in this sub-cell due to the lack of beach areas.

5.3.2 Hydraulic processes

The mean Spring and Neap tidal ranges for this sub-cell are shown in Figure 11 and detailed in the table below. The mean Spring Tidal Range is between 2.6 and 2.9m around the outer coastline of mainland Orkney and Hoy with a corresponding Neap Tidal range of between 1.1 and 1.3m.

Table 8 Sub-cell 10a - Predicted tidal levels and ranges

Location	MHWS (m CD)	MLWS (m CD)	Spring Range (m)	MHWN (m CD)	MLWN (m CD)	Neap Range (m)	CD to ODN (m)	CD to OD (local) (m)
Stromness	3.6	0.7	2.9	2.7	1.4	1.3	-1.69	-1.92
Burwick	3.4	0.8	2.6	2.7	1.6	1.1	-1.67	-1.92
Muckle Skerry	2.6	0.4	2.2	2.0	1.0	1.0	-	-
Burray Ness	3.3	0.6	2.7	2.5	1.3	1.2	-1.67	-1.92

The elevations quoted in the above table are all relative to Chart Datum (for the particular location). The conversion to the standard land based datum (Ordnance Datum Newlyn) is shown in the second last column. Orkney also has a local land based datum. The conversion from Chart Datum to Ordnance Datum (local) is shown in the final column.

There is little information on extreme water levels within this sub-cell. The 1:50 year return period surge is given to be between 1.25m and 1.5m around Orkney. Estimates of extreme water levels have been made at all of the A-class tidal gauge locations (Dixon & Tawn, 1994). No estimates were made for the Orkney coastline with the nearest predictions being for Lerwick and Wick. This work was extended to provide a spatial estimate every 20km around the Scottish mainland coast (Dixon & Tawn, 1997). However, this does not cover the Orkney Islands.

Tidal currents along the outer coastline of the Orkney Islands are significant and highly variable, particularly in the Pentland Firth and a number of the channels between islands. To the west of the Orkney islands, the east going flood stream divides off Rora Head on Hoy with part of the stream running north east and the other part running through the Pentland Firth, Figure 11. The direction is reversed on the westerly ebb. The strength of the stream increases rapidly into the Pentland Firth and conversely on the ebb the current speed reduces to the north west. Off Tor Ness the Spring rate on both flood and ebb is between $3ms^{-1}$ and $3.5ms^{-1}$. Within the Pentland Firth, tidal currents are complex and run at high speeds. Large eddies and other complex flow patterns occur with peak current speeds of up to $5ms^{-1}$ in the main channel of the Pentland Firth, Figure 11. However the main tidal flows tend to be pushed offshore by the rocky headlands which occur around this coastline, with current speeds closer inshore within the bays and beach areas being much less significant.

On the eastern coastline the flood tide is to the south west and the ebb to the north east. Between Mull Head and Point of Ayre, and within Copinsay Pass, peak Spring rates are of the order of $1.5ms^{-1}$ to $2ms^{-1}$ on both flood and ebb. To the south of Point of Ayre, the main tidal stream does not pass close to the coastline with current speeds off Holm and Water Sounds weak and variable in direction. Between Grim Ness and Old Head on the east coast of South Ronaldsay the tidal stream runs south for up to 9 hours of the tidal cycle with no corresponding north stream. The peak Spring current speed is about $0.5ms^{-1}$ but increases to the south where peak current speeds around Old Head are approximately $3ms^{-1}$.

In the entrance to Scapa Flow, tidal streams are extremely complex. Strong current speeds tend to be restricted to the main channels but cause many eddies to form in sheltered regions.

The Met Office European Wave Model has been used to predict the offshore wave climate to the east and west of the Orkney Islands and is shown in Figures 12 to 15. The offshore wave climate east of Orkney is not significantly dominated from any particular direction sector, but there is a marginally greater percentage of wave conditions experienced from the NNE, from which the most severe wave conditions are also experienced. The swell wave climate for the offshore region is shown in Figure 13. Swell dominantly occurs from the north easterly sector. Some of this swell will have been generated within the Norwegian Sea, but swell waves from the north and west diffracting around both the northern coastlines of Orkney and Shetland will also provide a significant component of the swell energy off the eastern coast of Orkney. The swell component does constitute a significant proportion of the total wave energy in this region and extreme swell conditions can be significant. Predicted extreme wave heights for the total sea and swell conditions for the east coast of Orkney are detailed in the table below:

Table 9 Offshore total sea and swell extreme significant wave heights east of Orkney

Return Period (Years)	**Total sea extreme significant wave height (m)**	**Swell sea extreme significant wave height (m)**
1	7.39	4.29
10	8.72	5.41
100	9.94	6.49

The total sea climate off the west coast of the Orkney Islands tends to be more severe than that experienced on the eastern coastline, with extreme events occurring more frequently. The total sea and swell wave climates for the offshore region to the west of Orkney are shown in Figures 14 and 15 respectively. The total sea wave climate is dominated from a narrow wave window between 240°N and 300°N with over 50% of conditions experienced from this sector. However, wave conditions over 8m can be experienced from any direction between south west and north. The swell climate is also dominated by waves from a narrow sector, with over 70% of conditions experienced from between 260°N and 320°N. Extreme significant wave heights for the total and swell sea are detailed in Table 10.

Table 10 Offshore total sea and swell extreme significant wave heights west of Orkney

Return Period (Years)	Total sea extreme significant wave height (m)	Swell sea extreme significant wave height (m)
1	10.65	4.82
10	12.79	5.94
100	14.82	7.01

The only known location around the coastline of this sub-cell where nearshore wave conditions have been recorded or predicted is at Burwick (HR Wallingford, 1985). Deep water (-50m CD contour) occurs close to the coastline all around this coast, but particularly along the west coast. Very little dissipation of offshore wave energy will occur before the severe offshore wave conditions reach the coastline. On the eastern coastline, the immediate seabed slope is slightly shallower, particularly off the mainland, which will afford some shelter to the coastline from the most severe wave conditions.

5.3.3 Littoral processes

The outer coastline of sub-cell 10a is a high energy environment dominated by the wave climate. The coastline is characterised by cliffs with few beach areas apart from a few pocket beaches, Figure 16. The existing beach sediments will have derived from a combination of eroded glacial till, from erosion of the sandstone cliffs, and from shell deposits which constitute a high proportion of the sand sized material. However, at present, despite ongoing marine erosion of much of the western coastline, (i.e. the sandstone cliffs) the supply of fresh sediment to the beach areas is limited, Figure 17.

Considerable attention is afforded to the Bay of Skaill due to the threat of coastal erosion to the Stone Age settlement of Skara Brae. The Bay of Skaill is a typical headland dominated pocket beach. The shape of the bay is largely determined by the width of the mouth of the bay (and the influence of the rock platforms at the mouth) and the wave climate, particularly the swell wave component. Around much of Scotland the relatively static sea level (in relation to the land elevation) over the last 3000 years has resulted in the planshape of such bays generally being in an extremely stable condition. However, the Orkney region has undergone postglacial submergence, i.e. the trend appears to have been continuous sea level rise (relative to the land mass) rather than the fluctuations in sea/land level which are evident around much of the Scottish mainland. It is known that Skara Brae was previously some distance from the sea and hence the Bay of Skaill may still be evolving in response to present sea levels, having not yet reached a static equilibrium planshape. Local residents have also indicated that there has been noticeable erosion of the southern headland over the last 50 years resulting in the mouth of the bay widening (HR Wallingford, 1994). This may also be causing significant adjustment in the planshape of the bay. The protection of this site is discussed in Section 5.7.3. There is some evidence to suggest that similar effects are occurring at other pocket beach areas on this western coastline.

The east coast beaches of this sub-cell also tend to be pocket type beaches, with rock platforms generally found at either end of each beach unit. The beaches tend to be dominantly sand, with the beach material derived largely from shell material. Sand will also have been derived from erosion of till deposits which will also have been the source for any shingle material occurring upon the beaches. The present day supply of material to the beaches along this coastline is limited, but there also tends to be little loss of beach material from such pocket beach systems. There is little information as to whether these pocket beaches are still evolving in the same manner as those on the western coastline or whether they are relatively stable with only episodic storm damage affecting them. However, the tombolo at Dingyshowe is presently very thin with a high risk of a permanent breach. The only location where there is any information of note on littoral processes is the accretion of material against the Churchill Barriers, particularly Barriers Nos. 3 and 4. However, erosion is occurring along the coastline to the south east of Barrier No 4 with the Piper-Flotta Oil Pipeline having recently become exposed. This is currently being investigated by HR Wallingford.

Summary of Erosion and Accretion

Most of this coastline is experiencing long term erosion. However, there is little quantitative information even at well known sites such as within the Bay of Skaill. Accretion if most evident on the eastern side of Churchill Barriers Nos. 3 and 4.

5.3.4 Coastal defences

There are a number of coastal defences within this sub-cell, Figure 18. Fronting Skara Brae is a mass concrete seawall. The wall is being outflanked at both ends, is causing beach lowering immediately in front due to wave reflections, and is susceptible to wave overtopping (HR Wallingford, 1994). To alleviate these problems a rock beach fronting the site is being proposed.

At The Ayre, which links Hoy to South Walls, a masonry seawall fronts the road which runs along the centreline of the isthmus. This was built around the turn of the century and has resulted in the build up of a sand beach on the southern coastline.

The only other defences are the Churchill Barriers. The effect of the barriers upon the sand movements are described in Section 5.3.3. Barrier No 2 is prone to substantial overtopping with the road having to be closed on a number of occasions. A detailed study of the overtopping problem along this barrier was conducted by HR Wallingford (1995).

5.4 Sub - cell 10b: Scapa Flow

5.4.1 Geology

A general description of the solid geology in the Orkney Islands is provided in Section 5.3.1. All of the ORS groups evident in the Orkney Islands outcrop along the coastline of Scapa Flow. The boundaries of the basin are heavily faulted, e.g. the North Scapa Fault which runs along the southern coastline of the mainland, which results in considerable variations in the lithology of the sandstones evident at the coast. Unlike the exposed high energy coastlines, ORS cliffs are largely absent in this sub-cell. Instead, the solid geology outcrops as a low rock platform which is capped by thick boulder clay deposits or peat. Only on Hoy are the boulder clay deposits largely absent. The general submergence of the Orkney

Islands can be seen in Scapa Flow where till deposits have been drowned and now floor much of the Bay.

5.4.2 Hydraulic processes

The mean spring and neap tidal ranges for this sub-cell are shown in Figure 11 and detailed in the table below. The mean spring tidal range varies between 2.4m in Widewall Bay and 3.0m at Stromness with corresponding neap tidal ranges of 1.4m and 1.6m respectively.

Table 11 Sub-cell 10b - Predicted tidal levels and ranges

Location	MHWS (m CD)	MLWS (m CD)	Spring Range (m)	MHWN (m CD)	MLWN (m CD)	Neap Range (m)	CD to ODN (m)	CD to OD (local) (m)
Widewall Bay	3.4	1.0	2.4	2.9	1.5	2.4	-1.67	-1.92
St Mary's	3.7	0.8	2.9	3.0	1.4	2.9	-	-
Stromness	3.8	0.8	3.0	3.1	1.5	3.0	-1.69	-1.92

The elevations quoted in the above table are all relative to Chart Datum (for the particular location). The conversion to the standard land based datum (Ordnance Datum Newlyn) is shown in the second last column. Orkney also has a local land based datum. The conversion from Chart Datum to Ordnance Datum (local) is shown in the final column.

There are no predictions of extreme water elevations within this sub-cell.

Tidal flows are only significant within the channels in the entrances to Scapa Flow. At the southern entrance current patterns between South Ronaldsay and Hoy are extremely complex and variable with strong eddies a common feature. In general peak spring current speeds are less than $2ms^{-1}$. At the western entrance current rates are much stronger. Peak spring rates of $4.25ms^{-1}$ occur with the ingoing stream slightly stronger than the outgoing stream. The current speed decreases rapidly into the Scapa Flow with there being little flow between Houton Head and Cava. Elsewhere within Scapa Flow current speeds are variable in direction and generally less than $0.25ms^{-1}$.

The entrances to Scapa Flow will dissipate much of the offshore wave energy preventing little propagation of waves generated around the Orkney Islands into Scapa Flow. Instead wave conditions within Scapa Flow will be dominated by locally generated wind-waves. The maximum fetch length (about 15km) extends from Scapa Bay to the south west. Under a Force 9 gale this will result in a significant wave height offshore of approximately 1.5m with a mean period of about 4.5s.

5.4.3 Littoral processes

There are few beach areas around the coastline of Scapa Flow although inactive shingle and cobble fringe beaches front much of the coastline, Figure 16. Few studies, other than the Beaches of Orkney Report (Mather et al, 1973), have been conducted of the beaches in this region. The availability of sediment within Scapa Flow for the formation and development of beaches is low. Scapa Flow was formed in Pre-glacial times and is flat bottomed with a covering of till. Limited reworking and sorting of this till by wave action will have provided an input of fine sediments to form the beach areas, e.g. at Waulkmill Bay. Where shingle and cobbles occur, this is likely to have derived from erosion of glacial tills. Present day sediment input is extremely limited, Figure 17.

The construction of the Churchill Barriers and the seawall between The Ayre and North Bay on Hoy has cut off an input of sand sized material into Scapa Flow which was previously moved through these channels by a combination of wave and tidal currents. There is some concern that the construction, particularly of the Churchill Barriers, has cut off a supply of sand to the beach at Scapa. This may be the case as the sediment at Scapa has a high shell content (relative to other beaches within Scapa Bay) indicating that potentially this sediment may have derived from shell material transported through the channels (the beaches on the eastern side of the Churchill Barriers have a very high shell content). However the rate of supply of material through the barriers would have been relatively low (i.e. it has taken 50 years to develop the present build up on the eastern sides of the barriers). It is more likely that the vertical seawall directly backing the beach has much more of an effect in the apparent loss of sand from the upper beach due to increased wave reflection during high tides than any loss of supply due to the Churchill Barriers.

Capital dredging has been conducted at Stromness (1989) by Stromness Harbour Authority and within Scapa Flow (1992) by Orkney Islands Council.

Summary of Erosion and Accretion

There are no documented, or known areas, of long term erosion or accretion within this sub-cell.

5.4.4 Coastal defences

There is only one location where coastal defence work has been conducted within Sub-cell 10b, Figure 18. Backing the eastern half of Scapa Bay a low vertical seawall protects the B9053 which runs directly behind it. The wall appears to be in a reasonable condition but will experience significant overtopping during a high tide with a storm from the south westerly sector. Wave reflections from the wall will also act to lower beach levels fronting the wall. If this does occur during storm conditions and the foundations become exposed there is a high risk of localised failure.

5.5 Sub - cell 10c: Mull Head to Cost Head (North coast of the Mainland)

5.5.1 Geology

The geology of the northern coastline of the mainland is similar in lithology to the rest of the Orkney Mainland, being dominated by Middle ORS. The influence of faulting is also a feature of this coastline, particularly around the Deer Sound region at the eastern end of this sub-cell However, the solid geology does not outcrop in the form of high cliffs as is evident on the more exposed coastline of these islands, apart from the coastline around Mull Head. Instead the solid geology tends to outcrop in the form of a low rock platform. This platform is near continuous along the coastline at the western end of this sub-cell but forms intermittent outcrops to the east. These intermittent outcrops acts as hinge points upon which the bay planshapes of the beach areas form.

Glacial deposits are limited to boulder clay which overlies the ORS along most of the coastal edge in this sub-cell. Much of the sediment occurring around the coastline of this frontage will have derived from marine erosion of these deposits. There is no evidence of postglacial sea levels ever being above present day sea levels hence there are no post glacial marine deposits. Similarly, there are few areas of blown sand deposits, although extensive beds of 'aeolianite' (cemented sand dunes) occur around Evie.

5.5.2 Hydraulic processes

The tidal cycle experienced around the Orkney Islands is semi-diurnal. The mean spring range is between 3.0 and 3.2m with the corresponding mean neap range being between 1.6m and 1.7m, Table 12.

Table 12 Sub-cell 10c - Predicted tidal levels and ranges

Location	MHWS (m CD)	MLWS (m CD)	Spring Range (m)	MHWN (m CD)	MLWN (m CD)	Neap Range (m)	CD to ODN (m)	CD to OD (local) (m)
Deer Sound	3.8	0.8	3.0	3.1	1.5	1.6	-1.54	-1.83
Kirkwall	4.0	0.8	3.2	3.2	1.5	1.7	-1.40	-1.66
Tingwall	3.9	0.8	3.1	3.2	1.5	1.7	-	-1.66

The elevations quoted in the above table are all relative to Chart Datum (for the particular location). The conversion to the standard land based datum (Ordnance Datum Newlyn) is shown in the second last column. Orkney also has a local land based datum. The conversion from Chart Datum to Ordnance Datum (local) is shown in the final column. There are no predictions of extreme water levels in this sub-cell.

Off Mull Head tidal currents can reach about $1.5ms^{-1}$ on the easterly going stream and about $0.85ms^{-1}$ to the west. These currents tend to act off these salient points with current speeds within the bays, such as Deer Sound and Inganess Bay being inappreciable. Similarly, along the nearshore zone of Wide Firth current speeds are insignificant close to the shoreline. The strength of the tidal stream increases along the coastline through Eynhallow Sound with peak Spring tide rates of up to $2ms^{-1}$ occurring on both flood and ebb.

Wave conditions experienced along much of this coastline will tend to be locally generated wind-waves due to the restricted fetch lengths and shallow water influences experienced to the north east. Only along the eastern part of this sub-cell (between Mull Head and Head of Work) will offshore wave conditions from the east propagate close inshore. The total sea and swell wave climates experienced off the east coast of Orkney are shown in Figures 12 and 13 with extreme conditions detailed in Table 9 of Section 5.3.2. However, shallow water effects will dissipate much of the offshore wave energy before it reaches the beach areas occurring along this frontage.

The existence of numerous of islands to the north east of this sub-cell will result in all wave conditions being fetch limited. The severity of wave conditions will vary greatly along this frontage and will depend to a large extent on wave direction with refractive and diffractive effects being important. The inshore climate has been derived within the Bay of Kirkwall (HR Wallingford, 1986a&b). This estimated that in the centre of the bay, to the north east of Crow Ness , the 1:1, 1:5, 1:20 and 1:50 year return period significant wave heights were of the order of 1.15m, 1.37m, 1.57m, and 1.71m respectively. By the time that these wave conditions have propagated into the inner part of the bay, they have lost their directional nature due to refraction effects. Other than this, there is little information on wave conditions along this coastline.

5.5.3 Littoral processes

Most of the beaches on the northern coastline of The Mainland are located to the east of Kirkwall within Inganess Bay and Deer Sound. The main beach areas are shown in Figure 16 with the dominant littoral characteristics presented in Figure 17. Much of this coastline is backed by glacial till deposits which rest upon the underlying Old Red Sandstone. Erosion of these deposits will have produced virtually all of the beach material for the formation of the beaches along this frontage. On the more sheltered beaches shell material is largely absent reflecting the lack of offshore wave energy from the east propagating into these shallow bays. However, at the more exposed sites along the outer sections of these bays, e.g. Redbanks and Sand of Ouse there is a much higher concentration of shell material. There is no information on present day littoral processes occurring along this coastline.

Much of the coastline to the west of Kirkwall is fronted by rock platform often with fringe cobble/shingle and sand beaches derived from erosion of the glacial tills. There is little apparent littoral transport occurring along this coastline, other than episodic erosion of the till material when severe storm conditions coincide with high tidal levels.

The only other beach area of note is at Evie in the north west of the sub-cell. The sand material occurring upon this beach is largely derived from shell debris. Swell wave action propagating into Eynhallow Sound will have been responsible for moving some of this material onshore in conjunction with the strong tidal currents which occur through the sound and will also be responsible for moving sediment onto the beaches. Hence there is the potential for a nett gain of beach material upon this beach (i.e. there is likely to be a low fresh input of beach material with little loss).

<u>Summary of Erosion and Accretion</u>
Long term erosion is likely to be occurring on much of this coastline but there is little documented evidence of this. Likewise there are no known areas of significant accretion.

5.5.4 Coastal defences

The only coastal defence work within this sub-cell is located around Kirkwall where a variety of masonry seawalls and rock revetments occur, Figure 18.

5.6 Sub - cell 10d: Orkney: The Northern Isles

5.6.1 Geology

The solid geology of the islands to the north east of the Orkney mainland is dominated by Middle Old Red Sandstone with both the lower and upper groups, i.e. the Rousay Flags and the Eday Beds, evident (described in Section 5.3.1). The ORS outcrops as cliff around much of the coastline of these islands, but their elevation is not nearly as high as those found on Hoy and the western coastline of the mainland. Much of the coastal edge is fronted by a low rock platform which has considerable influence upon the "softer" sections of coastline. The low rock platforms tend to act as hinge points upon which the bay type beach planshapes develop. This influence can be seen in the variety of tombolos, salients and spit features which are evident around these islands.

Glacial deposits are not as abundant on these islands as they are over much of the mainland. Boulder Clay does occur over much of Stronsay and Shapinsay, but elsewhere is patchy with few deposits on the islands of Sanday and North Ronaldsay. There is no evidence of former sea levels higher than today's in the Orkney Islands, hence the only postglacial coastal deposits which occur are shingle ridges and wind blown sands. Dune systems can be extensive, for example on Sanday and are mainly composed of fine shell sand.

5.6.2 *Hydraulic processes*

The tidal cycle experienced around the Orkney Islands is semi-diurnal. The mean spring range around the Northern Islands varies between 2.5m and 3.3m with the corresponding mean neap range being between 1.4m and 1.7m, Table 13.

Table 13 Sub-cell 10d - Predicted tidal levels and ranges

Location	MHWS (m CD)	MLWS (m CD)	Spring Range (m)	MHWN (m CD)	MLWN (m CD)	Neap Range (m)	CD to ODN (m)	CD to OD (local) (m)
Loth	3.6	0.3	3.3	2.8	1.1	1.7	-	-
Kettletoft Pier	3.5	0.5	3.0	2.8	1.2	1.6	-	-1.90
Rapness	3.4	0.7	2.7	2.8	1.2	1.6	-	-2.10
Pierowall	3.3	0.8	2.5	2.8	1.4	1.4	-	-2.10

The elevations quoted in the above table are all relative to Chart Datum (for the particular location). The conversion to the standard land based datum (Ordnance Datum Newlyn) is shown in the second last column. Orkney also has a local land based datum. The conversion from Chart Datum to Ordnance Datum (local) is shown in the final column.

There are no predictions of extreme water levels in this sub-cell.

There is very little information on tidal currents around the Northern Isles. The flood tide tends to flow in a general north west to south east direction between the islands with the ebb in the opposite direction. The streams are strongest in the main channels between the islands, i.e. along the Westray and Stronsay Firth Channel, within the Eday Sound, and the Gairsay Sound and Eynhallow Sound. Strong currents will also be experienced between many of the smaller islands. It is unlikely that tidal currents will directly affect the many beach areas which occur around these islands, with the main flows tending to be channelled offshore by the many rocky headlands. However, eddies which form due to strong currents passing across the mouths of bays, may have some effect on sediment movements in conjunction with wave activity.

The offshore wave conditions experienced to the east of Orkney are shown in Figures 12 and 13 with those to the west in Figures 14 and 15. Extreme offshore wave conditions to the east and west are shown in Tables 9 and 10 respectively. It is not possible to describe the wave climate experienced around the coastline of the Northern Islands in a general manner. Conditions vary, even over very short distances, due to changes in coastline orientation, rapidly varying fetch lengths, irregular bathymetry, complex refraction and diffraction wave patterns, and the influence of the strong current flows which occur. Most of the outer facing coastlines will experience very extreme wave conditions as deep water extends close inshore. Inshore wave conditions have been predicted at a number of locations, e.g. Rapness, Loth, Kettletoft, Whitehall (HR Wallingford, 1990, 1987a, 1987b, 1984a&b). A description of these inshore wave conditions is not provided as these conditions are only representative of the exact location for which they were derived and are of little use in the context of this report.

5.6.3 Littoral processes

There are a large number of beaches located around the coast of the Northern Islands of Orkney, Figure 16. The vast majority of sand sized beach material occurring around these islands is derived from shell debris. It is likely that present day fresh input from this source is relatively low. However, there are a number of beach areas where the shell content is insignificant. These tend to be along the south west coast of Westray, Stronsay and Shapinsay where till deposits overlie the Old Red Sandstone. Virtually all of the beaches around these islands either have an exposed shingle upper or storm beach, or are founded on a shingle ridge. This shingle will either have derived from erosion of till deposits or possibly glacial deposits on the seabed. Wave action will have constructed the shingle ridges which will then have moved landward as sea levels, relative to the land mass, rose.

There is little information on littoral processes particularly of long term areas of erosion and accretion, Figure 17. Most of the beach complexes appear to be relatively stable in terms of the present day marine processes with few significant changes to beach planshapes occurring and no obvious nett losses or gains of beach sediment. The stability of these beach areas is highly dependent upon the existence of the shingle storm ridges which are found either exposed on the upper beach or underlie the present sand beaches. These are highly efficient in dissipating wave energy and provide a high degree of protection to the coastal edge from erosion during storm conditions.

Despite the apparent stability of these beach areas there is a wide range of geomorphological features which are in the latter stages of their lifespan, for example the thin spit features which occur at the Bay of Newark and Sty Wick on Sanday. These are wave constructed features, which will have evolved during marginally lower sea levels, and are extremely sensitive to change in the incident hydraulic conditions. Any continued submergence of these coastlines due to falling land mass or rising sea levels will result in breaches in such features.

Summary of Erosion and Accretion
Long term morphological changes will be occurring on much of the beach areas within the Northern Isles of Orkney but there are no known documented details of erosion or accretion.

5.6.4 Coastal defences

There are few significant coastal defences around these islands.

5.7 Summary of effects of coastal processes on natural and cultural heritage sites

5.7.1 Introduction

The natural and cultural heritage of the coastline of Scotland is rich and diverse. Much of the character and many of the features of natural heritage interest are due to the effects of the last Ice Age and subsequent post glacial climatic variations. It is since the last Ice Age that evidence of the first inhabitants of Scotland can be traced. Effects of coastal processes have been instrumental in developing both the natural and cultural heritage around the coast. For instance many important coastal geomorphological features evident are due to processes acting at previously much higher sea levels. Archaeological sites also demonstrate changes in these processes over the last 10,000 years or so. For example Skara Brae, now requiring engineering protection from the sea, was once some considerable distance from the shoreline. Remains in Gleann Sheillach south of Oban indicate that 6000 years ago this site was at the head of a sea loch even though now it is 1.5km from the shoreline (Ashmore, 1994).

The present threat of erosion and the likelihood of future climatic changes considerably increases the risks of many of these sites being affected by erosion and/or flooding. However, as discussed in the next chapter, our present knowledge of either the patterns of future climatic change or how the coastline will respond to these changes is extremely limited. It is impossible at present to predict with any confidence what changes will occur in the coastline for example in the next 100 years or indeed in the next 10 years. However, the next sections attempt to present a broad based summary of the influences of present day and possible future coastal processes upon natural and culturally designated areas. **This report is concerned with the macro-scale processes occurring around the coastline. To generalise about the effects of coastal processes, particularly on individual cultural heritage sites, is extremely difficult, and many such sites require much more detailed, individual assessments to establish and prioritise the particular potential risks.**

5.7.2 Natural heritage sites

Figure 7 details the location of coastal SSSIs within Cell 10, with a summary of their main characteristics provided in Appendix 1. There are 19 designated coastal SSSIs within the Orkney Islands.

Sites designated on account of their solid geology will generally not undergo significant changes in the short term due to present day coastal processes. However, the situation on Orkney is different from that presently experienced on much of mainland Scotland. Around the coastline of mainland Scotland, previous (higher) sea levels have resulted in many cliffs and geological outcrops being above present day wave influence, i.e. they are relic features. In Orkney, these higher sea levels were not experienced with the coastline characterised by long term submergence. Hence wave action is still very much an active process on most of the solid geological features evident around the coastline of Orkney. The severity of the wave conditions experienced around the coastline of Orkney is resulting in long term erosion of most of the cliff areas. However, it is these wave processes which have formed many of the features upon which the designations have been based, such as geological exposures or landforms such as stacks and geos.

There are a number of geologically designated sites notified because of their Quaternary features, particularly exposures of glacial tills, e.g. Muckle Head and Selwick, Den Wick and Mill Bay SSSIs. These outcrops either overlie Old Red Sandstone rock platforms, e.g. Muckle Head and Selwick, or back a beach, e.g. Mill Bay. Ongoing marine erosion of the coastal edge of these features is a long term process and will continue to occur in the future maintaining these exposures. However, this will generally be limited to episodic onshore storm events acting with high tides.

Sites designated on account of their "soft" geomorphological features will be most susceptible to change from present day (and future) coastal processes. The complex landforms of central Sanday are the only major ones thus designated in the Orkney Islands. These have formed due to constructive wave processes acting in conjunction with submergence of the land mass with their development reliant upon the supply of sediment. At present the spits and tombolos evident are mature features with present day coastal processes generally having a detrimental effect principally due to the lack of available fresh sediment for their continued evolution. Such features are also highly sensitive to changes in the hydraulic climate. This is discussed further in Chapter 6.

5.7.3 Cultural heritage sites in Cell 10

There has been no specific coastal survey for the Orkney Islands to establish the threat of coastal erosion on sites of historic and archaeological importance (Ashmore, 1994). However, considerable work has apparently been conducted by the Regional Archaeologist and from information provided by local people. This had identified at least 100 sites by 1988 which were considered to be suffering from marine erosion. Given that the Orkney Islands are experiencing a long term submergence of the land mass the threat or risk to these sites is not going to improve and, if anything, is likely to increase.

To provide specific guidance on the sites most at risk in Orkney is beyond the scope of this study. Damage to cultural heritage sites in the immediate hinterland due to marine erosion will occur primarily through episodic events, i.e. storms. The magnitude of erosion at each individual site will be dependent upon the orientation of the coastline, the degree of shelter provided by offshore islands or headlands, and the direction of individual storms. As the coastline is highly irregular and indented, storm damage will vary from site to site, even over extremely short distances. However, virtually all sites on low-lying land backing the coast must be considered high risk.

The existing erosion problem in the Bay of Skaill and the threat to Skara Brae is highlighted in Section 5.3.3. This site is under considerable threat due to the ongoing evolution of the planshape of the bay. This is a long term process and is likely to continue into the future with two particular processes likely to pose the greatest threat:

- ongoing submergence of the landmass, particularly with any increase in sea level rise due to climatic changes;

- the apparent erosion of the headlands, and subsequent widening of the mouth of the bay.

Changes in both of these processes will alter the pattern and magnitude of wave energy entering the bay and also the subsequent transformation of the wave conditions as they approach the shoreline. This will lead to changes in the littoral transport patterns. Despite any rate of change being relatively low, long term protection of Skara Brae (which will not adversely affect other parts of the coastline within the bay) is a considerable task.

It is likely, although there is little other evidence, that the planshape of many of these pocket beach systems may still be evolving in response to changing sea levels due to the long term submergence of the Orkney Islands. However, at many sites this rate of change is low mainly due to the existence of shingle storm beaches which provide some protection to the coastal edge within these systems. Such storm beaches appear to occur on the majority of the beach systems in Orkney and are extremely effective in restricting landward retreat of the coastal edge due to wave attack. However, given the severity of storm conditions experienced, roll back of these shingle beaches will occur. Where sites of cultural heritage are situated upon any of the many tombolos or spits around the Orkney Islands, these sites will be at serious risk from marine erosion.

Along much of the northern coastline of the Mainland and that of much of the Northern Isles, till deposits occur at the coastline fronted by a Old Red Sandstone rock platform. Much of this coastline is still eroding, albeit again limited to storm conditions acting at high water levels, with the magnitude of erosion at a particular site dependent upon individual storm directions. Figure 9 shows a large number of sites recorded along such coastlines which must be considered high risk.

6 Climate change and its effect on coastal management

6.1 Introduction

The importance of climate change in the context of coastal management has generally been equated to the problems caused by an increase in mean sea level. This remains an important issue, particularly for low-lying areas where economically important assets are situated close to, or below, extreme tide level. However, recent winters in the UK have indicated a number of other potential impacts affecting the management of the coastline and its defences which may be more important, at least in the short-term. Such factors include an increased frequency of storms. Increased erosion of the coast may therefore be a greater concern in much of Scotland than flooding due to sea level rise. Much of Section 6.2 is taken from Brampton (1996).

6.2 Evidence of climatic change

6.2.1 General

The Intergovernmental Panel on Climate Change (IPCC) concluded that 'The balance of evidence from changes in global mean surface air temperature and from changes in geographical, seasonal and vertical patterns of atmospheric temperature, suggests a discernible human influence on global climate' (Houghton *et al.*, 1996). The conclusion of the IPCC rests on: (i) the physical effect of greenhouse gases on the atmosphere; (ii) observed climatic trends; and (iii) projections from global climate models.

The greenhouse effect results from certain gases in the atmosphere retaining heat that would otherwise be radiated into space. These greenhouse gases are relatively transparent to sunlight but absorb thermal infrared radiation emitted by the Earth's surface. The natural greenhouse effect already keeps the Earth over 30°C warmer than it otherwise would be; increasing concentrations of greenhouse gases warm the Earth still further.

The main greenhouse gases are carbon dioxide, methane, nitrous oxide and some industrial chemicals such as chlorofluorocarbons (CFCs) but also include water vapour. Significant modification of the atmosphere by human activities has occurred since the industrial Revolution. However, the magnitude of greenhouse gas emissions has increased enormously in recent decades. Increased carbon dioxide is the most important driver of global change contributing about 64% of the radiative forcing that produces global warming (Houghton *et al.*, 1996).

Global average surface air temperatures can be computed back to 1856. The record shows warming of about 0.5°C over the 140-year period to 1997, with the warmest year occurring in 1997 and the warmest six years all recorded since 1983 (Parker & Folland, 1995). The decade 1987-1996 has been 0.25°C warmer than the 1961-90 average.

6.2.2 Tidal and sea level change

Geomorphological evidence shows a long-term pattern of sea level rise relative to the land around much of the UK coast, stretching back over 10,000 years to the end of the last Ice Age. Generally rates of sea level rise during this period have been higher than they are today although there have been several periods of "stands" in level, or even periods of falling levels. However, since the end of the last Ice Age, the isostatic uplift of the land mass due to post-glacial recovery (in mainland Scotland at least) has been occurring at a greater rate. The net result has been a fall in sea levels relative to the land level in most of Scotland, except for the Northern and Western Isles where gradual submergence has continued. Evidence for this is largely from geological features such as raised beaches which are a common occurrence around much of the Scottish coastline. The rate of isostatic uplift since the last Ice Age has been one of an exponential decrease and at present over much of Scotland the rate of increase in sea levels (eustatic increases) is now occurring at a slightly greater rate, i.e. sea levels are now increasing relative to land levels albeit at a very low rate (and certainly a much lower rate than say experienced on the south east coast of England). Whilst the Intergovernmental Panel on Climate Change (IPCC) (Houghton *et al.*, 1996) estimates a global mean sea level of 12-95cm higher than 1990 by the year 2100, the rise around the Scottish coast is expected to lie at the lower end of these values. Estimates by Hill *et al.*, (1999) indicate that the net mean rise in sea level around the Scottish coast by 2050 will be up to 30cm with nearly a third of the coastline only experiencing a rise up to 10cm, although the Shetland Isles may experience a net rise in sea level greater than 30 cm. These regional variations reflect differences in the rate of crustal uplift across the country which moderate or exacerbate, locally, the global rise in sea level. The term "net rise" means that land uplift rates are taken into account.

It is important to note that an increase in extreme tidal levels may not, in the short-term, be the same as an increase in mean sea levels. There is not only a long-term variation in the height and frequency of surges (as in wave heights, see Section 3.3), but also a change in the range of the astronomical tides. This latter aspect has been observed, for example in Newlyn, but not apparently explained. An increase in extreme tidal levels might be expected to increase the chances of wave overtopping of beaches and coastal defences or to increase dune erosion.

However, the evidence for this is far from conclusive. Recent research (Woodworth et al, 1991) carried out by the Proudman Oceanographic Laboratory analysed the long-term tide record from Newlyn in Cornwall. This has indicated the influence of the 18.6 year periodicity (caused by the precession of the plane of the Moon's orbit around the Earth, relative to the elliptical plane). During certain stages of this 19-year cycle, the mean tidal ranges increased by about 20mm/year, and it can be expected that the spring tidal ranges will increase by an even greater amount. This effect lasts for several consecutive years. During such periods, the effects on the upper parts of the beach would presumably be much the same as if mean sea level was rising by about half that amount, i.e. about 10mm/annum. Therefore it can be assumed that there would be periods of rapid beach erosion and landward recession during these times (presumably followed 9 years later by periods of beach accretion as high water levels decline). At present we are at the end of one of these rapid rise periods.

6.2.3 *Wave climate change*

Wave action around most of the coastline of the UK is the principal mechanism affecting evolution of the nearshore zone, i.e. the region where water depths are less than 5m at low tide. Hence changes in wave heights, either in terms of general trends or in severe storms, are of considerable importance. There is now no doubt that such increases in wave height do occur and may continue to do so for some considerable time. Bacon and Carter, (1991) have conducted the most comprehensive review available of wave climate changes in the North Atlantic and North Sea. Their data suggests that mean wave height increased from about 1960 to a peak around 1980, with a subsequent decline. Recent winters, (particularly 1988-1989 and 1993) have produced severe storms in the northern North Sea which may affect these trends. This agrees with more recent work (Leggett et al, 1996) which analysed wave climate data in the northern North Sea between 1973 and 1995 and concluded that:

- in the northern North Sea mean significant wave heights (H_s) have increased by approximately 0.2-0.3m (5-10%) since 1973. Wave conditions have been higher since 1988/89, with a secondary peak in 1982/83.

- Peak H_s values since 1988 have generally been significantly higher than those from the period 1973-1987. Recent years have seen storms with peak H_s of 12.5-14m, whereas peak values recorded before 1987 were around 11-12m.

- Since the 1980s wave conditions appear to have become a little calmer in autumn and more severe in late winter.

There is also some qualitative information to suggest that the increase in severity of the wave climate in the North East Atlantic has occurred in parallel with an increase in the frequency of very deep low pressure systems in the North East Atlantic (Lynagh, 1996). This report suggests that the latest peak in the frequency of occurrence of these low pressure systems may be over and that the next few years will see a decrease in such systems. However, there is insufficient evidence to confidently predict whether such a decrease will occur or indeed if these variations are linked to variations in storminess.

Wave direction can be almost as important as wave height in coastal management. Any changes in long term average wind directions can cause large morphological changes. There is not a sufficient length of time series of reliable directional wave data to assess any trends in direction. Analysis of wind climate data has revealed that there has been very little change in the wind climate and no proof that recent increases in storminess are statistically significant. Unpublished work by Jenkinson and Collison (1977) found no significant change in wind speeds over the Atlantic or North Sea occurred between 1881 and 1976. Historical evidence analysed by Lamb and Weiss, (1979) detected a climatic cycle of about 200 years. Over the North Sea the change consisted mainly of changes in the relative proportions of northerly and westerly winds. At present, it was reported, we are experiencing an increase in the proportion of northerlies which may lead to an increase in mean wave heights affecting the east coast. It was forecast that this trend would continue for a further 70 to 100 years. However, there has been some concern that depressions from the Atlantic have been tracking further to the south than previously. This has increased the dominance of south easterly winds potentially affecting the rate (even the direction) of the nett alongshore drift at various locations. There is no available information to confirm whether this is a long term trend.

6.3 Effects on coastal management

6.3.1 Impact on beaches

General

One method for predicting shoreline erosion caused by sea level rise is known as the Bruun Rule (Bruun, 1983). This suggests that as sea levels rise, the beach will adjust to maintain a constant depth profile, i.e. the upper beach erodes, while the nearshore bed accretes. There is some evidence to suggest that this also happens in real life, but it should be realised that the method assumes a two-dimensional response when the development of a beach will almost always be three dimensional. The amount of sediment available is also a critical factor in the response of a beach to sea level rise, with those with a limited supply being more likely to retreat.

In the UK, the effect of sea level rise on beaches is probably not as great as those associated with changes in the wave climate, in the short term at least. An increase in the occurrence of very large waves will, for example, alter beach profiles or cause dune erosion which may take many months, or even years, to repair naturally. Conversely an increase in the occurrence of more modest waves, may be accompanied by a decrease in the largest wave heights. This would lead to a general steepening of the beach profile and a reduction in erosion. A change due to sea level rise may therefore go completely undetected.

Although a change in wave heights will cause changes to beach profiles, the long-term evolution of the shoreline is almost always linked to changes in the longshore transport of beach sediments or, more precisely, the changes in transport from point to point along the coast. The longshore transport does depend on wave height, but more crucially on wave direction. The former influence, in the long term, can only increase or decrease the rate at which the coastline is eroding or accreting. However, a change in the "average" wave direction will often cause a change in the present trends of erosion and accretion (affecting both rates and patterns). At some locations, it has been found that erosion problems have recently occurred on stretches of coastline which have been stable or accreting for many years.

Impact on the beaches in Cell 10

A large number of the beach units within the Orkney Islands are in the form of pocket or bayhead type beaches. The planshape of such beaches does not change dramatically as incident wave conditions in the nearshore zone are normally experienced from a relatively narrow wave window due to diffraction and refraction effects. Hence changes in wave direction are unlikely to have as much of an effect as they would do on an open, straight coast. Similarly there is little longshore transport evident as most of these beaches have orientated to a position dependent upon the incident wave conditions with no long term nett drift occurring. Thus a change in wave heights (of the magnitude likely to be experienced) will have no obvious effect on longshore transport processes. Research into the influence of sea level rise on pocket beaches (Diserens et al, 1992) also concluded that there was no clear linkage between sea level rise and the position of the high water line under the present day (relatively low) rates of change. However, there is some evidence to suggest that some of the pocket beaches around Orkney, e.g. Bay of Skaill, have not yet reached an equilibrium planshape possibly due to the continued (slow) submergence of the islands since the last Ice Age. If the rate of increase in sea level relative to the land mass is exacerbated due to climatic changes this could cause increased erosion as the planshapes of these bays adjust.

Of potentially greater impact upon the beaches of Orkney is likely to be either an increase in extreme water levels or in the magnitude or frequency of storm conditions. Virtually all of the beach systems suffer from storm damage at present and any increase in storm frequency or magnitude will result in an increase in backshore erosion. This type of erosional response will occur mainly along the sand beach/dune or sand beach/machair systems in Orkney where there is no protection provided by shingle or cobble sized material. There are relatively few beach systems where there is no shingle storm beach occurring on the upper part of the shoreline, or buried underneath the present sand beach. At locations where a shingle upper beach (or shingle storm beach) does occur this provides much more protection to the coastal edge from wave attack. However, landward retreat still occurs by rollover where the shingle material is progressively transferred from the shore face, pushed over the crest and onto the back face hence causing landward retreat. The average rate of retreat is approximately proportional to sea level rise and the gradient of the shoreface. Where there is sufficient volume of shingle material the crest of the shingle beach will increase in elevation to accommodate sea level rise. However, if beach material is sparse any increase in elevation is at the expense of the width of the shingle ridge which would reduce the degree of protection to the coastal edge.

The most obvious effect of a detrimental change in the climate may be to the range of sensitive geomorphological features evident around much of the coastline of Orkney. These include the spit features on Sanday and the countless other ayres and tombolos which occur around these islands. These features have previously been constructed by wave action and are dependent upon a sediment source for their continued evolution. At present most of these are relatively stable. There is no, or very little, fresh sediment input but the present day hydraulic conditions are relatively stable. However, if these were to change this would have a detrimental influence upon these features.

There is a considerable length of the Orkney coastline, such as much of the sub-cell 10c coast, where boulder clay deposits are fronted by a rock platform of Old Red Sandstone. The rock platform protects the coastal edge from wave attack under most normal conditions but erosion of the coastal edge does occur under high tides and storm wave conditions. Any increase in the magnitude or frequency of such events may increase the rate of landward retreat of the coastal edge.

Cliff erosion is still occurring along much of the coast in the Orkney Islands. This is due to the long term submergence of the Orkney Islands and the apparent absence of periods of formerly higher sea levels. Hence, there are few wave cut platforms to dissipate the severe wave conditions which propagate close in to the shoreline along the outer edges of these islands. Increases in the frequency or magnitude of storm events will cause an increase in cliff erosion.

The extent of coastal edge retreat will vary all along this coastline due to a whole range of interrelating factors such as orientation, degree of shelter by the solid geology, immediate bathymetry etc. Such changes will be gradual, i.e. there will be no sudden change in sea level, with the coastal regime gradually evolving in response.

6.3.2 *Impacts on man-made defences*

General

A study into the effects of sea level rise on coastal structures was carried out by Townend (1994). This showed that the effect of sea level rise on design parameters such as armour weight and run-up depended very much upon the location of the structure in the surf zone and whether waves were breaking or non-breaking at the structure. For instance with breaking waves rock armour weight requires an increase of over 100% for an increase in water depth of only 10%. However, in shallow water where waves are not breaking there is a slight reduction in the required armour weight and in the level of run-up with increases in sea level due to reduced wave shoaling. The effect of sea level rise will always cause an increase in the overtopping of defences irrespective of wave condition.

Possibly of greater importance in the design of coastal structures such as breakwaters and seawalls is the impact of increased storm activity. For example, the size of stable rock armouring on a revetment or breakwater depends on the cube of the design wave height. An increase in extreme wave heights of only 1% each year could, in a decade, lead to a requirement for armour unit weights to be some 38% heavier to achieve the same degree of safety.

In most situations, defences first fail "functionally", allowing erosion or flooding of the land behind. Occasionally, however a defence will suddenly fail "structurally", leading to a much greater danger to life and property, for example the collapse of the seawall at Towyn in North Wales. In most cases, the failure of defences results from a combination of factors, e.g. low beach levels, a high tide and large waves from a limited directional sector. A gradual change in the probability of occurrence of just one of these parameters may therefore not be apparent for many years.

Impacts on the man-made defences in Cell 10

Little coastal defence work has been conducted within Cell 10. Based on the present defences it is unlikely that there will be any noticeable increase in the occurrence of damage to structures other than due to natural ongoing deterioration.

The most apparent response to changes in either sea level, or increases in the magnitude or frequency of storm conditions will be an increase in the occurrence and rate of overtopping of defences. Only where defences are backed by properties, or at the Churchill Barriers, will this be noticeable. Given that the only major defences occur at Kirkwall and Stromness, both of which are in a relatively sheltered location and experience severe storm waves from a narrow direction sector only, it is debatable whether this is likely to be a major problem, except at the Churchill Barriers.

6.3.3 *Other effects*

There are a number of other climatic factors which may affect the coastline evolution and hence management techniques. Two of these are discussed below. In each case little is known of the extent of any variations in these climatic factors and whether these are of significance in managing the coast.

Rainfall

There is a known past variation in the rainfall occurring in the UK. In the south of England an oscillation of about 40 years period has been observed. A similar oscillation has apparently been recorded by Stirling University when investigating River Tay flooding. As rainfall increases, a number of effects are likely to occur at the coastline:

- De-stabilisation of soft cliffs

  Cliff falls are usually caused by a combination of marine erosion, e.g. undercutting their front face, and geotechnical problems, e.g. rotational slips. The latter effect is increased by greater rainfall and hence higher run-off, higher water tables etc. Such effects may occur on both the Old Red Sandstone Cliffs and on the boulder clay outcrops at the coast. However, there is unlikely to be such an increase in the frequency of such events that there is any noticeable increase in the volume of sediment within the immediate beach areas.

- Increased river flows

  In many parts of the world, rivers still bring large quantities of sand and gravel to the coast, providing fresh supply. Increased river flows would increase the capacity of the river to transport sediment. The few rivers in Orkney do not supply any appreciable volume of sediment to the littoral zone.

- Impacts on sand transport on beaches

  In locations where a beach is affected by surface water run-off from land, there are often localised erosion problems, e.g. around outfalls. The frictional resistance of sand is reduced by the water, making it easier to be mobilised by waves and currents. It is therefore likely that increased rainfall will tend to cause localised beach erosion.

- Impacts on dune building

  Wet sand on the foreshore will be much less easily transported by winds than if it is dry, reducing the supply to dunes. However, many dune binding grasses suffer in drought conditions, and are generally healthier in moister climates. This would help to increase the trapping efficiency, and encourage them to colonise new areas more quickly. It is not clear, therefore, whether increased rainfall will assist dune growth or be detrimental to it.

Changes in wind

As well as changes in wind conditions altering waves, discussed earlier, there are other direct effects which may affect the coastline:

- Aeolian sand transport

  Strong winds are capable of transporting large quantities of sand, both along the coastline and perpendicular to it. The former effect can add to, or counteract wave induced longshore drift, but tends to take place at higher levels on the beach profile. Onshore transport by wind typically dominates over offshore movement. This is partly because winds blowing over the sea are stronger (less affected by friction) than those blowing offshore.

  A change in wind strengths or directions may also alter existing patterns of sand transport. It is likely that this will be most noticeable in changes in dunes, rather than on the beaches themselves.

Much of the above discussion on climatic change and its impact on coastal response is based on logical argument rather than well documented case histories.

The impact of climatic change on the coastline of Cell 10 may well be noticeable due to the lack of beach sediments within many of the beach units and the apparent long term submergence of these islands. However, many of these beaches are remote with minimal present day human influences (apart from quarrying at some sites) and the beaches will respond in a natural manner without impacting seriously on infrastructure or other anthropogenic features. The complexity of the coastal and nearshore zone makes it difficult to predict morphological changes due to the range of inter-relating parameters which affect this zone. To identify and quantify the effect on the coastline of changes to any one, or a number, of these parameters would require good quality, long-term data to validate predictive methods and to identify changes in the marine (i.e. hydraulic) climate.

Trying to separate longer-term climate change effects from those caused by "normal" fluctuations in weather is a major challenge. There is a clear need for monitoring of the coastline, not only to understand the processes, but to provide a long-term data-set for future generations trying to deal with the effects of potentially more dramatic climate changes.

7 References and Bibliography

7.1 References

Ashmore P J (1994). Archaeology and the coastal erosion zone. Towards a Historic Scotland policy. Historic Scotland Report.

Bacon S & Carter D J T (1991). Wave climate changes in the North Atlantic and North Sea. Journal of Climatology, **2**, 545-558.

Barne J H, Robson C F, Kaznowska S S, Doody J P & Davidson N C eds (1996). Coasts and seas of the United Kingdom. Region 2: Orkney. Joint Nature Conservation Committee, Peterborough.

Brampton A H (1996). Climatic change and its effects on coastal management. In *Climatic change offshore N.W. Europe*. An assessment of impacts of changing meteorological and oceanographic (Metocean) conditions on offshore activities. Conference at Imperial College of Science, Technology and Medicine, 18 April 1996. Society for Underwater Technology.

British Oceanographic Data Centre (1991). United Kingdom Digital Marine Atlas. Proudman Oceanographic Laboratory, Birkenhead.

Bruun P M (1983). Sea level rise as a cause of shore erosion. Journal of the Waterways, Harbours and Coastal Engineering Division. ASCE, **88**, No WW1,117-130.

Carter R W G. (1988) Coastal Environments. Academic Press, London.

CIRIA/CUR (1991). The use of rock in coastal and shoreline engineering. CIRIA Special Publication 83/CUR Report 154. Construction Industry Research and Information Association.

CIRIA (1996). Beach management manual. CIRIA Special Publication 153. Construction Industry Research and Information Association.

Coles S G & Tawn J A (1990). Statistics of coastal flood prevention. Philosophical Transactions of the Royal Society of London, **332**, 457-476.

Department of the Environment (1995). Policy guidelines for the coast. November 1995. DoE, London.

Diserens A P, Motyka J M & Brampton A H (1992). Beach development due to climatic change. National Rivers Authority R & D Note 58. CONFIDENTIAL.

Dixon M J & Tawn J A (1994). Extreme sea levels at the UK A-class sites: Optimal site-by-site analysis. Proudman Oceanographic Laboratory Internal Document No. 65. Birkenhead.

Dixon M J & Tawn J A (1997). Spatial analysis for the UK coast. Proudman Oceanographic Laboratory Internal Document No. 112. Birkenhead.

Dodd N & Brampton A H (1995). Wave transformation models: a project definition study. HR Wallingford Report SR 400. HR Wallingford, Wallingford.

Graff J (1981). An investigation of the frequency distributions of annual sea level maxima at ports around Great Britain. Estuarine, Coastal and Shelf Science, **12**, 389-449.

Hill M O, Downing T E, Berry P M, Coppins B J, Hammons P S, Marquiss M, Roy D B, Telfer M G and Welch D. (1999). Climate changes and Scotland's natural heritage: an environmental audit. Scottish Natural Heritage Research, Survey and Monitoring Report No 132.

Houghton, J T, Jenkins, G J and Ephraums, J J (1990). Eds: *Climate Change. The Intergovernmental Panel on Climate Change Scientific Assessment.* Cambridge University Press, Cambridge.

Houghton J T, Meiro Filho L G, Callander B A, Harris N, Kattenberg A & Maskell K (Eds) (1996). *Climate Change 1995: The Science of Climate Change.* Contribution of Working Group 1 to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

HR Wallingford, (1984a). Marine investigation for improved ferry access to Sanday and Stronsay, Orkneys. HR Wallingford Report EX 1234. HR Wallingford, Wallingford.

HR Wallingford, (1984b). Marine investigation for improved ferry access to Sanday and Stronsay, Orkney. Wave climate and channel stability. HR Wallingford Report EX 1235, HR Wallingford, Wallingford.

HR Wallingford, (1985). Wave study for Burwick Bay, South Ronaldsay, Orkney. HR Wallingford Report EX 1329. HR Wallingford, Wallingford.

HR Wallingford, (1986a). Wave and coast protection study for Ayre Road, Kirkwall, Orkneys. HR Wallingford Report EX 1408. HR Wallingford, Wallingford.

HR Wallingford, (1986b). Kirkwall pier - a wave disturbance study. HR Wallingford Report EX 1509. HR Wallingford, Wallingford.

HR Wallingford, (1987a). Proposed pier at Loth, Sanday. A wave disturbance study. HR Wallingford Report EX 1545. HR Wallingford, Wallingford.

HR Wallingford, (1987b). Sediment movements in Kettletoft Bay, Sanday, Orkney Islands. HR Wallingford Report EX 1650. HR Wallingford, Wallingford.

HR Wallingford, (1988). Wave refraction study, Kettletoft, Sanday, Orkney Islands. HR Wallingford Report EX 1676. HR Wallingford, Wallingford.

HR Wallingford, (1990). Wave and coastal protection study for Rapness, Westray, Orkneys. HR Wallingford Report EX 2109. HR Wallingford, Wallingford.

HR Wallingford (1993). Coastal Management: Mapping of littoral cells. HR Wallingford, Report SR 328. HR Wallingford, Wallingford.

HR Wallingford (1994). Skara Brae Coastal Defences. HR Wallingford Report EX 3029. HR Wallingford, Wallingford.

HR Wallingford (1995). Wave Overtopping. Churchill Barrier No. 2, Holm Sound, Orkney. HR Wallingford Report EX 3203. HR Wallingford, Wallingford.

HR Wallingford (1997). Coastal Cells in Scotland. Scottish Natural Heritage Research, Survey and Monitoring Report No 56.

Hydrographer of the Navy (1986). Admiralty Tidal Stream Atlas. Orkney and Shetland. Hydrographic Department, Taunton.

Lamb H H & Weiss I (1979). On recent changes of the wind and wave regime of the North Sea and the outlook. Fachliche Mitterluugen. AMT fur Wehrgeophysik. Nr. 194.

Legget I M, Beiboer F L, Osborne M J & Bellamy I (1996). Long term Metocean measurements in the Northern North Sea. In *Climate change offshore N.W. Europe*. An assessment of the impacts of changing meteorological and oceanographic (Metocean) conditions on offshore activities. Conference at Imperial College of Science, Technology and Medicine, 18 April 1996. Society for Underwater Technology.

Lynagh N (1996). Weather and climate variability since prehistoric times and recent indications of continuing fluctuations in the NE Atlantic. In *Climate change offshore N.W. Europe*. An assessment of the impacts of changing meteorological and oceanographic (Metocean) conditions on offshore activities. Conference at Imperial College of Science, Technology and Medicine, 18 April 1996. Society for Underwater Technology.

MAFF (1995). Shoreline Management Plans. A guide for coastal defence authorities. MAFF. MAFF, London.

Marine Information and Advisory Service (MIAS) (1982). MIAS catalogue of instrumentally measured wave data. MIAS Reference Publication No 1, IOS, Wormley, Surrey.

Mather, A S, Smith, J S and Ritchie, W, (1973). The beaches of Orkney. Aberdeen University, Geography Department. Report to the Countryside Commission for Scotland.

Metocean (1994). Energy industry Metocean data around the UK. Metocean Report No 537.

Mykura W (1976). British Regional Geology: Orkney and Shetland. HMSO, Edinburgh.

Parker D E & Folland C K (1995). Comments on the global climate of 1994. Weather **50**, No. 8, August 1995.

Scottish Office (1996). Scotland's coast. A discussion paper. HMSO, Edinburgh.

Scottish Office (1997). National Planning Policy Guideline (NPPG) 13. Coastal Planning, Scottish Office Development Department, Edinburgh.

Spencer N E & Woodworth P L (1993). Data holdings of the Permanent Service for Mean Sea Level. Bidston Observatory, Birkenhead.

Steers J (1973). The coastline of Scotland. Elsevier, Kidlington.

Townend I H (1994). Variations in design conditions in response to sea level rise. Institution of Civil Engineers Proceedings. Water, Maritime & Energy, **106**, 205-213.

Woodworth P L (1987) Trends in UK mean sea level. Marine Geodesy, **11**, 57-87.

Woodworth P L, Shaw S M & Blackman D L (1991). Secular trends in mean tidal range around the British Isles and along the adjacent European coastline. Geophysics Journal International, **104**, 563-609.

7.2 Other publications

There are a number of other publications that may be of use in shoreline management but are not referenced within this report.

Allen, J, (1946). Laboratory experiments in connection with causeways closing the eastern entrances to Scapa Flow. Institution of Civil Engineers, Maritime and Waterways Engineering Division, Maritime Paper No. 4.

HR Wallingford, (1984). Orkney Islands, Analysis of tidal observations at Sanday. HR Wallingford Report EX 1223. HR Wallingford, Wallingford.

HR Wallingford, (1991). Stromness Pier extension. Wave modelling studies. HR Wallingford Report EX 2474. HR Wallingford, Wallingford.

King, J L (first paper) and Bishop, R W (second paper), (1950). Maintenance of some rubble breakwaters (a) Scapa Flow causeways, 1945-50, (b) Alderney breakwater. Institution of Civil Engineers, Maritime and Waterways Engineering Division, Maritime Paper No. 16.

Figures 1-18

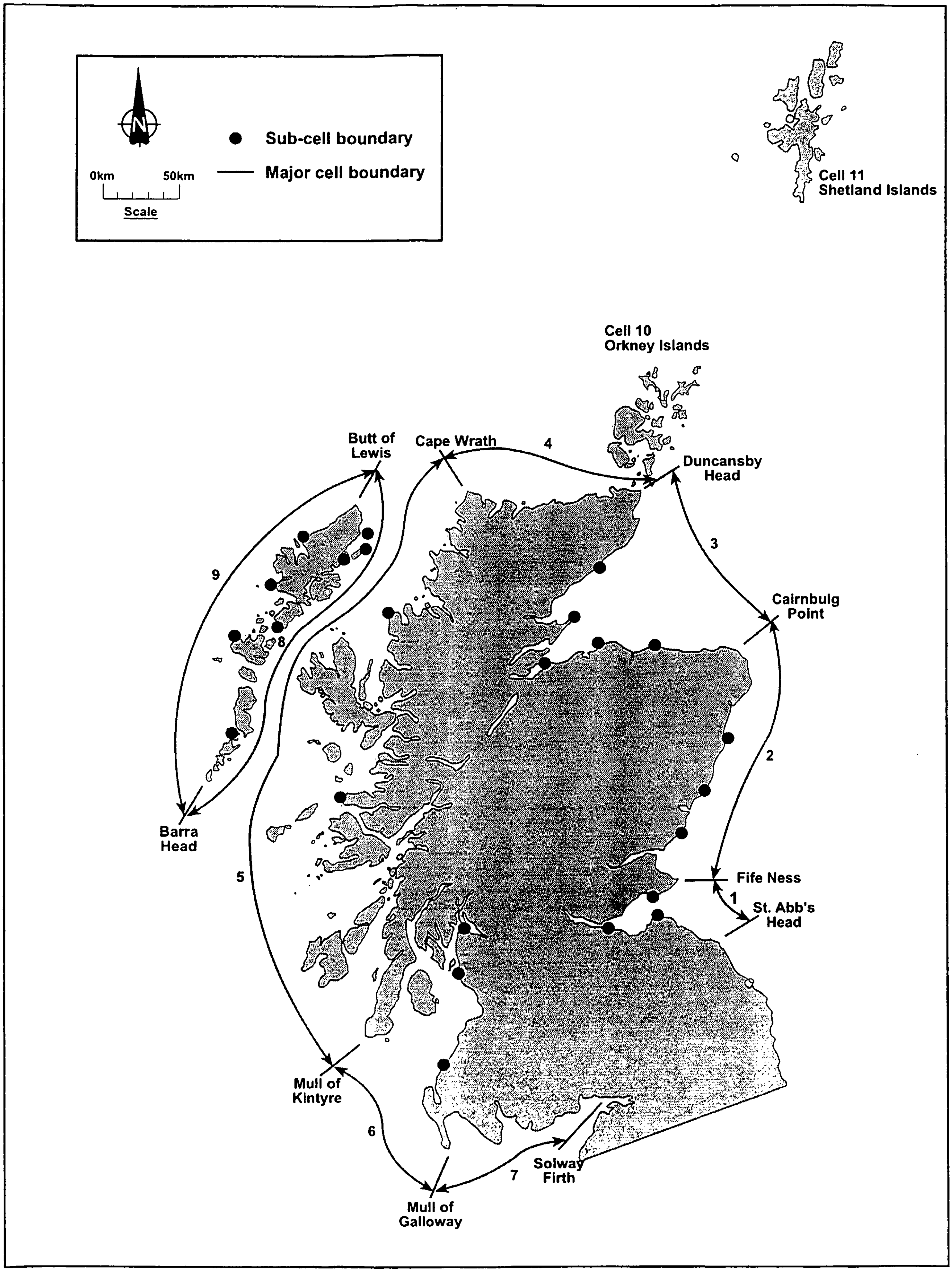


Figure 1 Coastal Cells in Scotland

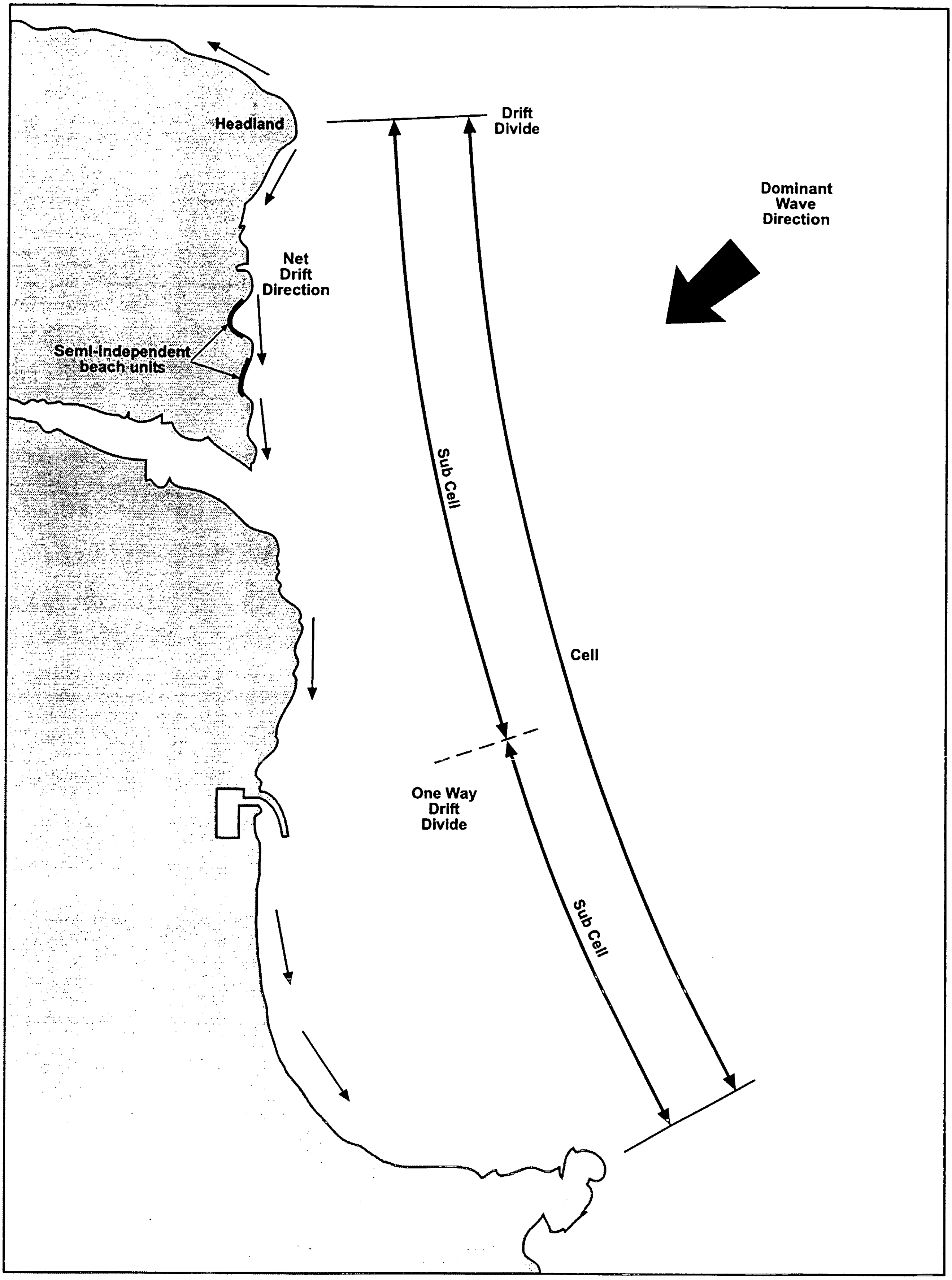


Figure 2 Idealised coastal cell

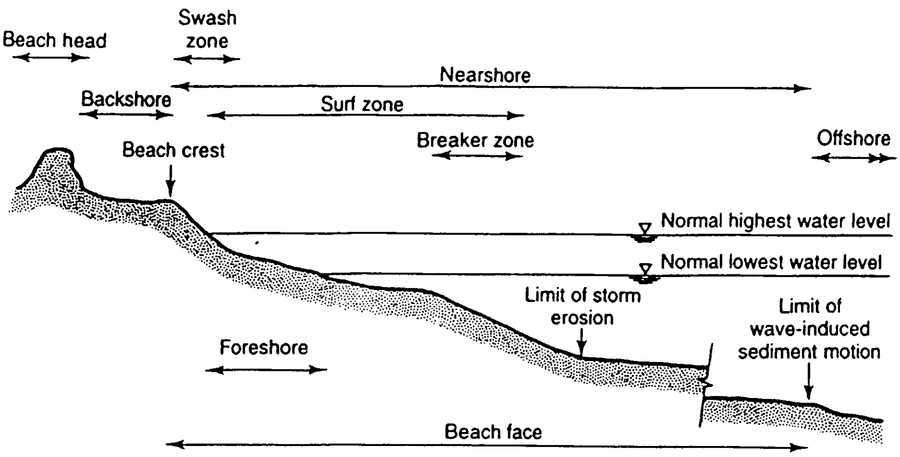


Figure 3 General beach profile and littoral zone

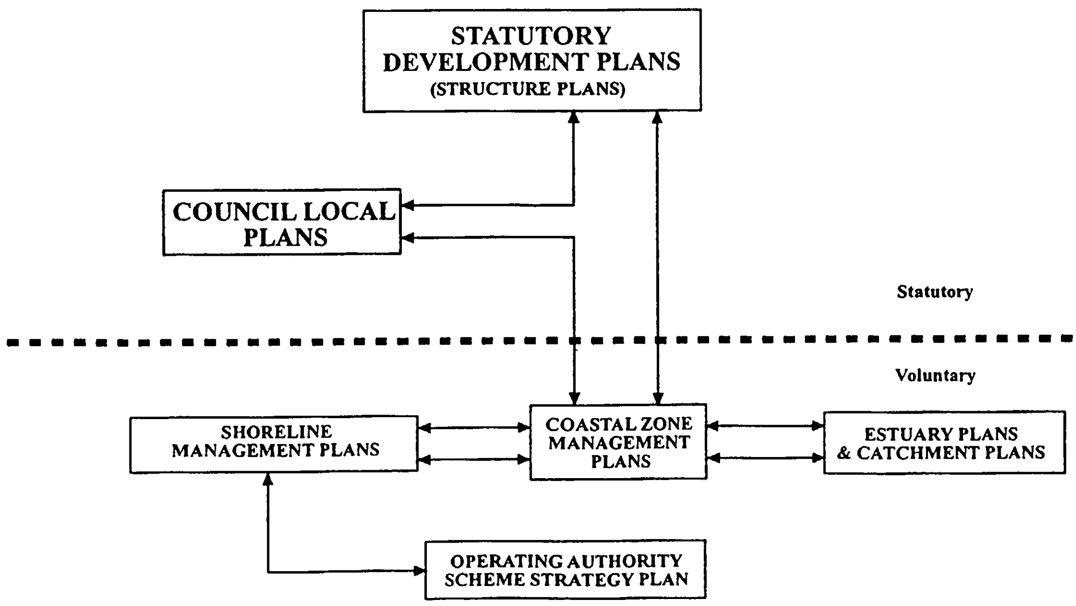


Figure 4 Relationship between coastal initiatives

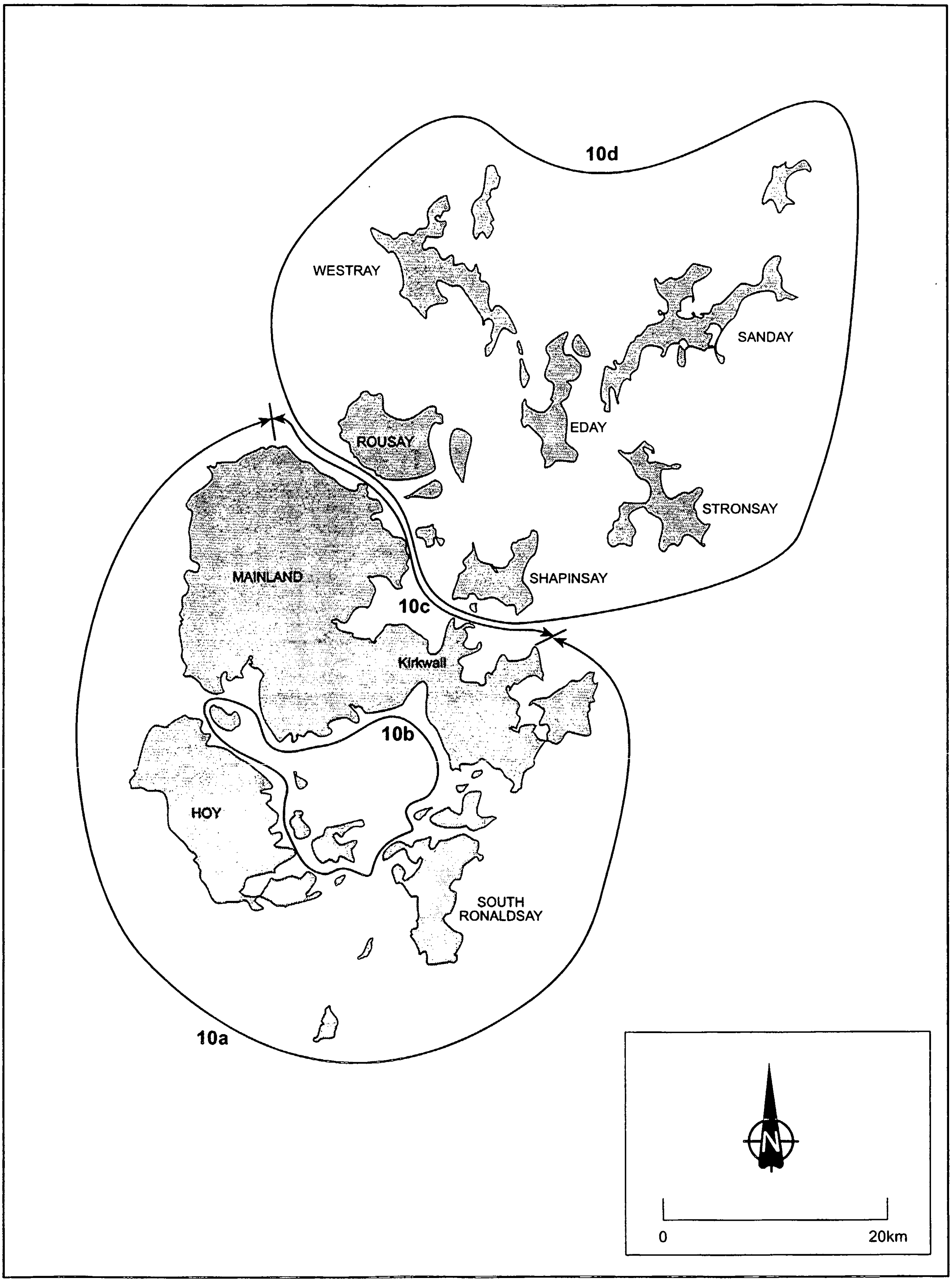


Figure 5 Cell 10 - The Orkney Islands

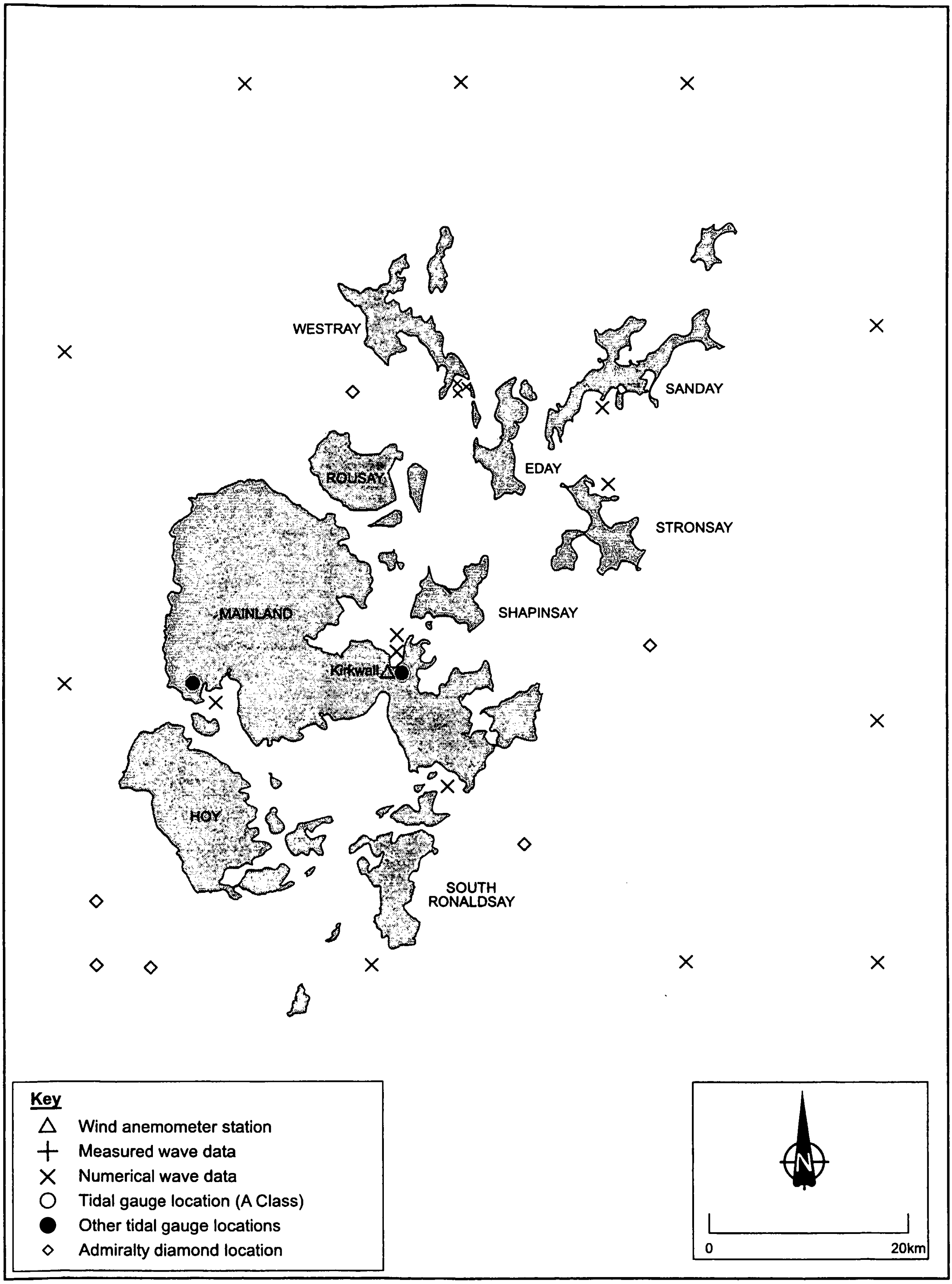


Figure 6 Cell 10 - Location of wind, tidal and wave data

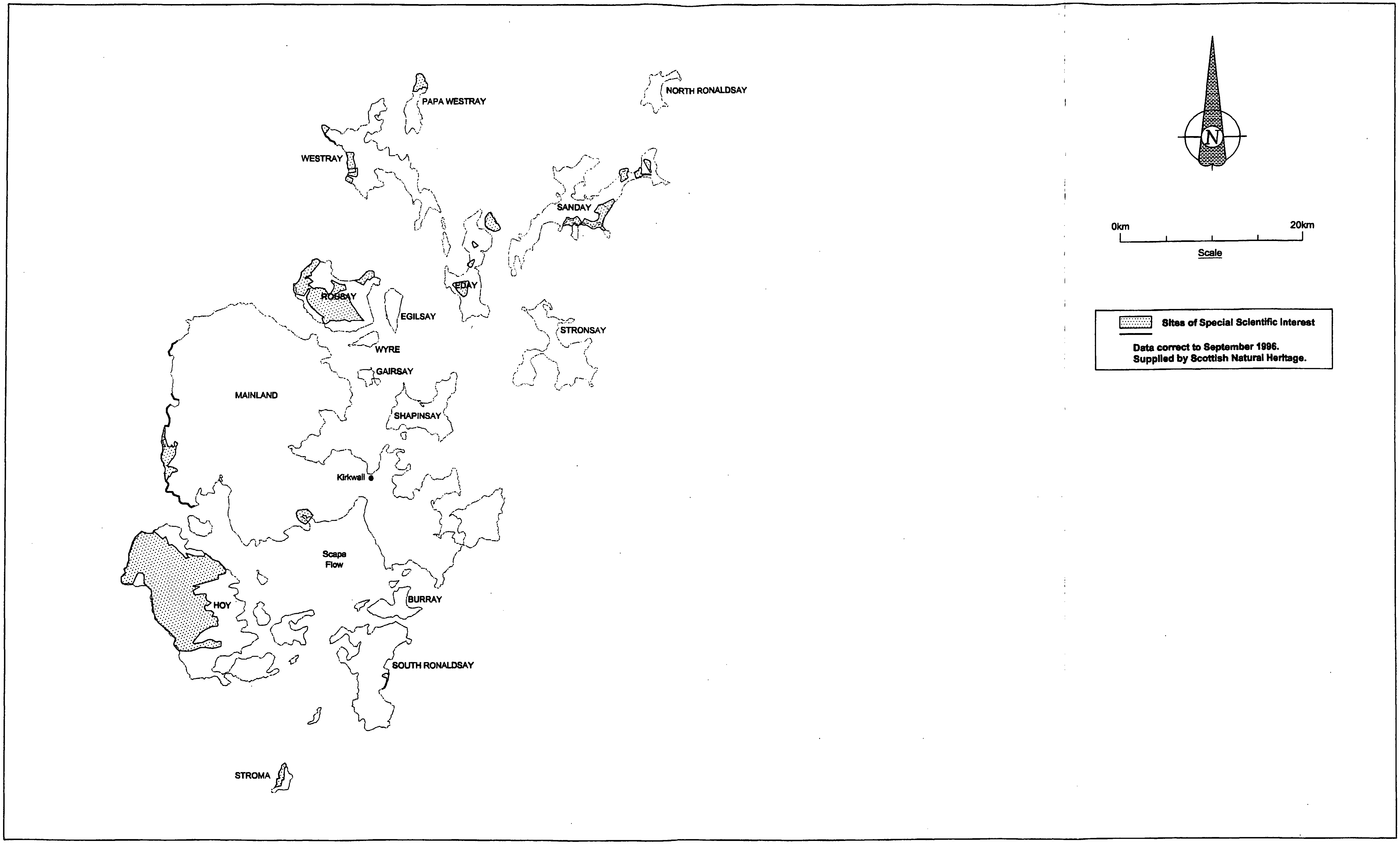


Figure 7 Cell 10 - Location of Sites of Special Scientific Interest

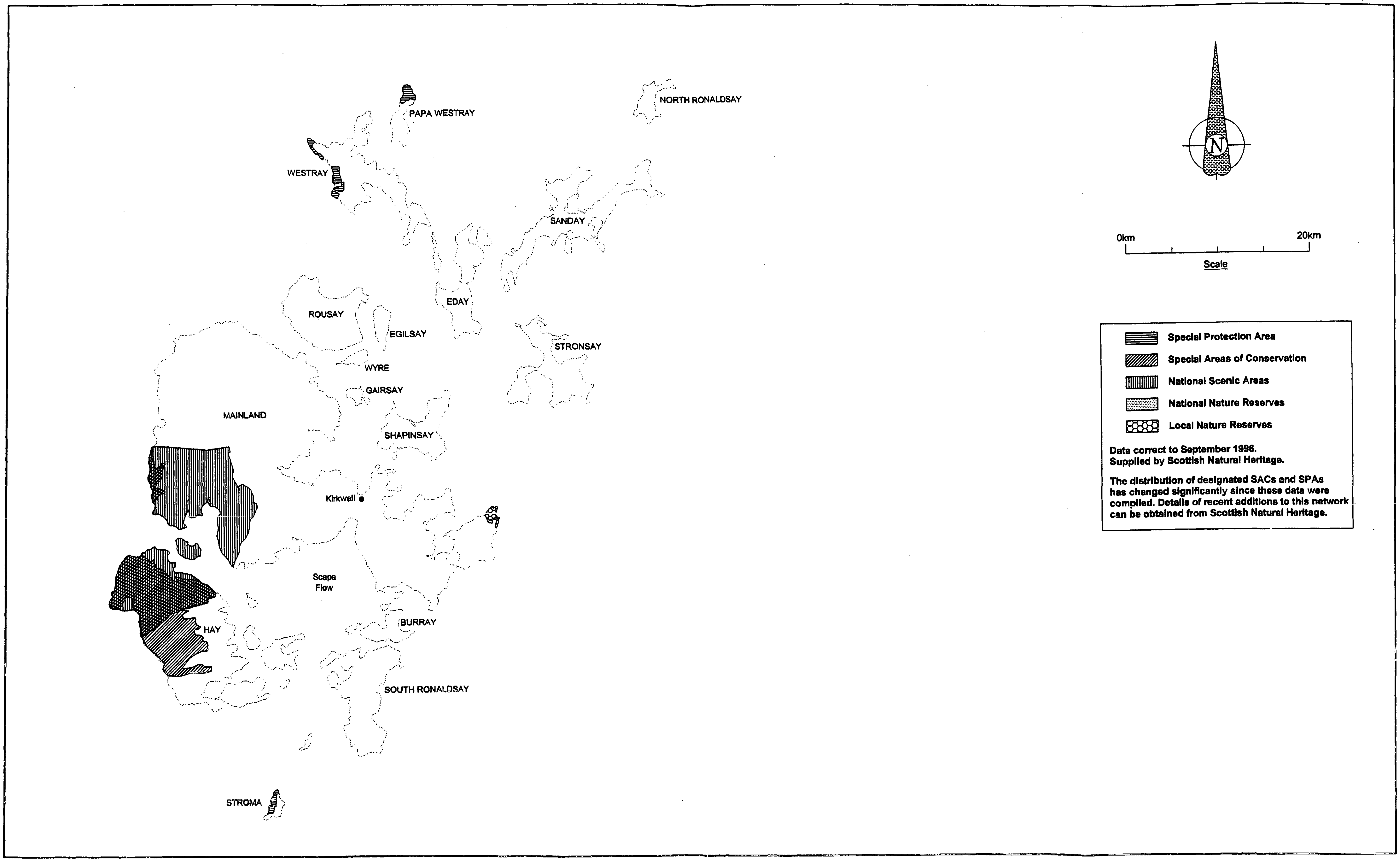


Figure 8 Cell 10 - Location of sites of natural heritage importance (other than SSSIs)

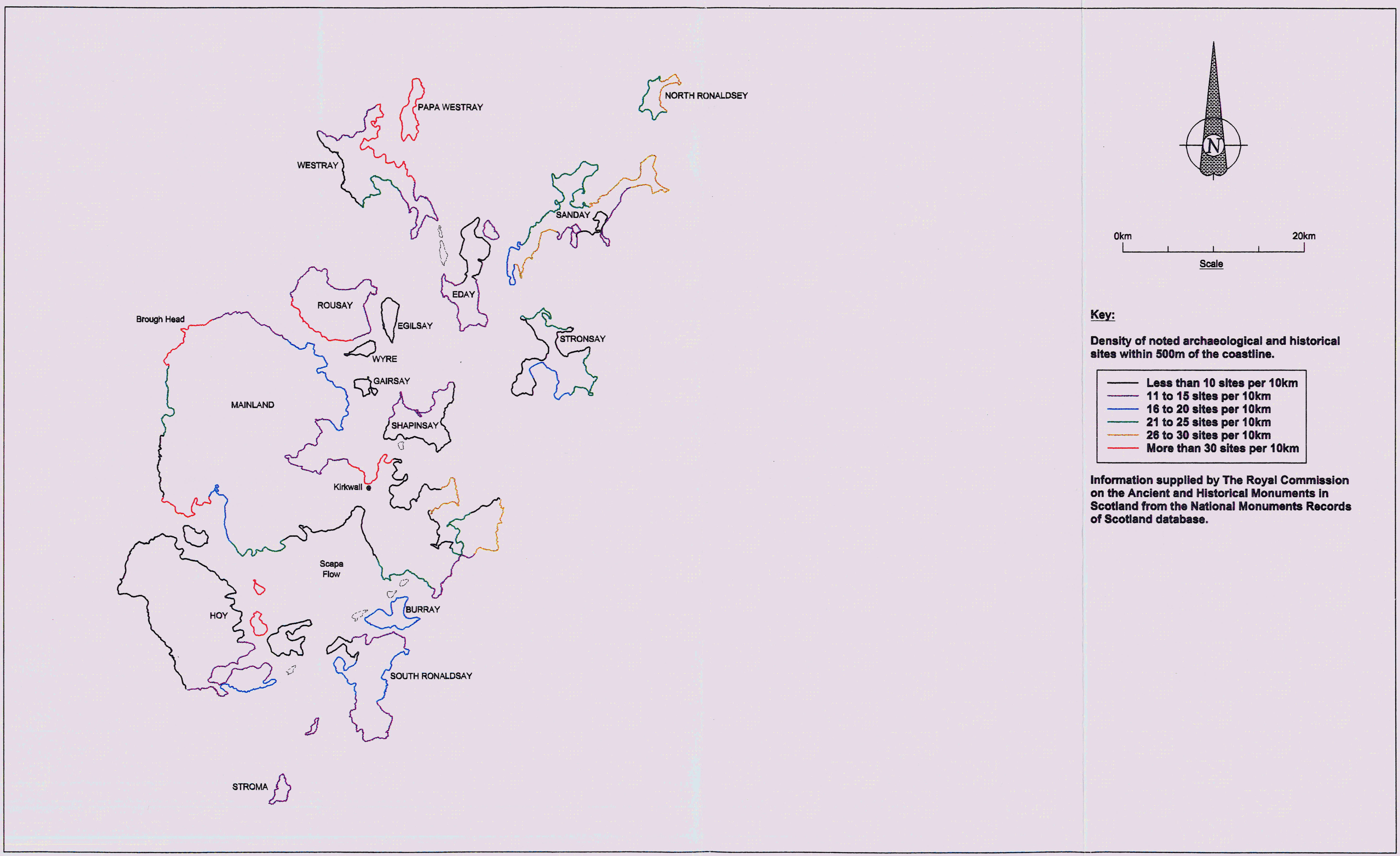


Figure 9 Cell 10 - Density of noted archaeological and historical sites

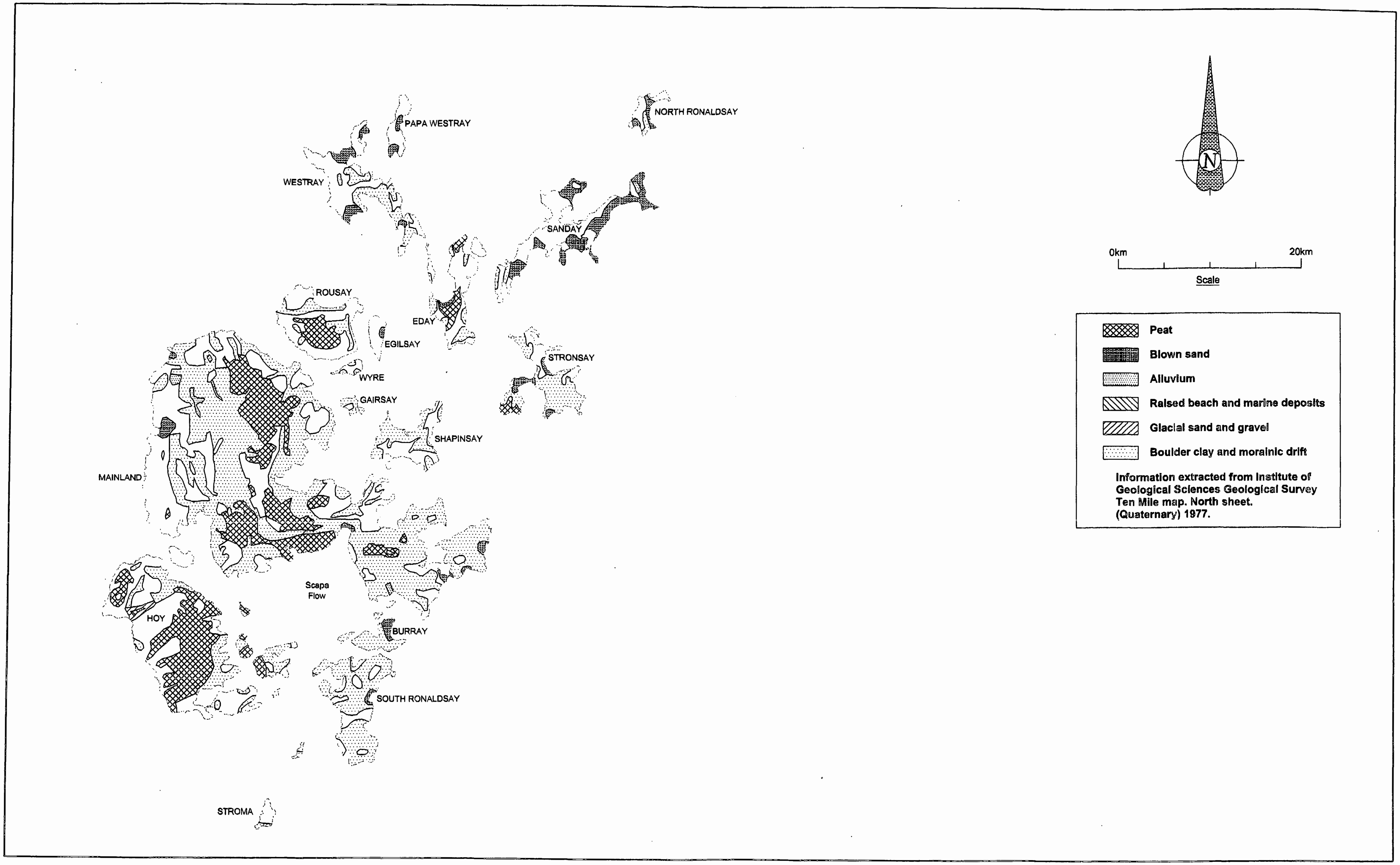
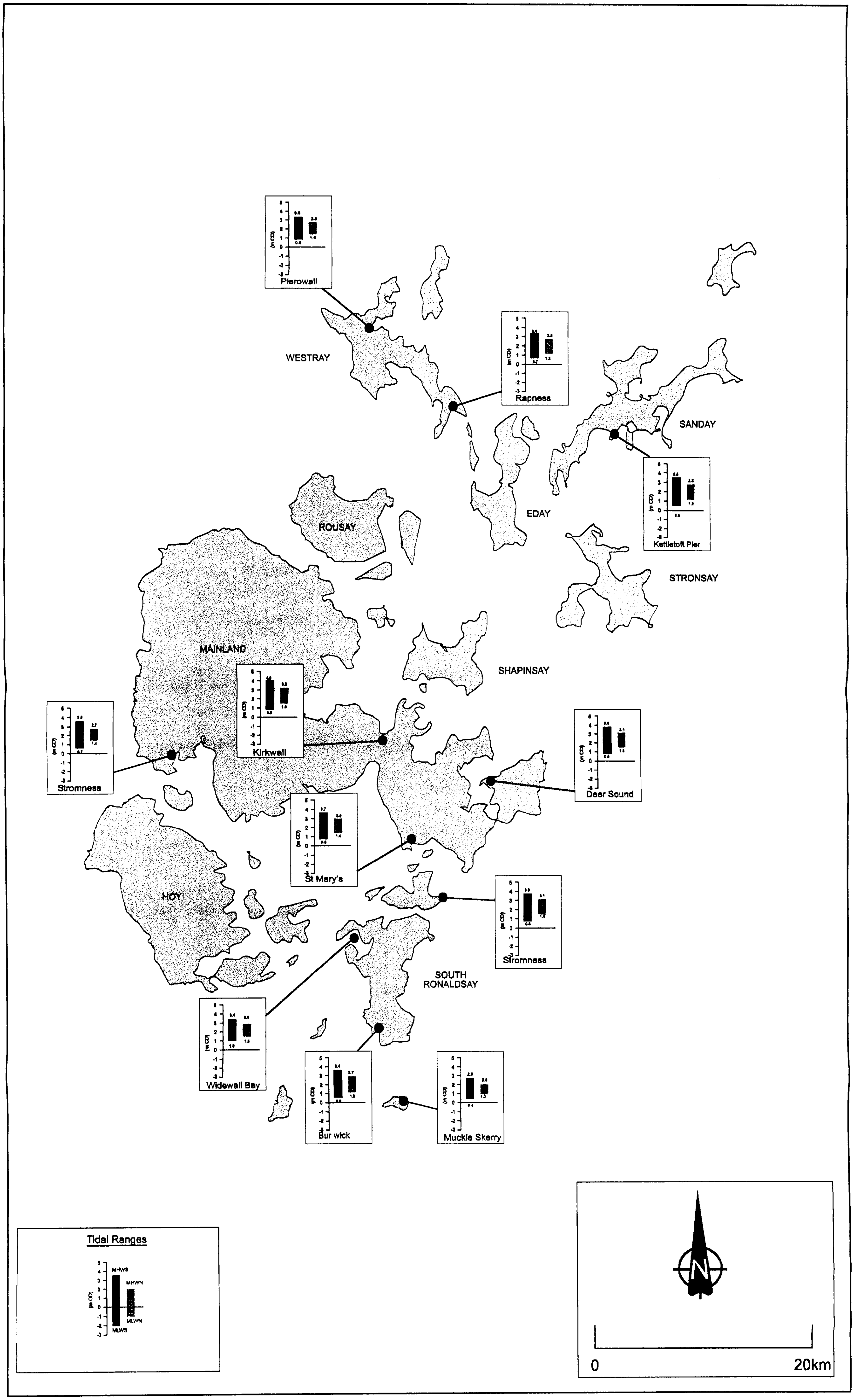


Figure 10 Cell 10 - Drift deposits

Figure 11 Cell 10 - Tidal levels and current information



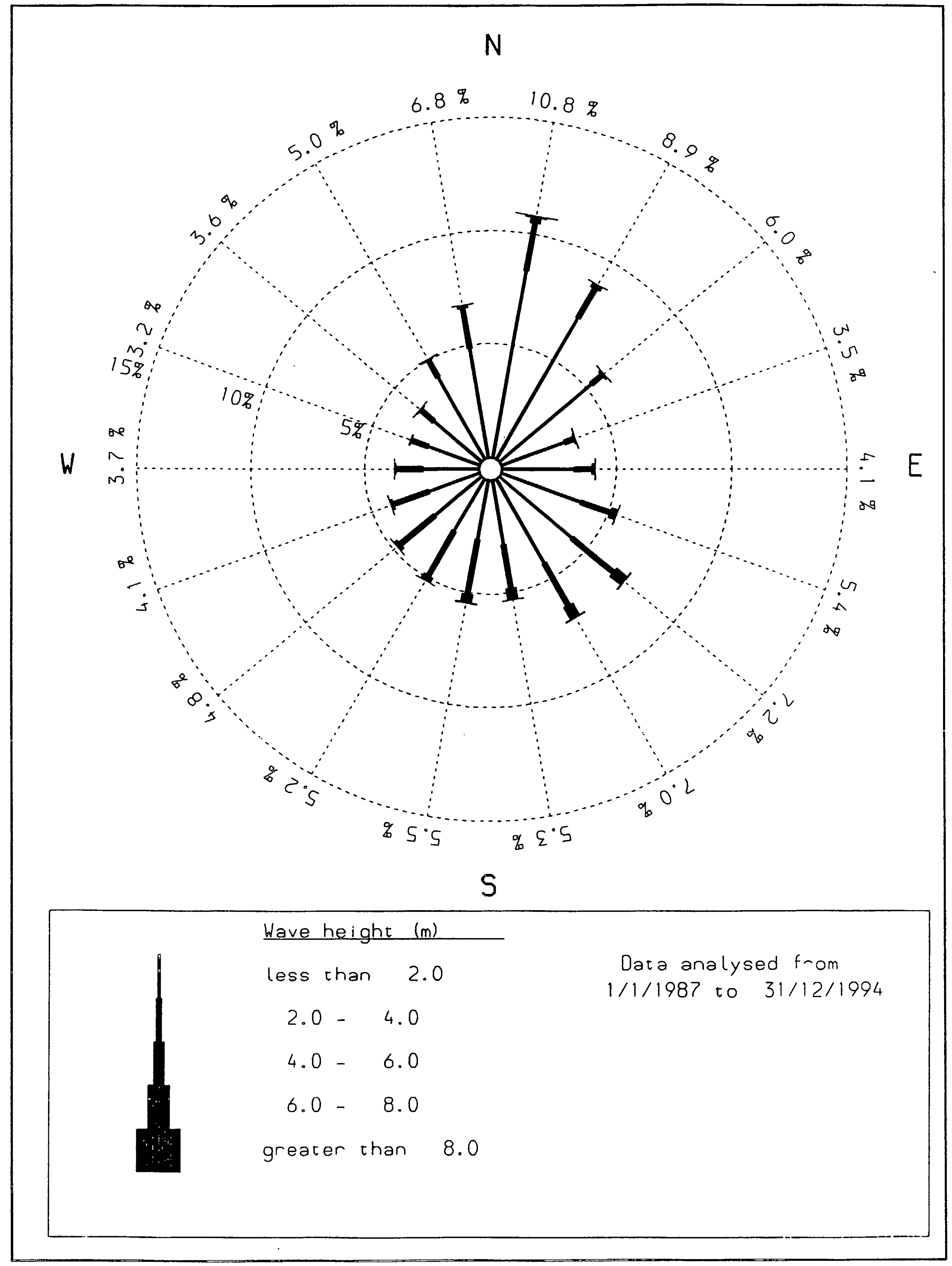


Figure 12 Total offshore wave climate east of Orkney

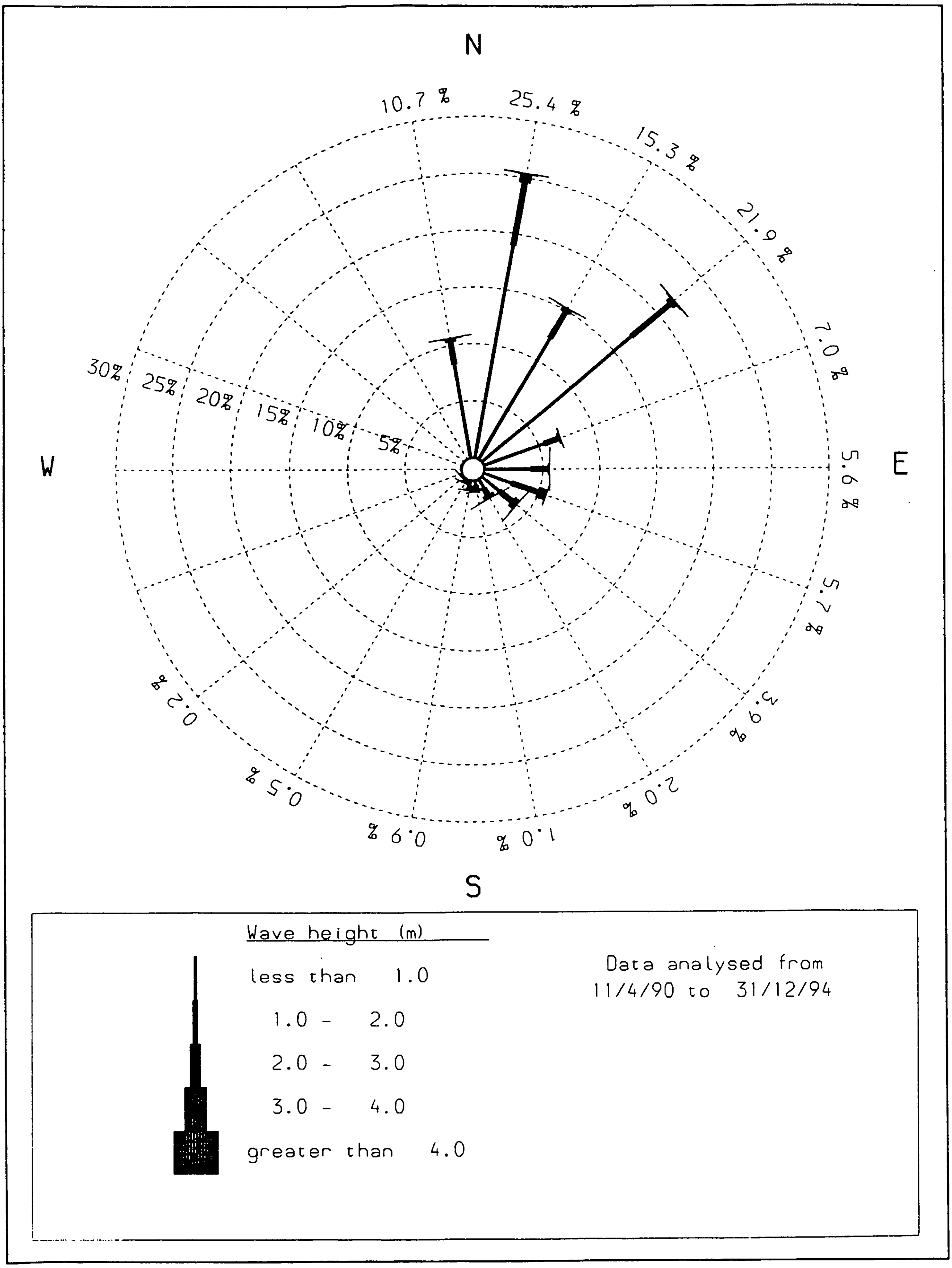


Figure 13 Swell offshore wave climate east of Orkney

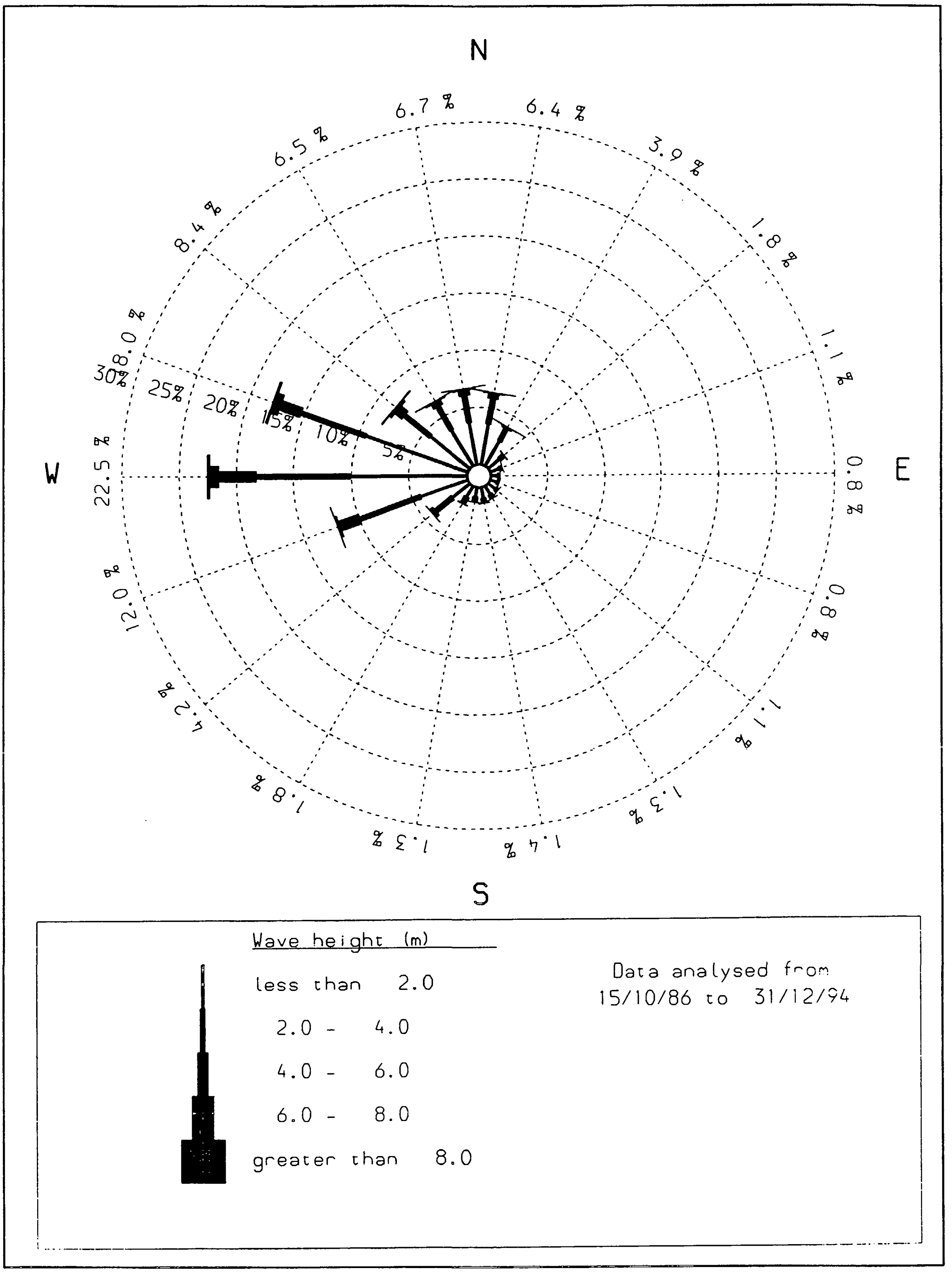


Figure 14 Total offshore wave climate west of Orkney

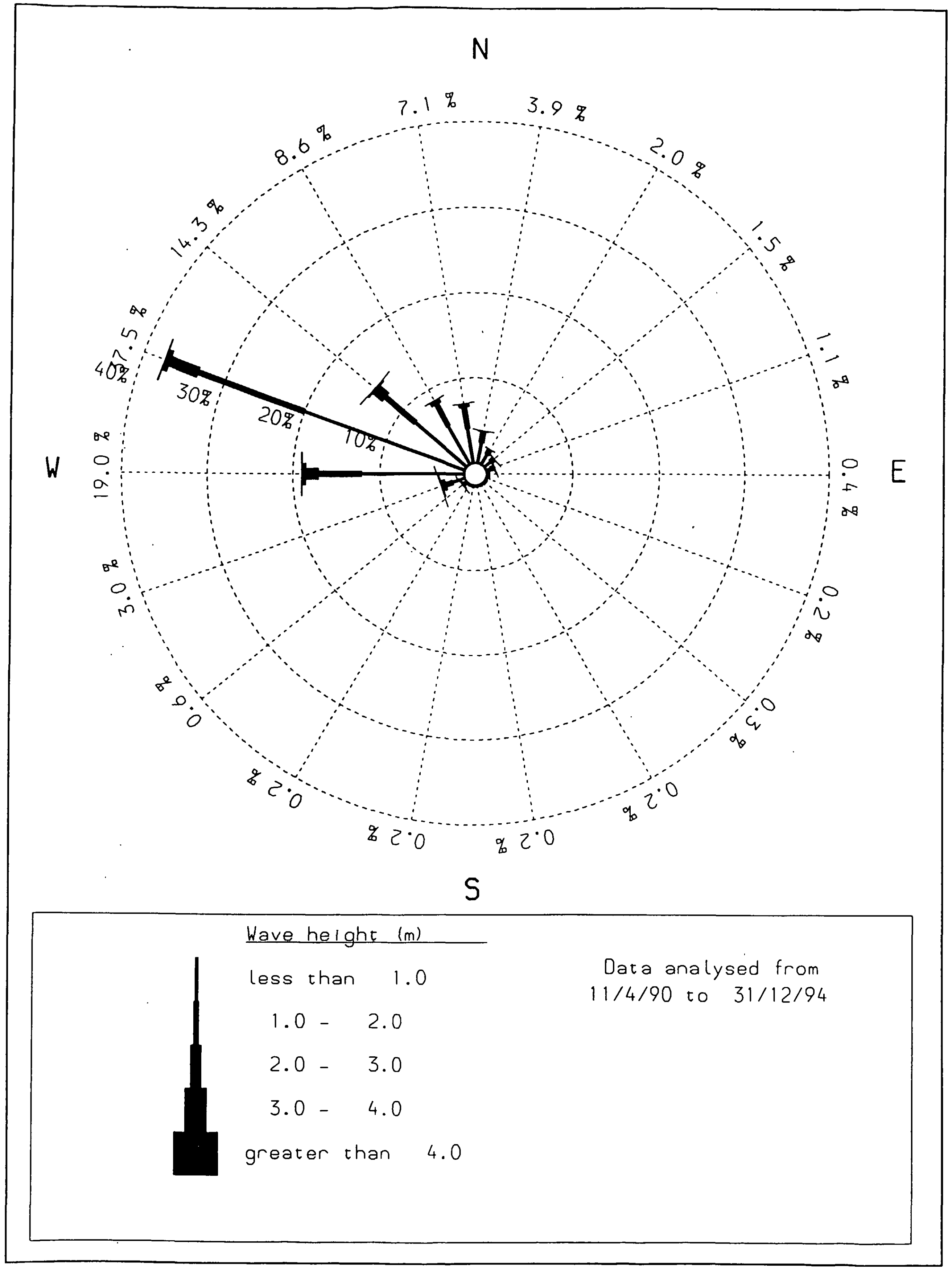
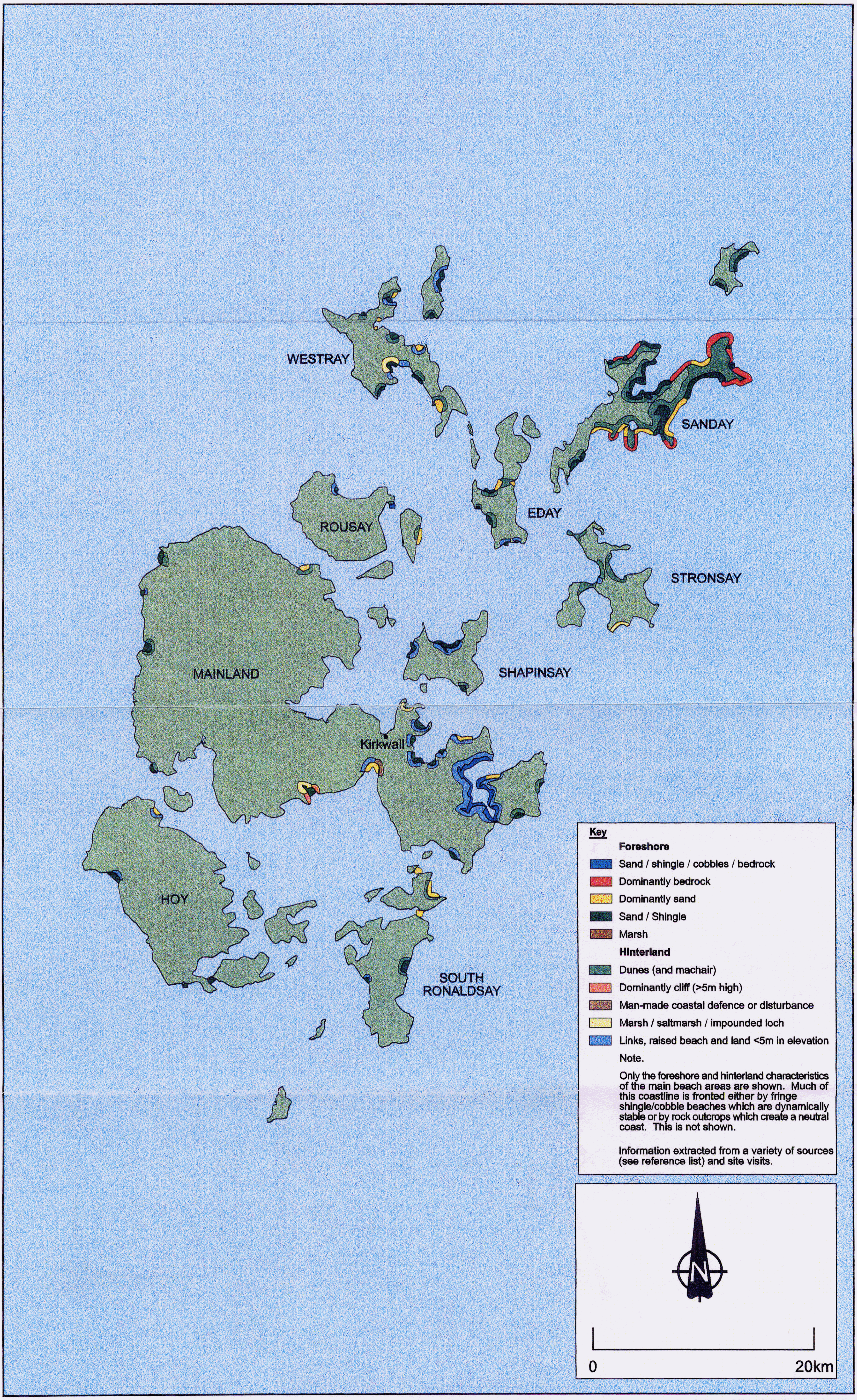


Figure 15 Swell offshore wave climate west of Orkney

Figure 16 Foreshore and hinterland characteristics



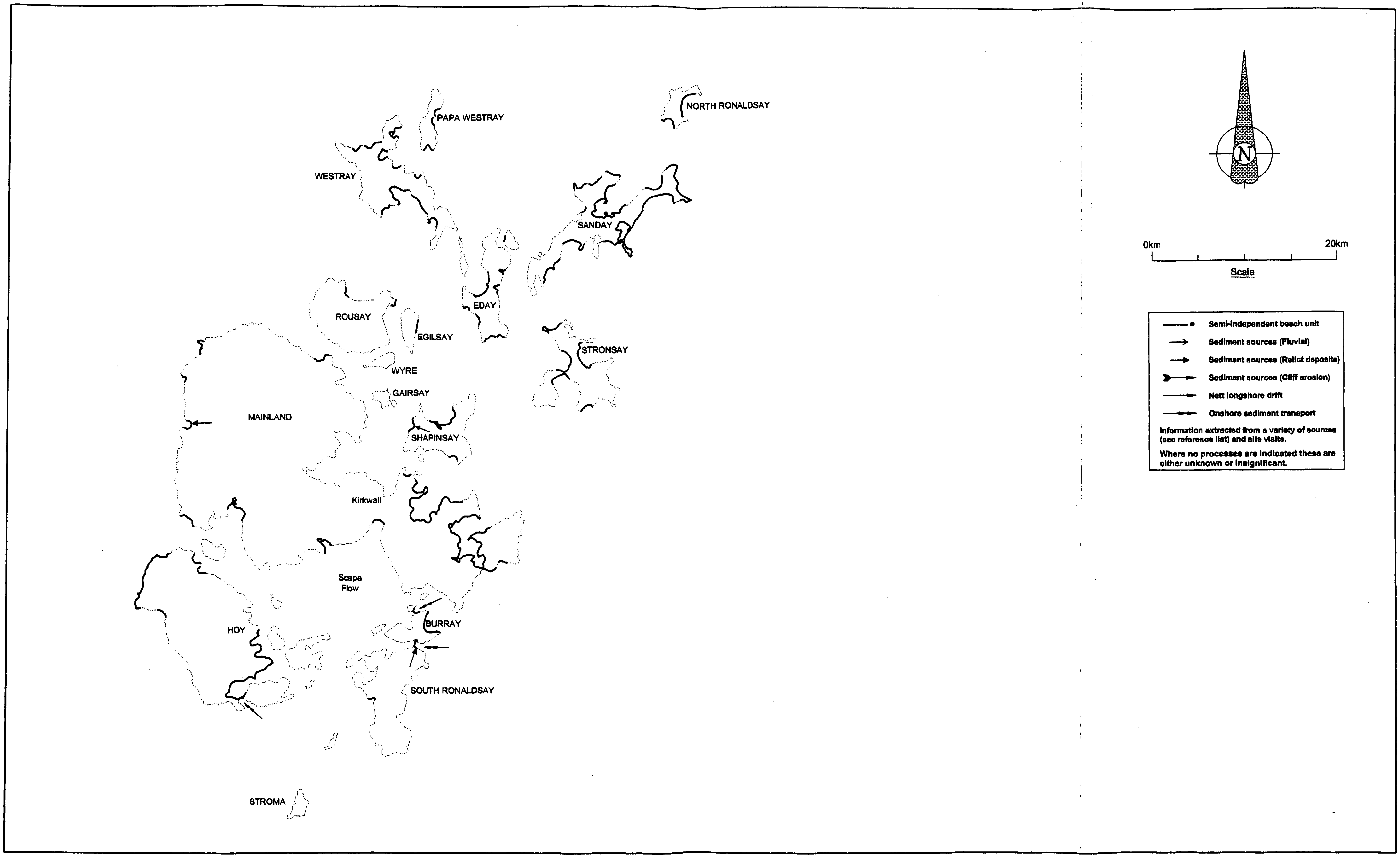


Figure 17 Dominant littoral processes

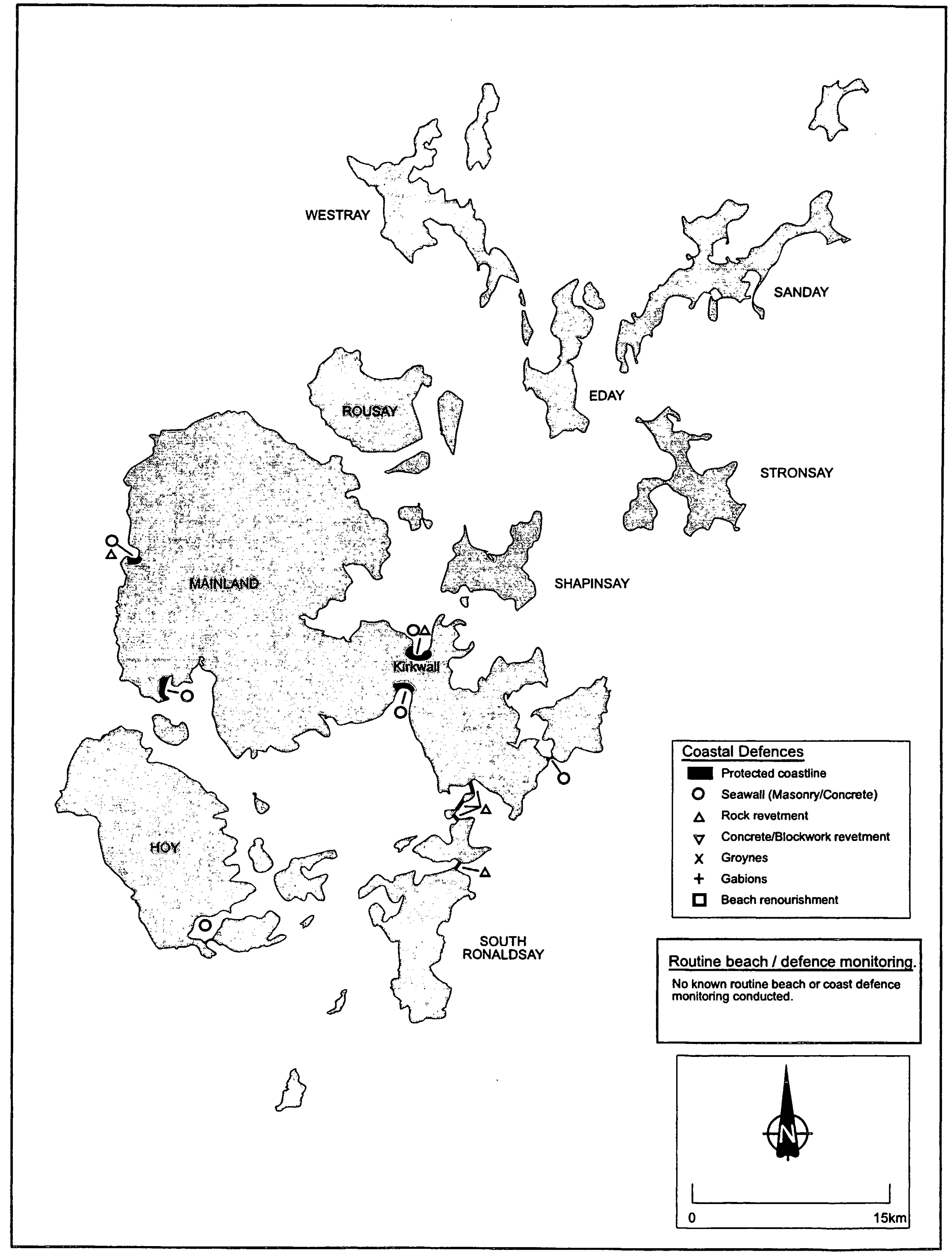


Figure 18 Coastal defence and monitoring

Appendix 1 Cell 10 – Details of Sites of Special Scientific Interest

Extracted from the British Oceanographic Data Centre's UKDMAP. Data correct to 1996.

Name	Grid Reference	Size (ha)	Date Notified	Site Designations
Marwick	HY226257	9.1	1986	Sea cliff (hard rock) Seabirds breeding
Bay of Skaill	HY233197	7.85	1991	Geological interest
Lochs of Harray & Stenness	HY295160	1930	1985	Open water Terrestrial invertebrates Site used for wintering wildfowl. Nationally important
Stromness Heath & Coast	HY226135	755	1991	Geological interest Dry grassland Maritime heath Peatland Phragmites reedbed Scrub Seabirds breeding
Muckle Head and Selwick	HY213053	1.7	1991	Geological interest
Hoy	HY225010	8186.1	1986	Geological interest Geomorphological interest Maritime heath Woodland Lower plants Terrestrial invertebrates Mammals noted Seabirds breeding
Ward Hill Cliffs	ND566885	35.6	1986	Sea cliff (hard rock) Dry grassland Maritime heath Flush or seepage line Lower plants Mammals noted Seabirds breeding
Copinsay	HY605015	151.76	1983	Rocky shore Sea cliff (hard rock) Seabirds breeding
Den Wick	HY576088	0.5	1991	Geological interest
Rousay	HY400310	2313	1989	Maritime heath Flush or seepage line Seabirds breeding
Mill Bay	HY665254	1.9	1991	Geological interest

Name	Grid Reference	Size (ha)	Date Notified	Site Designations
Doomy & Whitemaw Hill	HY547322	249	1983	Waders breeding Seabirds breeding
Mill Loch	HY565368	23.7	1983	Wildfowl breeding Comments: Red-throated divers
Calf of Eday	HY581391	242	1983	Seabirds breeding
Central Sanday	HY700403	654.7	1987	Geomorphological interest Saltmarsh Sand dunes Vegetated shingle Machair Lower plants Comments: Wintering waders
Northwall	HY740445	251.3	1983	Open water Machair Lower plants
Holm of Papa Westray	HY508520	47.6	1988	Wildfowl breeding Seabirds breeding
North Hill	HY500550	206	1984	Maritime heath Seabirds breeding
West Westray	HY425464	371.97	1985	Sea cliff (hard rock) Dry grassland Maritime heath Seabirds breeding

Appendix 2 Cell 10 – Location of known archaeological and historical sites within 500m of the coastline

Note: This map has not been published within the report but may be consulted (by prior arrangement) by contacting:

Earth Science Group
Advisory Services
Scottish Natural Heritage
2 Anderson Place
EDINBURGH
EH6 5NP

The underlying data are updated regularly by the National Monuments Record of Scotland and are available for inspection there, by prior arrangement.

Appendix 3 Useful addresses

Contact addresses for organisations referred to within the report and other useful contacts.

British Geological Survey (Scotland)
Murchison House
West Mains Road
Edinburgh — Tel: 0131-667 1000
EH9 3LA — Fax: 0131-668 2683

British Geological Survey (Coastal Geology Group)
Kingsley Dunham Centre
Keyworth
Nottingham — Tel: 0115 9363100
NG12 5GG — Fax: 0115 9363200

British Oceanographic Data Centre (BODC)
See Proudman Oceanographic Laboratory

Crown Estate Commission
10 Charlotte Square
Edinburgh — Tel: 0131 2267241
EH2 4DR — Fax: 0131 2201366

Historic Scotland
Longmore House
Salisbury Place
Edinburgh — Tel: 0131 6688600
EH9 1SH — Fax: 0131 6688789

HR Wallingford Ltd
Howbery Park
Wallingford
Oxon — Tel: 01491 835381
OX10 8BA — Fax: 01491 825539

Hydrographic Office (Taunton)
OCM ©
Admiralty Way
Taunton
Somerset — Tel: 01823 337900
TA1 2DN — Fax: 01823 284077

Institute of Marine Studies
University of St Andrews
St Andrews
Fife — Tel: 01334 462886
KY16 9AJ — Fax: 01334 462921

Institute of Oceanographic Sciences
See Proudman Oceanographic Laboratory

Joint Nature Conservation Committee
Monkstone House
City Road
Peterborough
PE1 1JY
Tel: 01733 562626
Fax: 01733 555948

Macaulay Land Use Research Institute
Craigiebuckler
Aberdeen
AB9 2QL
Tel: 01224 318611
Fax: 01224 311556

Marine Information Advisory Service (MIAS)
See Proudman Oceanographic Laboratory

Metoc plc (Metocean)
Exchange House
Station Road
Liphook
Hampshire
GU30 7DW
Tel: 01428 727800
Fax: 01428 727122

Ministry of Agriculture, Fisheries and Food
(Flood and Coastal Defence Division)
Eastbury House
30-34 Albert Embankment
London
SE1 7TL
Tel: 0207 238 6742
Fax: 0207 238 6665

National Museums of Scotland
c/o Royal Museum of Scotland
Chambers Street
Edinburgh
EH1 1JF
Tel: 0131-225 7534
Fax: 0131-220 4819

Ordnance Survey (Scottish Region)
Grayfield House
5 Bankhead Avenue
Edinburgh
EH11 4AE
Tel: 0845 605 0505

Proudman Oceanographic Laboratory
(British Oceanographic Data Centre, MIAS & Permanent Service for Mean Sea Level)
Bidston Observatory
Birkenhead
Merseyside
L43 7RA
Tel: 0151-653 8633
Fax: 0151-653 6269

Permanent Service for Mean Sea Level (PSMSL)
See Proudman Oceanographic Laboratory

Royal Commission on the Ancient and Historical Monuments of Scotland (RCAHMS)
John Sinclair House
16 Bernard Terrace
Edinburgh
EH8 9NX
Tel: 0131-662 1456
Fax: 0131-662 1477

Scottish Environment Protection Agency
Erskine Court
The Castle Business Park
Stirling
FK9 4TR
Tel: 01786 457700
Fax: 01786 446885

Scottish Executive (re Coast Protection Act (CPA))
Rural Affairs Department
European Environment and Engineering Unit
Victoria Quay
Edinburgh
EH6 6QQ
Tel: 0131-556 8400

Scottish Executive (re Food and Environment Protection Act (FEPA))
Rural Affairs Department
Pentland House
47 Robbs Loan
Edinburgh
EH14 1TY
Tel: 0131-556 8400

Scottish Executive
Marine Laboratory
PO Box 101
Victoria Road
Torry
Aberdeen
Tel: 01224 876544
Fax: 01224 295511

Scottish Natural Heritage
12 Hope Terrace
Edinburgh
EH9 2AS
Tel: 0131-447 4784
Fax: 0131-446 2277

Scottish Trust for Underwater Archaeology
c/o Department of Archaeology
University of Edinburgh
16-20 George Square
Edinburgh
EH8 9JZ
Tel: 0131-650 2368
Fax: 0131-650 4094

Scottish Tourist Board
23 Ravelston Terrace
Edinburgh
EH4 3EU
Tel: 0131-332 2433
Fax: 0131-343 1513

UK Meteorological Office
Marine Consulting Service
Johnstone House
London Road
Bracknell
RG12 2UR

Tel: 01344 420242
Fax: 01344 854412

UK Offshore Operators Association Ltd (UKOOA)
30 Buckingham Gate
London
SW1E 6NN

Tel: 020 7802 2400
Fax: 020 7802 2401

Appendix 4 Glossary

Abrasion platform	A rock or clay platform which has been worn by the processes of abrasion (i.e. frictional erosion by material transported by wind and waves)
Accretion	The accumulation of (beach) sediment, deposited by natural fluid flow processes
A Class tide gauge	One of a UK network maintained to the highest and most consistent standards
Amplitude	Half of the peak-to-trough range (or height)
Apron	Layer of stone, concrete or other material to protect the toe of a seawall
Armour layer	Protective layer on a breakwater or seawall composed of **armour units**
Armour unit	Large quarried stone or specially shaped concrete block used as primary protection against wave action
Asperities	The three-dimensional irregularities forming the surface of an irregular stone (or rock) subject to wear and rounding during attraction
Astronomical tide	The tidal levels and character which would result from gravitational effects, e.g. of the Earth, Sun and Moon, without any atmospheric influences
Back-rush	The seaward return of water following the **up-rush** of a wave
Backshore	The upper part of the active beach above the normal reach of the tides (high water), but affected by large waves occurring during a high tide
Barrier beach	A sand or shingle bar above high tide, parallel to the coastline and separated from it by a lagoon
Bathymetry	Refers to the spatial variability of levels on the seabed
Beach	A deposit of non-cohesive material (e.g. sand, gravel) situated on the interface between dry land and the sea (or other large expanse of water) and actively "worked" by present-day hydrodynamic processes (i.e. waves, tides and currents) and sometimes by winds
Beach crest	The point representing the limit of high tide storm wave **run-up**
Beach face	From the **beach crest** out to the limit of sediment movement
Beach head	The cliff, dune or seawall forming the landward limit of the active beach
Beach plan shape	The shape of the beach in plan; usually shown as a contour line, combination of contour lines or recognizable features such as beach crest and/or still water line
Beach profile	A cross-section taken perpendicular to a given beach contour; the profile may include the face of a dune or seawall, extend over the **backshore**, across the **foreshore**, and seaward underwater into the **nearshore** zone
Beach recharge	Supplementing the natural volume of sediment on a beach, using material from elsewhere - also known as beach replenishment/nourishment/feeding

Bed forms	Features on a seabed (e.g. ripples and sand waves) resulting from the movement of sediment over it
Bed load	Sediment transport mode in which individual particles either roll or slide along the seabed as a shallow, mobile layer a few particle diameters deep
Bed shear stress	The way in which waves (or currents) transfer energy to the sea bed
Benefits	The economic value of a scheme, usually measured in terms of the cost of damages avoided by the scheme, or the valuation of perceived amenity or environmental improvements
Berm	(1) On a beach: a nearly horizontal plateau on the **beach face** or **backshore**, formed by the deposition of beach material by wave action or by means of a mechanical plant as part of a **beach recharge** scheme (2) On a structure: a nearly horizontal area, often built to support or key-in an **armour layer**
Boulder	A rounded rock on a beach, greater than 250mm in diameter, larger than a **cobble** - see also **gravel, shingle**
Boundary conditions	Environmental conditions, e.g. waves, currents, drifts, etc. used as boundary input to physical or numerical models
Bound long wave	Long wave directly due to the variation in set-down at the breaker line due to wave groups
Breaching	Failure of the **beach head** allowing flooding by tidal action
Breaker depth	Depth of water, relative to **still water level** at which waves break; also known as **breaking depth** or limiting depth
Breaker index	Maximum ratio of **wave height** to water depth in the surf zone
Breaker zone	The zone within which waves approaching the coastline commence breaking, typically in water depths of between 5 and 10 metres
Breaking	Reduction in wave energy and height in the surf zone due to limited water depth
Breastwork	Vertically-faced or steeply inclined structure usually built with timber and parallel to the shoreline, at or near the **beach crest**, to resist erosion or mitigate against flooding
Bypassing	Moving beach material from the **updrift** to the **downdrift** side of an obstruction to **longshore-drift**
Chart datum	The level to which both tidal levels and water depths are reduced - on most UK charts, this level is that of the predicted lowest **astronomical tide** level (LAT)
Clay	A fine grained, plastic, sediment with a typical grain size less than 0.004mm. Possesses electro-magnetic properties which bind the grains together to give a bulk strength or cohesion
Climate change	Refers to any long-term trend in mean sea level, **wave height**, wind speed, drift rate etc.
Closure depth	The depth at the offshore limit of discernible bathymetric change between surveys.
Coastal cell	See Sediment cell

Coastal defence	General term used to encompass both coast protection against erosion and sea defence against flooding
Coastal forcing	The natural processes which drive coastal hydro- and morpho-dynamics (e.g. winds, waves, tides, etc)
Coastal processes	Collective term covering the action of natural forces on the shoreline, and nearshore seabed
Coastal zone	Some combination of land and sea area, delimited by taking account of one or more elements
Coast protection	Protection of the land from erosion and encroachment by the sea
Cobble	A rounded rock on a beach, with diameter ranging from about 75 to 250mm - see also **boulder, gravel, shingle**
Cohesive sediment	Sediment containing significant proportion of clays, the electromagnetic properties of which cause the sediment to bind together
Conservation	The protection of an area, or particular element within an area, whilst accepting the dynamic nature of the environment and therefore allowing change
Core	(1) A cylindrical sample extracted from a beach or seabed to investigate the types and depths of sediment layers (2) An inner, often much less permeable portion of a breakwater, or barrier beach
Coriolis	Force due to the Earth's rotation, capable of generating currents
Crest	Highest point on a beach face, breakwater or seawall
Cross-shore	Perpendicular to the shoreline
Current	Flow of water
Current-refraction	Process by which wave velocity is affected by a current
Cusp	Seaward bulge, approximately parabolic in shape, in the beach contours. May occur singly, in the lee of an offshore bulk or island, or as one of a number of similar, approximately regularly-spaced features on a long straight beach
Deep water	Water too deep for waves to be affected by the seabed; typically taken as half the **wavelength**, or greater
Deflation	Erosion of dunes by wind action
Depth-limited	Situation in which wave generation (or **wave height**) is limited by water depth
Design wave condition	Usually an extreme wave condition with a specified return period used in the design of coastal works
Detached breakwater	A breakwater without any constructed connection to the shore
Diffraction	Process affecting wave propagation, by which wave energy is radiated normal to the direction of wave propagation into the lee of an island or breakwater
Diffraction coefficient	Ratio of diffracted **wave height** to deep water **wave height**
Diurnal	Literally `of the day', but here meaning having a period of a `tidal day', i.e. about 24.8 hours

Downdrift	In the direction of the nett longshore transport of beach material
Drying beach	That part of the beach which is uncovered by water (e.g. at low tide). Sometimes referred to as `subaerial' beach
Dunes	(1) Accumulations of windblown sand on the **backshore**, usually in the form of small hills or ridges, stabilised by vegetation or control structures (2) A type of bed form indicating significant sediment transport over a sandy seabed
Duration	The length of time a wind blows at a particular speed and from the same direction during the generation of storm waves
Ebb	Period when tide level is falling; often taken to mean the **ebb current** which occurs during this period
Edge waves	Waves which mainly exist shoreward of the breaker line, and propagate along the shore. They are generated by the incident waves, their amplitude is a maximum at the shoreline and diminishes rapidly in a seaward direction
Epifauna	Animals living in the sediment surface or on the surface of other plants or animals
Event	An occurrence meeting specified conditions, e.g. damage, a threshold **wave height** or a threshold water level
Exponential distribution	A model probability distribution
Extreme	The value expected to be exceeded once, on average, in a given (long) period of time
Fetch	Distance over which a wind acts to produce waves - also termed **fetch length**.
Fetch-limited	Situation in which wave energy (or **wave height**) is limited by the size of the wave generation area (**fetch**)
Forecasting	Prediction of conditions expected to occur in the near future, up to about two days ahead
Foreshore	The intertidal area below highest tide level and above lowest tide level
Freeboard	The height of the crest of a structure above the **still water level**
Friction	Process by which energy is lost through shear stress
Friction factor	Factor used to represent the roughness of the sea bed
Frontager	Person or persons owning, and often living in, property immediately landward of the beach
Fully-developed sea	A wave condition which cannot grow further without an increase in wind speed - also fully-arisen sea
GIS	Geographical Information System. A database of information which is geographically orientated, usually with an associated visualization system
Gravel	Beach material, coarser than sand but finer than **pebbles** (2-4mm diameter)
Group velocity	The speed of wave energy propagation. Half the wave **phase velocity** in **deep water**, but virtually the same in **shallow water**

Groyne	Narrow, roughly shore-normal structure built to reduce longshore currents, and/ or to trap and retain beach material. Most groynes are of timber or rock, and extend from a seawall, or the **backshore**, well onto the **foreshore** and rarely even further offshore. In the USA and historically called a **groin**
Groyne bay	The beach compartment between two **groynes**
Gumbel distribution	A model probability distribution, commonly used in wind and water level analysis
Hard defences	General term applied to impermeable coastal defence structures of concrete, timber, steel, masonry etc, which reflect a high proportion of incident wave energy, cf **soft defences**
Hindcasting	In wave prediction, the retrospective forecasting of waves using measured wind information
Historic event analysis	Extreme analysis based on hindcasting typically ten events over a period of 100 years
Incident wave	Wave moving landward
Infauna	Animals living in the sediment
Infragravity waves	Waves with periods above about 30 seconds generated by wave groups breaking in the surf zone
Inshore	Areas where waves are transformed by interaction with the sea bed
Intertidal	The zone between the high and low water marks
Isobath	Line connecting points of equal depth, a seabed contour
Isopachyte	Line connecting points on the seabed with an equal depth of sediment
Joint probability	The probability of two (or more) things occurring together
Joint probability density	Function specifying the joint distribution of two (or more) variables
Joint return period	Average period of time between occurrences of a given joint probability event
JONSWAP spectrum	Wave spectrum typical of growing deep water waves
Limit of storm erosion	A position, typically a maximum water depth of 8 to 10 metres, often identifiable on surveys by a break (i.e. sudden change) in slope of the bed
Littoral	Of or pertaining to the shore
Littoral drift, Littoral transport	The movement of **beach material** in the **littoral zone** by waves and currents. Includes movement parallel (longshore drift) and perpendicular (cross-shore transport) to the shore
Locally generated waves	Waves generated within the immediate vicinity, say within 50km, of the point of interest
Log-normal distribution	A model probability distribution
Long-crested random waves	Random waves with variable heights and periods but a single direction
Longshore	Parallel and close to the coastline
Longshore bar	Bar running approximately parallel to the shoreline

Longshore drift	Movement of (beach) sediments approximately parallel to the coastline
Long waves	Waves with periods above about 30 seconds generated by wave groups breaking in the surf zone
Macro-tidal	Tidal range greater than 4m
Managed landward realignment	The deliberate setting back of the existing line of defence in order to obtain engineering and/or environmental advantages - also referred to as managed retreat
Marginal probability	The probability of a single variable in the context of a joint probability analysis
Marginal return period	The return period of a single variable in the context of a joint probability analysis
Meso-tidal	Tidal range between 2m and 4m
Micro-tidal	Tidal range less than 2m
Morphologically averaged wave condition	A single wave condition producing the same nett longshore drift as a given proportion of the annual wave climate
Mud flat	An area of fine silt usually exposed at low tide but covered at high tide, occurring in sheltered estuaries or behind shingle bars or sand spits
Nearshore	The zone which extends from the **swash zone** to the position marking the start of the **offshore zone**, typically at water depths of the order of 20m
Ness	Roughly triangular promontory of land jutting into the sea, often consisting of mobile material, i.e. a beach form
Numerical modelling	Refers to analysis of coastal processes using computational models
Offshore	The zone beyond the **nearshore zone** where sediment motion induced by waves alone effectively ceases and where the influence of the sea bed on wave action is small in comparison with the effect of wind
Operational	The construction, maintenance and day-to-day activities, associated with beach management
Overtopping	Water carried over the top of a **coastal defence** due to wave **run-up** exceeding the **crest** height
Overwash	The effect of waves **overtopping** a **coastal defence**, often carrying sediment landwards which is then lost to the beach system
Peaks over threshold (POT)	Refers to the maximum value of a variable during each excursion above a threshold value
Pebbles	Beach material usually well-rounded and between about 4mm to 75mm diameter
Persistence of storms	The duration of sea states above some severity threshold (e.g. **wave height**)
Phase velocity	The velocity at which a wave crest propagates, cf **group velocity**
Physical modelling	Refers to the investigation of coastal processes using a scaled model

Pierson-Moskowitz spectrum	Wave spectrum typical of fully-developed deep water waves
Piezometric surface	The level within (or above) a soil stratum at which the pore-pressure is zero
Pocket Beach	A beach, usually small, between two **headlands**
Preservation	Static protection of an area or element, attempting to perpetuate the existence of a given `state'
Probability density function	Function specifying the distribution of a variable
Profile of storms	Refers to the persistence of storms coupled with the rate of change of sea state (e.g. **wave height**) within the storms
Reef	A ridge of rock or other material lying just below the surface of the sea
Reflected wave	That part of an incident wave that is returned (reflected) seaward when a wave impinges on a **beach**, **seawall** or other reflecting surface
Refraction coefficient	Ratio of refracted **wave height** to deep water **wave height**
Refraction (of water waves)	The process by which the direction of a wave moving in **shallow water** at an angle to the contours is changed so that the wave crests tend to become more aligned with those contours
Regular waves	Waves with a single height, period and direction
Residual (water level)	The components of water level not attributable to astronomical effects
Return period	Average period of time between occurrences of a given event
Revetment	A sloping surface of stone, concrete or other material used to protect an embankment, natural coast or shoreline against erosion
Rip current	Jet-like seaward-going current normal to the shoreline associated with wave-induced longshore currents
Risk analysis	Assessment of the total risk due to all possible environmental inputs and all possible mechanisms
Runnel	Channels on a beach, usually running approximately shore-parallel and separated by beach ridges
Run-up, run-down	The upper and lower levels reached by a wave on a beach or coastal structure, relative to **still-water level**
Salient	Coastal formation of beach material developed by wave refraction and diffraction and longshore drift comprising of a bulge in the coastline towards an offshore island or breakwater, but not connected to it as in the case of a **tombolo** - see also **ness, cusp**
Sand	Sediment particles, mainly of quartz, with a diameter of between 0.062mm and 2mm, generally classified as fine, medium, coarse or very coarse
Scatter diagram	A two-dimensional histogram showing the joint probability density of two variables within a data sample
Sea defences	Works to alleviate flooding by the sea
Sea level rise	The long-term trend in mean sea level

Seawall	Solid coastal defence structure built parallel to the coastline
Sediment	Particulate matter derived from rock, minerals or bioclastic debris
Sediment cell	In the context of a strategic approach to coastal management, a length of coastline in which interruptions to the movement of sand or shingle along the beaches or nearshore sea bed do not significantly affect beaches in the adjacent lengths of coastline. Also referred to as a coastal cell
Sediment sink	Point or area at which beach material is irretrievably lost from a coastal cell, such as an estuary, or a deep channel in the seabed
Sediment source	Point or area on a coast from which beach material arises, such as an eroding cliff, or river mouth
Seiche	Standing wave oscillation in an effectively closed body of water
Semi-diurnal	Having a period of half a tidal day, i.e. 12.4 hours
Sequencing of storms	Refers to the temporal distribution of storms and therefore how they are grouped
Shallow water	Water of such depth that surface waves are noticeably affected by bottom topography. Typically this implies a water depth equivalent to less than half the **wave length**
Shingle	A loose term for coarse beach material, a mixture of gravel, pebbles and larger material, often well-rounded and of hard rock, e.g. chert, flint etc.
Shoaling	Decrease in water depth. The transformation of wave profile as they propagate inshore
Shoaling coefficient	Ratio of shoaled **wave height** to deep water **wave height**
Shoreline	One characteristic of the coast. Poorly defined but essentially the interface between land and sea
Shoreline management	The development of strategic, long-term and sustainable coastal defence policy within a **sediment cell**
Shore normal	A line at right-angles to the contours in the surf zone
Short-crested random waves	Random waves with variable heights, periods and directions
Significant wave height	The average height of the highest one third of the waves in a given sea state
Silt	Sediment particles with a grain size between 0.004mm and 0.062mm, i.e. coarser than **clay particles** but finer than **sand**
Soft defences	Usually refers to **beaches** (natural or designed) but may also relate to energy-absorbing beach-control structures, including those constructed of rock, where these are used to control or redirect **coastal processes** rather than opposing or preventing them
Spit	A long narrow accumulation of sand or shingle, lying generally in line with the coast, with one end attached to the land the other projecting into the sea or across the mouth of an estuary - see also **ness**

Standard of service	The adequacy of defence measured in terms of the return period (years) of the event which causes a critical condition (e.g. breaching, overtopping) to be reached
Still-water level (SWL)	Water level that would exist in the absence of waves
Strand line	An accumulation of debris (e.g. seaweed, driftwood and litter) cast up onto a beach, and lying along the limit of wave uprush
Sub-tidal beach	The part of the beach (where it exists) which extends from low water out to the approximate limit of storm erosion. The latter is typically located at a maximum water depth of 8 to 10 metres and is often identifiable on surveys by a break in the slope of the bed
Surf beat	Independent long wave caused by reflection of **bound long wave**
Surf zone	The zone of wave action extending from the water line (which varies with tide, surge, set-up, etc.) out to the most seaward point of the zone (**breaker zone**) at which waves approaching the coastline commence breaking, typically in water depths of between 5 to 10 metres
Surge	Changes in water level as a result of meteorological forcing (wind, high or low barometric pressure) causing a difference between the recorded water level and that predicted using harmonic analysis, may be positive or negative
Suspended load	A mode of sediment transport in which the particles are supported, and carried along by the fluid
Swash zone	The zone of wave action on the beach, which moves as water levels vary, extending from the limit of **run-down** to the limit of **run-up**
Swell (waves)	Remotely wind-generated waves. Swell characteristically exhibits a more regular and longer period and has longer crests than locally generated waves
Threshold of motion	The point at which the forces imposed on a sediment particle overcome its inertia and it starts to move
Tidal current	The movement of water associated with the rise and fall of the tides
Tidal range	Vertical difference in high and low water level once decoupled from the water level **residuals**
Tidal wave	The rise and fall in water level due to the passage of the tide
Tide	The periodic rise and fall in the level of the water in oceans and seas; the result of gravitational attraction of the sun and moon
Tides	(1) Highest astronomical tide (HAT), lowest astronomical tide (LAT): the highest and lowest levels, respectively, which can be predicted to occur under average meteorological conditions. These levels will not be reached every year. HAT and LAT are not the extreme levels which can be reached, as storm surges may cause considerably higher and lower levels to occur.

(2) Mean high water springs (MHWS), mean low water springs (MLWS): the height of mean high water springs is the average throughout a year of the heights of two successive high waters during those periods of 24 hours (approximately once a fortnight) when the range of the tide is greatest. The height of mean low water springs is the average height obtained by the two successive low waters during the same periods.

(3) Mean high water neaps (MHWN), mean low water neaps (MLWN): the height of mean high water neaps is the average of the heights throughout the year of two successive high waters during those periods of 24 hours (approximately once a fortnight) when the range of the tide is least. The height of mean low water neaps is the average height obtained by the two successive low waters during the same periods.

(4) Mean high water (MHW), mean low water (MLW): for the purpose of this manual, mean high/low water, as shown on Ordnance Survey Maps, is defined as the arithmetic mean of the published values of mean high/low water springs and mean high/low water neaps. This ruling applies to England and Wales. In Scotland the tidal marks shown on Ordnance Survey maps are those of mean high (or low) water springs (MH (or L) WS).

TMA spectrum	Wave spectrum typical of growing seas in limited water depths
Tombolo	Coastal formation of beach material developed by **refraction, diffraction** and **longshore drift** to form a `neck' connecting a coast to an offshore island or breakwater (see also **salient**)
Updrift	The direction opposite to that of the predominant longshore movement of beach material
Up-rush	The landward return of water following the **back-rush** of a wave
Water depth	Distance between the seabed and the **still water level**
Water level	Elevation of **still water level** relative to some datum
Wave celerity	The speed of wave propagation
Wave climate	The seasonal and annual distribution of **wave height, period** and **direction**
Wave climate atlas	Series of maps showing the variability of wave conditions over a long coastline
Wave direction	Mean direction of wave energy propagation relative to true North
Wave directional spectrum	Distribution of wave energy as a function of wave **frequency** and **direction**
Wave frequency	The inverse of **wave period**
Wave frequency spectrum	Distribution of wave energy as a function of frequency
Wave generation	Growth of wave energy by wind

Wave height	The vertical distance between the trough and the following crest
Wavelength	Straightline distance between two successive wave crests
Wave peak frequency	The inverse of wave peak period
Wave peak period	Wave period at which the spectral energy density is a maximum
Wave period	The time taken for two successive wave crests to pass the same point
Wave rose	Diagram showing the long-term distribution of **wave height** and direction
Wave set-up	Elevation of the water level at the coastline caused by radiation stress gradients in the surf zone
Wave steepness	The ratio of **wave height** to wavelength also known as **sea steepness**
Wave transformation	Change in wave energy due to the action of physical processes
Weibull distribution	A model probability distribution, commonly used in wave analysis
Wind rose	Diagram showing the long-term distribution of wind speed and direction
Wind sea	Wave conditions directly attributable to recent winds, as opposed to swell
Wind set-up	Elevation of the water level over an area directly caused by wind stress on the water surface
Wind stress	The way in which wind transfers energy to the sea surface

The Scottish Office

The Scottish Office commissions applied research to support the formulation, development and evaluation of its policies to improve the quality of the Scottish environment and the life of its people. Research also assists the Scottish Office in meeting its statutory responsibilities.

Historic Scotland

Historic Scotland is an Executive Agency within the Scottish Office. We discharge the Secretary of State for Scotland's functions in relation to the built heritage - that is, ancient monuments, archaeological sites and landscapes; historic buildings, parks and gardens; and designed landscapes.

We:

- promote the conservation of Scotland's historic buildings and monuments:
  - ∞ directly by looking after the buildings in our care, and
  - ∞ indirectly by compiling a schedule of ancient monuments and a list of historic buildings (both statutory), by providing advice and financial assistance to help conserve them, and, where they cannot be preserved and their recording is no one else's responsibility, by arranging for their survey or excavation;
- promote enjoyment of Scotland's built heritage, in particular by encouraging people to visit the properties in our care;
- advise and educate people on the rich heritage of Scotland's rural, urban and industrial landscape and its many ancient monuments and buildings.

Our aim is to protect Scotland's built heritage for the benefit of present and future generations, and to enhance its understanding and enjoyment.

Scottish Natural Heritage

Scottish Natural Heritage is an independent body established by Parliament in 1992, responsible to the Secretary of State for Scotland. Our task is to secure the conservation and enhancement of Scotland's unique and precious natural heritage - the wildlife, the habitats, the landscapes and the seascapes which has evolved through the long partnership between people and nature. We advise on policies and promote projects that aim to improve the natural heritage and support its sustainable use.

Our aim is to help people to enjoy Scotland's natural heritage responsibly, understand it more fully and use it wisely so that it can be sustained for future generations.