Angus Council

Angus Shoreline Management Plan SMP2

Appendix C – Baseline Process Understanding

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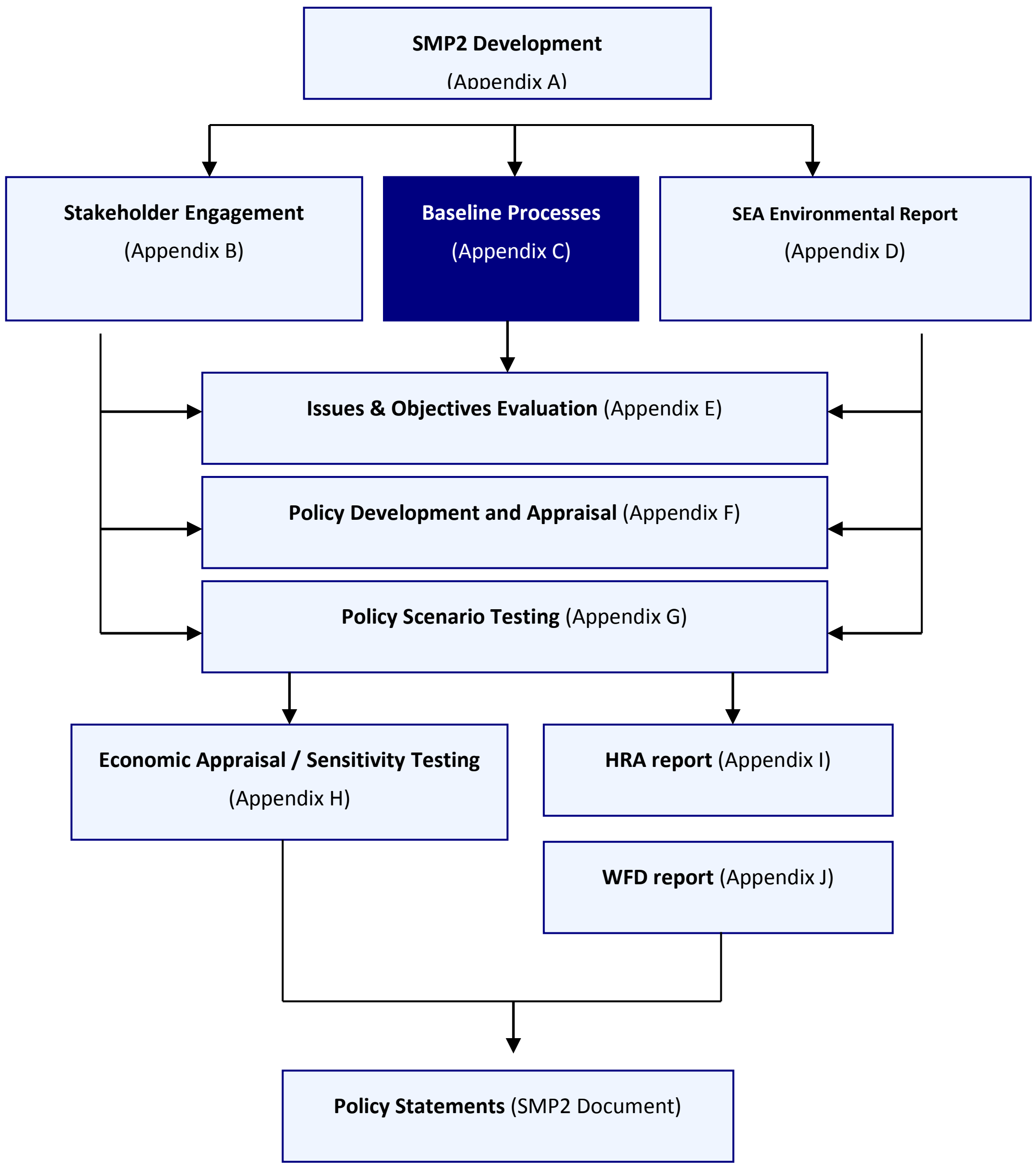
The Supporting Appendices

These appendices and the accompanying documents provide all of the information required to support the Shoreline Management Plan. This is to ensure that there is clarity in the decision-making process and that the rationale behind the policies being promoted is both transparent and auditable. The appendices are:

A: SMP2 Development	This reports the history of development of the SMP2, describing more fully the plan and policy decision-making process.
B: Stakeholder Engagement	All communications from the stakeholder process are provided here, together with information arising from the consultation process.
C: Baseline Process Understanding	Includes baseline process report, defence assessment, NAI and WPM assessments and summarises data used in assessments.
D: Strategic Environmental Assessment (SEA) Environmental Report	This report identifies and evaluates the baseline environmental features (human, natural, historical and landscape) and presents an overview of the environmental assessment process, showing how the requirements of the EU Council Directive 2001/42/EC (the Strategic Environmental Assessment Directive) are met.
E: Issues & Objectives Evaluation	Provides information on the issues and objectives identified as part of the Plan development, including appraisal of their importance.
F: Policy Development and Appraisal	Presents the consideration of generic policy options for each frontage, identifying possible acceptable policies, and their combination into 'scenarios' for testing. Also presents the appraisal of impacts upon shoreline evolution and the appraisal of objective achievement.
G: Policy Scenario Testing	Presents the policy assessment and appraisal of objective achievement towards definition of the Preferred Plan (as presented in the Shoreline Management Plan document).
H: Economic Appraisal and Sensitivity Testing	Presents the economic analysis undertaken in support of the Preferred Plan.
I: Habitat Regulations Assessment	Presents an assessment of the effect the plan will have on European sites.
J: Water Framework Directive Assessment	Presents the Water Framework Directive assessment of the potential hydromorphological changes and consequent ecological impact of the preferred SMP2 policies.
K: Metadatabase and Bibliographic database	All supporting information used to develop the SMP2 is referenced for future examination and retrieval.

Within each appendix cross-referencing highlights the documents where related appraisals are presented. The broad relationships between the appendices are illustrated below.



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C1 Assessment of Shoreline Dynamics

C1.1 Introduction

This appendix is a fundamental part of the development of the Angus Shoreline Management Plan 2 (SMP2) and defines the current understanding of how the coast functions and its present behaviour. The appendix focuses on the information that will help us make decisions on future management of the coast over the SMP2 timescale and ensure that policy choices are technically-sound and sustainable in terms of coastal processes.

Information from the baseline scenario assessments will underpin the whole SMP2 development and will be used to identify risks and test the response and implications of different management policy scenarios over different timescales.

C1.1.1 SMP Boundaries

The alongshore boundaries of this SMP review were defined in the Angus SMP1 (Angus Council, 2004) as Milton Ness in the North to Broughty Castle, Broughty Ferry in the South. The Angus coastline considered within this SMP lies within Coastal Cell 2 as defined by HR Wallingford in their Coastal Cells Scotland report (1997). It includes part of sub-cell 2a, from Fife Ness to Deil's Heid and all of sub-cell 2b, from Deil's Heid to Milton Ness. This includes part of the Aberdeenshire Council coast from the River North Esk to Milton Ness and part of the Dundee City Council coast from the Dighty Water to Broughty Castle. Whilst it is appreciated that the southern boundary at Broughty Castle is not a cell or sub-cell boundary, the Tay Estuary is an area where sediment tends to be deposited. As such, an estuary could be considered to form a suitable cell boundary. For the purposes of Shoreline Management, the Angus SMP1 concluded that a boundary at Broughty Castle was acceptable as the interchange of sediments between the Angus and the Fife coasts is unlikely to be significantly direct to require the estuary to be treated as one cell.

In terms of setting the inland boundaries, the SMP 2 review used those defined in SMP 1, identified taking into consideration land use, the natural environment, historical and archaeological features as well as considering the SMP objectives; adapted to include those areas at risk in a 0.5% AEP (coastal) flood event in year 100. Figures C1.1 to C1.4 show the Angus SMP 2 inland boundary location.

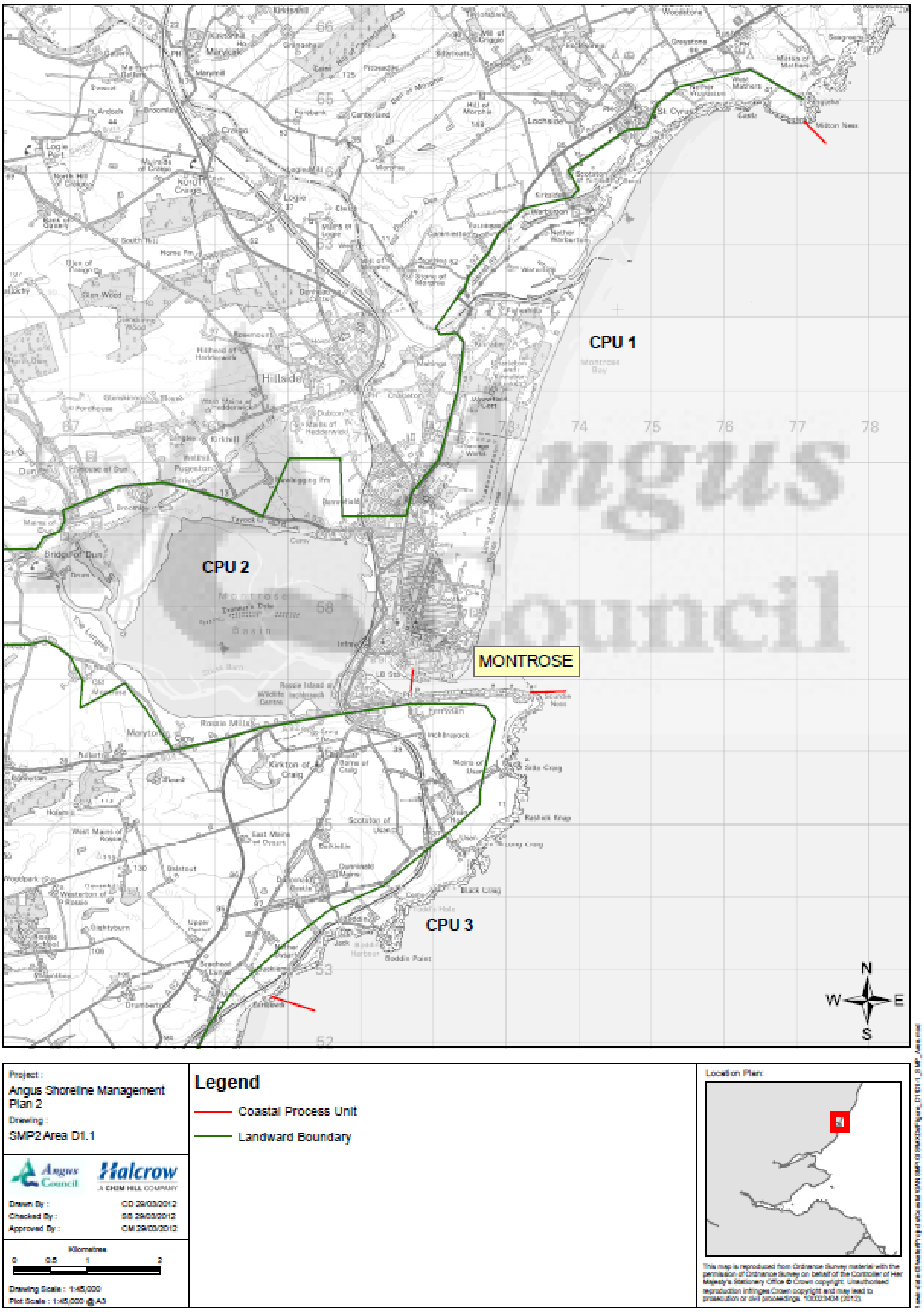


Figure C1.1 Angus SMP2 inland boundary and Coastal Process Units (Milton Ness to Rickle Craig)

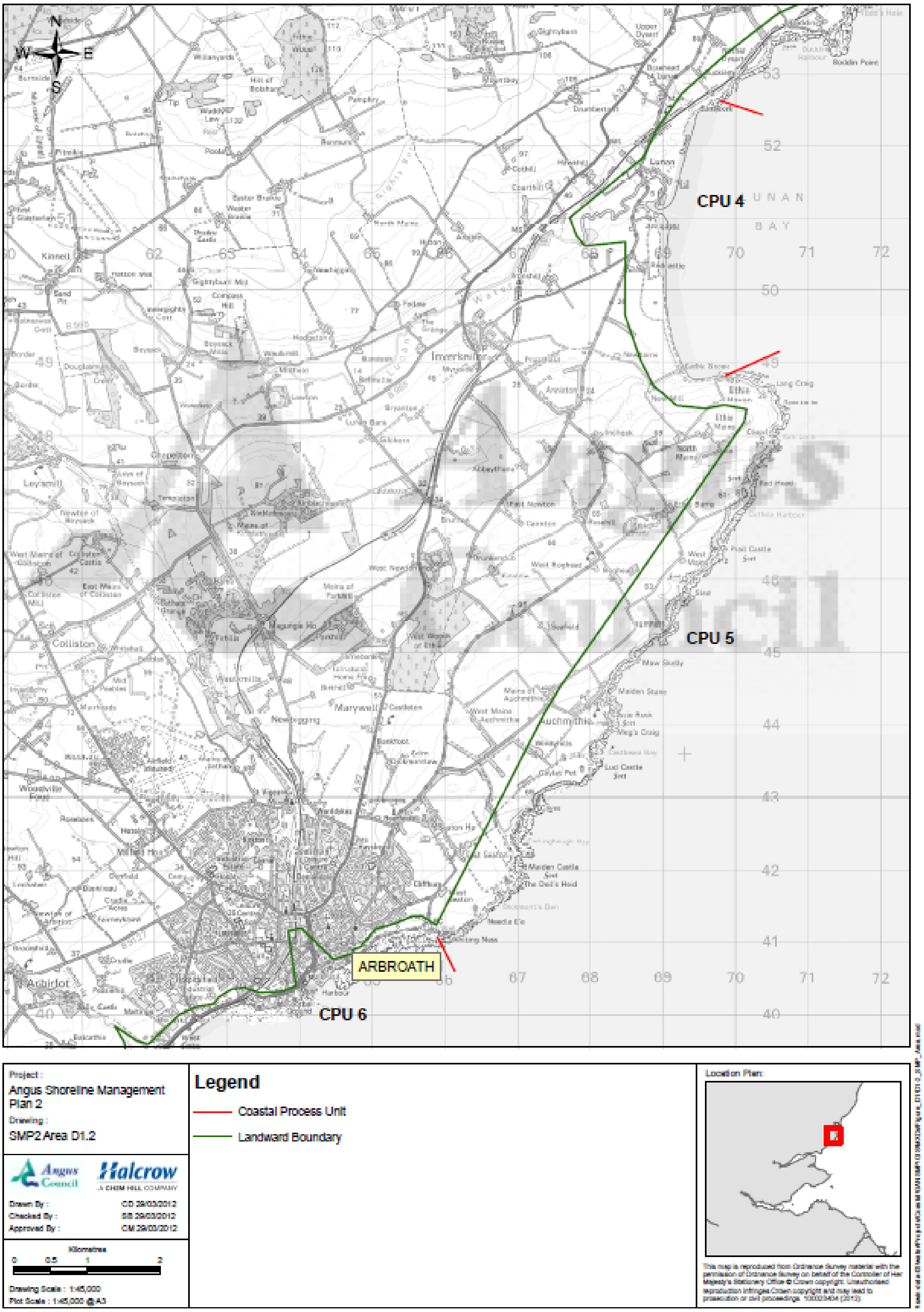


Figure C1.2 Angus SMP2 inland boundary and Coastal Process Units (Rickle Craig to Arbroath)

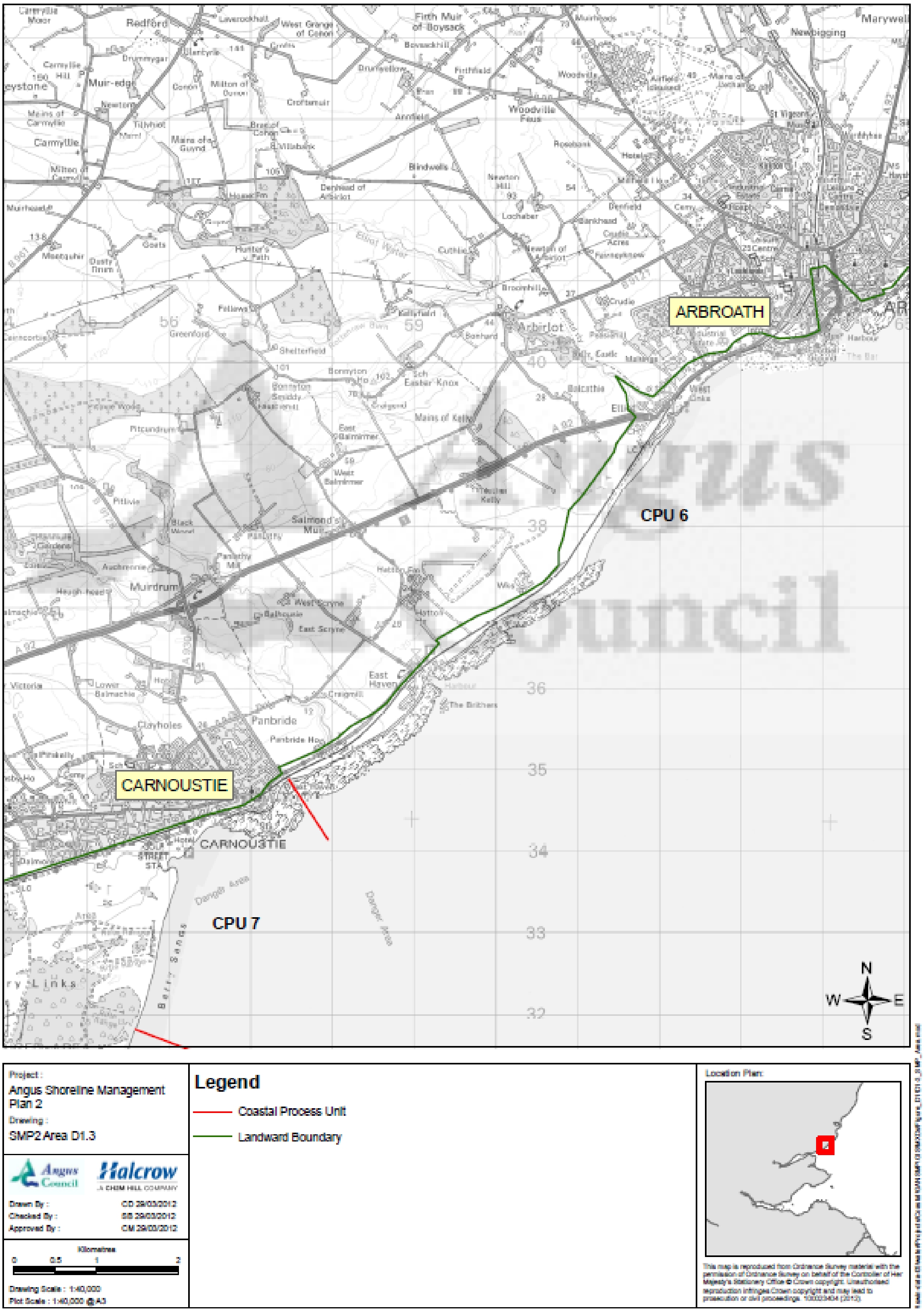


Figure C1.3 Angus SMP2 inland boundary and Coastal Process Units (Arbroath to Buddon Ness)

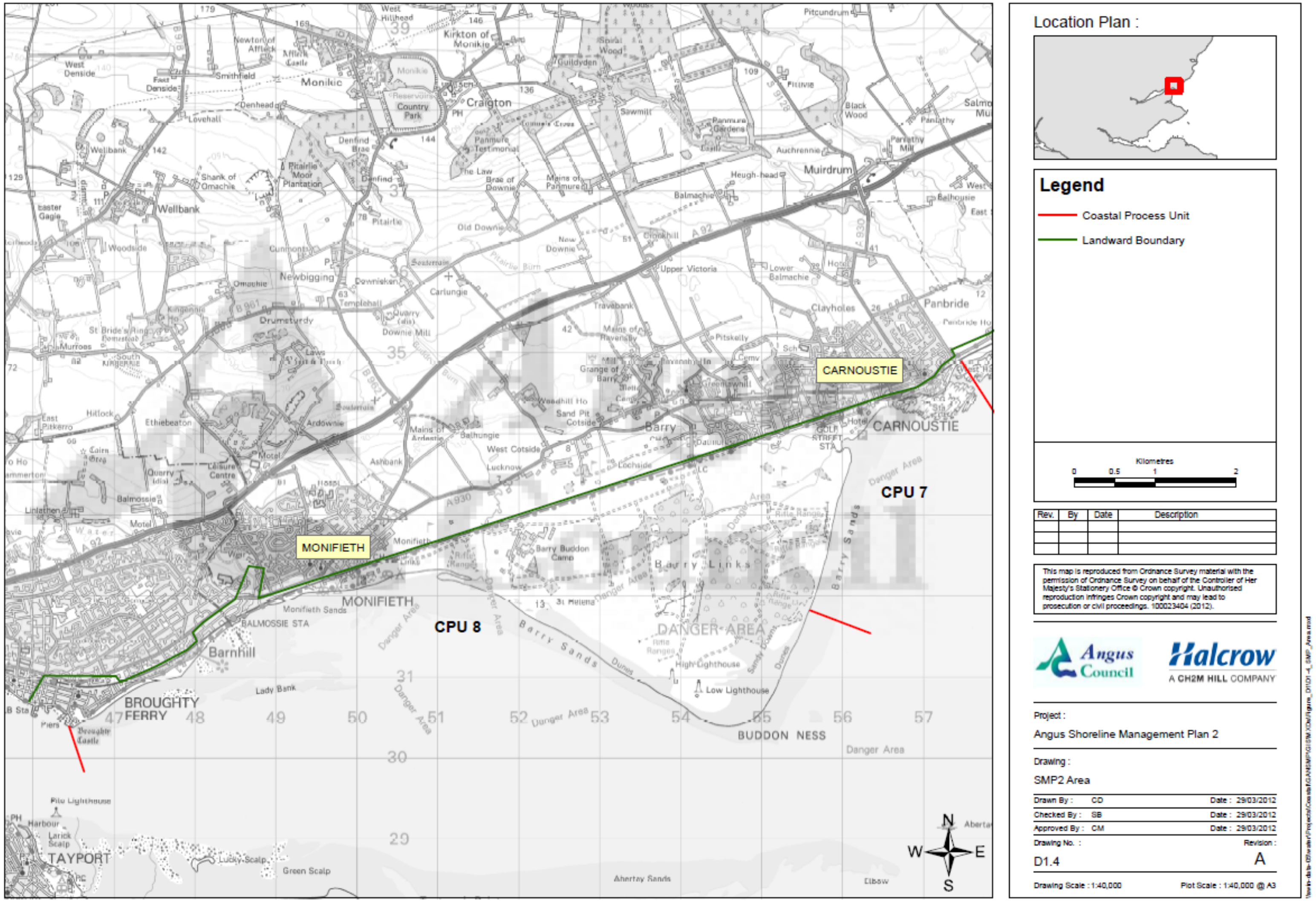


Figure C1.4 Angus SMP2 inland boundary and Coastal Process Units (Buddon Ness to Broughty Ferry)

C1.1.2 Outline of Appendix C

This first section, **C1 – Assessment of Shoreline Dynamics**, discusses the development of the baseline coastal process understanding; outlines the key information used and the general approach adopted. This section provides a general overview of current understanding, describing the large scale geology and coastal processes along the coast between Milton Ness in the North and Broughty Castle in the South.

Section **C2 – Coastal Process Statements** includes a series of individual baseline coastal process statements for each Coastal Process Unit, providing current understanding on coastal morphology, shoreline dynamics and behaviour and modifications in each area.

Section **C3 – Baseline Scenario Assessment Considerations**, explains the assumptions made regarding climate change and sea level rise and provides a general overview of coastal change in response to climate change. This section also includes a summary of the existing defences along the Angus frontage together with an assessment of condition, performance, residual life and impacts on the adjacent coastal processes and coastline.

The third section **C4 – Baseline Scenario 1 – No Active Intervention,** provides an assessment of coastal change for the next 100 years under No Active Intervention (NAI). Local-scale baseline summary assessments for each Coastal Process Unit are included.

Section **C5 – Baseline Scenario 2 – With Present Policies** provides an assessment of coastal change for the next 100 years under a With Present Policies (WPP) scenario. Again, local-scale baseline summary assessments are included for each Coastal Process Unit. This section also includes supporting data interpretation and assumptions tables which document all assumptions made regarding coastal change for each Management unit, for each baseline scenario.

No Active Intervention maps to support the baseline assessments, showing flood and erosion risks along the SMP2 frontage in years 20, 50 and 100, are included in **Annex C1.**

C1.2 Development of Baseline Process Understanding

C1.2.1 Background

Development of the first round of Shoreline Management Plans was based upon littoral cell boundaries, which had previously been defined as zones of alongshore sediment transport convergence and divergence. The benefit of the cell approach was that it reflected regional processes on a basis that was easy to communicate and it was therefore quickly adopted.

A study to identify the dominant coastal cells around the coastline of Scotland was published by Scottish Natural Heritage, the Scottish Executive and Historic Scotland (now Historic Environment Scotland) in 1997 (HR Wallingford, 1997). The identification of such cells provided the basis for wider planning purposes, such as the development of the Angus Shoreline Management Plan1 to provide a strategic basis for planning future coastal defences.

However, whilst the littoral cell concept is a valid approach, it is only one aspect of coastal system behaviour and other factors also need to be taken into account when assessing future shoreline evolution, and therefore the cell based approach has a number of shortcomings in making large-scale, longer-term predictions. Consequently, the latest SMP2 Guidance (Defra, 2006a) advocates a 'Behavioural Systems' approach, which involves the identification of the different elements that make up the coastal system and development of an understanding of the relationships and interactions between these various elements, on a range of both temporal and spatial scales. A systems approach has been used on four recent UK studies: (1) Futurecoast (Halcrow, 2002), (2) the Tindal Centre for Climate Change's coastal research programme (Hanson et al., 2007),(3) the EstSim project, and (4) the Environment Agency project: 'Characterisation and prediction of large scale, long-term change of coastal geomorphological behaviours' (Environment Agency, 2009).

Futurecoast (Halcrow, 2002) was commissioned by Defra to provide a consistent understanding of coastal dynamics and shoreline evolution around the coastline of England and Wales and give a vision of how the coast may look in 100 years. This report was intended to underpin this second round of SMPs. Although the project only appraised the coastlines of England and Wales, it has provided an example of an excellent framework for considering future long term evolution of the Angus shoreline, in that it covered a wide range of coastal environments and provided generic methodologies for appraising coastal behaviour and interactions.

In Futurecoast, the approach to understanding coastal behaviour involved the identification of large scale units, termed Coastal Behavioural Systems (CBS) from assessment of

- Shoreline and offshore geology;
- Offshore features and their interactions with the shoreline;
- Hydrodynamic and sediment processes;
- Holocene evolution;
- Historical trends; and
- Estuarine influences (Cooper and Jay, 2002).

For the purposes of coastal defence management these major CBS, like littoral cells or sub-cells may be rather large, and contain too many interests and issues for a single policy to effectively address. Therefore, within these a number of smaller local-scale units have been defined, known as Shoreline Behaviour Units (SBUs) (Futurecoast) or Coastal Process Units (CPUs). These are discrete lengths of shoreline in which the physical processes are relatively independent from the processes operating in an adjacent CPU, but the boundary between them is not totally "sediment tight". In turn, each CPU comprises a number of geomorphological elements along its length, such as cliffs, beaches, barriers, coastal dunes, tidal flats, or shore platforms. For management purposes, CPUs provide the framework for considering the potential wider impacts of policies on the adjacent shoreline.

C1.2.2 General Approach Adopted

The baseline process assessments carried out for this SMP2 review have adopted the 'Behavioural Systems' approach discussed above.

For consistency with the Angus SMP1, for the purposes of the baseline appraisals, the Angus coast has been split into 8 local Coastal Process Units (CPUs) based on the divisions used in SMP1. The CPUs were defined in SMP1 on the following basis:

- Geomorphological changes, such as between sections of coastlines characterised by cliffs, where there is little beach sediment transport and between sections of coastline characterised by beaches, where beach sediment transport does occur.
- Hydrodynamic changes, for example from a location where the dominant sediment movements are due to wave conditions to one where such movements are caused by tidal currents. It should be noted, however,

that such boundaries are rarely fixed in one place and are usually characterised by a transition zone that can vary in position depending on the particular hydrodynamic conditions.

Although appraised separately in this baseline report, in reality, CPU1 and CPU2 should be considered as one coastal process unit, as Scurdie Ness shelters the frontage between Splash and the River South Esk from waves from the southeast and therefore is important to coastal processes in the whole bay. Some sediment is also transported south into the River South Esk channel, of which in turn, some may also be transported into Montrose Basin. These linkages have therefore been discussed in both CPU1 and CPU2 coastal process statements and have been taken into consideration when undertaking the No Active Intervention (NAI) and With Present Policy (WPP) assessments.

Similarly, it would be more appropriate to consider Buddon Ness as a single CPU. The influence of Gaa Spit at the southern tip of the ness (CPU8) is of vital importance to the Carnoustie frontage. Changes in the shape or location of this spit complex will have a considerable influence on the way waves from the south easterly quadrant refract in to Carnoustie Bay and therefore both the temporal and spatial patterns and rates of erosion and accretion experienced along the coast. For this baseline assessment, Buddon Ness has been split between CPU7 and CPU8 due to the presence of a drift divide along the Barry Sands east frontage. However, linkages between these coastal process units have been discussed in both CPU7 and CPU8 coastal process statements and have been taken into consideration when undertaking the NAI and WPP assessments.

The Coastal Process Units used in the baseline assessments are summarised in Table C1.1 and extents shown in Figures C1.1 to C1.4.

Table C1.1 Coastal Process Units (CPU) along the Angus SMP2 coastal frontage.

Coastal Process Unit (CPU)	Location	Comments
CPU 1	Milton Ness to Montrose Harbour (Montrose Bay)	Open coastline characterised by a beach dune system along virtually the entire length. Littoral processes dominated by North Sea wave conditions although tidal currents are an important process at the southern end, at the outlet of Montrose Basin and Annat Bank. Net longshore transport tends to be to the north but is very sensitive to small changes in the wave climate that affect the rate and pattern of erosion at the southern end of Montrose Bay, where net transport is to the south. Little sediment is lost to the north around Milton Ness. The extent of the interchange of sediment between Montrose Bay and Montrose Basin is not known but is unlikely to be significant. Maintenance dredging of the River Esk South channel takes place yearly and since the late 1980's dredged material has been disposed to Aberdeen, St Cyrus or deposited off shore of Lunan Bay, effectively removing up to 50,000 m^3/yr of sediment from the Montrose Bay system.
CPU 2	Montrose Basin	Tidal basin with littoral processes dominated by tidal currents, flows from the River South Esk and locally generated wind wave conditions. Montrose Basin tends to be a "sink" for fine sediments. Unlikely to be any significant interchange of sediment between the beaches in Montrose Bay and Montrose Basin. This CPU also includes coastal frontages adjacent to the River South Esk channel that connects Montrose Basin with Montrose Bay.

Coastal Process Unit (CPU)	Location	Comments
CPU 3	Scurdie Ness to Rickle Craig	Cliff coastline dominated by wave processes. Cliffs do not supply any appreciable amount of sediment to the beaches in Montrose Bay or Lunan Bay and effectively block any interchange of beach sediment between the CPU 1 / 2 and CPU 4.
CPU 4	Rickle Craig to Lang Craig	Self-contained beach unit with little interchange of beach sediments between adjacent units due to the cliffed nature of the coastline to the north and south. Lunan Bay is relatively stable with little loss or gain of beach sediments and a near neutral net longshore transport.
CPU 5	Lang Craig to Whiting Ness	Cliff coastline dominated by wave processes. Cliffs do not supply any appreciable amount of sediment to the beaches in Lunan Bay or to the coastline south of Arbroath and effectively block any interchange of beach sediment between the CPU 4 and CPU 6.
CPU 6	Whiting Ness to West Haven	Open coastline characterised by sand / shingle beach with a rock platform along part of the frontage. Net longshore transport tends to be towards the south-west, with sediment processes generally dominated by wave conditions. It is possible that tidal flows have some influence in sediment transport processes towards the southern boundary. At West Haven there is likely to be a small interchange of beach sediments with the CPU to the south.
CPU 7	West Haven to Buddon Ness	Open coastline characterised by a wide sand beach with much of the hinterland protected by coastal defences. Littoral processes dominated by a complex interaction of wave conditions and tidal currents. Wave induced net longshore transport tends to be to the south along the outer part of Barry Links but can be to the north along the Carnoustie frontage. An anti-clockwise tidal gyre, due to strong ebb flows from the Tay Estuary, results in a near continuous southward tidal current, and transport of sediment within Carnoustie Bay. At Buddon Ness the influence of wave conditions from the north-east quadrant of the North Sea diminishes with the change in orientation of the coastline. At Buddon Ness, beach sediments tend to move from this CPU to CPU 8 or are moved onto Gaa Sands by ebb tidal currents.
CPU 8	Buddon Ness to Broughty Castle	Estuarine coastline with longshore transport processes dominated by tidal flows, and wave conditions from the south-east quadrant in the North Sea. Net longshore transport is dominantly to the north and west but patterns of erosion and accretion depend on position of the sand banks at the mouth of the Tay Estuary. Broughty Castle acts as a groyne, trapping beach sediment being moved to the west by wave action but beach sediment over the lower parts of the beach will either be recycled back to the east by ebb currents or transported onto the sand banks in the middle reaches of the Tay Estuary by flood currents.

Each CPU statement considers:

- Coastal morphology – This section includes discussion on the key geomorphological features present.

- Shoreline dynamics and behaviour
    - Interactions – This section includes discussion on the sediment linkages, mechanisms of sediment transport, local sediment budgets and interactions and potential feedbacks with adjacent stretches of coast.
    - Movement – This section focuses on available data on trends and rates of beach and backshore changes, the type of change and mechanisms of change.
- Modifications – This section discusses the key modifications made to this coast, in relation to coastal defences, reclamation, harbours and other major modifications.

C1.2.3 Key data sources used in the baseline understanding

The baseline process understanding has been compiled from a desk study of available data, reports and peer-reviewed literature, and the interpretation of this information in the context of the SMP. At the end of this document, there is a list of all information sources used in the development of the baseline understanding. In general, the key sources of information have been as follows:

Angus Shoreline Management Plan (SMP1)

The existing Angus SMP (Angus Council, 2004), produced by Angus Council, in partnership with coastal specialists HR Wallingford, was completed in 2004. The aim of the SMP was to provide a positive basis for sustainable shoreline management policies over the next 50 years and set a framework for the future management of the Angus coastline. This document includes a wealth of information and recommended strategic 50-year policies, based on a thorough assessment of process, which took account of long term environmental, as well as socio-economic factors, and with due consideration of potential impacts on adjacent areas.

The Angus SMP1 has been used as the main starting point for this SMP2 review. The SMP1 provides a strong foundation for SMP2 as much of the information contained in the plan is still relevant today.

Montrose Beach Environmental Development Plan

The Montrose Beach Environmental Development Plan (Milne and Dong, 2010, 2011) investigated ongoing erosion along the Montrose frontage. The study was undertaken by the University of Dundee and involved two phases:

- **Phase 1**: 'The Morphodynamics of Montrose Bay and Implications for Coastal Management' involved investigations into coastal processes and contributory factors to coastal change at Montrose Bay which provided the basis for subsequent analysis and identification of effective intervention solutions to erosion at the golf course frontage.
- **Phase 2:** 'Management of Erosion at Montrose Bay' used comprehensive knowledge of coastal processes at Montrose Bay to identify and assess the suitability of a range of management solutions for meeting the study remit of slowing down shoreline retreat. Based on this analysis, recommendations were made on engineering solutions that are considered effective in managing coastal erosion at the golf course frontage within budgetary constraints.

C1.3 Overview of the Angus Coast

C1.3.1 Geological framework and general morphological character

The Angus coastline lies within the Midland Valley of Scotland, which is bounded by the Highland Boundary Fault that crops out at the coastline just to the north of Stonehaven, and the Southern Upland Fault that intersects the coastline around Dunbar. Angus is characterised by undulating lowland underlain by Old Red Sandstone rocks formed during the Lower Devonian period, between 408 and 360 million years ago. These rocks comprise of a great thickness of red and grey sandstones, flagstones and conglomerates with interbedded lavas (Cameron and Stephenson, 1985). The solid geology of the Angus coastline is shown in Figure C1.5. Following this depositional phase, the period known as the Middle Devonian was a period of intense deformation, which has created differential erosion rates in the rock resulting in the wide variety of cliff features and rugged scenery along the cliff sections of the coast. There is only minor evidence of Upper Devonian Old Red Sandstone sediments along the coastline in the form of irregular layers of relatively soft conglomerates and soft cross-bedded sandstones. These sediments are found between the northern end of Victoria Park and the Deil's Heid (Steers, 1973) and rest unconformably on the Lower Devonian Sandstones. Devonian andesitic and basaltic lavas are most evident along the coastline between the mid-section of Lunan Bay to Scurdie Ness, apart from at Boddin Point where Devonian sedimentary rocks overlie the lavas. Along much of this section of coast, a wave cut rock platform fronts the cliffs. Heavily faulted lavas are also exposed at the coast at the southern end of Lunan Bay and as far south as Red Head, with basic lavas also appearing close to the headland at Milton Ness, which itself is composed of Upper Devonian sedimentary rocks (Trewin, 1987).

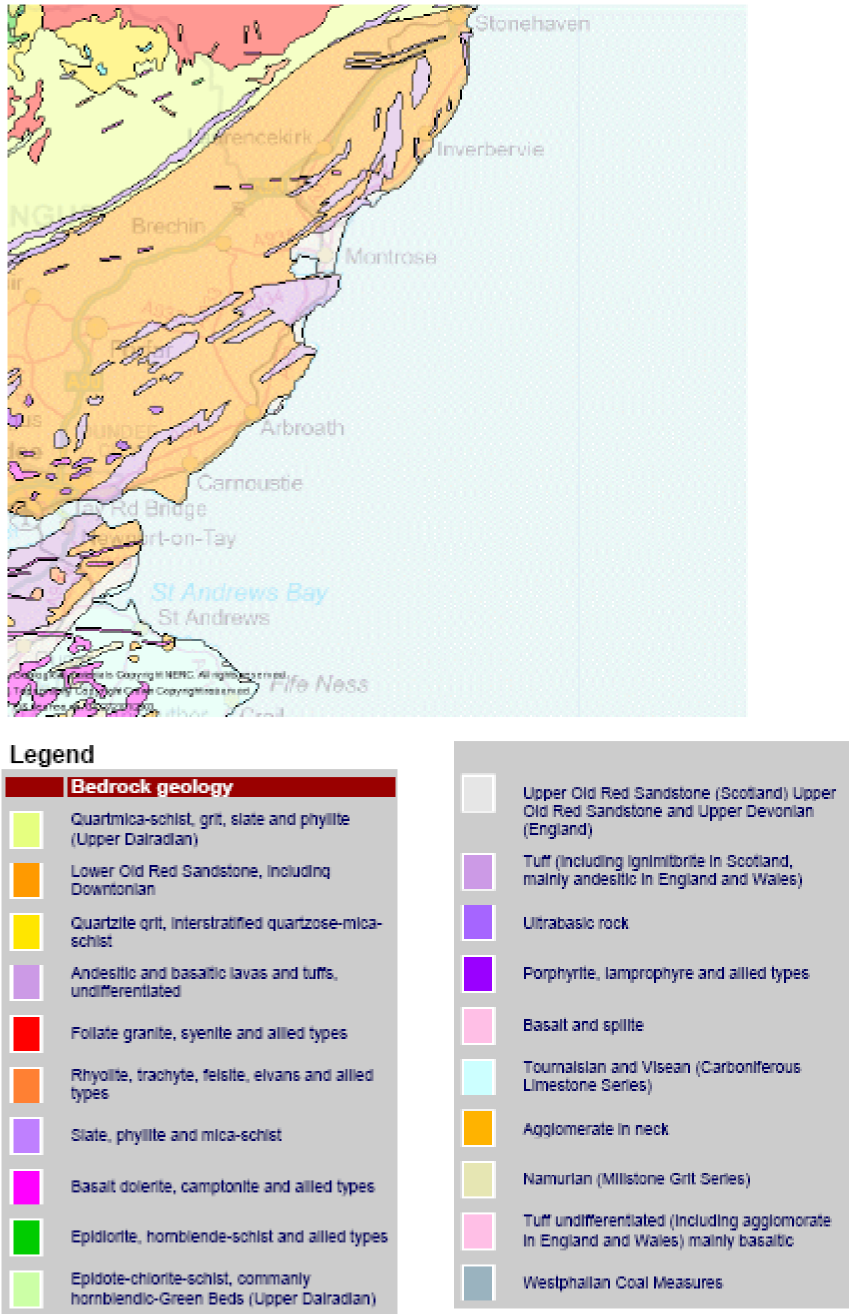


Figure C1.5 Solid geology of the Angus coastline (British Geological Survey, 2003)

To the south of Red Head, heavily faulted Old Red Sandstone forms the cliff coastline to Arbroath. The influence of marine erosion on the faults and jointing is extremely evident on the range of fossil and active stacks, geos, caves and sections of extensive wave cut platforms found along the coast. A broad rock platform occurs to the north of Arbroath Harbour and re-appears mid-way between Arbroath and Carnoustie. The platform, which extends almost 5km ending at Carnoustie, is composed of gently dipping sandstones and conglomerates of the Lower Devonian Old Red Sandstone and is broken only at East and West Haven.


Old Red Sandstone cliffs to the north of Arbroath (source: Angus Council, 2004)


Old Red Sandstone rock platform between Arbroath and Carnoustie (source: Angus Council, 2004)

Rocky headlands are important in that they can prevent or restrict longshore interchange of sediments between the more sheltered lengths of coastline fronted by beaches as they protrude seawards and act as barriers to longshore littoral sediment transport. Consequently, the beaches at Montrose Bay and Lunan Bay effectively function as independent sediment systems.

Sections of coast fronted by rock platform receive considerable natural protection from erosion as such platforms act to dissipate wave energy before it reaches the high water mark. Small changes in the elevation of the rock platform creates variations in the amount of wave energy that reaches the coastline, hence creating the upper beach forms that characterise the beach plan shape along the coastline north of Carnoustie. The influence of the rock platform in dissipating wave energy is highly dependent upon water depths over the rock platform. With issues such as future sea level rise, potentially resulting in increased water depths over the rock platform, this may reduce the influence of the rock platform on wave energy dissipation. The end result could be to increase the rate of coastal change behind sections of coast fronted by such features.

Quaternary Sediments and Post Glacial Morphological Development

The Quaternary era (< 2 million years before present) saw dramatic fluctuations of climate, ranging from cold glacial to warmer temperate conditions. The erosional and depositional activities linked to these climate changes, particularly those of the Late Quaternary (the last 116, 000 years), were critical in creating the morphology and sediments of the present day coastal zone (Smith, 1997). Like all other areas of Scotland, the Angus coastline experienced at least four major periods of glaciation during the Pleistocene epoch (Sutherland and Gordon, 1993). However, the glacial history of Angus is evidently complicated, and the sequence of events in the area has not yet been fully established (MacGregor, 1996). In terms of the evolution of the coastal zone, the most recent ice sheet advance and retreat is of predominant importance. This period of glaciation, characterised by the existence of the last Scottish Ice Sheet occurred during the Dimlington Stadial between approximately 26,000 and 13,000 years before present (BP) (Ballantyne and Harris, 1994).

The ice sheet flowed in a generally easterly direction from the western Grampian Highlands (MacGregor, 1996). The ice sheet is thought to have reached its maximum extent between 22,000 and 18,000 years ago, comprising an ice thickness of up to 1,500m, and extending approximately 25km beyond the present Angus coast onto the continental shelf of the North Sea which at that time was dry land (Smith, 1997).

During late glacial and post-glacial times, sea levels fluctuated due to the melting ice and minor periods of glacial re-advance (associated with falling sea-level). In conjunction with this, when the pressure of the ice was released the land began to isostatically re-adjust (i.e. began to rise in relation to the sea level). General periods of rise and fall are summarised in a simplified manner in Table C1.2.

Table C1.2 General periods of sea level rise and fall over the last 14,000 years.

Years Before Present	Relative sea level	Shoreline formation
14,000 – 11,000	Net fall	Late glacial shorelines in Angus
11,000 – 10,000	Net rise	
10,000 – 9,000	Net fall	
9,000 – 7,000	Net rise	Main post glacial shoreline formed with sea levels around 8m to 9m higher than present
7,000 – Present	Net fall	

The effect of glaciation and the subsequent variations in relative sea level can be seen in the various raised beach and fossil cliff formations occurring along the Angus coast. Rice (1962) identified four former shorelines, termed the 8m, 15m, 21m and 30m shorelines; with the 8m being the most recent:

- 30m - Best preserved around and to the north of Carnoustie.
- 21m - Preserved along a 7km stretch west of Elliot Junction (Wright, 1981).
- 15m - Obvious landscape feature at St Cyrus, Kinnaber and Lunan Bay (Wright, 1981) and also to the south of Arbroath.
- 8m - The most continuous section of raised beach evident along virtually the entire coast. Particularly evident between Dundee and Arbroath where the main east coast rail track is located on the surface, and from Lunan Bay to Montrose (Wright, 1981).

15m raised beach at Lunan Bay

8m raised beach platform between Arbroath and Carnoustie

The melting of the last ice sheet towards the end of the Pleistocene resulted in Angus being free of ice by around 13,000 years ago. This glacial retreat resulted in deposition of the large amounts of sediment, which were being transported by the ice. Such glacial deposits from the last ice sheet glaciation in the area account for virtually all the Quaternary deposits on the Angus coastline. In general terms, till deposits (boulder clay and morainic deposits) overlie the land at higher elevations at the coast, such as between Arbroath and Lunan Bay, Lunan Bay and Montrose, and St Cyrus. There are also localised deposits of fluvioglacial sand and gravels formed by the reworking of glacigenic sediments by the abundant meltwaters released from the retreating ice. A drift geology map of the Angus coast is shown in Figure C1.6.

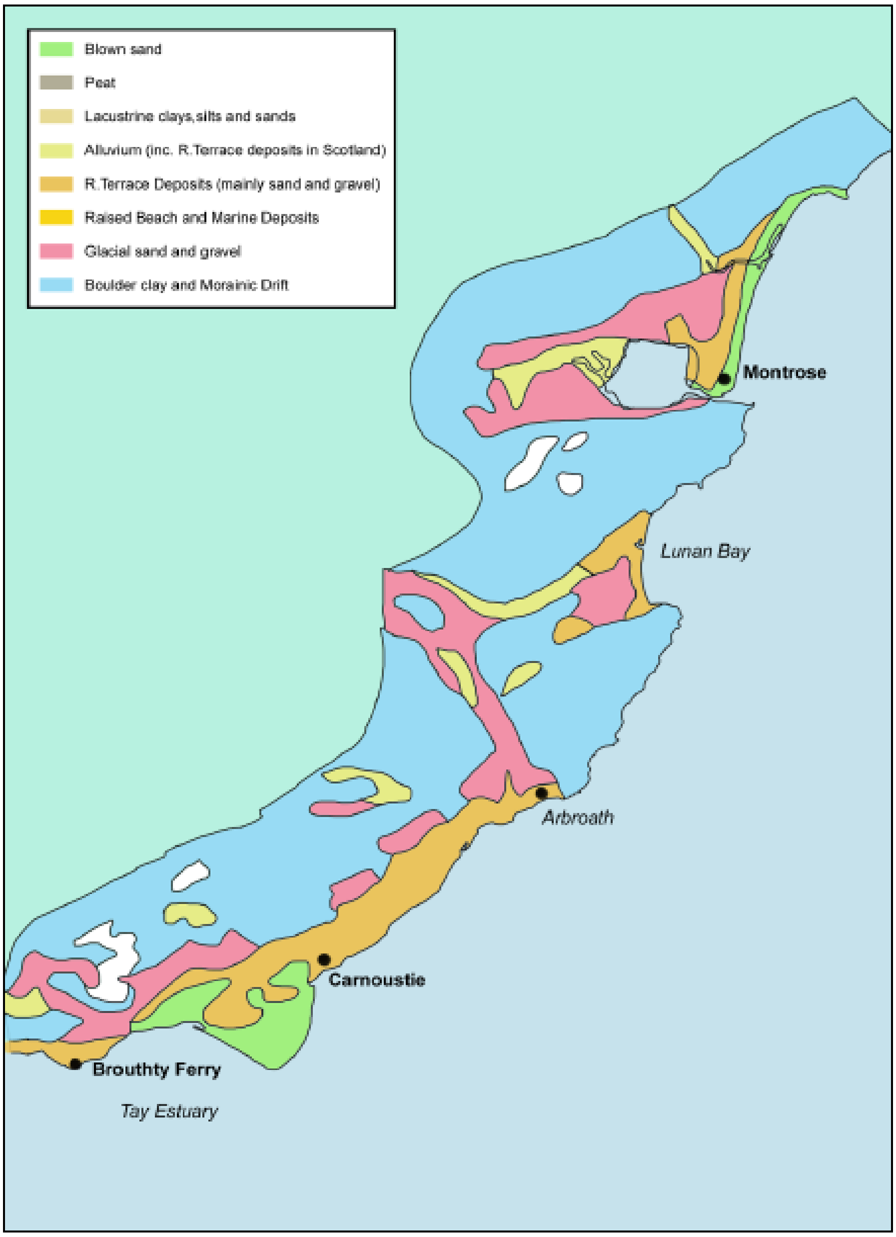


Figure C1.6 Drift geology of the Angus coast (British Geological Survey, 1977)

Superficial deposits of glacial sands and gravels occur around much of Montrose Basin, under the town and links. The coastal strip south of the North Esk, upon which the town of Montrose is situated, is over 1.5km wide. The peninsula is thought to be founded on a shingle bar of rounded boulders derived from conglomerates of the cliffs to the north and of boulder clay (Steers, 1973). To the west of this bar is generally clay with sandy links to the east. It is thought the entire area rests on glacial marine clay (Steers, 1973).

Montrose Basin is a rare example of an enclosed estuary created by reworked glacial deposits forming into a spit and links along the eastern flank cutting off the previously open bay feature from the North Sea (Smith and Cullingford, 1985). The only other close analogies to this landform in Scotland are Loch Fleet, in Sutherland, and Findhorn Bay, in Moray. During periods of higher sea level, the size of Montrose Basin would have been almost double what it is at present, with the present day 12m OD contour between Scurdie Ness and Milton Ness being approximately the position of the former coastline. The previously inundated land surrounding the basin is known as carseland, extending to over 10km^2 with the upper surface generally considered the highest sea level reached during the last 10,000 years (Smith *et al*., 1980). Part of the Montrose Basin SSSI citation is due to the importance of exposures at Maryton showing stratigraphic evidence of postglacial sea level fluctuations (Gordon, 1993). Beyond the carseland, fluvioglacial deposits and marine terraces linked to the retreat of the last ice sheet occur. Further details of relative sea level changes and the impact these had on Montrose Basin are provided by Smith and Cullingford (1985) and Dawson *et al*. (1988). Within the stratigraphy at this site a layer of silty fine sand deposited by a tsunami 7,000 years ago is also evident. This occurred due to submarine land slides, known as the Storegga slides, on the continental slope off the western coast of Norway and it is thought to have inundated up to several hundred metres inland along the eastern coastal region of Scotland (Dawson *et al*., 1988; Smith, 1997; Smith et al., 2004).

Similarly, fluvioglacial sands and gravels occur within the hinterland behind the southern part of Lunan Bay, Arbroath and Broughty Ferry, whilst the drift geology of the entire region is predominantly characterised by glacial till, or boulder clay, deposited directly from the last glacial ice to occupy the area. Again where such deposits occur in the coastal hinterland, they have been reworked by waves and tides to form the raised beach formations occurring along much of the coastline.

A particularly interesting geomorphological feature along the Angus coast is that of Buddon Ness, a large triangular raised beach foreland. Paterson (1981) investigated the development of the ness using information from a series of boreholes. He suggested that Buddon Ness is founded on medium to coarse grained pebbly sandstone similar to that cropping out at Carnoustie. Overlying this are clays, termed the Errol Beds, which were deposited during the retreat of the last ice sheet to cover Scotland. The Errol Beds form a wedge shaped mass with a base at around –5m OD and surface elevation at around ground level in the northern sections of Buddon Ness to a base of around –35m OD and surface elevation of around –20m OD towards the southern point. Upon this, glacially deposited sands were transported onshore by a rapidly rising sea level prior to around 6,500 to 7,000 years before present, which were then reworked by aeolian processes as sea levels began to fall. Buddon Ness is likely to be in a form of dynamic equilibrium in contemporary sediment transport processes with the interaction of waves from the open coast and tidal currents in the outer Tay Estuary reworking the existing sediment, but no / limited new sediment supply.

Marine sediments of Late Quaternary age also occur around the Tay Estuary (Cameron and Stephenson, 1985). Such sediments are generally laminated silts and clays, shelly clays, silts and silty sand, overlain by sands and gravels. The coarser sediments are generally reworked fluvioglacial deposits laid down in terrestrial conditions following a fall in sea level.

Since the last glaciation and subsequent postglacial period, the morphological changes occurring on the Angus coastline have been continuously driven by winds, waves and currents and, more recently, the increasing influence of humans. To fully understand such processes, it is necessary to consider the development of the coastline since sea levels began to become relatively stable approximately 6,500 years ago (Hansom, 2001). However, such information is essentially only available for the last 200 years or so, when changes in the coastline have been documented and mapped.

The earliest reliable map of the entire Angus coastline is that of Ainslie (1794) which is shown in Figures C1.7 and C1.8 for the Montrose, Lunan Bay and Arbroath to Broughty Ferry frontages. This suggests that the Angus coastline has not undergone any substantial changes in the last 200 years or so but there are examples of apparent morphological evolution since the map was drawn such as changes at the mouth of the Lunan Water in Lunan Bay, the North Esk in Montrose Bay and the reduced extent of the Gaa Sands to the south east of Buddon Ness.

Figure C1.7 Part of Ainslie's (1794) map of Angus showing the coast from Lunan Bay to Montrose.

Figure C1.8 Part of Ainslie's (1794) map of Angus showing the coast from Arbroath to Dundee.

More recent shoreline changes can be obtained from comparisons of the Mean High and Low Water Spring Marks on Ordnance Survey maps of the United Kingdom. The first Edition OS Maps for the Angus coastline were published between 1861 and 1865. An analysis, using four editions dated 1865, 1903, 1959 and 1976/84, was conducted by Mitchell (1997) in a report on coastal erosion in Angus for Scottish Natural Heritage. HR Wallingford (1993) also conducted a similar map analysis for the Montrose frontage. The small scale and infrequency of the surveys carried out by the Ordnance Survey do not allow a constantly changing coastline to be accurately described. The problem is compounded by the difficulties of establishing the date of the survey of the High and Low Water lines shown on the various maps. It is not uncommon for successive editions of such maps to use the same beach surveys when much of the rest of the map has been revised.

A separate historical map analysis was carried out for SMP1, which was compared with the previous analyses. Historical OS Maps had been obtained by Angus Council in digital format and stored within their GIS system. The MHWS and MLWS positions on these maps were extracted and cross checks were made against a range of fixed points on the ground, such as the railway line, road junctions, lighthouses and other buildings. Despite these checks there were still a number of inaccuracies evident between maps. In many cases, the MHWS and MLWS had not been re-surveyed between editions, or only small sections had been updated, for example where dynamic movements occurred such as at the mouth of the River North Esk. However, the maps did show the relative trends (as discussed in the individual Coastal Process Statements in Section 2), with the potential inaccuracies much less than other parts of the Scottish coast and therefore provide a reasonable estimate of the rate of coastal change along the Angus coast over the last 140 years.

C1.3.2 Offshore bathymetry and sea bed sediments

The solid bedrock floors adjacent to the Angus coast are overlain by a relatively thin cover of Holocene sediments deposited since the end of the last Ice Age. Figure C1.9 shows the seabed sediment and bedform distribution in the central North Sea (Gatliff, 1994). Most of the seabed sediments immediately off the Angus coast are sand sized, however, an area of muddy sand occurs offshore of Arbroath and Lunan Bay. Evidence of glacial deposits occurs about 5km offshore of the Angus coast in water depths of greater than 50m, with deposits of gravely sand occurring. Present day wave conditions will not rework these deep offshore deposits to provide a fresh input of sediment to the beaches along the Angus coast. Indeed, the uniformity of the offshore bathymetry to the north of Carnoustie suggests that there are unlikely to be any significant onshore or offshore net sediment transport pathways. Sediment will be transported over the seabed offshore of the Angus coastline by tidal currents, but as tidal currents tend to trend parallel to the coastline, so too will the sediment transport pathways.

The bathymetric contours along much of the Angus coast tend to trend relatively parallel with the coastline to a water depth of around 30m. Only around the mouth of the Tay Estuary does the pattern of bathymetric contours become more complex with a series of ebb delta sand bars to the north and south of the main channel of the outer Tay Estuary. To the north, Gaa Sands extends eastwards from the tip of Buddon Ness with Abertay Sands extending eastwards from Tentsmuir Point to the south of the main channel (Ferentinos and McManus, 1981)

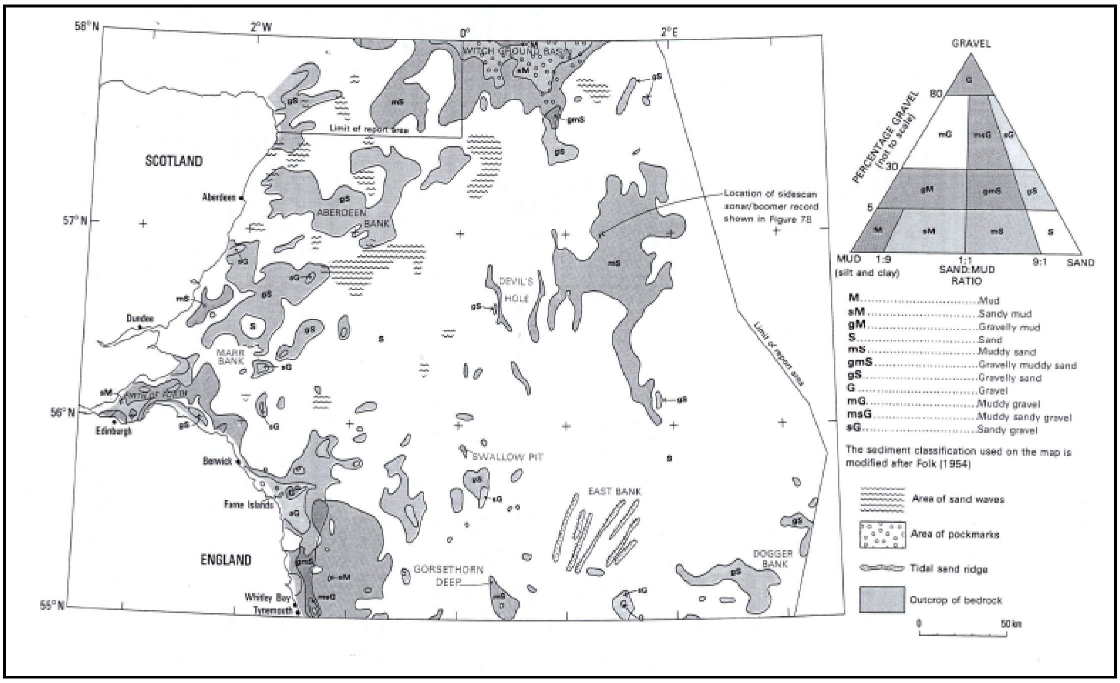


Figure C1.9 Seabed sediment and bedform distribution in the central North Sea (British Geological Survey, 1994).

C1.3.3 Environmental controls on coastal processes

Tidal regime

Contemporary sea level variations experienced around the coast are made up of two components, a tidal component, due to the gravitational effects of the Moon, Sun and to lesser extent planets, and a residual component, due to weather effects, including air pressure variations and wind. The astronomical tide is accurately predictable in advance from the analysis of tide gauge records and predictions are, for example, quoted in the Admiralty Tide Tables published by the UK Hydrographic Office. The tidal cycle experienced along the Angus coast is semi-diurnal, that is two high and two low waters are experienced every day. Dundee, Arbroath and Montrose are all Secondary Ports in the Admiralty Tide Tables with the closest Standard Port being Aberdeen. Typical tide levels along the Angus coast are shown in Table C1.3.

Table C1.3 Typical tidal levels along the Angus coast (metres relative to Ordnance Datum Newlyn (mODN)) Source: UK Hydrographic Office (2011)

	HAT	MHWS	MHWN	MSL	MLWN	MLWS	LAT
Dundee	3.3m	2.7m	1.4m		-0.9m	-2.0m	
Arbroath	3.2m	2.5m	1.4m		-0.8m	-2.0m	
Montrose	2.95m	2.25m	1.15m		-0.75m	-1.85m	
Aberdeen	2.65m	2.05m	1.15m	0.35m	-0.65m	-1.65m	-2.15m

It can be seen from these figures that the spring tidal "range" increases along the coast from Montrose to Dundee. This is partly due to the effects of the shape of the coastline and the changes in general seabed depth.

A number of studies of tidal flows have been conducted off the Angus coastline with the first published description of flows in the Tay Estuary (Firth of Tay) provided by Cunningham (1895). Charlton (1980) described flow patterns in the Tay Estuary in more detail using a scaled physical model owned by Dundee Port Authority and operated by Dundee University calibrated against drogue measurements, much of which is reproduced below. (It should be noted that the model no longer exists).

In more recent years, numerical models have been used to study flow patterns of both the Tay Estuary (Gunn and Yenigun, 1987; HR Wallingford, 1993) and Montrose Bay (HR Wallingford, 1995; Halcrow, 1998; Milne and Dong, 2010).

Offshore of Montrose, the flood and ebb tides are rectilinear, flowing parallel with the coast in a southwest and north east direction respectively. The flood tide flows for about 5 hours to the south-west before rotating clockwise for about 2 hours to then run north east, parallel to the coast for a further 5 hours during the ebb. Peak spring flows are 0.6m/s with peak neap flows 0.3m/s. Closer to the shoreline, tidal currents are an important process around the southern end of Montrose Bay at the entrance to the Harbour and are an important aspect in shaping the Annat Bank. However, this influence quickly decreases to the north at The Faulds. Tidal modelling (HR Wallingford, 1995) confirmed an earlier suggestion that the current flows southwards for most of the tidal cycle due to the flood flow on the rising tide and the formation of an anticlockwise eddy caused by strong ebb flows through the entrance to Montrose Basin during the falling tide. These currents are strongest during the latter stages of the rising tide and are less strong for about 1½ hours starting from about ½ hour after high tide.

Tidal flows at the entrance to Montrose Basin can be extremely strong with a spring rate of up to 7 knots (3.5m/s) and can result in back eddies along the shoreline and underwater or reverse flows through the water column. The tidal volume of Montrose Basin plays an important role in the flows at Montrose Harbour. Small variations in the levels of the mud flats within the basin can change the volume and phasing of the tidal flows passing through the entrance channel. Long-term siltation of the basin would reduce the tidal prism with the possible consequences of reduced flow velocities and a potential increased maintenance dredging commitment. Conversely erosion of the inter-tidal mudflats, or relative sea level rise, could increase the tidal prism and tidal flows through the harbour.

To the south of Montrose, the offshore flood and ebb tide flows continue to run parallel with the coast and across the mouth of the Tay Estuary and along the Fife coast. Offshore of Fife Ness, the Admiralty diamond indicates a flood tide running at 170°N and the ebb at 345°N with maximum spring and neap currents of 0.45m/s and 0.2m/s, respectively (Charlton, 1980).

Closer to the shoreline, the flood current flows south-westwards parallel to the coast from Arbroath to Carnoustie before turning westward in to the estuary and into St Andrew's Bay, creating a clockwise eddy from Fife Ness to Abertay Sands, (Charlton 1980). Within the outer Tay Estuary, the flood current flows directly westward towards Broughty Castle and also runs parallel to the coastline along the western flank of Barry Buddon and along the Monifieth frontage. Currents in the outer Tay Estuary are summarised in Figure C1.10. The ebb flows eastwards out of the estuary before turning north-eastwards towards Arbroath.

As ebb flow increases, and the sand bars at the mouth of the estuary begin to dry out, this main flow begins to swing clockwise to flow eastwards. Towards low water the ebb flow develops in to a complex rotation.

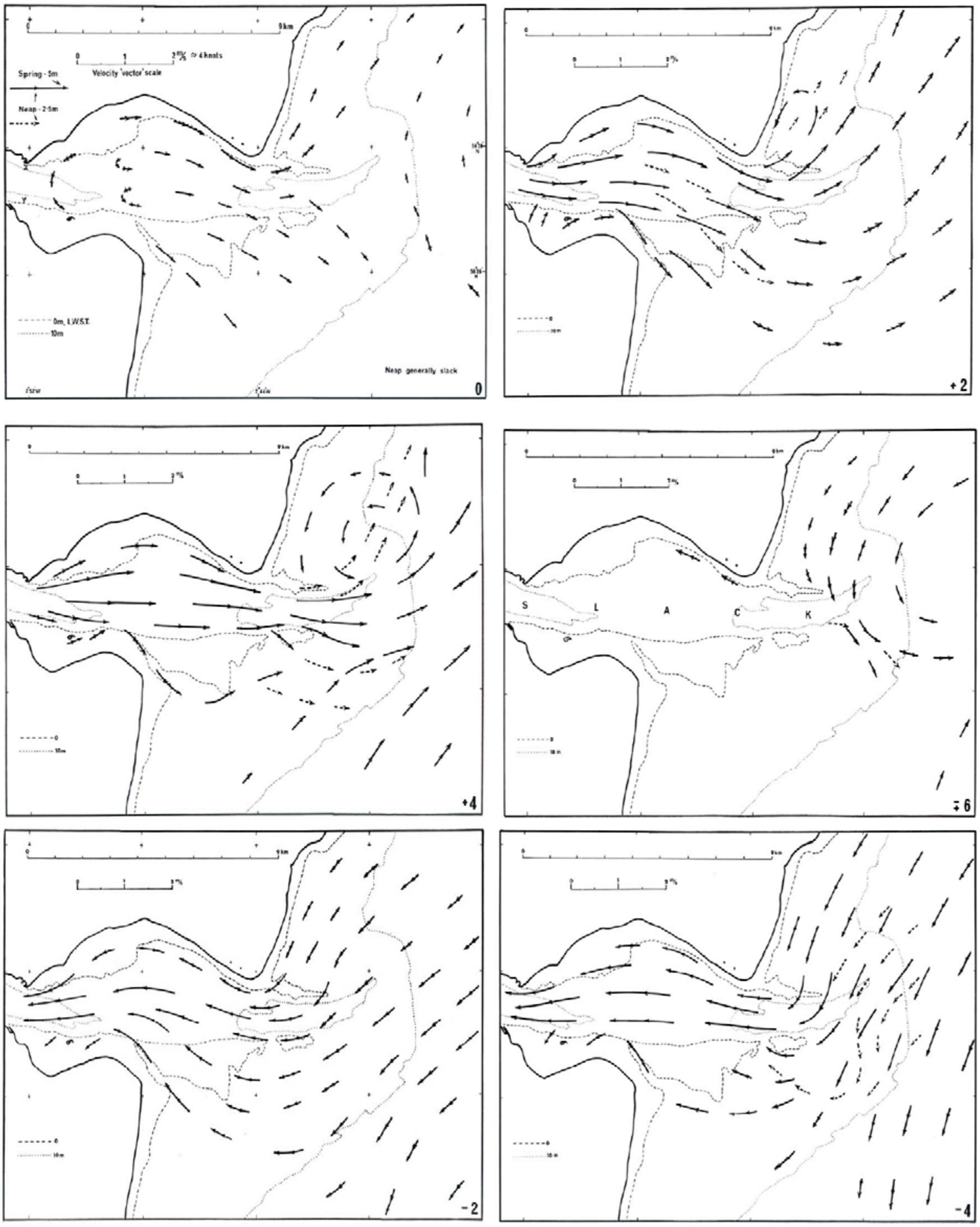


Figure C1.10 Summary of tidal currents over the tidal cycle at the entrance to the Tay Estuary (Charlton, 1980)

Charlton (1980) identified a series of residual current circulations (Figure C1.11). These are important processes in the transport of sediment near the entrance to the Tay. However, it is important to note that these circulations are inter-connected leading to complex sediment movements.

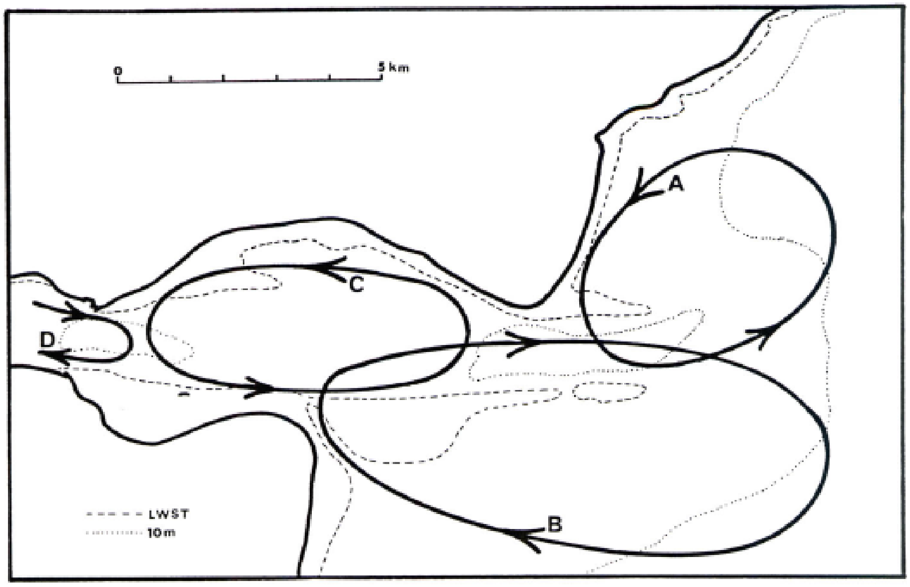


Figure C1.11 Tidal residual patterns at the mouth of the Tay (Charlton, 1980).

Storm surges

Actual water levels experienced at the coastline will vary from those predicted by the Admiralty Tide Tables. Atmospheric effects can cause substantial changes in tidal propagation producing either higher or lower levels than predicted. These differences, known as surges or tidal residuals, are caused by both variations in atmospheric pressure (with high pressure tending to depress tide levels) and by winds, which can exert significant stresses on even the very shallow water level slopes produced by the tides. The periods over which these residuals persist - and their magnitude - both vary. Of importance from a viewpoint of flooding or the performance of coastal defences are increases to predicted tidal levels due to storms or “storm surges”.

It is generally quite rare for the maximum surge height (difference between predicted and measured sea level) to occur at exactly the same time as a predicted high tidal level. In the design of coastal defences it is the expected total water level, which is important (i.e. the sum of the predicted tide height and any residual/surge). To estimate the maximum “total” water level (i.e. predicted tide plus surge elevation) likely to occur along the Angus coast therefore requires detailed consideration of the joint probabilities of surge and tidal height. This is a complex task, requiring careful measurements from tide gauges, sophisticated computer simulations of the propagation of both tides and surges under the influence of stormy weather in the North Sea, and careful statistical analysis of the information obtained.

For the Scottish coastline, the 1 in 50 year storm surge prediction is estimated to be approximately 1.25m (Baxter *et al*., 2011). Records from the Aberdeen tidal gauge (the nearest gauge to Angus where analysis on surges has been conducted) suggest that the highest water level above the maximum predicted tidal level was 60cm (Ball *et al*., 2008). A joint Defra/ Environment Agency / Scottish Government flood and coastal erosion risk management research and development project entitled ‘Development and Dissemination of Information on Coastal and Estuary Extremes’ (Environment Agency, 2011) provides a consistent set of extreme still water levels around the coast of England, Wales and Scotland.

Figures C1.12 and C1.13 give plots showing the comparison between the return period sea levels from the coastal flood boundary project (SSJPM) and those suggested by the annual maxima series (AMAX), calculated using the highest recorded in each annual data series at Aberdeen and Leith respectively.

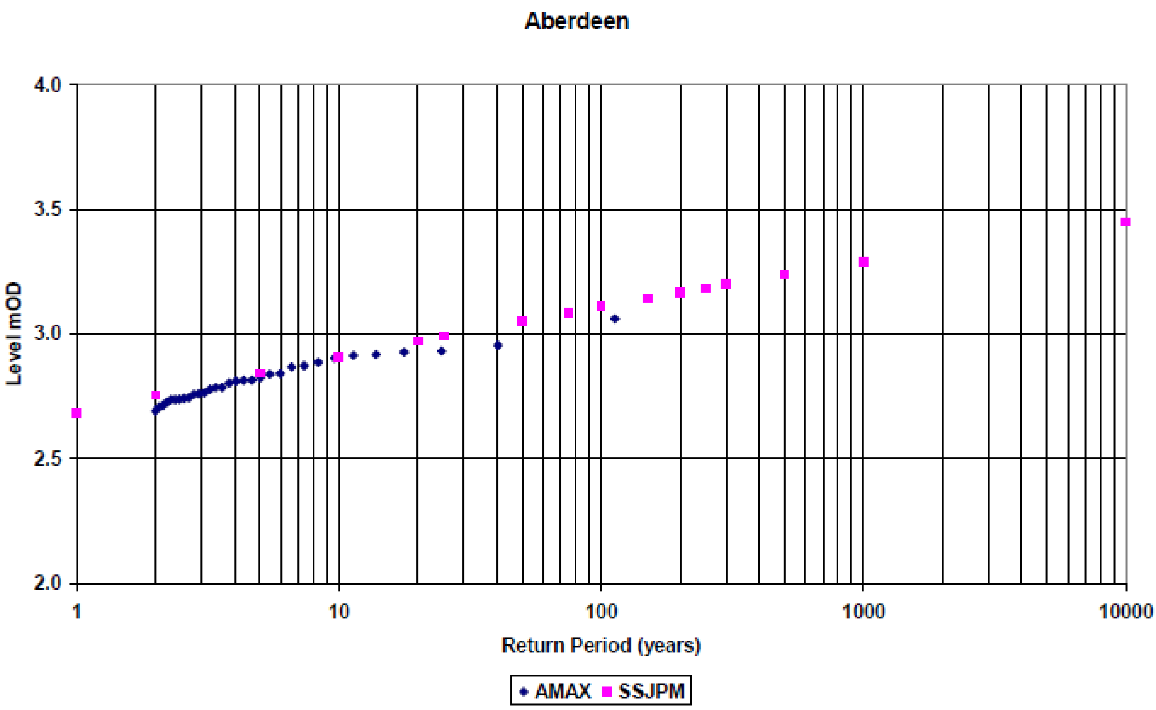


Figure C1.12 Comparison of tidal levels at Aberdeen (Environment Agency, 2011)

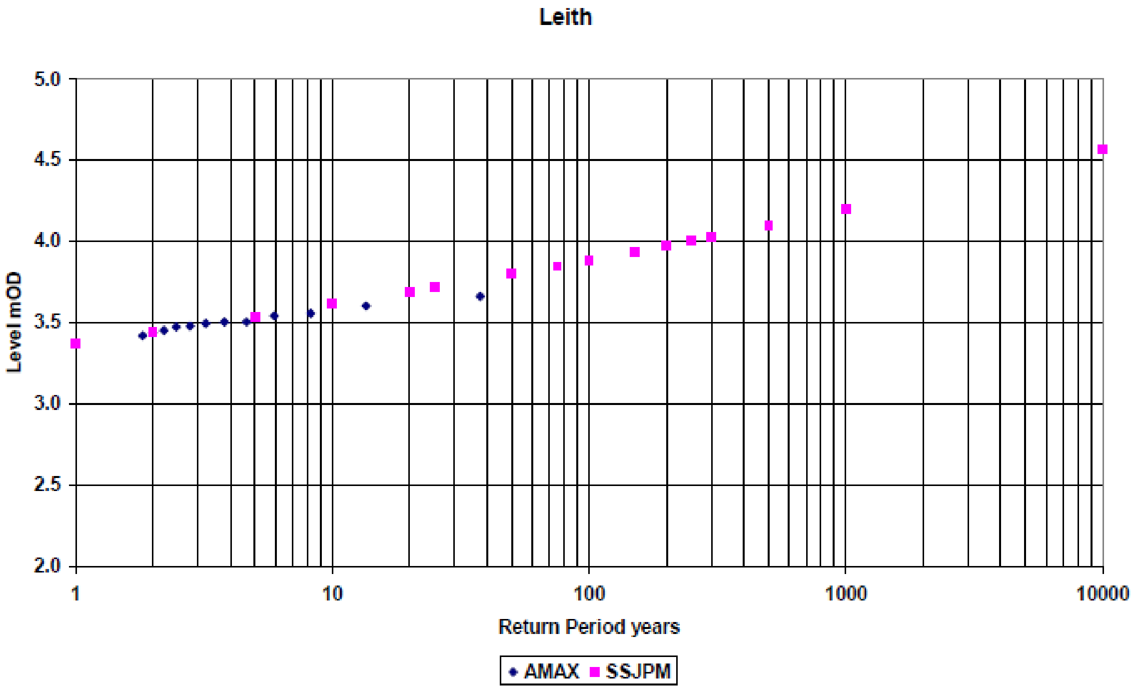


Figure C1.13 Comparison of tidal levels at Leith (Environment Agency, 2011)

A widely predicted consequence of global warming is the increase in mean sea levels, with a resulting increase in high tide levels as well. When storm surges are combined with higher water levels as a result of climate change, the risk of damage to the coast will increase. This is discussed further in Section C3.2.

Wind regime

Wave conditions and storm surges are strongly dependent on wind conditions. In this context it is not merely the local wind speeds that are important, but also wind direction, storm persistence and variability of conditions over the area in which the waves and surges are generated. Therefore in predicting wave and surge conditions directly from winds, it is useful to have time series data on wind speeds and directions.

The east coast of Scotland is well served with anemometer records. Winds have been recorded (and the information passed to the Met Office) at four coastal (or near coastal) locations:

- Leuchars: Data available from 1960
- Mylnefield: Data available from 1954 (digital data from 1960)
- Dyce Airport: Data available from 1957
- Bell Rock: Data available from 1962

A wind rose showing the magnitude and directional distribution of wind conditions extracted from the Meteorological Office European Wave Model for the area offshore of the Angus coast is shown in Figure C1.14. Little detailed analysis has been conducted of wind conditions, either from recorded or synthetic sources, to identify changes or trends in wind conditions. Such analysis has been limited to relatively short term data sets and / or is more than 25 years old:

- Wind analysis conducted by Caledonian Geotech (1987) using data from Leuchars and Bell Rock provides a comprehensive summary of wind conditions up to 1987 from the two stations.
- A comparison of wind conditions at Leuchars over the period 1987 to 1991, in relation to the longer term data records between 1970 and 1991, was conducted by HR Wallingford (1993) in connection with studying a coastal erosion problem at Montrose. This identified a substantial reduction in the occurrence of onshore winds of Force 5 or greater over the period 1987-1991, which would have reduced the occurrence of waves from the north east sector and hence reduced the volume of longshore transport of sand to the south within Montrose Bay.
- Halcrow (1998) also investigated wave climate changes using wind data from 1992 to 1996 from the Meteorological Office European Wave Model. This showed an increasing occurrence of onshore wave conditions over the period.

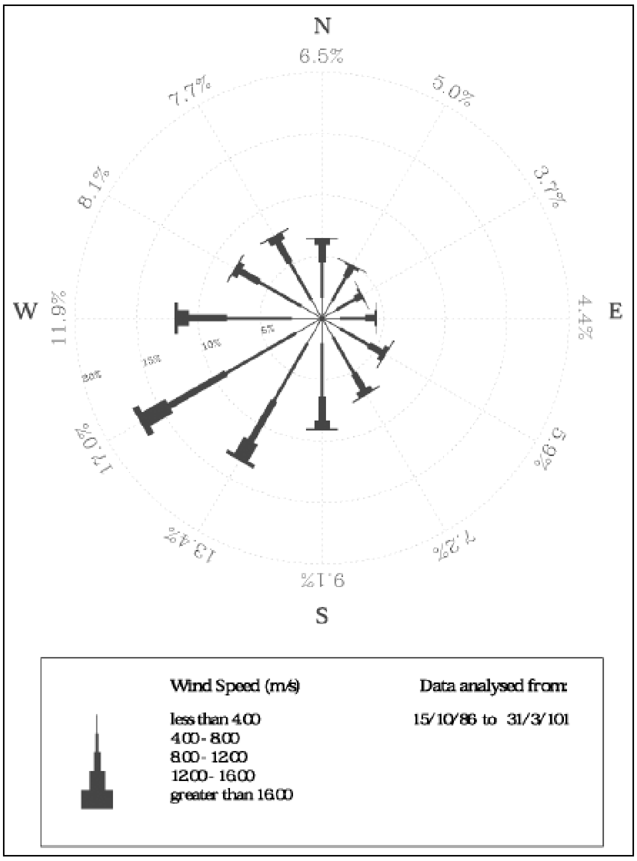


Figure C1.14 Offshore Wave climate to the east of Carnoustie

Wave regime

The Angus coastline experiences a wave climate with two main components. The wave climate is dominated by waves generated within the North Sea (known as wind-waves). The size of these waves offshore of the Angus coastline depends on the direction that the wind is blowing, its duration and the distance (or fetch) over which the wind acts to produce these waves. Fetch lengths extend over 500km within the directional sector between 25°N and 150°N. Hence strong winds from any direction within this sector have the potential for producing large wave heights off the Angus coast.

The second component of the wave climate experienced off the Angus coastline is that of swell wave activity. Swell is generated by distant storm conditions and is experienced off the Angus coastline with no correlation to the local wind conditions. Swell is generated from two main directions:

- Storm activity within the southern North Sea can result in swell off the Angus coastline from a direction of between about 120°N to 140°N.
- Storm activity in the North Atlantic with the resulting swell waves propagating into the North Sea and approaching the Angus coastline from between about 10°N to 50°N.

Caledonian Geotech (1987c) conducted some short-term non-directional wave measurements during the study of coastal erosion on the Angus coast:

- Tay Estuary: between June 1979 and June 1980, December 1984 to September 1985 and February to April 1987
- Carnoustie: between February and April 1981, January to June 1987

- Bell Rock: between April and June 1987

The study confirmed that storms with winds from the east or south-east were responsible for most of the episodic erosion along the south Angus coast. Further investigation using a radar system installed at the disused lighthouse at Buddon Ness was used to record directional wave data in the outer Tay Estuary and Monifieth Bay over a short period in 1987 (Boalch and McManus, 1988). This was used to demonstrate the significant impact that Abertay and Gaa Sands have on wave conditions approaching the south Angus coastline from the south-east quadrant both in terms of dissipating wave energy and refracting wave conditions. It was also used to demonstrate the importance that these sand bars have in the patterns of erosion and accretion experienced along the Buddon Peninsula and between Monifieth and Broughty Ferry.

Figure C1.15 shows the wave climate offshore of Montrose based on wind data from both Bell Rock and Fraserburgh (HR Wallingford, 1993). Due to the orientation of the coastline and shape of the wave generating area in the North Sea, the prevailing wave direction for locally generated wind waves is from the south and south-east. However, the largest waves tend to come from the east and south-east. More recently, hindcast wind and wave data covering the period between12 June 1991and 29 March 2007 for a location offshore from Montrose was obtained from the UK Meteorological Office for the purposes of numerically modelling the nearshore wave climate in Montrose Bay (Halcrow, 2007). These data indicate that the majority of wind waves that travel toward the shore are generated by south-easterly winds whilst most swell waves come from the north-east although there is a significant smaller component of swell waves derived from the south-eastern sector (Halcrow, 2007). Comparison of nearshore wind wave hindcast data covering the period 1976 to 1988 (HR Wallingford, 1993) with more recent nearshore data for Montrose Bay (Halcrow, 2007) suggest an increase in the frequency of south-easterly waves (Milne and Dong, 2010). It has been suggested that such an observed increase in the frequency of south-easterly winds during the 1980s and the consequential increase in the occurrence of waves from that direction was responsible for a contemporaneous strengthening of northerly longshore drift thus triggering the current trend of erosion at the golf course frontage at Montrose (Caledonian Geotech, 1987; HR Wallingford, 1993).

Figures C1.16 and C1.17 show the wave climate for swell and total sea (swell and wind generated waves) for the offshore location east of the Tay Estuary. Despite the prevailing swell wave direction being from around 30°N, swell from this direction would undergo significant refraction before reaching the Angus coastline, dissipating much of the wave energy.

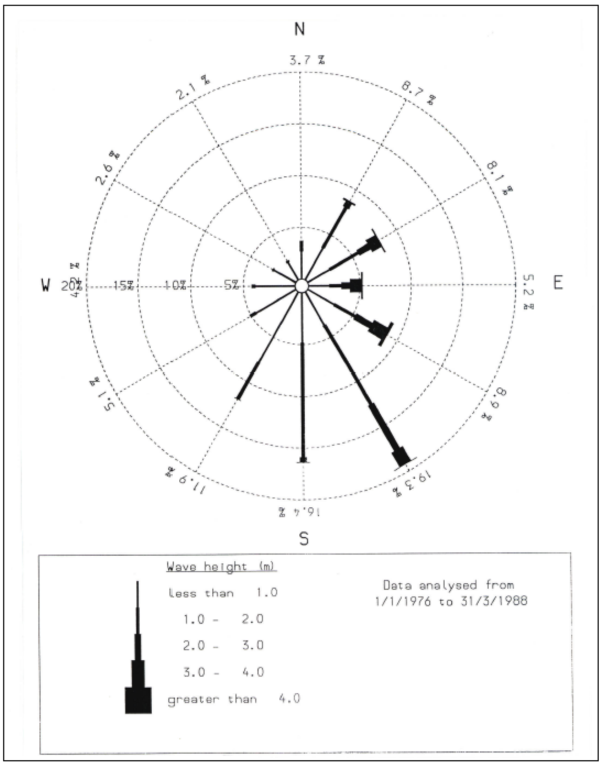


Figure C1.15 Offshore wave climate at Montrose (H R Wallingford, 1993)

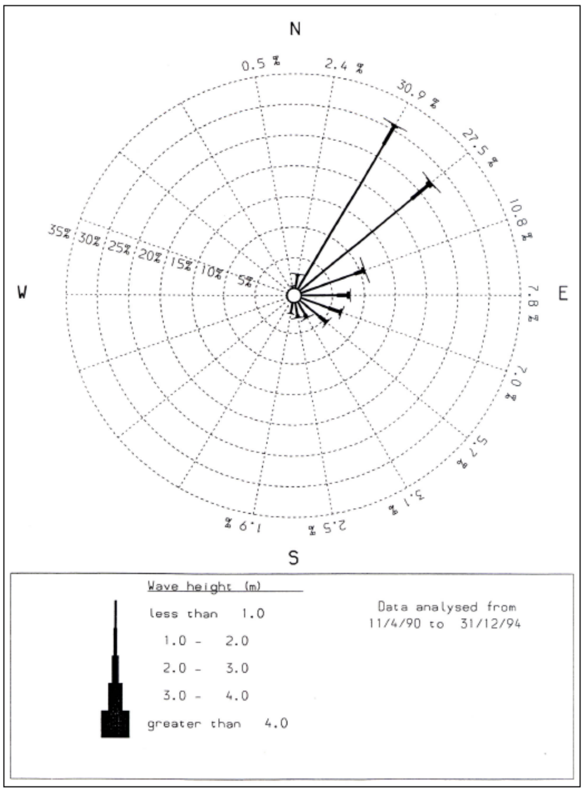


Figure C1.16 Swell wave climate offshore of the Tay Estuary (H R Wallingford, 1993)

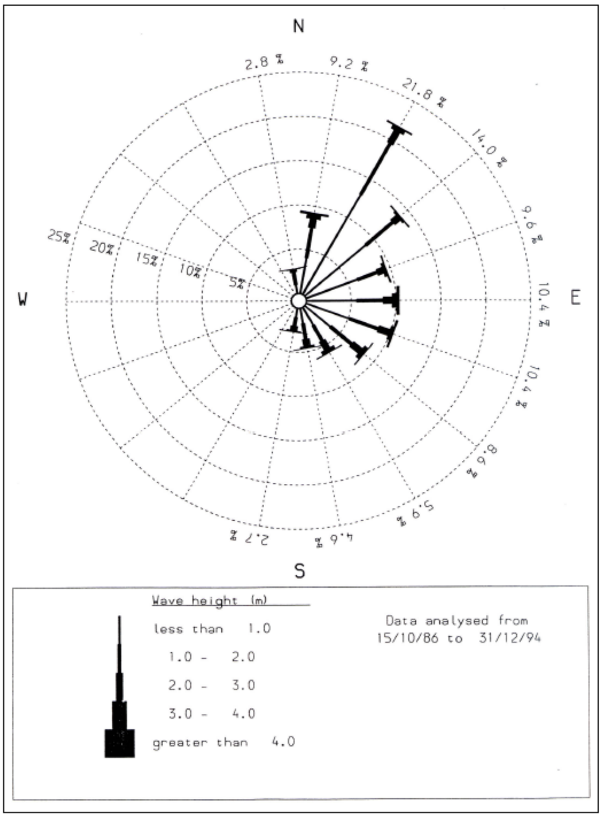


Figure C1.17 Total wave climate (swell + wind sea) offshore of the Tay Estuary (H R Wallingford, 1993)

The transformation of waves as they approach the shoreline has been assessed by Halcrow (1998, 2007) at Montrose, and also by Ferentinos and McManus (1981) along the Arbroath to Fife Ness coast. Ferentinos and McManus (1981) presented wave refraction diagrams for waves for the north-east and south-east. It showed that waves from the north-easterly quadrant resulted in a strong southward flowing longshore current between Arbroath and Buddon Ness and waves from the south-east producing the opposite effect, a strong northerly flowing longshore current. This also showed that the banks at the mouth of the Tay have considerable influence on wave conditions approaching the coastline. Wave transformation exercises at Montrose (Halcrow, 1998, 2007) have been used to model longshore transport at the site (Halcrow, 1998; Milne and Dong, 2010; Milne *et al*., 2012) which have shown that the local wave climate drives a net northerly longshore drift in most of Montrose Bay.

Extreme wave conditions along the Angus coastline have been calculated at a number of offshore locations including off the Tay Estuary (Ramsay and Brampton 2000); Montrose (HR Wallingford 1993) and at various locations along the eastern flank of Barry Buddon (HR Wallingford 1989). Halcrow (1998) also predicted extreme wave conditions inshore at Montrose at around the –4.6m OD contour. Extreme wave conditions from these studies are summarised in Table C1.4.

Table C1.4 Return periods of extreme wave conditions offshore of the Angus coast.

Return Period	Montrose (9km offshore)		Montrose (Golf course) (-4.6m OD contour)		30km east of the Tay Estuary	
	Hs (m)	Tm (s)	Hs (m)	Tm (s)	Swell Hs (m)	Total sea Hs (m)
1	7.8	9.0	3.4	6.6-8.7	3.6	6.23
2	8.4	9.4				
5	9.2	9.8	3.9	7.0-9.3		
10	9.9	10.1	4.0	7.2-9.5	4.49	7.62
20	10.5	10.4				
50	11.3	10.8	4.5	7.6-10.0		
100	11.9	11.1	4.7	7.8-10.3	5.36	8.95
Reference	HR Wallingford, 1993		Halcrow, 1998		Ramsay & Brampton, 2000	

Offshore of Montrose significant wave heights of 2m or more are predicted to occur around 17% of the time, whilst wave heights of 4, 6 and 8m are expected to be exceeded 1.9, 0.2 and 0.02% of the time respectively.

Sediment transport

Sediment transport along the Angus coast has been discussed in a number of previous studies and reports.

These include numerical modelling of sediment transport at Montrose (HR Wallingford, 1995; Halcrow, 1998; Milne and Dong, 2010), for the outer Tay Estuary (Ferentinos and McManus 1981; Sarrikostis and McManus 1987), and for Monifieth Bay (Al-Mansi, 1989).

Due to the relative stability of sea levels over the last 3000 or so years, sediment sources and losses are relatively well balanced. Present day erosion and accretion tends to be due to the re-distribution of existing beach and hinterland sediments both along the coast, and between the beach and nearshore zone.

At present natural sediment sources for the beaches along the Angus coast include:

- Reworking of relic hinterland deposits of post-glacial sand and gravel, such as erosion of dunes and links areas (dominant source)
- Eroded material from the sandstone and conglomerate cliffs north of Arbroath (minor source)
- Reworking of offshore relic post-glacial sand deposits (minor source)
- Input from St Andrews Bay / Tentsmuir transported in a complex manner across the sand bars at the mouth of the Tay (unknown but likely to be relatively minor)

Fluvial sediment, such as from the Tay, the North and South Esks, or the smaller river systems, e.g. Lunan Water, that discharge along the Angus coast, now supply very little sediment to the Angus beaches.

Human impacts

Human impacts along the Angus coastline are primarily associated with the larger coastal settlements of Montrose, Arbroath, Carnoustie, Monifieth and Broughty Ferry. The coastal hinterland in these localities has been extensively developed for industrial, recreational and residential purposes. Accordingly, much of the coastline has seen the *ad hoc* installation of hard engineering defences including rock revetments, groynes and concrete and masonry seawalls. The links morphology that characterise the backshore areas of much of the Angus shoreline have been developed as golf courses at Monifieth, Carnoustie, Elliot and Montrose and for tourism and recreation purposes.

Major harbours on the Angus coastline are found at Arbroath and Montrose. At Montrose the South Esk navigation channel is generally dredged on an annual to bi-annual basis in response to infilling by sediment derived from the neighbouring beach. The latest data indicate that an average of 52,556 m^3 is dredged per annum from the South Esk (Milne *et al*., 2012). Historically this sediment has been removed to Aberdeen, St Cyrus and disposed offshore in Lunan Bay, representing a significant loss of material from the Montrose nearshore system.


Montrose Port, 2012 (source: Halcrow)


River View Caravan park, Monifieth, 2012 (source: Halcrow)

C2 Coastal Process Statements

C2.1 CPU 1 – Milton Ness to Montrose Harbour

C2.1.1 Location Map

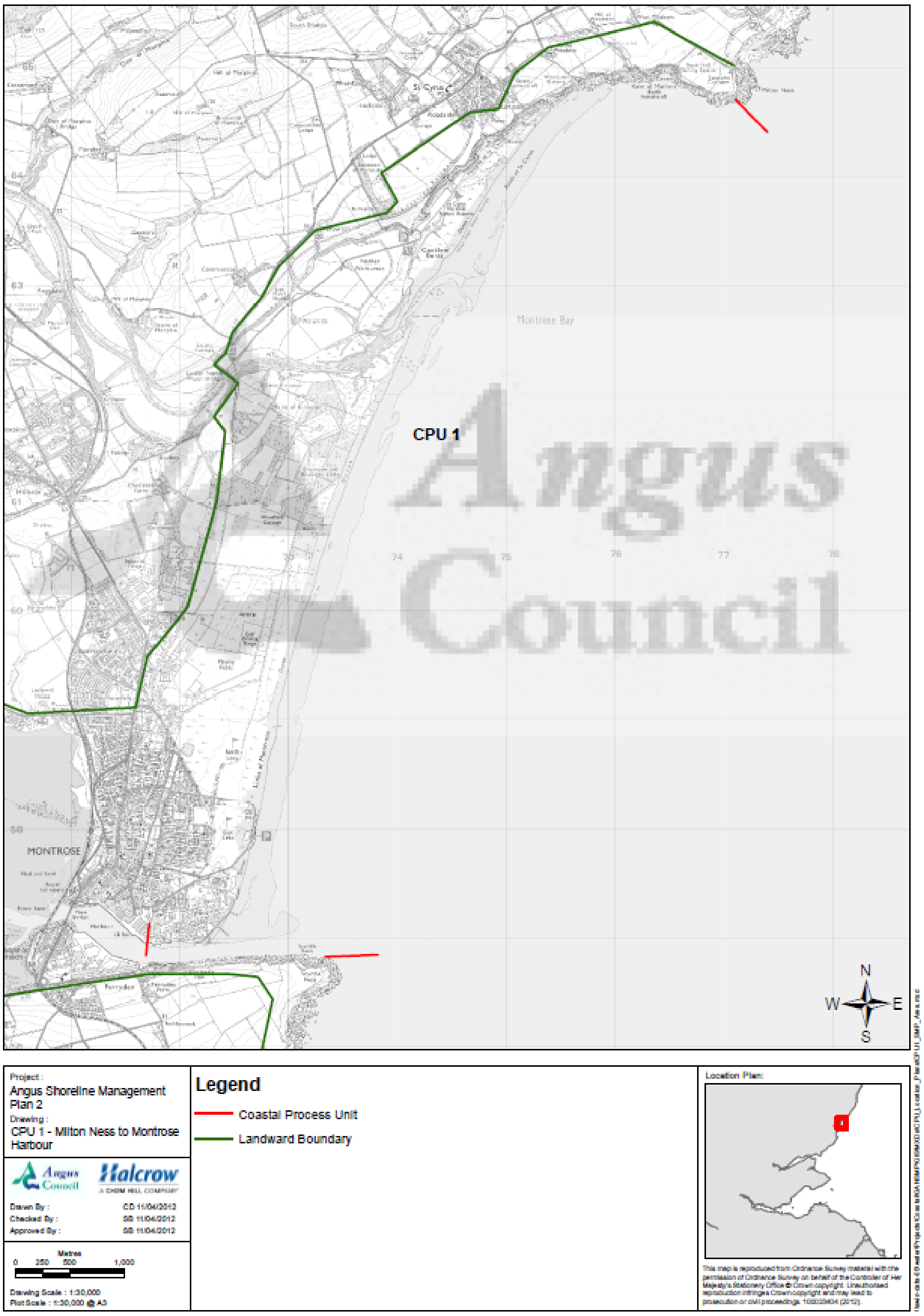


Figure C2.1 CPU 1 Milton Ness to Montrose Harbour

C2.1.2 Coastal Morphology

Montrose Bay is set between the volcanic cliffs at St Cyrus, at the northern end of the bay, and the headland of Scurdie Ness to the south. The River South Esk outlet from Montrose Basin is at the southern end of the frontage. The River North Esk dissects the coastline between Kinnaber and St Cyrus.


Milton ness, 2004 (source: Angus Council)


St Cyrus cliffs, 2012 (source: Halcrow)


River North Esk, 2004 (source: Angus Council)


River South Esk, Montrose, 2004 (source: Angus Council)


Montrose Links, 2012 (source: Halcrow)


Scurdie Ness, 2012 (source: Halcrow)

The peninsula upon which Montrose and the links are located is formed upon a shingle bar of rounded pebbles. It is uncertain how this shingle bar developed (for example whether it is a bay-bar feature formed when sea levels were falling or whether it was formed during a period when there was strong southerly longshore transport, or a combination of the two). As sea levels fell around 6,000 years ago, vast amounts of sand were blown inland, covering the shingle bar and creating the links and dunes seen today.

The beach within Montrose Bay is dominantly sandy with a section of shingle storm beach along the Kinnaber frontage. The beach gradient is low, particularly at St Cyrus where the intertidal beach is characterised by a well-defined ridge and runnel system. At the southern end of the bay, ebb flows from Montrose Basin have formed the Annat Bank with the intertidal beach at this location well over 600m wide. Immediately backing the beach along much of the length is a single frontal dune ridge. This ranges in elevation from around 10m to the north of the Pavilion, to a maximum of around 12m along the Kinnaber frontage, before reducing in height towards the mouth of the North Esk. At St Cyrus, the dune belt is lower and wider with recent embryonic dunes forming in front of the existing dune line. At the southern end of the bay, a second, lower dune ridge, approximately 100m further back can also be seen.


Shingle upper beach fronting the dunes at Kinnaber (source: F.D.Milne).


The prograding beach at St Cyrus showing developing embryo dunes (source: F.D.Milne).

C2.1.3 Shoreline dynamics and behaviour

Interactions

Present day sediment input to the coastline is limited to erosion of the hinterland deposits, i.e. erosion of the dunes along the southern part of the bay. Dune face erosion is particularly severe in the largely unprotected dunes fronting the Montrose Medal Golf Course, with estimated rates of erosion of 2.5m/yr (Milne and Dong, 2011).


Erosion in the beach-dune system fronting the Montrose Medal Golf Course (source: F.D.Milne).


River South Esk channel, 2012 (source: Halcrow)

There is unlikely to be any significant input of beach sediments from the two rivers (Ramsay and Brampton, 2000), or from further offshore due to the relative stability of sea levels since the mid-Holocene (Hansom, 2001). Montrose Bay is contained between the headlands at Scurdie Ness and Milton Ness and there is unlikely to be any appreciable longshore transport of beach sediment past these headlands either into or out of the bay. There is also relatively little natural loss of sediment from within the bay.

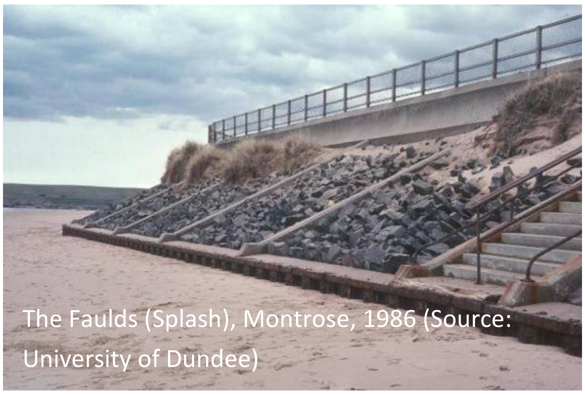
Dredging of the channel into Montrose Harbour does represent a net loss of beach sediment from Montrose Bay as it has historically been removed to Aberdeen, St Cyrus and deposited offshore from Lunan Bay and will not be transported back. This dredging, which commenced in conjunction with harbour expansion in 1973, generally occurs on an annual to bi-annual basis to maintain a depth sufficient to allow access for larger vessels in response to infilling by beach sand drifting from the north (Halcrow, 1998; Ramsay and Brampton, 2000).

Data on dredge totals are available from 1984, since when approximately 1,366,464 m^3 (around 50,000 m^3/yr) of sand has been removed from the coastal system. It has been suggested that this has created a negative sediment budget in Montrose Bay and is contributing to the predominantly naturally driven erosion along the Montrose frontage, including Montrose Golf Links, in recent years (Milne *et al*., 2012). Successive investigations over several years have recommended that it would be preferable to retain this dredged sediment within the coastal system (HR Wallingford, 1993; Halcrow, 1998; Milne and Dong, 2010, 2011).

Spatial and temporal trends in erosion and deposition within the bay are dominantly due to redistribution of sediment both along the coastline and within the bay and are most likely to be due to short to medium term fluctuations in the wave climate. Whether such fluctuations are part of a longer-term trend is difficult to establish at present. Over the last c. 20 years there appears to have been a pattern within beach systems similar to Montrose Bay (e.g. Lunan Bay, Cruden Bay) where the coastline has "re-orientated" clockwise with erosion generally greater along the southern sections of the bays and accretion towards the northern ends. However, the comparison of historical maps suggests that this has not been the general pattern over much of the latter part of the 19th Century and early to mid 20th Century, where if anything accretion has occurred along the southern sections of Montrose Bay.

At present within most of Montrose Bay, net drift is to the north due to the dominance of waves from the southeast quadrant. However, Scurdie Ness provides shelter to the frontage between the Faulds (Splash) and the River South Esk from waves from the southeast and therefore, south of the Faulds the net drift is to the south due to the strong tidal currents in this area. Dredging of the River South Esk channel will effectively remove material directed into the channel so it is not able to be transported back north. The erosion rate was calculated to be around 100,000m^3/year at The Faulds in 1993 (HR Wallingford, 1993) although recent studies suggest the sediment flux here is now much smaller (Milne and Dong, 2010). However, a relatively small change in the average wave direction could result in a significant change in the longshore transport rate or even net drift direction (HR Wallingford, 1993).

Persistent erosion in the dune belt fronting the golf course commenced in the late 1980s and has encompassed up to 60m of dune erosion at the southern frontage (Beedie, 2010; Milne and Dong, 2011). The current dominance of northerly longshore drift is the primary driver of this erosion, causing a natural sediment deficit along this part of the beach due to a generally positive littoral drift gradient and the comparatively short length of up-drift beach. Sediment starvation at this location is also exacerbated by the up-drift presence of the seawall at the Faulds (Splash) which prevents the compensatory release into the littoral zone of sediment from the protected hinterland (Milne & Dong, 2010; Milne *et al*., 2012). A lowering of the beach along the Splash frontage resulted in the need for further defences to protect the exposed defence toe.


The Faulds (Splash), Montrose, 1986 (Source: University of Dundee)


The Faulds (Splash), Montrose, 2010 (Source: University of Dundee)

Sediment eroded from the southern end of the bay (from Faulds northwards) is transported to the northern end of the bay where the beach is prograding (Hansom and Rennie, 2004; Hansom *et al*, 2010; Milne *et al*., 2012). The abundance of sand on this beach protects the coastal edge with little evidence of any erosion of the dune face, even under storm conditions. A complex series of intertidal ridges and runnels is evident, particularly during summer months (Ramsay and Brampton, 2000).

The net northward longshore transport rate of beach sediments can be seen in the dynamic changes in the position of the mouth of the River North Esk. Before 1879, the position of the river outlet was deflected to the north by a spit which must have been built up by a contemporary net northward longshore drift. However, the combination of a south-easterly storm, and the river in spate resulted in a breach of the spit and a new outlet forming (Turner *et al*., 2008; Hansom *et al*., 2010). However, this dramatic reorientation of the river mouth is likely to have been the consequence of longer term trends (Turner *et al*., 2008) and it has been suggested that this may have been facilitated by gradual thinning of the dune line prior to the storm due to a strengthening of southerly drift in the bay at the time (Milne *et al*., 2012). Following the reorientation event, the river mouth was gradually deflected northwards again reaching its current position, approximately 1km north of the original breach channel, in the 1970s. Saltmarsh developed in the old channel which subsequently diminished in recent years due to sediment accumulation at St Cyrus (Turner *et al*., 2008; Hansom *et al*., 2010; Milne *et al*., 2012).


Boardwalk over the old River North Esk channel, 2012 (source: Halcrow)


The old River North Esk channel, 2012 (source: Halcrow)

Tidal currents are also likely to be responsible for the movement of beach material, particularly along the Montrose frontage. Although these currents will not be of sufficient magnitude to suspend and transport a high volume of material, the stirring action of breaking waves will allow material to be brought into suspension, which can then be moved by such currents. Peak current speeds on both the flood and ebb tides are similar in magnitude. However, at high tide the current speeds flow strongly in a southerly direction and are capable of transporting beach material on the lower sections of the intertidal beach (HR Wallingford, 1995). This process can help explain the periodic filling of the dredged channel leading to Montrose Harbour.

Movement

Changes in the position of MHWS and MLWS along the Montrose town and golf course frontage were examined in the Angus SMP1 (Angus Council, 2004). Analysis showed some variability in the position of the Mean High and Mean Low Water over this period, most notably a general seaward movement of the MHWS line until recently. It is interesting to note that the high-water mark indicated on the 1865 map at the southern end of the golf course is apparently located only about 10 m landward of the current MHWS indicating that the current state of the dunes is almost analogous with that in the mid to late 19th century. This interpretation of historical maps also appears to be supported by archaeological evidence in the shape of recent exposure of shipwrecks contemporaneous with the 19th century and retrieval of musket balls and lead bullets eroded from the scarped dunes (Milne *et al*., 2012). The historic shoreline changes apparent in the maps demonstrate two important aspects:

- Temporal variations in the position of MHWS are greater along the golf course frontage (i.e. southern section of Montrose Bay) than further north in the central section of Montrose Bay.
- Up to the 1970's the MHWS along the southern part of Montrose Bay tended to be moving seaward, i.e. accretion was occurring. Since around the 1970s the MHWS position has retreated landward by up to 38m, or around 1m per year on average.

The mouth of the River North Esk is particularly dynamic. Prior to 1879, the outlet was deflected to the north by a long spit created due to the net northward longshore transport within the bay. This was breached during a storm in 1879. Subsequently, since this date, the River mouth has been migrating northward with a new spit developing. It is likely that the position of the river mouth will continue to change into the future reflecting the dynamism of the coastal system.

Continued erosion in front of the Glaxo site resulted in the implementation of a scheme at the very southern end of the bay in 1999. Implementation of the scheme, including rock armour revetments, groynes, recharge and dune planting has been successful in encouraging accretion and stabilisation of this frontage as seen at present.


Glaxo frontage pre 1999 scheme (source: Angus Council).


Glaxo frontage post 1999 scheme (source: Angus Council).

C2.1.4 Modifications

The most significant modifications in this CPU have occurred in the southern part of the bay in the vicinity of Montrose. At this part of the bay infrastructure was developed in the early to middle 20th century within the dynamic dune belt for recreational (a seafront pavilion - Splash) and industrial purposes (a pharmaceutical plant - Glaxo). Accordingly, in response to subsequent shoreline retreat, a series of hard engineering structures were constructed on an ad hoc basis, these include a seawall and rock armour groynes, strong points and revetments (Mannion, 1999; Angus Council, 2007).

A scheme implemented at the very southern end of the bay in 1999 to protect the pharmaceutical plant comprising larvikite rock armour revetments and rock groynes also included a beach recharge using sediment dredged from the South Esk Estuary (Mannion, 1999). Dredging of the South Esk channel to maintain access to the harbour takes place generally on an annual to bi-annual basis. As this material is disposed of off shore of Lunan Bay, or further afield to Aberdeen, approximately 50,000m^3/yr of material is effectively removed from the Montrose Bay system. Man made changes in this CPU, including dredging of the South Esk and hard defences in front of the Glaxo site, Caravan Park and beach front, and in the Montrose Basin CPU have contributed to exacerbating erosion along the Montrose Golf Links frontage.


Montrose links rock strong points, 2012 (source: Halcrow)


Splash frontage revetment, 2012 (source: Halcrow)


Montrose caravan park revetment, 2012 (source: Halcrow)


Glaxo buried rock defences, 2012 (source: Halcrow)

C2.2 CPU2 - Montrose Basin

C2.2.1 Location Map

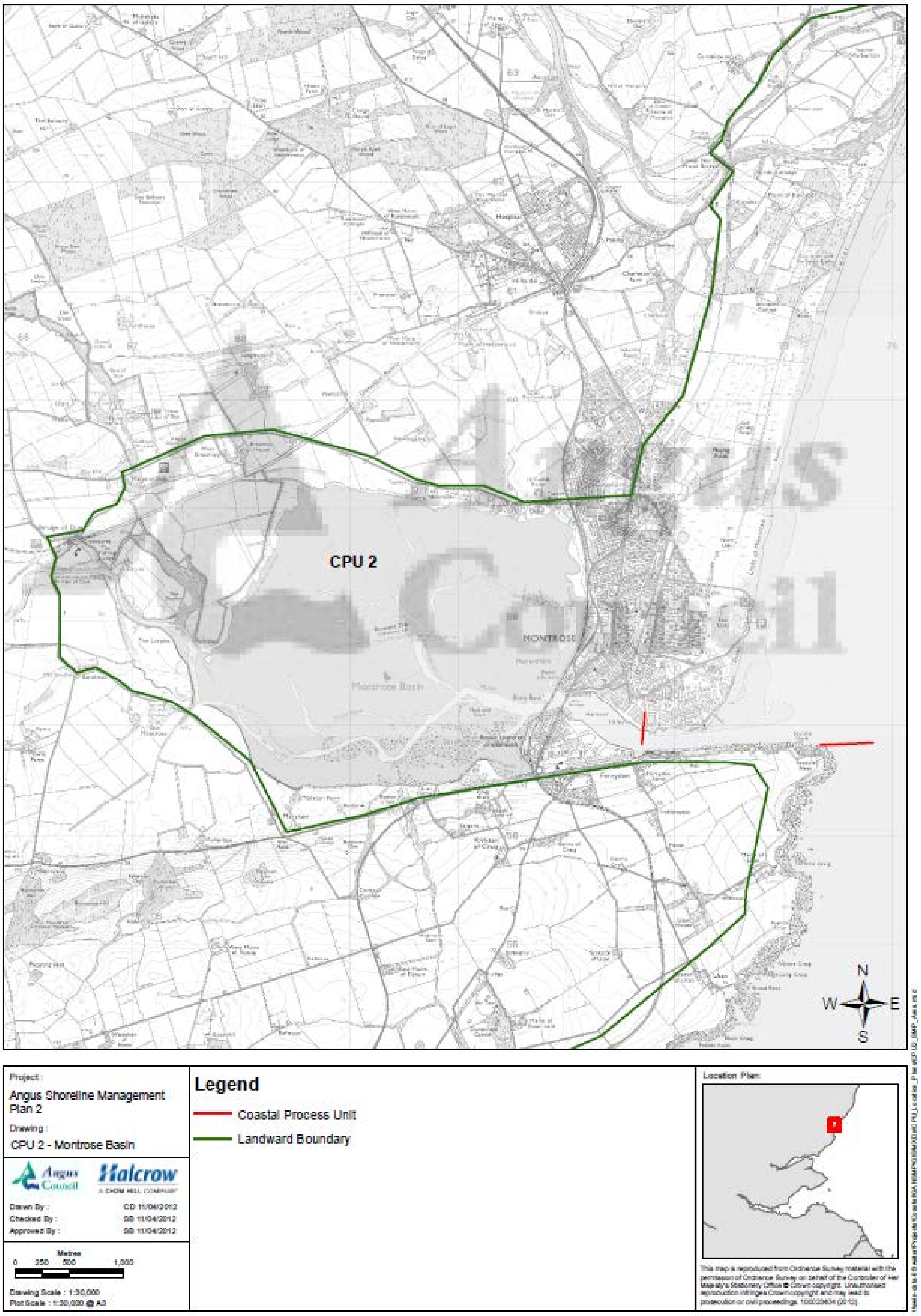


Figure C2.2 CPU 2 Montrose Basin

C2.2.2 Coastal Morphology

Montrose Basin is an example of an enclosed estuarine basin. The basin almost empties at low water with extensive mudflats exposed. The River South Esk and a number of smaller streams drain through the basin and the outlet to the south of Montrose (both saltmarsh and wet grassland are found along the western flank of the basin). Around the basin there is considerable evidence of raised beaches. During the period of highest sea levels following the last ice age, around 7,000 to 9,000 years ago, the basin would have been at least twice its present size with the seaward entrance being much larger along the eastern flank.

This CPU also includes the northern edge of the Scurdie Ness headland adjacent to the River South Esk channel extending from Ferryden to Scurdie Ness.


Montrose Basin facing west, 2004 (source: Angus Council).


Montrose Basin facing east, 2004 (source: Angus Council)


Montrose Port, 2012 (source: Halcrow)


Ferryden, 2012 (source: Halcrow)

C2.2.3 Shoreline dynamics and behaviour

Interactions

Littoral processes are dominated by tidal and river flows. The basin acts as a trap to fine sediment being transported down the River South Esk, and possibly also to sand transported in on the strong flood tides from Montrose Bay. The basin is gradually silting up; however, no information is available on the rate of siltation. Tidal flows on both the flood and ebb through the entrance to Montrose Basin are extremely strong reaching speeds of up to 3.5m/s (7 knots) on a spring tide.

Wave action is limited to a short tidal window around high tide. However, wave action is sufficient to cause erosion along sections of reclaimed land where no, or low cost, coastal defences are located, most notably at Tayloan and Rossie Island. On a high spring tide and easterly storm, wave conditions would be sufficient to cause damage to, and increase the risk of breaching of the flood embankments along the western flank of the basin.

At the mouth of the basin, Scurdie Ness provides shelter to the CPU 1 frontage between the Faulds (Splash) and the River South Esk from waves from the southeast.

Movement

Analysis of changes in the position of the MHWS line between 1865 and 2004 were investigated in SMP1 (Angus Council, 2004). Results suggest that comparatively little change has occurred due to the relatively mild wave climate experienced within the sheltered waters of basin. The majority of the changes have occurred due to land reclamation. The South Esk course shows sharp meander-like curves before reaching the basin and these may mark former outlet courses.

C2.2.4 Modifications

Land reclamation has taken place within the Basin, most notably:

- Along the western flank of Montrose, associated with the re-routing of the East Coast Railway Line along the eastern flank of the basin during the late 19th and early 20th Century.
- Further reclamation during the mid 20th Century around the north east corner of the basin at Tayloan.
- Reclamation of 23 hectares of intertidal area to the south and east of Rossie Island using dredged material (joining the island to the southern shore of the South Esk Estuary) in 1974 to facilitate expansion of Montrose harbour (Wright, 1981).

The reclamation of the low lying land along the western flank of the basin for farmland appears to have occurred before the first edition OS map with only minor changes in the position of the flood embankments occurring over the last 140 years.

An attempt to reclaim the northern part of the present basin for agricultural purposes was commenced in 1678 through the construction of a west-east trending wall in the basin, known as Dronner's Dyke. However, a severe storm coinciding with a high tide in the winter of 1679 destroyed the wall whilst it was still under construction resulting in the abandonment of the project. The much diminished ruins of the dyke are still present in the basin (Montrose Basin Heritage Society, 2004).

Mouth of Montrose Basin, 2004 (source: Halcrow)

East Coast Railway mainline, Rossie Island, 2012 (source: Halcrow)

C2.3 CPU 3 - Scurdie Ness to Rickle Craig

C2.3.1 Location Map

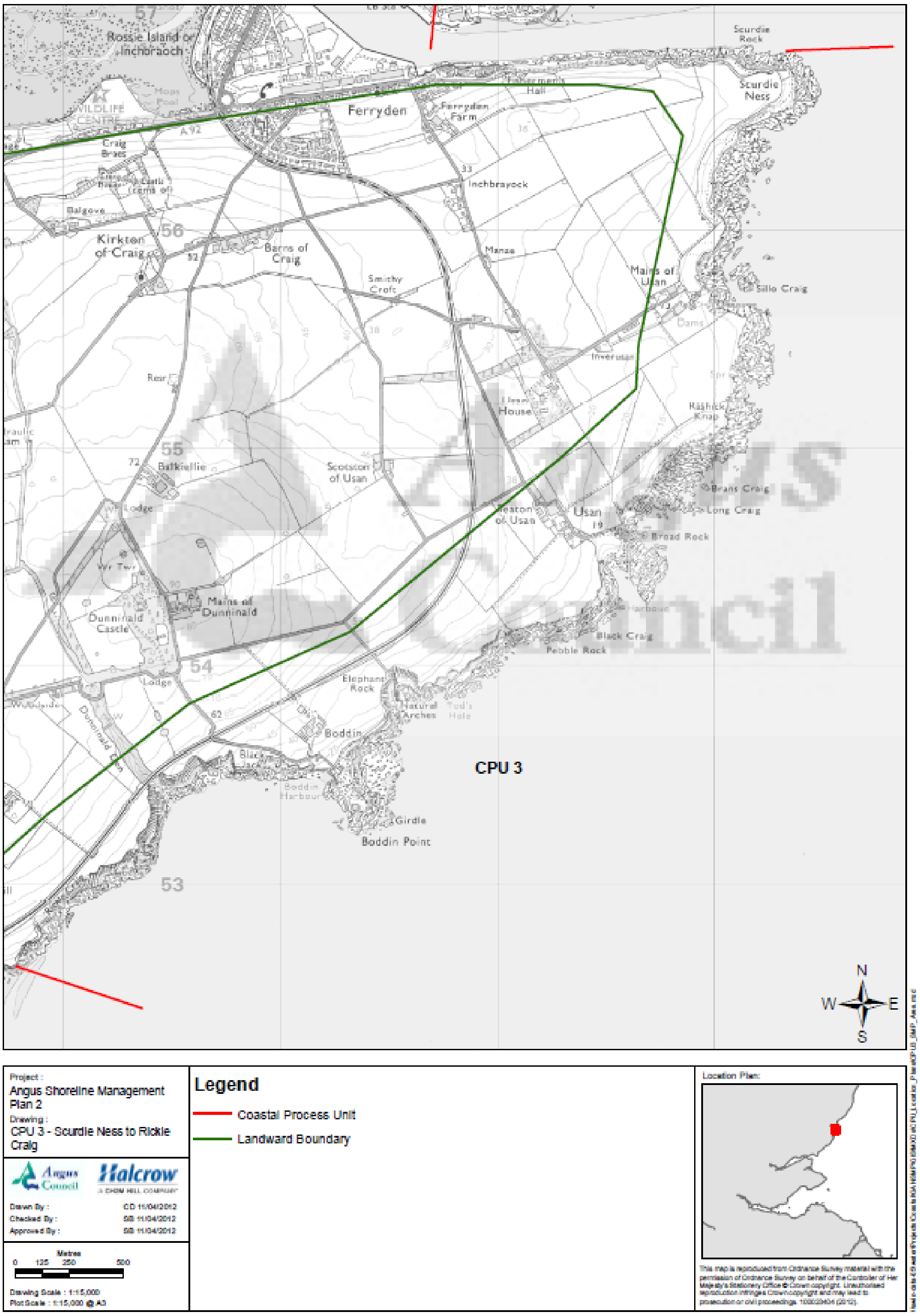
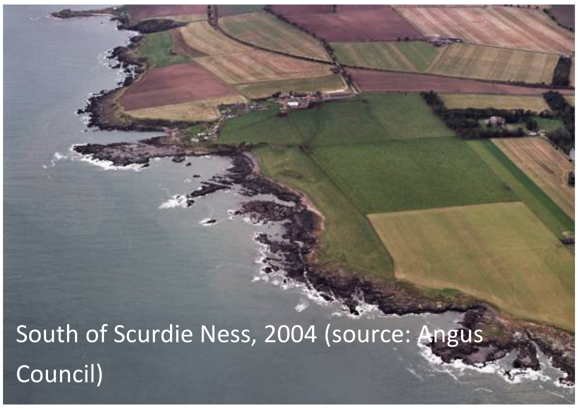


Figure C2.3 CPU 3 Scurdie Ness to Rickle Craig

C2.3.2 Coastal Morphology

The coastline from Scurdie Ness to Boddin Point and Rickle Craig is dominated by rocky coast cliffs. These formed mainly from lavas with the exception at Boddin Point where an outcrop of upper Old Red Sandstone overlies the lavas. The entire coastline is fronted by a fringing rock platform with some thin superficial shingle beaches found within some of the small bays. The rocky shore is important for the exposures of lava sequences but have little other morphological interest. Between Boddin Point and Rickle Craig, the cliffs are lower, less steep and are covered in till with a small pocket sand beach found at the base of the cliff south west of Boddin Point. A small area of elevated saltmarsh also occurs to the west of Boddin Point.


Scurdie Ness, 2004 (source: Angus Council)


South of Scurdie Ness, 2004 (source: Angus Council)


Boddin Point, 2004 (source: Angus Council)


North of Boddin Point, 2012 (source: Halcrow)


Rickle Craig, 2012 (source: Halcrow)


Rickle Craig, 2004 (source: Angus Council)

C2.3.3 Shoreline dynamics and behaviour

Interactions

Coastal processes of interest are those that have created the elevated saltmarsh area in this CPU. These are likely to be linked to episodic events supplying salt water to the saltmarsh through wave spray and possibly small amounts of overtopping.

Movement

The shoreline in this CPU is a hard rocky coastline and is accordingly relatively resilient to marine erosion. Nevertheless, erosion is threatening coastal archaeology in the form of the 18th century limekilns at Boddin Point. The limekiln structure was intact in 1977 but in recent years much of the south west part of the structure succumbed to the effects of erosion and further collapse is anticipated in the near future (Hambly *et al.*, 2010). At Scurdie Ness a cairn constructed in 2005 to mark the end of a coast to coast path is also threatened by coastal retreat (The Courier, 2011).

The 18th century limekilns at Boddin Point (source: F.D.Milne).

Erosion at Boddin Point, 2012 (source: Halcrow)

C2.3.4 Modifications

The calcareous Old Red Sandstone rock on the foreshore at Boddin Point was quarried from 1696 to 1831 for burning in the limekiln at the site. It has been suggested that this practice has, in conjunction with natural coastal erosion, altered the shape of the point (Hambly *et al.*, 2010).

C2.4 CPU 4 - Rickle Craig to Lang Craig (Lunan Bay)

C2.4.1 Location Map

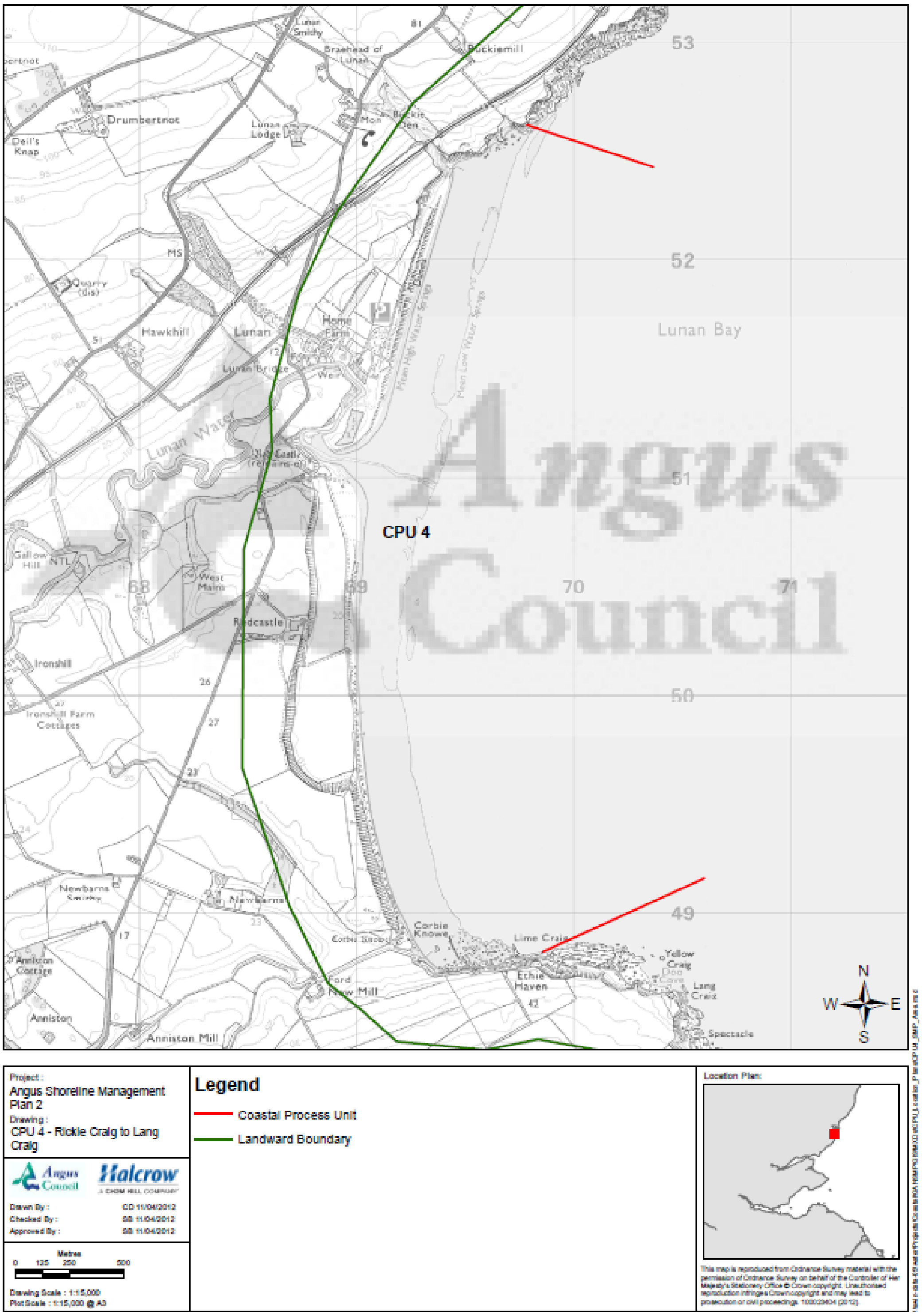


Figure C2.4 CPU 4 Rickle Craig to Lang Craig

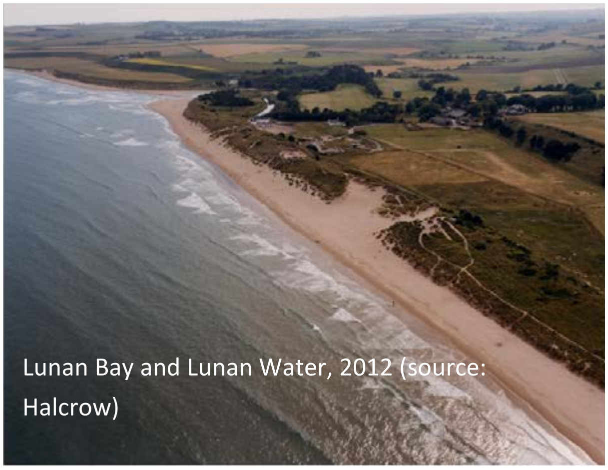
C2.4.2 Coastal Morphology

Lunan Bay is enclosed within the headlands at Boddin Point to the north and Lang Craig to the south. The bay is characterised by a wide intertidal sand beach often displaying an intertidal bar and beach cusps.

Small sections of a shingle storm beach are exposed along the central section of the frontage, just to the north of where the fossil cliff bends back inland. The beach is backed by a frontal dune ridge that extends along the entire frontage but is highest to the north of the outlet of the Lunan Water. To the north of the Lunan Water, a links area which is up to approximately 200m wide occurs landward of the frontal dunes. The entire frontage is backed by fossil till cliffs and at least two distinct raised beach areas.


Lunan Bay, 2012 (source: Halcrow)


Lunan Water, 2012 (source: Halcrow)


Lunan Bay and Lunan Water, 2012 (source: Halcrow)


Corbie Knowe, 2012 (source: Halcrow)


Ethie Haven, 2012 (source: Halcrow)


Corbie Knowe and Ethie Haven, 2004 (source: Angus Council)

C2.4.3 Shoreline dynamics and behaviour

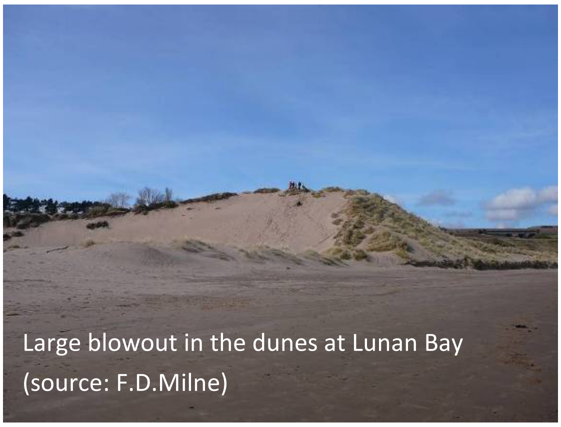
Interactions

As within Montrose Bay, there is little fresh sediment input to the beach system within Lunan Bay, with the only significant source being the reworking of hinterland sand deposits during periods of dune erosion.The cliffs to the north and south result in little sediment being transported alongshore into the bay from either erosion of the cliffs or from further afield. Glacial tills and fluvioglacial deposits are found over much of the Lunan Valley but little of these are being reworked at present by the Lunan Water to provide fresh beach sediments. Offshore sources presently provide little fresh material. Despite the material from the dredging operations at Montrose being deposited off Lunan Bay, it is likely that it is deposited too far offshore to be subsequently transported on to the beaches within Lunan Bay.

Within Lunan Bay, the beach appears to be in a state of dynamic equilibrium with little net longshore transport occurring along the beach. The position of the outlet of the Lunan Water does indicate a historically southward net longshore transport drift direction. In a similar manner to that at Montrose, this would appear to have been the case over much of the early to mid part of the 20th Century but the net drift rate appears to be relatively low. However, over the last 20 to 30 years, erosion has become a problem along the southern section, suggesting a period of net northward longshore transport over this time.

The beach displays a healthy seasonal onshore / offshore movement of beach material with winter storms tending to draw beach levels down and move sand temporarily offshore. The sand is then moved back onshore, raising beach levels during generally less stormy summer months. Periods of erosion of the upper beach and frontal dunes are likely to be linked to storm activity and may only affect certain sections of the frontage. The dunes around and to either side of the mouth of the Lunan Water are more dynamic than other sections of the frontage. A large blowout occurs through the dune line to the north of the Lunan Water; however, it is likely that anthropogenic activities have been the main cause of this blowout formation.

The variability of frontal dune erosion that can be experienced along the frontage is linked to localised beach changes caused by complex sediment movements. Sediment circulations due to the flows from the Lunan Water and strong wave induced rip currents that can occur in the nearshore zone, together with morphological features that occur on the beach (i.e. nearshore bars and beach cusps,) all influence and impact on the patterns of sediment movement. They also influence erosion - accretion patterns experienced along the frontage.


Large blowout in the dunes at Lunan Bay (source: F.D.Milne)


Frontal dune erosion, Lunan Bay, 2012 (source: Halcrow)

Movement

Shoreline change analysed in SMP 1 (Angus Council, 2004) shows a general seaward movement of the MHWS line between 1865 and 1903 but otherwise the MHWS position has been relatively stable with a low landward retreat of less than 10m over the last 100 years, albeit this rate appears slightly higher at the southern end. The minor movements of the outlet of the Lunan Water demonstrates that longshore transport within Lunan Bay is in long term equilibrium with minor fluctuations in position but no long term directional trend evident.

C2.4.4 Modification

Lunan Bay remains predominantly natural with no significant human modifications implemented in the coastal system. Boardwalks have however been recently installed to help address dune erosion issues caused by pedestrian trampling near Lunan Water and ad hoc defences are evident at Corbie Knowe.

Pedestrian walkway, Lunan Bay, 2012 (source: Halcrow)

Corbie Knowe defences, 2012 (source: Halcrow)

C2.5 CPU 5 - Lang Craig to Whiting Ness

C2.5.1 Location Map

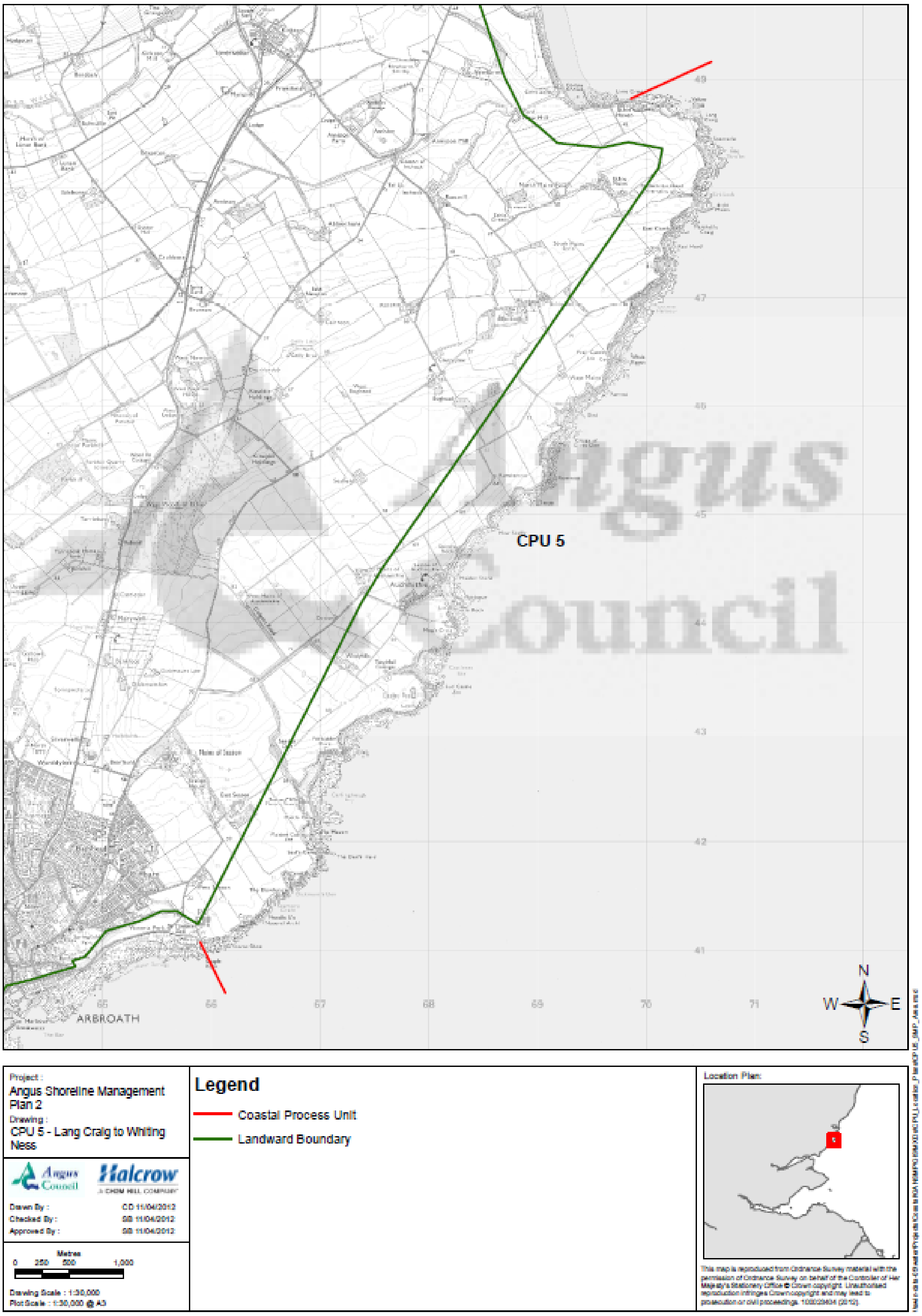


Figure C2.5 CPU 5 Lang Craig to Whiting Ness

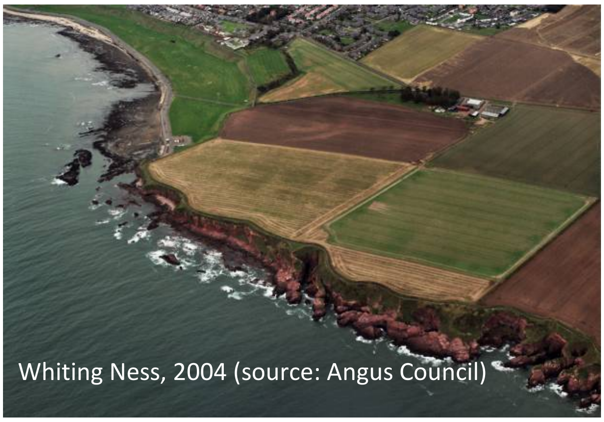
C2.5.2 Coastal Morphology

The coastline from Lang Craig to Whiting Ness is characterised by coastal cliffs with only some small shingle beach areas. The cliffs at the northern end of the frontage as far south as Red Head are composed of basaltic lavas and are of a rugged nature due to faulting and erosion of softer lavas and conglomerates.


Lang Craig, 2004 (source: Angus Council)


Auchmithie, 2012 (source: Halcrow)


Seaton Cliffs, 2012 (source, Halcrow)


Whiting Ness, 2004 (source: Angus Council)

To the south of Red Head, conglomerates and sandstones form the high and irregular coastal cliffs. There is a wide range of cliff morphological features evident including caves, blow holes, stacks and geos formed due to faulting and weaknesses within the rocks. The occurrence of the rock platform fronting the cliffs is variable along the frontage, being most notable at Auchmithie and the bays further south.

There are a number of small bay beaches notably at Auchmithie, Castlesea and Carlingheugh Bay. All are narrow and located on the rock platform and are dominated by shingle derived from the surrounding conglomerate or sandstone cliffs.

C2.5.3 Shoreline dynamics and behaviour

Interactions

Due to the nature of the coastline there are no littoral processes of significance to the long-term evolution of the coastline or beach areas in adjacent coastal units. Wave action will dominate and continue the slow erosion of the cliffs. Waves are also the dominant process forming the shingle beaches in a number of the bays. Given the shelter provided by the cliffs flanking these beach areas and the protection provided by the rock platform there is unlikely to be any significant change in beach processes or physical shape and form.

Movement

The cliffs display a wide range of erosional features but the rate of change is very low. No map analysis was conducted of the changes in MHWS and MLWS in this process unit in SMP 1.

C2.5.4 Modifications

Auchmithie was once a thriving fishing harbour, prior to its abandonment during the 1800's. Today all that remains are the remnants of the dilapidated harbour.

The Scottish Wildlife Trust Nature Reserve at Seaton Cliffs includes a coastal path which recently has been subject to rock falls in places, and landslips, primarily caused by drainage and fluvial processes rather than coastal processes.

Seaton Cliffs , cliff fall, 2012 (source: Halcrow)

Auchmithie harbour remains, 2012 (source: Halcrow)

C2.6 CPU 6 Whiting Ness to West Haven

C2.6.1 Location Map

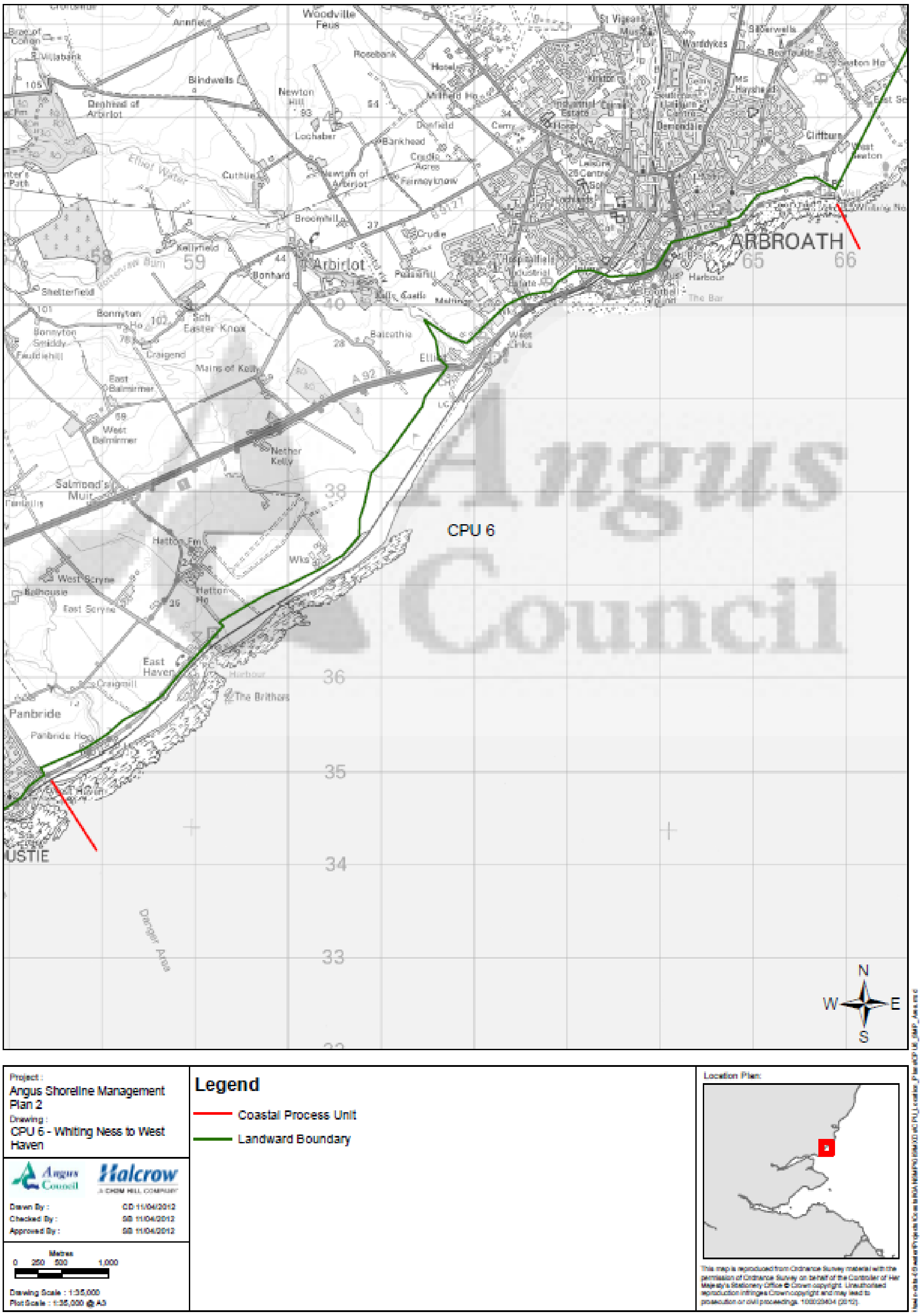


Figure C2.6 CPU 6 Whiting Ness to West Haven

C2.6.2 Coastal Morphology

The coastline to the south of Whiting Ness changes with the fossil cliff line becoming much lower in elevation and occurring well landward of the present day coast. The rock platform is present along parts of the coast from Whiting Ness to Inchcape Park and from Corse Hill to around Carnoustie Station, broken only over short stretches at East and West Haven. To the north of Arbroath Harbour, there is little beach, with the exception of some thin shingle deposits against the wall protecting Victoria Park and along the Seagate frontage. Victoria Park is situated on the most recent (8m) raised beach surface.


Whiting Ness, 2012 (source: Halcrow)


Victoria Park, Arbroath, 2004 (source: Angus Council)


Arbroath Harbour, 2004 (source: Angus Council)


Elliot Links, 2012 (source: Halcrow)


East Haven, 2012 (source: Halcrow)


North of West Haven, 2004 (source: Angus Council)

Backing Victoria Park are degraded cliffs, the crest of which is around the 30m raised beach surface (Wright 1981).

To the south of Inchcape Park, the rock platform disappears for around 4km and a wide sandy beach occurs. At the northern end the beach is low, but towards the end of the defences, a shingle storm beach backs the intertidal sand beach. A wide links area, corresponding to the surface of the 8m raised beach, extends along the entire frontage. Around Corse Hill, the rock platform re-emerges and extends to West Haven. A thin sand beach with patches of shingle rests on the platform with a thin, low dune line generally backing the beach. At both East and West Haven, the rock platform is absent, forming the natural harbour at both locations. A wide sand beach fronts both sections with a low dune belt backing the beach at East Haven but only a very narrow and low dune ridge at West Haven.

C2.6.3 Shoreline dynamics and behaviour

Interactions

As with most other locations along the Angus coast, there is little fresh input of sediment into the system. At the northern end, the construction of coastal defences has cut off any potential for reworking hinterland deposits within the links through erosion. Indeed, due to the shingle storm beach that fronts much of the northern section to around Corse Hill, where the rock platform re-emerges, the reworking of hinterland deposits is minimal. Net longshore transport tends to be to the south at present but this appears to be relatively finely balanced over the lower sand beach, with the shingle beach highly dependent on storm directions particularly around the mouth of the Elliot Water. The development of the shingle spits that deflect the Elliot Water to the south is an episodic process in response to particular sequences of storm conditions.


Shingle storm beach, Elliot Links, 2012 (source: Halcrow)


Rock platform, between East Haven and West Haven, 2012 (source: Halcrow)

Between Corse Hill and West Haven, the intertidal rock platform provides a great deal of protection to the sand beach that rests on it through energy dissipation, breaking and refraction effects. Longshore transport will tend to be episodic, being limited to periods of higher wave conditions occurring on high tides. The effect of the rock platform on the wave conditions and hence beach planshape response is highly dependent on long-term water level trends. Even very small differences in the elevation of the rock platform can have a noticeable impact on the beach planshape and the patterns of erosion and accretion experienced along the frontage. The harbours at both East and West Haven act as pockets catching sediment being transported to the south along the coastline. Whether the accretion is due to a period of increased southward net longshore transport over the latter part of the 19th and first half of the 20th Century is uncertain. However, given the changes at the mouth of the Elliot Water, the patterns of accretion and erosion within Montrose and at Carnoustie (see CPU 7) it would certainly appear to suggest that an increase in the dominance of wave conditions from the north easterly quadrant did occur over this period. Subsequently any increase in the occurrence of wave conditions from the south easterly quadrant (as was suggested as being the dominant cause of the recent erosion at Montrose) would tend to impact on the locations where previously accretion had been greatest, i.e. recent erosion would be most noticeable at East and West Haven.

A further issue may be due to any slight increase in mean water levels, resulting in greater wave energy reaching the beach and leading to a greater rate of longshore transport of sand along the sections fronted by the rock platform. In effect this would "smooth out" or reduce lateral variations in beach planshape that have occurred due to the variations in the elevation of the rock platform along the coast. However, whether this is a factor responsible for the patterns of accretion evident at East and West Haven in the past is debatable but it could be an issue with rising sea levels in the future. Finally, as East and West Haven were the locations with easiest access to the beach, the accretion may be attributable to other causes, such as sand extraction for construction during the 19th Century, which subsequently has ceased allowing the coastline to recover over the period covered by the OS Maps.

Sand being transported along the frontage, particularly the section where the beach lies on top of the rock platform, may be swept offshore by tidal currents and into the general tidal circulation system of Carnoustie / St Andrews Bay.

Movement

The rate of coastal change along much of this frontage is not nearly as dynamic as along other soft sedimentary sections of the Angus coastline, most likely due to the occurrence of the shingle and cobble storm beach. However, the mouth of the Elliot Water does demonstrate substantial variation in position. During the latter part of the 19th Century and early 20th Century, the mouth of the Elliot was in a similar position as it is today. However, by 1923, the mouth had been deflected by around 240m to the south by a southward growing shingle spit. It had obviously been deflected further but a breach appeared to have occurred approximately two thirds of the way along the spit. By the early 1960s the spit had deflected the mouth by up to 375m. However, a breach had occurred at the proximal end by the end of the 1960s with the mouth being deflected slightly northwards. Caledonian Geotech (1987) indicate that further shingle spit development to the south and subsequent breaching occurred prior to their study in the mid 1980's. However, stabilisation work involving gabions along the northern flank of the mouth of the Elliot Water appears to have increased the stability of the river mouth.

From Elliot to East Haven, the pattern has been of general retreat, although this varies both linearly and temporally along the frontage. There appears to have been a general pattern of erosion during the late 19th and early 20th centuries, followed by a period of accretion to around the 1960s whereupon erosion appears to have dominated to the present day.

Since 1865, the maximum landward movement of the High Water Mark is around 30m. However, due to periods of accretion, there has been a maximum retreat of around 26m since the 1960s. This retreat is most critical where the railway line is located close to the coast at Hatton.

At East Haven considerable accretion has occurred within the bay since the first edition OS Map, which suggests that the MHWS line was up to 50m further landward than it is today. This pattern of accretion appears to have continued until around the 1970s. Subsequently, the position of the MHWS line has retreated by around 8m. To the south of East Haven as far as West Haven, there has been a similar pattern of accretion up until the early 1960s followed by a period of retreat to the present day.

C2.6.4 Modification

Human modifications in the CPU are predominantly found along the Arbroath frontage including concrete and masonry seawalls, rock armour and the harbour. However, a small section of rock armour and evidence of tank traps are also present around the outfall at Elliot.


Victoria Park defences, 2013 (source: Halcrow)


Inchcape Park defences, 2012 (source: Halcrow)


Tank traps Elliot Links, 2012 (source: Halcrow)


Outfall defences Elliot, 2012 (source: Halcrow)

C2.7 CPU 7 West Haven to Buddon Ness

C2.7.1 Location Map

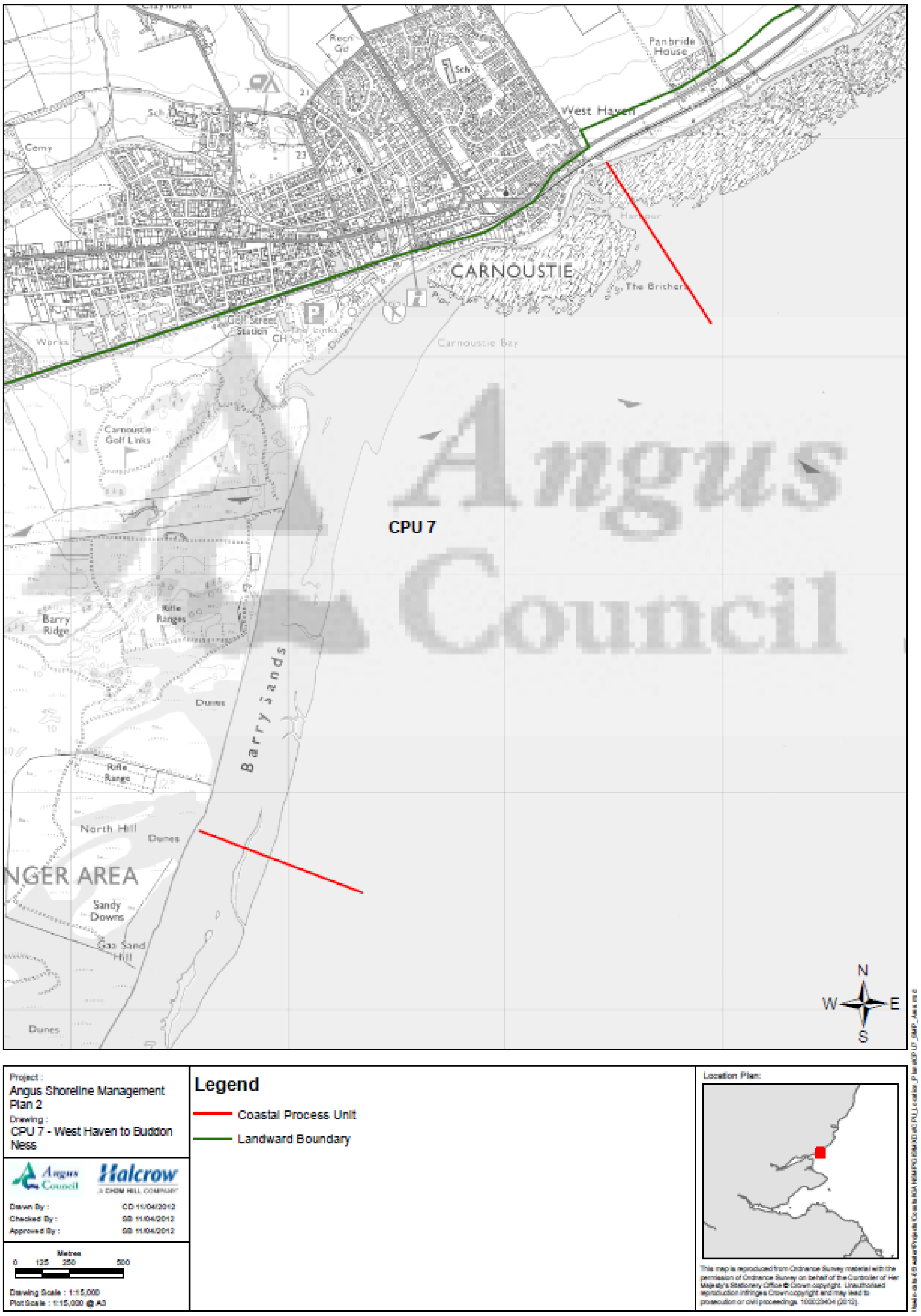


Figure C2.7 CPU 7 West Haven to Buddon Ness

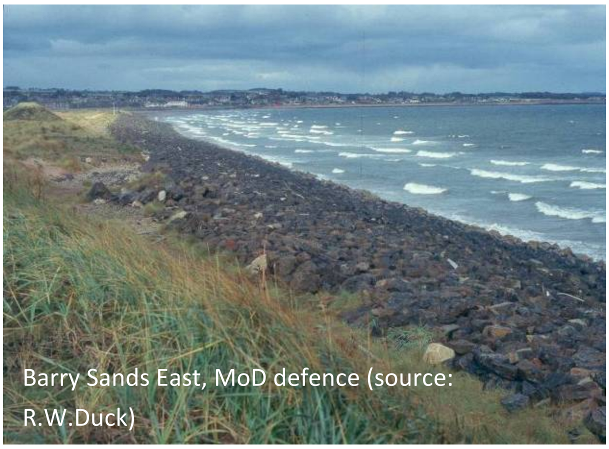
C3.7.2 Coastal Morphology

Coastal Process Unit 7 extends from where the intertidal rock platform disappears at West Haven to Buddon Ness.


West Haven, 2012 (source: Halcrow)


Carnoustie, 2012 (source: Halcrow)


Barry Burn, 2012 (source: Halcrow)


Barry Sands East, MoD defence (source: R.W.Duck)


Erosion at the end of MoD Defence, Barry Sands East, 2012 (source: Halcrow)

The outlet of the Barry Burn separates the two main beach units within Carnoustie Bay. The first is along the Carnoustie frontage, and the second along the eastern flank of Barry Links, known as Barry Sands East. Both beaches are predominantly sandy with a wide intertidal zone featuring a range of intertidal morphological features, such as bars and spits evident particularly along the Barry Sands East frontage. Much change has taken place here since the installation of a rock armour revetment by the MoD.

The coastal edge at Carnoustie is now completely protected by coastal defences. Backing this, the links area has been landscaped for recreational open space. A rock revetment also protects much of the dune line at Barry Sands East. There is a wide range of important dune and links morphological features, particularly the parabolic dune ridges that occur on Barry Buddon (Hansom, 2003) which is one of the reasons that the Ness is designated as a SSSI.

At the southern tip of Buddon Ness, Gaa Sands, a linear sand bar formed by ebb tidal currents from the Tay estuary, extends to the east.

C2.7.3 Large Scale shoreline dynamics and behaviour

Interactions

The mechanisms that move sand along the beach and within the bay and the subsequent patterns of erosion and accretion are a complex interaction of wave and tidal processes that are as yet poorly understood.

HR Wallingford (1999) provided a summary of the present understanding of littoral processes acting within Carnoustie Bay. The beach evolution at Carnoustie cannot be explained solely by variations in longshore transport caused by wave action. The longshore transport along the eastern flank of Barry Buddon is to the south, as can be seen by the continued erosion at the southern end of the rock revetment and the various intertidal spits and bars along the frontage. However, the tendency of a spit to form south of the mouth of the Barry Burn deflecting it northwards, and the pattern of erosion along the Carnoustie frontage would suggest a north easterly drift. This would suggest that there is, or has been, an area of drift divide (i.e. where sediment is moved in both directions along the coast away from a particular area) somewhere along the northern section of the rock revetment protecting the flank of Barry Links. This can be seen to some extent in the wave refraction diagrams presented by Ferentinos and McManus (1981), particularly for longer period swell wave conditions from the south-east.

Any increase in south easterly wave conditions, such as have possibly occurred since the end of the 1970s, and postulated as being a primary factor in the erosion experienced at Montrose and other locations along the Angus coastline over this period, could increase the impact of the drift divide. This could possibly explain the rapid onset of erosion along this section of the Barry Links during this period.

Whilst an increase in south easterly conditions may be one factor in the patterns of erosion within Carnoustie Bay, the influence of Gaa Spit is also of vital importance. Even very slight changes in the shape or location of this spit complex will have a considerable influence on the way waves from the south easterly quadrant refract in to Carnoustie Bay and hence both the temporal and spatial patterns and rates of erosion and accretion experienced along the coast. However, this does not provide the full picture of the littoral processes acting within Carnoustie Bay.

Given, that the wave induced drift along the Carnoustie frontage would appear to be to the north east, this would suggest that the area around West Haven should be accumulating sand (given that the drift to the north east of West Haven is to the south west). As this is not occurring to any great extent it would suggest that within Carnoustie Bay, tidal currents also play an important role in the movements of sediments within the bay and along the coastline. The ebb tide out of the Tay Estuary causes an anti-clockwise gyre or eddy in the area north of the Gaa Spit. This produces a southward running flow along the south east coast of Barry Links, in the same direction as the flows during the flood tide, i.e. there is a near continuous southward tidal flow in Carnoustie Bay. This net tidal flow will add to the tendency for a longshore transport of sand to the south, mainly over the nearshore seabed. Consideration of the tidal flows deduced from tidal flow modelling within St Andrews and Carnoustie Bay also suggests that there is an area of lower tidal flows to the north of the gyre. This would suggest that where tidal currents were lowest, accretion would occur over the seabed, which would then be moved onshore by constructive wave conditions.

In a previous HR Wallingford report (1989) concerning the erosion along the Barry Links frontage, two bathymetric surveys, dated 1969 and 1988, were compared. It was found that the seabed had lowered by about 1m over much of Carnoustie Bay. It was suggested that this lowering of the nearshore seabed was likely to be a contributing cause, rather than a consequence of the erosion along the Carnoustie frontage. The changes in seabed are more likely to have been caused by tidal currents than wave conditions, possibly induced by the changing orientation of the Tay Estuary channel and changes to Gaa Spit. Such lowering of the seabed may also have had considerable effect on both the size and way the waves approach the shoreline.

At Carnoustie, the patterns and rate of erosion and accretion are intrinsically linked to the movements of the Tay Estuary channel and the form of Gaa Spit, and the effects that these changes have on tidal flow and wave conditions. The process is one of a continuous feedback loop, with the changes in tidal flows and wave conditions themselves, promoting alterations in the position of the Tay Estuary channel and Gaa Sands. How these processes act and interact with each other is extremely complex and at present poorly understood. Furthermore, the impact of the rock revetment along the MoD frontage on morphological processes within Carnoustie Bay is also poorly understood. It is also possible that there is a loss of sand from the Carnoustie Bay frontage across the Tay Estuary to Tentsmuir and Abertay Sands, but again this process is not well understood or indeed proven. This makes attempting to predict what will happen in the future even more difficult. However, it is probably fair to say that the current problems are likely to continue for the foreseeable future.

Movement

At Carnoustie, much of the land to the seaward side of the railway line has accumulated since the first edition OS map around 1865. The dune ridges, and intervening “slacks” that formed naturally at Carnoustie over this period have subsequently been levelled forming the flat land used for recreational purposes (HR Wallingford, 1993). The southern flank of the outlet of the Barry Burn has also shown considerable accretion over this time.

The problems of erosion at Carnoustie started in the late 1970s, at a similar time as erosion started to become an issue at Montrose, Monifieth and to a lesser extent Lunan Bay and the coastline between Arbroath and Carnoustie. In response, a number of coastal defence measures were installed, both along the Carnoustie frontage and at Barry Sands East. A summary of these defence measures is provided by HR Wallingford (1999). This study also assessed more recent changes in the beach profiles over the period 1989 to 1997 along the Carnoustie frontage, which showed a continuous trend of falling beach levels over this time.

Along the northern section of Barry Sands East considerable accretion occurred up until the late 1970s, followed by considerable erosion, with the MHWS line moving by up to 90m landwards. However, towards the southern end there has been a general pattern of erosion since the first edition OS Map, with the MHWS line moving landward by up to 240m. Indeed, the MLWS line is now around the position of the MHWS mark on the 1st edition OS Map. The erosion at the southern end over this period appears to be linked to the considerable accretion that has occurred at Gaa Sands and also the patterns of accretion evident on the western flank of Barry Links. An assessment of the changes occurring at Barry Buddon and Gaa Sands and the changes that have occurred in the orientation of the main outer channel of the Tay Estuary is provided by Ferentinos and McManus (1981). Figures C2.8 and C2.9 from this study show the temporal movements of the channel, which has shown a long-term swing to the north east.

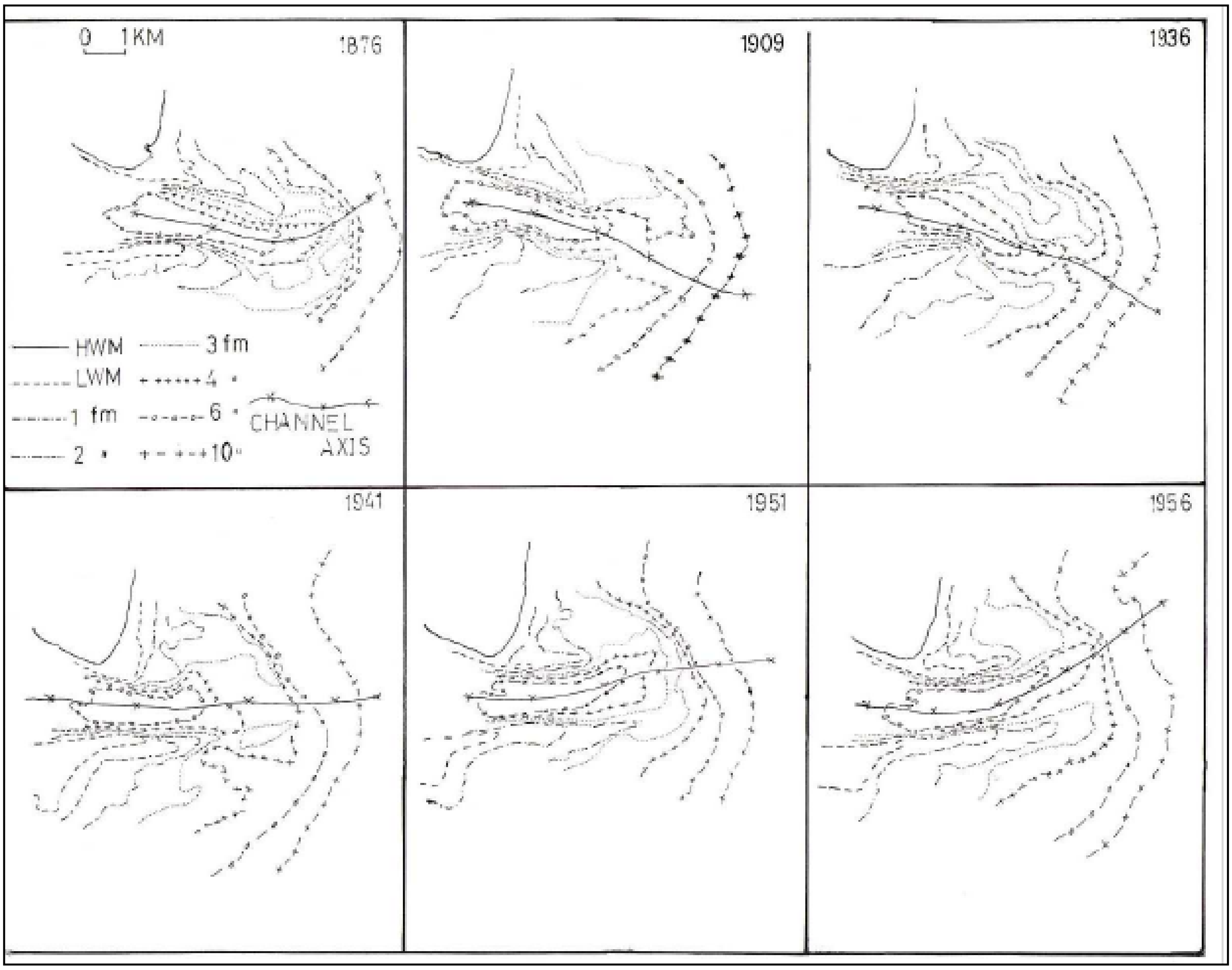


Figure C2.8 Sequence of change of channel arcuation and depth across the terminal lobe of the Tay Estuary sand bar (Ferentinos and McManus, 1981)

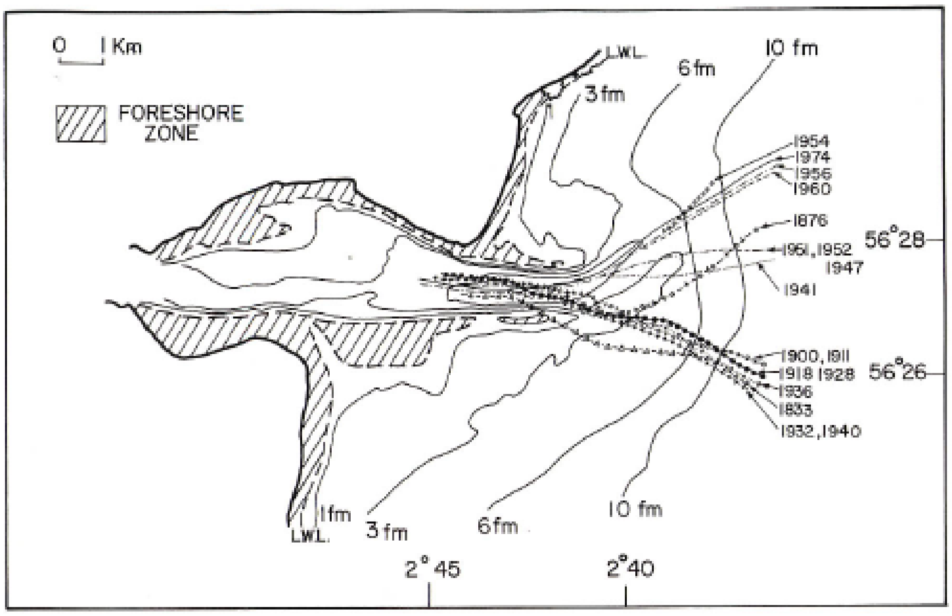
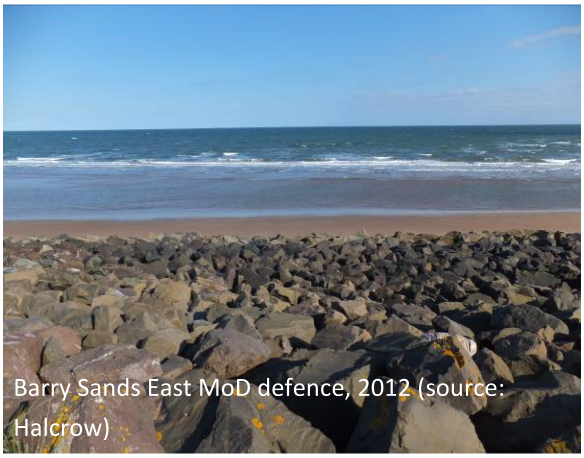


Figure C2.9 Long term variations in the orientation of the axis of the outer channel of the Tay Estuary (Ferentinos and McManus, 1981)

C2.7.4 Modification

The whole frontage from the leisure centre to the Barry Burn is protected by a rock armour revetment. Most of the eastern shore of the Barry Links is also protected by a rock armour revetment extending for approximately 2.6 km from the mouth of the Barry Burn to within 1km of Buddon Ness.


Barry Burn, 2012 (source: Halcrow)


Barry Sands East MoD defence, 2012 (source: Halcrow)

C2.8 CPU 8 Buddon Ness to Broughty Castle, Broughty Ferry, Dundee

C2.8.1 Location Map

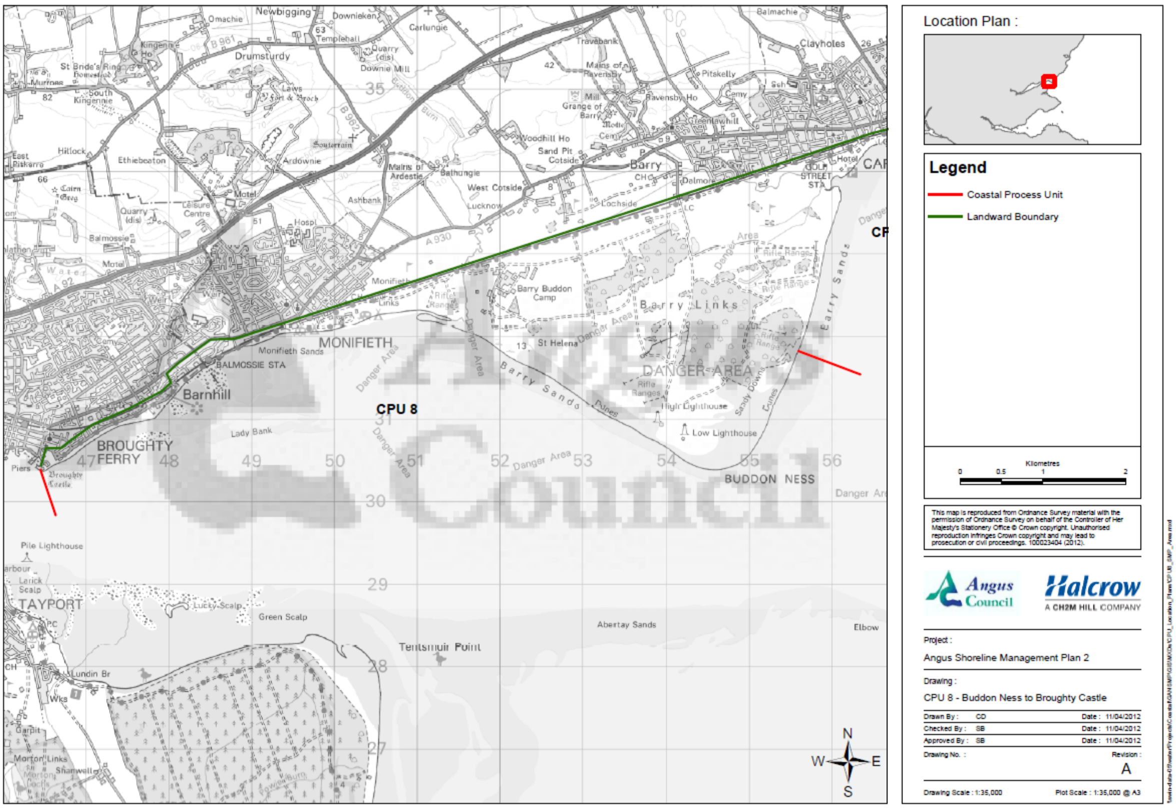


Figure C2.10 CPU 8 Buddon Ness to Broughty Castle

C2.8.2 Coastal Morphology

From Buddon Ness to Broughty Ferry, the coastline forms the northern flank of the outer Tay Estuary and as such, estuarial processes have a greater impact. It is also the only section of the Angus coast, excluding Montrose Basin, which is not influenced by wave conditions from the north easterly quadrant.

At the southern tip of Buddon Ness, Gaa Sands, a linear sand bar formed by ebb tidal currents from the Tay estuary, extends to the east.

The intertidal beach along the western flank of Barry Links tends to be narrower and steeper than occurs along the eastern flank, primarily due to the lack of influence of longer period swell wave conditions affecting this coastline. Around the tip of Buddon Ness, and along sections of the western flank, young embryo dunes are presently forming, intersected by short stretches of older eroding dune face. The older dune belt, which backs the beach, is wider and backed by similar undulating links and fossil dune ridges.

At the north western end of Buddon Links, a long spit deflects the Buddon Burn to the north-west. The tip of the spit is presently located at approximately the boundary of the MoD land.

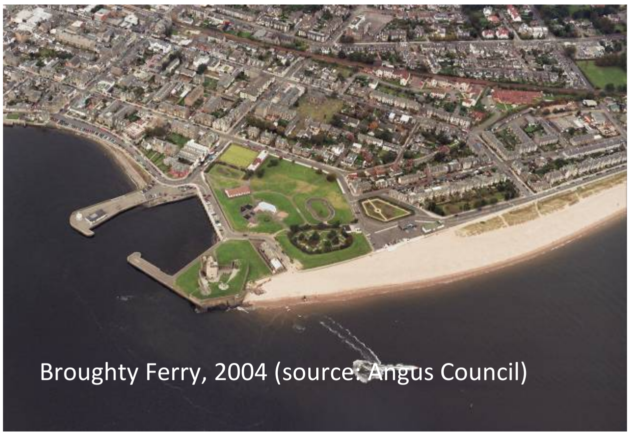
Prior to the 1980s, the Monifieth frontage had a healthy sandy beach and dunes. However, severe erosion has resulted in a significant loss of beach, with much of the frontage now protected by a rock revetment, with no dry beach at high tide. The intertidal zone is wide and gently sloping at Monifieth, but reduces in width towards the Dighty Burn. To the west of the Tayview Caravan Park, a sand beach once controlled by groynes and backed by a wide dune zone and fossil marine terrace, has now been depleted, exposing the rock platform along this frontage. Contemporary dune erosion has led to the installation of a new timber revetment, joining up the defences in the east to those at Dighty Water in the west.


Buddon Ness and Monifieth, 2012 (source: Halcrow).


Monifieth timber revetment, 2012 (source: Halcrow)


Buddon Ness, 2012 (source: Halcrow)


Monifieth Playing fields, 2012 (source: Halcrow)


Broughty Ferry, 2004 (source: Angus Council)

At the mouth of the Dighty Water and along adjacent sections, the beach is low and is an unattractive mixture of silt, sand, shingle, and with the backshore largely protected. To the west of the Dighty Water, the links area increases in width and the sand beach and dune ridge become wider, with a healthy sand beach and line of frontal dunes towards Broughty Ferry. The lower section of the beach at Barnhill is wide; comprising an ebb dominated sand bank known as Lady Bank. Towards Broughty Ferry, the width of the intertidal beach narrows.


Dighty Water, 2012 (source: Halcrow)


Broughty Ferry, 2012 (source: Halcrow)

C2.8.3 Large Scale shoreline dynamics and behaviour

Interactions

As within Carnoustie Bay, the mechanisms that move sand along the beach and within the bay and the subsequent patterns of erosion and accretion are a complex interaction of wave and tidal processes that are as yet poorly understood.

Longshore transport is dominated by wave action entering the Tay Estuary from the North Sea with sediment tending to be moved to the north-west along the western flank of Barry Links and to the west from Monifieth to Broughty Ferry. However, the patterns of erosion and accretion along the frontage suggest a more complex situation. At Monifieth, it is thought the severe erosion that has occurred there over the last 20 to 30 years is linked to the deepening of a nearshore channel that runs parallel to the coastline along the western flank of the Buddon Peninsula. Under storms from the south-east sector, where waves are refracted directly into the estuary, and up the channel, the deepening of this channel allows larger wave conditions to reach the Monifieth coast. Erosion was also known to have occurred due to wake waves from oil supply vessel movements into and out of the Tay Estuary. However, such vessels now slow down at the Tay Bar. It has been postulated that erosion may also be linked to the cut off of sediment due to the construction of the MoD defences along the eastern flank of Buddon Ness.

Whether the apparent increase that appears to have occurred in the amount of wave conditions from the south-easterly sector, is directly the cause of the erosion, or whether this increase has also been a factor in the deepening of the channel, is uncertain.

The patterns of erosion and accretion are also linked to the movements of the sand banks at the mouth of the Tay, and over the lower foreshore within Monifieth Bay. These banks affect the way waves refract[1] and 'bend' into the frontage. (Slight changes in the position, elevation or shape of these outer sand banks can have a considerable impact on changes in the way waves approach the shoreline, resulting in a variable net longshore transport along the frontage and the patterns of erosion and accretion evident. Due to the sensitivity of the coastline to changes in the configuration of the sand banks at the mouth of the Tay Estuary, it is difficult to identify any clear erosion / accretion trend. Any changes in the erosion and accretion patterns within Monifieth Bay are likely to be at the mercy of the evolution and changes that occur to these outer sand bars.

Tidal currents also have a considerable impact on sediment movements, particularly over the lower intertidal beach. The incoming tide tends to run along the north side of the Tay Estuary and the outgoing tide along the southern flank, which may lead to a gradual indirect transfer of sediment from north to south coasts, from within Monifieth Bay to Abertay Sands. Tidal currents acting around the headland at Broughty Castle will recycle beach sediments back along the lower intertidal beach onto Lady Bank.

Some of this sediment will be moved back on to the beaches by wave action but some will also be lost from the frontage due to the complex residual current patterns within the Tay Estuary. Flood tides will also transport beach sediment from the Broughty frontage, further up into the middle reaches of the Tay Estuary, where it is unlikely to be returned to the beaches within Monifieth Bay.

Movement

Mitchell (1997) quotes a number of interesting points regarding movements of the Buddon Ness in the 17th, 18th and 19th centuries, including:

- The first lighthouses, which were built in 1687, were constructed of wood and regularly moved on rollers due to the movements of the outer channel.
- The existing High and Low Lighthouses were constructed in 1865 but had to be moved by over 160 ft in 1871 due to movement of the channel.
- In the late 18th Century, measurements of erosion and accretion suggested that up to 56 acres of erosion and 46 acres of accretion had occurred over a short period of time.

At Buddon Ness and along the southern section of the western flank, the dynamic nature of the coastline is evident with large temporal and lateral movements in the position of the MHWS line between 1865 and 2004. At the southern end there would seem to have been considerable erosion over the first half of the 20th Century followed by accretion to the present day.

However, along the middle section of the eastern flank the patterns of erosion and accretion are more variable. At the mouth of the Buddon Burn, the development of the extension of the spit particularly over the last 50 years and which now deflects the Buddon Burn some 600m or so to the north-west is clearly evident.

Assessment of shoreline change in SMP1 (Angus Council, 2004) suggested a trend for erosion to the east of Monifieth, with the MHWS line retreating by up to around 160m over the last 100 years. However at present, the coast along the Riverview Caravan Park and playing fields frontage is experiencing accretion, where new

[1] *Refraction is the bending of waves because of varying water depths underneath. The part of a wave in shallow water moves slower than the part of a wave in deeper water. So when the depth under a wave crest varies along the crest, the wave bends.*

dune ridges have developed seaward of the defences which are now almost buried by sand. At Monifieth, the landward retreat of the MHWS line over the last 30 years has been around 45m.

Conversely, between Tayview Caravan Park and Milton Mill the coastline experienced accretion, with the MHWS line moving seaward by up to 45m over the last 100 years, but now erosion is evident along this frontage.

At Barnhill, the coastline is more stable despite land having been reclaimed for the creation of the recreational playing fields, with there being a general pattern of accretion and shoreline propagation over the last 30 or so years.

C2.8.4 Modification

Much of the frontage at Monifieth, from the football pitches to the western end of the Tayview Caravan Park, has been reclaimed.

The shoreline has seen an ad hoc installation of traditional hard engineering defences in response to coastal erosion. These comprise timber groynes, timber revetments, rock armour revetments and concrete and masonry seawalls. A new rock armour revetment was installed along part of Broughty Ferry beach in 2011 by Dundee City Council.

Rock armour revetment at Broughty Ferry (source: R.W.Duck)

New timber revetment at Monifieth, 2012 (source: Halcrow)

C3 Baseline Scenario Assessment Considerations

C3.1 Introduction

In line with SMP2 guidance (Defra, 2006a), two baseline scenarios have been appraised: 'no active intervention' (NAI) and 'with present policies' (WPP):

- **No Active Intervention (NAI)** - In line with the 2006 Defra Guidance, the likely evolution of the shoreline has been appraised under a NAI scenario, which assumes there is no further expenditure on maintaining/ improving defences and that therefore defences will fail at a time dependent upon both their residual life and other factors such as beach condition, exposure conditions etc. This draws upon information contained within the Existing Defence Report (Section C3.4).
- **With Present Policies (WPP)** – Similar to the SMP guidance 'With Present Management' scenario, the likely evolution of the shoreline has been appraised under a WPP scenario, which assumes that policies recommended for the next 50 years in the Angus SMP1 (Angus Council, 2004)continue over the SMP2 timeframe of 100 years.

The NAI and WPP scenarios were developed in line with Defra guidance (Defra, 2006a) and it is important to note that that these assessments were NOT intended to be realistic scenarios for managing the coast. They were developed as contrasting examples to form the basis of later policy appraisal and the WPP does not consider affordability or other constraints. The subsequent policy development will take account of agreed objectives and social, environmental and economic assessments.

In line with Defra SMP2 guidance for England and Wales, the response of the coast has been considered for three time periods: 0 to 20, 20 to 50 and 50 to 100 years. For each period, the tables clearly state the assumptions made regarding the state of defences at those times. In some locations the structures discussed are multi-functional and may not have a primary purpose as coastal defence structures, for example in harbours; our assumptions regarding these are therefore clearly stated, even though they may not be governed by coastal defence legislation.

Although the response of the coast is discussed at a local scale, the approach to determining impact and response has been iterative, through considering possible interactions with adjacent stretches of coast and subsequent large-scale response of the coast.

Each CPU baseline statement considers the following:

- What will the shoreline look like?
- Where will the shoreline be?
- What are the potential impacts of this scenario on sediment supply or control on wider evolution (i.e. downdrift effects/impact on the adjacent shoreline)?
- Why is the coast responding in this way (i.e. how has the management scenario affected the coastal behaviour)?

Although only broad estimates of future shoreline change can be made, particularly given the uncertainty with regard to coastal response to accelerated sea level rise, the intention of this appraisal is to identify the trends of change, consider areas where pressures might develop and determine the sensitivity of the various coastal systems to future change in such parameters as sea level rise, precipitation and offshore bathymetry.

No Active Intervention maps to support the baseline assessments, showing flood and erosion risks along the SMP2 frontage in years 20, 50 and 100, are included in **Annex C1.**

C3.2 Consideration of Future Climate Change

The global climate is constantly changing, but it is generally recognised that we are entering a period of man-made change. The anticipated implications of climate change, and in particular sea level rise, present a significant challenge to future coastal management. Over the last few decades there have been numerous studies into the potential impact of future changes. However, there remains considerable uncertainty in future climate modelling science and future global development patterns.

The UK Climate Impacts Programme (UKCIP) was established in 1997 to co-ordinate scientific research into the impacts of climate change. The Scottish Government is responsible for Climate Change policy in Scotland and therefore part funds the work of UKCIP and is represented on the UKCP09 Steering Group and User Group.

UKCIP publishes (on behalf of the Government) predictions of how the UK climate may change this century for a range of scenarios. UKCP09, the most recent predictions, were released in June 2009. This is the fifth generation of climate information for the UK, and provides probabilistic projections of climate change. UKCP09 comprises a package of information including publications, key findings, user support and customisable output: this is primarily available on-line at: http://ukclimateprojections.defra.gov.uk/

Although the text below provides a summary of latest climate change projections relevant to shoreline management along the SMP frontage, it is recommended that the website is consulted for more detailed information and guidance on how the projections data should be used.

C3.2.1 Storminess and storm surge

Along much of this shoreline, a key risk will be future changes in tidal surges, winds and storms. The combination of high tides and strong winds, increasing wave height and tidal surges (see Section 1.3.3), is a significant threat in terms of future coastal erosion and flooding.

Wind climate is a particularly important variable in the evolution of sand dune systems. As well as affecting frontal dunes, wind speed and direction also affects the stability of the system, affecting dune migration rates and the effect of wind stress on vegetation cover (Pye and Saye, 2005). UKCP09 has not, however, provided probabilistic projections for future changes in wind speed or direction.

A report by UKCIP (2009) (available from the UKCP09 website), which reviewed historical trends, stated that whilst severe wind storms around the UK have increased in recent decades, they are not above those observed in the 1920s. This report concluded that although there is considerable interest in possible trends in severe wind storms around the UK, these are difficult to identify due to low numbers of such storms, their decadal variability, and by the unreliability and lack of representation of direct wind speed observations. The report also stated that there continues to be little evidence that the recent increase in storminess over the UK is related to man-made climate change.

Projections do not currently exist for future storminess at a Scottish level, however the UKCP09 do provide projections for future storm surges around the UK. Changes in storm surge levels for return periods of 2, 10, 20 and 50 years (the level predicted to be exceeded on average once during the return period) were examined. The trends found were physically small everywhere around the UK, with projections suggesting that the surge level expected to be exceeded on average once every 2, 10, 20 or 50 years would not increase by more than 9cm by 2100 anywhere around the UK coast (not including mean sea level rise). More recently, advice published by the Environment Agency (2011b) for England and Wales recommends consideration of low probability, high impact scenario (H++ scenario) upper end surge allowances of 20cm, 35cm and 70cm for years up to the 2020s, 2050s and 2080s respectively..

The UKCP09 report concludes that in most locations the trend in storm surge levels cannot be clearly distinguished from natural variability; therefore, although this is recognised as an uncertainty within the predictions, no detailed analysis of potential impacts has been undertaken.

UKCP09 projections suggest a wide range of estimates for the UK wave climate by 2100. When the regional model is run into the future (to the 2070-2100 period) using the medium emissions scenario, winter wave heights are expected to reduce by around -0.2m to the North of the UK and experience very little change in the North Sea. Given the significant uncertainty both to the future position of future storm tracks over the UK and the projections of wave climate within UKCP09, in England the Environment Agency currently recommends that Risk Management Authorities employ a sensitivity analysis to understand the impact of possible changes to the wave climate on future flood risk and coastal change. For North and West coasts of Scotland a slight increase in significant wave height is predicted in the summer and autumn seasons, but in spring any increase is mainly limited to the West coast.

C3.2.2 Precipitation

In addition to sea level rise and storminess, another factor of climate change that is important to coastal evolution is precipitation. Analysis of existing UK precipitation records presented in UKCIP08 (2007) indicated that all regions of the UK have experienced an increase in winter rainfall contribution from heavy precipitation events, although the rainfall seasonality experienced across the UK has changed little over the past 50 years.

UKCP09 concluded that there was unlikely to be a significant change in annual mean precipitation by the 2050s, with the central estimate of change being 0% under medium emissions (with an uncertainty range of -5% to +6%). Central estimates of changes in precipitation on the wettest day of the winter by the 2080s with Medium emissions range from zero in parts of Scotland to +29% in parts of England. Corresponding changes in precipitation on the wettest day of the summer range from –9% in parts of southern England to +25% in parts of Scotland. Further information can be obtained from the UKCP09 website.

Dune systems are also potentially susceptible to changes in precipitation by limiting sand transport through wetting of beach and dune surfaces and influencing dune vegetation growth (Pye and Saye, 2005). Although precipitation changes are recognised as an uncertainty, this has not been directly taken into account in the shoreline evolution predictions due to (i) uncertainty in the exact impact of precipitation change, (ii) the fact that it is the intensity of the rainfall (rather than the total amount of rainfall) that is the key factor, for which there is no information.. Given the nature of this coastline, any effects are also likely to be localised.

Changes in precipitation patterns could also have implications for river flows, which in turn could affect meandering patterns, alignment of intertidal channels, development and breaching of sand spits, fluvial discharge and flood risks within inner estuaries. Again, although this is recognised as an uncertainty and a potential risk, no further analysis has been undertaken as part of this SMP.

C3.2.3 Relative sea level

Global sea level is believed to have risen by between 10cm and 20cm during the past century and best estimates predict approximately 50cm sea level rise over the next 100 years (i.e. an increase by a factor of 3). Rising sea levels are a consequence of thermal expansion of the oceans, melting of low latitude glaciers (Alps, Rockies etc.) and many other factors, each of which are reviewed every few years by the Intergovernmental Panel on Climate Change (IPCC). However, how this change in global sea level translates to relative sea level along the coast depends upon both local changes in vertical land movements (due to Glacial Isostatic Adjustment (GIA)) and regional factors such as ocean circulation.

The UK Climate Projections (UKCP09) provide climate change allowances and sensitivity ranges for the UK. UKCP09 relative sea level rise projections include for local land movements and local oceanographic effects and are available for three emission scenarios as a change relative to 1990 for any year up to 2100. They are presented as central estimates of change for each emission scenario with upper and lower confidence bands. The methodologies used to generate sea level ranges for the UK in the UKCP09 report use improved methods to estimate vertical land movement and models constrained by a range of observations, informed by the most recent IPCC Fourth Assessment Report (IPCC, 2007). The IPCC Fourth Assessment Report estimates that approximately 70% of global sea level rise over the 21st century will be due to thermal expansion, with the remainder due to melting of glaciers, ice caps and a combined contribution from the Greenland and Antarctic ice sheets. Outputs from UKCP09 are available from the website and include:

- Absolute sea level rise time series for the UK for high, medium and low emissions scenarios (central estimate, and 5th and 95th percentile).
- Relative sea level rise around the UK, combining absolute sea level rise and vertical land movement, at user specified coastal locations.

One component of future sea level rise is from the melting of large ice sheets; however, there is a lack of current scientific understanding of some aspects of ice sheet behaviour and as such there are known limitations to including this component in sea level projections. UKCIP02 did not take any account of catastrophic changes, such as the collapse of the Thermohaline Circulation or the collapse of the West Antarctic Ice Sheet, whereas UKCP09 provides a low probability, high impact range for sea level rise around the UK, known as the High-plus-plus (H++) scenario, in addition to their main scenarios. This provides some indication of the impact of large-scale ice sheet melting on sea level rise. The scenario takes its bottom value from the maximum global mean sea level rise given by the IPCC Fourth Assessment Report, and its top value is derived from indirect observations of sea level rise during the last interglacial period, where the climate was comparable in some ways to today, and from estimates of maximum glacial flow rate. The H++ scenario prediction of sea level rise around the UK coast is between 0.93m and approximately 1.9m by 2100. UKCP09 state that the top of this range is very unlikely to occur in the 21st century and that improvements in models and continued monitoring may, in the future, help to estimate the likelihood of this type of event, or rule it out completely.

The above projections of future sea level rise also do not take any account of catastrophic changes, such as the collapse of the Thermohaline Circulation (THC) which UKCIP02 did not consider. The Thermohaline Circulation is a massive circulation of water in the world's oceans, which brings considerable amounts of heat to Western Europe; the Gulf Stream is one element of the circulation. This circulation is primarily driven by changes in water density, but other process, such as winds and tides, also contribute. It is frequently referred to in scientific literature as the meridional overturning circulation (MOC) particularly when focussing on the component of the THC which takes place in the North Atlantic. Any change is this circulation could result in cooling in North West Europe even whilst most of the world experiences warming.

There has been some concern that climate change could trigger this circulation to shut down, which in turn could lead to significant cooling in North-West Europe, even whilst most of the world warms up. Over the next century, total collapse of the Thermohaline Circulation is considered unlikely (IPCC Fourth Assessment Report 4, Working Group I); and even under a scenario of the circulation weakening over the next 100 years, which would mean that the Gulf Stream would bring less heat to the UK, increased greenhouse gas heating would greatly exceed this cooling effect (Hulme et al., 2002, the UKCIP02 report). The effects of the gradually weakening MOC on UK climate are included in the UKCP09 climate projections.

UKCP09 projections show that, over the next century, sea level around Scotland is going to rise. Although in most of Scotland the land surface is actually rising due to post-glacial rebound, this is not rapid enough to negate sea level rise. Where there is positive post-glacial rebound, it reduces the absolute amount we can expect to deal with. However, a recent paper by Rennie and Hansom (2011) presents a controversial view on sea level trends in Scotland which suggests that in Scotland land uplift is now outpaced by sea level rise. These findings have been disputed and therefore care should be utilised in consideration of its conclusions.

Table C3.1 contains the UKCP09 Relative Sea Level Rise predictions at the 95 percentile predicted from 1990 levels for Montrose, Arbroath and Dundee, for the UKCIP low, medium and high ranges.

Table C3.1 UKCP09 Relative Sea Level Rise predictions for Montrose and Arbroath

Actual Year	SMP2 Epoch	Year from 1990 in UKCIP09	Montrose			Arbroath			Dundee		
			Low range	Medium range	High range	Low range	Medium range	High range	Low range	Medium range	High range
2015	**Present day**	25	**68mm** (0.068m)	**90mm** (0.090m)	**115mm** (0.115m)	**68mm** (0.0568m)	**89mm** (0.089m)	**114mm** (0.099m)	**65mm** (0.065m)	**86mm** (0.086m)	**111mm** (0.111m)
2035	**Year 20**	45	**139mm** (0.139m)	**181mm** (0.181m)	**231mm** (0.231m)	**138mm** (0.138m)	**180mm** (0.180m)	**230mm** (0.230m)	**133mm** (0.133m)	**175mm** (0.175m)	**225mm** (0.225m)
2065	**Year 50**	75	**271mm** (0.271m)	**351mm** (0.351m)	**447mm** (0.447m)	**269mm** (0.269m)	**349mm** (0.349m)	**445mm** (0.445m)	**261mm** (0.261m)	**342mm** (0.342m)	**437mm** (0.437m)
2115	**Year 100**	Use 100	**463mm** (0.463m)	**599mm** (0.599m)	**760mm** (0.76m)	**461mm** (0.461m)	**596mm** (0.596m)	**758mm** (0.758m)	**449mm** (0.449m)	**585mm** (0.585m)	**746mm** (0.746m)

C3.3 Predicting Future Evolution and Erosion / Flood Risk

C3.3.1 Introduction

The response of the coast depends upon a number of factors, but at a basic level depends upon resistance of the coastal feature and the energy or forcing acting on it. In general terms, rising sea level results in high tide water levels reaching further up the beach profile and therefore increased wave energy at the shoreline. Response of the coast to changes in forcing factors is also often complex with a number of feedbacks, such as sediment inputs from cliff erosion, affecting the net change.

An important objective of any plan for managing the shoreline of Angus, and its coastal defences, is a view of how the shoreline may develop in future decades, and how this might affect development planning in the immediate coastal zone.

Such future changes cannot be predicted with any certainty, not least because there is great uncertainty about how winds, wave conditions and storms may alter. The widely expected increase in the rate of sea-level rise, as a consequence of global warming, will tend to produce a general landward recession of the shoreline. Unlike many other parts of the UK coastline, however, increased dangers of marine flooding will only affect very localised parts of Angus, for example around the margins of Montrose Basin.

Likely changes in position will also depend on the type of shoreline being considered. The cliffs of hard rock, such as Old Red Sandstone, will retreat slowly, however much tidal levels and wave conditions alter. Sandy coastlines with dunes have changed rapidly in the past (i.e. at several metres/ year), and will always be likely to do so again in the future. Allowing major developments close behind such coastlines is therefore much more likely to lead to problems and potentially a requirement for coastal defences. This is particularly the case in those areas that lie seaward of past shorelines, such as along the Carnoustie and Monifieth seafronts.

Predictions of future change along the open coast, for the two scenarios presented in this Appendix, predominately builds upon information contained within SMP1 (Angus Council, 2004) and any other data available, including the baseline understanding of coastal processes (see Sections C1 and C2 of this appendix), understanding of the underlying geology and the generic response of various coastal systems, and previous measurements / reviews of coastal change.

The process adopted follows the Defra Guidance (2006; Volume 2, Appendix D), whereby an iterative approach is used to investigate response of the coastal morphology to changes in energy and sediment exchange as a result of feedbacks within the system. This relies on a generic understanding of the landforms present and expert interpretation of existing information - an approach known as 'expert geomorphological assessment (EGA)'. No additional modelling has been undertaken as part of this SMP Review.

There are significant uncertainties associated with prediction of future coastal evolution and a summary of the key unknowns is provided in Section C3.3.6. Despite the complications associated with understanding coastal systems and predicting their future evolutionary trends and tendency, generic assumptions can be made to enable statements to be made describing how, in theory, they form and evolve. Based upon this information, it is also possible to identify theoretical responses of various coastal elements to changes in certain controlling parameters. The identification of more precise responses would require quantified data relating to all potential parameters that may influence change and considerable historic information concerning previous coastal response to these parameters (Halcrow, 2002).

To develop a high level plan, such as an SMP, it is necessary to make broad assumptions regarding the likely trends of future change and response to climate changes (as discussed in Section C3.2). The sensitivity of the policy decisions on these high level assumptions will vary from location to location, both due to the availability of data and differences in the complexity of the coastal systems that operate. Appendix K 'Policy Sensitivity Analysis' will address this issue and will identify where policy decisions may depend upon the outcome of future monitoring and research.

The key assumptions, and coastal 'response models', used to make our predictions of future change are discussed in the following sections. At the more local level, these response models have been considered, together with the understanding of local level interactions, to develop a prediction of how each section of coast is likely to change over the short (0 to 20 years), medium (20 to 50) and long (50 to 100) timescales. The Steps that have been followed are explained in Table C3.2.

Table C3.2 Steps in the appraisal of scenarios; based upon Box D1 in the Defra Guidance (2006; Volume 2, Appendix D).

Steps	Description
Step 1 Assess coastal behaviour at CPU scale	For the policy to be tested, the wide-scale potential coastal realignment resulting from the new constraints, i.e. changed controls and linkages, has been assessed. Information from SMP1 and the CPU assessments above has been used to guide the analysis.
Step 2 Assess impact on CPU scale sediment transport regime	Any modification to present-day sediment transport regime has been considered, considering any change in the foreshore sediment balance for each local area that may result from the changes to coastal behaviour and realignment.
Step 3 Consider coastal response	Generic understanding of geomorphological feature behaviour has been used to assess probable behaviour of the various landforms in response to the new constraints, modified linkages, realignment potential and altered sediment regime.
Step 4 Consider local impacts	Considering first the 0 to 20 year period for the entire coast, and then the 20 to 50 year period, the local impact of the policy on the sediment balance has been considered, through identifying expected changes in sediment input, sediment output or sediment transport path.
Step 5 Predict backshore response	Through combining understanding from step 3 with the sediment balance information from step 4, the type of backshore response has been predicted, in particular any potential change in geomorphological form and subsequent alteration to the backshore/foreshore sediment exchanges that could take place.
Step 6 Consider impact on adjacent areas	Using the approach and information from Step 2, the potential impacts on adjacent areas and the wider area for both the 0 to 20 and 20 to 50 year periods have been considered.
Step 7 Consider feedbacks/ interactions	Possible feedbacks and interactions along the coast have been considered, which in places has resulted in a reappraisal of steps 2 to 6.
Step 8 Predict shoreline position	Where appropriate the extent of shoreline movement for each of the time periods has been predicted. In other locations the flood risk has been appraised.

C3.3.2 Open Coasts

At the simplest level, the response of a shoreline to changes in the forcing parameters, i.e. waves, tides, currents and winds, will depend upon the resistance of the landforms which make up the shoreline. Along most of our open coasts a key driver for future change will be the predicted increase in global sea level. In general, this will result in high and low tide line advancing landwards, with submergence of at least part of the present intertidal area. Along soft shorelines the natural response of the shoreline will be to roll landwards to accommodate sea level rise. Along steep hard rock coasts, where little marine erosion is taking place, the shoreline will remain fixed in position, but the level of high and low water will lie higher up the cliff. The extent of coastal erosion will also depend upon changes to the nearshore zone. Although sea level rise will generally lead to a deepening of the nearshore waters, and therefore an increase in wave energy at the shoreline, this may be offset by any increase in sediment supply, from fluvial, alongshore or even offshore sources.

The SMP open coastline is generally characterised by relatively resistant cliffs, fronted by localised fringing beaches and exposed rock platforms, interspersed by sandy bays and large dune systems.

Beaches

In general, sea level rise will result in deeper waters closer to the shore and therefore larger waves will break on the shore, resulting in beach erosion. Where beaches are backed by low topography, they may be able to roll landwards, with a net landward movement of the high tide line. However, where the beach is already narrow and backed by rising land, the beaches are likely to reduce in size or be lost, unless there is a sufficient input of sediment to maintain them. This sediment may come from the nearshore, alongshore or from local cliff erosion and will therefore vary on a local scale.

Along this coast, many of the beaches are contained within small bays, or embayments. Here, the headlands have a sheltering effect and refracted wave energy is dispersed, which protects the bays from storms and retains sediment on the beaches. Within these, with rising sea levels, beach sediment may be pushed up and landward, forming steeper and narrower beaches. Within deeper embayments, beaches may be retained for some time, due to the sheltering effect of the headlands. In many cases, however, beaches will become incrementally submerged, unless there is either a new input of sediment or low-lying land at the back of the bay, across which they could roll landwards.

Where beaches are backed by defences, increased exposure due to beach erosion and higher waves at the shore is likely to accelerate toe erosion, increase the risk of overtopping and reduce the life of the defences. Therefore if defences are to be retained, they may need to be strengthened (to resist increased wave loading), raised (to reduce the increased risk of flooding from overtopping) and include enhanced toe protection (to reduce the risk of undermining).

Cliffs

Along the cliffed frontages, the following trends may occur, under a scenario of sea level rise:

- raised level at which wave activity occurs (Carter, 1991), resulting in increasing exposure of fringing beaches and cliffs;
- along open coasts this may increase the potential for alongshore littoral transport (although actual transport will depend upon sediment availability);
- any fronting shore platforms will become submerged for longer periods of time and will become permanently inundated when sea level rise exceeds present tidal range;

- cliff toe will be attacked more frequently;
- where cliffs are cut into soft sediments, this will accelerate cliff erosion, releasing material to the foreshore. This eroded material may be moved alongshore increasing sediment supply to other areas, or may be retained as a beach in front of the cliffs, thereby reducing cliff erosion;
- where cliffs are cut into hard sediments, the rate of erosion is not expected to significantly increase and the high water level will simply move higher up the cliff face.

Although the general trend in cliff response can be predicted with some certainty, the rate of future change, particularly under a scenario of rising sea levels is less certain. There are a range of predictive methods available which have attempted to incorporate sea level rise in extrapolation of shoreline response, but each is constrained by assumptions and limitations which affect their application to cliffs. This is because a simple relationship between cliff erosion and sea level rise does not exist. The Bruun Model (Bruun, 1988) is probably one of the most widely used for cliffed coastlines, possibly because it involves the use of a small number of parameters. Application of the Bruun Rule is not, however, appropriate in all situations, for example: where there is a very gentle offshore gradient, large tidal range, areas of hard rock or areas where past behaviour has not been linear in nature, such as within the major dune systems. Therefore, along this coastline, which is characterised by hard rocky shores, generally resistant cliffs and extensive dune systems, the Bruun Rule is not considered appropriate.

Many of the cliffs within this SMP area are composed of hard rock and are therefore resistant to erosion; these cliff types are unlikely to significantly respond to sea level rise and the result will simply be that water levels lie higher up the cliff face. Historical rates of erosion, where available, have therefore been used as the best prediction. Elsewhere broad assessments of future response have been undertaken, based on a generic understanding of how various coastal cliff geologies are likely to respond.

Dunes

Some of the dune systems along this coastline have been heavily influenced by human activities and a range of management measures, however, other dune areas along this frontage can be regarded as entirely ‘natural’ (Pye and Saye, 2005).

Dune response to future climate change is very uncertain and depends upon:

- the magnitude of sea level rise;
- the degree of wind and wave climate change (including storm frequency and severity) and the resultant effects on different sections of coast;
- the degree to which stores of sediment within the nearshore zone will be reworked landwards to feed beaches and dunes, rather than moving into estuaries or deeper water;
- changes in other climatic factors, i.e. rainfall, temperature and evaporation, which could affect vegetation cover and groundwater conditions;
- future management regimes and dune usage.

As a general rule, unless there is a major increase in the availability of sediment, either from alongshore or from the nearshore, open coast dune systems are likely to experience frontal dune erosion as a result of predicted accelerated sea level rise, with the dunes, if not constrained, tending to roll landwards. Pye and Saye (2003) identify four possible ways in which this rollover process may occur, depending upon availability of sediment in both dune and beach systems:

- 'Equilibrium' rollover – this situation occurs when there is little sediment within the beach system, but a positive dune sediment budget. Dune height and width will remain unchanged, but the dune toe will move landward.
- 'Snowball' rollover – as above, this situation occurs when the beach budget is negative, but the dune budget is strongly positive. Dune height increases as the dunes roll landwards.
- 'Dissipation' rollover – in this situation, the beach sediment budget is negative whilst the dune sediment budget is neutral. Dune height decreases as sediment is lost from the dune system.
- 'Washover' rollover – here both the dune and the beach sediment budgets are negative, therefore the dune height and width both decrease over time, thereby reducing the defence function of the dune and possibly resulting in the dunes becoming overwashed or breached.

The possibility of these scenarios occurring has therefore been considered when appraising the likely future response of the dune systems. However, although these models describe the net trends of change, at a local level the effect of a rise in sea level will vary spatially and temporally and erosion in one area is likely to result in sediment accumulation in another. Dune rollover may also be prevented by coastal defence structures.

Dune systems are very sensitive to any change in the frequency and severity of storms; Pye and Saye (2005) suggest that any increase in storminess could either lead to the formation of new dune ridges, due to the landward movement of sediment from the nearshore, or conversely, to the development of blowouts. There remains, however, considerable uncertainty regarding future trends of storminess and a recent report by UKCIP (UKCIP, 2009) concluded that trends in severe wind storms around the UK are difficult to identify due to: low numbers of such storms, their decadal variability and the unreliability and lack of representation of direct wind speed observations. There is little evidence that the recent increase in storminess over the UK is related to man-made climate change. Therefore in the statements below predictions of future change have identified the sensitivity of dune systems to future changes in storminess and wind-wave climate, but have not qualified the potential impact.

C3.3.3 Estuaries

Predicting future evolution of estuaries has been the subject of the Estuaries Research Programme undertaken over a 10 year period. Despite this, predicting the future evolution of estuaries is still subject to significant uncertainties, especially where there are limited data for the estuaries relating to sedimentary infilling and historical trends of accretion and erosion.

There are three main response mechanisms to sea level rise; estuaries may experience:

- Drowning;
- Vertical sedimentation keeping pace with sea level rise; or
- Vertical sedimentation and horizontal translation of the estuarine morphology (rollover).

The type of response depends on sediment availability, transport processes and the rate of sea level rise.

If sea level rises rapidly and is accompanied by low sediment availability then progressive drowning is likely to occur. Slower rates of sea level rise, with abundant sediment availability, may allow the estuary to keep pace with sea level change through vertical accretion. This may be accompanied by a landward translation, which is known as the estuary rollover model (Pethick, 2000), and is a common model used for predicting estuary response to sea level rise. This process involves erosion in the upper intertidal in the outer estuary, and transport and disposition of this sediment to the estuary head. Further discussion of this model is provided in the Review and Formalisation of Geomorphological Concepts and Approaches for Estuaries (HR Wallingford et al., 2006).

Although sea level rise might be expected to increase the tidal prism of an estuary or widening of the estuary mouth, this may not occur if the estuary volume is reduced by inland transport and accumulation of sediment. Therefore, any increase in tidal prism may only be an initial and temporary response to sea level rise.

The balance between sediment supply and the rate of sea level rise is therefore critical to the prediction of future estuary evolution and also the prediction of how fringing intertidal and saltmarsh habitats may evolve. Loss of outer estuary salt marsh due to increased wave erosion following sea level rise is one of the outcomes of the rollover model. In addition to sea level rise, the rate of sedimentation may also be sensitive to changes in storminess, which in the SMP area could increase the movement of sand from the offshore zone towards the coast, leading to more rapid vertical, and possible lateral, growth of saltmarshes, although greater wave erosion of the saltmarsh edge would be expected in more exposed estuaries.

C3.3.4 Future Flood Risk

Future flood risk along the Angus coast will be determined by an interaction of global (eustatic) sea level rise, regional isostatic uplift and changes to tidal levels, storm surge frequency and wave heights (Ball et al., 2008). Trends measured from global tide gauge data indicate an eustatic sea level rise of approximately 1.8 mm yr-1 +/- 0.5mm yr-1 between 1961 and 2003 with satellite altimetry data (1993-2007) suggesting an increased rate of up to 3.1mm +/- 0.7mm yr-1 (Ball et al., 2008). However, in Angus such increases in global sea level are partly offset by an isostatic uplift of approximately 1mm yr-1 (Shennan and Horton, 2002). Accordingly, sea level around Angus may currently amount to approximately 2.1mm +/- 0.7mm yr-1. If such a rate of sea level rise continued until the end of this century, this would equate to an increase in relative sea level in Angus of approximately 18.5cm by 2100. Superimposed on this increase, it is anticipated that storm surge heights will increase, with Dawson et al. (2001) estimating a 1 in 50 year storm surge level (above mean tidal level) at Aberdeen of 3.05m by the 2080s, although a much smaller increase of 0-0.25m was predicted for Scotland as a whole by Lowe and Gregory (2005) (Ball et al., 2008). Any upturn in the frequency of storm surges and increases in wave heights by the latter part of this century will also increase coastal flooding. However, accurately predicting the nature of such changes in the marine climate and their impact on coastal areas is problematic (Ball et al., 2008).

The main areas at risk of future coastal flooding along the Angus SMP2 frontage are:

- In the vicinity of the River North Esk outlet, north of Montrose;
- Montrose (south);
- Montrose Basin (west);
- In the immediate vicinity of the Lunan outlet;
- Arbroath Harbour;
- West Links, Arbroath;
- Barry Burn, Carnoustie; and
- Broughty Ferry.

At Arbroath Harbour and West Links, coastal flooding from extreme sea levels is predicted to be limited due to the relative height of the land along the coast. Rather, the main potential source of future coastal flood risk along the frontage was due to wave overtopping in these locations (URS Scott Wilson, 2012). This was addressed as part of a scheme implemented in 2013.

C3.3.5 SMP1 Predictions of future shoreline change up to 2050

A brief summary of anticipated future shoreline changes was provided in SMP1 for each Coastal Process Unit (Table C3.3). This identified:

- Locations likely to be at risk from marine flooding;
- Stretches of coast that are already eroding significantly or that have done so in the past;
- An approximate width of land adjacent to the present shoreline that might be affected by erosion/flooding in the next few decades, based on past shoreline fluctuations with allowance for potential future sea level rise (up to 2050).

Table C3.3 SMP1 anticipated future shoreline changes under NAI up to 2050

Coastal Process Unit	Flood Risk	Erosion Risk	Potential Impact width* over next 50 years (from present day position)
CPU 1 Milton Ness to Montrose Harbour	No significant increase in flood risk	Risk of continued erosion, particularly along southern half of bay	100m
CPU 2 Montrose Basin	Potential increase in flood risk along low lying / reclaimed sections to the west of the basin protected by embankments	Risk of erosion along unprotected sections but rate will be relatively low	50m along unprotected north and south flanks All low lying areas to west of basin
CPU 3 Scurdie Ness to Rickle Craig	No flood risk.	Little erosion risk	20m
CPU 4 Rickle Craig to Lang Craig	Potential flood risk to property immediately north of Lunan Water	Continued erosion of dune line along entire bay. Potential for dune breach north of Lunan Water outlet	100m / Seaward of raised beach & Lunan Water flood plain
CPU 5 Lang Craig to Whiting Ness	No flood risk.	Little erosion risk	30m
CPU 6 Whiting Ness to West Haven	Minor flood risk at Elliot and from overtopping of seawalls at Arbroath	Continued erosion along frontage from West Links to West Haven	75m / seaward of railway line south of Arbroath

Coastal Process Unit	Flood Risk	Erosion Risk	Potential Impact width* over next 50 years (from present day position)
CPU 7 West Haven to Buddon Ness	Minor flood risk at Barry Burn	Continued beach erosion along entire frontage	100m along Carnoustie frontage 300m along Barry Links frontage
CPU 8 Buddon Ness to Broughty Castle	Little flood risk	Continued areas of erosion experienced along frontage which will vary both temporally and spatially	300m along Barry Links frontage Seaward of railway line from Monifieth to Barnhill Seaward of esplanade from Barnhill to Broughty Ferry
**It is important to emphasise that the approximate impact width stated in the final column of Table C3.4 <u>does not equate</u> to a prediction of shoreline retreat; on sandy coastlines, for example, it is possible that the shoreline might advance by a similar amount.*			

C3.3.6 Inherent Uncertainty with Predicting Future Evolution

When making future predictions it is important to accept that there is an inherent uncertainty. The predictions presented in the assessments for this SMP2 are based on our current understanding of how the system is behaving and its likely response to future predicted changes in sea level and changes in management practices.

Key areas of uncertainty are as follows:

- **Predictions of future sea level rise**: the predictions rely primarily on two sets of data: the IPCC predictions of eustatic (global) sea level rise and Shennan and Horton's (2002) work on isostatic changes. Both data sets contain uncertainties and assumptions, but currently they represent the best available information.
- **Future climate change**: there remains uncertainty regarding other factors of climate change that may affect the coast, e.g. changes in precipitation, storminess and wind-wave climates. Again, we have based our assumptions using the latest information, but accept that our understanding of how these factors may change will improve in the future.

Due to these uncertainties, the implementation of some policies may include the need for additional research and/or monitoring. The sensitivity of the preferred policies to these uncertainties and unknowns is addressed in Appendix K, and the Action Plan (included in the Main SMP document) outlines any monitoring and research requirements.

C3.4 Defence Assessment

A wide range of coastal defence structures have been constructed along the Angus coastline, many in the last 40 years or so as erosion has become more of a significant problem. Many of these defences are traditional linear hard defences such as seawalls or revetments. Such defences often protect a section of coastline but can lead to detrimental impacts such as accelerated beach lowering in front of the defence, or exacerbated problems on adjacent stretches of coastline. Until recently other methods, such as beach control structures and softer forms of coastal defence such as beach renourishment, have not been used with the exception of the groynes along the Monifieth to Broughty Ferry frontage, the rock strongpoints and groynes in Montrose Bay and the rock groynes with beach renourishment scheme installed at Montrose to raise and maintain beach levels around the Glaxo corner in 1999.

The standard of protection provided by a section of coastal defences depends on the margin of safety it provides against structural collapse or unacceptably high overtopping discharge. These two distinct limit states are related. The collapse or failure of coastal defences is a consequence of hydraulic forces as well as structural and geotechnical aspects. Overtopping discharge, as well as depending on the severity of storm conditions, is also a function of crest level and cross-sectional profile. Both overtopping and structural failure are highly influenced by the level of the beach in front of the defence.

A visual assessment of the coastal defences along the Angus coast was conducted for SMP1. The Angus SMP2 has built upon these assessments using more recent information / data where available from recent defence assessments and reports relating to the SMP2 frontage, and from site inspections. Along some stretches of coast defence, information is limited where they are privately owned and/or ad hoc. These uncertainties therefore may have potential implications on the preferred policy for these locations in the future. Lack of information on defence condition may mean that defences fail earlier or last longer than predicted, which will impact on when defences need replacing or maintenance regimes, and therefore associated costs. If a policy change is recommended over time, lack of defence information may also impact on the timing of policy change, for example managed realignment may need to be considered earlier if frontline defences are likely to fail earlier.

The present condition of each defence has been classified as:

Good Condition as built

Fair Some signs of wear, needs to be kept under observation; returnable to '*condition as built*' with simple maintenance, i.e. work advisable in order to prevent undue deterioration.

Poor Moderate works required; probably limited to a maintenance operation to return to satisfactory condition, i.e. work necessary to sustain adequate performance.

Bad Significant works needed; capital works probably required within five years to restore original condition.

The Defence Assessment table (Table C3.4) provides a summary of the existing defences along the Angus SMP2 frontage together with an assessment of defence condition, performance, residual life and impacts on the adjacent coastal processes and coastline. The Defence Assessment is used to inform both of the baseline scenario assessments. It primarily provides information to enable us to:

- Understand how defences and management practices may have affected coastal behaviour in the past; and,
- Understand how defences and management practices may affect coastal behaviour in the future, under various scenarios.

Table C3.4 Angus Shoreline Defence Assessment

Coastal Process Unit	SMP1 Man Unit	Location	Defence Type	Material	Approx. Length (m)	Year of construction	Condition	Estimated Residual Life – (Do Nothing Scenario) Years	Impacts on processes and adjacent coastline
CPU 1 Milton Ness to Montrose Harbour	1	Montrose Links Golf Course	2 strong points 	Rock	2 @ 80m	1994	Fair	20-30 years	• Localised dune protection • Minor impact on natural coastal processes
	1	Montrose Links Golf Course	Dune fencing	Timber	500m	2012	Good	10 years	• Dune protection
	2	Northern end of Splash	Groyne 	Rock	80m	1989/90/91	Good	20 years	• Helps maintain beach levels along Splash frontage
	2	Northern end of Splash	Revetment 	Rock	Unknown	1989/90/91	Good	30 years	• Potential outflanking to the north

Coastal Process Unit	SMP1 Man Unit	Location	Defence Type	Material	Approx. Length (m)	Year of construction	Condition	Estimated Residual Life – (Do Nothing Scenario) Years	Impacts on processes and adjacent coastline
	2	Splash frontage	Seawall 	Concrete / sheet piling / rock toe	390m	Wall 1954, Rock toe 1990s	Fair	30 years	• Potentially exacerbates beach lowering but not the dominant cause of beach lowering • Outflanking experienced to the north before remedial works installed • Prevents natural coastal retreat – potential for long term coastal squeeze.
	2	Caravan Park frontage	Rock armour 	Rock	335m	1991	Fair	30-40 years	• Prevents natural coastal retreat – potential for long term coastal squeeze.
	2	GlaxoSmithKline frontage	Revetment 	Rock	1030m	1999/ 2000	Good	40 years (after erosion of dunes)	• Prevents natural coastal retreat – potential for long term coastal squeeze.
	2	GlaxoSmithKline frontage	3 no. Groynes 	Rock	80m, 85m & 135m	1999	Good	40 years (after erosion of dunes)	• Groynes installed to maintain beach levels at Glaxo Corner. • Performing well to date.

Coastal Process Unit	SMP1 Man Unit	Location	Defence Type	Material	Approx. Length (m)	Year of construction	Condition	Estimated Residual Life – (Do Nothing Scenario) Years	Impacts on processes and adjacent coastline
	2	GlaxoSmithKline frontage	Beach renourishment	Sand / shingle	-	1999	Fair	-	• Increased beach levels at Glaxo corner.
	2	Pumping Station	Revetment	Gabions	95m		Fair - Poor	10 - 15 years	
	2	West of pumping Station	Ad hoc	Rubble			Poor	10 – 15 years	
CPU 2 Montrose Basin	1	West side of Road Bridge	Revetment 	Rock	20m		Fair	20 years	
	1	West of Road Bridge	Seawall	Gabions	20m		Poor	10-20 years	
	1	South section of rail track	Revetment	Masonry	Unknown		Fair	10-20 years	• Minimal present day impact. • Long term potential for loss of intertidal area with increasing sea level.
	1	North section of rail track	Seawall	Concrete	Unknown		Fair	10-20 years	• Minimal present day impact. • Long term potential for loss of intertidal area with increasing sea level.
	2	Tayloan	Ad hoc Seawalls	Masonry / Gabions / rubble / timber breastwork	160m (total)	Various	Poor - Bad	5-10 years	
	2	Tigh-na-Bruach	Seawall / revetment	Gabions	95m		Fair	15 years	

Coastal Process Unit	SMP1 Man Unit	Location	Defence Type	Material	Approx. Length (m)	Year of construction	Condition	Estimated Residual Life – (Do Nothing Scenario) Years	Impacts on processes and adjacent coastline
	2	Sleepyhillocks cemetry	Seawall	Masonry	260m		Fair	20-30 years	
	2	Western flank of Basin	Embankments	Earth with masonry / rock facing	6670m		Fair - Poor	20-30 years	• Prevents natural flood plain processes. • Increases river flows at western end of basin.
	3	Esk Road	Ad hoc seawalls 	Concrete / timber / gabions	200m (total)	Various	Poor - Bad	Timber / gabions: 5-10 years Concrete: 30 years	
	3	Ferryden	Various seawalls 	Concrete & small sections of masonry	450m		Fair - Poor	20-30 years	
	3	Ferryden Pumping Station	revetment	Rock	75m		Good	50 years	

Coastal Process Unit	SMP1 Man Unit	Location	Defence Type	Material	Approx. Length (m)	Year of construction	Condition	Estimated Residual Life – (Do Nothing Scenario) Years	Impacts on processes and adjacent coastline
CPU 4 Rickle Craig to Lang Craig	1	Corbie Knowe	Ad hoc seawalls & revetments 	Concrete / Gabions / rubble	200m (total)	Various	Poor - Bad	North: 10 years South: 15-20 years	• Exacerbate beach lowering but not dominant cause. • Minor outflanking to the north evident • Removal of shingle to fill gabions etc has had major impact on the natural protection provided by the beach
CPU 6 Whiting Ness to West Haven	1	Victoria Park	Seawall 	Concrete	1380m	Original construction 1930s, concrete balustrade replaced 2012-13	Fair	40-50 years	• Highly reflective wall
	1	Seagate	Seawall	Various sections of masonry / concrete	140m		Fair - Poor	20 years	• Potential to exacerbate beach lowering
	2	Harbour wall	Seawall	Masonry	480m				

Coastal Process Unit	SMP1 Man Unit	Location	Defence Type	Material	Approx. Length (m)	Year of construction	Condition	Estimated Residual Life – (Do Nothing Scenario) Years	Impacts on processes and adjacent coastline
	2	Inchcape Park	Seawall	Masonry	270m		Fair	20 years	
	2	Inchcape Park (Pumping Station)	Seawall	Masonry	30m		Poor	20 years	
	2	Harbour breakwater	Breakwater	Masonry	170m				
	2	Harbour breakwater	Breakwater	Concrete Units	95m		Fair - poor		
	3	Inchcape Park	Seawall	Masonry	25m		Poor - bad		
	3	Inchcape Park	Revetment	Rock	340m	2011	Good	30 years	• Lower reflectivity of the rock revetment has helped build up a small shingle beach at the toe
	3	Promenade	Seawall 	Concrete	515m	Recurve wave wall 2013	Fair - good	30-50 years	• High reflectivity exacerbates beach lowering

Coastal Process Unit	SMP1 Man Unit	Location	Defence Type	Material	Approx. Length (m)	Year of construction	Condition	Estimated Residual Life – (Do Nothing Scenario) Years	Impacts on processes and adjacent coastline
	3	West Links	Seawall 	Masonry / concrete	195m	Recurve wave wall 2013	Fair - good	30-50 years	• High reflectivity exacerbates beach lowering preventing sand / shingle beach levels from increasing • Long term potential for loss of intertidal area with increasing sea level
	3	West Links	Stepped Seawall	Concrete	120m		Fair	30-40 years	• High reflectivity exacerbates beach lowering preventing sand / shingle beach levels from increasing • Long term potential for loss of intertidal area with increasing sea level
	3	West Links (southern end)	Seawall	Concrete	280m		Fair	30-40 years	• High reflectivity exacerbates beach lowering preventing sand / shingle beach levels from increasing • Long term potential for loss of intertidal area with increasing sea level
	4	Dowrie	Revetment 	Rock	100m	2010	Good	50 years	

Coastal Process Unit	SMP1 Man Unit	Location	Defence Type	Material	Approx. Length (m)	Year of construction	Condition	Estimated Residual Life – (Do Nothing Scenario) Years	Impacts on processes and adjacent coastline
	4	Hatton (North of East Haven)	Seawall 	Concrete	100m		Poor	5 years	
	4	East of West Haven	Rubble revetment 	Rock	60m		Poor	5 years	
CPU7 West Haven to Buddon Ness	1	Carnoustie (fronting pumping station and Coast Guard)	Rock (rubble) 	Rock	50m		Poor	5 years	

Coastal Process Unit	SMP1 Man Unit	Location	Defence Type	Material	Approx. Length (m)	Year of construction	Condition	Estimated Residual Life – (Do Nothing Scenario) Years	Impacts on processes and adjacent coastline
	1	Carnoustie (east of Lochty Burn)	Revetment 	Rock	100m		Fair	40-50 years	• Long term potential for loss of intertidal area with increasing sea level
	2	West of Lochty Burn	Revetment	Rock	105m		Fair	40-50 years	• Long term potential for loss of intertidal area with increasing sea level
	2	Recreational Park frontage	Revetment 	Rock	250m	2004	Good	40-50 years	• Long term potential for loss of intertidal area with increasing sea level
	2	Barry Burn Mouth	Revetment 	Rock	200m	2012	Good	40-50 years	

Coastal Process Unit	SMP1 Man Unit	Location	Defence Type	Material	Approx. Length (m)	Year of construction	Condition	Estimated Residual Life – (Do Nothing Scenario) Years	Impacts on processes and adjacent coastline
	2	Barry Burn Mouth	Retaining Wall 	Block work	20m	2012		100 years	• Maintains discharge from burn to the sea.
	3	Barry Sands East	Revetment 	Rock	2570m	1993	Fair	30-40 years	• Long term beach lowering and potential for loss of intertidal area with increasing sea levels • Severe downdrift effects at southern end
CPU 8 Buddon Ness to Broughty Castle	2	Monifieth (Playing fields and Riverview Caravan Park)	Revetment 	Rock	1210m		Fair - Poor	20 years (without the fronting dunes)	• Dune development seaward so defences now effectively buried
	3	Monifieth (Recreation ground and east part of Tayview Caravan Park)	Revetment 	Rock	Unknown		Good	20 years	

Coastal Process Unit	SMP1 Man Unit	Location	Defence Type	Material	Approx. Length (m)	Year of construction	Condition	Estimated Residual Life – (Do Nothing Scenario) Years	Impacts on processes and adjacent coastline
	3	Monifieth (Tay View Caravan Park)	4 No. Groynes 	Rock	Unknown	2008-2012	Good	40 years	• Groynes installed to maintain beach levels
	3	Monifieth (West)	14 No. Groynes 	Timber	Unknown		Fair	<5 years	• Have been effective at controlling westerly longshore drift and maintaining beach levels
	3	Monifieth (West part of Tayview Caravan Park)	Revetment 	Timber		2011	Good	20-25 years	• Reflective structure may exacerbate beach erosion • Structure disconnects dunes from the beach reducing the potential for dune recovery
	3	Tayview Caravan Park to Milton Mills	Revetment 	Timber		2010	Good	15 years	• Reflective structure may exacerbate beach erosion • Structure disconnects dunes from the beach reducing the potential for dune recovery

Coastal Process Unit	SMP1 Man Unit	Location	Defence Type	Material	Approx. Length (m)	Year of construction	Condition	Estimated Residual Life – (Do Nothing Scenario) Years	Impacts on processes and adjacent coastline
	4	Milton Mills to Dighty Water	Revetment 	Rock	300m	2001	Good	40 years	
	4	Milton Mills to Dighty Water	4 No. Groynes 	Timber	Unknown	2001	Good	15 years	• Have acted to raise beach levels along the frontage between Milton Mills and the outlet of the Dighty Water
	4	Dighty water (east)	Gabions 	Rock				10 years	
	4	Dighty water (Network Rail asset)	Wall 	Masonry				30-50 years	

Coastal Process Unit	SMP1 Man Unit	Location	Defence Type	Material	Approx. Length (m)	Year of construction	Condition	Estimated Residual Life – (Do Nothing Scenario) Years	Impacts on processes and adjacent coastline
	4	South Balmossie Pumping Station, Barnhill	Revetment 	Rock	200m		Poor	10 years	
	4	Barnhill car park	4 No. Groynes 	Timber / Concrete	Unknown		Fair - Poor	<5 years	
	4	Barnhill car park	Revetment 	Rock	280m	2011	Good	50 years	
	5	Glass Pavilion car park	Revetment 	Rock	180m	2011	Good	50 years	• Removal of landward end of groynes to enable placement of rock • Cuts off natural interaction between the beach and dune system

Coastal Process Unit	SMP1 Man Unit	Location	Defence Type	Material	Approx. Length (m)	Year of construction	Condition	Estimated Residual Life – (Do Nothing Scenario) Years	Impacts on processes and adjacent coastline
	5	Esplanade	17 No. Groynes 	Timber	Unknown		Fair to bad	<5 years	• Groynes at eastern end have little impact on beach processes due to their deteriorated state. • Effective at maintaining beach levels where still in reasonable condition
	5	Broughty Ferry East	Seawall	Masonry	Unknown		Poor	5-10 years (without the fronting dunes)	• Fronted by dunes so no impact on beach at present
	6	Broughty Ferry	Seawall 	Concrete	Unknown		Fair	20-30 years (without a healthy fronting beach)	• Fronted by high healthy beach – little impact on beach as waves rarely reach wall

C4 Baseline Scenario I – No Active Intervention

C4.1 Introduction

The No Active Intervention (NAI) scenario assumes that there will be no further expenditure on maintaining/ improving existing defences. As a result, defences will start to fail as a consequence of undermining or deterioration of the structure due to its age. Prior to failure, defences may become less effective in reducing the risk of coastal erosion and flooding due to the future predicted rise in sea level.

The exact timing of failure of defences has not been defined, but is considered in terms of the three epochs: 0 to 20 year, 20 to 50 year and 50 to 100 year.

C4.2 Overview

At the SMP-scale, in the absence of significant climate change or acceleration in sea level rise over the next century, it is unlikely that there would be major changes to the existing pattern of sediment transport and shoreline evolution in the area. Local changes in shoreline erosion and accretion would take place due to changes in the wind / wave climate and due to changes in channel and bank morphology in Montrose Basin and the Tay Estuary. It is likely that accretion would be likely to continue at the down-drift ends of littoral sediment transport cells.

The effect of a significant increase in the rate of sea level rise would be to increase the erosional pressure on the beach and dune systems. On exposed shores, a significant proportion of the eroded sand would be likely to be reworked landwards by wave and wind action, thereby conserving the sand volume of landward-moving frontal dunes. Cannibalisation of sediment stored in the existing dune systems and back-barrier areas could also be expected. Any modest increase in storminess could result in further beach lowering and frontal dune erosion. The likelihood of this occurring is, however, very uncertain, and the latest UKCP09 data is inconclusive with regard to the potential for an increase in storminess as a result of climate change.

The volcanic and Old Red Sandstone cliffs, fronted by a fringing rock platform, have historically been experiencing very low rates of erosion, primarily through rock falls, and these rates are predicted to continue over the 100 year timeframe. The resistant nature of the cliffs will remain the dominant control on their erosion and therefore recession rates are not expected to be significantly affected by accelerated sea level rise in the future.

The following table (Table C4.1) is intended to provide local scale detail of the main changes predicted for each area, under a scenario of no active intervention.

C4.3 No Active Intervention Scenario Assessment Table

Table C4.1 No Active Intervention Scenario Assessment

Location	Predicted Change for No Active Intervention		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
CPU 1 Milton Ness to Montrose Harbour			
Milton Ness to Woodston Fishery	The cliffs along this frontage are undefended	The cliffs along this frontage are undefended	The cliffs along this frontage are undefended
	The volcanic cliffs, fronted by a fringing rock platform, have historically been experiencing very low rates of erosion, primarily through rock falls, and these rates are predicted to continue with negligible erosion therefore expected during this epoch. Small pocket beaches of shingle will remain at the toe of the cliffs.	Low rates of erosion are expected to continue during this epoch, <5m erosion possible over 50 years, primarily in the form of rock falls. Sea level rise may start to submerge the fringing rock platform, with potential narrowing of pocket beaches. It is not expected that sea level rise will significantly affect the rate of recession of cliffs along this frontage, due to their resistant nature.	Low rates of erosion is expected, with less than 10m of erosion predicted over the 100 year period, primarily in the form of rock falls. Potential loss of pocket beaches where they are unable to retreat due to the resistant cliffs behind, and the rock platforms fronting the cliffs may become submerged. However, the resistant nature of the cliffs will remain the dominant control on their erosion and therefore recession rates are not expected to be significantly affected by accelerated sea level rise.
Woodston Fishery to Montrose Links	Undefended intertidal sandy beach backed by a frontal dune ridge which extends along the majority of the frontage, dissected by the outlet of the River North Esk.	Undefended intertidal sandy beach backed by a frontal dune ridge which extends along the majority of the frontage, dissected by the outlet of the River North Esk.	Undefended intertidal sandy beach backed by a frontal dune ridge which extends along the majority of the frontage, dissected by the outlet of the River North Esk.
	Continued beach accretion along the St Cyrus frontage, providing natural dune protection. Erosion of the dune ridge during storms will provide minimal input of sediment to the enclosed system. Patterns of erosion and accretion will depend on the wave climate,	A continuation of existing erosion and accretion patterns is expected to continue unless the wave climate / drift patterns change (erosion south, accretion north). Accretion is likely to continue north of the River North Esk outlet.	A continuation of erosion and accretion patterns is expected to continue unless the wave climate / drift patterns change (erosion south, accretion north). Accretion is likely to continue north of the River North Esk outlet.

Location	Predicted Change for No Active Intervention		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
	therefore changes in the wave climate may affect sediment drift rates, directions and erosion and accretion within the bay. Natural movement and reorientation of the River North Esk channel will continue; the southern spit is likely to continue to grow northward under present wave climate conditions. Erosion rates of dunes to the south of the River North Esk mouth are likely to continue, increasing from north to south. Around <10m of erosion is possible within this epoch based on erosion predictions of <0.5m/yr south of the river outlet. Around 20m of erosion is possible north of Montrose Links based on 1m/yr rates.	The mouth of the River North Esk is likely to continue to naturally move and re-orientate over time. Erosion rates of dunes to the south of the River North Esk mouth are likely to continue, increasing from north to south. South of the North Esk outlet, around <25m of erosion is possible by year 50 based on erosion predictions of <0.5m/yr. Around 50m of erosion is possible by year 50, north of Montrose Links based on 1m/yr rates.	Natural movement and reorientation of the River North Esk channel will continue. South of the River North Esk outlet, Sea level rise would be expected to result in some beach narrowing and frontal dune erosion over time. Erosion rates of dunes to the south of the River North Esk mouth are likely to continue, increasing from north to south. South of the North Esk outlet, around <50m of erosion is possible by year 100 based on erosion predictions of <0.5m/yr. Around 100m of erosion is possible by year 100, north of Montrose Links based on 1m/yr rates.
Montrose Links	Two isolated rock revetments around golf holes will become less effective throughout this epoch and become isolated on the shore	Failure of revetments, undefended dune ridge	Undefended dune ridge
	There is expected to be continued erosion of the steeply faced dunes along the Montrose Links frontage. Continued retreat is anticipated between hard defended points; however this is likely to be variable and dependent on wave climate. Around 50m of erosion is possible within this epoch based on erosion predictions of 2.5m/yr (Milne and Dong, 2011). Increased localised erosion / cutback of dunes to the north of Splash due to the outflanking of hard defences at Splash and associated restriction of sediment movement north in this location.	Frontal erosion of dunes will continue through cliffing. However erosion is likely to be variable being highly dependant on wave climate and direction of littoral transport. Potential for around 125m of erosion over 50 years. Until the two revetments fail, they will continue to act to hold up erosion locally. Following failure of these defences there will be rapid erosion of the dunes back to the natural shoreline position and sediment will be released back into the system. Following the failure of defences at Splash, there will be rapid erosion of the backing dunes to a more natural shoreline position. Consequently,	Continuing erosion of the frontal dunes and golf course is predicted to occur, as sea levels rise. Potential for around 250m of erosion over the 100 year period.

Location	Predicted Change for No Active Intervention		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
		stored sediment will be released back into the system feeding fronting beaches, and (dependant on wave climate) those further north.	
Northern end of Splash to Montrose Harbour	Rock groynes, Sea wall and revetments (NAI Scenario assumes that South Esk channel maintenance dredging continues)	Failure of defences along the splash and caravan park frontage. Glaxo defences will remain. (NAI Scenario assumes that South Esk channel maintenance dredging continues)	Glaxo defences may remain if the fronting beach is stable. (NAI Scenario assumes that South Esk channel maintenance dredging continues)
	Defences at Splash artificially hold the shoreline approximately 40-60m seaward of its natural position, preventing natural coastal retreat. The reflective nature of the defences and coastal squeeze against the defences will result in narrowing of the beach.	Before defence failure, coastal squeeze of the beach against defences (i.e. beach narrowing) is expected with sea levels rise. Erosion of dunes following the failure of defences at Splash will be rapid, eroding back to a more natural position and will release stored sediment to fronting and adjacent beaches. Renourished beach volumes within the groyne bays at the Glaxo works may remain stable with potential new supply of sediment from the adjacent dunes immediately north.	Erosion of dunes estimated as approximately 2.5m/yr. Likely erosion of the play park and sections of Trail Drive. With a continued sediment supply from immediately north, the Glaxo frontage may remain stable, however, the beach may narrow as sea levels rise. If the beach erodes significantly and defences eventually fail, damage to infrastructure or industrial property would occur. Following failure of defences in Montrose Basin, inundation of low lying areas over time may increase the tidal prism and increase flows through the harbour channel. Consequently, this may increase erosion of the adjacent beach and dunes in this section.
CPU 2 Montrose Basin			
Montrose Harbour and Railway frontages	Montrose - Revetments and seawalls protecting railway infrastructure	Failure of revetments and seawalls	Failure of revetments and seawalls
	As the frontage is sheltered, the intertidal area will remain relatively stable. However, movement of the Tayock Burn channel may erode the sand /	Failure of coastal defences would lead to a significant disruption to the railway. Such failure could also lead to inundation of low lying land	Inundation of low-lying areas could allow the creation of new intertidal areas. This could increase the tidal prism of the Basin, which could

Location	Predicted Change for No Active Intervention		
	Years 0 – 20	**Years 20 – 50**	**Years 50 – 100**
	mudflats and threaten the integrity of defences over time.	under certain conditions. Erosion of exposed higher land is likely to be episodic (during storms) along this sheltered frontage, with rates of <0.1m/yr predicted. Following defence failure, natural meandering of the Tayock Burn may increase as the channel will be unconstrained, resulting in further erosion of banks depending on meandering patterns.	lead to increased siltation if sediment is available and an increase in flows through the harbour entrance and water levels within the basin. Erosion of exposed higher land is likely to be episodic (during storms) along this sheltered frontage, with rates of <0.1m/yr predicted.
Montrose Basin	Failure of ad hoc defences at Esk Road	Failure of remaining ad hoc seawalls, revetments, embankments	No defences present
	Assuming a continued supply of sediment, saltmarsh accretion / stability is expected. There is potential for episodic erosion of the coastal edge under certain conditions (<0.1m/yr).	Assuming continued sedimentary infilling, it is predicted that the Basin as a whole will maintain its overall stability under a scenario of future sea level rise. As defences fail or become ineffective, there will be flooding of the low-lying land behind, including previously reclaimed land, creating new intertidal areas. The lateral extent of flooding will be limited by higher land. This could increase the tidal prism and may increase flows in the Basin. Flows into and out of these new intertidal areas would create new channels or result in the expansion of the existing creek network. There is potential for episodic erosion of the coastal edge under certain conditions (<0.1m/yr).	During this period, the Basin will be responding to both changes in the management of the area as a whole and also rising sea levels. Therefore during this period more significant changes could occur. Inundation of low-lying areas would allow the creation of new intertidal areas. These areas would begin to revert to silt and mudflats and in places there would be marsh development, dependant on channel movement within the Basin. Marsh development will act to provide natural flood protection to the hinterland over time. Inundation of low-lying areas could increase the tidal prism of the Basin, which could lead to an increase in flows through the harbour entrance and water levels within the basin. There is potential for episodic erosion of the coastal edge under certain conditions (<0.1m/yr).
Ferryden to Scurdie Ness	Various structures including seawalls and revetments in front of the port, ad hoc private defences protecting properties and access roads	Gradual deterioration and potential loss of coastal defences towards the end of this epoch.	Failure of coastal defences. Undefended section between Ferryden and

Location	Predicted Change for No Active Intervention		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
	at Ferryden. Undefended section of resistant rocks, shore platform and shingle fringing beach between Ferryden and Scurdie Ness.	Undefended section between Ferryden and Scurdie Ness.	Scurdie Ness.
	Defences are expected to remain due to the sheltered nature of this frontage. However, overtopping of defences may become more of an issue throughout this epoch. Minimal erosion of undefended cliffs and shingle beach expected (<2m in 20 years).	There could be increased overtopping of defences and potential flooding of properties with sea level rise. It is not expected that sea level rise will significantly affect the rate of recession of the undefended cliffs along this frontage, with less than 5m total erosion expected by the end of this epoch, predominantly through localised cliff falls, due to their resistant nature. However, sea level rise may start to submerge the fringing rock platform and shingle fringing beach.	Defence failure would cause considerable damage and flooding during storm conditions to property or infrastructure backing the defence. From Ferryden to Scurdie Ness, less than 10m total erosion is predicted to occur by the end of this epoch, predominantly through localised cliff falls. Potential loss of the shingle fringe beach where it is unable to retreat due to resistant cliffs behind, and the rock platforms fronting the cliffs may become submerged. However, the resistant nature of the cliffs will remain the dominant control on their erosion and therefore recession rates are not expected to be significantly affected by accelerated sea level rise.
CPU 3 Scurdie Ness to Rickle Craig			
Scurdie Ness to Rickle Craig	The cliffs along this frontage are undefended	The cliffs along this frontage are undefended	The cliffs along this frontage are undefended
	The volcanic cliffs along the majority of this frontage, fronted by a fringing rock platform, have historically been experiencing low rates of erosion and this is predicted to continue with negligible erosion therefore expected during this epoch. Minimal erosion of the outcrop of upper Old Red Sandstone at Boddin Point is anticipated.	Low rates of erosion are expected to continue during this epoch, with less than 5m total erosion expected by the end of this epoch, predominantly through cliff falls. Sea level rise may start to submerge the fringing rock platform. Potential loss of some pocket beaches. It is not expected that sea level rise will significantly affect the rate of recession of cliffs along this frontage, due to their resistant nature.	Less than 10m total erosion is predicted to occur along this coastline over 100 years, predominantly through cliff falls. Potential loss of some pocket beaches where they are unable to retreat due to resistant cliffs behind, and the rock platforms fronting the cliffs may become submerged. However, the resistant nature of the cliffs will remain the dominant control on their erosion and therefore recession

Location	Predicted Change for No Active Intervention		
	Years 0 – 20	**Years 20 – 50**	**Years 50 – 100**
	Small shingle pocket beaches will remain.		rates are not expected to be significantly affected by accelerated sea level rise.
CPU 4 Rickle Craig to Lang Craig (Lunan Bay)			
Lunan Bay	Natural wide intertidal sand beach backed by a frontal dune ridge, dissected by the outlet of the Lunan Water. Failure of ad hoc seawalls and revetments at Corbie Knowe during this epoch.	Natural wide intertidal sand beach backed by a frontal dune ridge, dissected by the outlet of the Lunan Water No defences present at Corbie Knowe.	Natural wide intertidal sand beach backed by a frontal dune ridge, dissected by the outlet of the Lunan Water. No defences present at Corbie Knowe.
	The beach / dune system will continue to provide a natural form of defence to the backing agricultural land. The shoreline position is likely to continue to be stable. In the southern half of the bay, frontal dunes may be more vulnerable to wave attack during storms, however this may alter if the wave climate changes. To the north of Lunan Water, destabilisation of dunes with blowouts may be exacerbated by wind erosion and anthropogenic pressures. Minor natural fluctuations of the position of the Lunan Water channel may occur over time. Defences at Corbie Knowe will exacerbate beach lowering and outflanking of defences to the north will continue. Following failure of defences the local shoreline may erode back to a more natural alignment relatively quickly and then erosion rates are likely to slow. Flood risk will increase to remaining properties.	The beach / dune system will continue to provide a natural form of defence to the backing agricultural land. The shoreline position is likely to continue to be stable with areas of erosion and accretion fluctuating along the bay. Sea level rise and storm erosion will result in erosion of the frontal edge of the dunes. It is unlikely that this erosion will impact on farmland along the southern half of the bay or result in loss of property or historic interest at the mouth of the Lunan Water. Under a severe easterly storm, there is a risk of breaching of the dune ridge to the north of the Lunan Water outlet. This could lead to flooding of land, including the car park, and a flood risk to property in the immediate hinterland. Natural movement of the Lunan Water channel will continue. Slow erosion at Corbie Knowe will continue.	Erosion of the frontal edge of the dunes is expected to continue as sea levels rise. However, if dune erosion is significant, over time there is potential for a release of stored sediment as backing raised beaches and till cliffs are exposed. If this occurs fresh sediment will be provided to the beach and consequently beach composition may change and accretion may occur, resulting in a reversal of the erosive trend, despite sea level rise. This would not however, benefit other adjacent frontages as Lunan Bay is a closed sediment system. As the bay ‘deepens’ over time the area may become more sheltered. Natural movement of the Lunan Water channel will continue. The beach will narrow at Corbie Knowe as sea levels rise due to the limited accommodation space for natural beach roll-back.
CPU 5 Lang Craig to Whiting Ness			

Location	Predicted Change for No Active Intervention		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
Lang Craig to Whiting Ness	The cliffs along this frontage are undefended. Remnants of old harbour at Auchmithie.	The cliffs along this frontage are undefended	The cliffs along this frontage are undefended
	The cliffs along the majority of this frontage, fronted by a fringing rock platform, have historically been experiencing low rates of erosion and these are predicted to continue with negligible erosion expected during this epoch, although there is potential for periodic cliff falls. Small shingle pocket beaches will remain.	Low rates of erosion are expected to continue during this epoch, with less than 5m of erosion possible by the end of this epoch, mostly in the form of cliff falls. Sea level rise may start to submerge the fringing rock platform. Potential loss of some pocket beaches. It is not expected that sea level rise will significantly affect the rate of recession of cliffs along this frontage, due to their resistant nature.	Less than 10m of erosion is predicted to occur along this coastline by the end of the 100 year period, predominantly in the form of cliff falls. Potential loss of some pocket beaches where they are unable to retreat due to resistant cliffs behind, and the rock platforms fronting the cliffs may become submerged. However, the resistant nature of the cliffs will remain the dominant control on their erosion and therefore recession rates are not expected to be significantly affected by accelerated sea level rise.
CPU 6 Whiting Ness to West Haven			
Whiting Ness to Arbroath Harbour	Seawall at Victoria Park and Seagate	Failure of the seawall at Seagate and Victoria Park	No defences
	The fronting sea wall at Victoria Park will remain throughout this epoch. The reflective nature of this defence combined with the wide rock platform will mean little material will accumulate in this location. South of Victoria Park to Seagate the beach may roll back where unconstrained, but may narrow over time in front of the seawall, due to its reflective nature.	There will be an increased frequency and magnitude of overtopping over time, leading to flooding of assets and Kings Drive. Lowering and narrowing of the shingle beach at Seagate will increase vulnerability of the defence toe as sea levels rise. Gradual deterioration of the coastal defences could lead to sudden failure under extreme events. Following defence failure at Victoria Park, damage to the esplanade and Kings Drive may result in erosion of the raised beach and reactivation / re-working of hinterland deposits. There is likely to be rapid erosion of the raised beach back to a more natural alignment (up to 45m of erosion	Potential erosion of the raised the beach at Victoria Park will continue as sea levels rise, albeit at a relatively low rate (0.5m/yr assumed). Permanent submergence of fringing rock platforms is also possible, increasing vulnerability of the shoreline to wave attack. The beach at Seagate will continue to narrow and lower as sea levels rise.

Location	Predicted Change for No Active Intervention		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
		could be experienced in places). The release of material would potentially feed a new beach at a more set back location and stabilise the frontage. However, with sea level rise, erosion could be up to 0.5m/yr. Failure of defences at Seagate will result in increased flood risk to, and potential loss of properties along the frontage. Rollback of the existing beach will be constrained by properties and infrastructure and therefore narrow and lower as sea levels rise.	
Arbroath Harbour	Harbour breakwaters, quay walls, inner seawalls and revetment.	Harbour breakwaters, quay walls, inner seawalls and revetment. Potential failure of concrete block breakwater to the south of the harbour.	Failure of harbour breakwaters and then inner quay walls and coastal defences.
	Assuming the harbour breakwaters remain throughout this epoch there is likely to be little change in shoreline position from present. Despite the outer breakwaters providing some protection, the seawalls along Inchcape will continue to be subjected to considerable wave action and increased overtopping frequency and magnitude will occur over time.	Narrowing of the small shingle beach will occur as sea levels rise. Failure of the concrete block breakwater would result in the loss of recreational open space and infrastructure, but will provide potential accommodation space for landward migration of the beach.	Failure of any of the outer harbour walls, under a severe storm, would lead to considerable disruption to the harbour and infrastructure and damage to property. However, it is likely that if the harbour walls fail in terms of function, they will still remain in some form, and will continue to provide a degree of protection and shelter to the shoreline.
Inchcape Park and West Links	Revetment and seawalls.	Deterioration of revetment and seawall.	Failure of defences.
	High reflectivity of seawalls will exacerbate beach lowering of already low beaches. Consequently, increased frequency and magnitude of overtopping will occur over time, resulting in increased flood risk to the hinterland area.	Potential for loss of the intertidal area and lowering and narrowing of beaches as sea levels rise will increasingly undermine defences. Once defences fail, erosion of the raised beach will be reactivated (approximately 0.5m/yr), providing	Following failure of defences a more natural system will develop. As sea levels rise, erosion of the raised beach will release sediment into the system, maintaining a beach in this location and feeding beaches to the south. Erosion rates are

Location	Predicted Change for No Active Intervention		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
		new sediment to the local beach and to those south of this frontage. Due to the location of the shore platform, Inchcape Park is likely to remain a promontory. Flooding potential and damage to infrastructure and recreation space will increase.	estimated as 0.5m/yr).
West Links to West Haven	Predominantly undefended frontage. Revetment at Elliot outfall will remain. Short seawall at Hatton protecting the railway will deteriorate and fail.	Revetment at Elliot outfall will deteriorate and fail towards the end of this epoch. Natural sand and shingle beach fronted by a rock platform along the majority of the frontage.	Natural sand and shingle beach fronted by a rock platform along the majority of the frontage.
	Along this mostly undefended section, erosion and accretion patterns are likely to continue, with current sediment transport south. The shore platform and cobble storm beach at the dune toe will continue to provide natural protection to this stable frontage, however, a slow minimal retreat of the beach to is likely to continue, as has been observed over the last 30 years. Following failure of the defence at Hatton the railway will be at increasing risk of damage.	Erosion and accretion patterns are likely to continue, dependant on wave climate and sediment transport direction. Continued slow rates of beach retreat and frontal dune erosion is likely. The shore platform and storm beach will continue to provide protection to the backing dune system, however, with sea levels rise the influence of the platform may reduce as it becomes submerged. At East and West Haven flood and erosion risk to property may become an issue over time as sea levels rise.	The rock platform fronting the beach may become submerged as sea levels rise. The natural protection afforded by the rock platform to the beach will therefore diminish over time and potentially result in increased frontal dune erosion over this period, however, erosion rates are still expected to be relatively low, <5m over 50 years. Released sediment may act to feed local beaches and those downdrift towards East and West Haven.
CPU 7 West Haven to Buddon Ness			
West Haven to Carnoustie Station	Carnoustie defences will remain. Deterioration of ad hoc defences at the Look Out Station.	Carnoustie defences will remain in some form. Failure of defences at the Look Out Station.	Carnoustie defences may remain in some form, however if the fronting beach erodes defences may fail.
	The intertidal rock platform will continue to provide natural protection to this stable frontage.	The intertidal rock platform is expected to continue to provide natural protection to the	The rock platform fronting the beach may become increasingly submerged as sea levels rise.

Location	Predicted Change for No Active Intervention		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
	The frontal dune system will however, be susceptible to storm damage, especially at the Look Out Station.	frontage, however, this influence will reduce with sea level rise. The dunes will remain relatively stable, however, the frontal dune system will be susceptible to storm damage and erosion will occur, albeit at a low rate where defences have failed.	The natural protection afforded by the rock platform to the beach will therefore diminish over time. Although the dune system is assumed to remain fairly resilient there will be potential for migration of the dunes landward where accommodation space is available, as sea levels rise. Frontal dune erosion rates are expected to be low once defences fail at Carnoustie (<0.1m/yr).
Carnoustie Station to Barry Burn	Predominantly defended frontage including rock revetments and gabions	Revetments will deteriorate	No defences
	The fronting beach may narrow and lower due to the reflective nature of the defences and coastal squeeze against the defences over time. Overtopping of defences will become more of a problem over time. The position of the Gaa Spit, wave climate and tidal processes will continue to have considerable influence on erosion and accretion patterns in Carnoustie Bay.	As defences deteriorate, recreational land will be at risk of overtopping. However, due to the scale of these defences, they are likely to continue to have an influence on coastal processes where the intertidal beach will continue to narrow and lower seaward of the remaining structures as sea levels rise. The position of the Gaa Spit, wave climate and tidal processes will continue to have considerable influence on erosion and accretion patterns in Carnoustie Bay.	Potential for rapid erosion of the backing links following defence failure, back to a more natural embayment position, potential for up to 50m of erosion by the end of the epoch. Activation of dune erosion will provide new sediment to the local beach system. Following this, frontal dune erosion will continue as sea levels rise (<0.1m/yr) The position of the Gaa Spit, wave climate and tidal processes will continue to have considerable influence on erosion and accretion patterns in Carnoustie Bay.
Barry Sands East	Rock revetment	Failure of rock revetment towards the end of the epoch.	No defences
	The defences will continue to effectively restrict naturally highly dynamic movement of the beach and backing dune system and restrict natural sediment exchange between the beach and dunes. Consequently there is potential for beach	As sea levels rise, beach lowering and potential for loss of intertidal areas may be an issue in front of the defence. This will act to undermine defences and increase overtopping over time. As long as the revetment remains along the Barry	Frontal dune erosion will continue as sea levels rise. Erosion rates / patterns along this frontage will however, be influenced by the existence / location of the drift divide and wave and tidal conditions.

Location	Predicted Change for No Active Intervention		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
	lowering adjacent to the defence and undermining of the revetment. Downdrift erosion of frontal dunes to the south of the defences at Barry Sands East is likely to continue. Erosion patterns will however, be influenced by the existence / location of the drift divide and wave and tidal conditions along this frontage.	Sands East frontage, downdrift erosion of frontal dunes to the south of this defence will continue. Following defence failure, potential for rapid erosion of the links area, back to a more natural alignment. Activation of dune erosion will provide new sediment to the local beach system and Carnoustie Bay. Erosion patterns will however, be influenced by the existence / location of the drift divide and wave and tidal conditions along this frontage.	
CPU 8 Buddon Ness to Broughty Castle			
Buddon Ness and Barry Sands West	Undefended intertidal sandy beach and backing dune system	Undefended intertidal sandy beach and backing dune system	Undefended intertidal sandy beach and backing dune system
	The highly dynamic system will continue to evolve naturally. Downdrift erosion of frontal dunes to the south of the defences at Barry Sands East is likely to continue. Accretion of the beach and dunes is predicted to continue at Buddon Ness. Erosion and accretion patterns along the Barry Sands West frontage are likely to continue with the growth of the spit deflecting the Buddon Burn outlet towards the west.	The highly dynamic system will continue to evolve naturally. As sea levels rise the erosion of frontal dunes and natural beach roll back will continue over time. Erosion and accretion patterns are likely to fluctuate, however continued accretion of Buddon Ness is predicted. As long as the revetment remains along the Barry Sands East frontage, downdrift erosion of frontal dunes to the south of this defence will continue.	The beach and frontal dunes will naturally tend to erode / roll back landwards as sea levels rise. Erosion and accretion patterns are likely to fluctuate, due to the highly dynamic system. These patterns will be predominately influenced by tidal conditions at the mouth of the Tay Estuary and the influence of Gaa Sands and Spit.
MoD boundary to Dighty Water (Monifieth)	Rock and timber revetments Timber groynes will deteriorate and fail	Rock revetments remain	No defences
	Future evolution along this frontage will be highly dependant on sediment supply and movement of	Future evolution along this frontage will be highly dependant on sediment supply and movement of	Future evolution along this frontage will be highly dependant on sediment supply and movement of

Location	Predicted Change for No Active Intervention		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
	channels and bank systems at the mouth of the Tay Estuary. If present conditions continue, accretion is predicted along the eastern part of the frontage between Riverside Caravan Park and the MoD boundary. Along the western part of the frontage towards Milton Mill, erosional trends are likely to continue. As the groynes become less effective it will be more difficult to maintain a beach in this location. Backing dunes in this location should remain relatively stable, whilst protected by the timber revetment. However, the revetment will act as a barrier between the beach and dune system, inhibiting natural processes and interaction between the two systems. Consequently sediment supply to the dune system will be restricted and erosion may result over time. Immediately east of Dighty Water, the revetment is expected to remain throughout this period.	channels and bank systems at the mouth of the Tay Estuary. If present conditions continue, accretion / stability is predicted along the eastern part of the frontage between Riverside Caravan Park and the MoD boundary. Along the Marine Drive frontage the rock revetment may still remain in some form and therefore the trend of beach lowering is likely as sea levels rise. To the west, Failure of timber defences, coupled with beach loss will increase vulnerability of the backing dune system to wave attack and consequently erosion, averaging 0.25m / year has been assumed (7.5m by year 50). However, this will also allow sediment transfer between the beach and dune systems and vice versa. The rock revetment east of Dighty Water is still likely to be functional during this period; however overtopping risk and beach narrowing due to coastal squeeze may increase as sea levels rise.	channels and bank systems at the mouth of the Tay Estuary. In the east of the frontage, if sediment supply is restricted or the channel moves landward, present accretion / stability trends may reverse. As sea levels rise and defences fail, the backing dunes will experience frontal erosion (20m by year 100 assuming 0.25m/year) and migrate landward where accommodation space is available, where space is limited beach lowering and narrowing will increase. The railway will be at risk following failure of the defences east of Dighty water. The beach will continue to narrow and lower as sea levels rise.
Dighty Water to Broughty Castle	Revetment, groynes and a seawall at Broughty Ferry East	Failure of revetment and groynes to the east. Seawall at Broughty Ferry remains.	No defences in the east. Deterioration of seawall at Broughty Ferry.
	Future evolution along this frontage will be highly dependant on sediment supply and movement of channels and bank systems at the mouth of the Tay Estuary. Under continued present conditions, west of Dighty Water, erosion is predicted due to lack of	Future evolution along this frontage will be highly dependant on sediment supply and movement of channels and bank systems at the mouth of the Tay Estuary. Following deterioration and failure of defences to the east of the frontage, erosion of the hinterland	The pattern of erosion in the east and accretion in the west is likely to continue, dependant on the influence of offshore banks and bars, wave conditions and a continued sediment supply. As sea levels rise backing dunes will migrate landward where accommodation space is

Location	Predicted Change for No Active Intervention		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
	sediment supply from the east. Throughout this epoch groynes will continue to deteriorate and become less effective at holding the beach, providing a release of sediment to feed and maintain the stability of beaches in the west of this frontage towards Broughty Castle. Dunes along the frontage are likely to remain stable, with any erosion likely to be due to anthropogenic activities rather than coastal processes.	may occur, however remnants of the rock defences are likely to remain into this epoch, providing a small amount of continued protection. Along the central frontage, if sea level rise becomes an issue, frontal dune erosion may become more frequent; where accommodation space is available dunes will migrate landwards. Dunes along the Broughty Castle frontage are likely to continue to show stability providing a continued sediment supply from the east. If sea level rise increases, the beach is likely to narrow and frontal dunes may be at risk of erosion more frequently. Where the seawall remains, landward migration of the dunes will be restricted.	available. Where infrastructure or defences restrict movement beaches will narrow and dune erosion will increase.

C5 Baseline Scenario 2 – With Present Policies

C5.1 Introduction

This alternative baseline scenario has been considered to inform the development of a series of sustainable high level shoreline management policies along the coast. The SMP does not involve detailed assessment of current or future standards of coastal erosion or flood risk protection. Further strategic assessment and studies may be required to consider particular areas/ frontages in greater detail.

The With Present Policies (WPP) baseline scenario assumes that policies recommended in SMP1 (Table C5.1) continue until technically impossible (for example, if the beach on which the defences sit is totally lost), or when current policies become ineffective, with identification of where additional maintenance or improvements may be required (for example to cope with rising sea levels). If the intention of current policy is to minimise the risk of flooding, it is assumed that the defences will be maintained or improved to provide a suitable standard of protection.

Table C5.1 Recommended preferred policies in Angus SMP1 (Angus Council, 2004)

Location	SMP1 Short Term Policy	SMP1 Long Term Policy (up to 2050)
CPU 1		
MU 1/1 Montrose Bay	**No Active Intervention** (<5-10 years)	**No Active Intervention** If dune erosion becomes an issue the policy may need to be changed to Limited Intervention to allow dune stabilisation measures.
MU 1/2 Montrose Golf Course	**Limited Intervention / Managed Retreat** (relocate golf holes at risk) (<5-10 years)	**No Active Intervention**
MU 1/3 Splash and GlaxoSmithKline	**Hold the Line** (<5-10 years)	**Hold the Line**
CPU 2		
MU 2/1 Harbour and Montrose Railway	**Hold the Line** (<5-10 years)	**Hold the Line**
MU 2/2 Montrose Basin	**Selectively Hold the Line: Hold the line** (Taycock, Rossie Island, Western flank) **/ No active Intervention (part)** (<10-15 years)	**Selectively Hold the Line: Managed Realignment (part) / Hold the line (part) / No active Intervention (part)**
MU 2/3Ferryden to Scurdie Ness	**Selectively Hold the Line: Hold the line** (Ferryden) **/ No active Intervention (part)** (<5-10 years)	**Selectively Hold the Line: Hold the line** (Ferryden) **/ No active Intervention (part)**

Location	SMP1 Short Term Policy	SMP1 Long Term Policy (up to 2050)
CPU 3		
MU 3/1 Scurdie Ness to Rickle Craig	**No Active Intervention** (<10-15 years)	**Selectively Hold the Line: Hold the line** (Railway) **/ No active Intervention**
CPU 4		
MU 4/1 Lunan Bay	**Selectively Hold the Line: Limited Intervention / Hold the Line** (Corbie Knowe) (<10-15 years)	**Selectively Hold the Line: Limited Intervention / Hold the Line** (Corbie Knowe)
CPU 5		
MU 5/1 Lang Craig to Whiting Ness	**No Active Intervention**	**No Active Intervention**
CPU 6		
MU 6/1 Victoria Park and Seagate	**Hold the Line** (<10-15 years)	**Hold the Line**
MU 6/2 Danger Point to Inchcape Park (Arbroath Harbour)	**Hold the Line** (<10-15 years)	**Hold the Line**
MU 6/3 Inchcape Park to West Links	**Hold the Line**	**Hold the Line**
MU 6/4 West Links to West Haven	**Selectively Hold the Line: No Active Intervention (part) / Limited Intervention (part) / Hold the Line (part)** (<10-15 years)	**Selectively Hold the Line: Hold the Line (part) / Limited Intervention (part) / No Active Intervention (part)**
CPU 7		
MU 7/1 West Haven to Carnoustie Railway Station	**Selectively Hold the Line: Limited Intervention / Hold the Line** (<10-15 years)	**Selectively Hold the Line: Limited Intervention / Hold the Line**
MU 7/2 Carnoustie Bay	**Hold the Line**	**Hold the Line**
MU 7/3 Barry Sands East	**Hold the Line**	**Hold the Line**
CPU 8		
MU 8/1 Buddon Ness and Barry Sands West	**No Active Intervention**	**No Active Intervention**
MU 8/2 Monifieth	**Hold the Line** (<10-15 years)	**Hold the Line**
MU 8/3 Monifieth West	**Hold the Line** (<10-15 years)	**Hold the Line**
MU 8/4 Barnhill	**Hold the Line** (<10-15 years)	**Hold the Line**
MU 8/5 Broughty Ferry	**Hold the Line** (<10-15 years)	**Hold the Line**

Location	SMP1 Short Term Policy	SMP1 Long Term Policy (up to 2050)
East		
MU 8/6 Broughty Ferry	**Hold the Line** (<10-15 years)	**Hold the Line**

The text below aims to convey that unless maintenance or improvement works are undertaken, then existing defences are unlikely to provide a suitable standard of protection in future due to climate change and associated changes including sea level rise. High level assumptions with respect to existing defences have been clearly stated at the start of each section.

C5.2 Overview

A discussion of the SMP-scale, under a scenario of no active intervention, i.e. assuming that defences are allowed to deteriorate and fail, is provided in Section C4, and for much of the undefended coast many of the predicted changes would be the same.

The effect of continuing to maintain existing defences is that continued protection will be afforded to the key areas of socio-economic importance; however, the ability of the shoreline to respond naturally to changes in wind, waves, bathymetry and sea level, will be impeded.

The effect of a significant increase in the rate of sea level rise would also increase the pressure on these coastal defences along the exposed open coast. Along the undefended shorelines, a significant proportion of the eroded sand would be likely to be reworked landwards by wave and wind action, thereby conserving the sand volume of landward-moving frontal dunes; however, where defences have reduced the interaction between the beach and dune, or where the landward movement of dunes is prevented, this sediment may ultimately be lost offshore. Similarly, where defences prevent the natural landward retreat of beaches, a reduction in beach / dune sand volume is likely to occur over the longer term, placing increased stress on the defences. There will be deeper water and greater wave exposure at the seawalls. These conditions will not be conducive to beach retention and any sediment arriving on these frontages is likely to be rapidly transported offshore again. This will also increase the vulnerability of these defence structures; more frequent work to maintain their integrity will be required to prevent erosion and maintain the shoreline in its present position, with eventually more substantial defences being necessary.

The following table (Table C5.2) provides local-scale detail of the main changes predicted for each area under a WPP scenario.

C5.3 With Present Policies Scenario Assessment Table

Table C5.2 With Present Policies Scenario Assessment Table

Location	Predicted Change for With Present Policies		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
CPU 1 Milton Ness to Montrose Harbour			
Milton Ness to Woodston Fishery	The cliffs along this frontage are undefended SMP1 policy: **No Active Intervention** (<5-10 years)	The cliffs along this frontage are undefended SMP1 policy: **No Active Intervention** (If dune erosion becomes an issue the policy may need to be changed to Limited Intervention to allow dune stabilisation measures).	The cliffs along this frontage are undefended
	The volcanic cliffs, fronted by a fringing rock platform, have historically been experiencing very low rates of erosion, primarily through rock falls, and these rates are predicted to continue with negligible erosion therefore expected during this epoch. Small pocket beaches of shingle will remain at the toe of the cliffs.	Low rates of erosion are expected to continue during this epoch, <5m erosion possible over 50 years, primarily in the form of rock falls. Sea level rise may start to submerge the fringing rock platform, with potential narrowing of pocket beaches. It is not expected that sea level rise will significantly affect the rate of recession of cliffs along this frontage, due to their resistant nature.	Low rates of erosion is expected, with less than 10m of erosion predicted over the 100 year period, primarily in the form of rock falls. Potential loss of pocket beaches where they are unable to retreat due to the resistant cliffs behind, and the rock platforms fronting the cliffs may become submerged. However, the resistant nature of the cliffs will remain the dominant control on their erosion and therefore recession rates are not expected to be significantly affected by accelerated sea level rise.
Woodston Fishery to Montrose Links	Undefended intertidal sandy beach backed by a frontal dune ridge which extends along the majority of the frontage, dissected by the outlet of the River North Esk. SMP1 policy: **No Active Intervention** (<5-10 years)	Undefended intertidal sandy beach backed by a frontal dune ridge which extends along the majority of the frontage, dissected by the outlet of the River North Esk. If erosion becomes an issue affecting dune stability, undertake dune stability measures.	Undefended intertidal sandy beach backed by a frontal dune ridge which extends along the majority of the frontage, dissected by the outlet of the River North Esk. If erosion becomes an issue affecting dune stability, undertake dune stability measures.

Location	Predicted Change for With Present Policies		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
		SMP1 policy: **No Active Intervention** (If dune erosion becomes an issue the policy may need to be changed to Limited Intervention to allow dune stabilisation measures).	
	Continued beach accretion along the St Cyrus frontage, providing natural dune protection. Erosion of the dune ridge during storms will provide minimal input of sediment to the enclosed system. Patterns of erosion and accretion will depend on the wave climate, therefore changes in the wave climate may affect sediment drift rates, directions and erosion and accretion within the bay. Natural movement and reorientation of the River North Esk channel will continue; the southern spit is likely to continue to grow northward under present wave climate conditions. Erosion rates of dunes to the south of the River North Esk mouth are likely to continue, increasing from north to south. Around <10m of erosion is possible within this epoch based on erosion predictions of <0.5m/yr south of the river outlet. Around 20m of erosion is possible north of Montrose Links based on 1m/yr rates.	A continuation of erosion and accretion patterns is expected to continue unless the wave climate / drift patterns change (erosion south, accretion north). With rising sea levels, some beach narrowing and frontal dune erosion would be expected to result, over time. Accretion is likely to continue north of the River North Esk outlet. The mouth of the River North Esk is likely to continue to naturally move and re-orientate over time. Erosion rates of dunes to the south of the River North Esk mouth are likely to continue, increasing from north to south. South of the North Esk outlet, around <25m of erosion is possible by year 50 based on erosion predictions of <0.5m/yr. Around 50m of erosion is possible by year 50, north of Montrose Links based on 1m/yr rates. Dune stability measures would help limit localised dune erosions.	A continuation of erosion and accretion patterns is expected to continue unless the wave climate / drift patterns change (erosion south, accretion north). Accretion is likely to continue north of the River North Esk outlet. Natural movement and reorientation of the River North Esk channel will continue. South of the River North Esk outlet, Sea level rise would be expected to result in some beach narrowing and frontal dune erosion over time. Erosion rates of dunes to the south of the River North Esk mouth are likely to continue, increasing from north to south. South of the North Esk outlet, around <50m of erosion is possible by year 100 based on erosion predictions of <0.5m/yr. Around 100m of erosion is possible by year 100, north of Montrose Links based on 1m/yr rates. There is however, potential for these rates to increase over this epoch due to the reduced sediment supply resulting from continued defence of Splash. Dune stability measures would help limit localised dune erosion.
Montrose Links	Relocate the golf holes and remove inactive defences	Undefended natural dune beach system SMP1 policy: **No Active Intervention**	Undefended natural dune beach system

Location	Predicted Change for With Present Policies		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
	SMP1 policy: **Limited Intervention** / **Managed Retreat** (relocate golf holes at risk) (<5-10 years)		
	Continued erosion of the steeply faced dunes along the Montrose Links frontage. Continued frontal dune erosion is anticipated between hard defended points; however this is likely to be variable and dependent on wave climate. Around 50m of erosion is possible within this epoch based on erosion predictions of 2.5m/yr (Milne and Dong, 2011). Increased localised erosion / cutback of dunes to the north of Splash due to the outflanking of hard defences at Splash and associated restriction of sediment movement north in this location.	Frontal erosion of dunes will continue through cliffing. However erosion is likely to be variable being highly dependant on wave climate and direction of littoral transport. Potential for around 125m of erosion over 50 years. Following failure / removal of the hard points there will be rapid erosion of the dunes back to the natural shoreline position and sediment will be released back into the system.	Continuing erosion of the frontal dunes and golf course is predicted to occur, as sea levels rise. Potential for around 250m of erosion over the 100 year period. There is however, potential for this rate to increase over this epoch due to the reduced sediment supply resulting from continued defence of Splash.
Northern end of Splash to Montrose Harbour	Rock groynes, Sea wall and revetments South Esk channel maintenance dredging continues. SMP1 policy: **Hold the Line** (<5-10 years)	Rock groynes, Sea wall and revetments maintained. Additional toe armouring will be required to reduce risk of undermining of the defences at Splash. Beach recharge South Esk channel maintenance dredging continues. SMP1 policy: **Hold the Line**	Rock groynes, Sea wall and revetments maintained. Beach recharge South Esk channel maintenance dredging continues.
	Defences at Splash artificially hold the shoreline approximately 40-60m seaward of its natural position, preventing natural coastal retreat. The reflective nature of the defences and coastal squeeze against the defences will result in narrowing of the beach. The Glaxo frontage is likely to remain stable.	Narrowing and lowering of the beach in front of defences will continue with sea level rise. Overtopping and therefore flood risk to assets risk will increase. Groynes may continue to help maintain a wider beach fronting the Glaxo site, however, this beach will also lower as sea levels rise, due to coastal	As sea levels rise, beaches will lower and narrow. Further recharge campaigns may be required to maintain beach levels and standards of protection required along the frontage.

Location	Predicted Change for With Present Policies		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
		squeeze against the defence. Beach recharge will be required to maintain beach levels and standards of protection required along the frontage.	
CPU 2 Montrose Basin			
Montrose Harbour and Railway frontages	Montrose - Revetments and seawalls protecting railway infrastructure SMP1 policy: **Hold the Line** (<5-10 years)	Defences will need ongoing maintenance and improvements during this epoch. SMP1 policy: **Hold the Line**	Defences will need ongoing maintenance and improvements during this epoch.
	As the frontage is sheltered, the intertidal area will remain relatively stable. However, movement of the Tayock Burn channel may erode the sand / mudflats and threaten the integrity of defences over time.	Potential for erosion and coastal squeeze of the intertidal area against the defences due to Tayock Burn channel migration and potentially sea level rise.	Erosion and coastal squeeze of the intertidal area against the defences may occur, dependant on movement of the Tayock Burn channel and potential sea level rise.
Montrose Basin	Existing defences along the west of the Basin, at Tayock and Esk Road, Rossie Island will need ongoing maintenance and improvements during this epoch. SMP1 policy: **Selectively Hold the Line: Hold the line** (Taycock, Rossie Island, Western flank) **/ No active Intervention (part)** (<10-15 years)	Hold the Line policy - Existing defences along the west of the Basin, at Tayock and Esk Road, Rossie Island will need ongoing maintenance and improvements during this epoch. Management Realignment policy - existing defences at Tayock and Esk Road, Rossie Island will need ongoing maintenance and improvements during this epoch. Set-back defences may be required in a set-back location to reduce flood risks to property and infrastructure along the western flank of the Basin. SMP1 policy: **Selectively Hold the Line: Managed Realignment (part) / Hold the line (part) / No active Intervention (part)**	Existing defences along the west of the Basin, at Tayock and Esk Road, Rossie Island will need ongoing maintenance and improvements during this epoch. Under a managed realignment policy, set-back defences along the west of the Basin, and existing defences at Tayock and Esk Road, Rossie Island will need ongoing maintenance and improvements during this epoch.
	Assuming a continued supply of sediment,	Assuming continued sedimentary infilling, it is predicted that the Basin as a whole will maintain	Assuming continued sedimentary infilling, it is predicted that the Basin as a whole will maintain

Location	Predicted Change for With Present Policies		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
	saltmarsh accretion / stability is expected. There is potential for episodic erosion of the coastal edge under certain conditions (<0.1m/yr).	its overall stability under a scenario of future sea level rise. There is potential for episodic erosion of the coastal edge around the basin under certain conditions. Under a hold the line policy there is potential for erosion and coastal squeeze of the intertidal area against defences due to channel movement and, over time, sea level rise. Under a managed realignment policy, along the western Basin, as defences fail, become ineffective, or are removed, there will be flooding of the land behind, including previously reclaimed land, creating new intertidal areas. The lateral extent of flooding will be limited by higher land or new set-back defences. This could increase tidal prism and may increase flows and water levels in the Basin. Flows into and out of these new intertidal areas would create new channels or result in the expansion of the existing creek network. There is potential for episodic erosion of undefended sections of the coastal edge under certain conditions (<0.1m/yr).	its overall stability under a scenario of future sea level rise. Under a hold the line policy, there is potential for erosion and coastal squeeze of the intertidal area against defences due to channel movement and, over time, sea level rise. Undefended locations may be at risk of erosion and or flooding as sea levels rise, with the potential for creation of habitat over time in these locations. Under a managed realignment policy, new habitats will created / increased in new intertidal areas. This could result in further changes to river flow patterns and sediment movement. Flows into and out of these new intertidal areas would create new channels or result in the expansion of the existing creek network. There is potential for episodic erosion of undefended sections of the coastal edge under certain conditions (<0.1m/yr).
Ferryden to Scurdie Ness	Various structures including seawalls and revetments in front of the port, ad hoc private defences protecting properties and access roads at Ferryden will need ongoing maintenance and improvements. Undefended section of resistant rocks, shore platform and shingle fringing beach between Ferryden and Scurdie Ness.	Defences will need ongoing maintenance and improvements during this epoch. SMP1 policy: **Selectively Hold the Line: Hold the line** (Ferryden) **/ No active Intervention (part)**	Defences will need ongoing maintenance and improvements during this epoch.

Location	Predicted Change for With Present Policies		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
	SMP1 policy: **Selectively Hold the Line: Hold the line** (Ferryden) **/ No active Intervention (part)** (<5-10 years)		
	Overtopping of defences may become more of an issue throughout this epoch. Minimal erosion of undefended cliffs and shingle beach expected (<2m by year 20).	Increased overtopping of defences and potential flooding of properties is likely with sea level rise. It is not expected that sea level rise will significantly affect the rate of recession of the undefended cliffs along this frontage, with less than 5m total erosion expected by the end of this epoch, predominantly through localised cliff falls, due to their resistant nature. However, sea level rise may start to submerge the fringing rock platform and shingle fringing beach.	Increased overtopping of defences and potential flooding of properties is likely with sea level rise. From Ferryden to Scurdie Ness, less than 10m total erosion is predicted to occur by the end of this epoch, predominantly through localised cliff falls. Potential loss of the shingle fringe beach where it is unable to retreat due to resistant cliffs behind, and the rock platforms fronting the cliffs may become submerged. However, the resistant nature of the cliffs will remain the dominant control on their erosion and therefore recession rates are not expected to be significantly affected by accelerated sea level rise.
CPU 3 Scurdie Ness to Rickle Craig			
Scurdie Ness to Rickle Craig	The cliffs along this frontage are undefended SMP1 policy: **No Active Intervention** (<10-15 years)	The cliffs along this frontage are undefended. A linear defence and slope stability improvements may be required in front of the railway at Rickle Craig. SMP1 policy: **Selectively Hold the Line: Hold the line** (Railway) **/ No active Intervention**	The cliffs along this frontage are undefended If applicable, railway protection will need ongoing maintenance and improvements during this epoch.
	The volcanic cliffs along the majority of this frontage, fronted by a fringing rock platform, have historically been experiencing low rates of erosion and this is predicted to continue with negligible erosion therefore expected during this	Low rates of erosion are expected to continue during this epoch, with less than 5m total erosion expected by the end of this epoch, predominantly through cliff falls. Sea level rise may start to submerge the fringing	Less than 10m total erosion is predicted to occur along this coastline over 100 years, predominantly through cliff falls. Potential loss of some pocket beaches where they are unable to retreat due to resistant cliffs

Location	Predicted Change for With Present Policies		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
	epoch. Minimal erosion of the outcrop of upper Old Red Sandstone at Boddin Point is anticipated. Small shingle pocket beaches will remain.	rock platform. Potential loss of some pocket beaches. It is not expected that sea level rise will significantly affect the rate of recession of cliffs along this frontage, due to their resistant nature.	behind, and the rock platforms fronting the cliffs may become submerged. However, the resistant nature of the cliffs will remain the dominant control on their erosion and therefore recession rates are not expected to be significantly affected by accelerated sea level rise.
CPU 4 Rickle Craig to Lang Craig			
Lunan Bay	Natural wide intertidal sand beach backed by a frontal dune ridge, dissected by the outlet of the Lunan Water. Ad hoc seawalls and revetments at Corbie Knowe. SMP1 policy: **Selectively Hold the Line: Limited Intervention / Hold the Line** (Corbie Knowe) (<10-15 years)	Limited intervention north of the Lunan Water to prevent breaching to the north of the Lunan Water outlet. Defences at Corbie Knowe will need ongoing maintenance and improvements during this epoch. SMP1 policy: **Selectively Hold the Line: Limited Intervention / Hold the Line** (Corbie Knowe)	Limited intervention north of the Lunan Water to prevent breaching to the north of the Lunan Water outlet. Defences at Corbie Knowe will need ongoing maintenance and improvements during this epoch.
	The beach / dune system will continue to provide a natural form of defence to the backing agricultural land. The shoreline position is likely to continue to be stable. In the southern half of the bay, frontal dunes may be more vulnerable to wave attack during storms, however this may alter if the wave climate changes. To the north of Lunan Water, destabilisation of dunes with blowouts may be exacerbated by wind erosion and anthropogenic pressures. Minor natural fluctuations of the position of the Lunan Water channel may occur over time. Defences at Corbie Knowe will exacerbate beach lowering and outflanking of defences to the north	Limited intervention may be required to slow the erosion of frontal dunes to the north of the Lunan Water. Elsewhere the dunes will continue to erode naturally. It is unlikely that this erosion will impact on farmland along the southern half of the bay or result in loss of property or historic interest at the mouth of the Lunan Water. Natural movement of the Lunan Water channel will continue. Defences at Corbie Knowe will exacerbate beach lowering and outflanking of defences to the north. Overtopping of defences may increase as sea levels rise.	Slow rates of erosion of frontal dunes to the north of the Lunan Water with limited intervention. Elsewhere the frontal dunes will continue to erode naturally as sea levels rise. However, if dune erosion is significant, over time there is potential for a release of stored sediment as backing raised beaches and till cliffs are exposed. If this occurs fresh sediment will be provided to the beach and consequently beach composition may change and accretion may occur, resulting in a reversal of the erosive trend, despite sea level rise. This would not however, benefit other adjacent frontages as Lunan Bay is a closed sediment system. As the bay 'deepens' over time the area may become more sheltered.

Location	Predicted Change for With Present Policies		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
	will continue. Coastal defences are unlikely to prevent damage to frontal property and the immediate hinterland under a severe storm from the north-east.		Natural movement of the Lunan Water channel will continue. Defences at Corbie Knowe will exacerbate beach lowering and outflanking of defences to the north.
CPU 5 Lang Craig to Whiting Ness			
Lang Craig to Whiting Ness	The cliffs along this frontage are undefended. Remains of harbour at Auchmithie. SMP1 policy: **No Active Intervention**	The cliffs along this frontage are undefended SMP1 policy: **No Active Intervention**	The cliffs along this frontage are undefended
	The cliffs along the majority of this frontage, fronted by a fringing rock platform, have historically been experiencing low rates of erosion and these are predicted to continue with negligible erosion expected during this epoch, although there is potential for periodic cliff falls. Small shingle pocket beaches will remain.	Low rates of erosion are expected to continue during this epoch, with less than 5m of erosion possible by the end of this epoch, mostly in the form of cliff falls. Sea level rise will start to submerge the fringing rock platform. Potential loss of some pocket beaches. It is not expected that sea level rise will significantly affect the rate of recession of cliffs along this frontage, due to their resistant nature.	Less than 10m of erosion is predicted to occur along this coastline by the end of the 100 year period, predominantly in the form of cliff falls. Potential loss of some pocket beaches where they are unable to retreat due to resistant cliffs behind, and the rock platforms fronting the cliffs may become submerged. However, the resistant nature of the cliffs will remain the dominant control on their erosion and therefore recession rates are not expected to be significantly affected by accelerated sea level rise.
CPU 6 Whiting Ness to West Haven			
Whiting Ness to Arbroath Harbour	Defences at Victoria Park and Seagate will need ongoing maintenance and improvements during this epoch. SMP1 policy: **Hold the Line** (<10-15 years)	Defences at Victoria Park and Seagate will need ongoing maintenance and improvements during this epoch. SMP1 policy: **Hold the Line**	Defences at Victoria Park and Seagate will need ongoing maintenance and improvements during this epoch.
	At Victoria Park, the reflective nature of the defence combined with the wide rock platform	There is potential for increased frequency and magnitude of overtopping over time, unless	There is potential for increased frequency and magnitude of overtopping over time, with sea

Location	Predicted Change for With Present Policies		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
	will mean little material will accumulate in this location. South of Victoria Park to Seagate the beach may roll back where unconstrained, but may narrow over time in front of the seawall, due to its reflective nature.	changes are made to the defence profile. Lowering and narrowing of the shingle beach at Seagate in front of defences is likely to continue, therefore beach management works may be required.	level rise. The rock platform fronting the beach may also become submerged. Further beach management works are likely to be required to address the lowering and narrowing of the shingle beach at Seagate in front of defences as sea levels rise.
Arbroath Harbour	Harbour breakwaters, quay walls, inner seawalls and revetment will require ongoing maintenance and improvements. SMP1 policy: **Hold the Line** (<10-15 years)	Harbour breakwaters Defences will need ongoing maintenance and improvements during this epoch. SMP1 policy: **Hold the Line**	Harbour breakwaters Defences will need ongoing maintenance and improvements during this epoch.
	There is likely to be little change in shoreline position from present. Despite the outer breakwaters providing some protection, the seawalls along the Inchcape frontage will continue to be subjected to considerable wave action and increased overtopping frequency and magnitude will occur over time, therefore changes to the defence profile may be needed.	Narrowing of the small shingle beaches will occur as sea levels rise.	Narrowing and eventual loss of the small shingle beaches in front of defences at Inchcape is likely as sea levels rise.
Inchcape Park and West Links	Revetment and seawalls will require ongoing maintenance and improvements. SMP1 policy: **Hold the Line**	Defences will need ongoing maintenance and improvements during this epoch. SMP1 policy: **Hold the Line**	Defences will need ongoing maintenance and improvements during this epoch.
	High reflectivity of seawalls will exacerbate beach lowering of already low beaches. Consequently, increased frequency and magnitude of overtopping will occur over time, therefore changes to defences are likely to be required to address this.	Potential for loss of the intertidal area and lowering and narrowing of beaches as sea levels rise. This will put increasing pressure on defences therefore capital works may be required to maintain / increase the standard of protection.	Narrowing and eventual loss of fronting beaches is likely due to coastal squeeze against the hard defences with sea level rise. Overtopping and flood risk will increase over time.
West Links to West Haven	Predominantly undefended frontage. Revetment at Elliot outfall and railway protection	Predominantly undefended frontage. Railway protection at Hatton will require ongoing	Predominantly undefended frontage. Railway protection at Hatton will require ongoing

Location	Predicted Change for With Present Policies		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
	at Hatton will require ongoing maintenance and improvements; this may also include extending the defence line. Provision of measures to slow down erosion / address flood risk at East and West Haven may be required. SMP1 policy: **Selectively Hold the Line: No Active Intervention (part) / Limited Intervention (part) / Hold the Line (part)** (<10-15 years)	maintenance and improvements; this may also include extending the defence line. Provision of measures to slow down erosion / address flood risk at East and West Haven and the potential need for capital works to reduce risks to properties may be required. SMP1 policy: **Selectively Hold the Line: Hold the Line (part) / Limited Intervention (part) / No Active Intervention (part)**	maintenance and improvements; this may also include extending the defence line. If applicable, ongoing maintenance and improvements to new defences at East and West Haven or ongoing provision of measures to slow down erosion.
	Along this mostly undefended section, erosion and accretion patterns are likely to continue, with current sediment transport south. The shore platform and cobble storm beach at the dune toe will continue to provide natural protection to this stable frontage, however, a slow minimal retreat of the beach to is likely to continue, as has been observed over the last 30 years. If an erosional trend or increased flood risk is realised at East and West Haven, provision of measures to address these issues may be required.	Erosion and accretion patterns are likely to continue, dependant on wave climate and sediment transport direction. Continued slow rates of beach retreat and frontal dune erosion is likely. The shore platform and storm beach will continue to provide protection to the backing dune system, however, with sea levels rise the influence of the platform may reduce as it becomes submerged. If an erosional trend is realised or flood risk increases at East and West Haven, more substantial defences may be required. If this is the case, care would be required to ensure they would not cause adverse impacts on downdrfit frontages.	The rock platform fronting the beach may become submerged as sea levels rise. The natural protection afforded by the rock platform to the beach will therefore diminish over time and potentially result in increased retreat of the shoreline over this period, however, erosion rates are still expected to be relatively low, <5m over 50 years. Erosion of frontal dunes to the north will act to feed local beaches and those downdrift towards East and West Haven. However, increased overtopping and flood risk to East and West Haven may be a problem with sea level rise if beach levels drop in front of new defences.
CPU 7 West Haven to Buddon Ness			
West Haven to Carnoustie Station	Carnoustie defences will remain buried. Revetment the Look Out Station will require ongoing maintenance.	Defences may require ongoing maintenance and improvements. If dune erosion becomes an issue, dune stabilisation and restoration work may be required	Defences will require ongoing maintenance and improvements. If dune erosion increases, work may be required to slow down this erosion or capital works (e.g.

Location	Predicted Change for With Present Policies		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
	SMP1 policy: **Selectively Hold the Line: Limited Intervention / Hold the Line** (<10-15 years)	to slow down this erosion. SMP1 policy: **Selectively Hold the Line: Limited Intervention / Hold the Line**	dune stabilisation, groynes or beach recharge) may be required to hold the line.
	The intertidal rock platform will continue to provide natural protection to this stable frontage. The frontal dune system will however, be susceptible to storm damage.	The intertidal rock platform is expected to continue to provide natural protection to the frontage, however, this influence will reduce with sea level rise. The dunes will remain relatively stable, however, the frontal dune system will be susceptible to storm damage and erosion. If frontal erosion of the dunes becomes an issue, works may be implemented to help slow this erosion.	The rock platform fronting the beach may become submerged as sea levels rise. The natural protection afforded by the rock platform to the beach will therefore diminish over time. Although the dune system is assumed to remain fairly resilient there will be potential for increased frontal erosion, as sea levels rise. Consequently more substantial works may be required in some locations to protect properties at risk.
Carnoustie Station to Barry Burn	Defences will require ongoing maintenance and improvements. SMP1 policy: **Hold the Line**	Defences will require ongoing maintenance and improvements. SMP1 policy: **Hold the Line**	Defences will require ongoing maintenance and improvements.
	The beach is likely to continue to lower and narrow in front of defences. Defences may need to be upgraded to address increasing overtopping issues over time. The position of the Gaa Spit, wave climate and tidal processes will continue to have considerable influence on erosion and accretion patterns in Carnoustie Bay.	The intertidal beach will continue to narrow and lower seaward of the defence structures as sea levels rise. The position of the Gaa Spit, wave climate and tidal processes will continue to have considerable influence on erosion and accretion patterns in Carnoustie Bay.	The intertidal beach will continue to narrow and lower seaward of the defence structures as sea levels rise. More substantial defences may be required to address overtopping issues over this epoch. The position of the Gaa Spit, wave climate and tidal processes will continue to have considerable influence on erosion and accretion patterns in Carnoustie Bay.
Barry Sands East	Ongoing maintenance and improvement of defences SMP1 policy: **Hold the Line**	Ongoing maintenance and improvement of defences SMP1 policy: **Hold the Line**	Ongoing maintenance and improvement of defences

Location	Predicted Change for With Present Policies		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
	The defences will continue to effectively restrict naturally highly dynamic movement of the beach and backing dune system and restrict natural sediment exchange between the beach and dunes. Consequently there is potential for beach lowering adjacent to the defence. Overtopping of defences will become more of a problem over time. Downdrift erosion of frontal dunes to the south of the defences at Barry Sands East is likely to continue. Erosion patterns will however, be influenced by the existence / location of the drift divide and wave and tidal conditions along this frontage.	As sea levels rise, beach lowering and potential for loss of intertidal areas may be an issue in front of the defence. Further defence crest protection may be required to reduce erosion caused by overtopping. As long as the revetment remains along the Barry Sands East frontage, downdrift erosion of frontal dunes to the south of this defence will continue. Erosion patterns will however, be influenced by the existence / location of the drift divide and wave and tidal conditions along this frontage.	Beach lowering and loss of intertidal areas will continue in front of the defence as sea levels rise. Further upgrade of defences may be required. As long as the revetment remains along the Barry Sands East frontage, downdrift erosion of frontal dunes to the south of this defence will continue. Erosion patterns will however, be influenced by the existence / location of the drift divide and wave and tidal conditions along this frontage.
CPU 8 Buddon Ness to Broughty Castle			
Buddon Ness and Barry Sands West	Undefended intertidal sandy beach and backing dune system SMP1 policy: **No Active Intervention**	Undefended intertidal sandy beach and backing dune system SMP1 policy: **No Active Intervention**	Undefended intertidal sandy beach and backing dune system
	The highly dynamic system will continue to evolve naturally. Downdrift erosion of frontal dunes to the south of the defences at Barry Sands East is likely to continue. Accretion of the beach and dunes is predicted to continue at Buddon Ness. Erosion and accretion patterns along the Barry Sands West frontage are likely to continue with the growth of the spit deflecting the Buddon Burn	The highly dynamic system will continue to evolve naturally. As sea levels rise the erosion of frontal dunes and natural beach roll back will continue over time. Erosion and accretion patterns are likely to fluctuate, however continued accretion of Buddon Ness is predicted. As long as the revetment remains along the Barry Sands East frontage, downdrift erosion of frontal dunes to the south of this defence will continue.	The beach and frontal dunes will naturally tend to erode / roll back landwards as sea levels rise. As long as the revetment remains along the Barry Sands East frontage, downdrift erosion of frontal dunes to the south of this defence will continue. Erosion and accretion patterns are likely to fluctuate, due to the highly dynamic system. These patterns will be predominately influenced by tidal conditions at the mouth of the Tay Estuary and the influence of Gaa Sands and Spit.

Location	Predicted Change for With Present Policies		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
	outlet towards the west.		
MoD boundary to Dighty Water (Monifieth)	Defences will need ongoing maintenance and improvements. Dune management measures to the east of Dighty Water. SMP1 policy: **Hold the Line** (<10-15 years)	Defences will need ongoing maintenance and improvements. Beach recharge may be required to help maintain beach levels. SMP1 policy: **Hold the Line**	Defences will need ongoing maintenance and improvements. Beach recharge may be required to help maintain beach levels.
	Future evolution along this frontage will be highly dependant on sediment supply and movement of channels and bank systems at the mouth of the Tay Estuary. If present conditions continue, accretion is predicted along the eastern part of the frontage between Riverside Caravan Park and the MoD boundary. Along the western part of the frontage towards Milton Mill, erosional trends are likely to continue. Defences may need to be upgraded to address overtopping issues and to maintain a beach over time. Backing dunes in this location should remain relatively stable, whilst protected by the timber revetment. However, the revetment will act as a barrier between the beach and dune system, inhibiting natural processes and interaction between the two systems. Consequently sediment supply to the dune system will be restricted and erosion may result over time. Immediately east of Dighty Water groynes may need to be upgraded to maintain the fronting beach.	Future evolution along this frontage will be highly dependant on sediment supply and movement of channels and bank systems at the mouth of the Tay Estuary. If present conditions continue, accretion / stability is predicted along the eastern part of the frontage between Riverside Caravan Park and the MoD boundary. In the west, and central sections, the trend of beach lowering is likely to continue with sea levels rise due to coastal squeeze against defences. If long term erosion is evident, beach and dune management measures will be required. Groynes will need to be replaced or recharge undertaken to help maintain the beaches in these locations. Dunes, effectively ‘cut off’ from the beach system, behind defences may need further stabilisation measures to maintain stability.	Beach lowering and narrowing is expected along the whole frontage as sea levels rise, with long-term intertidal loss to the east and west of the area. Future evolution along this frontage will be highly dependant on sediment supply and movement of channels and bank systems at the mouth of the Tay Estuary. In the east of the frontage, if sediment supply is restricted or the channel moves landward, present accretion / stability trends may reverse. In this case, additional beach management measures may be required to protect the frontage from erosion. To the west and mid frontage, further beach recharge campaigns or groynes may help maintain the beach where coastal squeeze is an issue in front of defences.

Location	Predicted Change for With Present Policies		
	Years 0 – 20	Years 20 – 50	Years 50 – 100
Dighty Water to Broughty Castle	Defences will need ongoing maintenance and improvements. The beach and dune system at Broughty Ferry also provides a natural defence line. SMP1 policy: **Hold the Line** (<10-15 years)	Defences will need ongoing maintenance and improvements. The beach and dune system at Broughty Ferry also provides a natural defence line. SMP1 policy: **Hold the Line**	Defences will need ongoing maintenance and improvements.
	Future evolution along this frontage will be highly dependant on sediment supply and movement of channels and bank systems at the mouth of the Tay Estuary. West of Dighty Water, continued erosion is predicted due to lack of sediment supply from the east. Implementation of beach management structures may however, improve beach levels and reduce the erosion trend. The stability of beaches and dunes to the west of this frontage towards Broughty Castle is likely to continue, maintaining a natural line of defence.	Future evolution along this frontage will be highly dependant on sediment supply and movement of channels and bank systems at the mouth of the Tay Estuary. Beach management structures should help maintain a beach in the east of the frontage, however beach lowering may increase with sea levels rise. Along the central frontage, if sea level rise becomes an issue, frontal dune erosion may become more frequent and new defences may be required to reduce erosion. In front of defences beach levels will reduce as sea levels rise. Assuming a continued sediment supply stability of the dunes and beach is expected, providing protection to the seawall at Broughty Ferry into this epoch. If sediment supply reduces this trend may reverse and further beach management measures required to maintain the beach and dune system.	The pattern of erosion in the east and accretion in the west is likely to continue, dependant on the influence of offshore banks and bars and wave conditions and a continued sediment supply. As sea levels rise, beaches will lower and narrow in front of defences. Where undefended and accommodation space is available, beach and backing dunes will migrate landward over time.

C5.4 Data Interpretation and Assumptions

Table C5.3 Data interpretation and Assumptions

Location	Available data	Assumptions made in predictions of coastal change for NAI and WPP				Uncertainty
			Short Term (to 2029)	Medium Term (to 2059)	Long Term (to 2109)	
CPU 1 Milton Ness to Montrose Harbour						
Milton Ness to Woodston Fishery	SMP1 (Angus Council, 2004) no information on rates of cliff retreat. Rates for similar types of cliffs and exposure conditions have been taken from Futurecoast (Halcrow, 2002). 'very low' (<0.1 m/ yr) potential rates of erosion for lava cliffs, primarily in the form of episodic erosion such as rock falls.	NAI	Resistant cliffs with very low rates of cliff erosion. Therefore less than <2m erosion in 20 years, predominantly through localised cliff falls.	Resistant cliffs with very low rates of cliff erosion. <5m erosion possible in 50 years, based on <0.1m/yr erosion predominantly through localised cliff falls.	Resistant cliffs with low rates of cliff erosion. <10m erosion possible in 100 years, based on 0.1m/yr erosion predominantly through localised cliff falls. Possible permanent submergence of fringing rock platforms.	Limited information on long term erosion rates. Risk of localised cliff falls – not possible at SMP scale to predict location of such events. Limited details on the level of the rock platforms and therefore the risk of them becoming permanently submerged.
		WPP	As for NAI	As for NAI	As for NAI	
Woodston Fishery to Montrose Links	No information on dune erosion / accretion rates.	NAI	Dune system assumed to be fairly resilient. Current patterns of accretion and erosion are likely to continue.	Dune system assumed to be fairly resilient to sea level rise, although frontal dunes could be affected. Current patterns of accretion	Dune system assumed to be fairly resilient to sea level rise, although frontal dunes could be affected. Current patterns of accretion	Uncertainty regarding future behaviour of the River North Esk outlet. System would be vulnerable to any significant changes in the

Location	Available data	Assumptions made in predictions of coastal change for NAI and WPP				Uncertainty
			Short Term (to 2029)	Medium Term (to 2059)	Long Term (to 2109)	
			North of the River North Esk outlet: accretion South of the River Esk Outlet: estimated as <0.5m/year (<10m in 20 years) North of Montrose links: estimated as 1m/year (20m in 20 years)	and erosion are likely to continue. North of the River North Esk outlet: accretion South of the River Esk Outlet: estimated as <0.5m/year (<25m by year 50) North of Montrose links: estimated as 1m/year (50m by year 50)	and erosion are likely to continue. North of the River North Esk outlet: accretion South of the River Esk Outlet: estimated as <0.5m/year (<50m by year 100) North of Montrose links: estimated as 1m/year (100m by year 100)	wind-wave climate - high level of uncertainty regarding this parameter. Dunes vulnerable to any change in frontal dune stability, e.g. due to human pressure from trampling.
		WPP	As NAI	As NAI	As NAI	
Montrose Links	Potential dune retreat rate of 2.5m/ yr (Milne and Dong, 2011).	NAI	Beach / dune erosion of up to 50m based on 2.5m/yr Assumes hard points and defences at Splash still remain in this epoch	Beach / dune erosion of up to 125m based on 2.5/yr Assumes all defences fail during this epoch	Beach / dune erosion of up to 250m based on 2.5m/yr	System would be vulnerable to any significant changes in the wind-wave climate - high level of uncertainty regarding this parameter. Dunes vulnerable to any change in frontal dune stability, e.g. due to human pressure, such as trampling. This frontage will also depend upon future policy regarding dredging of the River South Esk channel and also the distribution of this material.
		WPP	As NAI Assumes defences at Splash still remain in this epoch	As NAI Assumes defences at Splash still remain in this epoch	As NAI Assumes defences at Splash still remain in this epoch	
Northern end of	Potential dune retreat rate	NAI	Rock groynes, Sea wall and revetments	Failure of Splash and caravan park defences	Glaxo defences may remain if fronting beach	Exact timing of defence failure is uncertain under NAI (Glaxo

Location	Available data	Assumptions made in predictions of coastal change for NAI and WPP				Uncertainty
			Short Term (to 2029)	Medium Term (to 2059)	Long Term (to 2109)	
Splash to Montrose Links Harbour	of 2.5m/ yr of Montrose Links (Milne and Dong, 2011)		expected to remain.	assumed during this epoch. Following defence failure, beach / dune erosion estimated as approximately 2.5/yr	is stable. Beach / dune erosion estimated as approximately 2.5/yr	defences are presently buried). Existence of a drift divide along the Splash frontage is uncertain. Highly modified frontage; therefore uncertainty in how it may evolve in the future under NAI. This frontage, and the whole bay will also depend upon future policy regarding dredging of the River South Esk channel and also the distribution of this material.
		WPP	Assumed defences remain and continue to fix the shoreline position and minimise flood and erosion risk.	Assumed defences remain and continue to fix the shoreline position and minimise flood and erosion risk.	Assumed defences remain and continue to fix the shoreline position and minimise flood and erosion risk.	
CPU 2 Montrose Basin						
Montrose Harbour and Railway frontages	No erosion rates available	NAI	Assumed defences remain and continue to fix the shoreline position. Flood risk based on latest flood maps	Failure of defences. Low rates of episodic erosion expected: <0.1m/yr based on historic map analysis. Flood risk based on latest flood maps	Low rates of episodic erosion expected: <0.1m/yr. Flood risk based on latest flood maps	Exact timing of defence failure is uncertain under NAI. Highly modified frontage; therefore uncertainty in how it may evolve in the future under NAI. Future meandering behaviour of the Tayock Burn channel is uncertain.
		WPP	Assumed defences remain and continue to fix the shoreline position and minimise flood and erosion risk.	Assumed defences remain and continue to fix the shoreline position and minimise flood and erosion risk.	Assumed defences remain and continue to fix the shoreline position and minimise flood and erosion risk.	

Location	Available data	Assumptions made in predictions of coastal change for NAI and WPP				Uncertainty
			Short Term (to 2029)	Medium Term (to 2059)	Long Term (to 2109)	
Montrose Basin	No erosion rates available. SEPA flood map	NAI	Bank erosion likely to be episodic, during certain conditions (<0.1m/yr based on historic map analysis). Flood risk based on latest flood maps	Bank erosion likely to be episodic, during certain conditions (<0.1m/yr). Flood risk based on latest flood maps	Bank erosion likely to be episodic, during certain conditions (<1m/yr). Flood risk based on latest flood maps	Assumes a continued supply of sediment to the basin. Bank erosion rates are uncertain, and erosion is expected to occur primarily under severe conditions.
		WPP	Undefended areas as NAI.	Undefended areas as NAI.	Undefended areas as NAI.	
Ferryden to Scurdie Ness	SMP1 (Angus Council, 2004) no information on rates of cliff retreat. Rates for similar types of cliffs and exposure conditions have been taken from Futurecoast (Halcrow, 2002). ‘very low’ (<0.1 m/ yr) potential rates of erosion for lava cliffs, primarily in the form of episodic erosion such as rock falls.	NAI	Defences assumed to remain during this epoch. Resistant cliffs with very low rates of cliff erosion. Therefore less than <2m erosion in 20 years, predominantly through localised cliff falls.	Defences assumed to fail towards the end of this epoch. Resistant cliffs with very low rates of cliff erosion. Therefore less than <5m erosion in 50 years, predominantly through localised cliff falls.	Resistant cliffs with very low rates of cliff erosion. Therefore less than <10m erosion in 100 years, predominantly through localised cliff falls. Possible permanent submergence of fringing rock platforms.	Limited information on long term erosion rates. Risk of localised cliff falls – not possible at SMP scale to predict location of such events. Limited details on the level of the rock platforms and therefore the risk of them becoming permanently submerged.
		WPP	Assumed defences remain and minimise flood and erosion risks locally. Erosion of resistant rocks as NAI.	Assumed defences remain and minimise flood and erosion risks locally. Erosion of resistant rocks as NAI.	Assumed defences remain and minimise flood and erosion risks locally. Erosion of resistant rocks as NAI.	
CPU 3 Scurdie Ness to Rickle Craig						

Location	Available data	Assumptions made in predictions of coastal change for NAI and WPP				Uncertainty
			Short Term (to 2029)	Medium Term (to 2059)	Long Term (to 2109)	
Scurdie Ness to Rickle Craig	SMP1 (Angus Council, 2004) no information on rates of cliff retreat. Rates for similar types of cliffs and exposure conditions have been taken from Futurecoast (Halcrow, 2002). 'very low' (<0.1 m/ yr) potential rates of erosion for Old Red Sandstone and lava cliffs, primarily in the form of episodic erosion such as rock falls.	NAI	Resistant cliffs with low rates of cliff erosion. Therefore less than 2m erosion based on <0.1m/ yr predominantly through localised cliff falls.	Resistant cliffs with low rates of cliff erosion. <5m erosion possible, based on <0.1m/yr erosion predominantly through localised cliff falls.	Resistant cliffs with low rates of cliff erosion. Less than 10m erosion possible, based on <o.1m/yr erosion predominantly through localised cliff falls. Possible permanent submergence of fringing rock platforms.	Limited information on long term erosion rates. Risk of localised cliff falls – not possible at SMP scale to predict location of such events. Limited details on the level of the rock platforms and therefore the risk of them becoming permanently submerged.
		WPP	As NAI	As NAI	As NAI	
CPU 4 Rickle Craig to Lang Craig						
Lunan Bay	No information on dune erosion / accretion rates.	NAI	Failure of defences at Corbie Knowe. Dune system assumed to be fairly resilient. Current patterns of erosion and accretion will continue. Following defence failure, erosion at Corbie Knowe estimated to be <0.1m/year after initial cut back.	Dune system assumed to be fairly resilient to sea level rise, although frontal dunes could be affected. Erosion at Corbie Knowe estimated to be <0.1m/year.	Dune system assumed to be fairly resilient to sea level rise, although frontal dunes could be affected. Erosion at Corbie Knowe estimated to be <0.1m/year.	Uncertainty regarding future behaviour of the Lunan Water outlet. Dune system would be vulnerable to any significant changes in the wind-wave climate - but high level of uncertainty regarding this parameter. Dunes vulnerable to any change in frontal dune stability, e.g. due to human

Location	Available data	Assumptions made in predictions of coastal change for NAI and WPP				Uncertainty
			Short Term (to 2029)	Medium Term (to 2059)	Long Term (to 2109)	
		WPP	As NAI Assumed defences remain at Corbie Knowe.	As NAI Assumed defences remain at Corbie Knowe.	As NAI Assumed defences remain at Corbie Knowe.	pressure.
CPU 5 Lang Craig to Whiting Ness						
Lang Craig to Whiting Ness	SMP1 (Angus Council, 2004) no information on rates of cliff retreat. Rates for similar types of cliffs and exposure conditions have been taken from Futurecoast (Halcrow, 2002). 'very low' (<0.1 m/ yr) potential rates of erosion for Old Red Sandstone and lava cliffs, primarily in the form of episodic erosion such as rock falls.	NAI	Resistant cliffs with low rates of cliff erosion. Therefore less than 2m erosion based on <0.1m/ yr predominantly through localised cliff falls.	Resistant cliffs with low rates of cliff erosion. <5m erosion possible, based on <0.1m/yr erosion predominantly through localised cliff falls.	Resistant cliffs with low rates of cliff erosion. Less than 10m erosion possible, based on <0.1m/yr erosion predominantly through localised cliff falls. Possible permanent submergence of fringing rock platforms.	Limited information on long term erosion rates. Risk of localised cliff falls – not possible at SMP scale to predict location of such events. Limited details on the level of the rock platforms and therefore the risk of them becoming permanently submerged.
		WPP	As NAI	As NAI	As NAI	
CPU 6 Whiting Ness to West Haven						
Whiting Ness to Arbroath Harbour		NAI	Assumed defences will remain during this epoch and continue to fix the shoreline position	Defences are expected to fail during this epoch. Rapid erosion of raised beach to a more natural alignment (up to 45m of erosion), thereafter frontage is likely to be	Possible permanent submergence of fringing rock platforms. Potential erosion rate of raised beach: 0.5m/yr assumed.	Exact timing of defence failure is uncertain under NAI. Erosion rate of raised beach uncertain. Limited details on the level of the rock platforms and

Location	Available data	Assumptions made in predictions of coastal change for NAI and WPP				Uncertainty
			Short Term (to 2029)	Medium Term (to 2059)	Long Term (to 2109)	
				relatively stable, however, with sea level rise, erosion could be up to 0.5m/yr.		therefore the risk of them becoming permanently submerged.
		WPP	Assumed defences remain and continue to fix the shoreline position and minimise flood and erosion risk.	Assumed defences remain and continue to fix the shoreline position and minimise flood and erosion risk.	Assumed defences remain and continue to fix the shoreline position and minimise flood and erosion risk. Possible permanent submergence of fringing rock platforms.	
Arbroath Harbour		NAI	Assumed defences and harbour structures will remain.	Assumed inner defences will start to fail, but that harbour structures will remain.	Assumed that any remaining defences will fail and that harbour structures will deteriorate.	Harbour structures are not coastal defences and therefore their future role and integrity will be dependent upon future harbour operations. Exact timing of defence failure is uncertain under NAI.
		WPP	Assumed defences and harbour structures will remain therefore little change in shoreline position.	Assumed defences and harbour structures will remain therefore little change in shoreline position.	Assumed defences and harbour structures will remain therefore little change in shoreline position.	
Inchcape Park and West Links		NAI	Assumed defences remain and continue to fix the shoreline position.	Assume defences deteriorate and fail towards the end of this epoch. Erosion rate of 0.5m/yr assumed once defences fail.	Erosion rate of 0.5m/yr assumed	Exact timing of defence failure is uncertain under NAI. Erosion rate of raised beach uncertain.

Location	Available data	Assumptions made in predictions of coastal change for NAI and WPP				Uncertainty
			Short Term (to 2029)	Medium Term (to 2059)	Long Term (to 2109)	
		WPP	Assumed defences remain and continue to fix the shoreline position and minimise flood and erosion risk.	Assumed defences remain and continue to fix the shoreline position and minimise flood and erosion risk.	Assumed defences remain and continue to fix the shoreline position and minimise flood and erosion risk.	
West Links to West Haven	Between Elliot and East Haven, accretion to the 1960s then 26m of retreat between 1960s and 2004) (Angus Council, 2004) At East Haven, accretion until the 1970s then retreat of 8m between 1970s and 2004 (Angus Council, 2004)	NAI	Dune system assumed to be fairly resilient. Current patterns of erosion and accretion will continue.	Dune system assumed to be fairly resilient. Current patterns of erosion and accretion will continue.	Dune system assumed to be fairly resilient. Potential for <5m of erosion over 50 years (<0.1m/yr). Current patterns of erosion and accretion will continue. Possible permanent submergence of fringing rock platform in the south.	System would be vulnerable to any significant changes in the wind-wave climate - but high level of uncertainty regarding this parameter. Dunes vulnerable to any change in frontal dune stability, e.g. due to human pressure. Limited details on the level of the rock platforms and therefore the risk of them becoming permanently submerged.
		WPP	As NAI	As NAI	As NAI	
CPU 7 West Haven to Buddon Ness						
West Haven to Carnoustie Station	No dune erosion rates available	NAI	Dune system assumed to be fairly resilient. Current patterns of erosion and accretion will continue.	Dune system assumed to be fairly resilient. Current patterns of erosion and accretion will continue.	Dune system assumed to be fairly resilient. Current patterns of erosion and accretion will continue. If defences are exposed and then fail potential	System would be vulnerable to any significant changes in the wind-wave climate - but high level of uncertainty regarding this parameter. Dunes vulnerable to any

Location	Available data	Assumptions made in predictions of coastal change for NAI and WPP				Uncertainty
			Short Term (to 2029)	Medium Term (to 2059)	Long Term (to 2109)	
					for <5m of erosion over 50 years (<0.1m/yr). Possible permanent submergence of fringing rock platform.	change in frontal dune stability, e.g. due to human pressure. Limited details on the level of the rock platforms and therefore the risk of it becoming permanently submerged Exact timing of defence failure is uncertain under NAI.
		WPP	Dune system assumed to be fairly resilient. Current patterns of erosion and accretion will continue. Present defences will remain.	Dune system assumed to be fairly resilient. Current patterns of erosion and accretion will continue. Present defences will remain.	Dune system assumed to be fairly resilient. Current patterns of erosion and accretion will continue. Present defences will remain.	
Carnoustie Station to Barry Burn	No dune erosion / accretion rates available	NAI	Defences are assumed to remain in this epoch.	Defences will deteriorate but still remain in some form.	Rapid erosion of dunes following defence failure. Potential for around 50m of initial erosion estimated, followed by <0.1m/yr.	Exact timing of defence failure is uncertain under NAI. Highly modified frontage; therefore uncertainty how it may evolve in the future under NAI. The influence of the Gaa Spit and wave and tidal conditions on this frontage are uncertain.
		WPP	Defences are assumed to remain in this epoch.	Defences are assumed to remain in this epoch.	Defences are assumed to remain in this epoch.	
Barry Sands East	50m of dune retreat between 1993 and 2003 south of the revetment (Hansom & Rennie, 2003), otherwise no other dune erosion rates available. Using Google Earth measurements, cut back of	NAI	Defences assumed to remain and fix shoreline position.	Rapid erosion of dunes following defence failure to a more natural alignment.	Erosion and accretion patterns are uncertain.	Exact timing of defence failure is uncertain under NAI. Highly modified frontage; therefore uncertainty how it may evolve in the future under NAI. Location / existence of a drift
		WPP	Defences assumed to remain and fix shoreline position.	Defences assumed to remain and fix shoreline position.	Defences assumed to remain and fix shoreline position.	

Location	Available data	Assumptions made in predictions of coastal change for NAI and WPP				Uncertainty
			Short Term (to 2029)	Medium Term (to 2059)	Long Term (to 2109)	
	approximately 70m by 2012 (3.5m/yr).		Assumes MoD use of Buddon Ness continues.	Assumes MoD use of Buddon Ness continues.	Assumes MoD use of Buddon Ness continues.	divide along this frontage. The influence of the Gaa Spit and wave and tidal conditions on this frontage are uncertain.
CPU 8 Buddon Ness to Broughty Castle						
Buddon Ness and Barry Sands West	50m of dune retreat between 1993 and 2003 south of the revetment (Hansom & Rennie, 2003), otherwise no other dune erosion rates available. Using Google Earth measurements, cut back of approximately 70m by 2012 (3.5m/yr).	NAI	Dune system assumed to be fairly resilient however accelerated erosion south of the Barry Sands East revetment. Current patterns of erosion and accretion will continue.	Dune system assumed to be fairly resilient to sea level rise, although frontal dunes could be affected and erosion will continue south of the Barry Sands East revetment. Current patterns of erosion and accretion will continue.	Dune system assumed to be fairly resilient to sea level rise, although frontal dunes could be affected. Current patterns of erosion and accretion will continue.	The influence of the Gaa Spit and wave and tidal conditions on this frontage are uncertain. Rates of dune erosion / accretion uncertain.
		WPP	As NAI Assumes MoD use of Buddon Ness continues.	As NAI Assumes MoD use of Buddon Ness continues.	As NAI Assumes MoD use of Buddon Ness continues. Continued erosion south of the Barry Sands East revetment.	
MoD boundary to Dighty Water (Monifieth)	No dune erosion / accretion rates available	NAI	Defences assumed to remain and fix shoreline position. Groynes will deteriorate and fail. Current patterns of erosion and accretion	Rock revetments remain. Assumed 0.25m/yr dune erosion once defences fail	Failure of defences. Assumed 0.25m/yr dune erosion	Exact timing of defence failure is uncertain under NAI. Sediment supply to the frontage is uncertain. Changes to the Tay Channel, offshore sand banks and bars will continue to influence the

Location	Available data	Assumptions made in predictions of coastal change for NAI and WPP				Uncertainty
			Short Term (to 2029)	Medium Term (to 2059)	Long Term (to 2109)	
			will continue.			wave climate and future erosion and accretion patterns along this frontage.
		WPP	Assumed defences remain and continue to fix the shoreline position and minimise flood and erosion risk. Current patterns of erosion and accretion will continue.	Assumed defences remain and continue to fix the shoreline position and minimise flood and erosion risk.	Assumed defences remain and continue to fix the shoreline position and minimise flood and erosion risk.	
Dighty Water to Broughty Castle	No dune erosion / accretion rates available	NAI	Defences assumed to remain Current patterns of erosion and accretion will continue. Assumed 0.25m/yr dune erosion in the east	Seawall at Broughty Ferry assumed to remain. Current patterns of erosion and accretion will continue. Assumed 0.25m/yr dune erosion in the east	Failure / deterioration of defences. Current patterns of erosion and accretion will continue. Assumed 0.25m/yr dune erosion in the east	Exact timing of defence failure is uncertain under NAI. Sediment supply to the frontage is uncertain. Changes to the Tay Channel, offshore sand banks and bars will continue to influence the wave climate and future erosion and accretion patterns along this frontage.
		WPP	Defences assumed to remain. Current patterns of erosion and accretion will continue.	Defences assumed to remain. Current patterns of erosion and accretion will continue.	Defences assumed to remain. Current patterns of erosion and accretion will continue.	

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Annex C1 No Active Intervention Maps