Directorate of Economy and Environment
Director Stuart Love

Isle of Wight Shoreline Management Plan 2

Appendix C: Baseline Process Understanding

December 2010

Coastal Management;
Directorate of Economy & Environment, Isle of Wight Council

Appendix C: Baseline Process Understanding

Contents

Executive Summary

This document reviews coastal processes and coastal defences and provides baseline scenarios for future shoreline change. It draws together the outputs and conclusions from a range of key texts and studies and presents important baseline understanding which forms an integral part of the Shoreline Management Plan and underpins the technical development of policies.

A 'Behavioural Systems' approach has been employed, which involves the identification of the different elements that make up the coastal structure and developing an understanding of how these elements interact on temporal and spatial scales. An essential requirement of this approach is to consider the coast as a whole system of interrelated features and processes.

The document is structured as follows:

C1: Assessment of Shoreline Dynamics
This report provides the current understanding of the overall pattern of coastal behaviour, drawing from a number of high-level reports such as the SCOPAC Sediment Transport Study (2004), Futurecoast (2002), SMP1 (1997) and Coastal Defence Strategies.

C2: Defence Appraisal
This report provides an assessment of every coastal defence within the study area, including a description of each defence element, overall condition grade, residual life and related natural features. This appendix is supported by detailed records of the coastal defence assets of the Isle of Wight Council and the Environment Agency around the Isle of Wight coast and estuaries.

C3: Baseline Scenarios of Future Shoreline Change
The baseline scenarios take forward the data provided in Appendices C1 and C2 to predict the response of the coast to the failure or maintenance of coastal defences and it identifies erosion rates to determine the future shoreline position. Two scenarios are examined:

- No Active Intervention (NAI)
- With Present Management (WPM)

The Isle of Wight coastline is approximately 165 km in length and whilst it is complex and extremely varied, it is possible to identify some general characteristics and trends in terms of geomorphology and coastal processes. The north coast of the Isle of Wight is characterised by low lying coastal slopes with five estuaries draining north into the Solent. Future coastal risks in the north of the Island are likely to include tidal flood risk, particularly focusing around the Eastern and Western Yar estuaries. In contrast, the southern coast is characterised by steep coastal cliffs and landslides. A prominent feature of the south coast is the Undercliff landslide complex. The south coast is particularly vulnerable to storms waves from the Atlantic and some sections of the south coast are subject to rapid rates of erosion.

The assessment of coastal defences calculated that 36% of the Island's coast is defended, the majority by seawalls. Defences range in condition from 1 (very good) to 5 (very poor), with the majority of defences on the Island having a condition grade of 2 or 3. The report concludes that the Island has a legacy of aging defences and 92% of the defences are expected to fail within the first epoch (0-20 years).

Based on an appreciation of coastal process systems and the defence appraisal, the baseline scenarios provide an understanding of how the shoreline is likely to evolve in the future and the influence that coastal management is likely to have on that behaviour.

Note regarding an Estuary Assessment in Isle of Wight SMP2:

The Isle of Wight SMP2 includes full consideration of the five inlets and estuaries along the north shore of the Isle of Wight:

- Western Yar Estuary
- Newtown Estuary
- Medina Estuary
- Wootton Creek
- Bembridge Harbour

A change from SMP1 to SMP2 has been the inclusion of the Medina Estuary, upstream of the Cowes floating bridge, and further consideration of Wootton Creek.

This SMP does not contain a stand-alone estuary assessment, for the following reasons:

- The estuaries, although important and significant features of the Isle of Wight coast, are nevertheless relatively minor in scale in the national context. Therefore it was important to include full coverage of the IW coast in SMP2 in coordination with the Environment Agency's Catchment Flood Management Plan in an appropriate manner.
- During early discussions in late 2006 the Isle of Wight Coastal Manager and the Environment Agency IW CFMP Project Manager discussed and agreed effective boundaries between the SMP2 and the EA Catchment Flood Management Plan. The CFMP was subsequently prepared to these boundaries by 2008, concluding with the Summary Report published in December 2009. Therefore the SMP2 was required to match these boundaries to ensure there was not a gap in coverage of coastal and flood risk planning. Furthermore, the scale of the estuaries and inlets was appropriate for inclusion in SMP2. This rendered the additional potential SMP2 assessment to define the inclusion or exclusion of Estuaries unnecessary.
- Significant expertise on the Isle of Wight Estuaries was included in the CSG (Client Steering Group) throughout the development of SMP2, to ensure full representation, including assessment in the following Appendices C1, C2 and C3. This representation included: the Isle of Wight Estuaries Officer representing both the Western Yar Estuary and the Medina Estuary (The Isle of Wight Estuaries partnership brings together Cowes Harbour Commissioners, Natural England, the Environment Agency, the Isle of Wight Council and Yarmouth Harbour Commissioners), including significant research on the Medina Estuary by ABPmer. The National Trust represented their ownership and experience of Newtown Estuary. Wootton Creek has not been subject to management to the same degree as the Medina Estuary, therefore research is not available at the same detailed level, but the Creek was included in the North-East Coastal Defence Strategy and the Wootton Old Mill Pond in a Water Level Management Plan, providing valuable information on this area (supported by experience of the CSG in managing issues in the area). Regarding Bembridge Harbour, representatives on the SMP2 CSG from the Isle of Wight Council, the Environment Agency and Natural England were also part of the group developing the Eastern Yar Flood and Erosion Risk Management Strategy during the same time period, which included detailed examination of Bembridge Harbour and created a strong link to SMP2.

Therefore, it was felt that available expertise on the Estuaries was incorporated fully into the SMP2 process.

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Director **Stuart Love**

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C1: Assessment of Shoreline Dynamics

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Acknowledgements:

Acknowledgement is given to the SCOPAC Sediment Transport Study (University of Portsmouth, 2004) as a key information source used in the production of this report, alongside Defra's Futurecoast Report (Halcrow, 2002).

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C1: Assessment of Shoreline Dynamics

Contents

Glossary

Term	Definition
AONB	Area of Outstanding Natural Beauty: A statutory designation by the Countryside Commission. The purpose of the AONB designation is to identify areas of national importance and to promote the conservation and enhancement of natural beauty. This includes protecting its flora, fauna, geological and landscape features.
Accretion	Accumulation of sand or other beach material due to the natural action of waves, currents and wind.
Adaptation	Implies that there may be some actual change in the way a feature, such as a habitat or a community, functions. In supporting adaptation, management has to recognise certain principles: • That adaptation may take time and may evolve slowly so that change to the overall community does not happen immediately. • That management should not encourage a progressively more vulnerable situation to develop, where there is a sudden change from one condition to another. • That specific aspects of a feature, such as individual properties or elements of habitat may change or be lost, but without substantial loss to the value of the community or the overall ecological function of the feature.
Anthropogenic	Impacts that originate from humans.
Armour	Structural protection (rock or concrete) for the shoreline
AA/HRA	Appropriate Assessment. Also referred to as a Habitat Regulations Assessment (HRA). The AA is an independent check of the potential impacts of policies being put forward by the SMP with specific reference to designated European nature conservation sites (such as SACs, SPAs, etc.)
ATL	Advance the Line. Policy decision to build new defences seaward of the existing defence line where significant land reclamation is considered.
Back beach/back shore	The section of beach extending landwards from the high water mark to the point where there is an abrupt change in slope or material; also referred to as the backshore.
Bar	Fully or partially submerged elongated elongated mound of sand, gravel or other unconsolidated material built on the sea-bottom in shallow water by waves and currents.
Beach face	Upper surface of the beach.
Beach nourishment	Artificial process of replenishing a beach with material from another source.
Beach profile	Side view of a beach which may extend from the top of the backshore, the face of a dune line, or a sea wall, into the sea.
Benefits (related to issue)	The service that a feature provides. In other words, why people value or use a feature. For example, a nature reserve, as well as helping to preserve biodiversity and meet national legislation, may also provide a recreation outlet much like a sports centre provides a recreation function.
Berm crest	Ridge of sand or gravel deposited by wave action on the shore just above the normal high water mark.
BAP	Biodiversity Action Plan. An element of UK environmental legislation, aimed at enhancing and protecting biodiversity within key habitat areas.
Brackish water	Freshwater mixed with seawater.
Breaker	
Breaker zone	Area in the sea where the waves break.
CSG	Client Steering Group. The CSG is comprised of representatives from the key operational bodies and statutory consultees involved with coastal and estuarine management within the SMP area. They provide an overseeing steer and guidance role to technical consultants and generally oversee the consultation and approvals activities required within the SMP2 programme.
Clastic	Pertaining to a sediment or rock composed chiefly of fragments derived from pre-existing rocks or minerals
Coastal defence	A term used to encompass both coastal protection against erosion and sea defence against flooding.
Coastal defence	A detailed assessment of the strategic coastal defence option(s) for a management

Term	Definition
strategy plan	unit(s), based on Flood and Coastal Defence Project Appraisal Guidance 2.
Coastal habitat management plan (CHaMP)	A non-statutory management plan which identifies potential future changes to coastal habitats and potential compensation measures for any losses to a European designated site or group of sites.
Coastal squeeze	The reduction in habitat area that can arise if the natural landward migration of a habitat under sea level rise is prevented by the fixing of the high water mark, e.g. a sea wall.
Coastal zone management plan	Plans through which local authorities and others implement planning objectives and policies for an area of the coast, which deal with a range of issues such as landscape management, development, recreation, conservation, etc.
Concern	This is a stated actual or perceived problem, raised by an individual or stakeholder. A concern can be strategic or local.
Consequence	An outcome or impact such as economic, social or environmental impact. It may be expressed as a quantity (e.g. monetary value), categorical (e.g. high, medium, low) or descriptive (see FCDPAG4).
Conservation	The political/social/economic process by which the environment is protected and resources are used wisely.
CV	Capital Value. The actual value of costs or benefits.
Deep water	Area where surface waves are not influenced by the sea-bottom.
Defra	Department for Food, Environment and Rural Affairs
Defra Procedural Guidance	The Shoreline Management Plan (SMP) Procedural Guidance produced by Defra to provide a nationally consistent structure for the production of future generation Shoreline Management Plans.
Downdrift	Direction of longshore movement of beach materials.
Downdrift effects	Impacts occurring in the lee of any coastal activity resulting from associated changes to the coastal processes, particularly sediment supply.
Dredging	Excavation, digging, scraping, draglining, suction dredging to remove sand, silt, rock or other underwater sea-bottom material.
Dune	Accumulations of wind-blown sand in ridges or mounds that lie landward of the beach and usually parallel to the shoreline.
Ebb-tide	The falling tide, part of the tidal cycle between high water and the next low water.
Economic appraisal	An appraisal which takes into account a wide range of costs and benefits, generally those that can be valued in money terms.
Ecosystem	Organisation of the biological community and the physical environment in a specific geographical area.
Enhance (improve)	The value of a feature increases.
Erosion	The loss of land or encroachment by the sea through a combination of natural forces e.g. wave attack, slope processes, high groundwater levels.
Estuary	Mouth of a river, where fresh river water mixes with the seawater.
European site	Any site that has been designated as a site of international nature conservation importance either as a Special Protection Area (SPA), a Special Area of Conservation (SAC) or a Ramsar Site. In regard to planning considerations it is Government policy to treat potential SPAs, candidate SACs and listed Ramsar Sites as if they were already designated.
EIA	Environmental Impact Assessment. Detailed studies that predict the effects of a development project on the environment. They also provide plans for mitigation of any significant adverse impacts.
EMF	Elected Members Forum. The EMF is comprised of elected council members from within the SMP area. They are consulted with at key stages of the SMP programme. Endorsement of the preferred plan is sought from the EMF prior to public consultation.
Epoch	The three periods of time in which the Shoreline Management Plan is reviewed in. The first epoch is 0-20 years, the second epoch is 20-50 years and the third epoch is 50-100 years.
ESA	Environmentally Sensitive Area. A non-statutory designation for an area where special land management payments are available through agreement with Defra to provide farming practices which are beneficial to the environment.
Feature	Something tangible that provides a service to society in one form or another or, more

Term	Definition
	simply, benefits certain aspects of society by its very existence. Usually this will be of a specific geographical location and specific to the SMP.
Fetch	The distance that the wind has passed across the water in one direction (the greater the fetch, the larger the wind-driven waves will be).
Flooding	Refers to inundation by water whether this is caused by breaches, overtopping of banks or defences, or by inadequate or slow drainage of rainfall or underlying ground water levels. Flooding due to blocked drains and sewers or the escape of water from a water supply service will usually be the responsibility of the local water company and does not fall within the scope of a Shoreline Management Plan.
Flood-tide	Rising tide, part of the tidal cycle between low water and the next high water.
Flood Zone	A geographical area officially designated subject to potential flood damage. The Environment Agency defines Flood Zone 2 and Flood Zone 3 (see below).
Flood zone 2	The area that could be affected by flooding from the sea, if there were no flood defences in place. Flood zone 2 shows the area that could be affected by an extreme flood from the sea, with up to a 0.1 per cent (1 in 1000) chance of occurring each year.
Flood zone 3	The area that could be affected by flooding from the sea, if there were no flood defences in place. Flood zone 3 shows the area that could be affected by a flood event that has a 0.5 per cent (1 in 200) or greater chance of happening each year.
Fluxes	The rate of flow of water, as the tide or current, through a defined area.
Foreshore	Zone between the high water and low water marks.
Gabions	Wire mesh rectangular containers filled with stones.
Geomorphology/ Morphology	The branch of physical geography/geology which deals with the form of the Earth, the general configuration of its surface, the distribution of the land, water, etc.
GIS	Geographic Information System. Software which allows the spatial display and interrogation of geographical information such as ordnance survey mapping and aerial photography.
Greenhouse effect	Heating of the earth's atmosphere due to a presence in gases like carbon dioxide.
Groyne	Shore protection structure built perpendicular to the shore; designed to trap sediment.
Groyne field	Series of groynes acting together to protect a section of beach.
Habitat action plan	A biodiversity action plan for a habitat.
Habitat directive	EC Directive 92/43 on the conservation of natural habitats and of wild fauna and flora.
Habitat regulations	The conservation (Natural Habitats & c.) Regulations 1994. This transposes the Habitats Directive into UK Law.
Hazard	A situation with the potential to result in harm. A hazard does not necessarily lead to harm.
HTL	Hold the Line. Policy decision to maintain or upgrade the level of protection provided by defences or natural coastline.
Heritage Coast	A non-statutory designation by the Countryside Commission for coasts of scenic quality, their largely undeveloped nature and their special wildlife and historic interest. Local authorities assist with the management of Heritage Coasts often with Heritage Coast officers.
Integrated	An approach that tries to take all issues and interests into account. In taking this approach, managing one issue adds value to the way another is dealt with.
Isobath	A line on a chart joining places of equal depth or hight e.g. a contour
Issue	All issues and aspirations are related to flood and coastal defence and grouped or categorised under the three main themes: Technical; Environmental; or Socio-economic
Key stakeholder	A person or organisation with a major interest in the preparation of, and outcomes from, a shoreline management plan. This includes agencies, authorities, organisations and private bodies with responsibilities or ownerships that affect the overall management of the shoreline in a plan.
Land reclamation	Process of creating new, dry land on the seabed.
Landslide	A coastal landslide can be regarded as a flow of sediment from an area of elevated topography to the foreshore. Slope instability and a semi-continuous sediment

Term	Definition
	cascade is maintained by basal erosion which can act in two ways: (i) degraded materials are removed from the base of the slope, which prevents a stable slope angle being achieved; (ii) basal erosion of in-situ strata can undercut the cliff toe so that the slope is steepened to a greater repose angle than would naturally be maintained by the ground-forming materials. From a coastal viewpoint the result is the same, in that sediment is supplied to the littoral zone, and, assuming it is removed thereafter, the coast retreats.
LDF	Local Development Framework. The Isle of Wight LDF is called the Island Plan.
Lithology	Mineralogy, grain size, texture, and other physical properties of granular soil, sediment, or rock.
Littoral	The littoral zone extends from the high water mark, which is rarely inundated, to shoreline areas that are permanently submerged. It always includes the intertidal zone and is often used to mean the same as the intertidal zone.
Longshore current	A movement of water parallel to the shore, caused by waves and tides.
Longshore transport	Movement of material parallel to the shore also referred to as longshore drift.
LNR	Local Nature Reserves. A statutory designation for sites established by local authorities in consultation with Natural England. These sites are generally of local significance and also provide important opportunities for public enjoyment, recreation and interpretation.
Maintain	That the value of a feature is not allowed to deteriorate.
Managed realignment	The reintroduction of tidal waters to previously enclosed or reclaimed land Defra def - Allowing the shoreline to move backwards or forwards, with management control or limit movement (such as reducing erosion or building new defences on the landward side of the original defence).
Management Area (MA)	Management Area, defined by SMP2. A collection of Policy Units (PU) that are interdependent and should therefore be managed collectively.
MDSF	Modelling and Decision Support Framework. Mapping linked computer tool used in the evaluation of assets at risk from flooding or erosion.
Mean sea level	Average height of the sea surface.
MHW	Mean High Water. The average of all high waters observed over a sufficiently long period.
MLW	Mean Low Water. The average of all low waters observed over a sufficiently long period.
MR	Managed Realignment. Policy decision to manage the coastal processes to realign the 'natural' coastline configuration, either seaward or landward, in order to create a future sustainable shoreline position
Natura 2000	European network of protected sites which represent areas of the highest value for natural habitats and species of plants and animals which are rare, endangered or vulnerable in the European Community.
NAI	No Active Intervention. Policy decision to not to invest in providing or maintaining defences or natural coastline. NAI is also a scenario or prediction used in SMP2 to understand potential future coastal change. The scenario assesses the consequences of applying a NAI policy to the shoreline, allowing existing defences to fail and coastal change to occur.
Nearshore	The region of land extending from the backshore to the beginning of the offshore zone.
NNR	National Nature Reserves. A statutory designation by Natural England. These represent some of the most important natural and semi-natural ecosystems in Great Britain and are managed to protect the conservation value of the habitats that occur on these sites.
Objective	A desired state to be achieved in the future. An objective is set, through consultation with key parties, to encourage the resolution of the issue or range of issues.
Offshore breakwater	Structure parallel or angled to the shore, usually positioned in the sea, which protects the shore from waves.
Offshore zone	Extends from the low water mark to a water depth of about 15 m (49 ft) and is permanently covered with water.
Operating	A body with statutory powers to undertake flood defence or coast protection activities,

Term	Definition
authority	usually the Environment Agency or maritime District Council.
Pile	Long heavy section of timber, concrete or metal, driven into the ground or seabed as support for another structure. Especially around/or at the toe of a shore protection structure.
Policy	In this context, "policy" refers to the generic shoreline management options (No Active Intervention, Hold the Existing Line of Defence, Managed Realignment, Retreat or Advance the Existing Line of Defence, and Hold the Retired Line).
PDZ	Policy Development Zone. A length of coastline defined for the purpose of assessing all issues and interactions to examine and develop management scenarios. These zones are only used in the procedure of developing policy. Policy Units and Management Areas are then used for the Final definition of the policies and the management of the coast.
Policy Scenario	A combination of policies selected against the various feature/benefit objectives for the whole SMP frontage.
Policy Unit (PU)	Policy Unit, defined by SMP2. A section of coastline for which a certain coastal defence management policy has been defined. These are then grouped into Management Areas (MA).
PV	Present Value. The value of a stream of benefits or costs when discounted back to the present day. For this SMP the discount factors used are the latest provided by Defra for assessment of schemes, i.e. 3.5% for years 0-30, 3.0% for years 31-75, and 2.5% thereafter.
Residual life	The time to when a defence is no longer able to achieve minimum acceptable performance criteria in terms of serviceability or structural strength.
Residual risk	The risk which remains after risk management and mitigation. It may include, for example, risk due to very severe storms (above design standard) or risks from unforeseen hazards.
Retaining wall	Wall built to hold back earth.
Revetment	Shore protection structure made with stones/ rock laid on a sloping face.
Risk assessment	Consideration of risks to people and the developed, historic and natural environment.
Risk management	The process of analysing exposure to risk and determining how to best handle such exposure.
Ramsar	Designated under the, "Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat" 1971. The objective of this designation is to prevent the progressive encroachment into, and the loss of wetlands.
RIGS	Regionally Important Geological/Geomorphological Sites. A non-statutory designation identified by locally developed criteria and are currently the most important places for geology and geomorphology outside statutorily protected land such as SSSI's.
Schedule IV	'Waters excluded for purposes of definitions of 'sea' and 'seashore' (refer to Coast Protection Act, 1949).
Scour	Removal of underwater material by waves or currents, especially at the toe of a shore protection structure.
SAC	Special Area of Conservation. This designation aims to protect habitats or species of European importance and can include Marine Areas. SACs are designated under the EC Habitats Directive (92/43EEC) and will form part of the Natura 2000 site network. All SACs sites are also protected as SSSI, except those in the marine environment below the Mean Low Water (MLW).
SFRA	Strategic Flood Risk Assessment. The Isle of Wight SFRA assesses flood risks on the Isle of Wight, and in particular the flood risks associated with areas being considered for future development as part of the emerging Local Development Framework (LDF).
SM	Scheduled Monument. A statutory designation under the Ancient Monuments and Archaeological Areas Act 1979. This Act, building on legislation dating back to 1882, provides for nationally important archaeological sites to be statutorily protected as Scheduled Ancient Monuments.
SEA	Strategic Environmental Assessment. In SMP terms an SEA is an independent audit of the SMP process and the policies it puts forward. SEA assesses policies for potential impacts against a series of environmental themes.
Seawall	Massive structure built along the shore to prevent erosion and damage by wave

Term	Definition
	action.
Sediment	Particles of rock covering a size range from clay to boulders.
Sediment cell	A length of coastline and its associated near shore area within which the movement of coarse sediment (sand and shingle) is largely self contained. Interruptions to the movement of sand and shingle within one cell should not affect beaches in an adjacent sediment cell.
Sediment sub-cell	A sub-set of a sediment cell within which the movement of coarse sediment (sand and shingle) is relatively self contained.
Setback	Prescribed distance landward of a coastal feature (e.g. the line of existing defences).
Shore	Narrow strip of land in immediate contact with the sea.
Shoreline	Intersection of a specific water height with the shore or beach, e.g. the high water shoreline is the intersection of the high water mark with the shore or beach.
Significant effect	Where a plan or project is likely to affect a European Site it is necessary to decide whether or not it would have a significant effect. If there is any doubt, the operating authority must consult English Nature/Countryside Council for Wales. They will advise whether, in their view, the proposed scheme would be likely to have a significant effect.
Sink	Area at which beach material is irretrievably lost from a coastal cell, such as an estuary, or a deep channel in the seabed.
SLA	Special Landscape Area. A non-statutory designation for an area usually identified by local authorities as having a strategic landscape importance.
SMA	Sensitive Marine Area. A non-statutory designation for nationally important locations around the coast that require a cautious and detailed approach to management. They are identified by Natural England for their important benthic populations, spawning or nursery areas for fish, fragile intertidal communities, or breeding, feeding, and roosting areas for birds and sea mammals.
SMP	Shoreline Management Plan. A non-statutory plan, which provides a large-scale assessment of the risks associated with coastal processes and presents a policy framework to reduce these risks to people and the developed, historic and natural environment in a sustainable manner.
SNCI	Site of Nature Conservation Importance. A non-statutory designation defined by the Wildlife Trusts and Local Authorities as sites of local nature conservation interest. These form an integral part in the development of planning policies relating to nature conservations issues.
SPA	Special Protection Area. A statutory designation for internationally important sites, being set up to establish a network of protected areas of birds.
SSSi	Sites of Special Scientific Interest. A statutory designation notified by Natural England representing some of the best examples of Britain’s natural features including flora, fauna, and geology.
Stakeholder	A person or organisation with an interest in the preparation of a shoreline management plan or affected by the policies produced. This broad interpretation has been taken to include agencies, authorities, organisations and private persons. See "Key stakeholder".
Storm surge	A rise in the sea surface on an open coast, resulting from a storm.
Strategic	Used to describe the undertaking of any process in a holistic manner taking account of all associated impacts, interests of other parties and considering the widest possible set of potential options for the solution of a problem. In the context of this document, the word 'strategic' does not imply any particular level in the hierarchy of the planning process.
Sustain	Refers to some function of a feature. A feature may change, but the function is not allowed to fail.
Sustainable policies	Sustainable policies lead to coastal defence solutions that avoid tying future generations into inflexible and/or expensive options for defence. They will usually include consideration of interrelationships with other defences and likely developments and processes within a coastal cell or sub-cell. They will also take account of long-term demands for non-renewable materials.
Swell	Waves that have travelled out of the area in which they were generated.
Temporal	Referring to the passage or a measurement of time

Term	Definition
Tidal current	Movement of water in a constant direction caused by the periodic rising and falling of the tide. As the tide rises, a flood-tidal current moves in one direction and as the tide falls, the ebb-tidal current moves in the opposite direction.
Tidal inlet	A river mouth or narrow gap between islands, within which salt water moves landwards during a rising tide.
Tidal prism	The volume of water within an estuary between the level of high and low tide, typically taken for mean spring tides.
Tide	Periodic rising and falling of large bodies of water resulting from the gravitational attraction of the moon and sun acting on the rotating earth.
Toe protection	Material, usually large boulders, placed at the base of a sea defence structure like a seawall to prevent wave scour.
Topography	Configuration of a surface including its relief and the position of its natural and man-made features.
Transgression	The landward movement of the shoreline in response to a rise in relative sea level.
Updrift	Direction opposite to the predominant movement of longshore transport.
VMCA	Voluntary Marine Conservation Areas. A statutory designation to protect the marine conservation importance of a site and to provide a focus for liaison, co-operation and education for a sustainable marine environment.
Water table	The upper surface of groundwater; below this level, the soil is saturated with water.
WFD	Water Framework Directive. European legislation which seeks to improve the quality of both freshwater and coastal water bodies.
Wave direction	Direction from which a wave approaches.
Wave refraction	Process by which the direction of approach of a wave changes as it moves into shallow water.
Wetlands	Low-lying areas that are frequently flooded and which support vegetation adapted to saturated soils e.g. mangrove swamps.
WPM	With Present Management. WPM is a scenario or prediction used in SMP2 to understand potential future coastal change. The WPM scenario essentially describes the current regime of management which exists for a given frontage. WPM scenario assumes that defences will be maintained in their present position and other management practices, e.g. beach re-nourishment, will continue as at present.

C1. Assessment of Shoreline Dynamics

C1.1 Introduction

This Appendix assesses the coastal processes shaping the evolution of the Isle of Wight coast, describing the character of different sections of the coastline in accordance with the Shoreline Behaviour Statements defined in the Futurecoast report (Futurecoast, 2002):

- North-east coast: Old Castle Point (East Cowes) to Culver Cliff
- South-east coast: Culver Cliff to Dunnose
- Southern coast: Dunnose to Rocken End (along the Ventnor Undercliff)
- South-west coast: Rocken End to the Needles
- Western coast: The Needles to Cliff End (Fort Albert, Colwell Bay)
- North-west coast: Cliff End to Old Castle Point

It also contains relevant information produced post-Futurecoast or at a level of detail not included within Futurecoast, e.g. longshore variations in sediment transport rates. The two can be read in conjunction with one another to provide a full understanding of coastal dynamics and behaviour across different spatial and temporal scales.

This report makes use of the Sediment Transport Study 2004, which was produced by the Geography Department, University of Portsmouth for SCOPAC (Standing Conference on Problems Associated with the Coastline). Details relating to hydrodynamic regime and functional behaviour and organisation of landforms in this coastal processes report have largely been taken from the Sediment Transport Study which is currently the best available research for this area of the coast. The Sediment Transport Study is publicly available on the SCOPAC website - www.scopac.org.uk/sedimenttransport.htm

A map is provided below illustrating all the large-scale and local-scale process unit boundaries used in each section of the report.

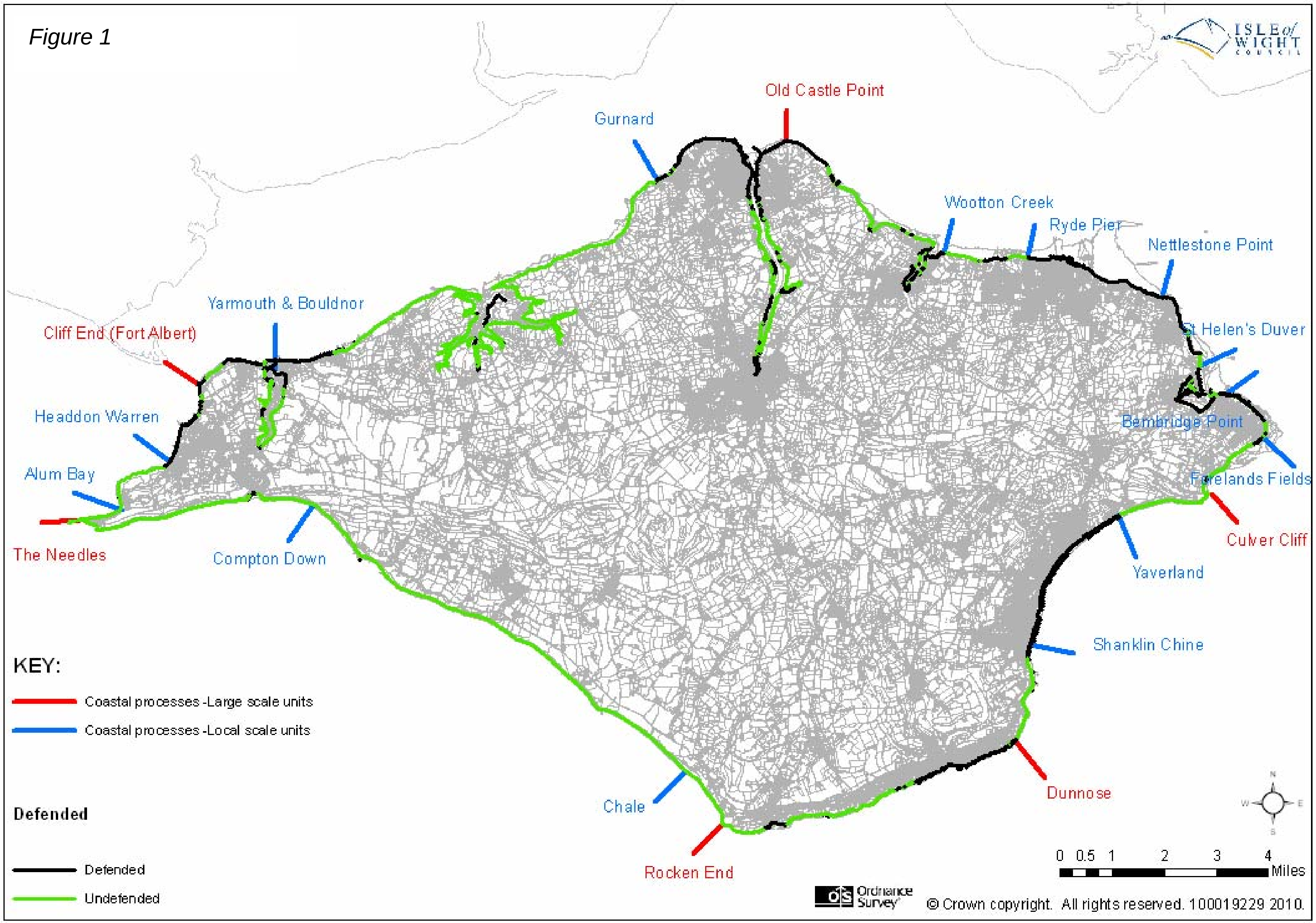

Figure 1
ISLE of WIGHT COUNCIL
Old Castle Point
Gurnard
Wootton Creek
Ryde Pier
Nettlestone Point
St Helen's Duver
Bembridge Point
Forelands Fields
Culver Cliff
Yaverland
Shanklin Chine
Dunnose
Rocken End
Chale
Compton Down
The Needles
Alum Bay
Headdon Warren
Cliff End (Fort Albert)
Yarmouth & Bouldnor
KEY:
Coastal processes -Large scale units
Coastal processes -Local scale units
Defended
Defended
Undefended
0 0.5 1 2 3 4 Miles
Ordnance Survey
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C1.2 General Overview

The Isle of Wight Coast and estuaries form a dynamic coast approximately 168km in length, with a wide variety of coastal scenery in a relatively small area. The northern coast of the Isle of Wight is generally characterised by relatively low-lying coastal slopes, with five estuaries and rivers draining north into the Solent. By contrast the southern coast is generally characterised by steep coastal cliffs and landslides.

The Isle of Wight coastline has been shaped by major sea level fluctuations which have occurred in response to periods of glaciation. During the last cold period of the Ice Age sea levels fell by up to 140 metres. At this time, the Island's Chalk spine would have extended to the Isle of Purbeck in Dorset. As the ice sheets melted and sea levels rose over the period 15,000 to 5,000 years BP (before present), the Chalk ridge was eroded and the valley behind flooded, forming the Solent and separating the Isle of Wight from the mainland. During this period of fluctuating sea levels the Isle of Wight coastline was subject to rapid rates of erosion. The sediments resulting from the erosion of the Island's cliffs were transported to form various sand and gravel banks in the eastern Solent.

Figure 2: Aerial view of the Isle of Wight, viewed from the south (Isle of Wight Council)

The solid geology and structure of the Island is dominated by a strong east-west monocline – a Chalk ridge which cuts through the centre of the Island and is exposed at either end to form headlands at The Needles in the west and Culver Cliff in the east. This ridge is the result of tectonic activity 30 million years ago (the Cainozoic era) causing a folding of the Isle of Wight rocks. To the north of the ridge the relatively sheltered coastline is characterised by low lying land and estuaries. To the south the coastline is characterised by high sea cliffs and is more exposed to the effects of erosion. A prominent feature of the south coast is The Undercliff - an ancient coastal landslide complex extending from Luccombe in the east to Blackgang in the west. The feature is approximately 12km in length and extends approximately 500m inland and nearly 2km seawards. The Undercliff is formed from the Lower Cretaceous and Chalk outlier known as the Southern Downs.

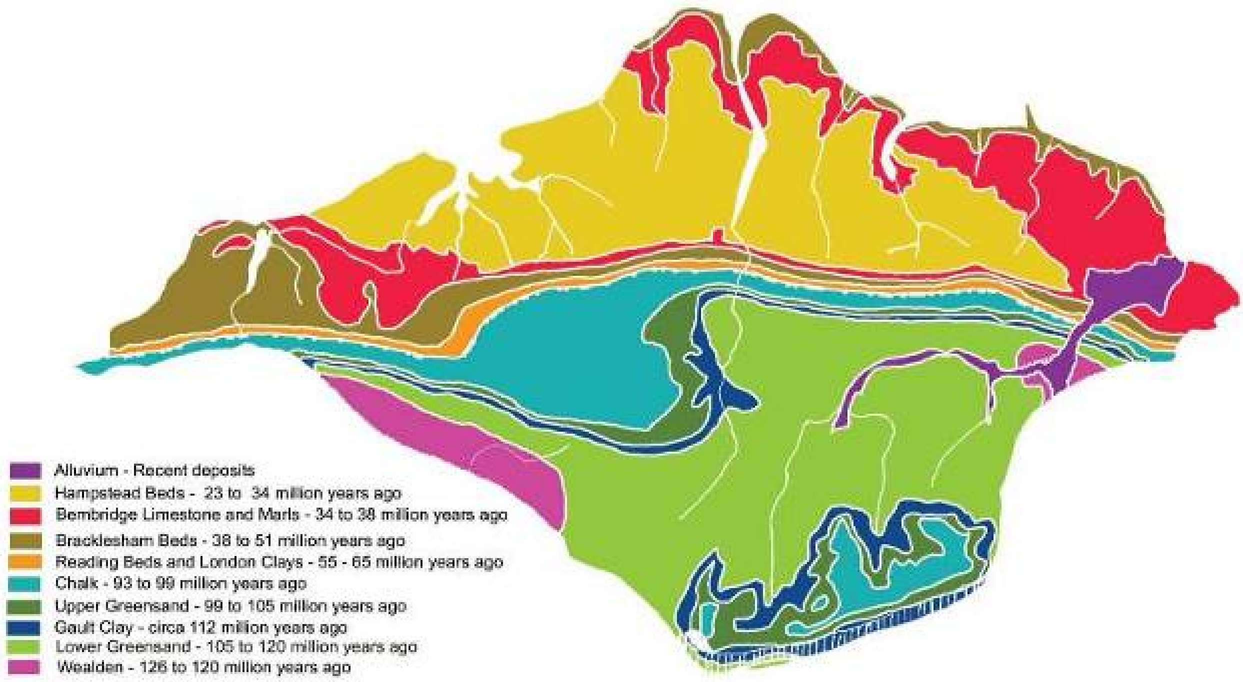

Figure 3: Geological map of the Isle of Wight (Isle of Wight Council)

Within its relatively small area, the Island's coast is extremely varied and dynamic. Marine erosion has continued around most of the Island to produce a near-continuous cliff line that varies greatly in terms of morphology and rates and styles of weathering and landslide activity. The cliffs adopt characteristic forms according to topography, the properties of their ground forming materials and exposure of their toes to marine erosion. The south coast in particular is vulnerable to large storms crossing the Atlantic and rates of erosion are particularly rapid in the softer Wealden rocks along the south-west coast of the Island. The exposed (high energy) southern coasts also allow greater potential for shoreline sediment transport compared to those along the sheltered environments of the Solent to the north. Nevertheless, strong tidal currents are generated in the western Solent and these contribute additionally towards sediment mobility in specific areas.

There are five estuaries located on the north and north-eastern coasts of the Island: the Western Yar; Newtown Estuary; Medina Estuary; Wootton Creek; and Eastern Yar. The Island's estuaries have been internationally recognised as important for nature conservation and are included in the Solent European Marine Site. The nearshore and offshore zones are characterised by a thin layer of sand and gravel that form gravel banks at some locations. Sediment transport in the nearshore zone is complex around the Island's coastline, as movement of sediment is interupted by estuaries, headlands and offshore features such as St. Catherine's Deep off the extreme south of the Island.

Sediment transport plays a central role in coastal processes and a study of the sedimentary system is essential to gaining a clear picture of coastal processes and assessing past, present and future coastal change. "The results of the EUROSION case studies and other Europe wide evidence, suggests that too often in the past insufficient attention has been paid to the functioning of the whole sedimentary system" (EUROSION, 2004).

There are distinct differences between the exposed southerly and westerly facing coasts (potentially rapid marine erosion) and the relatively sheltered north coast (modest toe erosion). Cliff erosion materials deposited on the foreshore are valuable inputs to the immediate littoral system and also contribute to beaches further downdrift. Cliff sediments provide more permanent protection of the cliff toe if they are sufficiently durable to remain on the local beach and are not removed by littoral drift. In spite of continued cliff erosion sediment inputs, local beaches are not large, suggesting that most materials continue to be removed and that the Island's beaches are open systems dependent upon continued inputs for their stability and even survival. Since sedimentation is generally confined to small spits at inlets, or within the estuaries themselves, the Island apparently functions as a sediment source or donor to other areas including the offshore zone.

Around the coast of the Isle of Wight, seabed sands and gravels are highly mobile during peak flow conditions, with a general eastward transport of bedload sediment. In sites where this general trend is interrupted, for example at Thorness Bay and Hurst Narrows, sand and shingle banks have formed. A number of these shingle banks have been extensively dredged in the past, including Pot Bank, off the Needles, and Solent Bank off Newtown.

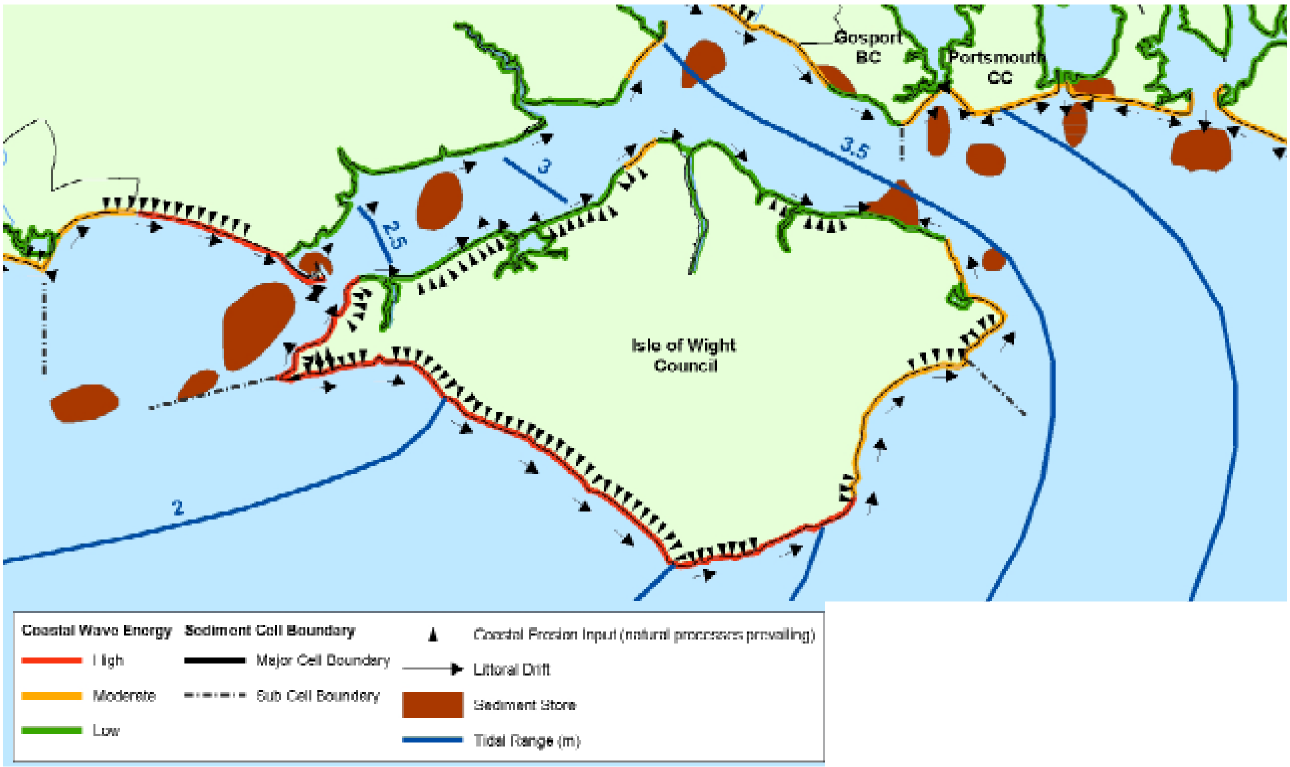

Figure 4: Sediment budget around the Isle of Wight coast

A number of sections of the Islands coastline have been modified by the construction and maintenance of hard coastal defences; namely Cowes, Ryde, Ventnor, Sandown Bay and in the extreme north-west. This means that in some areas natural shoreline dynamics may be altered, which has implications for future shoreline management.

Figure 5: Key towns and transport links on the Isle of Wight, with the majority of large settlements located along the coast. Isle of Wight Council, 2009.

Southeast Strategic Regional Coastal Monitoring Programme:
The Southeast Strategic Regional Coastal Monitoring Programme provides a consistent regional approach to coastal process monitoring, providing data on large number of beach profile lines around the Isle of Wight coast as well as data on wave and tide conditions. Some data predating the strategic monitoring programme exists for some areas of the coastline but data is not consistent. Baseline data was collected in 2003/4 onwards and a summary of the results from the monitoring programme on the Isle of Wight since the programme started until Spring 2009 are presented in the local scale units below. This is a relatively short time base over which beach changes have been monitored, and detailed interpretation and decision-making is not advisable on the basis of these short-term changes, which may not be representative of longer-term trends. However, these results provide and indication of short-term trends and will be reviewed in future years as more data is collected. Further details are available in Annex A and in the Southeast Strategic Regional Coastal Monitoring Programme Isle of Wight Annual Report (Channel Coastal Observatory, 2009).

C1.3 Large Scale: Old Castle Point to Culver Cliff

Interactions:

The north-east Isle of Wight coast forms the southern margin of the Eastern Solent, and provides shelter for the busy shipping lanes. The coast is mostly low-lying, or only of moderate relief. Erosion predominates, resulting in the development of varied cliff forms. The north-east coast includes the inlets of Bembridge Harbour and Wootton Creek.

The east Solent is relatively rich in coarse sediments, although most are channel rather than shoreline deposits. Tidal currents are less rapid in the East Solent (generally <1ms^{-1}) compared to the West (>2ms^{-1}) and predominantly clays, silts and fine sand are mobile in these conditions (Dyer, 1980; Webber, 1980). Sediment is transported from the south-east coast (Whitecliff and Sandown Bays), into the East Solent whereupon the majority is deposited on the north-east coast, especially at Ryde Sands, a sediment sink (Lonsdale, 1969; Dyer, 1980).

NE Isle of Wight (Old Castle Point to Culver Cliff: Sediment Transport Sources, Pathways and Sinks

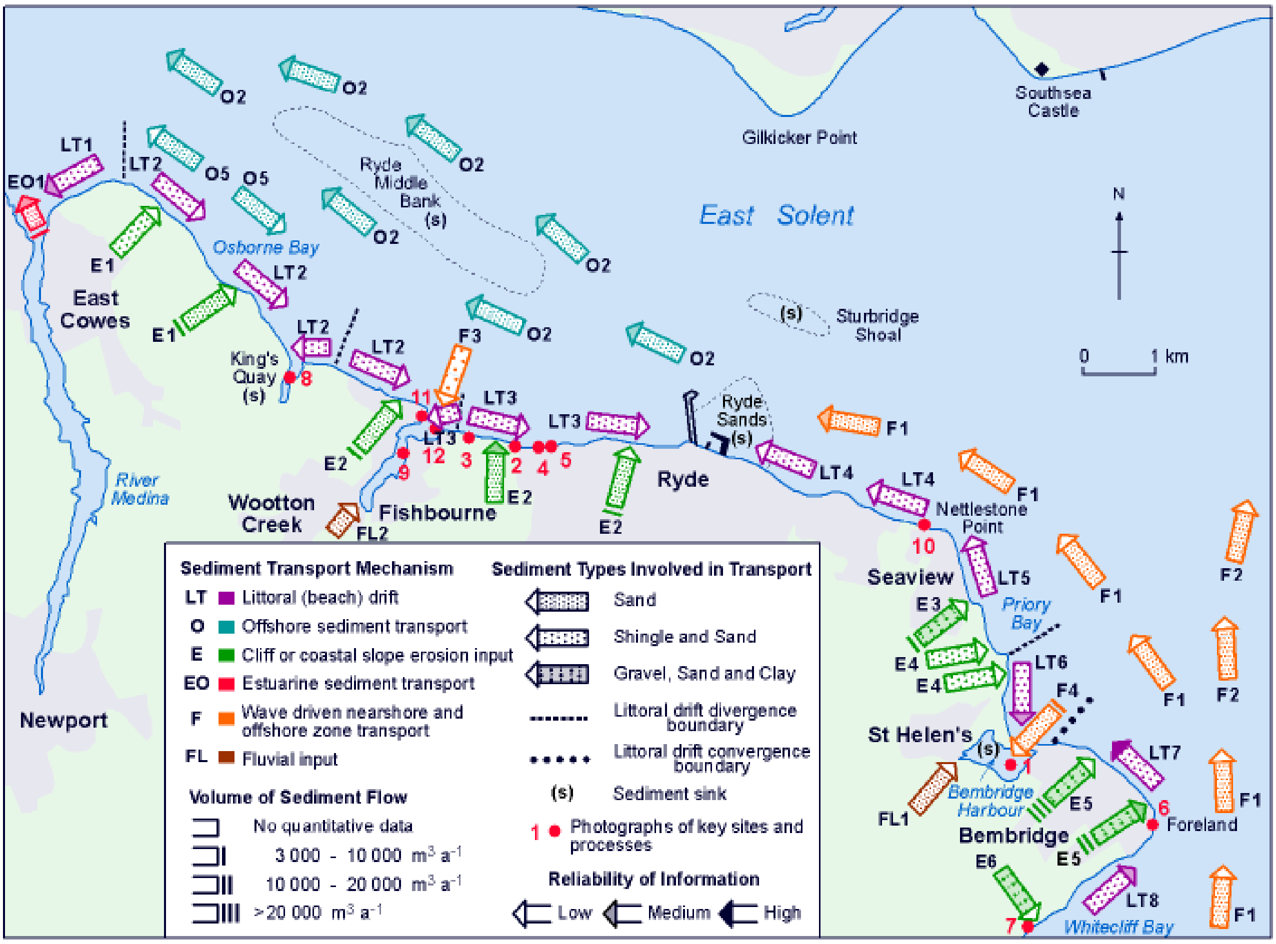

Figure 6: Sediment transport sources, pathways and sinks on the north east coast, from SCOPAC Sediment Transport Study, 2004.

The coast to the east of Ryde Sands is open to waves generated in Hayling Bay and also diffracted waves from the English Channel. Wave energy is therefore moderate and approaches from a predominantly east or south-east direction. By contrast, the foreshore at Ryde and to the west is largely protected from incoming south eastward waves by Ryde Sands. The prevailing waves are therefore generated in Southampton Water and the East Solent and are fetch limited. This coast is therefore subject to low energy wave action from a dominant north-west direction. Offshore gradients are relatively gentle and the shoreline is not greatly affected by tidal currents except at the small inlets of Wootton Creek and Bembridge Harbour. Tidal flow through narrow entrances to these inlets generates rapid currents which interrupt littoral sediment transport causing local circulation effects and associated changes in coastal configuration.

Significant variations in coastal orientation and exposure have produced contrasting directions and rates of littoral drift according to location. To the west of Ryde, incident waves are fetch limited and slow eastward net drift predominates on small sand/shingle beaches that are fronted by wide muddy foreshores occupied by occasional limestone reefs, enigmatic shingle structures, ancient peat beds and eroding clay shore platforms. Wave exposure increases to the east of Ryde and the foreshore is dominated increasingly by sandy sediments that drift in a dominant north west direction. Two littoral sediment transport pathways thus converge upon Ryde Sands where a major accumulation of sand has developed.

With the exception of raised beach deposits at Bembridge, the local geological types of the cliffs yield mostly fine sediments as they erode and tend to contribute to the suspended sediment load of the Solent waters rather than to local beaches. Excluding Ryde Sand, much of the coast has few other sources of supply and it is possible that local coast erosion is nonetheless the most significant sediment input as fluvial inputs are extremely small.

The sediment that is deposited on Ryde Sands appears to be derived entirely by erosion of local cliffs. As the sediment yield from these cliffs is low, protection and stabilisation can have significant impacts on the availability of shoreline sediments. It is likely that an additional source of sediment is an offshore feed of sand from Sandown Bay. Discontinuities are identified in these pathways resulting from minor headlands and inlets where littoral drift is in both directions towards the entrance as at East Cowes, Wootton Creek and the Duver, St Helens. Accompanying littoral drift divergences are recognised in the vicinity of Old Castle Point, Nodes Point and on the eastern shore of Wootton Creek entrance. These locations are by nature susceptible to sediment starvation and are especially sensitive to variations in sediment supply. Significant erosion problems at the Duver and Fishbourne are in close proximity to these drift divergences.

The detailed pattern of littoral and offshore sediment transport pathways are complex and are described in detail in the SCOPAC Sediment Transport Study, 2004.

Shoreline Movement:
Most of this coastline is occupied by either active cliffs subject to basal marine erosion and mass movement processes or by a steep or moderately steep coastal slope currently removed from the influence of breaking waves by beaches and/or defence structures. Both are developed in relatively unresistant sandstones, marls and clays which yield readily to both marine and sub-aerial geomorphological processes. Interbedded limestones outcrop at several localities, notably the Bembridge Limestone. This provides somewhat greater resistance and is responsible for the majority of headlands and offshore reef-like platforms. It breaks down into inter-joint blocks and creates a persistent local boulder apron that partly protects the upper foreshore and cliff toe by dissipating some incoming wave energy.

The rock outcrop pattern is determined by geological structure, in particular a series of shallow folds whose axes are roughly parallel with the north coast but are truncated by the approximately north to south alignment of the east coast (White, 1921; Bird, 1997). Stratal dips tend, overall, to be inland, thus contributing to slope stability. Nonetheless, there are several sites of present, or past, slope failure associated with critical pore water pressures in porous or permeable rocks, particularly where they are underlain by rocks which, although permeable, have less capacity for the storage of groundwater. Because the topography of the north-east Isle of Wight is less elevated than in any other part of the island, coastal cliffs and slopes are modest in height, nowhere exceeding 35m. This factor also helps to suppress the scale and frequency of slope failure and the dynamics of mass movement. The mature woodland cover of much of the north-facing coastal slope also contributes to stability.

The overall pattern, and localised rates, of coastal recession have been calculated from serial analysis of topographic maps from 1863 to 1975, with updating to 1995 from air photographs, where available (Halcrow, 1996; Isle of Wight Council, 2004). Within the latter study (the North East Coastal Defence Strategy Study) there is also an evaluation of the likely patterns of future evolution and recession to 2050 and 2100. These figures are expressed as mean values covering specific historical periods, and conceal fluctuations in time and space; they are selectively quoted in the following summaries for each of the units currently contributing sediment to littoral transport processes.

C1.3.1 Local Scale: Old Castle Point to Wootton, including Wootton Creek

Interactions:

Old Castle Point is a drift divergence zone, with some accretion against the eastern side of Cowes breakwater (Shrape Breakwater, at the mouth of the Medina Estuary) since its construction in 1936/37 indicating a long-term trend for weak net westward littoral drift from Old Castle Point, located approximately 1km to the east. Similar accumulations against other smaller structures provide a corroboration of this drift direction. However, this is a localised phenomenon, and the overall trend on the north-east coast of the Isle of Wight is for eastwards sediment drift over 10km from Old Castle Point towards Ryde Sands.

Much of this coastline is occupied by a steep, but relatively stable (in places graded) wooded coastal slope lacking active cliffing (Roberts.and Jewell, 2000). Erosion has been most active at Woodside, where a slope failure plane has been intermittently triggered by loss of toe weight following marine erosion since at least the late nineteenth century (Harlow, 1980). Breaches of the now dilapidated defences at certain sites, e.g. Norris Castle, have recently reactivated old mudslides (Roberts and Jewell, 2000). Recession of MHWM averages between 0.15m/yr (metres per year) and 0.40m/yr (Posford Duvivier, 1994), with evidence of some recent acceleration (e.g. some 18m of retreat at Woodside Point, 1975-1995). Posford Duvivier (1999) calculated a cliff erosion yield of clay, silt and sand of 2,500m3/yr and shoreface erosion of between 2,600 and 7,800m3/yr for this unit. Where limestones are eroded, they tend to persist as large inter-joint blocks scattered on the foreshore and suffer loss from both solution and abrasion.

Twin spits composed of sand and gravel have developed at the entrance to King’s Quay and their orientation is indicative of transport both eastwards and westwards into the entrance. The eastern (westward trending) spit at King’s Quay therefore suggests a very local drift reversal, possibly associated with tidal current and wave interactions at the inlet, but no studies have examined this feature.

Wootton Creek estuary is a sheltered inlet extending inland 2km south-west to the village of Wootton, where the tidal flow is partially controlled by a road bridge structure, behind which the Old Mill Pond extends over 1km further to the south. There is a small spit on the east side of the mouth, and at Wootton Hard on the western side. The spits are located within the estuary and represent the inner limit of wave action. Although there are extensive sand areas offshore, the beaches on either side of the mouth are narrow and discontinuous. There is no river discharge data, but the flow must be relatively low. Nevertheless, a plume is frequently apparent on the ebb tide. The estuary tidal limit is at a former mill pond. Wootton Creek acts as a partial sediment sink, intercepting some of the eastward littoral drift, but allowing bypassing of the majority.

Sediment transport is interrupted by the Wootton Creek inlet where two main pathways into the inlet have been identified (Harlow, 1980, in SCOPAC, 2004):

1) A small proportion of eastward moving sediment is diverted into the inlet by littoral drift along the western shore which supplies the shingle spit of Wootton Hard.

2) The majority of sediment is transported eastward along a spit extending from the western shore and crossing the tidal channel to be driven ashore opposite Quarr Abbey. At this point, transport divides: some of this material is moved south further into the inlet and accumulates against the Wightlink ferry terminal. The majority of material is transported eastward along a series of barrier-like banks on the lower foreshore and then driven onshore to resume beach drift towards Ryde.

Plate 1: Wootton Creek (Isle of Wight Council).

Wootton Creek has many of the characteristics of a lower river valley submerged by sea level rise commencing in the early Holocene. Its mudbanks indicate net sediment gain since sea level rise stabilised to approximately 1.5 mma^{-1} at circa 5,500 BP. The main sources, over this timescale, and probably from 7,000 BP, are suspended clays and silts introduced by the flood tide and fluvial discharge. Several first and second order streams discharge into the creek, but much of their combined suspended load now settles out in the Old Mill Pond, now dammed at Wootton Bridge. The latter dates to about 1820, and may have imbalanced the natural sediment budget of Wootton

Creek. Much of the catchment area tributary to Wootton Creek is underlain by erodible clays and sandstones, so past sediment yield may have been significant. However, the sediment flux at the creek exit is weak, so input has been largely routed to infill (Isle of Wight Council, 2004).

The cross sectional area of the estuary is large relative to the volume, and the intertidal/total area ratio at 0.93 is higher than average for the Island. This appears to be the result of slow infilling without active wave processes to modify the mouth. The estuary appears to be ebb dominant, but there are no flow data. However, because of its low volume, maximum flows are likely to lead to significant flushing.

In Wootton Creek there is a narrow low-angle backshore of coarse clastic material, succeeded seawards by a muddy clay foreshore. Clastic material (such as sands, silts and aggregates) spreads across the foreshore close to the eastern boundary of this unit. Patches of fine well-sorted sand occur close to the dredged channel in the outer estuary. Lowering of beach levels since the early 1980s (possibly earlier) is difficult to account for but it is most likely to be related to diminished supply from feed sources, presumed to be from the east or from shipping activity (Isle of Wight Council, 2004).

The dominant wind waves incident on this shoreline, from Castle point to Wootton, are from the eastern Solent/Hayling Bay and the North West/Central Solent and Southampton Water. The former are refracted swell waves originating in the western English Channel, with the addition or superimposition of waves generated by easterly winds. Local fetch distances are small. Significant wave heights are between 1.0 (western fetch) and 1.9m (eastern fetch), with extreme heights of approximately 1.4m associated with surge conditions experienced once in 50 years. An Extreme Water Level of 2.7m OD (Ordnance Data) for a 1 in 50-year recurrence has been calculated. The east facing shore is comparatively more exposed to higher waves than the shoreline east of Fishbourne. The shoals and banks in the East Solent, e.g. Ryde Middle Bank and Sturbridge Shoal, generate complex patterns of wave refraction and diffraction that reduce effective wave heights. The intertidal mudbanks cause waves to flatten and break further from the shoreline although the dredged channel may cause some focusing of wave energy. Wave activity is significantly reduced in the estuary of Wootton Creek (Isle of Wight Council, 2004).

A local complication are waves generated by ferry movements, including reflection during high tide levels; these have been calculated at 0.3–0.4m in height, but up to 0.7m should they combine with incident wind waves of appropriate frequency. Vessels also create a displacement surge effect, briefly (but repeatedly) raising water levels. The banks, channels and shoals close to, and seaward of, MLWS may also induce localised refraction and diffraction of boat-generated waves. (Isle of Wight Council, 2004).The North East Coastal Defence Strategy Study (2004) outlines that the deepening of the approach channel to the Ferry Terminal, and continued maintenance dredging has led to enhanced potential for intertidal mudflat erosion due to the surge effect generated by the approaching ferries. The effects of ferry movements within the creek on the defences are not clear.

From on-site monitoring of wind waves and boat waves, it was concluded that between 20% and 50% of sediment transport on the inlet shores could be attributed to boat waves with the remainder resulting from wind waves (Robert West and Partners, 1990, in SCOPAC, 2004). Both types of wave cause dominant sediment transport into the inlet so that increased storminess or increased ferry sailings are likely to increase sediment interception by the inlet.

Results of the Strategic Regional Coastal Monitoring Programme (units IW2 to IW5):
There has been little change in the cross-sectional areas of the foreshore between Old Castle Point and Wootton Creek since the initial baseline survey was conducted in 2003, with the exception of some minor accretion of an area close to the mouth of Wootton Creek. At Wootton Creek only one baseline survey has been conducted, with interim profiles commencing in 2007. In

the short term the majority of profiles show no change. However, there is currently not enough data at this location to provide adequate analysis of coastal processes in the mid to long term.

Shoreline Movement:
The mean high water mark has been static or slowly retreating, controlled by coastal defences, coastal slopes, or sea cliffs. Significant retreat of the mean low water mark has resulted in foreshore narrowing throughout this frontage. Re-activations of the lower portions of coastal slopes are in progress behind failures in defences around Osborne Bay. The spits at King's Quay have migrated and re-curved into the estuary. In particular, the eastern spit has retreated by 30-50m into the estuary since 1972. The twin spits at Wootton Creek have migrated from the outer estuary towards the inner estuary.

West of Woodside Point, there has been a consistent trend of MHWS recession since the mid-19th century; cliff retreat has been modest, at a rate of between 0.10 (1909–1975) and 0.18 ma^{-1} (1975–1995). Woodside Point, however, retreated some 35m between 1863 and 1972, and approximately 15–20m between 1975 and 1995. Immediately north of Wootton Hard, where exposure to wave action is reduced, recession of somewhat less than 10m occurred between 1860 and 1980. Accelerated erosion of Woodside Point in recent decades has been ascribed to the focusing of refracted waves induced by the deepening of the approach channel to Wootton Creek, but remains speculative. Wootton Hard receded landwards approximately 40m between 1946 and 1994 (derived from combined map and aerial photographic evidence). The eastern spit has migrated landwards some 30m since the mid-1940s, thus suggesting a similar process of transgressive recession. It may now be stable in platform and volume as no distal growth or re-curvature has been observed since the late-1950s. Fine-grained sediment arriving at the tip of this spit is presumably moved into the tidal channel and thence seawards. East of Fishbourne Landing Stage, cliff top retreat of 18–20m has occurred since the mid-19th century (Isle of Wight Council, 2004).

Long-term erosion of the eastern foreshore near the mouth of Wootton Creek has revealed the sequential occupation of this site from the Neolithic period, although continuation of erosion will threaten this resource.

Predictions of Shoreline Evolution:
In the next 100 years the evolution of this shoreline will be influenced by the maintenance of coastal defences, sea level rise and sediment supply.

The majority of defences in Osborne Bay appear abandoned and are unlikely to be maintained or replaced. At these locations, the old defences would slightly delay the progression of erosion as they disintegrate. Defences at Woodside and around Wootton Creek would hold the mean high water mark, but the foreshores immediately in front are likely to erode and narrow.

Futurecoast (2002) estimated that in Osborne Bay, continuing erosion of the narrow depleted foreshores and coastal slope toes would be likely to remove basal support and over the forthcoming 30 to 100 years re-activate shallow landslides on the steepest sections of the coastal slopes, generating significant recession of cliff scarps within several embayments that could develop as landslide complexes. Wave energy is low so that landslide debris could remain protecting the slope toe for lengthy periods following initial failures.

The North East Coastal Defence Strategy Study (2004) anticipates that over the next 100 years the mouth of Wootton Creek and coastal frontage will be at risk from coastal erosion if the existing defences are allowed to fail. There is evidence of historic spit migration and foreshore lowering which may cause variation in the coastal erosion rates. Within the estuary the western shore of Wootton Creek has the potential for recession if landward erosion of the waterline occurs, e.g. if it becomes more exposed to wave action or the existing defences are allowed to fall into disrepair.

Furthermore, some of the land near Wootton Bridge is currently prone to limited flooding every 5 years or so. With sea-level rise and possible increased wave energy within the estuary due to the possible change of geomorphological form at the mouth of the estuary, the probability of flooding here is likely to increase with time.

C1.3.2 Local Scale: Wootton Creek to Ryde Pier

Interactions:

Erosion is active between Fishbourne and Pelhamfield, but eastwards the coastal slope has either been incorporated into the built environment or fails to make any marked feature. Small-scale rotational sliding and cliff toppling is currently active at Fishbourne and in front of the Quarr Abbey estate. This has long been a locally active cliff line, as reported by Colenutt (1938) and deduced by archaeological excavation of the adjacent foreshore palaeo-landscape (Tomalin, 1991; 1993; Long and Scaife, in press). The supposed impact of ferry movements in accelerating erosion (Robert West and Partners, 1990) remains an unresolved question, though recent beach profile surveying through the Strategic South East Monitoring Programme has revealed little change between 2003 and 2007. Toe erosion of the relic coastal slope and some reactivating slips are apparent eastwards to Binstead behind dilapidated defences. Indeed, landslip debris obscuring the cliffline at Ryde, exposed until about 1870, is described by Reid and Strahan (1889). A mean recession rate of 0.05m/yr, 1909-1975 indicates low potential for supply to the shore, although there is evidence of an acceleration, to 0.71m/yr, over the period 1975-1995 suggesting that this input should become more significant in the future. Posford Duvivier (1999) have proposed a cliff erosion sediment yield of approximately 2,000m^3/yr and a shoreface erosion of 9,750m^3/yr. Sediments released are fine sands, silts and clays and most are likely to be removed from the beach as suspended load by waves and currents.

Some sediment crossing the Wootton Creek inlet is intercepted by tidal currents, but these are insufficient for significant transport (Hydraulics Research, 1988) and it is hypothesised that most sediment entrained by currents is deposited in the channel a short distance seaward, whereupon it is liable to be driven onto the barrier banks to the east (Harlow, 1980). Wootton Creek therefore acts as a partial sediment sink, intercepting some of the eastward littoral drift, but allowing bypassing of the majority.

he wide foreshore comprises a poorly sorted mixture of muds, sands and shingle, with some better sorted shingle banks. Increasing proportions of sand occur towards Ryde. Numerous features such as peat beds, an ancient submerged oak forest and a diversity of archaeological materials all testify to there once being a habitable zone extending some 200-300m further seaward than at present (Tomalin, 1993). Subsequent erosion and inundation connected with rising sea-levels of the past 3,000 years account for the present shoreline position (Bray, 1994). Indeed the erosion process is increasing and the rich archaeological resources of this zone are threatened.

Eastern parts of this frontage are dependent upon the Ryde Sands for shelter from wave attack from Spithead. Cliff re-activations could supply predominantly fine sediments to the Solent.

Results of the Strategic Regional Coastal Monitoring Programme (units IW6 & IW7):

From spring 2003 to spring 2009 there was no significant change in beach volumes in this area, except between 2007 and 2009, the foreshore nearest to the mouth of Wootton Creek has eroded. (Channel Coastal Observatory, 2009). To the west of the pier, there is a general pattern of erosion in the intertidal area. The back of the beach has patches of erosion and accretion in the far west of the unit, and more widespread erosion closer to the pier. These patterns are thought to reflect natural variability (Channel Coast Observatory, 2008).

Shoreline Movement:

The mean high water mark has been static or slowly retreating, controlled by coastal defences, coastal slopes, or sea cliffs. Significant retreat of the mean low water mark has resulted in foreshore narrowing throughout this frontage. There has been a recent acceleration of cliff recession at Woodside and Quarr, attaining high levels of recession.

Predictions of Shoreline Evolution:

Futurecoast (2002) estimated that without defences, continued cliff erosion is likely at Quarr and continuing re-activations are likely at Binstead. In addition, small areas of the narrow low-lying valleys at Quarr and Binstead could become inundated within 30 years as sea-levels rise because they possess very little natural upper beach protection and rely upon defences. Their tidal prisms would probably be too small to maintain permanent inlets so brackish lagoons or marshes subject to periodic inundation would be most likely to form.

C1.3.3 Local Scale: Ryde Pier to Nettlestone Point

Interactions:

Eastward drift terminates at Ryde where there is a convergence of shoreline transport and an incoming north-westward drift pathway as indicated by sediment accumulations predominantly against the eastern sides of groynes around Ryde Esplanade and the marina. Sediment is deposited to form Ryde Sands, a substantial nearshore bank that affords protection to Ryde from wave attack. A relatively sheltered and low energy shore unit is identified to extend along the heavily protected coast from Nettlestone Point to Ryde. Accretion on the eastern sides of groynes and outfalls at Spring Vale indicates net westward drift as noted by previous reports (Posford Duvivier (1990b). This transport pattern is attributable to dominant waves from the east and southeast and to diffracted southerly and south-westerly waves from the English Channel.

The coast around Ryde is enclosed entirely by sea-wall structures and coastal slopes appear stable. Whilst there are no obvious signs of instability on these modest slopes, they could form eroding cliffs of up to 20m O.D. height should their toe protection fail or be removed.

Plate 2: Ryde Sands are backed by seawalls, Ryde marina and the town of Ryde, view at relatively high tide (Isle of Wight Council).

The wide, sandy intertidal foreshore that comprises Ryde Sands, is a major accumulation of sandy sediments extending up to 2km seaward and 3km along the shore. Narrow shingle beaches are developed on the upper foreshore. The hinterland comprises moderately steep coastal slopes between Ryde and Puckpool Point rising to 20m. Between Puckpool Point and Nettlestone Point there is a low-lying marshy infilled valley with lagoons protected by a narrow barrier beach of sand and shingle (Seaview Duver). Nettlestone Point is a relatively resistant controlling feature formed of Bembridge Limestone. Nettlestone Point itself suffers from sediment depletion and operates as a partial transport barrier within the littoral pathway.

Plate 3: Ryde Sands, view east from Appley at low tide, towards Ryde Pier in the distance, February 2009.

Ryde Sands is a zone of sediment drift convergence and a sink for shoreline sediments drifting from the east and west. It is therefore partially sensitive to variations in supply pathways. Its sensitivity is partial because its stored sediment volume is very large in comparison to estimates of the annual drift of the supply pathways. Since the bank is effectively maintained in its present position by a delicate balance of hydrodynamic forces, any sustained alteration in the local wave climate could result in a longshore migration of the bank such that the protection afforded to upper foreshores could alter. Ryde Sands presently shelters the frontage to the west from easterly waves.

Results of the Strategic Regional Coastal Monitoring Programme (units IW7 to IW11):
The area between Ryde Pier and Nettlestone Point has been predominantly stable from 2004-2009. However, east of the pier there is a sizeable region of accretion at the mouth of Ryde harbour. The sand flats show a pattern of patchy erosion and accretion, representing the

movement of sediment around the flats. Towards Puckpool Point, the upper beach has accreted and the intertidal area has eroded (Channel Coast Observatory, 2008).

Shoreline Movement:

Map comparisons undertaken for the design of Ryde Harbour in the early 1990s revealed relatively stable conditions with little net sediment transport (Gifford and Partners, 1990). Net transport may not be great, as no significant siltation of the dredged channel giving access to Ryde Harbour has been reported. As was observed by Gifford and Partners (1989, 1990) further research into sediment transport is required on Ryde Sands and should involve assessment of the contribution of diffracted waves from the English Channel.

There has been reclamation of a 100m to 200m wide strip of Ryde Sands upon which Ryde esplanade has been built. Seawalls and groynes are present throughout this entire frontage.
Ryde Sands is clearly an accretional feature by origin, but the extent to which accretion continues to the present day is uncertain. Identification of historical trends at Ryde Sands is difficult for much of the esplanade is built forward onto the beach such that historical map comparisons do not show meaningful trends in mean high water. Some retreat of the mean low water mark, up to several hundred metres, is indicated by map comparisons over the past 100 years, but shorter term trends are mixed. Consequently, it remains uncertain whether Ryde Sands is continuing to accrete, or whether it could be subject to foreshore erosion that is common to much of the Solent.

The shingle upper beach fronting Seaview Duver has narrowed and thinned slowly in recent decades so that mean high water in many places is defined by the seawall. The lower foreshore has also narrowed persistently between Puckpool Point and Nettlestone Point over the past 100 years.

Predictions of Shoreline Evolution:

Futurecoast (2002) estimated that without defences, there is potential for the following impacts:

1) Under an eroding regime at Ryde Sands, the upper foreshore would be relatively exposed and wave action may begin to cut through the reclaimed land of Ryde Esplanade (30 to 50 years) and back into the steep slopes in front of St Cecilia's Abbey and Apply Park to eventually activate new eroding cliffs (>50 years).
2) Under an accreting regime at Ryde Sand there could be some initial erosion of the reclaimed areas, but over the medium term (>50 years), the upper beach would be likely to build up providing natural protection against storm wave action, and the effects of sea-level rise. A thin strip of dunes could form in the medium to long term (50-100 years).
3) To the east of Puckpool Point, foreshore narrowing is likely to be exacerbated by rising sea-levels. Puckpool Point itself would no longer be maintained as a minor headland by its defences and would begin to be eroded.
4) Seaview Duver would be likely to become increasingly susceptible to overwashing and breaching and an intertidal lagoon could form within 30 years. The currents generated at the new inlet could disrupt shoreline sediment transport and generate a small ebb tidal delta of sediment on the lower foreshore, although the tidal exchange is likely to be quite small. Consequently, the inlet could be unstable and periodically re-seal and breach, perhaps seasonally.


Plate 4: View west from Seaview over Seaview Duver towards Puckpool (Isle of Wight Council).

Futurecoast (2002) estimated that with present management practices, there is potential for the following impacts:

1) Under an eroding regime at Ryde Sands, the foreshore in front of defences would gradually narrow and lower exposing the defences to increasing levels of wave energy. Beaches would be lost and replaced by strips of foreshore exposed only at mid to low tide.
2) Under an accreting regime at Ryde Sands, the upper beach would be likely to build up in front of defences providing natural protection against storm wave action, and the effects of sea-level rise.
3) The headland of Puckpool Point would be maintained and the land behind Seaview Duver would be maintained as a freshwater marsh. To the east of Puckpool Point, foreshore narrowing is likely to be exacerbated by rising sea-levels and static upper foreshore defences

C1.3.4 Local Scale: Nettlestone Point to St. Helens Duver

Interactions:

The embayments of Priory and Seagrove Bays have been formed by erosion of soft clayey strata between rocky (Bembridge Limestone) headlands. Their log-spiral plan forms are characteristic of a north westward net drift. The headlands partly intercept littoral sediments thus accounting for the moderately wide sandy beaches in northern and central parts and severe depletion in the south of each bay. Numerical modelling studies have suggested that sediment mobility is likely to be greater within the nearshore zone than at the beach (Posford Duvivier, 1991a), so that headland bypassing by fine sands is likely. Various sea-wall and groyne structures have been installed in these areas so as to protect the toe of the coastal slope. These measures have not been entirely successful in Priory Bay due to undermining following falling beach levels and landslides that have surged over and through the walls.

The partly unprotected cliffs (up to 30m in height) and shore platform are subject to active erosion, but a significant source of loss of potential feed to the littoral drift pathways may result from on- to offshore transport of fines. Nodes Point is composed of limestone, which breaks down by solution as well as abrasion. The presence of privately-constructed defences dating back to the 1930s, although now largely ineffective, has in the past inhibited toe erosion and cliff sediment inputs to the shore. Major extension and intensification of the activity of these cliffs are anticipated due to sea-level rise and increased winter rainfall that is estimated for the future. Some sands and limestones would be yielded although the majority of supply will be clays. Interestingly the cliff landslides will at first accentuate the two headlands bounding Priory Bay as their toes extend seaward, but later will reduce their definition as debris is eroded and transported and the headlands are eroded back. There are no site-specific calculations for sediment yield for this sector, although Posford Duvivier (1999) give a figure of between 13,000 and 38,000m^3m/yr of mostly fine grades for the shore face erosion of the Pelhamfield to Bembridge frontage as a whole. A supply of coarse materials is available intermittently in the cliffs comprising a thickness of up to 5m of Pleistocene fluviatile gravels at the top of the succession (Samson 1976).

The foreshore comprises a narrow shingle upper beach and a sandy lower foreshore. A sand bar and rocky foreshore ledges are present off The Priory and Nodes Bays, respectively. The cliffs of Seagrove Bay are presently inactive having been protected at their toes by seawalls. Active cliff erosion occurs at Horestone Point, in southern Priory Bay and along Nodes Bay. Intervening areas appear vegetated and inactive.

There is an abandoned and dilapidated seawall in southern Priory Bay. There is also continuous seawall protection around Nettlestone Point and along Seagrove Bay and a cliff stabilisation scheme was undertaken in 2000 in southern Seagrove Bay.

There exists a northward nearshore drift pathway that has the potential to contribute material from this frontage to Ryde Sands. Material released from Nodes Bay, however, is likely to be supplied to St Helen's Duver.

Results of the Strategic Regional Coastal Monitoring Programme (units IW12 to IW13):
Since 2004 this section of coast has been mostly stable, with localised evidence of small scale erosion and accretion. (Channel Coastal Observatory, 2009).

Shoreline Movement:
Intertidal foreshores have on balance narrowed over the past 100 years although shorter term trends are mixed. A multiple rotational base failure occurred on the relict coastal slope in southern Seagrove Bay in 1942, but has subsequently been stabilised by a recently completed scheme. Formerly inactive cliffs are being re-activated and are beginning to erode freely in Priory and Nodes Bays.

Predictions of Shoreline Evolution:
Futurecoast (2002) estimated that without defences, there is potential for a general re-activation and intensification of the activity of coastal slopes and cliffs over the next century. Cliff landslides could at first accentuate the two headlands as their toes extend seaward, but thereafter reduce their definition as debris is eroded and transported. There is also potential for the coastal slopes of Seagrove Bay to become re-activated within 30 years by toe erosion occurring in the absence of defences. Rotational failures in southern parts of the bay are likely to resume almost immediately.
Sediments yielded by cliff erosion are likely to contribute to local foreshores and counter previous narrowing trends, eventually contributing towards drift inputs to both Ryde Sands and St Helen's Duver.

Futurecoast (2002) estimated that with present management practices, relatively few differences are anticipated compared to the unconstrained scenario, except that the coastal slopes behind the seawalls in Seagrove Bay are likely to remain inactive. This would prevent cliff sediment inputs from feeding the local beach within the bay, but the volumes of sands and gravels are small so the defences would not have a significant impact on the supply pathway around Nettlestone Point.

C1.3.5 Local Scale: St. Helens Duver to Bembridge Point, including Bembridge Harbour

Interactions:

Sediment accumulation preferentially on the north side of groynes on the Duver, St Helens indicates southward drift and the presence of a drift divide between Nodes Point and St Helens Church (Posford Duvivier, 1991b). The south trending alignment of the Duver, a sand dune spit and SSSI suggests that the feature developed during long-term north to south drift. A historical map dated 1791 shows the Duver spit in more or less its present position, thus confirming that north to south drift was dominant before this time (Posford Duvivier, 1991a). The present day spit is protected by a sea wall and its stored sediments are no longer available to nourish the foreshore. Beach sediments drift to the southern tip of the spit where they are intercepted by tidal currents within the Bembridge Harbour entrance and flushed offshore by dominant ebb currents. In the past, these sediments were possibly driven back onshore near St Helens church, but recent large scale dredging of Bembridge Harbour approaches (200,000m^3 in 1987) may have interrupted this circulation (Posford Duvivier, 1991a). Beach levels fell significantly along the Duver in the late 1980s so that improvements to the existing groyne system were necessary so as to minimise further beach losses to the tidal channel. The contribution of dredging to these erosion problems is difficult to establish due to lack of information. The Duver is especially vulnerable to interference because it is supplied by such short littoral drift pathway and its sediment sources are therefore limited to local coastal erosion (minimal sediment yields) and onshore feed.

Bembridge Harbour is a small, enclosed estuary sheltered by double sandy spits. It currently covers an area approx. 600m by 1km wide. The former estuary to the south-west was drastically truncated in the 1880s, when over 80% of its area was reclaimed. It used to run nearly 4km inland to the town of Brading. At the current Harbour entrance, the largest spit is that extending from the north-west direction, which is composed mainly of stabilised sand, known as St. Helen’s Duver. At low tide the harbour almost dries, apart from a channel into the River Yar behind. There are residential houseboats, marinas and sailing. The river flow is small. The river flow is contained due to Bembridge sluices. These restrict the flows at low tide, and maintain water levels in the marshes.

The cross sectional area is large compared with the tidal prism volume, as a consequence of the reclamation. Also the estuary is short relative to the mouth width. However, the intertidal area at 0.83m is about average for the tidal range. It thus appears that though the estuary has filled in, the mouth has not totally recovered from the modifications. It is ebb dominant, and the maximum flow ratio is low.

Plate 5: Bembridge Harbour, sheltered by St. Helen's Duver spit (on the right), with the reclaimed Eastern Yar valley behind (Isle of Wight Council).

It is likely that little riverine sediment enters the estuary. The estuary is likely to be a strong sink for fine sediment, though its capacity will be small, and the spits at the mouth may be a weak sink for sandy sediment.

Tidal flow through the narrow entrance to the inlet can generate rapid currents which interrupt littoral sediment transport causing local circulation effects and associated changes in coastal configuration. There is net transport of sediment into the harbour. An issue on this frontage is the long-term sustainability of the Harbour, as evidence indicates that the harbour and approach channel are tending to silt up. The harbour has a history of accretion of fine sediments, with accelerating sedimentation in recent decades. The main areas of accretion are seaward of the southern end of Embankment Road and on the flood tidal delta inside the entrance to the harbour where between 1983 and 2008 the ground elevation has increased by up to 0.1m/yr. Rates less than 0.05m/yr are more typical in central parts of the Harbour and elsewhere are in the order of 0.02m/yr. Tidal currents are insufficient to remove all littoral drift material from the east from the entrance channel. Therefore, the channel refills after any dredging. (Eastern Yar, 2009).

The Harbour is open to the sea at all states of the tide and therefore exposed to tidal surges and storm surges. St. Helens Duver and Bembridge Point spit shelter Bembridge Harbour from any swell waves, with the waves experienced within the Harbour being locally generated wind waves which are expected to have significant wave heights of less than 0.3m.

A substantial ebb-tidal delta was associated with the inlet, but it is now largely a relict feature following major reclamation of the Eastern Yar estuary. The area of the Bembridge Harbour tidal delta is sediment-rich and receives inputs of nearshore drifting sediments from the direction of Bembridge Foreland and loses sediments northwards towards Nettlestone Point. It appears to operate as an important zone of storage and transportation for predominantly sandy sediments moving around the east coast of the Isle of Wight towards Ryde Sands. Some of its sediments have become redistributed inshore creating a wide intertidal zone of shoals and channels.

This land is presently defended from inundation by embankments around the margins of Bembridge Harbour and seawall stabilisation of the vulnerable barrier at Yaverland, Sandown Bay. The relict delta has been, and is continuing to be, reworked and some of its sediments are being driven into the harbour inlet causing shoaling of channels and rapid accretion at Bembridge Point.

Results of the Strategic Regional Coastal Monitoring Programme (unit IW14):
This area has been stable since Spring 2008. From Spring 2004 a pattern of erosion occurred with some erosion seen around Bembridge Harbour and a low level of accretion at the northern end of St Helen's Duver. (Channel Coastal Observatory, 2009).

Shoreline Movement:
Bembridge Harbour, a remnant of the reclaimed Eastern Yar estuary, contains substantial double sand and gravel spits that have accreted at the northern (St Helen's Duver) and southern (Bembridge Point) margins of the inlet. St Helen's Duver has grown in width and accreted southward in historical times, forming a dune complex. It has consolidated over the past century and became fully vegetated. In recent decades it has tended to erode along its seaward face and, following protection, has suffered from falling foreshore levels.

Predictions of Shoreline Evolution:
Futurecoast (2002) estimated that without defences, there is potential for the following impacts:
1) Comprised of loose dune sands stabilised only by a thin vegetation cover, the seaward face of St Helen's Duver is extremely sensitive to erosion without defences. Sediments would be likely to become entrained and transported southward by the dominant littoral drift and become deposited within the Bembridge Harbour channel. Initially, the frontal shoreline of the Duver would retreat, but breaching would become increasingly likely after 30 to 50 years as a seaward fronting ridge of vegetated dunes was removed and the spit became thinner.
2) Bembridge Point would be likely to accrete more rapidly in future as cliffs updrift re-activate and contribute additional sediments to the northward drift pathway.
3) Sediment is likely to continue to be transported landward from the relict ebb tidal delta until this feature becomes adjusted fully to the present reduced-size Bembridge Harbour tidal prism. Bembridge Harbour and its entrance channels would be likely to continue to slowly silt up.

A large portion of the Eastern Yar valley could become inundated in future if defences are not maintained around Bembridge Harbour, or if a breach occurs at Yaverland, Sandown Bay (see section C1.4).

Futurecoast (2002) estimated that with present management practices, there is potential for the following impacts:
1) Sediment is likely to continue to be transported landward from the relict ebb tidal delta until this feature becomes adjusted fully to the present reduced-size Bembridge Harbour tidal prism. Bembridge Harbour and its entrance channels are therefore likely to continue to suffer shoaling and siltation.
2) The stabilised dunes and dune grassland of the St Helen's Duver will be maintained, although the foreshore in front of defences would continue to narrow.
3) The foreshore around Bembridge Point has tended to accrete significantly in recent decades under current management practices, which includes an active foreshore mining operation. Accretion is therefore likely to continue or increase slightly in future, given that some inactive cliffs updrift to the east are likely to re-activate and supply additional sediments.

Recent study by the Eastern Yar Flood and Erosion Risk management Strategy has concluded that without defences, the Duver is likely to remain in some form as its natural behaviour is re-established.

C1.3.6 Local Scale: Bembridge Point to Forelands Fields

Interactions:

This section of coast is characterised by low active and relict cliffs (5-15m height) formed of Bembridge Marls capped by variable thicknesses of shingle-rich raised beach deposits. Erosion contributes significant quantities of beach-forming shingle and sand. The relict cliffs are primarily located to the north-west of the lifeboat slipway, whereas active cliffs are located to the south-east of this point.

Plate 6: The village of Bembridge, looking north-west towards Bembridge Harbour (Isle of Wight Council).

Bembridge limestone outcrops on the foreshore to form an extensive series of ledges and reefs that provide protection to the cliffs against wave attack at low and mid tide. Narrow upper beaches are formed of mixed sand and shingle derived from local cliff sources.

Dominant north-westward littoral drift from the Foreland to Bembridge Point is indicated by sediment accumulations on the south east side of groynes, outfalls and the substantial accumulation of Bembridge Point itself (Posford Duvivier, 1995). Sands and gravels supplied by local coast erosion are transported along this pathway and have been deposited at Bembridge Point since at least 1862 according to comparisons of historic maps. Accretion is related to a long established provision of groynes intended to control infilling of the inlet. Beach extraction has been practised at this site.

Potential longshore drift driven by breaking waves has been calculated at 14,000m^3/yr at Bembridge Point and 90,000m^3/yr at Colonel's Hard. Most of this would represent fine sands transported on the shoreface with only a proportion comprising beach drift (Posford Duvivier, 2000).

Piecemeal revetment and groyne defences have been constructed throughout this frontage. Formal seawalls extend either side of the lifeboat slipway and from The Foreland to Foreland Fields. Seawalls at the latter frontage have stabilised a 300m length of formerly eroding cliffs. Several small-scale beach recharges have also been practised since the 1980s.

Results of the Strategic Regional Coastal Monitoring Programme (units IW16 to IW18):
Between Spring 2004 and Spring 2009 sediment volumes have been mostly unchanged in the north of the section closer to Bembridge Harbour, however there has been a small amount of accretion in the area around Ethel Point and erosion at Bembridge Ledge. (Channel Coastal Observatory, 2009). The 2003 – 2008 topographic difference model shows a region of significant erosion along the edge of the dredged navigation channel (Channel Coastal Observatory, 2008).

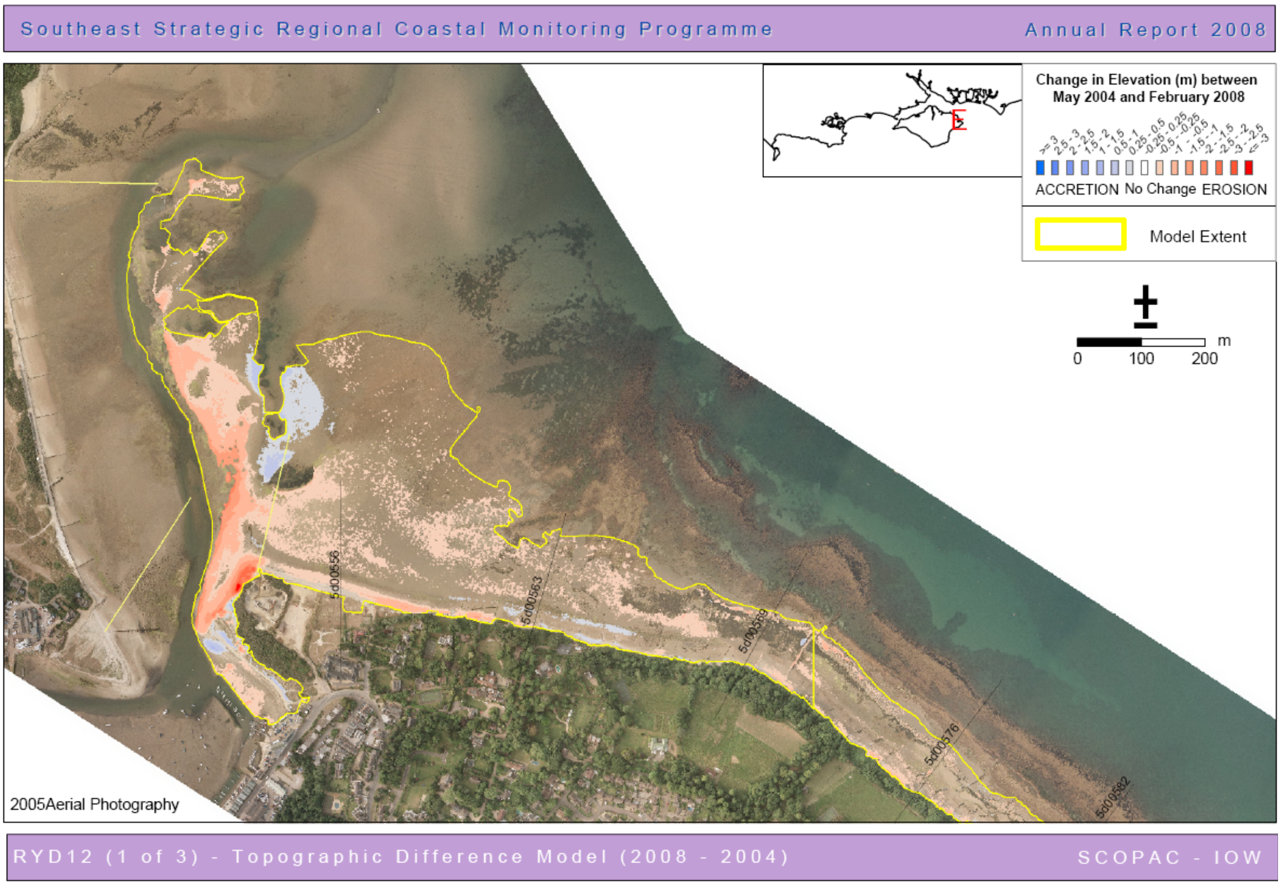

Figure 7: Topographic Difference Model for Bembridge Harbour entrance

Shoreline Movement:
The cliffs around Foreland has averaged medium rates of active erosion over the past 100 years, although rates have increased in recent decades (see below). These cliffs have fed considerable quantities of raised beach deposits to contribute to local beaches. Beach and foreshore levels have tended to decline along much of the frontage in recent decades, a probable consequence of stabilisation of some of the former eroding cliff sediment sources.

Parts of the coast are protected by groynes and various revetment structures. Erosion rates of the unprotected segments are generally between 0.30m/yr and 0.75m/yr and vary spatially according to the proximity of coast protections and shelter afforded by limestone shore platforms (Posford Duvivier, 1989a). A rate of 0.3m/yr to 0.4m/yr is reported for the Warners Holidays frontage and 0.5m/yr for the coast north of Foreland (Barrett, 1985). It is reported that erosion is now controlled effectively by two small beach nourishments undertaken in 1984 and 1988 (Posford Duvivier, 1995). The extreme western part of the frontage at Bembridge Point is undergoing net accretion, but erosion at up to 0.15m/yr is recorded for the coast eastwards to Tyne Hall (Posford Duvivier, 1990a). Supply is not quantified, but erosion of a cliff 6m in height and 2km in length at 0.4m/yr would yield 4,800m^3/yr. Allowances for offshore loss of clay and fine sand and for cliffs stabilised by coast protection probably significantly reduces this figure. Future protection strategies developed for this frontage, should acknowledge that such schemes could cut beach sediment supply, thereby entailing further artificial nourishment or recycling to maintain beach levels.

Re-activation of landsliding behaviour has occurred recently along several parts of the formerly inactive cliff frontage between the lifeboat slipway and Bembridge Point.

This frontage supplies significant quantities of coarse shoreline sediments downdrift so that variations in behaviour that affect cliff erosion sediment inputs and shoreline sediment transport can have impacts on other frontages to the north.

Predictions of Shoreline Evolution:
Futurecoast (2002) estimated that without defences, there is potential for the following impacts:
1) A general re-activation and intensification of the relict and active cliffs is anticipated throughout the frontage due to the present depleted state of beaches together with the effects of future sea level rise.
2) Low cliffs between The Foreland and Foreland Fields are relatively exposed and are likely to re-activate rapidly without defences and once again contribute material from the raised beach deposits to local beaches.
3) Cliffs between the Lifeboat Slipway and Bembridge Point are likely to reactivate rather more slowly as erosion only gradually removes supporting debris accumulations at their toes. As they re-activate, their cliff tops would begin to migrate landward. However, due to their increased height (up to 15m) they should contribute significant quantities of raised beach deposits and Oligocene sands to local beaches, thus affording some protection against erosion at their toes.
4) Cliff recession rates may stabilise further into the future as re-activation progresses and increasing quantities of coarse sediments contribute to the local beaches and enhance their capacity to dissipate wave action.

Futurecoast (2002) estimated that with present management practices relatively few differences are anticipated compared to the unconstrained scenario, except that the low cliffs between The Foreland and Foreland Fields will remain stable and not contribute sediments to the beaches. The knock-on effect of this could be that beaches would take longer to restore naturally so that downdrift depletion could expose remaining active and relict cliffs to more aggressive toe erosion.

C1.3.7 Local Scale: Forelands Fields to Culver Cliff

Interactions:
Rapid erosion of the mostly fine grained cliffs has yielded a plentiful supply of well-sorted, mobile sand for the construction of a wide, flat beach at Whitecliff Bay. There is a small backshore fringe of Chalk and flint coarse gravel and cobbles, and the progressive northwards reduction in the size and frequency of the Chalk gives a clear indication of net northwards longshore transport. The stepped outcrop of Oligocene limestones at Black Rock Point interrupts shoreline drift, but relatively little shingle has accumulated to the south. Historical evidence for large-scale pebble quarrying in the early years of this century (Colenutt, 1938) may have produced a deficit of coarse sediment that can now be replaced only very slowly. North of Black Rock Point, the beach is wider and is differentiated clearly into a shingle-dominated backshore component and a silty-sand foreshore. A significant proportion of the shingle is derived from the long-term erosion of the thick overburden of gravels at the cliff crest, making up a 5m O.D. raised beach. Future supply from this source is now limited by natural recession of the cliff line (much of it is no longer accessible to breaking waves) and seawall construction. The reefs, ledges and lagoons of Bembridge Ledge provide an effective buffer to wave energy (except when waves are propagated from the south-east or east). Each ledge represents the outcrop of a distinct litho-stratigraphic horizon in the Bembridge Limestone sequence; they are virtually horizontal, but have a local relief of up to 2m.

Several centimetres of sand may blanket the upper ledges after the incidence of storm waves suggesting that significant quantities may be transported. The tidal streams (1-4ms^{-1} as measured off Long Ledge) flow approximately parallel to the coastline, and may operate in conjunction with wave action to promote longshore transport of sand around the Foreland.

The cliffs cut into the soft Eocene and Oligocene sands, clays and limestones, are unprotected along most of this frontage. They are subject to failure creating complex landslide morphologies of scarps and degradation terraces with major mudslides developed in the Reading and London Clay strata in the extreme south of the bay. The small lengths of informal defences in Whitecliff Bay (Posford Duvivier, 1997) are of marginal significance in restraining sediment yield. They are unlikely to persist in view of the international geological conservation significance of this site. Much of the clay and silt sized sediment mobilised by periodic slope failures and other mass movement processes is probably transferred offshore in suspension. The sand fraction contributes to the exceptionally wide intertidal zone between Culver Cliff and Long Ledge. In the northern part of this unit, a set of curvilinear limestone ledges forms a nearshore-offshore reef, thus inhibiting erosion of the adjacent cliffs. The prominent, slightly oversteepened, Chalk cliffs and fronting boulder-strewn platform form a distinctive, but slowly eroding, southern boundary.

Southward of Foreland Fields the coastal relief rises to 40m at Black Rock Point and the cliffs formed in gently northward dipping Bembridge Marls exhibit an increasing degree of landsliding. In the north a partly inactive simple cliff form occurs towards Black Rock Point where a fully active stepped profile is developed, evident with benches being controlled lithologically by thin limestones occurring within the predominantly clayey strata.

Plate 7: View from Culver Cliff headland, looking north-west over Bembridge Ledges towards Forelands, July 2009.

The cliffs in Whitecliff Bay comprise a steeply northward dipping sequence of soft sand and clay Palaeocene, Eocene and Oligocene strata. The shoreline is set back up to 300m from the Chalk headland of Culver Cliff, illustrating the effects of differential erosion according to rock structure and lithology. Cliff behaviour is controlled by lithology with complex cliffs developed in interbedded sequences around Black Rock Point, simple rock fall and gully dominated cliffs in sandy strata in central parts of the bay and mudslides forming tracks and embayments extending deep inland in the clayey southern cliffs.

Piecemeal revetment and gabion defences at the cliff toe exist along a limited length in Whitecliff Bay. These largely have been ineffective in stabilising the cliff. This frontage supplies significant quantities of sandy shoreline sediments downdrift so that variations in behaviour that affect cliff erosion, sediment inputs and shoreline sediment transport can have impacts on other frontages to the north.

Results of the Strategic Regional Coastal Monitoring Programme (unit IW19):
In the period from 2003 to 2007 the east of this unit showed signs of erosion occurring at the back of the beach, with concentrated regions of accretion occurring on the foreshore. In Whitecliff Bay the pattern of sediment transport from south to north was evident, with sand being eroded from the south and deposited in the north (Channel Coastal Observatory, 2008).

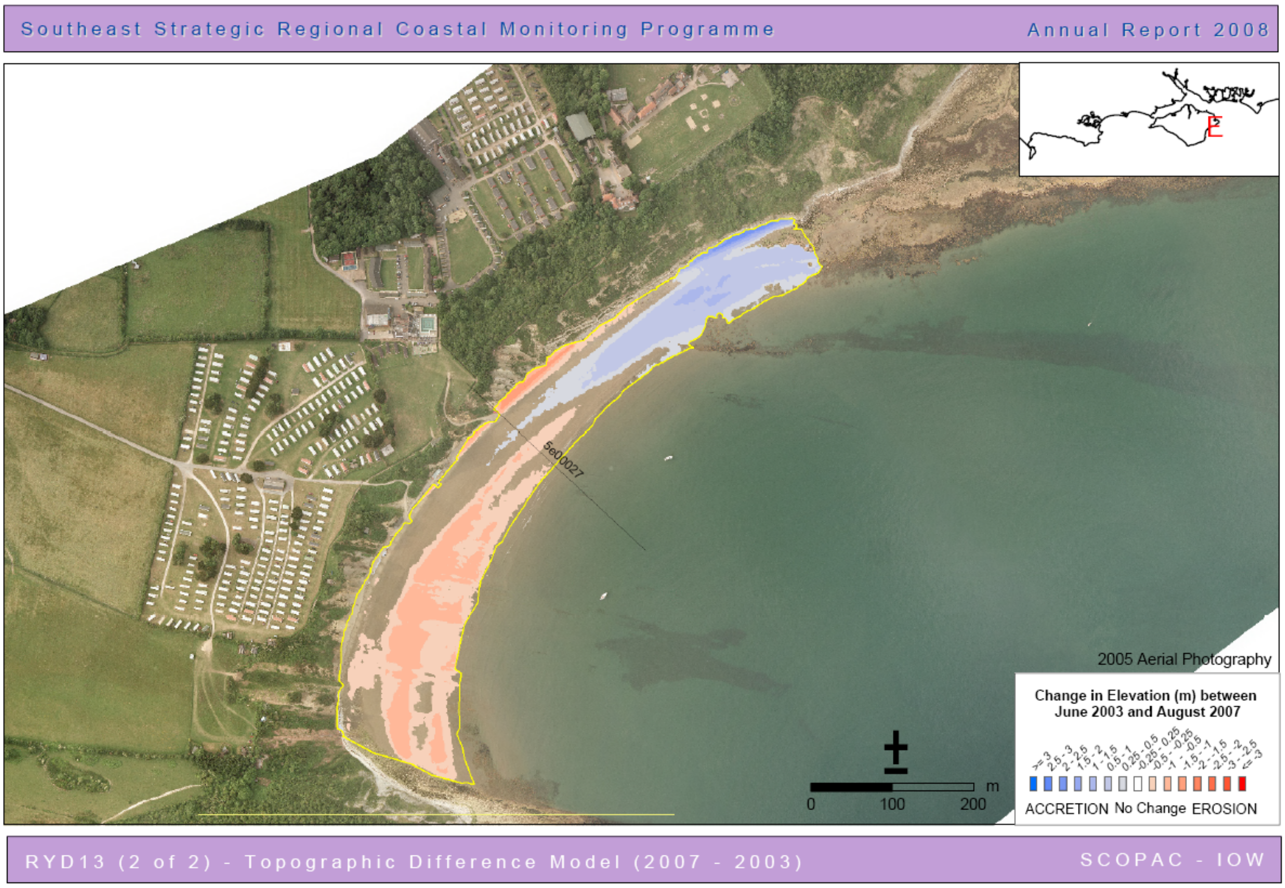

Figure 8: Topographic Difference Model for Whitecliff Bay

Shoreline Movement:
Long term cliff recession has occurred at medium rates over the past century. Significant increases in cliff activity and recession have been observed in recent years. The beach has retreated with the cliffs although the foreshore also has narrowed to a moderate extent.

Historical cliff top recession of some 0.3 to 0.5m/yr in Whitecliff Bay (1909-1975) contrasts with a rate of 0.10 to 0.15m/yr north of Black Rock. There are no reliable calculations for cliff foot retreat, though visual inspection proves this to be an active process. Recession is likely to accelerate in the estimated wetter winter conditions of the future that would promote landsliding. Major focal points are likely to be the Reading and London Clay mudslides in the south and around Bembridge School where the Bembridge Marls are susceptible to increased mudsliding and translational or rotational slides.

Predictions of Shoreline Evolution:
Futurecoast (2002) estimated that without defences, cliffs immediately to the south of Foreland Fields would be likely to experience erosion at their toes, eventually triggering new failures and conversion to fully active retreating profiles. Sediments yielded by increasing cliff erosion would be likely to contribute to local foreshores and counter previous narrowing trends, eventually contributing towards drift inputs to the Bembridge frontage and the drift pathway that operates towards Ryde Sands.

With present management practices Futurecoast (2002) estimated that relatively few differences are anticipated compared to the unconstrained scenario due to the limited effectiveness of the low cost defences.

C1.4 Large Scale: Culver Cliff to Dunnose

Interactions:

The coast between Culver Cliff and Dunnose has developed through marine erosion of the predominantly soft clays and sands of the Wealden and Lower Cretaceous groups. Erosion would have operated over the past 5,000-6,000 years, since the rising sea-level has approached its present elevation. Extensive shore platforms provide evidence for long-term recession in outcrops of more resistant bedrock, and appear to extend seawards of low water. In total, several kilometres of recession have occurred; sufficient to release large quantities of predominantly sandy sediment.

South and East Isle of Wight (St Catherine's Point to Culver Cliff): Sediment Transport

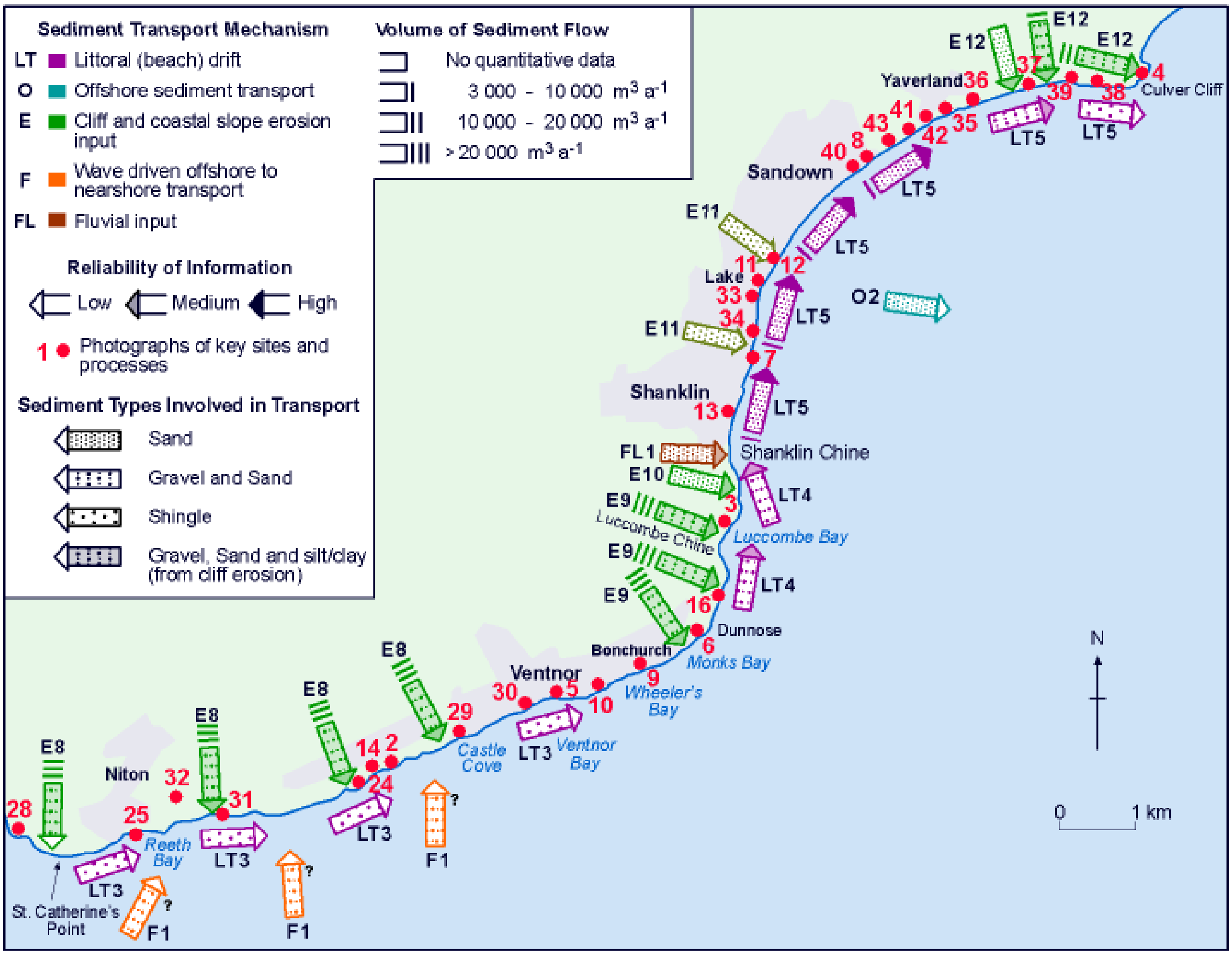

Figure 9: Sediment transport sources, pathways and sinks on the south east coast, from SCOPAC Sediment Transport Study, 2004.

The east-facing coast is relatively protected from waves generated by dominant westerly winds, although it is subject to the residual energy of swell waves refracted by a combination of offshore seabed topography and the acute change in coastal plan at Dunnose. It is, however, fully exposed to a fetch distance of just over 200km, extending east and east-south-east within the Channel; over which large waves can be propagated in association with easterly gale-force winds.

Almost the entire length of this coastline is characterised by active cliff development, with adjoining beaches and shore platforms of variable length, height and width. Between Shanklin Chine and Culver Cliff there are clearly defined offsets in beach width associated with the numerous groynes, which indicate that the dominant longshore transport is from south to north. Long term maintenance of the beaches of Sandown Bay is dependent upon continuation of cliff erosion inputs. Sands may be yielded from cliffs throughout the frontage, but are available in the highest proportions between Luccombe Chine and Sandown. Whilst some sandy sediments have remained within the bay, most have been transported elsewhere. It has been suggested that this material could have contributed to Ryde Sands although other areas of potential accumulation also exist to the east of the bay.

With the emergence of the twin resorts of Shanklin and Sandown in the 19th century, installation of substantial sea walls and promenades has removed the former cliff line from the direct influence of wave-induced attack. The coastal frontage between Shanklin Chine and Yaverland is fully protected by a variety of structures. These include sea walls, revetments and groyne fields that have been subject to both renewal and extension for more than a century.

Although isolated from wave activity by sea defences, the former 40m high sea cliffs along the coastline remain geomorphologically active, due to sub-aerial weathering and mass movement (Rendel, Palmer and Tritton, 1988). Various protection techniques including cliff-top regrading, drainage, timber shuttering, geofabric/grass matting, netting, rock bolting and talus reprofiling and removal have been implemented to manage this problem (Clark et al, 1993; Rendel Geotechnics, 1991; 1992; McInnes, 2000) over a 3.5km length at Shanklin, including recent cliff stabilisation works at Shanklin in May 2008.

Immediately north-east of Yaverland the seawall terminates and there is no northwards protection against marine erosion. Coastal recession has truncated a tributary of the Eastern Yar valley at Yaverland. Sediments migrated into this valley in the form of a barrier beach that appears to have prevented marine inundation and has preserved the regular plan-form of Sandown Bay.

At the southern end of this section of coast, between Dunnose and Shanklin, there are few defences. On the assumption that active cliff erosion is the chief source of sand contributing to the beaches in Sandown Bay, net littoral drift is from south to north. The principal features of the beach and foreshore of this sector have not changed appreciably in recent decades if the description by Colenutt (1938) is to be relied upon.

Plate 8: View north-west from Shanklin across Sandown Bay, towards Culver Cliff (Chalk headland) in the distance. The former sea cliffs are stabilised in the centre of the bay and sediment transport is from south to north-west, forming important amenity beaches (Isle of Wight Council).

Shoreline Movement:
The natural behaviour of parts of this coastline have been largely influenced and constrained by past management practices and the presence of coastal defences. At sites such as Shanklin, sea walls and promenades have removed the former cliffline from the direct influence of wave-induced attack. Vertical shoreface erosion rates of 1.2 to 4 mm/yr along the coastline north of Shanklin Chine are estimated by Posford Duvivier and British Geological Survey (1999).

The groyne system between Shanklin and Sandown has succeeded in retaining substantial quantities of sand, transported from south to north by the net direction of littoral drift. Supply deficit is also a consequence of the removal of sediment supply from cliff erosion as a direct result of seawall/esplanade construction. With the exception of the Littlestairs section (up to 1974), this entire coastline has been "walled up" since the late 1940s. The only sources of natural replenishment now available are from the erosion of the sandstone cliffs south of Appley Steps, and, possibly from offshore.

Along the undefended sections of this coastline there is evidence of substantial retreat. For example, at Yaverland the foundations of early nineteenth century buildings at Yaverland Fort, now exposed on the foreshore, indicate 0.5km of cliffline retreat, and on the Gault Clay outcrop, between 1870 and 1980 (Barrett, 1985). Repeated semi-rotational slides, and their rapid removal by wave action, have resulted in as much as 20m of cliff top retreat in less than one year at specific sites (Barrett, 1985) with instability evident up to 70m inland.

Futurecoast (2002) estimates that if this shoreline were unconstrained in the future, cliffs in central parts of the Bay would re-activate immediately, retreat at moderate to high rates and resume their inputs of sandy sediments to the foreshore. The relatively resistant headlands of Dunnose and Culver Cliff would continue to be slowly eroded, but are sufficiently large to continue to exert a control over shoreline evolution.

C1.4.1 Local Scale: Culver Cliff to Yaverland

Interactions:
The relatively resistant Chalk of Culver Cliff forms the promontory at the northern boundary of Sandown Bay. The cliffs are fronted by variable accumulations of Chalk debris according to recent cliff falls, but otherwise descend directly to deep water. The cliffs adopt a simple linear form and fail mainly by rock falls and toppling failures. Infrequent larger failures can result in 5m to 20m of cliff top retreat within single events. Flint nodules within the cliffs are released by erosion, but otherwise most cliff erosion products are removed in suspension by wave action. The north facing portion of the headland, within Whitecliff Bay, is relatively stable. Tension cracks, indicating potential for future major failures, are evident in some places along the cliff top.

Cliff-top indentations and major talus accumulations immediately opposite the Culver Down monument provide characteristic evidence of slope evolution by massive rockfalls involving single event detachments of cliff top masses some 15m in width. Such failures are infrequent so that overall long term recession is slow.

Between Culver Cliff and Yaverland the coast is undefended and thus offers no protection against marine erosion. The outcropping strata are lithologically varied but collectively unresistant, excepting the Chalk. Shallow translational slides and mudflows are characteristic of the Wealden shales and clays, and give an irregular low, cliff profile that frequently exhibits basal notching. The Ferruginous Sandstone of Red Cliff is comparatively more coherent and supports a near vertical lower cliff face.

A thin, but wide sand foreshore is developed at the cliff toe with a narrow shingle upper beach ridge. Occasional rocky ledges protrude through the sand of the foreshore. In spite of differences in style of cliff activity a remarkably curvilinear cliff toe plan-form is maintained suggesting consistent long-term recession, perhaps controlled by the ‘anchoring’ presence of the Culver Cliff headland. Long-term cliff recession has occurred at medium rates over the past century, although short term rates can be high and significant acceleration has been observed in recent years.

In addition to sediment losses from cliff erosion, abrasion and scour of the intertidal shoreface also contributes input to the littoral transport system. A range of figures are presented in Posford Duvivier (1999), all of them derived from the application of a basic methodology to local conditions of shoreface width, water depth and rock erodibility. Rates vary from 2 to 35mm/yr of vertical erosion, yielding from less than 500 to over 24,000m^3/yr of sediment. Quantities are largest where sandy or clayey rocks form the shoreface substrate on the West and South coasts. It is presumed that almost all of this sediment is fine grained and this therefore not retained local beaches.

Results of the Strategic Regional Coastal Monitoring Programme (units IW20 to IW21):
This topographic difference model (2003-2007) highlights the change in beach profile on this section of beach to a more concave shape. Sediment has been eroded from the centre of the beach and deposited onto the back of the beach and the offshore bar (see map below). There has been accretion close to Culver Cliff with some erosion taking place closer to Yaverland (Channel Coastal Observatory, 2008).

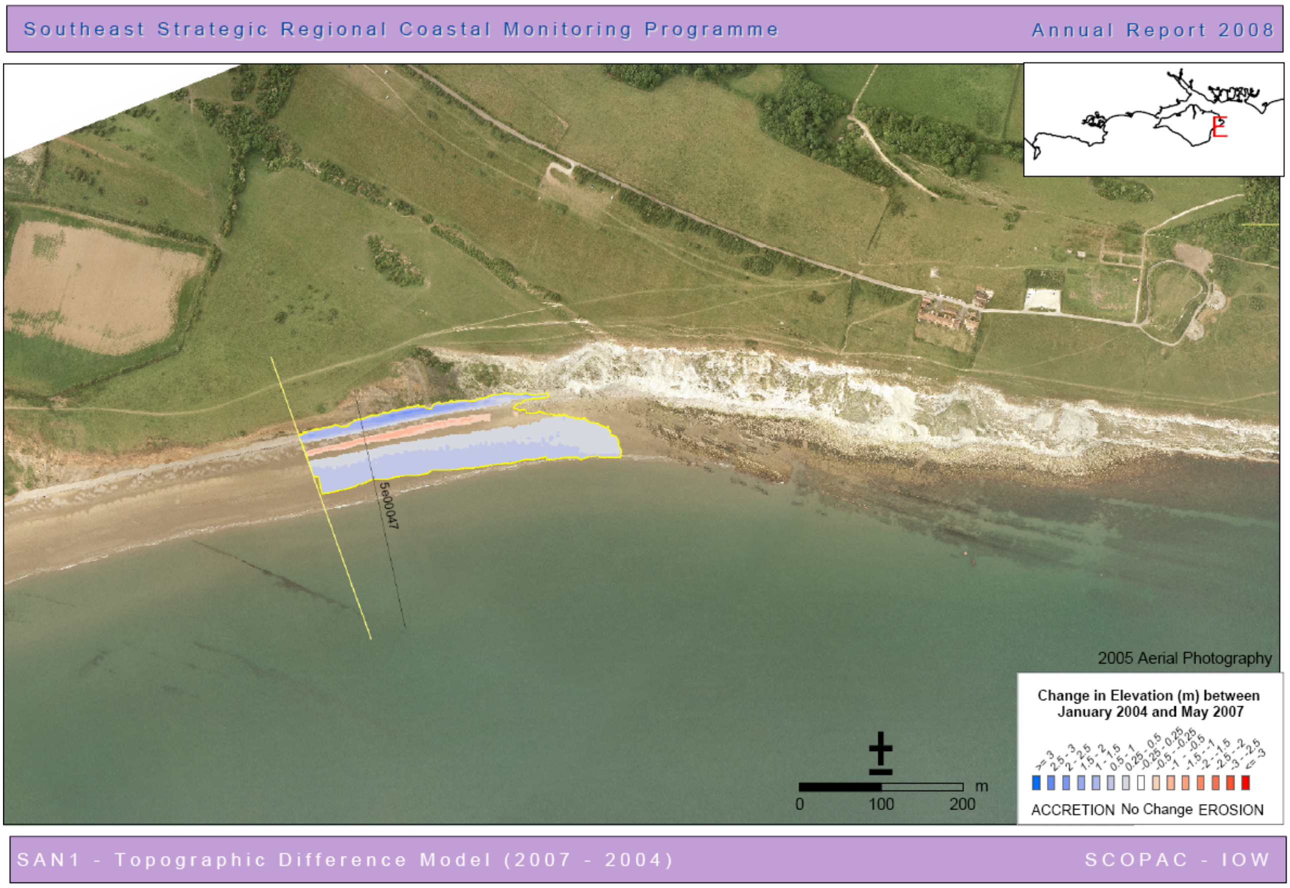

Figure 10: Topographic Difference Model for Yaverland

Shoreline Movement:

The Culver Cliff headland provides a control on recession at the northern margin of this frontage. Cliff erosion along the softer rocks south of Culver Cliff contributes considerable quantities of sands and clays to the shore, although the fates of these materials are uncertain. It has been suggested that they could contribute to the northward drift pathway that transports sediments towards Ryde Sands.

The rate of erosion in the Wealden Marls at Yaverland was calculated to be 60m between 1910 and 1945 (Lewis and Duvivier, 1973/74), with annual rates varying between 0.5 and 2m/yr, depending on beach width. Foreshore recession of 0.3m/yr, 1896-1969 is indicated from Ordnance Survey maps (Posford Duvivier, 1981). A figure of 0.35m/yr, for the coastline south of the Chalk outcrop, is contained in an analysis of all historical sources (Posford Duvivier, 1997; Posford Duvivier and British Geological Survey, 1999).

Repeated semi-rotational slides, and their rapid removal by wave action, have resulted in as much as 20m of cliff top retreat in less than one year at specific sites (Barrett, 1985) with instability evident up to 70m inland. Hutchinson (1965) reported that the remains of a seawall built in 1924 to protect Yaverland Castle was 80m seawards of the cliffline in 1964. There are no reliable records of shoreline change along the south facing Chalk cliffline seawards to Culver Cliff, but basal accumulation of boulders, shallow slides, rockfalls and talus cones, indicates the contemporary, as well as long-term, effectiveness of both marine and sub-aerial denudation. Posford Duvivier (1999) propose an overall recession rate of 0.23m/yr. Active erosion is evidenced by caves, incipient stack formation and a well-defined shore platform at Whitecliff Ledges northwards to the blunt headland defining Whitecliff Bay. Taking average cliff height and the above quoted erosion rate, Posford Duvivier (1997) suggest that the Chalk Cliffs yield some 30,000m^3yr, of which about 2% (<500 m^3)consists of flint.

Predictions of Shoreline Evolution:
Futurecoast (2002) estimated that with or without defences the cliffs would continue to exhibit an eroding tendency. This would include a tendency for cliffs in Sandown Bay to resume their erosion and contribute sediments to the shore. Drift from the south could then gradually build the foreshore of this frontage and provide slightly improved protection against wave attack at the cliff toe. The extent of this influence is difficult to assess because: (i) a tidal breach at Yaverland would be likely to generate an ebb tidal delta that would intercept and store sediment; and (ii) there appears to be a natural process in operation along this frontage that removes sediments seaward from the foreshore.

C1.4.2 Local Scale: Yaverland to Shanklin Chine

Interactions:
Between Yaverland and Sandown, a sand and shingle barrier beach developed on a wide sandy lower foreshore. The hinterland is extremely low-lying over a frontage of about 600m where it represents the valley floor of a tributary of the Eastern Yar River. Coastal recession has truncated a tributary of the Eastern Yar valley at Yaverland. Sediments migrated into this valley in the form of a barrier beach that appears to have prevented marine inundation and has preserved the regular planform of Sandown Bay.

The beach in the Bay is composed almost entirely of medium sand with sand and gravel up against the sea defences at Shanklin and Sandown. Occasional severe draw down of the sands beaches has revealed a shingle basement (Lewis and Duvivier, 1974), but this is probably derived from transport from the south. Clearly-defined offsets in beach width associated with the numerous groynes indicate that the dominant longshore transport is from south to north.

The whole of this frontage has been subject to intensive protection, with successively more comprehensive measures, incorporating seawalls and groynes, installed since the 1860s. Unusually complete and detailed records have survived, and are summarised in several consultants' reports (Lewis and Duvivier 1974, 1981; Posford Duvivier, 1989a, 1990c). These documents record the length, height and date of construction of all the major groynes and provide measurements of volumes of sand retained updrift. Several exceptionally large concrete groynes, constructed in the late 19th Century, proved highly efficient at intercepting drift, leading to beach build up of up to 80m at Shanklin; upon which The Esplanade and its associated properties were built. A similar practice was adopted at Sandown, although the beach build up resulting was considerably less. These actions have 'impounded' large quantities of sediment that would otherwise have nourished northern (downdrift) parts of the bay and there have been many instances where inter-groyne sectors of the beach have suffered depletion. Barrett (1985) quotes a mean value 0.2 to 0.4m/yr retreat for the remaining Littlestairs cliffs prior to their protection in the mid-1970s. Assuming that there has been little subsequent change in cliff height, this rate would yield about 3,000m^3/yr of sand from this small section alone. This example demonstrates potential sediment shortfall to the littoral system resulting from the protection.

Because of the curved shape of Sandown Bay, the rate of littoral transport diminishes northwards in response to both the number and size of groyne fields downdrift and a reduction in the obliquity of angle of dominant wave front approach. The long-term problems of retaining a wide and stable beach have therefore been greater in the northern part of this sector, perhaps also because it is furthest removed from fresh sediment inputs to the south. Cliffs within central Sandown Bay no longer supply fresh sediments as a direct result of seawall/esplanade construction. The only other potential sources of natural replenishment now available are from offshore. The latter has not been investigated in any quantitative sense, but it has been suggested that Sandown Bay tends to lose rather than gain material from offshore (Dyer, 1980).

Surveys and observations undertaken in the 1980s (Posford Duvivier, 1989a) appear to indicate that some of the inter-groyne beaches have stabilised and achieved an equilibrium condition. In others, the absence of an adequate backshore berm has promoted wave reflection from seawalls, and therefore scouring of the sand surface and possibly also the underlying bedrock. Careful adjustments to the groynes based upon the results of a comprehensive beach monitoring programme can assist in alleviating specific problems. In the longer term, it should be recognised that there is a potentially serious sediment shortfall within the bay and it is essential to ensure that the cliffs to the south remain free to erode and to supply vital sediments.

Along the Lake to Shanklin frontage, are soft rock cliffs, of approximately 40m in height, formed in sandy Lower Greensand strata. The cliffs comprise a simple near vertical free face and a cliff toe talus accumulation of variable size that under natural conditions is eroded by waves and contributes sediments to the beach. Recession is long established within the bay and occurs by rock fall, seepage erosion and gullying. There is a gently shelving nearshore and wide sandy foreshore with small quantities of shingle on the upper beach.

Plate 9: Cliff fall at Littlestairs, along Lake Cliffs, in December 2000 (Isle of Wight Council).

Plate 10: Shanklin Esplanade, showing the former sea cliffs which are subject to rockfall and talus slope failure, with the stabilised built up sediments forming Shanklin Esplanade below, in July 2009.

Although isolated from wave activity by sea defences, the former sea-cliffs remain geomorphologically active, due to sub-aerial weathering and mass movement. Movements are primarily infrequent rockfalls from free faces (detached masses of up to 2m width) and also slides within the talus slopes that accumulate at the cliff toe. Barton (1985) estimates 5m of slope crest recession between 1907 and 1969 (0.08m/yr) for part of the cliff line between Shanklin Chine and Hope Road, a figure derived from measurement of the dimensions of basal scree deposits. Another value of 0.02-0.03m/yr is quoted incorporating behaviour up to 1981 (Barton, 1991). Not only does recession cause hazards at the cliff top, but also at the toe, where Victorian and later developments have allowed too little space for extension of stable talus slopes. Removal of talus exacerbates the situation by increasing the likelihood of further rockfalls. A variety of remedial measures have been applied to control immediate problems (re-profiling, netting, catch-fencing, rock bolting etc.), but planning measures involving development/redevelopment exclusion zones are needed to provide a long term solution in this sensitive amenity area.

Results of the Strategic Regional Coastal Monitoring Programme (units IW22 to IW27):
Over the longer term between spring 2003 and Spring 2009 along this coastline there is evidence of localised erosion and accretion. The southern part of Sandown Bay is generally dominated by accretion, whereas the area north of Dinosaur Isle shows a dominant erosional trend. In the recent past (Spring 2008 to spring 2009) there has been a predominance of erosion against sea walls at Yaverland and at the back of Hope Beach. However some areas of the beach south of Sandown Pier have shown some accretion.

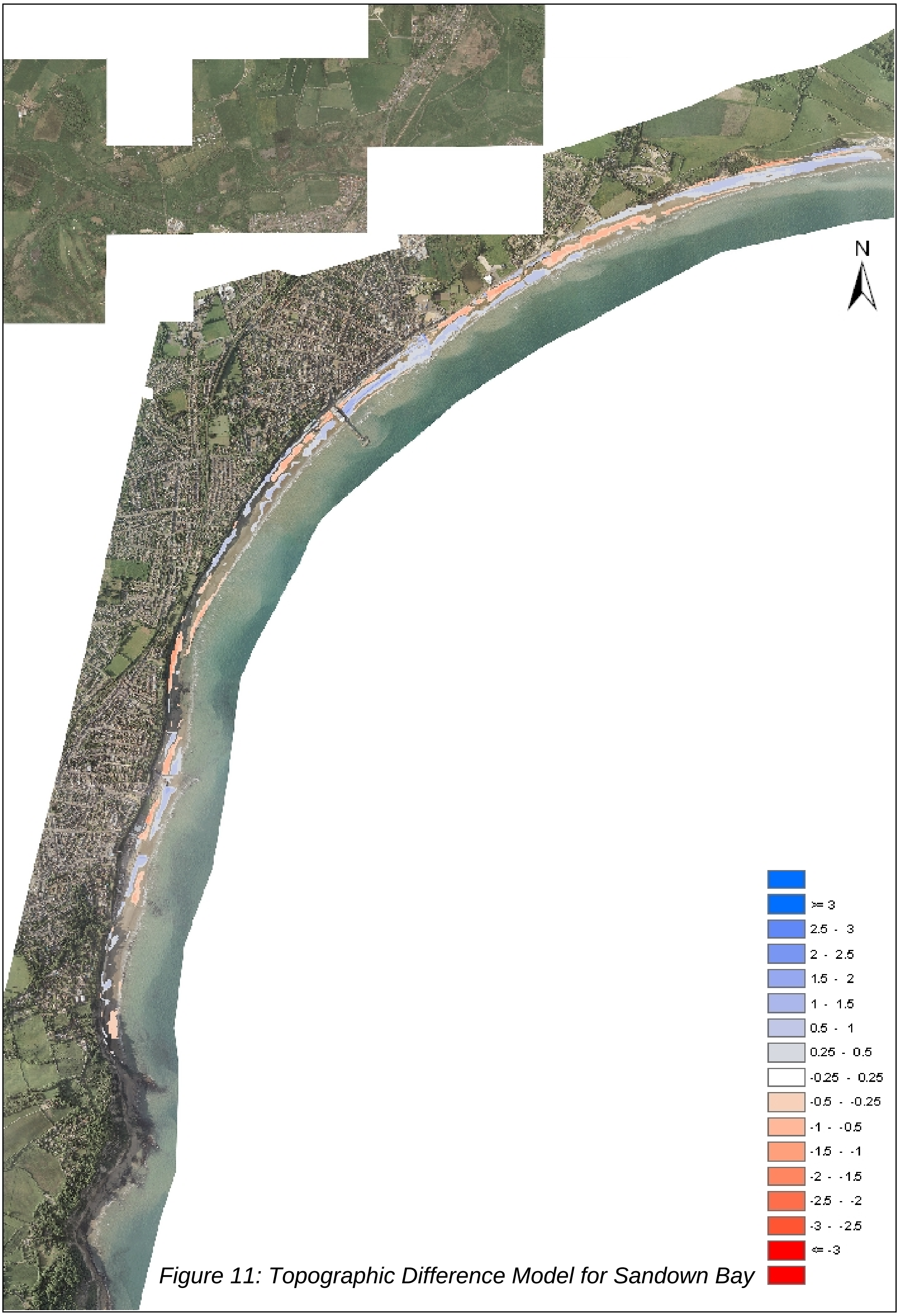

Figure 11: Topographic Difference Model for Sandown Bay

Shoreline Movement:
Typical long-term recession of the cliffs, prior to their protection, occurred at medium rates. Following toe protection by the seawalls, the free faces of the cliffs have continued to fail, but much less frequently than previously, resulting in present low rates of recession. In recent years these cliffs have been subject to numerous small-scale rock falls and also some larger failures within talus accumulations that have built up at the cliff toes. This has been attributed to unusually heavy winter rainfall that raises groundwater levels, reduces stability and promotes seepage erosion.

Initial groyne construction was highly successful in intercepting beach sediments and causing beach build up. However, in recent decades beaches have lost sediments and the foreshore has lowered and narrowed. Many lengths of seawall are now subject to direct wave attack at high water.

Predictions of Shoreline Evolution:
Potential for recession of the cliffs along this frontage would release considerable quantities of sands and clays to the shore that could nourish downdrift parts of the bay and potentially contribute to the northward drift pathway that transports sediments towards Ryde Sands. Continued protection of these cliffs, however, will ensure that little sediment will feed this potential transport pathway.

Futurecoast (2002) estimated that without defences the beach between Yaverland and Sandown would rapidly be subject to overwashing, landward migration and breaching. With the beach in a depleted condition, the large hinterland extending into the valley of the Eastern Yar, could potentially be inundated and would generate a large tidal prism that could maintain a permanent tidal inlet. If this were to occur, the inlet would generate an ebb tidal delta of sediment immediately offshore in the bay. As the delta grew it would provide shelter to the barrier behind and enhance its stability, although it could starve the downdrift shore of sediment such that the Yaverland cliffs could be exposed to additional toe erosion. A corresponding flood tidal delta could form within the new estuary, further depleting the shoreline of sediment. Its growth would be controlled by storm wave action that would periodically drive sediment into the inlet.

The barrier beach would gain sediments from updrift when cliffs in Sandown Bay became re-activated. It is uncertain whether drift would be sufficient to naturally seal the inlet, or whether spits might periodically extend across the inlet in association with episodes of sealing and renewed breaching. Drift would certainly be sufficient to feed the growth of spits and the tidal deltas adjacent to the inlet.

The soft sandy cliffs at Shanklin would re-activate immediately, becoming undercut at the toe and retreat would occur at moderate to high rates by rock fall, seepage erosion and gullying processes. Erosion would result in a resumption of inputs of sandy sediments to the foreshore that would nourish the depleted beaches of the bay and increase beach widths significantly within 50 years. The initial rapid cliff recession response may be slowed in the medium term as beach accretion provides additional protection to the cliff toes.

As the beaches receive sediments from the cliffs and accrete they may adjust their profiles through a redistribution seaward of sands to build up the nearshore bed in response to rising sea-level. It would tend to cause additional recession of the upper shoreline and soft cliffs at a rate dictated by the rate of sea level rise. A lag would be expected between any change in rate of sea-level rise and a response of the cliff recession rate.

With present management, the beach will continue to lower further in front of the defences such that direct wave action is likely to strike the seawall at mid tide level and above. Over time, the turbulence generated is likely to cause scour of beach substrata and exposure/undercutting of the seawall apron leading eventually to structural damage, or a requirement for increasingly frequent and costly maintenance (Futurecoast, 2002).

C1.4.3 Local Scale: Shanklin Chine to Dunnose

Interactions:

The principal features of the beach and foreshore of this sector have not changed appreciably by comparison with the earlier descriptions by Colenutt (1938). The backshore and inter-tidal zone comprises wave-cut bedrock shore platforms (Yellow and Horse ledges) that are littered with large Greensand and sandstone boulders. Sand beaches are intermittent in the south and contained between debris lobes derived from cliff landsliding. Between Yellow Ledge and Shanklin Chine, a progressively more defined backshore shingle berm is developed, being confined partly by a low wooden revetment immediately to the south of Shanklin Chine. Within Luccombe Bay, an extensive medium sand beach and foreshore has accumulated. All of this material must derive from the mechanical breakdown of Greensand and Chalk landslide debris in the vicinity, and west, of Dunnose. Three degraded groynes at the north of Luccombe Bay, have intercepted drift and indicate the general north eastern direction of transport. This unit remains mostly unprotected and acts as a source and zone of northward transmission for much of the sediment that forms the beaches of Sandown Bay.

At Dunnose, there is a sharp change in coastal orientation, but cliff height and form is initially similar to the immediate west of Ventnor. The 40m high cliffs in the south part of this sector are cut into landslide debris, but more into the Gault Clay and Lower Greensand further north. South of Luccombe Chine there is evidence for marine erosion of the cliff base, although translational slides and mudflows are frequent and often temporarily conceal bedrock. Terrace recession has exposed mudslide and landslide material within the Gault Clay, resulting in some reactivation of cliff top retreat. Mudslides move across successively lower benches, where they are contained as temporary stores. Cliff profiles assume a more degraded form where there are substantial accumulations of boulders across the foreshore. These derive from fresh falls, slides and toppling failures and the removal of less resistant clays and sands within landslip debris aprons created by previous major landslips. The cliffs north of Luccombe Chine assume a more complex composite form with one or more distinct benches. The area directly inland of Luccombe Chine has a well-documented history of part translational and part rotational slope failure (Geomorphological Services, Ltd., 1989). The re-exposure of failure planes in both the Gault Clay and consolidated landslip material by toe erosion may have been a trigger to major landslide events in 1810, 1820, 1988 and 1995 although groundwater conditions - notably critical pore water pressures - are important. The latter event displaced approximately 800,000m^2 of rock debris (Rendel Geotechnics, 1995b). Despite a wide inter-tidal sandy beach (over 100m at maximum spring tides) at the mouth of Luccombe Chine, basal cliff trimming and notching by waves is an active process. Debris loading of the benches by landslip debris from above is associated with groundwater seepage at the junctions between interbedded sandstones and clays. Geomorphological Services, Ltd., (1989), calculates that breaking waves of a probable maximum height of 3m could be propagated across an easterly fetch of up to 170km, and might generate rip currents of sufficient velocity to rapidly remove the fine-grained fraction of cliff fall debris and beach sediments.

Results of the Strategic Regional Coastal Monitoring Programme (units IW28 to IW29):

The Strategic Monitoring Programme covers only the section between Shanklin Chine and Luccombe in this unit. From Spring 2008 to Spring 2009 this section was mostly stable with a small amount of accretion in the south of the section closer to Luccombe. However between Spring 2003 and spring 2009 there was erosion in the south half of the section and some slight accretion closer to Shanklin Chine. Sediment volume was more stable in the centre of the unit near Yellow Ledge. (Channel Coastal Observatory, 2009).

Shoreline Movement:

There are no estimates of rates of erosion in this coastal sector based on measurements; the few figures quoted in the literature rely upon analysis of the position of the cliff top on successive editions of Ordnance Survey maps, the accuracy of some being in doubt. Barrett (1985) and Halcrow (1997) quote a rate of recession of 0.2 to 0.3m/yr at Dunnose, Posford Duvivier (1981) calculated a retreat rate of 0.3m/yr and Posford Duvivier in 1987 suggested to 0.5m/yr for this length of shoreline (in SCOPAC, 2004). This may not take full account of the loss of temporary stores of landslip material, and it undoubtedly generalises significant spatial variation, e.g. a rate of 1.0 to 2.5m/yr in the vicinity of Borderwood Lodge (Halcrow, 1997). A mean recession rate of 0.4m/yr gives a total potential sediment yield of 75,000m^3/yr (Posford Duvivier, 1999). At Luccombe, this latter figure may be a close approximation to the recession rate maintained over the past 140-150 years (Posford Duvivier, 1990c), but is probably exceeded along the shoreline between Yellow and Horse Ledges. North of Horse Ledge, cliff toe erosion is inhibited to some extent by partly redundant groynes, and the scree that has accumulated in front of Knock Cliff and Appley Steps may indicate that small scale but frequent rockfalls and toppling failures, due to weathering and stress relief, are now more significant than basal notching by waves. The general morphology of the near-vertical cliff line between Yellow Ledge and Shanklin Chine indicates the longer term dominance of block failure and bench formation associated with aquicludes (rock layers with very low permeability that can't give rise to any appreciable leakage). Here, and also at Luccombe (Geomorphological Services, Ltd., 1989; Moore, et al, 1991), the rate of cliff top recession, at 0.3m/yr, appears to have accelerated over the past century, inducing failure reactivation on several occasions (Posford Duvivier, 1990c).

Predictions of Shoreline Evolution:
Futurecoast (2002) estimated that without defences recession of the cliffs within this frontage is likely to continue or accelerate for the following reasons:

1) The cliffs are sensitive to winter rainfall promoting higher pore water pressures within the landslides;
2) Continued cliff retreat around Luccombe and to the south will cut further into the flanks of Shanklin and Luccombe Downs and is likely to re-activate relic landslides leading, on occasion, to rapid landward progressions of cliff top instability by several tens, or possibly hundreds, of metres within specific events.

In the long-term (100 years or more), it is possible that retreat would extend sufficiently far inland and upslope to affect the in situ Chalk of the downs, whereupon major new failures of the cliff top can be anticipated. Cliff height and landslide potential may therefore increase through time. This process appears most advanced at The Landslip where retreat has cut over halfway up the east flank of Bonchurch Down and the Chalk could be affected within 100 years.

Any acceleration of cliff recession is likely to supply additional quantities of sands and gravels to beaches in Sandown Bay, although fresh boulder aprons could also be formed on the foreshore that would afford additional protection to the cliff toes.

With present management practices few significant differences from the unconstrained scenario are anticipated, except that groynes immediately to the south of Shanklin Chine could intercept drift from the south to maintain shingle upper beaches and provide some protection to the local cliff toes (Futurecoast, 2002).

C1.5 Large Scale: Dunnose to Rocken End (The Undercliff)

Interactions:

The Undercliff is an ancient coastal landslide complex forming the Isle of Wight's south coast, extending from Luccombe and Bonchurch in the east to Blackgang in the west. The feature is approximately 12km in length and extends approximately 500m inland and nearly 2km seawards. The Undercliff is formed from the Lower Cretaceous and Chalk outlier known as the Southern Downs. Its physical form today is the result of marine erosion at the toe of the landslide acting on a gently dipping (approximately 1.5° seaward) stratigraphy comprising Upper Greensand and Lower Chalk sequences overlying Gault Clay. The landslide complex was activated as a result of aggressive coastal erosion following a rise in sea level after the last Ice Age, between 10,000-7,000 years ago.

Because the Undercliff is an exceptionally dynamic and unique section of coast, it is treated here as a separate unit.

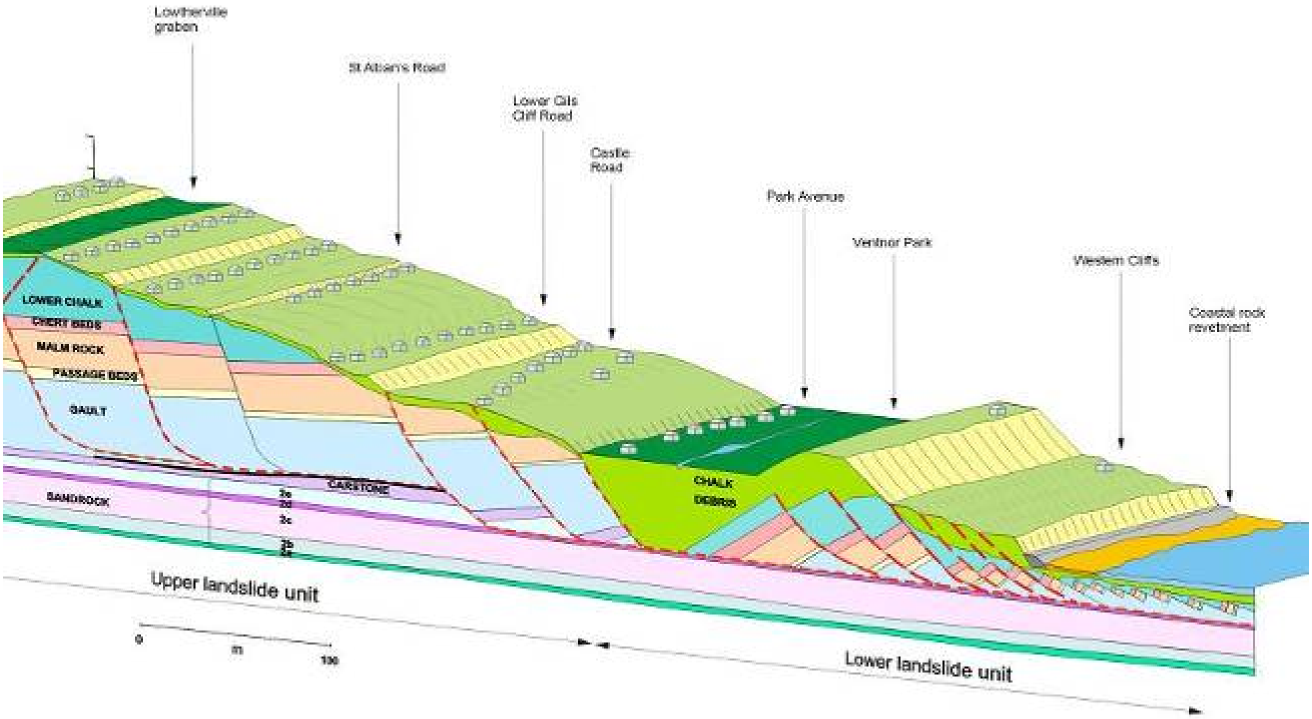

Figure 12: Schematic cross-section through the Undercliff Landslide Complex underneath the town of Ventnor, showing deep-seated failures within the Gault Clay and clay layers within the Sandrock. The town of Ventnor and surrounding villages developed on the south-facing terraces of the landslide complex. The landslide extends out under the sea, with toe protection in the form of coastal defences helping to stabilise the terraces above (Isle of Wight Council).

Plate 11: View west along the Ventnor Undercliff Landslide Complex from St. Lawrence to Ventnor. The landslide complex extends 12km along the south coast of the Isle of Wight, from Blackgang to Bonchurch. (Isle of Wight Council).

Plate 12: Landsliding and cliff retreat encroaching near the village of Bonchurch (Isle of Wight Council).

The south-facing Undercliff has a maximum fetch of 150km (except at Blackgang, which is directly exposed to Atlantic swell waves), defined by the opposing Channel coast of France, although it is also in receipt of refracted ocean swell from the west and south-west (SCOPAC, 1991/2004). Although coastal defences protect large sections of the developed coastline of the Undercliff, the coastline is subject to high-energy wave attack resulting from storm events, which can lead to a significant loss in beach material over a relatively short time period where coastal protection is not present.

Storm surges are associated with the passage of intense depressions or fast moving fronts through the English Channel, which typically develop to the west of the UK, moving in a north-easterly direction. They can add over 1m to astronomically predicted sea-level (Posford Duvivier and Portsmouth University, 1999). Hence, they typically propagate through the Channel from west to east, reaching a maximum near the Isle of Wight and decreasing thereafter (Futurecoast, 2002).

Tidal currents are often strong, especially during spring tides and where either the shape of the coast or the seabed contours cause a concentration of the flows. Along the Undercliff coast, tidal currents are particularly strong in the vicinity of St Catherine's Point, resulting from the coastal topography and seabed depth helping to concentrate flows at this location. Water velocities at this point can reach 2m/s (HR Wallingford, 1993). The relatively high-energy tidal currents generated in the vicinity of St Catherine's Point, Niton could potentially transport a significant load of sediment, but the seabed at this location is mainly composed of exposed bedrock and thus there is little free sediment actually available for movement.

Sediments off the Undercliff coastline consist almost entirely of gravel and sandy gravel. Generally, the seabed is planar and experiences little or no movement. An exception to this are the gravel bedforms present in deep water off the south-east coast of the Island. These deposits form narrow furrows of a few metres in width with a sudden drop of the order of a few tens of centimetres at the sides onto the furrow floor, along which coarse sands and fine gravels may move (Halcrow, 1997). It is thought that the amount of sediment movement along these furrows is small, although it is sufficient to prevent faunal colonisation in the immediate vicinity of the furrows.

The relief of the majority of the seabed around the Island is fairly slight, with large areas effectively featureless. However, one feature of note off the south coast of the Island is St Catherine's Deep, an enclosed deep channel that reaches depths of up to 80m below the current seabed (SCOPAC, 1991&2004). The feature is approximately 21km long and 1.2 km wide. The depth is considered to be too great to have been formed by recent waves and tides, and may be an ancient estuary mouth (HR Wallingford, 1993). St Catherine's Deep lies offshore from the major Undercliff landslide complex and runs parallel to the coastline. It appears to be parallel to the strike of the underlying geological formations and its erosion may, therefore, reflect the relatively less resistant sand and clay beds within the Lower Cretaceous Formations that are exposed on the sea bed.

The erosion appears to be connected with the headland of St Catherine's Point although the inception of erosion may be related either to tidal scour, during a previous interglacial period, or to scour during an earlier stage of the Holocene marine transgression. It is also possible that marine scour has accentuated a previously incised fluvial valley formed during a sea level lowstand. It is not known whether marine erosion continues to the present time and, therefore, whether it forms a potential offshore source of sediment, although tidal streams are presently very strong at this location. The bathymetric deep means that deep water is present relatively close to the toe of the Isle of Wight Undercliff and this may have an effect on wave energy striking this section of coast. Off the south-western coast of the island, ledges orientated west-south-west to east-north-east are similarly parallel to the strike of the underlying Lower Cretaceous Formations and reflect harder bands within the sequence. The majority of the remainder of the seabed area south of the Island is uniformly sloped offshore with the exception of some sediment banks.

Chandler and Hutchinson (1984) investigated the nearshore shallow-water bathymetry and determined that there is limited evidence of planed-off remnants of steeply back-tilted, landslipped blocks in the intertidal zone between Steephill Cove and Ventnor Bay. There are other incidents of large rock accumulations forming broad, shallow-water reefs at Dunnose, Reeth Bay and Rocken End. Chandler and Hutchinson (1984) postulates that these could possibly represent the more resistant 'lag' components of former mixed landslip deposits.

Between Ventnor and St Catherine's Point, several well defined pocket beaches consisting of 'pea' gravel (well sorted, sub-angular to sub-rounded flint clasts of a mean diameter of 10mm) have developed. These beaches are adjusted to incident wave approach and exhibit weak west to east littoral drift. There appears to be little exchange between adjacent bays, but by-passing may take place when there are oblique south-westerly long period waves. Some beaches, particularly at the eastern end of this coastline, have been subject to draw down, indicating that potential rates of transport exceed available supply (SCOPAC Sediment Transport Study, 2004). Tidal currents may play a minor role in moving finer grained material. Average cliff top retreat rates along this section of coast are of the order of 0.4m per year. Erosion of the cliff face yields a mixture of clay, sand, marl, chert and Chalk. The quantity of coarse sediment is insignificant in comparison with the total potential supply rate of the order of 120,000m^3/yr (Posford Duvivier, 1997).

Plate 13: The town of Ventnor, built on the terraces of a landslide complex (Isle of Wight Council).

The geomorphological history of cliff-line instability is the most important and direct input into contemporary morphological character of the Undercliff coast. Most of the coastline that fronts the Undercliff is developed within the debris of massive landslides. The landslides themselves form a zone some 500m to 750m in width. These are fronted by sea cliffs of variable height, ranging from 10 to 80m elevation, typically with spreads of Upper Greensand rocks and boulders providing foreshore platforms (boulder aprons) and with narrow, occasional frontages of gravel beach sediments. The landslides forming the Undercliff are only marginally stable and so are very sensitive to disturbing forces that can trigger movement. Instability is more easily triggered on slopes that have been prepared by coastal erosion and unloading at their toes.

An important factor in controlling the nature and degree of ground movement along the Undercliff is the exposure and susceptibility of the coast to erosion. The prevailing wind and the greatest waves come from the south-west. As a result, the south-west Undercliff in the vicinity of Niton and Blackgang is the most susceptible to erosion, and the eastward facing sections between Bonchurch and Luccombe are more sheltered. The Lower Greensand is generally weaker and more susceptible to erosion than larger blocks of the Upper Greensand, and parts of the landslide debris can be fairly resistant (Hutchinson, 1991). Wind, frost and seepage erosion are also active contributors to erosion all along the Undercliff to varying degrees within the different lithologies.

The shoreline is stabilised by continuous seawalls and boulder revetments between Monks Bay and Ventnor. Defences, mainly in the form of rock revetments, are also present between Ventnor and Steephill Cove, with seawalls in the east of this section. Defences function directly to halt toe erosion and also to provide support to the toe of the coastal slope that is intended to reduce occurrences of instability within the relict landslides above. Several cliff stabilisation schemes involving re-grading and drainage have been developed in addition to the general toe protection and weighting. Interventions around Ventnor and Bonchurch appear to have significantly reduced the occurrences of landslide re-activations within the landward terraces. If continued, these measures could considerably delay re-activations such that the western Undercliff (largely unprotected) could in future become highly active whereas the east (largely protected) might remain relatively stable.

Plate 14: Landslide reactivation along the Niton Undercliff, following prolonged winter rainfall in 2000/2001, affecting the coastal road and a caravan park (Isle of Wight Council).

Results of the Strategic Regional Coastal Monitoring Programme (units IW30 – 39)

Between 2004 and 2009 the majority of Reeth Bay showed an erosional trend (Channel Coastal Observatory, 2009) but on the shorter time scale (2008-2009) accretion was the dominant process. Around Ventnor, there was a pronounced pattern, with sediment build up against the harbour wall and erosion at the back of beach, from 2004 to 2009. It appears that sediment within Ventnor bay is largely self contained, moving from one area to another.

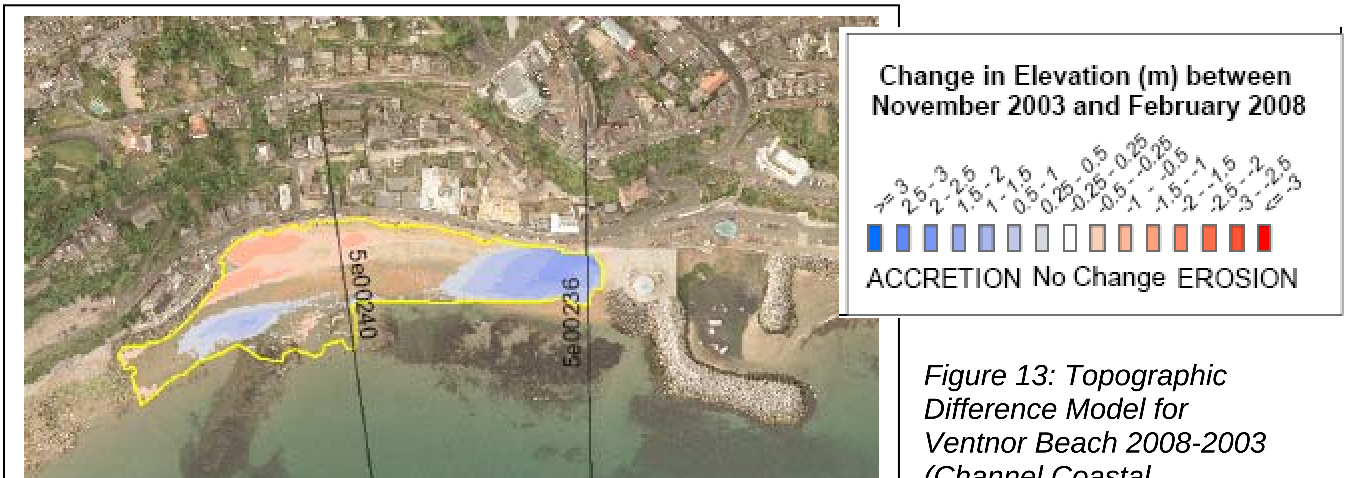

Figure 13: Topographic Difference Model for Ventnor Beach 2008-2003 (Channel Coastal Observatory, 2008).

Shoreline Movement:

Cliff retreat has historically been relatively slow along this coast. Pocket beaches migrate landward as the cliffs erode and over time this process gradually extends the widths of the boulder aprons. The main exception is at Rocken End, Niton where there has been rapid erosion of the toe of the 1928 rockfall and debris slide. Recession increased between 1975 and 1995 at many locations compared to earlier epochs (Halcrow, 1997). Most of the Ventnor frontage (Steephill Cove to Monk's Bay) has been protected over the past 100 years and cliff recession is now negligible. Recession rates of 0.43m/yr were recorded along this frontage between 1866 and 1909, before the current protection schemes were in place, and give an indication of how the frontage would behave in terms of marine erosion if the coastal protection works were to be removed.

The western and central frontages of the Undercliff were characterised by spatially variable advance and recession with a slight overall bias toward mean high water (MHW) advance between 1866 and 1909. At Ventnor, much more significant accretion was recorded, probably due to sediment interception by early groynes. Immediately to the east (downdrift) there was recession, perhaps due to terminal scour. Between 1909 and 1975, a widespread MHW recession occurred, which was more pronounced in western parts between Rocken End, Niton and Binnel Bay, St Lawrence. A possible explanation for this is that the debris lobe produced by the 1928 Gore Cliff rockfall and debris slide could have blocked a beach sediment transport pathway from the southwest, creating a shortfall downdrift to the east.

Historically, the Undercliff has remained relatively stable, but over the past fifty or so years ground movements have increased in frequency at Monks Bay, in parts of Ventnor, St Lawrence and at Niton. Stability is related closely to groundwater conditions, and recent wet winters have been characterised by exceptional landslide activity, it is likely that millennia of toe erosion have also critically reduced the support at the landslide toes. Over the past decade major re-activations have occurred at Niton (Castlehaven and a recent movement to the east inland from Puckaster Cove) and St Lawrence (Woodlands and a recent re-activation immediately to the west).

The entire frontage is formed within a zone of massive relict landslides subject to marine erosion at their toes and sensitive to large-scale re-activation. The relict landslides form distinct units that interlock with each other and are mutually supporting. It means that a re-activation of one unit may lead to destabilisation of its neighbours and eventually result in a much wider re-activation of the Undercliff. Large-scale re-activations of landsliding would considerably increase the delivery of sediments to the local shoreline and potentially supplement supply of sand to Sandown Bay.

Predictions of Shoreline Evolution:
The relict landslides are sensitive to an increase in frequency of ground movements due to future climate change (sea-level rise that promotes increased toe erosion and increased winter rainfall promoting higher pore water pressures within the landslides).

The implications of climate change predictions for the Undercliff are both spatial and temporal; firstly, there are concerns that hitherto marginally stable areas of the Undercliff may become unstable due to reactivation of ground movement and the occurrence of new landslides, secondly, in areas previously affected by ground movement or landslides, the frequency and rate of ground movement and landsliding is expected to increase (Moore *et al* 1997). The main consequence of predicted climate change on the stability of the Undercliff is likely to be an increased risk of damage to assets due to ground movement, particularly in built up areas, such as Ventnor.

Studies for the UK (UKCIP09) strongly suggest that in the future the climate will be less predictable and characterised by higher frequency of climatic extremes. A greater seasonality is expected on average resulting in warmer and drier summers and wetter winters. The western Undercliff could be potentially more vulnerable to the increased variability of winter rainfall leading to increase landslide activity characterised by major events. Conversely the predicted increases in winter rainfall could be mitigated by increases in evapotranspiration consequently leaving the frequency of accelerated landslides, especially minor instability, substantially unchanged.

The close association between ground movements and rainfall, together with the possible effects of coastal erosion, leads to serious implications in terms of future climate change. Climate change is predicted to increase significantly the frequency and intensity of winter rainfall causing corresponding increases in groundwater levels, which in turn will cause accelerated ground movement and increase the probability of a major landslide event at Ventnor. Increases in sea level will cause further erosion of the foreshore and sea cliffs which will cause a decline in overall stability of the landslide complex (Halcrow Group Ltd, 2006).

Futurecoast (2002) estimated that without defences a natural trend for re-activation of the relict landslides of the Undercliff is likely to persist and intensify in the future, based on the following contributory factors:

1) Sea cliff erosion is likely to continue at, or close to, historical rates. As the cliffs retreat, vital toe support is removed and the overall coastal slope will steepen. This will tend to 'prepare' the slopes above such that relatively smaller events could be sufficient to trigger re-activations.

2) Slopes are sensitive to winter rainfall promoting higher pore water pressures within the landslides and potentially triggering re-activations of the 'prepared' slopes.

3) The relict landslides are deep-seated, and interlock with other relict slides further upslope such that stability may be mutually dependent and potentially large areas could become at risk following initially modest re-activations.

In the long term, re-activation of landslides would facilitate excavation of residual debris from the undercliffs leading to the initiation of new failures within insitu geological materials and renewed recession of the backscar. The likely timescale for such events is difficult to estimate (probably >100 years), although it appears that processes operating towards full slope re-activation are occurring more rapidly in western than in eastern parts. Major landslides within the Undercliff are likely to generate significant seaward extending lobes of debris and reinforce the protection afforded at the slope toes by the boulder aprons.

Futurecoast (2002) estimated that with present management practices, sea cliff stabilisation and toe weighting around Ventnor and Bonchurch appear to have significantly reduced the occurrences of landslide re-activations within these parts of the Undercliff. If continued, these measures could considerably delay re-activations such that the eastern section of the Undercliff around Ventnor might remain relatively stable for >100 years, whereas western and central parts could in future become increasingly active (as explained for the unconstrained tendency above).

The foreshores in front of defences are likely to lower and narrow only relatively slowly due to the resistant nature of the boulder aprons. The sub-tidal bed may, however, be free to erode such that toe support would gradually be reduced.

C1.6 Large Scale: Rocken End to The Needles

Interactions:

Rising sea-levels of the mid to late Holocene re-occupied former degraded cliffs initiating renewed erosion of its soft Cretaceous sands and clays to form a rapidly retreating linear or slightly embayed cliff coastline some 15km in length. As the coast retreated it has produced a shallow nearshore shelf, or shore platform extending seaward for some 4km which is thought to indicate the extent of late Holocene coastal recession.

Recession has been controlled partly by the occurrence of more resistant strata forming the northwest (Chalk) and southeast (the Undercliff boulder aprons) extremities of this segment.

The eroding coastline has truncated the northward flowing Western Yar River and its southwestward flowing tributaries evident today as steeply incised chines. Much of the land lost to erosion is therefore thought to be part of the drainage basin of the Western Yar.

Although significant volumes of material would have been released as a result of such rapid recession along a wide front, the majority of sediment yielded would have been clays and sands that were rapidly removed offshore by wave action.

Variations in the cliff morphology and style of recession would have developed along this unit as a result of variations in ground elevation, lithology, stratigraphy and geological structure revealed as the cliffs retreated. Minor headlands have developed at Hanover and Atherfield points due to local occurrences of harder lithologic units that have formed protective foreshore reefs. However, the rates of retreat are such that headlands of this type would have had limited longevity. A highly distinctive feature of the West Wight coastline is the presence of a number of deeply-incised coastal valleys, or chines, that interrupt the continuity of the cliffs. Their origin is uncertain, but they might represent the remnants of tributaries of a previous Western Yar river system that has been destroyed by rapid coastal erosion.

This frontage occupies one of the most exposed locations on the south coast of England with long fetches in excess of 4,000km to the south-west extending directly into the north-east Atlantic as well as shorter fetches to the south across the English Channel. It is exposed to significant swell wave activity as well as to energetic locally-generated wind waves. The well-documented history of shipwrecks along this largely unprotected rugged coast is a testimony to this fact. HR Wallingford (1999) calculated, using numerical modelling of synthetic data for wave climate that the range of maximum wave height, for a 1 in 1 year recurrence, is up to 5m for the coastline between Freshwater Bay and the Needles. For example, at Compton Bay, it extends up to 4.26m. Estimations for longer recurrence intervals are also given. Variation is due to the range of different wave types and approaches.

Tidal range is small so that wave energy is concentrated over a limited vertical range. However, the shallow nearshore and shore platform provides for some dissipation and breaking of very large waves a distance offshore. Wave exposure and the steepness of the nearshore profile are greatest towards the south-east so that Chale Bay experiences the most energetic shoreline wave conditions. Tidal currents generally are weak at the shoreline, except at the headland extremities of The Needles and Rocken End.

West and South Isle of Wight (The Needles to St Catherine's Point): Sediment Transport

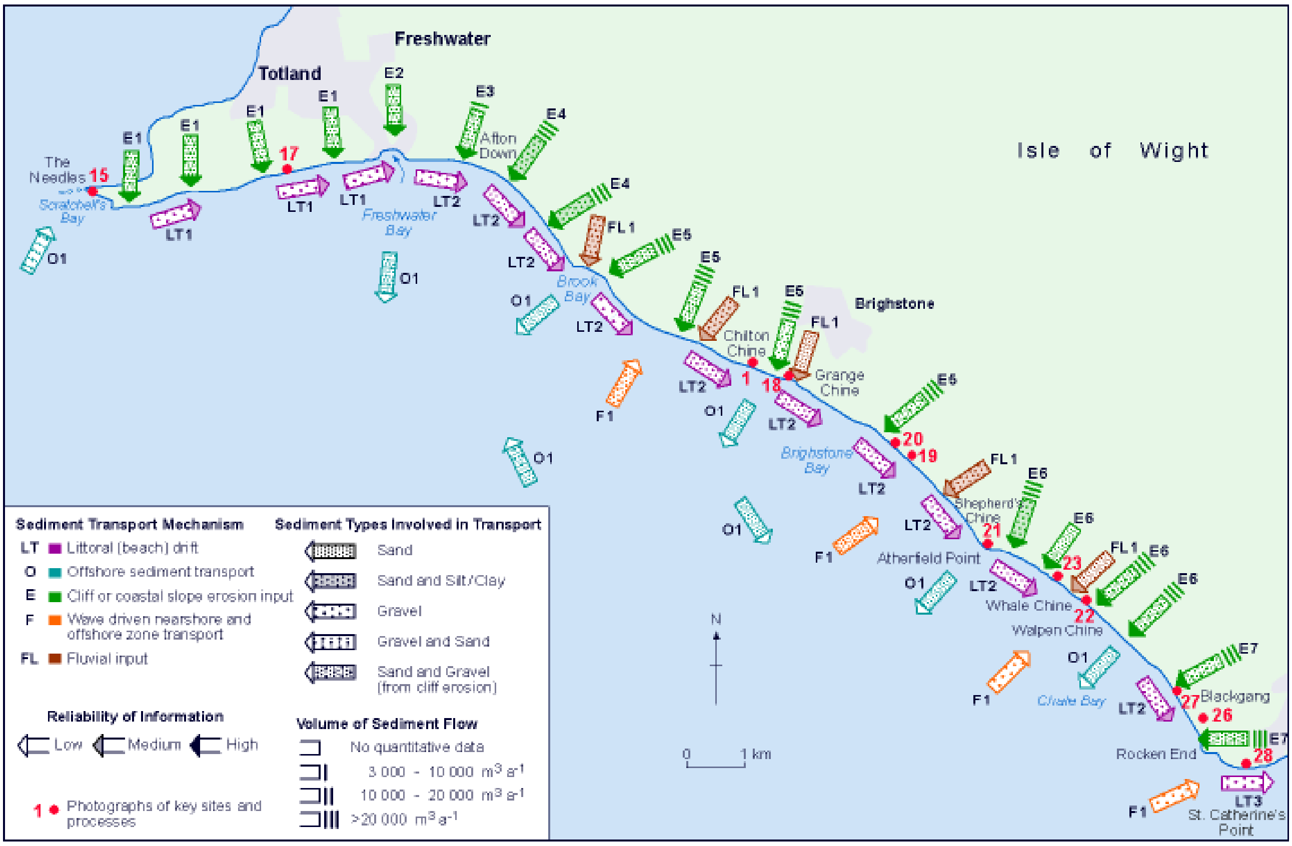

Figure 14: Sediment transport sources, pathways and sinks on the south west coast, from SCOPAC Sediment Transport Study, 2004.

The offshore to onshore supply of sediment by wave-induced or tidal currents may account for a proportion of beach stores at certain locations. However, knowledge of nearshore sediments and possible pathways of transfer to littoral transport is very limited and is largely a matter of conjecture (Brampton et al, 1998). It is known that parts of the shoreface between The Needles and St Catherine's Point are current-swept bedrock surfaces (Posford Duvivier and British Geological Survey, 1999), thus implying limited supply potential. Tidal currents achieve relatively high velocities of 1.5 to 2.1 ms^{-1}, and flow sub-parallel to the coastline. They may effect scour around large boulder accumulations and gravel patches. Sand and sandy gravels occur as large lobate accumulations seawards of the inshore rock platform and reefs, especially south of Freshwater Bay and between Atherfield and Walpen Chine. This may represent a sediment sink that could supply some net onshore feed (Brampton et.al, 1998). However, echo-sounder survey data, commissioned by English Nature (1995, unpublished) did not reveal evidence of sediment mobility in these areas.

The descriptions of littoral drift by several authors (Posford Duvivier 1989a, 1990a and b; Barrett 1985; Kay 1969) also give indirect implications of onshore feeds of sand and gravel from offshore or nearshore stores. This remains highly speculative (Rendel, Palmer and Tritton, 1993, Halcrow, 1997; Brampton, et.al, 1998). Halcrow (1997) have postulated a possible offshore to onshore feed of medium sand to fine gravel, derived in part from relict fluvial sediment deposited by the now largely destroyed channel network of the West Yar. This might operate to supply beaches, but there is no substantive evidence to confirm this pathway. Brampton et.al (1998) also postulate net onshore movement of gravel south of Brook Bay, on the argument that cliff and shoreface erosion south of the Chalk outcrop provides insufficient coarse clastic debris for beach building.

It is possible that sediment is discharged as traction or bedload by the several chines along the western and south-eastern shorelines. Flint (1982) suggests that most of the debris transported by the chine streams of the west coast are in the fine sand and silt fractions, though this conclusion is not based on sampling. The bedload of some of the more deeply incised valleys is coarse, and derives from large ironstone doggers exposed in valley-side slopes. Whale and Brook Chines have boulder chokes at their mouths, indicating occasional high discharge and bedload-transport competence. However, the petrographic character of this material is an unlikely source for durable beach gravel. Nonetheless, local beaches may retain a small proportion of the sediment discharged by the chine streams. Human interference with discharge: load ratios may have affected this contribution in the last century or more, as Flint (1982) notes that Shepard's Chine, north of Atherfield Point, has cut down at least 15m since 1820 as a result of local diversion of drainage. Rendel Geotechnics and University of Portsmouth (1996) calculate that the West coast chines collectively transport 803 tonnes/yr of suspended load and 259 tonnes/yr of bedload. Of these quantities, only 82 tonnes/yr, is delivered to the coastal transport system; the remainder is diverted to various forms of channel storage, both naturally and artificially induced.

As a general trend, beaches consist of a gravel backshore and sandy foreshore, and progressively steepen between Freshwater Bay and Rocken End. The beaches are rarely especially high in profile or well-developed, affording very limited protection to cliff toes. The gravel component becomes more dominant in this direction, although the median grain size of coarse clastic material gets smaller in a south-eastwards direction.

Along the south-west coast, concrete sea walls with concrete aprons and sheet steel toe piling defend the small settlement of Freshwater in Freshwater Bay. The remainder of the coast consists of agricultural land with isolated settlements and is unprotected. The theme park of Blackgang Chine is the main tourist development along the coast, along with the Needles Battery.

Shoreline Movement:
Extrapolation of measurements of coastal recession for the past 150 years (e.g. Posford Duvivier, 1989a, 1999; Halcrow, 1997; Tomalin, 1977 –in SCOPAC, 2004) supports the conclusion that there has been up to 6km of retreat of the western coast since the start of Holocene sea level recovery between 12,000 and 11,000 years BP. This estimate can be applied with most confidence to those sectors where there are outcrops of comparatively weak, erodible sandstones, clays, marls and interbedded limestones.

The Chalk of Tennyson and Afton Downs forms high, steep rockfall-dominated cliffs that retreat at slow to modest rates. The main central portion of the frontage, formed in soft Lower Greensand and Wealden clays and sands, forms rapidly eroding cliffs typically adopting simple landslide morphology. Local transitions to complex landslides and rockfall-dominated forms do, however, exist. In the south-east, Upper Greensand and Gault Clay overlie interbedded sandy and clayey strata in a major landsliding-generating sequence, resulting in a complex landslide behaviour characterised by periodic high magnitude cliff top recession events.

The high cliffs around Blackgang appear to be becoming more unstable and accelerating in recession rate. They can be expected to become increasingly active in future, eventually leading to major new backscar failures. Many other soft rock cliffs along this coast are also likely to be susceptible to accelerating recession, especially in response to future climate change. Accelerated landsliding and cliff recession would considerably increase the delivery of sediments to the shoreline.

It is known that the erosion of this coast yields substantial quantities of sediments making it an important regional source. However, there is a major uncertainty relating to the fate of these inputs, especially their relation to depositional environments such as the Solent and its estuaries. Cliff recession may accelerate in future because all cliffs along this frontage are sensitive to heavy winter rainfall promoting higher pore water pressures within permeable strata, potentially triggering failures. The cliffs are also sensitive to sea-level rise that could increase toe erosion and result in increased landsliding and retreat of the cliff top.

C1.6.1 Local Scale: Rocken End to Chale

Interactions:

This unit incorporates the western extremity of the Undercliff coast of the southern Isle of Wight, characterised by episodic events of slope failure that have created highly complex cliff behaviour units. Although this area has much in common with the eastwards continuation of the Undercliff, its south-western aspect has promoted higher rates of basal marine erosion than encountered elsewhere.

Partly because of the dramatic scale of this landslide system, but due also to its high intrinsic geological and geotechnical interest, considerable research has been undertaken (e.g. Hutchinson, 1965, 1983, 1987 and 1991; Hutchinson, et al, 1981; Bromhead et al., 1991). Arising directly from the substantial movements in January 1994, further studies have been commissioned by the local authority (Rendel Geotechnics, 1994, 1995b; 1995c). The latter have been concerned with the assessment of hazard vulnerability and its management, but have also proposed a morphological and morphodynamic characterisation of the landslide complex in the vicinity of Blackgang.

Cliff elevation varies between 70m and 110m, with a further 60m to 80m added where there is a rear scarp developed in Upper Greensand. The coastal slopes are made up of a complex pattern of mass movement forms arranged within a cascading sequence of landslide systems.

The coastline is characterised by high eroding soft rock cliffs subject to high wave exposure and complex landsliding within two distinct areas. The first area extends between Rocken End and Blackgang, and contains cliffs up to 180m in height that are cut into Upper Greensand and Gault Clay overlying interbedded sandy and clayey Lower Cretaceous strata in a major landslide generating sequence. The morphology comprises a near-vertical inactive backscar, a wide undercliff occupied by multiple rotational failure zones, succeeded downslope by mudslides developed across a mid-slope scarp and compound block failures developed on clay-rich horizons in the basal Sandrock. The lower slope is dominated by accumulations of debris fallen from upslope and by steep actively eroding sea cliffs. The frontage as a whole has a history of landslide re-activation driven by marine erosion of sea cliffs that oversteepens and unloads the coastal slope. Groundwater also plays a significant role and major failures appear triggered by periods of exceptionally high winter rainfall. The second area extends along the Chale Undercliff, where cliffs of 60 to 110m in height are cut into the Lower Cretaceous Atherfield Clay, Sandrock and Ferruginous Sandstone strata. Upper Greensand and Gault Clay are not present and the full cliff profile is active. A sequence of near-horizontal terraces and free face segments coincide with clays and sandstones respectively to form an undercliff of up to 200m in width. Cliff recession takes place through spatially and temporally variable combinations of falls, mudslides and erosion by groundwater seepage.

Plate 15: Gore Cliff, with failures from the backscar of the landslide complex and in the Gault Clay and coastal slopes below, near the site of the 1928 Great Cliff Fall which severed the coastal road. July 2006

Despite the intermittent delivery of large quantities of landslide debris to the foreshore, some of it of boulder size, beach formation is modest and the cliff toe therefore remains exposed to marine erosion. The majority of the material is removed from the shoreline and its fate is uncertain. Sands may contribute to the nearshore bed and suspended sediments could be transported into the Solent, or become moved greater distances along the Channel.

The coastal topography and seabed depth off St Catherine's Point, on the extreme south of the Isle of Wight, give rise to strong tidal currents flowing around the tip of the Island. This flow has a high transport potential, but the seabed here is formed of exposed bedrock which means that no material is actually carried in the flow. The lack of sediment cover here is probably due to the continued tidal scour having removed any material once present to less active areas.

Results of the Strategic Regional Coastal Monitoring Programme (IW39):
The Southeast Strategic Regional Coastal Monitoring Programme does not cover this section of coastline. (Channel Coastal Observatory, 2009).

Shoreline Movement:
The Blackgang sea cliffs and beach retreat relatively steadily at moderate rates. However, behaviour within the Undercliff is highly variable. During Victorian times, this part of the Undercliff was developed for a number of residences and was sufficiently stable to be occupied by the main coastal road to Niton and Ventnor. Thereafter, instability has migrated landward from the sea cliffs as inactive pre-existing landslide zones within the Undercliff have been re-activated.

The main Undercliff bench descends from approximately 55m OD at Walpen Chine to beach level at Blackgang Chine, with some subsidiary minor benches to the immediate south-east. These were apparently better defined, and by implication were more stable, throughout the nineteenth century. Over a small area immediately southeast of Blackgang Chine, the cliffs are in a relatively stable condition; Hutchinson, et al (1981) suggests that seepage erosion is suppressed here because sub-surface drainage is directed towards the Chine. Elsewhere, groundwater-fed stream flow and debris transport, shallow mudflows, rotational slides and rear scarp weathering and mass wastage are the dominant erosion processes. The coastal cliff complex from a point seaward of Gore Cliff has a long history of instability, with major rockfalls and landslides occurring at regular intervals (Hutchinson, 1987; Bromhead et al, 1991; Hutchinston et al, 2002; McInnes and Jakeways, 2000; Rust, 2002; Rendel Geotechnics, 1994 and 1995). Nearly 300m of cliff retreat has taken place since approximately 1880 (2.5 m/yr). At Gore Cliff, there is strong toe erosion in the Ferruginous Sands and Sandrock, with a recorded mean rate of shoreline recession of 0.6m/yr between 1862 and 1980 (Hutchinson, et al 1981). Preece (1980, 1987) records mollusca and Romano-British artefacts in a Chalky hill wash deposit, which he interprets as having been derived by mass movement acting on a slope with a north-easterly aspect. This implies a substantial recession and probable geomorphological re-modelling of the Undercliff in this vicinity over at least two millennia. The direct contribution of marine erosion to the initiation of slope instability remains uncertain, as various other hydrogeological and geotechnical attributes are of importance (Hutchinson, 1965, 1987; Bromhead, et al 1991; Rendel Geotechnics, 1994). However, the consensus view (Rendel Geotechnics, 1994; McInnes, 2000) is that unloading and oversteepening of the cliff base provides the mechanism that prepares for slope failure events that are triggered by periods of intensive or prolonged rainfall adding critically to pore water pressures determined by local groundwater reservoirs (Bromhead et al, 1991; Hutchinson et al, 1991; 2002; Lee et al, 1998).

Rates of cliffline recession have been calculated by several researchers, largely with reference to the retreat of the marine cliff. The doubtful survey accuracy of cliff features on this coastline on successive Ordnance Survey maps renders this data potentially unreliable although it is to be presumed that the cliff top has been mapped accurately. Cliff retreat varies within and between each of the major morphological subdivisions; Rendel Geotechnics (1995) quote a rate of approximately 2.5m/yr, 1980-1984 for the Gault Clay scarp. This is probably representative of a phase of accelerated movement, as earlier measurements covering the period 1861-1980 (Hutchinson, et al, 1981) indicate a lower long-term mean of 0.41m/yr. Halcrow (1997) calculated recession averaging 0.14m/yr for the period 1866-1909, although recession increased thereafter with typical rates of 2.0m/yr. It was noted that the recession process was linked to major reactivations of ancient landslides in 1928, 1935, 1952, 1978 and 1994. The episodic nature of recession at this site means that as much as 50m of retreat is possible in a single event (Bray, 1994). Minor ground movements involving tension cracks and pressure ridges extend inland. Mean recession rates therefore need to be considered in combination with the maximum recession likely in a single event. Sea-level rise over the next 50 years and beyond may increase access of wave erosion to the cliff base and thus sustain higher rates of recession. If so, the evolutionary model of cliff behaviour points to increased frequency of landslide events, although predictions of their locations, magnitudes and timings are not yet possible. It should be noted that this active unit provides the most appropriate analogue for the behaviour of the Undercliff should its toe protection and debris aprons be removed.

Plate 16: Blackgang cliffs, looking south-east, with Blackgang Chine Theme Park located on top of the actively eroding and retreating cliffs (Isle of Wight Council).

Predictions of Shoreline Evolution:

Futurecoast (2002) estimated that without defences continuation of existing rates of cliff toe erosion is likely throughout this frontage, but its effects on the cliffs above are likely to differ according to location.

Between Blackgang and Rocken End continued re-activation of the undercliffs is likely such that they become activated fully up to the toe of the Upper Greensand backscar. The episodic nature of landslide re-activation and movement mean that the zone of destabilisation could migrate by as much as 50m inland within single events and minor ground movements involving tension cracks and pressure ridges can extend even further until confined by the backscar. As material is excavated from the undercliffs by landslides moving over the sea-cliffs, the backscar will lose vital support from its toe and will become increasingly susceptible to renewed first time rotational failures that could cause recession of the cliff top of 10 to 30m within single events.

At Chale, the cliffs are already fully re-activated so that continued toe erosion is likely to result in continuation of the high rates of retreat that appear characteristic of recent decades.

Cliff top retreat at Chale Cliffs is also episodic, but comprises first time failures and events are smaller in magnitude (maximum 10-20m).

All cliffs and coastal slopes within this frontage are sensitive to heavy winter rainfall promoting higher pore water pressures within the landslides and potentially triggering re-activations, or new failures if recent trends for wetter winters continue.

C1.6.2 Local Scale: Chale to Compton Down

Interactions:
This section of coast is characterised by eroding soft rock cliffs of moderate height (10m to 50m) exhibiting lithological control of behaviour and morphology. Cliffs are exposed to high wave energy increasing towards the south-east. This long eroding cliff frontage delivers large quantities of predominantly sand and clay sediment to the shoreline. Most sediments are removed from the shoreline by wave action and their fate is uncertain. Sands may contribute to the nearshore bed and suspended sediments could be transported into the Solent, or become moved greater distances along the Channel.

Plate 17: *View along the eroding south-west coast of the Isle of Wight from near Blackgang in 2009 (N.Dix).*

The position of the 10m isobath along this straight, actively eroding cliffed coastline approaches to within 500m of mean low spring tides, and the effect of Atlantic swell waves is greater here than on adjacent parts of the west Wight shoreline. Atherfield Point, and its offshore ledges, results from an outcrop of a more resistant unit within the Lower Greensand. The cliffs are formed primarily within the Ferruginous Sands and Sandrock and maintain near-vertical profiles with occasional narrow ledges. Long term recession rates of 0.6m/yr (Posford Duvivier, 1997) and 0.66 m/yr for 1866-1995 (Halcrow, 1997) for this unit, with spatial variability due to subtle changes in rock resistance and exposure to wave energy, are characteristic. An erosion yield of 45,000m^3/yr between Shepard's and Whale Chines is derived from the above recession rate. (Posford Duvivier 1997).

Plate 18: Whale Chine and the cliffs of the south-west coast (Isle of Wight Council).

Cliff elevation rarely exceeds 80m, and declines in a few locations to as low as 10m. The cliffline is cut into a repetitive succession of different lithologies, chiefly clays, shales, marls and sandstones. Wave abrasion of the cliff toe occurs throughout this sector, wave energy is partly dissipated by wide shore platforms. Any factors disturbing the present relationship between the shore platform and sea-level (e.g. accelerating sea-level rise, or downcutting of platforms) are likely to prepare conditions for acceleration of cliff retreat. Detailed morphological variety is provided by spatially variable combinations of sub-aerial processes and products. There is a very limited literature on the geomorphological character of this coast, which will be sub-divided into three cliff behaviour units on the basis of visual inspection. They are spatially co-extensive and each recurs at several locations.

(a) Retrogressive Shallow Mudslide/flow Cliffs

A low bounding cliff top scarp slope, of between 1m and 5m height, shows evidence of landward recession through arcuate re-entrants and small scale block failures. Shallow translational slides, mudflow and slump structures, compression ridges and linear furrows diversify the surface of many debris stores derived from cliff top failure. The confluence of low-angle debris cones is sometimes discernible. Exemplified by the cliffline to the south of Brook Bay and north of Atherfield Point. A rate of cliff recession of 1m/yr is estimated from the aerial photographs and 1975 O.S. map for the mudslide cliffs immediately west of Atherfield Point Coastguard lookout.

(b) Scarp and Gully Cliffs

An upper free face of modest height, often defined in superficial gravels, is succeeded by a deeply-dissected, gulleyed basal slope. This unit is characteristic of shale and marl lithologies, particularly the outcrop of the Wealden Group. Gulleys are often sub-parallel, but also exhibit complex patterns of integration. They provide pathways for overland flow across impermeable strata, and promote linear erosion of the basal elements of the lower slope unit that may be partly the product of successive slumps and shallow slides. Seepage erosion is an active process, but does not usually create bench or terrace features. Despite an absence of measured rates of recession, it is apparent that material is moved relatively rapidly from cliff top to cliff toe. Cliff foot erosion varies between intermittent and continuous, dependent upon the throughput and release of debris. Where sandstones or siltstones are present at the cliff toe, these form low vertical cliffs over which flow landslide debris to debris cliffs fans on the beach.

(c) Free Face Cliffs

This is the simplest of the three types and consists of a steep rectilinear slope and small summit convexity. Basal marine erosion is the dominant process, with rock material released along widely-spaced parting planes. It is characteristic of subsidiary headlands, such as Atherfield and Hanover Points and of the cliffs north of Chiltern Chine, where there is little beach accumulation.

Results of the Strategic Regional Coastal Monitoring Programme (units IW40):

Only the section between Brook Chine and Compton Chine is covered by the Strategic Monitoring Programme. Between Spring 2008 and Spring 2009 there was erosion at the eastern end of Compton Bay, however the beach was stable in the centre and accreted slightly further west along the bay. In the longer term there has been a trend of erosion in the west and accretion in the east.

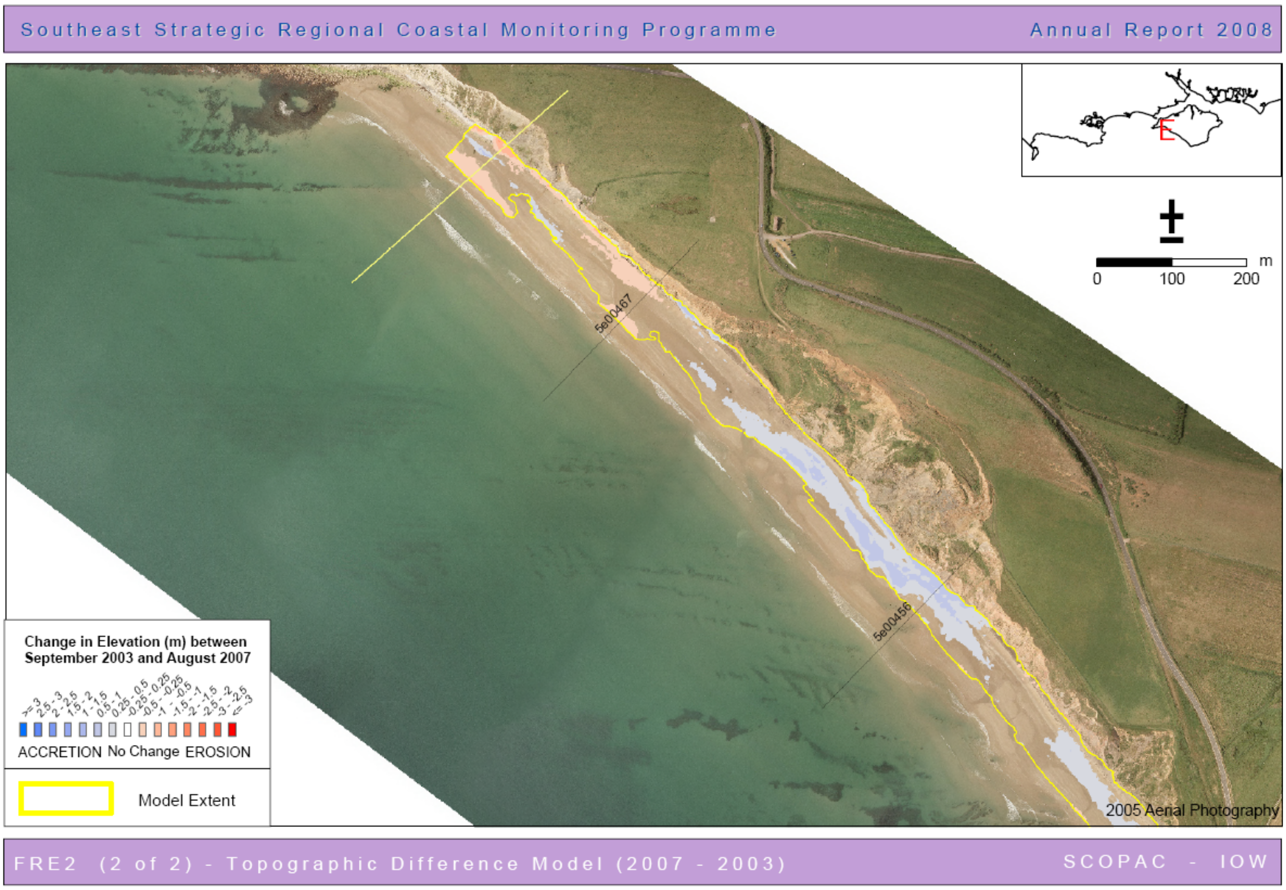

Figure 15: Topographic Difference Model for Compton Beach


Plate 19: Erosion of the car park behind Compton Bay, July 2006.

Shoreline Movement:
Historically, this is an eroding coast with some evidence for up to 700m of recession since Roman times. Between Compton Down and Hanover Point, recession has been fairly steady, although there are examples in recent years of high to extreme recession of the cliff top associated with rotational or translational failures in areas where ground conditions are especially favourable for landsliding e.g. opposite High Grange.

Between Hanover Point and Atherfield Point, there has been long-term continued recession, although some localised areas of high recession in recent decades has been associated with low cliffs eroding back into soft sediments e.g. Brook Bay. From Shepherd's Chine to Chale, there have been moderate to high rates of recession. This section is possibly more exposed to wave action where deep water extends closer inshore off Atherfield Point.

Beaches within this frontage have migrated landward at the cliff toe as the coast is eroded, exposing a widening dissipative shallow nearshore or gently sloping shore platform.

Predictions of Shoreline Evolution:
Futurecoast (2002) estimated that without defences continuation of existing rates of cliff toe erosion are likely throughout this frontage, resulting in continued cliff retreat at, or close to recent historical rates. Large quantities of sediment will continue to be delivered to the shoreline and transported to other areas.

Moderate to high rates of recession are likely to be characteristic of this frontage for the foreseeable future because any tendency for self-regulation of recession is likely to be extremely limited. This is because the widening shore platform is unlikely to significantly increase the dissipation of wave energy over the next 100 years or longer and the majority of the sediments delivered by cliff erosion are removed from the shoreline and do not afford protection against wave attack.

Plate 20: View from Compton Bay Car Park north-west towards the Chalk ridge. The settlement of Freshwater Bay is located at the low point in the Chalk cliffs. July 2006.

C1.6.3 Local Scale: Compton Down to The Needles

Interactions:

This coastline is characterised by high (80-130m) steep to vertical cliffs comprise mostly free face segments that are the product of basal undercutting by waves separated at Freshwater by a small low-lying embayment formed where coastal recession has truncated a narrow valley and cliff height is reduced to a mean of 25m, with a seawall in the centre of the bay protecting the flat land of the Western Yar Estuary behind. The main landforms are very steeply northward dipping Chalk sea cliffs developed by erosion of a southward-facing portion of the Purbeck – Needles – Culver Chalk ridge. The cliffs are fronted by variable accumulations of Chalk debris according to recent cliff-falls. A dissipative shore platform is present between Compton Down and Freshwater Bay, but further to the west the cliffs descend directly to deep water. Shingle beaches have accumulated within Scratchell's and Freshwater Bays.

Plate 21: Freshwater Bay, forming a low point along the high Chalk coastal cliffs of Afton Down to the east and Tennyson Down to the west (Isle of Wight Council).

Plate 22: Freshwater Bay, with the low lying land of the Western Yar Estuary extending southwards towards the south coast of the Isle of Wight (Isle of Wight Council).

The cliffs adopt a simple linear form and fail mainly by rock falls of variable magnitude. Flint nodules within the cliffs are released by erosion, but otherwise most cliff erosion products are removed in suspension by wave action. Flints released from the erosion of cliffs between Freshwater Bay and Compton Down are supplied to beaches downdrift to the south-east. Defences in Freshwater Bay prevent breaching of the beach and avert risk of a tidal connection developing between the West Yar estuary and Freshwater Bay.

Beach material is presumed to derive directly from the release of flint nodules from the steeply-dipping bedding planes of the Upper Chalk at a rate of 1500m^3/yr (Posford Duvivier, 1997, 1999) from a total yield of 15,000m^3/yr of Chalk debris. Recession of this cliff line is relatively slow, with intermittent rockfalls. A rate of shoreline recession of 0.14m/yr is suggested by Posford Duvivier (1991a) and 0.15m/yr was calculated by Halcrow,(1997) covering the period 1866-1995. The shoreface is relatively steep, with the 10m isobath between 200 and 300m from the shoreface. This limits capacity for debris storage.

The Needles headland is an important control affording shelter from dominant south-westerly waves to central and eastern parts of Christchurch Bay and the extreme north-west Isle of Wight coast.

The instability of the cliff top free face at Afton Down, which has created a problem for the A3055 at this point, has revealed spalling (rockfalls in weathered material) and other weathering losses along widened joins trending parallel to the coastline. Cliff top recession is probably promoted by physio-chemical weathering of joint-directed fissures opened up by pressure release; the superficial slippage of unconsolidated "head" accentuates free face recession (Barton and McInnes, 1988; McInnes, 1994). As similar structural conditions prevail throughout this unit, the Afton Down situation is probably reproduced elsewhere, although the largest of the recent rockfalls has features diagnostic of toppling and block failures.

The pocket beach of Freshwater Bay is composed wholly of well-rounded and abraded flint cobbles, suggesting that the bay is a re-entrant trap receiving sediment from both east and west. The lack of in situ flints in the Chalk cliffs in the eastern part of the Bay suggests their movement by littoral transport from the west, but there may be an input from the mass wasting and marine erosion of the soliflucted Chalky-flint deposits infilling the truncated valley profile of the Yar. This would have been more significant before the completion of the first generation of sea defences in the late nineteenth century. Severe damage sustained by the sea wall esplanade and groynes, necessitating extensive repairs and reconstruction in the 1900s, 1953 and 1966, indicate the effectiveness of both abrasion and scour (Posford Duvivier, 1989b).Swell waves approach this coastline with minimal refraction, creating a substantial reflective beach that affords significant cliff toe erosion within the perimeter of the bay. However, a near-vertical cliff profile is retained, suggesting a low-order dynamic equilibrium between supply and removal of debris (Geodata Institute, 1989). Changes in the stability of this beach were induced by beach mining in the early part of this century (Colenutt, 1904); the refurbishment of the seawall and slipway are largely to offset the effects of abrasion (Lewis and Duvivier, 1981; Posford Duvivier, 1989b).

Seawall stabilisation of the beach in Freshwater Bay prevents breaching and averts risk of a tidal connection developing between the West Yar estuary and Freshwater Bay.

Results of the Strategic Regional Coastal Monitoring Programme (units IW40-IW42):
The only monitoring in this section relates to Freshwater Bay. From 2003-2009 the western section has shown erosion while the eastern section has accreted. This is a closed system with the sediment in the Bay moving from one end to the other.

Shoreline Movement:
Measurements of rates of recession for this unit are sparse; May and Heeps (1985) suggested 0.08m/yr, whilst Barton and McInnes (1988) derive a figure of 0.05m/yr for the Afton Down cliff face. Localised free face recession might be as high as 0.3m/yr, but much of the movement is episodic rather than continuous. Between Freshwater Bay and Compton Down, May (1966) calculated a rate of shoreline recession of 0.01m/yr, which is significantly less than for Chalk cliffs of similar exposure and dimensions at other south coast locations. Posford Duvivier (1981, 1989b, 1997, 1999) propose an average long-term rate of 0.15-0.6m/yr, yielding some 15,000m^3/yr of Chalk and 500m^3/yr of flint gravel. Halcrow (1997) calculated a long-term recession of around 0.1m/yr from 1886 to 1975, but with an increase to 0.42m/yr for 1975-1995 attributable to failures in superficial deposits at the cliff top.

Recession of the cliff top at Afton Down has posed a particular threat to the A3055 since 1981. The cliff slope hereabouts is partly defined by east-to-west trending joints, but is mantled by slip debris derived from Chalky Head materials above. Detailed geotechnical surveys and sophisticated monitoring have been undertaken because of the threat to public safety and in 2003 a road stabilisation scheme was completed.

The overall erosion rate along this sector of the coastline is comparatively slow, and may be partially explained by the exceptional width of the offshore zone. The 10m depth contour in the north of Compton Bay indicates a 1300m wide offshore platform so that incident wave energy is strongly dissipated. However, the Chalk yields very little sediment suitable for beach building, so that protection against breaking waves is slight.

Prior to the provision of coastal defences within Freshwater Bay, recession occurred at a mean rate of around 0.5m/yr for the period 1866-1909 (Halcrow 1997). Occasional rockfalls yield a small quantity of clastic material, but in the western part of the bay the cliffs support an overburden of loosely consolidated Chalk and flint fragments (Coombe Rock) that is subject to mass wasting and gullying. Posford Duvivier (1999) calculate an erosion loss of approximately $2000m^3$/yr of mixed sediment sizes, of which less than $100m^3$/yr is flint gravel that is retained on the local beach.

Predictions of Shoreline Evolution:
Futurecoast (2002) estimated that without defences cliff recession is likely to continue at, or close to, recent historical rates. Since many of the cliffs are cut into the southern flanks of the Chalk ridge, cliff height will increase as recession progresses. The cliffs would continue to supply small quantities of flints to the foreshore some of which may enter Freshwater Bay and some may drift south-east into Compton Bay.

At Afton Down, it is likely that continued cliff recession would induce shallow slides within upslope head deposits that could affect sections of the main road. Furthermore, there are several large tension cracks that have appeared landward of the cliff top that are indicative of incipient large-scale toppling failures perhaps involving cliff top losses of 5-15m within single events. It is likely that similar processes would operate on the seaward sloping cliff tops of Tennyson Down.

The Western Yar valley is vulnerable to marine inundation if the beach in Freshwater Bay is overwashed and breaches. It is uncertain whether a breach would seal naturally, or whether the whole Western Yar valley could flood such that the land to the west would become an island and tidal flows could occur between the West Solent and Freshwater Bay.

With maintenance of the current defences at Freshwater Bay, the present beach configuration would be maintained and flooding of the Western Yar valley from the south would be prevented.

C1.7 Large Scale: The Needles to Cliff End (Fort Albert)

Interactions:

This unit comprises the north facing valley side of the former Solent River that became occupied/re-occupied by marine inundation some 7,000 to 8,000 years before present. It is considerably more exposed than the corresponding mainland shore to waves and tidal currents. Erosion has therefore prevailed of the toes of coastal slopes formed in soft Palaeocene, Eocene and Oligocene clays and mantled by relict landslides. In this situation the slopes and cliffs are inherently sensitive to erosion and renewed landslide activity, even when the driving marine forces are relatively weak.

Spatial variation in sediment yield from eroding cliffs is, in part, a function of the contrast in hydraulic regime east and west of Fort Albert. To the east, dominant waves are fetch-limited, whilst westwards the more open coast receives attenuated and refracted swell as well as locally propagated waves. H.R. Wallingford (1999) undertook numerical modelling of modified swell waves for Totland Bay, using HINDWAVE applied to synthetic data. For an annual return period, Hs (mean) was computed to be between 0.22 and 1.71m, depending on wave approach. For a 1 in 10 year frequency values are between 0.33 and 2.05m.

The Needles headland provides shelter to this frontage from waves approaching from the south and south-east. Despite this, this frontage is potentially exposed to dominant waves approaching from the north-west, west and south-west. Between Alum Bay and Fort Albert, Cliff End, the coast is exposed both to tidal currents and modified open sea, including swell waves. Maximum significant wave heights of up to 2.36m (Webber, 1969; Posford Duvivier, 1990a, 2000; HR Wallingford, 1999) might occur at a 1 in 50 to 1 in 100 year frequency south of Fort Albert.

Plate 23: View of the Needles headland at the western tip of the Isle of Wight: From left to right: Tennyson Down (Chalk ridge), The Needles, Alum Bay (coloured sands), Headon Warren and view towards Totland (far left) (Isle of Wight Centre for the Coastal Environment).

The narrow Chalk ridge exposed along the south of Alum Bay is relatively resistant to erosion and forms high cliffs, rising to 100m. The remainder of the coast comprises Eocene and Oligocene strata, a sequence of poorly consolidated sands, silts and clays interbedded with thin and mostly soft limestones. Strata immediately succeeding the Chalk to the north dip almost vertically so that the Reading Clay and Thames Group formations have extremely limited outcrops in Alum Bay.

The combination of relatively non-resistant rock material and a spatially varied exposure to waves and currents has resulted in the formation of a predominantly eroding coastline characterised at several locations by well-developed cliffs and landslides. Headlands occur on more resistant strata that also outcrop on the foreshore to form protective ledges or platforms. In places the prominence of headlands has been accentuated by nineteenth century construction of forts and associated coast protection structures. The shoreline exhibits a varied and complex sediment transport pattern due to both coastal configuration and hydraulic regime.

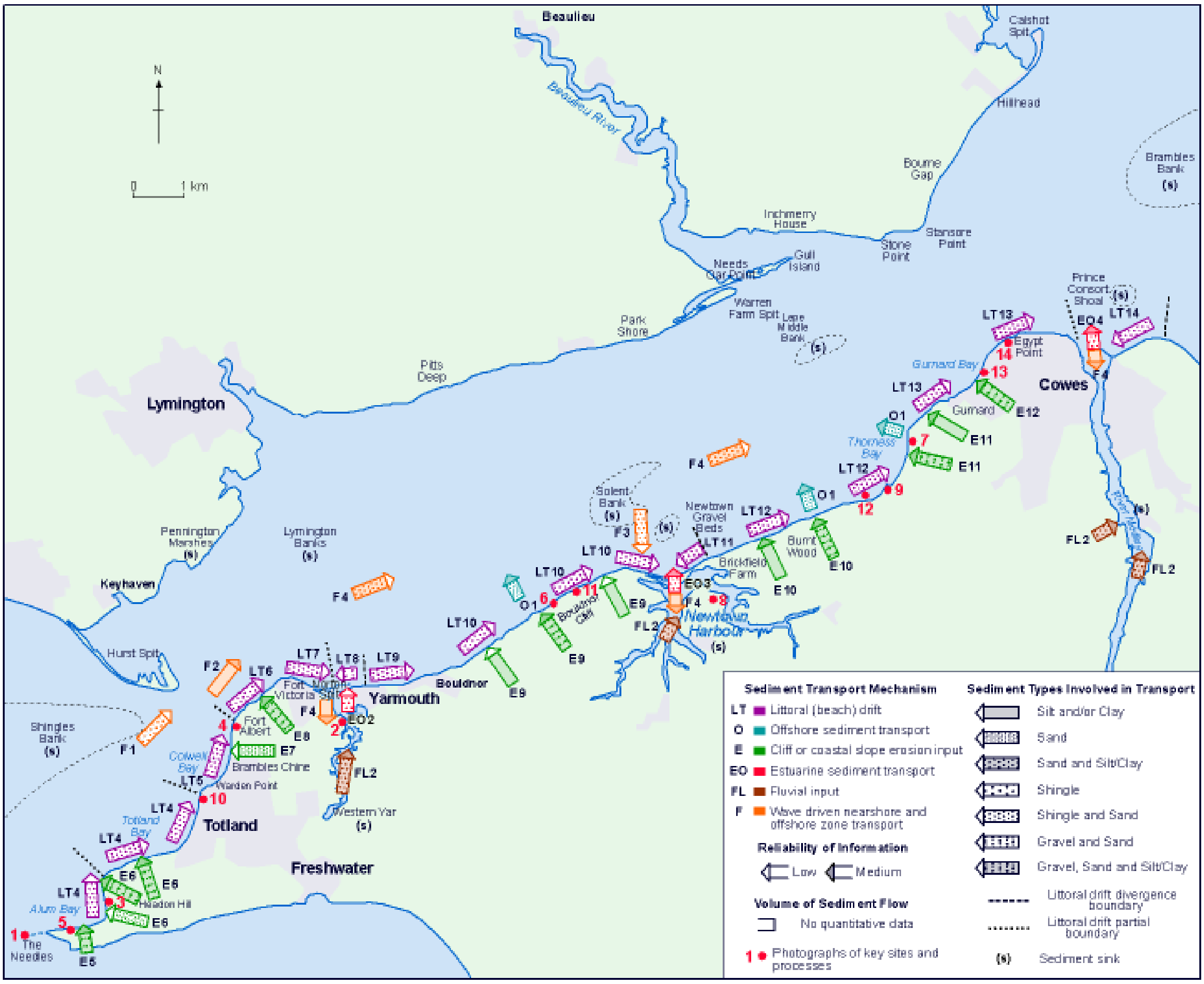

Figure 16: Sediment transport sources, pathways and sinks on the north west coast, from SCOPAC Sediment Transport Study, 2004.

Rapid erosion of high cliffs along much of this shoreline yields large quantities of predominantly fine sediments. These materials are not usually stable on the foreshore, thus widespread offshore transport of fine sediments can be inferred. Little direct evidence of this process is available although the relatively rapid removal of landslide debris on the foreshore is well documented (Hydraulics Research, 1977b; Moorman 1939; Posford Duvivier, 1989a; Halcrow, 1997). The majority of sediments are probably transported offshore in suspension, but no precise information on pathways, quantities and ultimate 'sink' areas is available. Estimates of quantities removed annually, based on approximate measurements of shoreface width and depth and cliff recession rates, are given in Posford Duvivier (1999).

Entry of coarse sediments into the West Solent from Christchurch Bay is normally restricted by tidal conditions at Hurst Narrows. Examination of tidal curves for Lymington, Yarmouth (Isle of Wight) and Totland reveal marked asymmetry, because the ebb flow is concentrated into a shorter time period than the flood (Webber 1980). The ebb flow is therefore considerably more rapid than the flood and transport of coarse bedload sediments (sand and gravel) is therefore likely to be in a net southeastward direction, parallel to the shoreline between Fort Albert and the Needles, determined by peak current velocities.

Coarse sediments may enter Hurst Narrows during exceptional conditions. A combination of high wave energy and a storm surge from the southwest coincident with peak flood tide velocities can be sufficient to transport pulses of coarse sediment into the West Solent against the prevailing net transport direction. This would certainly explain the growth of re-curves and the extension of Hurst Point and may also supply materials to the main channel. Such a process is unlikely to operate on the Isle of Wight shores of Hurst Narrows due to shortage of mobile gravel.

The extent to which these transport pathways are significant sources of supply of sediment to beaches between Fort Albert and Alum Bay remains uncertain. Studies of the Pot Bank dredging area by Hydraulics Research (1977a) identified significant coarse sediment circulation from Hurst Narrows offshore to feed Shingles Bank and Dolphin Sand in Christchurch Bay and, to a lesser extent, Pot Bank. Although much of the analysis, involving comparison of successive editions of Admiralty hydrographic charts, concentrated on Pot Bank (located south-west of the Needles) it was concluded that sediments from this offshore directed pathway from Hurst Narrows did not directly feed the beaches of the north-west Wight coast. Evidence is not conclusive because sediment throughputs may occur with no net alteration in seabed levels. A general survey of the Isle of Wight coast revealed that in this sector beaches were generally depleted, and thus concluded that there was little supply of coarse material from offshore (Barrett, 1985). A study of the potential effect of dredging of the Shingles Bank (Bradbury et al. 2003) also did not identify any onshore supply of sediments to these beaches, although it did highlight the important function of the Shingles Bank in providing shelter against waves approaching from the west.

Net suspended sediment transport is likely to be into the West Solent at Hurst Narrows due to the greater duration of the flood current. Thus, it is likely that fine marine sediments and suspended clay sediments derived from cliff erosion of the west Isle of Wight and Christchurch Bay coasts become drawn into the West Solent. Remote sensing studies of suspended sediments within Christchurch Bay and the Western Solent support these conclusions (Strisaenthong, 1982; McFarlane, 1984, in SCOPAC, 2004).

Both the potential for, and actual rates of, littoral drift vary along the north-west Wight coast due to spatial changes in wave climate and the role of tidal currents. Between the Needles and Fort Albert, the coast is subject to obliquely approaching refracted Atlantic swell waves, modified by the shallow water of the western English Channel and Christchurch Bay, especially the Shingles Bank. Drift potential is therefore high (SCOPAC, 2004).

Although medium- to high-energy wave conditions might be expected due to the exposure of this coastline, this frontage benefits from the presence, 1 to 2km offshore, of the Shingles Bank. This is a major accumulation feature containing between 25 and 50 million m^3 of sand and gravel, which refracts and dissipates incoming waves from the south-west, west and north-west that otherwise would directly strike the shore. Resultant wave energy is therefore medium to low, decreasing from Alum Bay towards Cliff End.

It is thought that Alum, Totland and Colwell Bays were once linked by shoreline drift, but headlands have increased in prominence as the Bays have become more deeply eroded so that each of the three Bays now behaves independently of the others.. As the Bays are relatively closed systems, they receive sediment inputs only from erosion of local cliffs. Much of the material yielded is too fine to remain on beaches and is transported seaward, where tidal currents may transport it south-westward of the Needles or north-eastwards into the Western Solent. Although some sands and thin superficial deposits of gravels are available throughout the cliff coast of this frontage, the major sources of shoreline sediments have been the flints from the Needles Chalk and sands and some gravels and limestones from Alum Bay and Headon Warren. Segmentation of the bays has tended to isolate Colwell and latterly Totland Bays from these sources. Remaining shore sediments tend to drift northward at low rates within each Bay towards the local headland, whereupon they are entrained and removed by strong tidal currents generated within Hurst Narrows.

The Shingles Bank was dredged in 1996 to provide recharge material for Hurst Spit. If such operations were to significantly reduce crest levels of Shingles Bank, they could adversely affect its wave refraction and dissipation function, such that this frontage would experience increasing wave energy. Shingles Bank is believed to be fed by sediments drifting from Christchurch Bay and along Hurst Spit and into Hurst Narrows. It therefore could be sensitive to the management practices in Christchurch Bay that have significantly reduced drift inputs to Hurst Spit. Although there is some evidence of historical crest lowering, a clear trend has yet to be established.

Seawalls, promenades and cliff drainage schemes have been constructed to stabilise the shoreline in Totland Bay and southern Colwell Bay. The prevention of local sediment inputs from the formerly eroding local cliffs is thought to have contributed to the falling beach levels observed over the past century.

Shoreline Movement:
Much of the north-west Wight coast is subject to active erosion, but its morphology varies spatially from simple high-angle cliffs, as at Colwell Bay, to compound slopes with multiple scarps and intervening degradation zones, e.g. Headon Hill. This is principally related to the mechanisms of mass movement and slope failure.

The type and rate of coastal slope retreat is controlled by the geology and hydrogeology of outcropping strata, and antecedent topography (height of the coastal slope), thus promoting slope failure through various slide and slip mechanisms (Hutchinson and Bromhead, 2002). All these factors vary spatially, so rates of retreat and volumes and grades of sediment input are also non-constant. Reports of past coastal erosion and landsliding reveal similar rates of activity and landform development to the present day situation (Norman, 1887; White, 1921; Colenutt, 1938; Moorman, 1939). Thus, it is likely that this coast has retreated throughout much of the late-Holocene period following the establishment of interconnection between the West Solent and Christchurch Bay. Evidence of this is provided by recognition of an ancient landslide deposit, extending up to 100m offshore, from a foreshore lobe of boulders off Brickfield Farm (Munt and Burke, 1987).

This frontage is still adjusting in response to: (i) breaching of the former Chalk ridge extending between the Isle of Wight and Purbeck; and (ii) breaching of the West Solent that resulted in generation of strong tidal currents close inshore. Consequently, a tendency is likely for continued erosion.

Future increases in rates of sea-level rise and winter rainfall would accelerate the landsliding of currently active cliffs between Alum Bay and Fort Victoria (Halcrow Maritime et al, 2001). Increased supply of sediments to the shore would be likely to occur as a result.

C1.7.1 Local Scale: The Needles to Alum Bay

Interactions:
North-facing, near-vertical Chalk sea cliffs developed by erosion of the mainland-facing extremity of the Purbeck–Needles–Culver Chalk ridge. The cliffs are fronted by variable accumulations of Chalk debris according to recent cliff-falls, but otherwise descend directly to deep water. The cliffs adopt a simple linear form and fail mainly by rock falls following oversteepening of the profile by toe erosion. Infrequent larger failures can result in several metres of retreat within single events. Flint nodules within the cliffs are released by erosion and supplied to the beach in Alum Bay, but otherwise most cliff erosion products are removed in suspension by wave action.

The Needles headland exerts an important control on wider shoreline evolution, affording shelter from dominant south-westerly waves to the frontage between the Needles and Cliff End, and also to Hurst Spit on the mainland. This headland also controls the direction of tidal flows exiting from Hurst Narrows such that it influences the configuration of seaward parts of the Shingles Bank.

The northern face of the Chalk ridge runs from the Needles to Alum Bay. The Chalk is significantly more resistant than other geological units outcropping further northeast but is nevertheless subject to erosion, albeit at slow mean rates in the order of 0.1m/yr (May, 1966; Halcrow, 1997; Posford Duvivier, 1999), although this is likely to increase in the future due to sea level rise and the extreme exposure of the headland. It should be noted that the recession process is episodic with major cliff falls and long intervening periods of little activity. Erosion takes place by basal undercutting followed by periodic localised falls that generate temporary accumulations of scree at the cliff toe. The cliff face then retreats very slowly by sub-aerial processes until marine erosion removes the debris at the toe and another cycle of undercutting can begin. Several large falls have occurred in recent decades causing localised recession of up to 10m within single events. The significance of the Chalk is that it contains insitu flint nodule bands, which are released as irregular gravels that become abraded to form beach pebbles. However due to the short frontage and modest retreat rate the overall supply is quite small. An estimated shoreface erosion rate of 3mm/yr, combined with the above recession value, would yield approximately $100m^3$/yr of coarse flint debris (Posford Duvivier, 1999). The relative absence of other durable lithologies in the cliffs between the Needles and Warden Point make them the most important gravel source for local beaches (Lewis and Duvivier 1962, 1973), especially in Alum Bay.

Results of the Strategic Regional Coastal Monitoring Programme (unit IW43):
The Southeast Strategic Regional Coastal Monitoring Programme does not cover this stretch of coastline. (Channel Coastal Observatory, 2009).

Shoreline Movement:
Relatively low recession rates of the cliffs are typical due to their sheltered north-facing orientation. It means that fallen debris can persist for a relatively long period as a protective apron thereby reducing opportunities for basal erosion of in situ strata.

Predictions of Shoreline Evolution:
Futurecoast (2002) estimated that without defence cliff recession would be likely to continue at, or close to, historical rates with the small quantities of flints eroded from these cliffs comprising the main inputs of fresh gravels to the Alum Bay beach.

C1.7.2 Local Scale: Alum Bay to Headon Warren

Interactions:
Alum Bay is a west-facing bay cut into soft Eocene sand and clay sediments. The geological strata dip steeply northward and rest against the Chalk. Composed of interbedded cycles of clay, silt and sand the cliffs form generally steep profiles that erode readily by rock fall, gullying, translational slides and mudsliding (within the clayey areas, especially the Reading Clay). A steep and relatively narrow shingle beach provides partial protection at the cliff toe.

In the south of Alum Bay, Reading Beds and London Clay dip steeply (75 degrees to 85 degrees), but the outcrops of the Bracklesham and Barton Groups are wider because of a rapid reduction in dip angles as the Isle of Wight monocline fold levels out northwards. All strata in Alum Bay are soft and easily eroded, comprising clays, sandstones and occasional grit and pebble horizons. The near vertically inclined strata in the south of the bay are primarily sandy and form relatively steep simple cliffs that fail by rockfall. Exceptions are the Reading and London Clay outcrops immediately north of the Chalk where mudslides and a wider less steep degrading coastal slope has formed. These materials are supplied to the foreshore by cliff falls, flows and mudslides (Hutchinson, 1965; Hydraulics Research, 1977b) and gulleying (Gifford and Partners, 1994).

Northward of Alum Bay, at Headon Warren, the topography rises considerably and a series of complex landslides and partially active scarps has formed on the coastal slopes. Cliffs are composed of gently northward dipping strata outcropping on the north-facing coast in a near-horizontal interbedded sequence of clays, sands and thin limestones. Weakly resistant Barton Clay and Sands outcrop at beach level so that the cliff toe is sensitive to marine erosion and overall recession rates are rapid. A wide multiple bench and scarp morphology has developed in which thin limestones define the in situ surfaces of benches that are covered by overburdens of landslide debris derived from degradation upslope. Failures occur both by mudsliding over the benches and periodic deep-seated failures of backing scarps. The soft limestones are of significance as they break down into boulders that afford some short-term protection to the cliff toes and have resulted in emergence of Hatherwood Point as a local headland.

Recession of these high cliffs provides considerable quantities of sand and clay to the shoreline, the majority of which is removed seaward by waves and tidal currents. The limestone boulder aprons at the shoreline significantly interfere with drift, although it is thought that some sands and gravels drift north-eastwards into Totland Bay.

Northwards, alternating sands clays and limestones form units of differing resistance and permeability generating deeper seated landslides and giving to a wide degradation zone incorporating benches and scarps towards and around Hatherwood Point on the western flanks of Headon Hill. Headon Hill rises to 120m and is underlain by Oligocene age Headon Beds, Osborne Beds, Bembridge Limestone, Bembridge Marls and a thin cap of Pleistocene Plateau Gravels. The varying resistance and permeability of these strata have led to development of a complex coastal slope, with mudsliding over a series of partially concealed scarps and both translational and deep seated failures, especially towards the cliff top (Hutchinson, 1965, 1983, Hutchinson and Bromhead, 2002). The cliff top and toe environments are partially ‘decoupled’ by the interposition of the degradation zone.

A wide range of sediment grades is supplied to the shore by these processes. Little quantitative work has been undertaken, but analysis of the lithology of Headon Beds yielded a composition of 20% sand, 20% limestone and 60% clay (Lewis and Duvivier 1973). The other beds are predominantly clays and sands with a major limestone unit and small quantities of gravel from the superficial drift deposits. The limestones are of significance for they break down into joint-controlled boulders and thus provide some protection to the toe of the coastal slope (Hydraulics Research 1977b). There has been no quantitative estimation of their residence time, but this is probably limited due to the relatively low durability of these limestones.

The remainder of the cliff input comprises fine sands, silts and clays that are susceptible to rapid suspended transport offshore. Only coarse sands, gravel and limestones can contribute to beach volume in the long-term and the potential availability of these materials in the cliffs is limited. Posford Duvivier (1999) conclude that the 250m wide and 10m deep shoreface is scoured to a depth of between 14 and 44mm/yr, yielding 15,800m^3/yr of fine sediment. Most of this is removed offshore by suspended transport.

Results of the Strategic Regional Coastal Monitoring Programme
Alum Bay is surveyed by the monitoring programme but results are currently not available for this area.

Shoreline Movement:
A major phase of landslide activity produced rapid cliff top or scarp recession over the period 1909-75 at Headon Warren, thereafter the cliff top remained relatively static. Such events are episodic and are interspersed between prolonged inactive periods at the cliff top. During such periods activity is concentrated in lower parts of the coastal slope involving degradation of detached blocks as they are transported down to the shore. The overall result has been mean recession at relatively high rates over the last century: this is thought to be representative of the long term recession rate.

It should be noted that although the cliff toe has fluctuated in position, there has been little net retreat due to episodic seaward movement of landslide lobes.

Map comparisons covering the period 1868-1963 revealed long-term cliff retreat at Alum Bay and Headon Hill of between 0.2-0.5m/yr (May, 1966). Corresponding estimates by Halcrow (1997) for 1909-95 were 0.24m/yr for Alum Bay and 0.69m/yr for Headon Hill. Posford Duvivier (1997; 1999) give a rate of between 0.35 and 1.1m/yr for the sector between Widdick and Alum Bay Chines. Total erosion yield is calculated at 110,000m^3/yr of which 22,500m^3/yr is estimated to be sand, gravel and limestone boulders. It should be noted that the value for coarse materials is not based on field sampling and is rather uncertain, although 500m^3/yr is quoted for flint gravel from superficial deposits that cap the hill.

Predictions of Shoreline Evolution:

Futurecoast (2002) estimated that without defences the sea cliffs would continue to experience toe erosion, promoting conditions of instability. Consequently, the cliffs would continue to erode episodically through landsliding behaviour. Although at Headon Warren the upper cliff has been relatively stable over recent decades, it will become subjected to re-activation of landsliding in the longer-term future. This could potentially occur at some point within the next century, although the presence of a considerable volume of debris material from previous failures provides a degree of protection at the cliff toe.

C1.7.3 Local Scale: Headon Warren to Cliff End (Totland and Colwell Bays)

Interactions:

Two north-eastward facing embayments backed by eroding soft rock cliffs and occupied by narrow pocket beaches of sand and shingle. Warden Point, a local headland that is defined by the presence of resistant limestone foreshore reefs, separates the bays.

The cliffs of Totland and southern Colwell Bays would have eroded naturally and would have been similar in form to those of central Colwell Bay prior to their protection in the early 20th Century. The unprotected cliffs of central and northern Colwell Bay are composed of soft permeable strata overlying impermeable clays in a classic landslide-generating sequence. Rapid seepage erosion, simple landslides and occasional deeper-seated failures are the main recession mechanisms. A wider degradation zone and increased propensity for mudsliding is evident closer to Fort Albert.
Seawall and groyne defences dating from 1910 to 1925 are continuous around Totland Bay extending northwards to include the southern portion of Colwell Bay. Some sections of the cliffs above seawalls are artificially drained in Totland Bay and at Fort Albert.

Plate 24: Totland Bay, where cliff reactivations have slumped over the seawalls. July 2009

The cliffs of Totland and southern Colwell Bays presently form relatively steep, partly vegetated slopes following protection of their toes by defences. Although the intention has been to stabilise the cliffs, in many places this has not been achieved fully because significant landsliding has occurred within the slopes above the seawalls, resulting in some cliff top recession.

Plate 25: *Eroding coastal cliffs in the north of Colwell Bay. View from Colwell Bay (where the south of the bay is defended by a seawall) looking north-east to Fort Albert (Cliff End), June 2009.*

The major accumulation of Shingles Bank located 1 to 2km offshore strongly dissipates and refracts incoming waves from the south-west, west and north-west serving to moderate the shoreline wave climate. Sediments drifting to northern parts of Totland and Colwell Bays are believed to become entrained by strong tidal currents generated at Hurst Narrows and transported either into the West Solent, or seaward to the south-west.

Colwell Bay is characterised by rapidly eroding low clay cliffs (15-25m). Only the south-western (Warden point - Colwell Chine) and north eastern (Fort Albert) extremities exhibit relative stability where toe protection structures and artificial drainage have been installed progressively over the past 30 years. The cliffs are formed within the Headon Hill Formation being composed of a lower clayey Colwell Bay Member that is overlain by the sandy Linstone Chine Member. Permeable strata overlie impermeable clays in a classic landslide generating sequence. Rapid seepage erosion and occasional deeper-seated failures are the main recession mechanisms. A wider degradation zone and increased propensity for mudsliding is evident closer to Fort Albert and has prompted recent stabilisation measures (Posford Duvivier, 1989a).

Incoming north-eastward littoral drift is intercepted by groynes in central and southern Totland Bay, thus accounting for the greatest beach volumes in these parts (Barrett, 1985). The beach comprises a steep shingle upper and sandy lower profile. Comparisons of beach profiles measured in 1908 and 1961 between Widdick Chine and the pier (Lewis and Duvivier, 1962) have identified foreshore lowering of up to 1m that was attributed to dilapidation of the groynes (reconstructed 1993). Warden Point at the eastern extremity of Totland Bay is a natural headland resulting from outcrop of resistant limestone strata on the foreshore to form Warden Ledge. The prominence of the point has been accentuated by coast protection structures originally installed in the 19th century to protect Fort Warden. The foreshore narrowed and lowered significantly between 1886 and 1960, so that deep water now extends to the toes of the sea walls (Lewis and Duvivier, 1973; 1981; Barrett, 1985). New groynes were installed in 1960. Although the natural Warden Point headland would previously have influenced eastward littoral drift, it is probable that these human-induced coastal changes now completely prevent eastward drift to Colwell Bay (Lewis and Duvivier, 1981; Barrett, 1985). This frontage is therefore open to small sediment inputs from the south west, but free transport is hindered by groynes and prevented completely at Warden Point. Direct cliff inputs are prevented by protection structures. The Bay is therefore virtually an enclosed system and dependent upon management interventions to maintain stability.

Results of the Strategic Regional Coastal Monitoring Programme (units IW44 to IW47):
Accretion has been the dominant process over the long term between 2003 and 2009, with some localised areas of erosion, including significant erosion in the central section of Totland Bay and also in Colwell Bay to a lesser degree. (Channel Coastal Observatory, 2009).

Shoreline Movement:
Prior to protection, the cliffs of Totland and Colwell Bays retreated at relatively high rates. Protection almost completely halted recession, but an increasing tendency for instability and failures affecting the cliff top has been observed in recent decades. High recession rates have been recorded over recent decades in central-northern Colwell Bay where retreat of the unprotected cliffs remained extremely active. Beaches in both bays have suffered losses of sediment and lowering and narrowing over the past century.

Totland Bay has been subject to historical coast erosion and cliff-top recession has been measured at mean rates of 0.1-0.3m/yr (maximum 0.56m/yr) covering the period 1907-1961 (Lewis and Duvivier, 1962). A series of cliff falls and a major mudslide in 1960-61 prompted the extension and upgrading of the protection and stabilisation measures. Further improvements to the sea-wall, groynes and cliff drainage were completed in 1993. Seepage erosion within the interbedded clay/sand/limestone members of the Headon Hill Formation is nevertheless a continuing problem, especially to the north of the pier, where shallow rotational failures are over-riding the back of sea defences and destroying slope drainage measures. Rapid recession presently occurring within similar unprotected materials in neighbouring Colwell Bay is a useful analogue of the behaviour that might be expected should the protection fail or be removed. There are no longer any freely eroding cliffs within the bay and no direct sediment inputs to the beaches are possible (Lewis and Duvivier, 1973; Posford Duvivier, 1989a).

Various mean long-term recession rates at Colwell Bay of between 0.4 and 0.6m/yr (Hutchinson, 1965; Hydraulics Research, 1977a; Lewis and Duvivier, 1981, 1986; Barrett, 1985; Posford Duvivier, 1989a) have been quoted for periods covering the past 100 years. Slight differences result from differing measurement periods, but these values indicate consistently rapid retreat. Acceleration of retreat rates to 0.5-1.0m/yr (maximum 2m/yr) have been recorded for the period 1970-85 around Brambles Chine (Lewis and Duvivier, 1986; Posford Duvivier, 1989a). It is uncertain whether such behaviour represents natural short term variation within a stable long term recession cycle, or whether it might be a specific response to altered conditions e.g. increasing exposure of the toe to marine erosion. The eroding cliffs yield sands, clays and occasional soft limestones. Much of their material inputs are lost offshore and do not contribute to local beach volumes.

Predictions of Shoreline Evolution:
Futurecoast (2002) estimated that without defences the sea cliffs would continue to experience toe erosion, promoting conditions of instability: a process exacerbated by generally declining beach levels. Consequently, the stabilised cliffs would re-activate rapidly and the presently active cliffs would continue to erode episodically through landsliding behaviour. Increases in sediment supply to the foreshore would result, but this is unlikely to enhance beach volumes significantly because

most of the cliff materials are sand and clay and mechanisms exist for rapid removal seaward of these sediment grades.

With present management practices existing defences will reduce the frequency of landsliding events within the backing sea cliffs, but are unlikely to completely eliminate instability where high groundwater levels are a factor. Periodic slope failures will therefore still occur. The fronting beaches will continue to narrow along defended frontages resulting in increasing exposure of defences to wave energy. In combination, these potentially increasing stresses from landward and seaward could significantly reduce stability of the structural defences and consequently trigger further landslides within the sea cliffs, leading to cliff top retreat and increasing damage to the structures. It is likely that shoreline stability cannot be sustained at these locations with current management practices so that significantly improved defences, or an alternative management approach would be required in the short to medium term (20 to 50 years).

Unprotected parts of this frontage may erode more rapidly as they will be further starved of sediments due to the updrift defences in Totland and southern Colwell Bays. The enhanced sediment supply arising would only partly enhance beach volumes because most of the cliff materials are sand and clay and mechanisms exist for rapid removal seaward of these sediment grades.

C1.8 Large Scale: Cliff End (Fort Albert) to Old Castle Point

Interactions:

Between Fort Albert and Cowes, the coast is sheltered from the open sea and incident waves generated in the West Solent are fetch-limited and generally are less than 1m in height. Dyer (1971) has shown that ebb and flood tidal streams have sinuous courses in the West Solent; thus the relative effectiveness of tidal currents varies spatially, with strongest flows adjacent to meander bends. Locally strong currents are generated by exchange of tidal waters at the mouths of the Western Yar, Newtown Harbour and Medina Estuaries.

The coast has been formed by erosion into gently north eastward dipping, soft clayey, late Eocene and early Oligocene strata of the Solent Group (Insole and Daley, 1985). Mudslides are an especially prevalent slope degradation mechanism within these strata. The coastal topography is generally undulating with high points at Bouldnor Cliff (61m), Burnt Wood (57m) and Gurnard Cliff (45m) where major landslide systems have developed. Many of the slides, particularly at Boulder Cliff have probably involved base failure (Hutchinson, 1965). Rapid tidal currents flow through the Western Solent channel. The deep-water channel is relatively close to the Isle of Wight coast and in combination with wave action its currents assist in removing fine debris from cliff toes, thereby allowing conditions of instability to continue.

The overall sediment input from the eroding cliffs is considerable, but the fates of these materials are poorly understood. Most of the erosion products are transported offshore and do not contribute to protect local beaches. It may be that the majority are transported away eastwards by the residual flow in the channel, although a series of re-circulating eddies identified within the channel would also have the potential to deliver materials to the mainland shores opposite. It is likely that they are deposited within more sheltered regions such as in Southampton Water and the harbours of the Eastern Solent. This conclusion is supported by studies of clay mineral compositions (Algan et al., 1994) that suggest that fluvially derived clays are greatly diluted in such areas by incoming marine clays consistent with those produced by erosion of Oligocene strata around the Solent. The high eroding cliffs of this unit appear to be the most important sources of fresh fine grained sediment within the Solent. Coarser sediments drift predominantly eastwards along the foreshore and become concentrated in double spits at estuaries and within embayments defined by minor headlands. Wide, low gradient mixed sediment inter-tidal zones are characteristic. Eastward of Gurnard, marine erosion is generally less active and many of the coastal slopes above the shoreline retain relict landslides.

Rivers on the north coast of the Island are small due to limited catchments and therefore contribute negligible sediment to the coast. Rendel Geotechnics and the University of Portsmouth (1996) estimate that all of the rivers discharging sediment to this coastline potentially contribute some 2,450 tonnes/yr of suspended load and 740 tonnes/yr of bedload material. However, various barriers and regulation of flows reduce the delivery volume very substantially. The River Medina has a mean flow of $0.5m^3s$ and this comprises only 0.67% of the tidal volume entering at the mouth during a corresponding tidal period (Webber 1978). Thus, marine sediment input to estuarine mudflats and saltmarshes must be the dominant source of supply and fluvial sources are considered to be relatively insignificant.

The estuaries and creeks within this frontage exert an influence on the shoreline, particularly as their inlets generate strong tidal currents that intercept shoreline drift and most posses double spits at their mouths which store sand and gravel that could otherwise contribute to foreshore stocks. The configurations of spits at estuary entrances do not appear stable due to shortages of sediment such that there is a tendency for these features to be driven into each estuary, possibly in association with breaching events. Stable ebb-tidal deltas do not appear to have formed seaward of inlets in spite of their ebb-dominance. The latter is possibly a function of past dredging although this is not known at Newtown Harbour. An alternative explanation is that the rapid shore-parallel tidal currents of the West Solent remove sediments flushed out of inlets such that they become incorporated into channel (e.g. Solent Bank) rather than delta deposits. Due to the absence of sheltering tidal deltas and the likely migration of spits, waves would tend to penetrate increasingly into the estuaries, potentially accelerating the erosion of saltmarshes and intertidal foreshores within.

Weak littoral drift generally operates north eastward along the whole coast with the exception of local reversals on the eastern entrances to inlets. Littoral drift is from both sides towards the inlets of Newtown Harbour, the Western Yar and the Medina. The eastern margins of such inlets are especially depleted and cause coastal defence problems.

The shoreline exhibits a varied and complex sediment transport pattern due to both coastal configuration and hydraulic regime. Transport sub-cells on the open coast are separated by headlands, and each of the three estuaries has distinct, albeit small scale, circulation patterns (Halcrow, 1997). Tidal regimes at the mouths of estuaries and inlets in the West Solent are characterised by a rapid short duration ebb current and a more pronged lower velocity flood (MacMillan, 1955, 1956; Webber 1969, 1980; Price and Townend, 2000). This regime favours net input of suspended sediments into inlets, so that tributary estuaries and creeks flanking the West Solent are subject to progressive infilling and are flanked by mudflats and accreting saltmarshes.

Most of the coast is natural but there has been localised shoreline stabilisation by seawalls at Yarmouth and Cowes, together with various ad hoc interventions at some intervening locations. Norton Spit at the entrance to the Western Yar has been stabilised and its sediments impounded such that natural adjustments of this feature are no longer possible. Solent Bank, a major gravel and sand accumulation within the Western Solent, has been denuded of sediment by aggregate dredging over the period 1950-1990. This intervention has resulted in removal of around 10 million m^3 of material, with consequent lowering of the bank by over three metres. The impacts of these actions upon the shoreline of this frontage are difficult to determine although wave shoaling and refraction could have been affected (primarily at low tide). The entrances to the Western Yar and Medina estuaries have been dredged on several occasions to maintain navigable channels for car ferries. Dredging at estuary entrances and within the main West Solent channel represents a net output from the sediment budget and may result in loss of sediments that might otherwise be transported to shorelines. Furthermore, operations close inshore can cause drawdown that could contribute to the steepening of local inter-tidal zones.

Limited beach nourishment has been undertaken at several locations in response to falling beach levels so as to temporarily prevent undermining of coast protection structures and reduce the historical trend of inter-tidal narrowing (Halcrow, 1997). In all cases, volumes are small and designs governed by the perception of critical losses rather than through and systematic long term monitoring of beach profiles and volumes. The main sites are:

- Yarmouth Pier to Yarmouth Common: Small scale gravel replenishment has been introduced in response to falling beach levels east of Fort Victoria (Hydraulics Research, 1977a).
- Norton Spit: Stabilisation of the spit by groynes and revetments and ad hoc reinstatement of beaches by gravel nourishment/replenishment (Lewis and Duvivier, 1981; Barrett, 1985; Posford Duvivier, 1989a) has been undertaken over the past 25 years.
- Fort Victoria: There has been co-ordinated shingle replenishment and groyne construction immediately east of Fort Victoria, to prevent shoreline recession affecting the coastal access road (Lewis and Duvivier, 1981; Barrett, 1985; Posford Duvivier, 1989a). The source materials have been predominantly rounded pebbles from Solent Bank, and other marine sources.
- Old Castle Point to Shrape Breakwater, Cowes Harbour entrance.

Shoreline Movement:
Inundation of the previous Solent River system occurred during the Holocene Transgression so as to produce an estuarine channel open at each end (the Solent) of which this unit forms the

southern margin. Holocene inundation is believed to have proceeded up the eastern Solent before erosion to the west was sufficient to permit a connection with Christchurch Bay. Tidal currents were then transformed from very weak to very strong causing scour and enlargement of the Western Solent.

In marked contrast to the sedimentation dominated northern Solent shores, the coast of this unit has undoubtedly been subject to long term retreat causing the Western Solent to widen and supplying much sediment. Evidence is provided by recognition of an ancient landslide deposit extending up to 100m offshore on a foreshore lobe off Brickfield Farm (Munt and Burke, 1987).

This frontage is characterised by the occupation/re-occupation by marine inundation and erosion of coastal slopes formed in soft Palaeocene, Eocene and Oligocene materials and mantled by relict landslides. It is inherently sensitive to erosion, even when the driving forces are relatively weak. The general evolution trend in future years would therefore be for continued erosion of presently active cliffs together with progressive re-activations of relict coastal slopes.

Potential exists for a breach through the foreshore just east of Yarmouth, enabling the creation of a small tidal inlet at Thorley Brook. Shoreline sediments could become entrained by tidal currents generated at the new inlet and become flushed seaward and lost to the tidal flows of the West Solent.

C1.8.1 Local Scale: Cliff End to Yarmouth, including the Western Yar Estuary

Interactions:
Eroding soft rock cliffs and foreshore debris lobes are continuous from Fort Albert to Fort Victoria. The clayey materials of the cliffs degrade by mudsliding and simple translational slides, creating a shallow actively retreating coastal slope. Strong tidal currents are effective in removing clayey debris that accumulates at the cliff toe. The shore is drift-aligned with respect to dominant waves approaching from the west. The coastal slope is thickly vegetated and complex in morphology, making the cliff top difficult to discern although, long term toe erosion of a relatively high rate has been recorded from comparisons of historic maps.

An inactive or relict low coastal slope extends from Fort Victoria (Sconce Point) to Norton. Its beaches comprise a narrow strip of sand and gravel above a narrow muddy foreshore. The coastal slope is protected by defences so that the only historical trend has been for narrowing of the foreshore.

Shore stabilisation by seawalls and short groynes is present from Sconce Point to the eastern margin of Yarmouth including Norton Spit. Sconce Point itself has been stabilised by the construction of Fort Victoria. A breakwater has been built eastward from the tip of Norton Spit to train and protect Yarmouth Harbour and the Western Yar estuary entrance. Dredging of Yarmouth Harbour entrance has been undertaken for navigation purposes and in 2009 a trial of beneficial use moved the dredged shingle to the north of the breakwater in order to keep the sediment in the system and help to defend the breakwater structure.


Plate 26: Eroding coastal slopes south of Fort Victoria, June 2009

The geology of the coastal slope is obscured by vegetation and disturbed by landsliding, but White 1921) and geological maps indicate Headon and Osborne beds overlain by Bembridge Limestone and Marls, so cliff erosion input must be predominantly clays with some sands and soft limestones (Halcrow, 1997). Posford Duvivier (1997) estimate an annual cliff erosion yield of 5,000m^3. It is reported that small quantities of gravel are also supplied (Lewis and Duvivier, 1973, 1981). This coast is more sheltered from wave erosion than areas to the west, but is swept by rapid tidal currents of Hurst Narrows so relatively little beach material accumulates. The shoreface between Fort Albert and Fort Victoria is some 250m wide and 20m deep; given an estimated 0.5m/yr erosion rate, the yield of fine sediment is approximately 7,000m^3/yr (Posford Duvivier, 1999). For the shoreface between Fort Victoria and Bouldnor, the respective values may be in the order of 1mm/yr and 3,000m^3/yr.

Sediment drift operates from west to east, but is weak due to limited fetches and shortages of shoreline sediments. Small to moderate quantities of fine sediments yielded by erosion of cliffs between Cliff End and Sconce Point are likely to be transported eastwards in suspension and potentially be available for transport into the Western Yar estuary. Net eastward drift of gravel between Fort Albert and Fort Victoria is indicated by accumulation against sea walls at Fort Victoria (Lewis and Duvivier 1973, 1981), although the morphological evidence is only partial. There is a wide sandy foreshore, but corresponding sand accumulation is absent at Fort Victoria (Lewis and Duvivier, 1973). It is therefore possible that sand is progressively lost offshore to tidal currents and is transported eastward (Halcrow, 1997). Alternatively, there may be no net drift of sand, so that it becomes evenly distributed along the foreshore. Coast protection structures severely restrict drift transport at Fort Victoria, but it has been suggested that limited eastwards movement of coarse sediment was possible around the fort before it was halted by construction of two groynes over the period 1870-73 (Lewis and Duvivier, 1973). This coastal segment has therefore functioned as a self-contained unit since the pathway around Fort Victoria was denied.

From Fort Victoria to Yarmouth Harbour entrance the drift direction is presumed to be eastward, but beach levels are low and transported volumes are extremely limited (Lewis and Duvivier, 1973). Nourishment programmes have supplied beach material immediately east of Fort Victoria and at Norton Spit, but groynes have been constructed here to retain sediment and thus drift quantities are small or non-existent (Lewis and Duvivier, 1981; Barrett, 1985; Posford Duvivier, 1989a; Halcrow, 1997). The alignment of Norton Spit indicates that historically net drift has been eastward (Hydraulics Research, 1977a; Dyer, 1980; McInnes, 1994), although inspection of sediment distribution against groynes fails to reveal a preferred drift direction.

The Western Yar Estuary is protected by a narrow eastward trending sand and gravel spit at Norton. The Western Yar Estuary runs inland 3km almost due south from Yarmouth towards Freshwater. Although Norton Spit has in the past grown across the Western Yar estuary mouth it has retreated landward over the past century and is now stabilised. Norton Spit, a popular local amenity area, is stabilised by old railway line and sleepers that need regular replacement. The spit is an important component of the SSSI and is being increasingly inundated from the inlet to the south. The dunes are trying to migrate south and the beach is building and will soon overtop the wooden stabilisation structure that also protects the path. The town of Yarmouth has been built upon a shorter counterpart spit on the low-lying eastern bank and the spit provides protection from wave attack to the Western Yar outer estuary. There is a narrow intertidal foreshore and very little beach material in front of defences. The foreshore at Yarmouth has lowered and narrowed in front of seawall defences. The low-lying valley of Thorley Brook runs parallel to the shore a few tens of metres inland of the shoreline to the immediate west of the town. Further to the west, is a shore frontage of low relict cliffs protected by a seawall. At the Freshwater causeway there are tidal flaps that mark the southern tidal limit of the estuary and protect Afton Marsh from tidal flooding.

Morphology of the mouth of the Western Yar Estuary indicates littoral drift towards the inlet on both sides (Dyer 1980; Halcrow, 1997). This suggests a weak net westward drift over the sector to the immediate east of the inlet mouth, which conflicts with the generally accepted eastward drift direction on this coast as a whole, but is confirmed by small sediment accumulations against the eastern sides of groynes. In spite of groyne construction and some small replenishments, there is a history of low beach levels along this frontage (Hydraulics Research, 1977a; Lewis and Duvivier, 1981), so it is likely that actual drift is currently nil. The littoral transport divergence thus implied is difficult to locate precisely because of the small volume and rate of sediment movement. As it may not operate for fine-grained sediments, it is therefore a partial, and probably transient, boundary. This interpretation is based on limited evidence and is therefore of low reliability and requires verification.

The coastal areas of the Western Yar Estuary are subject to rapid tidal currents and open sea waves which enter Hurst Narrows. Dominant ebb currents in the Western Solent cause seaward flushing of coarse bedloads and input of suspended sediments into the Yar estuary, most likely derived from clay cliff erosion in the immediate vicinity between Bouldnor and Newtown (Western Yar Estuary Management Committee, 2004). Fluvial transport from the Western Yar catchment is negligible with predominantly marine clays having partially infilled the estuary.

A sequence of dominantly fine-grained estuarine sediments, up to 14m thick, has been described for the Western Yar Estuary (Devoy, 1987; Tomalin, 2000) representing pulsed (unsteady) sediment input over the past 7000 years of sea-level transgression. This may have a marine source, but no mineralogical analysis has been undertaken to confirm this. Maintenance dredging has also been undertaken in response to slow but progressive siltation in Yarmouth Harbour (MacMillan, 1955; Western Yar Liaison Committee, 1998), although in this case the tidal prism, which has been reduced by piecemeal land claim since medieval times, provides a possible explanation.

The Yarmouth Estuary tidal inlet is a natural littoral transport boundary, however the adjoining shores are so heavily stabilised that there is very little coarse material in transit that might be intercepted. The SCOPAC Sediment Transport Study (2004) concludes that the dominant flow in the Yar Estuary is during the ebb tide and it has been estimated that its sediment carrying potential is five times that of the flood (MacMillan, 1956; Price and Townend, 2000). No measurement of sediment transport has been undertaken to verify this statement. It is reported that sand can be transported into Yarmouth Harbour by strong northerly gales, but training of the ebb flow by breakwater structures is generally successful in flushing such material back offshore (MacMillan, 1956). Maintenance dredging of the harbour and approaches is carried out on a regular but small scale basis and comparison of hydrographic surveys have revealed that bed levels are relatively stable It is therefore concluded that the dominant flushing effect of the ebb current rapidly removes fine-grained sediments previously transported into the mouth (Western Yar Liaison Committee, 1998). In the past, significant quantities of sediment may have been transported across the mouth to create Norton Spit, but this is now impeded by groyne and breakwater systems either side of the harbour entrance.

Plate 27: The town of Yarmouth, at the head of the Western Yar Estuary (Yarmouth Harbour Commissioners).

Results of the Strategic Regional Coastal Monitoring Programme (units IW47 to IW50):
Much of the short term trends show little or no change in sediment volume between 2008-2009 with the exception of the far west of the unit which has undergone accretion. The longer term trend shows little or no change in beach area. However, there are isolated regions of accretion around the former pier and erosion to the west of this (see map below) (Channel Coastal Observatory, 2008).

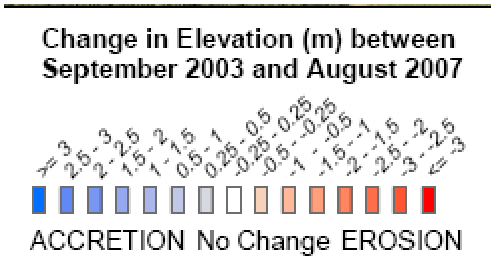

Figure 17: Topographic Difference Model for Norton (Fort Victoria) 2007-2003 (Channel Coastal Observatory, 2008).

Shoreline Movement:
Along the unprotected sections of this unit, the soft clays at the cliff toe appear to be eroded faster than the rate of supply of material from mudslides, thus some lower slopes are oversteepened and controlled by shallow failures (Halcrow, 1997). Serial map comparisons do not indicate any discernible cliff-top erosion, possibly due to the thickly vegetated and complex morphology of the upper slope (Lewis and Duvivier, 1973). Despite this, long-term toe erosion at 0.5m/yr has been calculated (Lewis and Duvivier, 1981; Posford Duvivier, 1989a, 1990b, 1997; Halcrow, 1997). It would appear that aggressive toe erosion is leading to progressive reactivation of relict landslides upslope, so that the scale of landsliding is likely to increase in future as the full slope becomes active.

Predictions of Shoreline Evolution:
Futurecoast (2002) estimated that without defences:

- The cliffs between Fort Albert and Sconce Point would continue to recede through mudsliding, with the fresh material derived largely from being transported offshore in suspension.
- From Sconce Point to Norton continuing foreshore erosion may in the long term cut into the relict coastal slope eventually triggering formation of low eroding cliffs over 30 to 50 years. This process is likely to be slow due to the low wave energy.
- Norton Spit is depleted and would be likely over the forthcoming 30 years to become subject to landward migration such that it would increasingly recurve into the estuary and possibly breach. This process may be slowed by sediment inputs released from updrift as recession processes within cliffs re-activate. However, the spit could migrate and breach before this potential sediment supply becomes fully active. Any breach in the spit could allow greater wave penetration into the Western Yar estuary.
- The Yarmouth shoreline is likely to retreat at slow to moderate rates as the foreshore is narrow and provides limited protection. Immediately east of Yarmouth there is the possibility that shore erosion over the forthcoming 50 to 100 years could cut through into the lowland valley of Thorley Brook to produce a small new tidal inlet. This could potentially link to the Western Yar estuary leaving the town of Yarmouth as an island.

With present management practices Futurecoast (2002) estimates that between Fort Albert and Sconce Point the unconstrained response described above will not be unduly affected. Where defences exist elsewhere, the upper shore would be held static by the structures, but slow rates of foreshore lowering and narrowing would continue due to sediment starvation. Breaches of Norton

Spit and Thorley Brook would therefore be prevented, but the defences themselves would gradually become increasingly exposed to wave action.

The Western Yar Estuary appears to be capable of continuing to accrete fine sediments and monitoring of the saltmarsh since 2004 has shown that it is relatively stable. The monitoring will continue as the saltmarsh may be sensitive to future climate change and sea-level rise unless vertical accretion can compensate (Halcrow Maritime et al, 2001).

C1.8.2 Local Scale: Bouldnor to Gurnard, including Newtown Estuary

Interactions:
Large quantities of primarily fine sediments are contributed to the West Solent by cliff erosion within this frontage. This constitutes the major direct input of fresh sediments to the Solent and may be of critical importance to its sediment budget and maintenance of intertidal features.

Cliff recession yields significant sediment volumes, but much is clay and silt so only a small proportion, estimated at 15% (Bray and Hooke, 1997), of total cliff input is stable on the beach. Posford Duvivier (1997) estimate a total annual sediment yield of 65,000m^3, of which less than 500m^3 is gravel. Some gravels are supplied from Pleistocene cliff-capping coarse deposits (Hydraulics Research, 1977a; Posford Duvivier, 1995; Halcrow, 1997) and Moorman (1939) reported gravel scree beneath the steep upper cliff. Mapping and sediment sampling of the gravel outcrops has not been undertaken so exact contributions remain unquantified although they could be significant on this low drift coast. The erodible shoreface materials may be scoured to a depth of 0.12m/yr, yielding some 23-25,000m^3/yr of fine sediment (Posford Duvivier, 1999), which is transported offshore as suspended load.

Map and field evidence indicates that cliff erosion supplies material from (i) the Bembridge and Osborne Beds; (ii) Plateau Gravels, which cap the high cliffs immediately south of Gurnard Ledge (White, 1921). The solid strata contribute predominantly clay sediments that are transported offshore but also some limestone boulders, which temporarily remain on the foreshore as boulder arcs that mark the seaward, limit of former mudslide surges. Posford Duvivier (1997; 1999) estimate a total sediment yield of 75,000m^3/yr for the sector between Newtown Harbour and central Gurnard Bay. Estimates suggest that less than 500m^3 is coarse material, although mapping and sampling of the gravel outcrops has not been undertaken so exact contributions remain unquantified, although they could be significant on this low drift coast. The rate of inter-tidal shoreface abrasion is calculated at between 4 and 24mm/yr (Posford Duvivier, 1999), providing a yield of rapidly removed suspended sediment of 2,500 to 14,000m^3/yr.

Other studies have revealed beach and associated nearshore changes which may indicate complex sediment transfers both on and offshore, involving possible bedload transfer of coarser sediment grades. Trott (2001) records late Iron Age and Roman artefacts that have accumulated on a gravel bank close to maximum low water at Bouldnor. As there is no evidence for the derivation of this material from cliff erosion, the tentative conclusion is that there is considerable mobility of coarse material in the inter-tidal zone. Aerial photographs also reveal various gravel bars and other morphological features within the intertidal zone that could be indicative of shoreward migration of gravel from channel deposits.

Cliffs developed within the predominantly clayey strata of the Bouldnor Formation (Solent Group) rise from beach level at Bouldnor village to 61m at Bouldnor Cliff and 35m at Hamstead Cliff before declining steadily east to the Newtown Harbour inlet. Dip is locally reversed (from NE to SW) due to the proximity of the Hampshire Basin syncline so that underlying Bembridge Marls and Bembridge Limestone rise to beach level in the north east. The coastal slope exhibits complex morphology and degrades by mudslides, relatively shallow multiple translational slides and infrequent deep-seated rotational slides (Moorman, 1939; Hutchinson, 1965; Bromhead, 1979). At

Bouldnor Cliff, morphology comprises a steep upper scarp with several embayments each feeding small mudslides, which move over a series of lithologically controlled terraces. Mudslides converge to form a major mudslide lobe that extends periodically across the foreshore during surging phases and suffers marine erosion thereafter. Similar landforms are developed at lesser scales throughout this unit. Air photos show the foreshore to be littered with old boulder arcs; the residue of previous mudslides. Mudslide movement is seasonal and controlled by precipitation, groundwater availability and enhanced porewater pressures generated by undrained loading at the head of the mudslide (Hutchinson and Bhandari, 1971; Bromhead, 1979). It is postulated that enhanced porewater pressures by undrained loading has greater effect on initiating a slide than toe erosion by marine processes (Bromhead, 1979). This could explain the continued instability and rapid mudsliding despite the limited wave energy available for toe erosion. The nature of landsliding varies spatially according to the properties of the geological unit at the toe of the cliff, especially the level of the resistant Bembridge units. At Bouldnor Cliff this resistant layer lies at 1-3m above mean sea-level and provides optimum conditions for mudsliding. To the west, the resistant layer is well below this level and the soft clays exposed at beach level are rapidly eroded at rates in excess of mudslide supply. The slope becomes oversteepened facilitating deep-seated failures. To the east, resistant strata rise well above beach level (as demonstrated by the prevalence of foreshore reefs) and protect the base of the slope from marine erosion so that recession is less rapid and mudslides are less well developed (Hutchinson, 1983).

The coast between Bouldnor and Newtown Harbour is characterised by sediment inputs from local coastal erosion. Clays are removed offshore in suspension, but sands and gravels forming narrow back beach sediment drift eastward to supply the western shingle spit (Hamstead Duver) at Newtown Estuary entrance. Eastward alignment of this spit provides clear evidence of long term eastward drift. Drift is not continuous along this unit, but is intercepted periodically by lobes of landslide debris that surge across the beach from the cliffs above. Obstructions are removed gradually by marine erosion so as to permit a long term drift. Air photos reveal sediment accumulations against the western side of such lobes with scour to the east, a combination indicative of eastward drift. Supply between Bouldnor and Newtown Harbour from updrift (westwards) is negligible and most beach sediment is derived from local cliff and foreshore erosion. Consequently, beaches are often little more than a patchy veneer of gravel and coarse sand overlying an erosional surface cut into substrate materials.

The Newtown Estuary occupies a low valley complex, with narrow twin gravel spits protecting diverging branches of the estuary behind, extending over 3km inland. An in-filled low valley also occurs further east within Thorness Bay, fronted by a gravel beach. The Newtown Estuary gravel entrance spits are exposed and evolving, the eastern spit overtopping at high tides. The estuary has very little development surrounding it, with large areas of the site owned and managed by the National Trust since 1965. Newtown Estuary is unique in the Solent in retaining a major concentration of the native S. maritima, and features eight nationally scarce species of flora and a diverse fauna including three nationally rare (red data book) species and 14 nationally scarce species (Gardiner et al, 2007).

The historical change and roll back of the spits since 1898 has been investigated by the BRANCH project (Gardiner et al, 2007) by mean high water analysis, which revealed that the average erosion rate along the frontage of the western spit was 0.6m/yr. Along the eastern spit average rollback of 0.62 m/yr occurred along the spit frontage between 1962 and 1995, with less change prior to this. The eastern spit has historically breached and the higher portions of the spit (in the east) are currently undergoing active slope erosion of fine sediments on the outer and inner faces. There is limited sediment supply to the spits and they are likely to continue to break down with sea level and allow increased wave penetration into the Estuary.

The SCOPAC Sediment Transport Study (2004) also examined the behaviour of the Newtown Spits. The western shingle spit (Hamstead Duver) at Newtown Estuary entrance has shown significant morphological variation according to analysis of maps and charts covering the period

1879-1973 (Hydraulics Research 1977a). Recession has been the dominant feature and it can be argued that this could be caused by variation in littoral drift sediment inputs. Drift could have reduced recently due to a variety of reasons: (i) increased coast protection and correspondingly reduced supply from the coast west of Yarmouth; (ii) landslide blockages of the foreshore between Bouldnor and Hamstead; (iii) variations in cliff activity and sediment yield. Other factors may also affect the spit such as sea-level rise, the tidal regime of the estuary (altered by flooding of a previously reclaimed area in 1954) and possible onshore-offshore sediment transfers involving gravel banks in the west Solent (Hydraulics Research, 1977a; 1981).

The eastern shingle spit at Newtown entrance is aligned westward from the solid coast which indicates net westward drift (Dyer, 1980; Lewis and Duvivier, 1981), and is overtopped on high-tides. Potential underlying geological strata may help to retain the curved plan form of the coast. Westward drift is probably a local phenomenon associated with the inlet entrance with a littoral drift divide located approximately opposite Brickfield Farm. The short unit length and fine sediment inputs of adjoining cliffs mean that drift rates are probably low due to shortages of material. Indeed, the spit has a history of depletion (perhaps a result of the proximity of the drift divide) and recedes landwards over saltmarshes that are then exposed again in the seaward face and eroded. Timber groynes and revetments have been installed in past attempts to stabilise the spit. Any breaches in the spit would widen the inlet and alter the harbour's tidal regime, including the maximum tidal levels around its perimeter.

At Newtown Harbour it is reported that sediment mobility is greatest at the harbour entrance, with fine silt and clay accumulating as mudflats and marsh sediments within the inner estuary (Hodgson, 1962; Hydraulics Research, 1981; Tubbs, 1999). The bed of the main channel is composed of coarse pebbles and ebb tidal currents exceeding $0.5ms^{-1}$ have been recorded (Howard, Moore and Dixon, 1988). As a result, offshore flushing of coarse sediments may occur, fed by gravel driven by wave action along the spits flanking the harbour entrance. Although this has not been experimentally proven, the opposed alignment of these spits suggests drift convergence at the harbour mouth that would feed the losses seaward (Lewis and Duvivier, 1981). Previous research has not reported the existence of an ebb tidal delta, although the Newtown Gravel Banks surveyed by Hydraulics Research (1977a and 1981) may perform this function. It is uncertain whether coarse sediments are recycled back shorewards from these banks, although several distinctive bar-like features can be observed within the intertidal zone.

The SCOPAC Sediment Transport Study (2004) also reports that a comparison of a time series for the twin gravel spits that flank the harbour entrance from both OS maps and Admiralty hydrographic charts revealed significant changes in morphology, as well as shoreline retreat, over the period 1879-1951, over which time the adjoining shorelines also evolved. The sediment source for periods of spit growth was attributed to net onshore supply, involving complex sediment circulation between Solent Bank, Newtown Gravel Banks and Newtown Spits (Hydraulics Research 1977a). Possible transport mechanisms and pathways are poorly understood because a phase of spit recession between 1914-1951 occurred at the same time as major growth of Solent Bank. Significantly increased bed levels over Newtown Gravel Beds between 1963 and 1973 accompanied diminution of the size of Solent Bank (Hydraulics Research 1977a). This evidence suggests the following:

- Significant transfers and/or exchanges of sediment may occur between Solent Bank, inshore gravel banks and onshore spits.
- Morphological changes suggest possible onshore transport from Solent Bank and offshore transport from the shingle spits. Both pathways apparently supply the Newtown Gravel Beds, although whether they can operate nearly simultaneously has not been researched.

Interpretation of this information is uncertain because little reliable evidence for the transport mechanisms is available and it is not obvious how these changes relate to the recirculating eddy of tidal sediment transport identified by Dyer (1971). Information on sediment transport in this area is therefore of low reliability, with regard to directions and pathways, but of somewhat higher reliability as an indicator of ongoing onshore-offshore sediment exchange (SCOPAC, 2004)

A proportion of the sediment stored in inter-tidal flats and saltmarsh is presumed to derive from input by the small rivers discharging into Newtown Harbour. Most input however, is likely to have been transported by the flood tide, and originate from cliff, platform and shoreface erosion of suspended sediment from the adjacent open coastline. The tidal prism of the harbour has not been constant, as a result of piecemeal land claim in the nineteenth and twentieth centuries, and the submergence of a previously reclaimed area resulting from a storm surge in 1954 (Halcrow, 1997).

Saltmarsh erosion occurs in the harbour (Howard et al, 1988; Raybould, et al., 2000; Bray and Cottle, 2003) and the strong ebb current may remove silt released by this process. Spartina anglica 'dieback' can be traced to 1935 in the Solent, but its role in trapping and subsequently releasing sediment has not been researched at this site (Tubbs, 1999). In comparison to most other Solent estuaries, Spartina loss has been limited and some areas remain accreting. In Newtown Harbour S. anglica only appeared in 1932 and has spread slowly. This site is unique in the Solent in retaining a major concentration of the native S. maritima, especially around the area of Walter's Copse. Total area of all types of saltmarsh has been estimated as being 120 ha. Die-back is not reported as occurring within Newtown Harbour, indeed slow colonisation by S. anglica appears still to be continuing. (SCOPAC, 2004)

Plate 28: Newtown Estuary, view looking east along the Eastern spit, showing the furthest section of the Eastern Spit partially submerged/overwashed at high tide. November 2009.

East of Newtown Harbour there are simple low cliffs developed in clays of the Bouldnor Formation. Abundant landslide debris and fallen trees on the beach indicate rapid recession. There is a mixed, mud, sand and boulder foreshore that becomes increasingly wide to the east of Newtown.

The foreshore is interrupted periodically by lobes of landslide debris that surge across the beach from the cliffs above.

Topography rises rapidly eastwards to a height of 57m near Burnt Wood with corresponding change in cliff landslide activity. There is a wide degradation zone characterised by shallow multiple translational landsliding and transport of debris in mudslides that form lobes across the foreshore (May, 1966; Hutchinson, 1965). The lower part of the coastal slope at Burnt Wood is composed of the more resistant Bembridge units, while the upper slopes are composed of clays (Bouldnor Formation) and capped by plateau gravels. Retreat is generally less rapid here, probably due to the outcrop of resistant Bembridge strata slightly above beach level. Mean cliff top retreat of 0.36m/yr was measured from map comparisons covering the period 1868-1963 (May, 1966). Material supplied is predominantly clay, with some gravels. Erosion of insitu gravel-bearing deposits exposed on the foreshore also contributes (Lewis and Duvivier, 1981).

The cliffs between the Thorness and Gurnard rise to 45m and comprise clays and marls of the Bouldnor formation overlying Bembridge limestone at beach level. The limestones outcrop as foreshore reefs to form the protective Gurnard Ledge. There is much evidence of coast erosion with debris accumulations on the foreshore being fed with material from mudslides and shallow translational slides within a cliff degradation zone (May 1966; Hydraulics Research 1977a, 1981). This site is un-researched and few other details are available in the literature. The partly vegetated appearance of the landslide degradation zones suggests that recession may be slower than at corresponding sites to the west, a possible result of the additional protection afforded by Gurnard Ledge. The ledges themselves have also receded by up to 0.6m/yr over the period 1862 to 1938 which suggests that their protective capacity is limited (Hydraulics Research, 1977a). Cliff erosion supplies predominantly clay sediments, but also some limestone boulders which temporarily remain on the foreshore.

Net north-eastward drift between Brickfield Farm and Gurnard is indicated by eastward deflection of stream mouths by small, mixed sediment bars at Thorness and Gurnard (Hydraulics Research, 1977a; Dyer, 1980; Posford Duvivier, 2000; Tubbs, 1999). Drift is fed by local cliff erosion, with only a small proportion of sediment yield retained by beaches in front of cliffs on this frontage. A considerable quantity of gravel is stored on the upper and mid foreshore within Thorness Bay, where it has formed a barrier across the stream and its low marshy valley. It is uncertain whether all of this material could have been supplied by drift from local eroding cliffs, or whether material could have arrived as small barrier beaches, or swash bars that have moved onshore, fed from relic gravel sources in the West Solent. Gurnard Ledge certainly functions as a partial impediment to drift tending to assist coarse sediment retention within Thorness bay, causing depletion of the beaches to its northeast.

Results of the Strategic Regional Coastal Monitoring Programme (units IW51 to IW54):
Beach sections surveyed between Spring 2008 and Spring 2009 have shown either no change or slight accretion of sediment. From 2003 to 2009 the trend has been accretion or no change. This is due to the beach being narrow and rocky, with little mobile sediment (Channel Coastal Observatory, 2008 & 2009).

Shoreline Movement:
High long term cliff recession rates are typical within this frontage, although it should be noted that the cliff top recession process involves high magnitude low frequency failures that can result in loss of between 5 and 25m within single events associated with intense mudsliding downslope.

The upper foreshore has retreated in accord with cliff recession along the majority of this frontage, but mean low water appears to have moved back more rapidly so that the foreshore has narrowed. The western spit at Newtown (Hamstead Duver) has retreated and re-curved partially into the harbour. However, there is some evidence of long term accretion in the form of: (i) a relict spit located in the harbour entrance behind the active one; and (ii) growth of a gravel beach or small foreland in front of the eastern most parts of Hamstead Cliffs such that relict slopes have formed. It appears that this accretion is fed by sediments drifting eastwards following delivery to the shore at Hampstead and Bouldnor Cliffs.

The eastern spit at Newtown entrance has a history of sediment depletion and has receded landwards over saltmarshes that subsequently became exposed and eroded in the seaward face. Timber groynes and revetments have been installed in past attempts to stabilise the spit, but recently it has breached to form a small new inlet subject to tidal flows at high water.

Mean long-term cliff-top retreat over the period 1868-1963 was 0.61m/yr (May, 1966; Posford Duvivier, 1997), but a high rate of 3m/yr was recorded for a part of the Bouldnor Cliff complex over the period 1922-1962 (Hutchinson, 1965). Historical map comparisons by Halcrow (1997) indicate long-term (1909-1995) mean cliff top recession of 1.13m/yr for western and central Bouldnor and 0.84m/yr for Hampstead Cliff. Although, map comparisons covering the period 1908-1971 indicated locally rapid recession of mudslide lobes toe at rates of up to 1.6m/yr (Webber, 1977), it appears that cliff top recession has been more rapid than recession of mean high water at the toe leading to an overall flattening of the slope profile (Halcrow, 1997).

The entire coast between Whippance Farm (Thorness Bay) and Gurnard displays evidence of coast erosion, with cliffs up to 45m in height, much active mudsliding and shallow translational slides that supply and debris accumulations on the foreshore (Hutchinson, 1965; Hydraulics Research 1977a, 1981; May 1966; Halcrow, 1997; Posford Duvivier, 2000, Moore and McInnes, 2002). The landform assemblage is comparable to that at Bouldnor and Burnt Wood, but smaller in scale. Recession has been measured at 0.36m/yr for the period 1868-1963 (May, 1966) and 0.6m/yr, 1862-1938 (Hydraulics Research, 1977a). Some basal protection afforded by Bembridge Limestone ledges at Gurnard Ledge, and to the east, results in some increased cliff stability and slower retreat rates slower to the northeast of the Ledge compared to the cliffs to the south. These ledges eroded by 0.6m/yr to 1.2m/yr over the period 1862 to 1938 which suggests that their protective capacity is limited (Hydraulics Research, 1977a; Posford Duvivier, 1997; 1999). Historical map comparisons by Halcrow (1997) indicate long-term (1909-1995) mean cliff top recession of 0.48m/yr for the cliffs to the south of the Ledge and 0.18m/yr for those to the northeast.

Predictions of Shoreline Evolution:
Futurecoast (2002) estimated that without defences the trend for narrowing of the foreshore suggests that debris and cliff toe erosion are likely to continue or intensify into the future such that the cliffs are likely to remain unstable and actively eroding.

Increases in sediment supply to beaches due to the acceleration of freely eroding cliffs would be unlikely to generate substantial protective beaches because most of the cliff materials are clay and mechanisms exist for seaward removal of these sediment grades. Instead, there may be very local increases in beach accumulation at Hamstead Duver and in Thorness Bay.

The breached eastern Newtown Spit would be unlikely to seal naturally due to limited sediment supply, possibly resulting from the proximity of the drift reversal and divide. Instead it is likely that the breach would enlarge in the short-term and the spit breakdown further as sea level rises. The corresponding western spit is rather more stable because it is sustained by a modest sediment supply from the cliffs to the west. It would be likely to remain static, or slowly migrate into the harbour inlet. The effect of these changes would primarily be to permit increased wave penetration into the harbour with implications for the erosion of saltmarshes and mudflats.

The estuaries appear to be capable of continuing to accrete fine sediments and their saltmarshes have been relatively stable, although trends for slow to moderate saltmarsh erosion have become apparent recently in the Western Yar and Medina. Since these are all valley type estuaries with relatively steeply sloping margins their saltmarshes are likely to be sensitive to future climate change and sea-level rise unless vertical accretion can compensate (Halcrow Maritime et al, 2001).

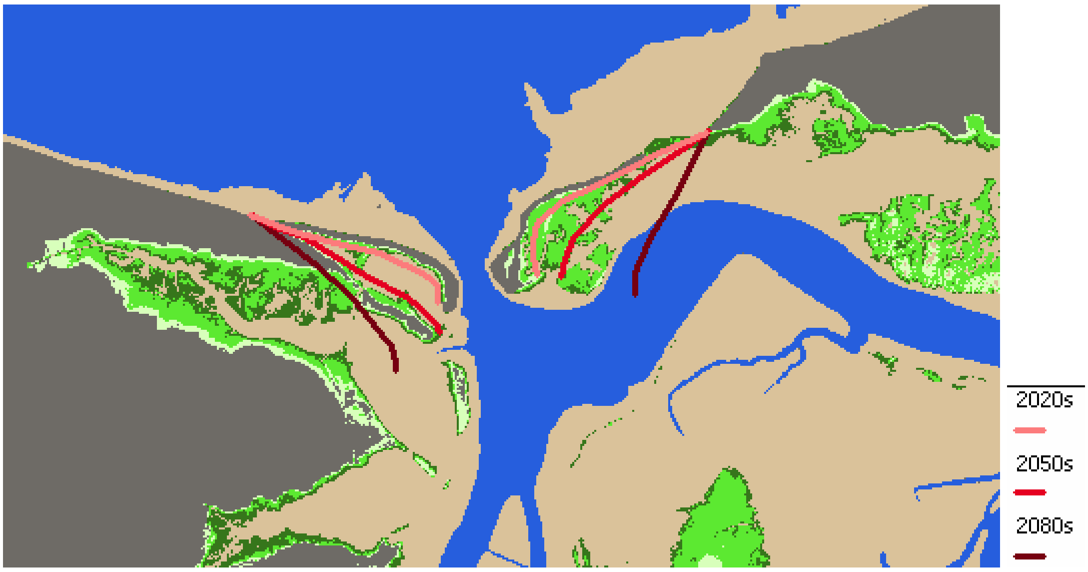

Figure 18: Potential future spit recession in Newtown Estuary, as calculated by the BRANCH Project, and described in more detail below. Copyright of the BRANCH Project (Gardiner et al, 2007).

The BRANCH project (Gardiner et al, 2007) predicts future spit retreat at Newtown by the 2020s, 2050s and 2080s under a medium-high sea-level rise scenario, using the Leatherman equation to predict future retreat allowing for sea level rise (ie. Future recession rate = Historical recession rate x (future sea level rise / historic sea level rise)). This prediction assumes a likely pivot point and minimal retreat of the neighbouring cliffs, historical sea level rise of 0.137cm/yr, and historical retreat rate of 0.6m/yr for the western spit and 0.62m/yr for the eastern spit. This simplifies the issues contributing to spit recession. The Western spit is likely to continue rolling back, although the presence of an inner spit may affect this behaviour. On the eastern side the spit is likely to continue to roll back south eastwards away from the prevailing wave direction, but may submerge as it reaches the deep water channel. Increased erosion of neighbouring cliffs may feed additional sediments into the system, potentially replenishing the spits, however increased wave action and storm frequency could also promote even faster retreat and assist the breaching of the eastern spit, opening up the Estuary to increased wave action, particularly the eastern side and the vulnerable saltmarsh habitat.

C1.8.3 Local Scale: Gurnard to Old Castle Point, including the Medina Estuary

Interactions:
This is a relatively self-contained frontage, although re-activation of cliff recession supplies predominantly fine sediments to the Solent.

Along the Gurnard frontage a wooded coastal slope extending to a height of 40m is protected at its toe by low cost revetments and assorted sea walls in generally poor repair. Slope morphology comprises numerous undulations, hollows and ridges which indicate past landsliding. Site observations have revealed several active landslides which have extended downslope and surged out across the foreshore (Hydraulics Research, 1981). The slope is formed in similar materials to that of Thorness Bay and could exhibit a similar degree of landslide activity should it be exposed to active toe erosion. Even with satisfactory toe protection, seepage erosion could continue.


Plate 29: Gurnard Luck, May 2009

Weak net eastwards littoral drift is reported along the depleted beach from Gurnard around Egypt Point (Posford Duvivier, 1990a). Concrete rubble groynes at Egypt Point selectively intercept sediments, but quantities are small because of the presence of protection structures and a lack of available material (Halcrow, 1997; Posford Duvivier, 2000). Beaches comprise sandy gravels becoming coarse gravel and cobbles under the seawall and are very depleted around Egypt Point, but widen eastwards to Cowes (Posford Duvivier, 2000).


Plate 30: Cowes Esplanade, looking west towards the Medina Estuary (Isle of Wight Council).

The north-facing coastal slopes extending under the towns of Cowes and Gurnard are the most northerly landmass on the Isle of Wight, and are affected by significant slope stability and landslide problems from Gurnard to Market Hill. The coastal slopes of Oligocene clays, marls and limestones form a prominent headland separating the Medina River and Estuary from the Western Solent. The headland is characterised by a plateau forming the higher ground above gently sloping coastal cliffs up to 35m in height. Degraded coastal slopes, coastal mudslides and deep-seated coastal landslides occur over four cliff behaviour units or coastal landslides. The system extends offshore below the current sea defences. The nature of ground movement is by i) sub-surface movements associated with the progressive creep of deep-seated landslides; ii) surface or superficial slope movements arising from the erosion or failure of steep slopes, the differential movement and settlement of clay slopes and compression or ground heave. Contemporary problems arising from ground movement tend to result almost entirely from superficial movements, the nature and significance of which varies along the frontage. At Gurnard, the slopes were reactivated after the winter of 2001. At Gurnard Cliff, coastal mudslides have resulted in undermining and recession of the cliff top, active settlement of the cliffs and translational movement of debris to the foreshore. Outward displacement and heave of mudslide lobes at the base of the coastal cliffs has prompted the destruction of coastal defences along this section. (Moore & McInnes, 2002). Poor drainage, increased rainfall, beach steepening and increased toe erosion will promote active landsliding and could result in rapid retrogression upslope towards cliff top development.

Westwards directed, but very weak, littoral drift occurs between a drift divergence at Old Castle Point towards the Shrape breakwater. Falling beach levels and lack of significant accretion against the breakwater indicate low drift rates, which have necessitated some recent beach nourishment. The lack of supply is due to the small source area and the impact of protection structures in reducing cliff erosion (Posford Duvivier, 1994). Cowes Harbour entrance therefore represents a drift convergence boundary, although the very small quantities of sediment moved by littoral transport towards the Medina entrance, together with the Shrape breakwater, makes this little more than a notional feature.

Plate 31: To the west of Old Castle Point, the towns of Cowes and East Cowes (on the right) at the mouth of the Medina Estuary, with the Shrape Breakwater protecting the entrance to the harbour (Isle of Wight Council).

The Medina Estuary extends 6.8km from its tidal limit at Newport Harbour northwards to Cowes and East Cowes. It lies in a wide shallow valley with a gentle incline on either side. Sediment build up has formed characteristic mudflats covering 66 hectares which support a large number of species, including shellfish, algae and locally and regionally important species of worm, also important sources of food for fish and bird populations. The estuary's shoreline is approximately 14.4km. At low water a single, relatively wide but shallow channel remains. The mid and upper reaches are largely bordered by agricultural land, hedgerows and woods, whereas the lower reaches and mouth are lined by docks, boatyards and marinas. (Medina Estuary, iwight.com 2009).

The estuary narrows at the point where the floating bridge crosses and this constriction is considered to be a geological control on the estuary, such that the future evolution of the estuary will remain strongly influenced by this zone. Due to this it is argued that the 'true' estuary mouth is at this location and the areas to the north exhibit some characteristics of an open coast bay (ABPmer, 2007).

The Medina Estuary operates as a natural littoral transport boundary as its dominant ebb tidal flow generates net offshore flushing of incoming shoreline sediments. The process is probably less significant than in the past because there is very little incoming littoral drift due to widespread shoreline stabilisation and drift interception. The flushing effect was enhanced by construction of the East Cowes (Shrape) breakwater in 1936/37 which reduces the amount of suspended sediment entering the Estuary, and ebb tidal flow was shifted westward by the breakwater into the centre of the inlet. The flood currents dominate along the western margin. Comparisons of hydrographic charts dating back to 1856 indicate that some cyclic variations of the sea bed may have occurred prior to construction of the breakwater, but subsequently the bed has been relatively stable (Webber, 1969; Bunce et al., 1987). This is attributable to the net offshore transport of sediment which maintains stable channel configurations and prevents siltation even in recently dredged berths (Webber, 1969). Small sand and gravel banks exist where dominant ebb and flood flows crossover; these are probably not sediment sinks but temporary accumulation zones for sediment subject to net offshore transport (Webber, 1969). Banks further offshore such as Prince Consort Shoal and Brambles Bank are probably permanent sediment sinks (Dyer, 1980) and in the past might have been supplied with sediments flushed seaward out of the Medina inlet.

The SCOPAC Sediment Transport Study (2004) records that the River Medina has a mean flow of $0.5m^3s^{-1}$ and this comprises only 0.67% of the tidal volume entering at the mouth during a corresponding tidal period (Webber 1978). Thus, marine sediment input to estuarine mudflats and saltmarshes must be the dominant source of supply and fluvial sources are considered to be relatively insignificant.

Historical chart analysis, a review of estuary processes and morphometric analysis on the estuary (ABPmer, 2007) suggests that accretion of fine material has continually occurred since 1856 (albeit at a relatively slow rate) but the man-made interventions, mostly between the 1920s and 1950s, probably caused a temporary change to the system. This changed the hydrodynamics, inducing additional flows at the lower states of the tides (particularly ebb) which have scoured the low water channel. This scour has mainly been at the edges, removing the finer fractions of sediments to leave the coarser gravels as bed armouring thus reducing the effect depth-wise. This temporary change appears to have worked through the system up to the area around Island Harbour and the net accretionary regime has re-established down estuary. The rates of future accumulation are, however, likely to be lower than those before the construction of the Shrape breakwater due to its effect on reducing the supply of sediment into the system. The Shrape breakwater has contributed (along with coastal protection works) to reduce the overall supply of sediment to the estuary, compared to 1856 but since the 1980s the estuary has had a net accretionary trend, particularly over the intertidal. Rates of change are small, being measured in millimetres per year. There has been a net reduction in surface area (at high water) due to coastal squeeze, predominantly from embankments and reclamation.

Since the 1940s the area of saltmarsh has reduced by 10.3 ha as a consequence of direct reclamation, capital dredging or impoundment such as at Island Harbour as well as from natural processes. A reduction in saltmarsh has occurred throughout the Solent Area and therefore a proportion of the natural change may reflect regional trends rather than local developments. The rate of erosion has slowed considerably in recent years. Upstream of Dodnor, the net accretionary trend has been continuous but may be reduced for a period in the future as the effects of the developments continues to work its way up the estuary, unless the effect has decayed sufficiently not to cause a significant change relative to the accretion and erosion thresholds.

Plate 32: View north from Newport along the Medina Estuary towards Cowes and East Cowes at the Estuary mouth (Isle of Wight Council).

Results of the Strategic Regional Coastal Monitoring Programme (units IW55 to IW1):
Between 2008-2009 much of this section has shown no change apart from a small area of accretion in the western section. From Spring 2003 to Spring 2009 the unit has been mostly stable apart from localised accretions and slight erosion between West Gurnard and Egypt Point. (Channel Coastal Observatory, 2009).

Shoreline Movement:
North of the small valley occupied by Gurnard Marsh, a partly active wooded coastal slope up to 35m in height is protected by revetments and sea walls, currently in generally poor condition. The slope continues east to West Coves, but to the east of Gurnard slipway, it becomes less steep, and is protected at its toe by seawalls and an esplanade. Slope morphology comprises numerous irregularities, which indicate past and active seepage erosion and the presence of relic deep-seated and shallow landslides (Posford Duvivier, 2000; Isle of Wight Centre for the Coastal Environment, 2000, Moore and McInnes, 2002). Although an average rate of cliffline recession of between 1.5 to 3.0m/yr between approximately 1850-1950, is suggested by Hutchinson (1965), present conditions do not support such rapid recession of the entire cliff. It could be that the rates quoted relate to local areas where inactive landslides have rapidly reactivated upslope.

Between Egypt Point and West Cowes the upper coastal slopes exhibit evidence of instability, but the toe has been protected by an esplanade and sea wall since 1894, so no contemporary sediment supply occurs (Hydraulics Research, 1977a; Hutchinson, 1965; Halcrow, 1997; Posford Duvivier, 2000) so long as it maintains its function. A low shoreface erosion rate of 1,300m^3/yr (Posford Duvivier, 1999) is a function of protection from high-energy waves. It should be noted that increases in winter rainfall (effective precipitation) that are likely to result from future climate change could have serious implications as it would raise groundwater levels, potentially causing more widespread reactivation of the coastal slope along this frontage (Halcrow Maritime et al, 2001).

Predictions of Shoreline Evolution:
Futurecoast (2002) estimated that without defences, the toes of the coastal slopes would be likely to be eroded at slow to moderate rates. Over 30 to 100 years, this could remove support and destabilise the relict landslides on the slopes above. The frontage from Gurnard to the Royal Yacht Squadron is most exposed to wave attack and also supports the steepest slopes, suggesting that it may be the most vulnerable to future re-activation.

The morphology of the active cliffs at Thorness may provide an analogy for the type of morphology that could ultimately form, although a lengthy time period of 50 to 100 years could be required for such a transition. The full re-activation process could involve rapid but intermittent inland migration of the active cliff scarp by up to 200m. It should be noted that although the full re-activation process could involve relatively long timescales the initial ground movements could occur quite rapidly following the onset of toe erosion. Areas affected would be highly localised and related to the distribution of relict landslides on the slopes. Although toe erosion would prepare the slopes for instability, the re-activation events themselves would most likely be triggered by high groundwater levels.

Although the toe of coastal slope is protected in some areas, with present management practices landsliding processes could still be re-activated due to rainfall increasing the pore water pressure in the cliffs. Present re-activations are concentrated around Gurnard Bay, so this area may be the most sensitive to this factor.

The Medina Estuary appears to be capable of continuing to accrete fine sediments and the saltmarsh has been relatively stable since the 1980s, Since this is a valley type estuary with relatively steeply sloping margins the saltmarsh is likely to be sensitive to future climate change and sea-level rise unless vertical accretion can compensate (Halcrow Maritime et al, 2001).

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Annex A: South East Strategic Regional Coastal Monitoring Programme

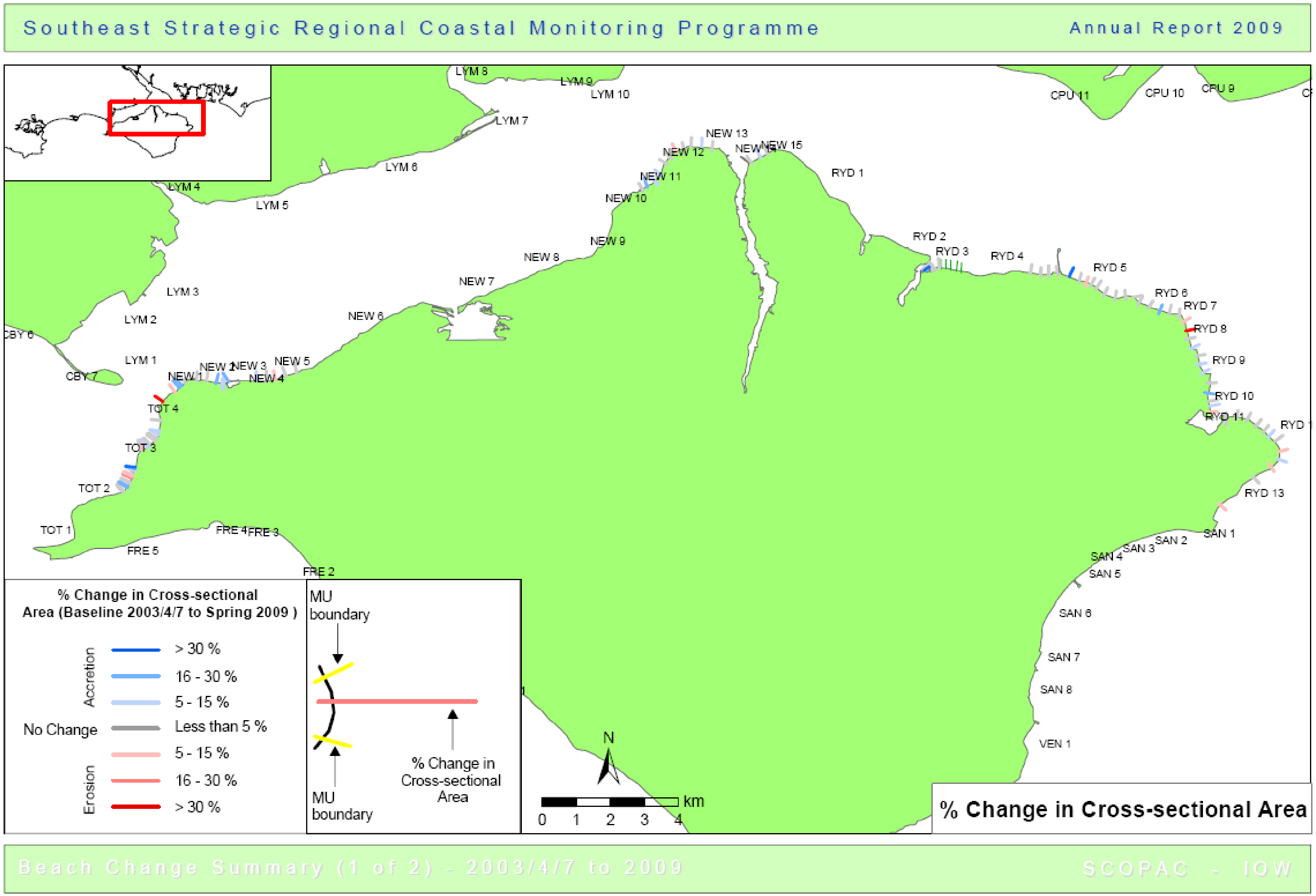
The Southeast Strategic Regional Coastal Monitoring Programme provides a consistent regional approach to coastal process monitoring, providing information of the development of strategic shoreline management plans, coastal defence strategies and operational management of coastal protection and flood defence.

The programme came into being on 1 August 2002 and the first phase extended to March 2007. The second phase is underway and is funded until 31 March 2012, with an expectation that the programme will continue indefinitely. The programme is managed on behalf of the Coastal Groups and is funded by DEFRA, in partnership with the maritime Local Authorities and the Environment Agency Southeast Region.

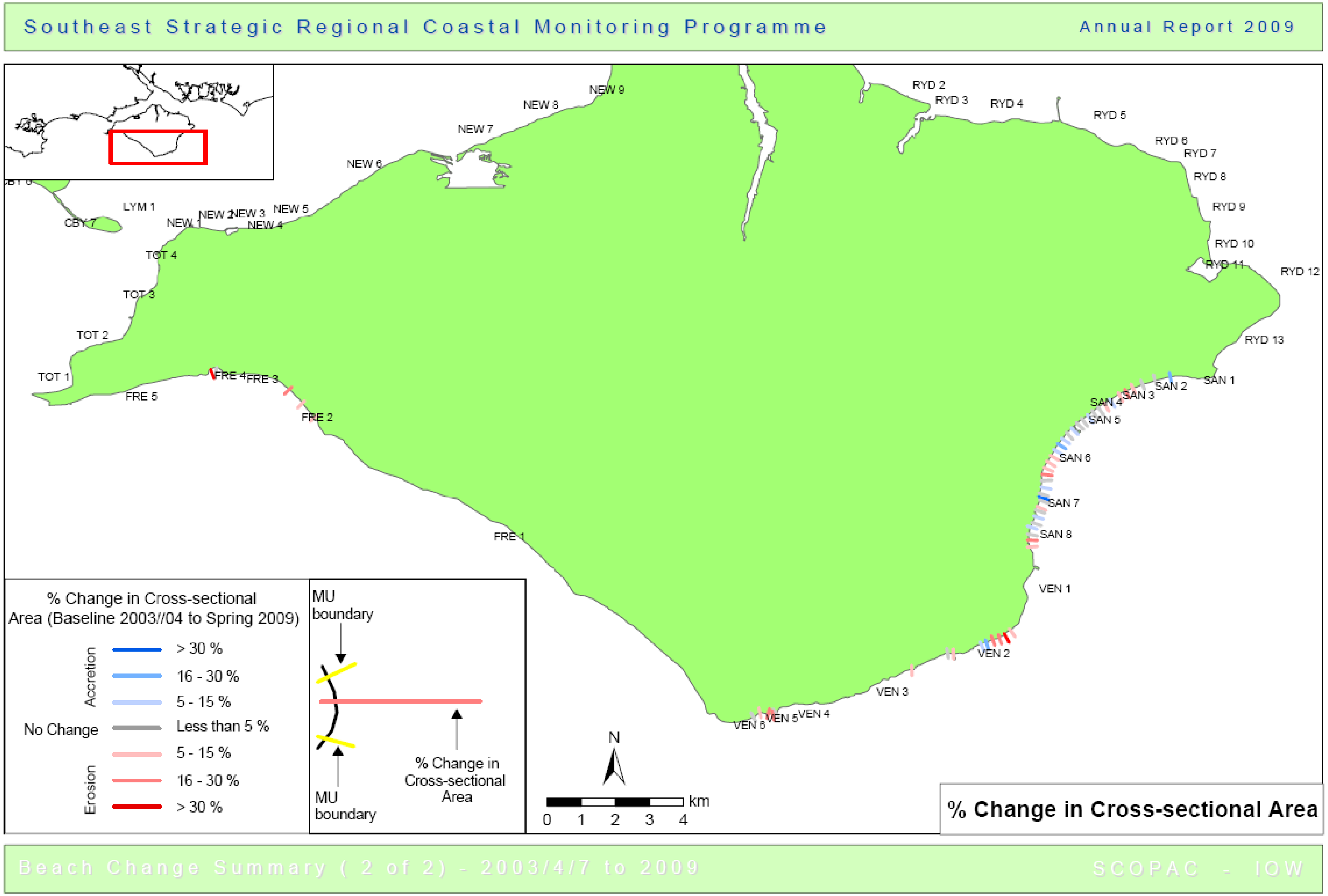
Data are collected via a series of contracts and also by in-house Local Authority teams. All data collected by the programme are made freely available, via the Channel Coastal Observatory website – www.channelcoast.org. A specialist team has been established at the Channel Coastal Observatory to manage the programme and develop the data analysis, storage and dissemination procedures.

The first beach surveys took place during the winter of 2002 and changes are reported until spring 2007. This provides a short time base over which beach changes have been monitored. Detailed interpretation and decision-making is not advisable on the basis of these short-term changes, since the changes may not be representative of longer-term trends. Comment is limited, therefore, to only those sites which show obvious short-term problems, or where long-term data are deemed to be of sufficient quality. As the Programme progresses, more detailed and meaningful reporting will be possible.

Changes within each Management Unit are summarised on two maps (one for the north and one for the south of the Island), shown below. The percentage change in cross-sectional area has been calculated from the initial survey (usually 2003/4, occasionally 2007) to Spring 2009. These Beach Change Summary Maps provide an at-a-glance condition of the whole of the Isle of Wight, with the coloured lines representing accretion, no change or erosion for each unit. Further details are available in the Southeast Strategic Regional Coastal Monitoring Programme Isle of Wight Annual Reports (Channel Coastal Observatory, 2009).



Beach Change Summary Map -Northern Isle of Wight Coast: Baseline 2003/4/7 to Spring 2009, South East Strategic Regional Coastal Monitoring Programme Isle of Wight Annual Report 2009.



Beach Change Summary Map –Southern Isle of Wight Coast: Baseline 2003/4 to Spring 2009, South East Strategic Regional Coastal Monitoring Programme Isle of Wight Annual Report 2009.

Directorate of Economy and Environment
Director Stuart Love

Isle of Wight Shoreline Management Plan 2

Appendix C: Baseline Process Understanding

C1: Annex B
Climate Change and Sea Level Rise

December 2010

Coastal Management;
Directorate of Economy & Environment, Isle of Wight Council

C1: Annex B -Climate Change and Sea Level Rise

Contents

Summary of contents

This report provides an appraisal of climate change and sea level rise, including causes, effects and management at a global scale. The impacts of climate change vary spatially and so predictions of climate change are discussed at a regional scale. A summary of the likely impacts of climate change is provided.

The report continues by examining the likely impacts of climate change and sea level rise on the Isle of Wight, with particular reference to impacts of climate change on the coastal environment.

Current national government guidance on sea level rise predictions is outlined, and the predictions are applied to calculate future sea level rise for the Isle of Wight. Specifically, the Defra guidance ‘Flood and Coastal Defence Appraisal Guidance FCDPAG3 Economic Appraisal Supplementary Note to Operating Authorities – Climate Change Impacts’ was used in the production of this report.

Key sources of data used in the production of this report include various publications by the IPCC (Inter-governmental Panel on Climate Change) and the UKCIP (United Kingdom Climate Impacts Programme).

1. Introduction to Climate Change

Climate change is not a new phenomenon. The World's climate has always been changing. What is different now is that it is the belief of many scientists that man-made impacts on climate have become discernible in addition to natural change.

On a day-to-day basis we receive frequent reports of apparently exceptional weather conditions that have recently been recorded. This is not a new trend, it is fundamental to the recording of meteorological information that natural variability will lead to the recording of extremes from time to time, so such events alone cannot be considered as evidence of climate change. Indeed, it has not yet been proven that frequencies of extreme events are changing, although the IPCC 2007 Synthesis Report: Summary for Policymakers report says that it is very likely that we will experience regional-scale increases in the frequency of hot extremes, heat waves and heavy precipitation. The recording of such weather events does improve our understanding of the climate that we should expect. However, it is an acknowledged scientific fact that the composition of the atmosphere is changing significantly and that human activities that result in the emission of so-called greenhouse gases are implicated strongly. The greenhouse effect itself is a natural occurrence, which has operated for billions of years. Without the natural greenhouse effect the earth's temperature would be some 33°C cooler. The majority of scientific opinion now agrees that human influences on the global climate are beginning to become detectable above and beyond natural changes. This is particularly the case for near surface global mean temperature. Since the industrial revolution man has been changing the composition of the atmosphere, primarily by the burning of fossil fuels. Evidence from ice cores supplemented by direct measurements since the mid-1950s shows a steady rise in concentrations of greenhouse gases from the late 1700s changing to a rapid rise post 1950. Through the study of historical weather records and future projections with numerical models there is good evidence to suggest that human influenced climate change is taking place, and is likely to accelerate in the future.

Climate change is likely to impact on a wide range of issues from habitat survival or migration, through to water resource strategies, and adaptation of infrastructure design. Climate change could also trigger an agricultural response through changes in rural land-use and soil management.

Sea levels are rising globally with regional and local variations. However, owing to its inherent complexity, neither climatological observations nor present climate models are sufficient to project how the climate will change or sea level rise with certainty.

While changes in mean sea level should be of concern to coastal planners, it is the occurrence of extreme high water events that causes most problems with coastal erosion and flooding. It is possible that changes to the frequency and intensity of storm surges may occur under a warmer climate.

The coast of the Isle of Wight is vulnerable to storm waves of exceptional energy, particularly the exposed south-west coast. If the frequency and magnitude of storms are to increase, alongside sea level rise, then the Isle of Wight coasts (particularly the exposed south-west and north-west coasts) will be subject to increased erosion and cliff instability. A further consequence of sea level rise for the Isle of Wight will be overtopping of current defences, which although minimal at present, is likely to increase over the lifetime of the SMP. Tide-locking of floods is also an issue of concern. It is therefore paramount that climate change implications be taken into consideration when developing new coastal management and defence strategies.

SMPs and Strategy Studies follow national government guidance allowing for sea level rise withing their decision-making. Net sea level rise allowances were published by Defra in 2006: A variable allowance over time of 4mm/yr to 2025, 8.5mm/yr between 2025 and 2055, 12mm/yr between 2055 and 2085, and 15mm/yr beyond 2085.

2. The Global Response to Climate Change

Climate change is a global issue that will affect us all. Speaking at a press conference at the annual summit of the leaders of the eight leading industrialised nations, UN Secretary General Ban Ki-Moon called climate change the "defining issue of our era" and urged leaders to prepare for what is to come. Steps are now being taken by leading political figures to publicise the importance of preparing for climate change, and as quoted by Kofi Annan (2006), the changes caused by past greenhouse gas emissions can't be rectified. The Environment Commissioner, Stavros Dimas from the European Commission (2006), stated that "the time of theoretical debates about climate change is over; we need practical and effective actions". The British Government have heeded this and "have made it a top priority for this government, both domestically and internationally" (Blair, T., 2007). Local authorities have also become involved.

The most authoritative reports on the science of climate change are those produced by the Inter-governmental Panel on Climate Change (IPCC), which brings together the leading scientists from around the world. The World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) set up the IPCC in 1988, with the objective of assessing the scientific, technical and socio-economic information relevant for the understanding of the risk of human-induced climate change. The IPCC does not carry out new research or monitor climate, but it bases its assessments on published and peer reviewed scientific technical literature. The IPCC 1992 report was fundamental to the development of the UN Framework Convention on Climate Change (UNFCCC), which was agreed at the Earth Summit in Rio de Janeiro in 1992 and has been ratified by over 170 countries. Under the Convention, developed countries agreed to return their greenhouse gas emissions to 1990 levels by 2000.

With more information and the results of Global Climate Models (GCMs), the UNFCCC recognised that further cuts in global emissions were needed to prevent serious climatic impacts in future. Each year, the countries that ratified the Rio Convention held a Conference of Parties (COP). In 1997 the 3rd COP meeting was held in Kyoto, Japan. After reviewing the original targets of the Rio Convention and finding them to be too weak, the countries came up with new targets. The text of the Kyoto Protocol was adopted in Kyoto on 11 December 1997. The protocol sets out to reduce climate emissions of developed countries by some 5.2% below 1990 levels over the period 2008-2012. Additionally, the Kyoto Protocol introduced mechanisms to allow developed countries to buy emission reductions that have taken place in other countries and count them as their own. These mechanisms are Joint Implementation, Clean Development and Emissions Trading. Carbon sinks for the sequestering of CO2, for example the proposed 'Kyoto Forests' are also allowed under the protocol. The protocol was first agreed in 1997, but required the agreement of countries responsible for at least 55% of global emissions measured in 1990. The US, the world's largest emitter of greenhouse gases, withdrew from the protocol in 2001, saying it would gravely damage the US economy. The Bush administration also criticised the protocol for not forcing developing nations including India and China to cut emissions immediately. Australia, which has a large coal industry, has also refused to ratify Kyoto. After the United States refused to ratify it, only Russia, responsible for 17% of emissions, could enable this threshold to be passed. In November 2004 Russian President Vladimir Putin signed the Kyoto protocol, finally allowing the protocol to be formally sanctioned. The Kyoto Protocol became a legally binding treaty on 16 February 2005. Countries that fail to meet the targets will face penalties and the prospect of having to make deeper cuts in future. "The entry into force of Kyoto is the biggest step forward in environmental politics and law we have ever seen," said Jennifer Morgan, director of the World Wide Fund for Nature (WWF) conservation group's climate change programme. The President of the UN General Assembly, H. E. Sheikha Haya Rashed Al Khalifa (2007), pronounced that "we have a real opportunity to raise our overall level of awareness about the science, the impact and the challenges we face from climate change, but also the opportunities ahead for a more sustainable future".

3. Climate Change Evidence and Predictions

3.1 Introduction

It must of course be recognised that the earth's climate has always been changing, and this is evidenced particularly well through geological records. There is evidence that there have been ice ages at time intervals of some 150 million years or so and such ice ages last for several million years. The period from 1.6 million years ago to 10,000 years ago has been referred to as the age of Ice Ages. This was a largely ice age period however there were several interglacials lasting about 20,000 years during that time. It is believed that changes in planetary and solar orbits cause ice ages, and it is inevitable that the Earth will eventually enter another ice age, but this is over a much longer timescale, thousands of years, whilst that of human influence is hundreds of years. There are a number of other known 'natural' reasons why our climate varies in addition to the impacts of the so-called enhanced greenhouse effect. These include volcanic activity (which can release dust) and fluctuations in the solar output from the sun. However, these effects are believed to be minor when compared with the anticipated impacts of anthropogenic global warming.

It is estimated that for the next thirty years or more fossil fuels will maintain their dominant position in the global energy mix. Even if the concentrations of all greenhouse gases and aerosols had been kept at year 2000 levels, a further 0.1°C per decade would be expected (IPCC, 2007). The impacts of a changing climate will influence coastal related hazards by altering their frequency and intensity to become extreme events (Defra, 2007).

Although there has been much study of climate change, it is still not yet possible to relate individual extreme events, such as the heavy rainfall and subsequent major flooding events of 2000, 2007 and 2009, directly to anthropogenic changes to the atmospheric composition. However, consensus of expert opinion suggests that extreme events such as these will become more frequent and intense in a more energetic future climate as global temperatures rise.

3.2 Temperature

Due to the greenhouse effect global temperatures have risen by 0.76°C between 1850 and 2005 (IPCC, 2007) and are expected to increase by 2-3°C within 50 years (Stern 2006). According to the IPCC (2007) "eleven of the last twelve years (1995-2006) rank among the twelve warmest years in instrumental record (since 1850)". Research into the greenhouse effect and temperature rise has led to observations in ocean temperatures and results show "that the oceans have taken up around 84% of the total heating of the earths system over the last 40 years" (Stern, 2006) leading to thermal expansion. Temperature rise has influenced the melting of land based ice and "if the Greenland and West Antarctic ice sheets began to melt irreversibly, the world would be committed to substantial increases in sea level in the range 5-12m over a timescale of centuries to a millennia" (Stern, 2006) with an immediate affect of 1-3mm/yr rise. These contributions to sea level rise have resulted in a 10cm sea level rise since 1990 (UKCIP, 2007) in the UK with some areas of the world experiencing a 30cm rise. The action taken to mitigate and prevent catastrophic sea level rise must be long term because "both past and future anthropogenic carbon dioxide emissions will continue to contribute to warming and sea level rise for more than a millennium, due to the timescales required for removal of this gas from the atmosphere" (IPCC, 2007).

Over the last three centuries the mean temperature over central England rose by about 0.7º C, with 0.5º C of this rise in the last century (Hulme & Jenkins, 1998). When considering global mean surface temperatures, there has been a warming of about 0.7º C since the end of the 19th century, and some 0.5°C since about 1970 (Met Office, 2000). The temperature statistics also show that four of the five warmest years in the 340-year long central England temperature record were in the 1990s and that 1999 was the joint warmest year ever. Globally, 1999 was significantly cooler than the record year of 1998, primarily due to temperature changes over the Pacific due to the cyclic El Nino/La Nina circulation.

3.3 Rainfall

The IPCC (2007) predict that "heavy precipitation events and their frequency (or proportion of total rainfall from heavy falls) increases over most areas" and are virtually certain to occur within the 21st century. It has been observed that "winters over the last 200 years have become much wetter" (UKCIP, 2007) but it is predicted that climate change will increase the frequency of "heavy winter precipitation" with "more intense rainfall events over many Northern Hemisphere mid-to-high latitude land areas" (UKCIP, 2007).

As well as rainfall events increasing it is predicted that storm surges and thunderstorms will both increase and these factors added to the increase in rainfall all implicate flooding, coastal erosion and instability. According to Stern (2006) "storms are currently the costliest weather catastrophes in the developed world" and with an increase in their frequency and intensity this cost can only grow and "according to insurance industries weather related losses have increased by 2% per year since 1970" (Stern, 2006).

3.4 Sea Level Changes

The sea level occurring at any time is made up of the following primary components:

- Mean sea-level;
- A tidal component due to gravitation effects of the sun, moon and planets;
- Frictional effects on the propagation of the tidal wave and, occasionally, amplification due to bathymetric effects;
- A storm surge component due to meteorological effects and interactions between the above components.

When considering temporal changes in mean or extreme sea levels, it is important to also include changes in local land level due to tectonic or post-glacial geological influences.

While changes in mean sea-level should be of concern to coastal planners, it is the occurrence of extreme high water events that causes most problems with coastal flooding and erosion. The tidal forcing component is relatively fixed, but changes in mean sea-level can cause changes in propagation of the tidal wave. Changes to the frequency and intensity of storm surges may also occur under a warmer climate.

Changes in mean sea-level relative to land levels are clearly important for the design and management of coastal defences. Such changes may also impact on sediment transport and morphological change.

It is generally recognised that global mean sea-level has been rising for many years. Indeed, sea levels on the south coast of England were some 25m lower than present some 10,000 years ago, and rapidly rose to almost present levels about 5,000 years ago, since when there has been a slowing rate of rise. Whilst global sea-levels have been rising, local changes can often be dominated by movements of the land-mass. This includes recovery after loading during the last Ice Age, consolidation of soft materials, as ground water is removed, and tectonic movements etc. The Permanent Service for Mean Sea-level (PSMSL), which is operated from the Proudman Oceanographic Laboratory (POL), catalogue mean sea-level data from sites all over the world. The mean sea-level data are measured against a local reference datum, and so provide measures of sea level relative to the land.

Although most estimates available for future sea-level rise are globally based it is not expected that mean sea-level rise will be constant everywhere. This is principally because the heating up of the oceans will not be uniform. Geographical patterns of sea-level change due to differing thermal expansion have been estimated using general circulation models (GCMs) at the Hadley Centre. The present generation of GCMs do not represent the melting of ice sheets and glaciers internally, and such calculations are undertaken off-line and added to the results.

Sea level rise may encourage enhanced deposition in estuaries and the lower reaches of rivers. However, this scenario will only arise if higher water levels and increased wave action increase the supply of long shore spit building material and fine sediment to the estuaries i.e. through erosion of unstable cliff material. Otherwise, the spits will be sediment starved and are likely to break down which would increase the tidal and wave energy within the estuaries leading to enhanced mudshore erosion

Low-lying areas will be subject to increased threats from periodic inundation, particularly where there is an absence of defences and/or where beaches suffer reductions in volume. Areas of intertidal mudflats and saltmarshes are at risk from increased erosion, especially if protective spits in the mouths of the estuary inlets are breached.

If the spits are breached, tidal and wave energy will increase within the outer estuary areas, which initially is likely to erode the muddy saltmarsh and tidal flat sediments. Eventually these areas may be lost and replaced by sand flats associated with the redeposition of the spit sediments, the greater wave exposure and consequent higher energy conditions in the outer estuary.

In cases where the backshore of estuaries and inlet are unprotected, saltmarsh and intertidal environments will adjust naturally to rising water levels by migrating landwards to slightly higher ground – thus maintaining their relationship with sea level.

Where defences exist fronted by fringing saltmarsh or mudflat areas, it is likely that these areas will be eroded and diminished as any remaining intertidal areas are “squeezed” between rising sea levels and static backshore defences. This process termed coastal squeeze, results in the rapid erosion and degradation of these natural flood defences and increases the risk of flooding and coastal erosion.

Sea level rise predictions can be found in section 4 below.

3.5 Storm Surges

There has been far less research on the frequency and magnitude of storm surges than there has been on changes in mean sea-level. Since there is considerable uncertainty over the influence of global warming on the frequency, magnitude and track alignment of depressions, there is much greater uncertainty over future changes in surges than for mean sea-level changes or tides. The most appropriate way to study the impacts of climate change on storm surges is to use predicted future climate data from the GCM experiments to drive storm surge models covering the northwest European shelf. Flather and Williams (2000) reported on earlier studies that had found small changes between control and 2xCO_2 simulations, which were barely significant when natural variability was taken into account. They also described more detailed work still in progress using GCM output to drive a 12km grid size nested storm surge model. Preliminary results presented indicate small (<5cm) increases in the 1 in 50yr surge in the eastern English Channel, and even smaller decreases west of the Isle of Wight. However, the results were found to be very sensitive to the method of analysis adopted for extrapolating the extremes.

3.6 Modelling and Prediction

Given the potential importance of regional climate changes for the development of national policies, and the impacts of extreme, climate-related weather events such as droughts, floods, and hurricanes on agriculture and human safety, how reliable are the projections of future change?

Computer-run, mathematical simulations or models of the atmosphere and ocean are the principal tool for predicting the response of the climate to increases in greenhouse gases. The most sophisticated of these, called general circulation models, or GCMs, express in mathematical form what is known of the processes that dictate the behaviour of the atmosphere and the ocean. There are limits, however, to how much complexity can be handled by the computers on which the models are run.

Owing to this inherent complexity, neither climatological observations nor present climate models are sufficient to predict how climate will change with certainty. The most authoritive approach is that adopted by the Intergovernmental Panel on Climate Change, which is based on projections of the expected growth of greenhouse gases and the combined results of many GCMs.

Climate scenarios present coherent, systematic and internally consistent descriptions of changing climates. Scenarios are typically used as inputs into climate change vulnerability, impact or adaptation assessments. The climate change scenarios developed for use in UKCIP studies rely largely on two sets of GCM experiments completed by the Hadley Centre during 1995 and 1996. These experiments were undertaken using a coupled ocean-atmosphere GCM called HadCM2. This model has been extensively analysed and validated and represents one of the leading global climate models in the world. It features prominently in the Forth Assessment Report of the IPCC (2007).

Since no single climate change scenario can adequately capture the range of possible climate futures, four alternative climate scenarios for the UK are presented – Low, Medium-Low, Medium-High and High. For these four scenarios, the world warms globally by the 2020s by between 0.6°C and 1.4°C, a decadal rate of warming of between 0.11°C and 0.28°C per decade. For comparison, the observed rate of global warming for the past two decades has been about 0.14°C per decade. By the 2080s, the UKCIP98 scenarios generate a warming range of 1.1°C to 3.5°C. The global-mean sea-level changes and carbon dioxide concentrations associated with the four UKCIP98 scenarios similarly reflect a range of values that may be used in climate change impact assessments.

Scientists from the Hadley Centre for Climate Prediction and Research, part of the UK Met Office, recognise the limitations of global climate models resulting from the coarse resolution employed. Local climate change is influenced greatly by local features such as mountains, which are not well represented in GCMs. Regional climate models (RCMs) using a typical resolution of 50km, have been constructed for limited areas by the Hadley Centre, UK.

3.7 Potential impacts of Climate Change

The consequence of higher antecedent effective rainfall will lead to increases in coastal erosion, landsliding and re-activation of pre-existing landslide complexes. The UKCIP98 scenarios estimate an increase in mean effective rainfall. Other potential climate change effects, such as increases in the number and duration of wet year sequences, the intensity of rainfall events and sea-level rise are all likely to have additional significant effects on coastal instability.

Extreme high water events will change both the intensity of flooding and erosion in coastal areas and according to UKCIP (2007) “extreme sea levels will be experienced more frequently” while the IPCC (2007) only predict it likely for an “increased incident of extreme high sea level” to be experienced during the 21st century.

The difficulty with flood risk planning is that flooding occurs spontaneously making it difficult to predict and costly to resolve (European Environment Agency, 2004) however without suitable action, flooding events, their intensity and damage will increase with costs increasing from 0.1% of GDP to 0.2-0.4% in the UK alone when the temperature increases by 3-4ºC (Stern Review, 2006). Between 1998 and 2002 48% of all natural disasters were due to floods (European Environment Agency, 2004). Flooding is determined by a combination of peak sea level (extreme sea levels), wave activity and storm surges.

Coastal erosion will also increase with extreme high water events however unlike flooding; erosion is a gradual process (European Environmental Agency, 2004). The EUrosion project (EUrosion,

2004) calculated that a fifth of Europe's coastlines are being actively affected by erosion, "with coastlines retreating by between 0.5-2m/yr… even by 15m". Response (2006) further calculated that along 20,000km of coastline in Europe 15,000km are actively retreating and 5,000km are artificially protected. Sediment transport, deposition and supply are an integral part of the coastal system and reflect the coastal changes and climatic influences. Due to the increase in coastal erosion it's predicted that sediment supply will also increase resulting in cliff instability.

Sediment transport is an integral part of the coastal system and its trends reflect coastal change and climatic influences. It is likely that sediment supply and transport will be influenced by climate change. As well as changes to sediment transport at the coast, the increased frequency in extreme climatic events could lead to significant changes in river processes, such as increased amounts of sediment supply and more frequent large discharge flood events capable of transporting significant volumes of sediment through the low gradient channels to the coast. Changes to the sedimentary system may carry a number of potential impacts for habitats.

4. National government guidance on sea level rise for use in coastal plans and strategies

4.1 Defra Guidance

In 2004 the Office of Science and Technology published the Foresight Future Flooding report, which took a long-term view of national flooding and coastal erosion risks to 2100. Foresight estimated that there were £130 billion of assets (homes, businesses etc) at risk of coastal flooding and also at least £10 billion of assets at risk of coastal erosion. The study predicted that future climate change could lead to potentially significant increases in future risk by the end of this century with annual losses due to flooding increasing to between 2 and 20 times current values and coastal erosion annual losses rising by 3-8 times. Of course, actual changes in risk will be highly dependent on patterns of growth and new development (which both affect the value of damages from flooding and erosion) and future flood and coastal erosion risk management activity.

In October 2006 the Department for Environment, Food and Rural Affairs (Defra -the National Government department responsible for coastal erosion and flood risk issues) published a Flood and Coastal Defence Appraisal Guidance Supplementary Note to Operating Authorities on climate change impacts (Defra, 2006). This Supplementary Note set a consistent and sustainable approach to tackling the impacts of climate change, especially in appraisal and decision making processes associated with flood and coastal erosion risk management. It is based on the High emissions scenario estimate from the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report.

The guidance recognises the need for adaptation to best manage the risk of sea level rise. This might be through re-alignment of infrastructure, or working with natural processes, or ensuring that our flood risk management systems can be adapted or strengthened further to accommodate the changes in risk faced over time.

The predictions of future sea level rise amounts that should be taken into account in any coastal scheme, strategy or plan are shown in Table 1. The latest guidance takes into account land movement and the effects of thermo-expansion of the sea, up to 2115. Additional contributions from tidal surge and waves are not included. The new sea level rise estimates predict an exponential rise, replacing the previous straight line graphical representations; the predictions are lower in the short term, but higher in the medium to long term.

Key points to consider are:

- Net sea level rise allowances incorporate thermal expansion of the oceans and melt from land glaciers and vertical adjustments of the land. Additional contributions from tidal surge and waves are not included.

- Global mean sea level rise projections up to the 2080s were taken from the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) High estimates. Global mean sea level rise projections for the 2110s were extrapolated from the 2020s, 2050s and 2080s.
- Regional variations in net sea level rise allowances reflect latest information on vertical land movements.
- The baseline for calculating sea level rise for a given year is taken from 1990.
- There are significant uncertainties in climate change predictions and there may be studies that suggest allowances could be higher (for example, research from Thames 2100). However, figures in this supplementary guidance are considered most appropriate for flood and coastal risk management and planning, and should be used until further updates are provided.

Administrative or Devolved Region	Assumed Vertical Land Movement (mm/yr)	Net Sea-Level Rise (mm/yr)				Previous allowances
		1990-2025	2025-2055	2055-2085	2085-2115	
East of England, East Midlands, London, SE England (south of Flamborough Head)	-0.8	4.0	8.5	12.0	15.0	6mm/yr* constant
South West and Wales	-0.5	3.5	8.0	11.5	14.5	5 mm/yr* constant
NW England, NE England, Scotland (north of Flamborough Head)	+0.8	2.5	7.0	10.0	13.0	4 mm/yr* constant

*Updated figures now reflect an exponential curve, and replaces the previous straight line graph representations.

Technical notes supporting Table 1, Regional net sea level rise allowances

(i) Global mean sea level rise projections up to 2100 were taken from the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) under A1FI emissions (Table II.5.1), noting that the values for A1FI and A1T are incorrectly transposed in the IPCC report. Global mean sea level rise projections for 2115 were extrapolated.

(ii) Net sea level rise allowances are sensitive to assumptions about thermal expansion of the oceans, melt from land glaciers and ice caps, melt from Antarctica and Greenland, climate model sensitivity, greenhouse gas emissions, and vertical adjustments of the land.

(iii) Differential heating of oceans and changing ocean currents are not taken into account, but regional variations in sea level rise could be as high as ±50% about the global mean11.

(iv) Recent glacier mass balance modelling suggests that the contribution from melting mountain glaciers and ice caps may be half that used in the IPCC projections12.

(v) Recent model evidence suggests estimated contributions from Antarctic and Greenland ice melt to sea level rise will need to be revised upwards13 by as much as 5mm/yr14.

(vi) The IPCC mean sea level rise projections reflect high emissions and high climate model sensitivity.

(vii) Regional variations in net sea level rise allowances draw from latest information on vertical land movements around the UK15.

(viii) Contributions from tidal surge and waves, or the joint occurrence of fluvial and tidal flooding are not included. These effects are localised and model projections show mixed results16[,17].

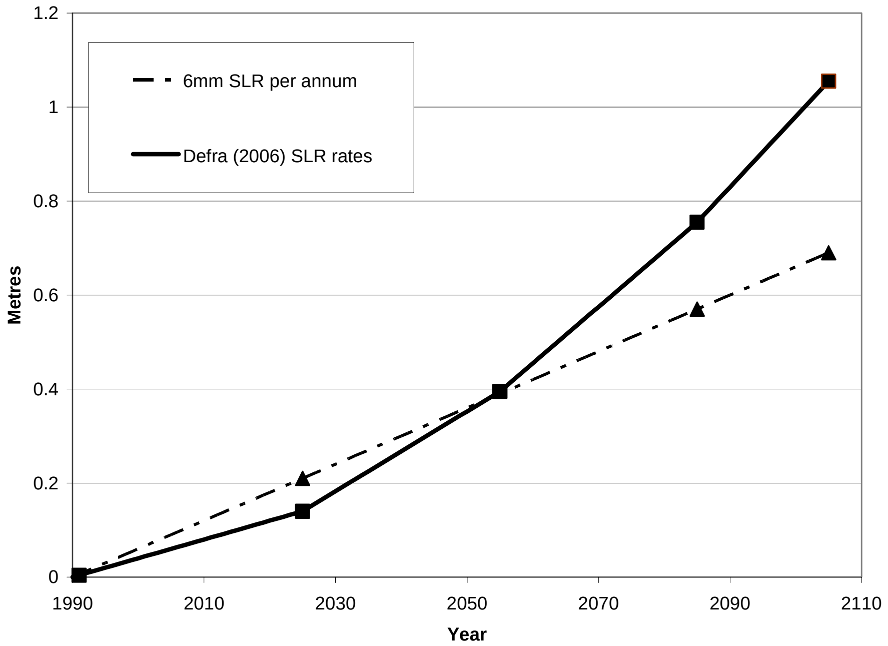
(ix) All values are given with respect to 1990 and rounded to the nearest 0.5 mm/yr.
Calculation of sea level rise is worked out using the following two examples.

For the **south west region** sea level rise in **2020**:
3.5mm/yr * [30 years from 1990) = **105mm.**
For the **north east region** in **2065**:
2.5mm/yr to 2025 = 88mm; 7mm/yr between 2026-2055 = 210mm;
10mm/yr between 2056-2065 = 100mm Total = 88 + 210 + 100 = **398mm.**

There are significant uncertainties in climate change predictions. However, figures in this supplementary guidance are considered appropriate in relation to flood and coastal risk management and planning, and should be used until further updates are provided.

Table 1: Sea level rise predictions published by Defra in 2006 as a supplementary note to Operating Authorities, defining the allowances to be used in coastal management schemes and plans.

The graph below illustrates the latest predicted sea level rise compared with previous old 6mm per annum allowance.



Graph showing sea level rise predictions published by Defra in 2006 as a supplementary note to Operating Authorities, defining the allowances to be used in coastal management schemes and plans. The new exponential curve (based 4mm/yr, 8.5mm/yr, 12mm/yr then 15mm/yr over successive future 30-year epochs, as defined in Table 1 above) replaces the previous allowance of 6mm/year. Courtesy of North Solent SMP.

4.2 UKCP09 climate change predictions

UK Climate Impacts Programme published a new set of climate change predictions for the UK on 18th June 2009 (known as UKCP09). It is a comprehensive update on climate change for the UK and will improve the understanding of future coastal extremes and future rainfall and river flows. UKCP09 not only gives data for different emissions scenarios, but across a range of probability levels.

The future coastal extremes in UKCP09 have been largely derived from work commissioned by the Thames Estuary 2100 Strategy (the TE2100 project). This research showed that current Defra guidance on sea level rise is still suitable for planning for flood risk in the tidal Thames.

Defra and the Environment Agency are considering whether supplementary guidance is required for use in future coastal strategies and management plans. All SMP2 Action Plans will have an action to consider the plan findings in respect of key new information, with UKCP09 being one of the key issues.

5. Sea level rise predictions for the Isle of Wight

The Isle of Wight SMP2 assumes that sea will rise in accordance with the allowances published by Defra (2006), in line with current guidance.

Table 2 below shows sea level rise predictions for the Isle of Wight coastline, used in the development of this Shoreline Management Plan (allowances sourced from Defra, 2006). The amounts of predicted sea level rise (in centimetres) are displayed as increases above the standard 1990 baseline sea level, or alternatively as increases from the start of 2009, until 2105.

Epochs	Sea level rise in cm:	
	From 1990 (standard baseline):	From 2009:
By 2025	+14cm	+7cm
By 2055	+39.5cm	+32cm
By 2105	+105.5cm	+98cm

Table 2: Sea level rise predictions for the Isle of Wight (based on Table 1).

The consequences of sea level rise on the Isle of Wight coast are assessed in detail in Appendix C3.

6. Managing the Isle of Wight Coast in a Changing Climate

6.1 Introduction

Climate change records from the Ventnor Undercliff lend support to the conclusions of the IPCC. An increase of 150mm or 20% in annual rainfall was recorded between 1839 and 2000 at Ventnor. Strong links between antecedent rainfall, coastal landsliding and ground movement have been reported by Lee and Moore (1991), Ibsen and Brunsden (1994) and Brunsden and Chandler (1996). These studies demonstrate the significance of wet year sequences, which are probably of greater importance than increases in average conditions and the occurrence of extreme precipitation events, although the latter are clearly important as a trigger of ground movement and landslides. In this respect, it should be noted there are many preparatory and triggering factors other than climate effects that can contribute to coastal slope instability (Jones & Lee, 1994; Hutchinson, 1988; McInnes, 2000).

It is likely that climate change impacts will include changes to the rainfall pattern, with wetter winters and drier summers. Within the context of climate change, the potential for reactivation of coastal slopes mantled by relict landslides due to increased toe erosion resulting from sea level rise and elevated groundwater levels due to increased effective rainfall requires consideration. Such slopes are identified around the Undercliff and north coast of the Isle of Wight. The exceptionally wet winter of 2000/01 resulted in intensification of reactivations at some locations and is an analogue of the conditions that might be expected to occur more frequently in the future.

Coastal erosion, land instability and flooding can impact human society and the biodiversity of the coastal zone. According to research by UKCIP (2007) the existing flora in the coastal zone has extended its growing season by a month since 1900. Climate Challenge (2007) revealed that over the 350 years of coastal water temperature records there has been a temperature increase and subsequent change in the distribution of marine species. As well as changing the distribution and growth pattern of flora and fauna, climate change can lead to the destruction of habitats and possible extinction of rare species such as the Autumn Squill found in St Helen’s Duver and the Glanville Fritillary butterfly found on the south-west of the Island at Hanover Point.

The Isle of Wight Council, along with other local authorities, have taken steps towards an active approach to the challenges of climate change. The Nottingham Declaration (2000) was developed with the view that the major role belonged to the local authorities. The Declaration acts as a ‘pledge’ towards their active role in climate change by working towards three main approaches:

- Acknowledgement of climate change;
- Welcoming international and national policy as well as benefits climate change can bring;
- And a commitment to work with international and national councils as well as communities.

In May 2007 the Isle of Wight Council made an important and lasting commitment to address the causes and impacts of climate change through its signing of the Nottingham Declaration, recognising in doing so, that climate change is likely to be one of the key drivers of change within the Isle of Wight community over the next century. The Declaration will commit the Council to a significant decrease in greenhouse gas emissions from its own operations as well as encouraging all sectors of the local community and its partners to take the opportunity to act in a similar way.

Understanding the risk management framework and the broader social and political context provides a basis for speculating about how climate change and sea-level rise will impact upon the European coastline over the next 100 years or so. It should be stressed that because of the nature of social systems, there is probably more uncertainty as to how society and politicians will respond to these changes than their impact on coastal processes.

6.2 Increased Demand for Coast Defence Funds

Over the next 100 years, climate change and sea-level rise will result in an increase in the probability of damaging events. However, it is uncertain as to how the operating authorities will be able to manage the increased risks. To maintain the current standards of coastal protection will require considerable investment in defence improvements and maintenance. The risk management framework will need to adjust to increased competition for financial resources.

One possible consequence is that defences that are currently protecting marginally economic and clearly uneconomic sites will either be abandoned or maintained at a lower standard of protection. It is possible that there will be modifications to what are considered to be acceptable risks and suitable standards of protection. It should be appreciated, however, that society has become less risk tolerant. It follows that there may be a need to improve the standards of protection in high-risk urban areas to reflect these trends. This would lead to increased polarisation in the exposure to risk experienced by individuals in built up and rural areas.

6.3 Biodiversity

The vast majority of the English landscape is fragmented. As a result, many of our important species are effectively constrained to relatively small, isolated wildlife areas, with sharp boundaries between them and adjacent land sites of unsuitable habitat. This makes species unable to move in response to a rapidly changing climate (Environment Agency, 2007).

However, it should be noted that a changing climate presents opportunities as well as risks. Though some habitats will most likely be lost in a particular area due to climate change, other habitats may thrive under the new climatic conditions.

6.4 Increased Competition for Coastal Resources

Climate change and sea-level rise is likely to generate additional pressures on a variety of coastal zone uses, from tourism and amenity uses, marine aggregate extraction (e.g. for beach feeding programmes), port and harbour operations to nature conservation and the protection of historical sites and monuments.

These and other pressures will be manifest in heightened competition between different interest groups over how best to manage coastal resources. As society's values and political attitudes towards social welfare change, so the rationale behind the public subsidy of private property may be challenged. It seems likely that the debate over the true costs (financial and environmental) and benefits of coastal defence to society will develop and intensify. This could lead to modifications to the risk management framework, especially greater emphasis on environmental and social costs in the project appraisal procedures.

The need to reconcile competing demands on limited resources will probably lead to the risk management framework becoming more complex, with a greater need for formal consents and consultation, with more formal public participation in the decision making process. There may be greater opportunity of trade-offs and bargaining. Further delays and increased expenditure on plan development and implementation are, perhaps, inevitable. The ever-increasing complexity of the framework will reinforce the institutional barriers to innovative solutions to coastal defence issues, favouring the status quo.

It is clear that both the physical environment (increased hazard) and cultural environment (changing attitudes and priorities etc.) will be sensitive to the effects of climate change and sea-level rise. The legislative and administrative framework, however, is likely to be relatively insensitive, being the product of gradual evolution rather than radical change. Thus, there will be a tendency to attempt to address climate change and sea-level rise within the existing legislative and administrative framework.

6.5 Co-ordinated Decision Making

There is a need to consider the possible compoundment of risk due to continued management of the coastline, i.e. raising flood defences, toe protection measures. Clearly this is idealist, but the point should be made that defences do fail, and the stresses to be placed on defences in the future will clearly be greater given climate change and sea-level rise. This means that the chance of catastrophic failures will be increased, especially if funding and engineering designs are not factored up to accommodate these stresses. At the same time we have increasing pressure for development in hazardous places which often takes place where defences are in place giving a false sense of security - the risk remains; consequently the potential losses are also increasing. Decisions by planners, developers and the engineering fraternity are often taken in isolation, when clearly there is a need to consider these 'holistic' consequences at an early stage of decision-making (pro-active) rather than dealing with the disasters and clear-up that may well have been avoided.

There are two responses to climate change – mitigation and adaptation. Mitigation measures are actions to reduce human impacts on the climate system, by reducing our emissions of greenhouse gases. Adaptation measures are actions in response to climate changes. Mitigation and adaptation measures may be interrelated. The Environment Agency's Guidance for Practitioners states "Our response to climate change needs to include both adaptation and mitigation: we should aim to manage the unavoidable and avoid the unmanageable" (Environment Agency, 2007).

7. Conclusions

There can no longer be any doubt that our climate is changing. Whether this change is caused by anthropogenic or natural factors is not the issue – the impacts of a changing climate are already being felt globally. Extreme weather events are a major source of climatic-related impacts and it is predicted that climate change may increase the frequency of severe weather events. Given that there exists strong links between weather patterns and coastal processes, there are clear implications associated with our current knowledge of climate change. Risks associated with climate change are increasing and will continue to increase according to most global climate change scenarios.

Key Strategic Issues

- Climate change is a key driver of flood and coastal erosion risk; this will be an integral consideration in strategic decisions;
- Climate change has the capacity to alter almost all coastal processes and landforms;
- Coastal management policies should aim to be sustainable in the context of this long term change.

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