REPORT

SXG 390

"A review of the understanding of slope stability, geo-morphological changes, landslides and their causes in coastal areas of S. and SE England, in relation to the implications of climate, climate changes and land-usage."

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Abstract:

An elevated public awareness of 'green' issues now exists and with this awareness comes a political need to commit government to address associated issues. Coastal erosion is only of concern when it affects communities, amenities and the potential for further development. It is a natural process but the interface with community raises issues of risk assessment, hazard potential, loss of amenities, land and life. Coastal protection and shoreline management have recently taken on a creative approach recognising that hard-engineering schemes, a favourite of previous decades, is not only expensive but a fundamental interference in what is already a complex system. South-east England is endowed with a characteristic interleaving of Cretaceous chalk, permeable sandstones and glacial clays, strata that contrive to facilitate water ingress, the propensity for slip planes and the potential for bulk sliding, falling and reworking. Considerable folding and faulting occurred during the Miocene in areas such as Dorset, the Isle of Wight and the (inverted) Weald and created today's dip angles biasing the morphology of strata towards greater instability and exposure to the effects of climate and marine dynamics. The anticipated rise in sea level and the polarisation of climatic changes predicted for south-east England towards hot, dry summers and stormy wet winters also contrive to aggravate what is already a delicate and exposed system that has experienced significant degrees of erosion in recent and more distant periods. Landslips and erosion affect populations and amenities and should therefore be the focus of detailed analysis, attempting to rationalise hazard potential and assess risks to community. This report examines the research and data available, attempts to assess current strategies used in controlling changes to coastal environments, monitoring and recording changes in coastal morphology, and considers future strategies and their strengths and weaknesses in the light of climate change predications.

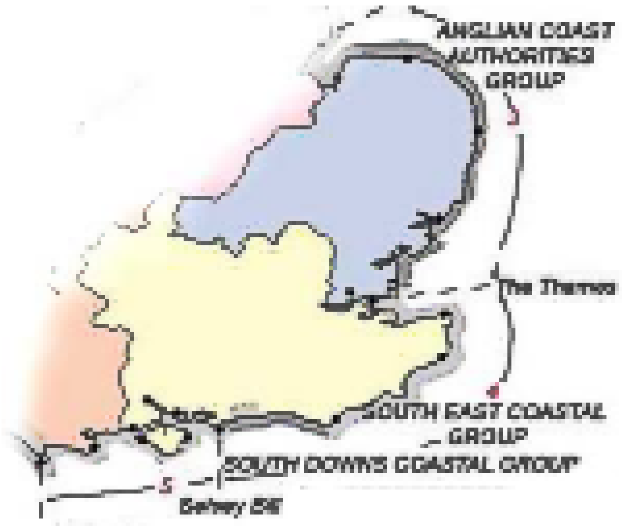
Key Words:

Climate, SE England, Coast, Landslide, Erosion, Slope-stability, Hazard, Risk, Flooding, Salt-Marsh, Managed realignment, Managed relocation

Preface

The prospect of climate change brings with it the possibilities of major new hazard concerns. Combined with these anticipated changes, the geology and urbanization of many coastal zones in the south and east of the UK elevates the need for a new series of risk assessments.

The likelihood of land-movement in the area covered by the map alongside is directly related to the lithology, the dip of the strata, the prevailing wind direction and fetch, (*there is a 3000km fetch to the North of Norfolk*) the currents and the morphology of the submarine shore and shelf features and of course, the climate.



Several of these influencing factors have remained broadly the same for a long time whilst the prospect of changes in wind direction and strength, current direction and strength and sea level may reduce the effectiveness of many of the protective defence structures currently in place around the UK coasts .

This scale defined by this report can only realistically consider some aspects of the issues in need of reflection and will therefore focus mainly on the Norfolk to Sussex section of coastline.

W. Richmond   September 2003

List of abbreviations / acronyms

DEFRA	Department for Environment, Food and Rural Affairs
MAFF	Ministry of Agriculture, Fisheries and Food
LOIS	Land Ocean Interaction Study
SCOPAC	Standing Conference on Problems Associated with the Coastline
UKCIP	United Kingdom Climate Impact Programme
EA	Environment Agency
OCRM	Ocean and Coastal Resource Management
NRA	National Rivers Authority
GIS	Geographic Information System
LIDAR	Light Direction and Ranging

Contents

Index for Report and Review sections

References for the Literature Review

References for the Main Report

Page list for Appendix Figures

List of tables

List of figures - Literature Review

Appendix Page

List of Photographs

Introduction:

Around 70% of the world's sandy shorelines have been retreating over the last 100 years [1] and with sea level predicted to rise this percentage may increase further. Sea level rise will exacerbate erosion of exposed cliffs and shorelines resulting in a greater likelihood of falls, slumping and landslides. Given this outlook, it is not surprising that academics, polticians [2], planners and developers work to gain an insight into likely outcomes. Planning for development, especially in coastal zones, involves a variety of risk assessments of potentially unstable land [3].

The principle cause of rates of future coastal changes is considered here to be climate-change and it is this topic that may partially be responsible for the renewed interest and heightened levels of research. Reviewing an apparently increasing volume of papers and publications covering issues associated with erosion and environment does not in itself indicate that more papers are being produced, but perhaps that researchers now perceive a greater 'market of interest'. The prospect of rising sea level and a change in climate, a change that is expected to produce polarised extremes of temperature and precipitation, might reasonably be expected to have an impact on the dynamic response of those slopes that are even now currently considered 'less than stable'. It is therefore proposed to examine the papers and publications relating to the expected scale of change in climate and the implications that are allied to those changes.

Lithologies of Southern Britain include glacial clays, marine and fluvial sands, shallow and deeper water carbonates and also include some of the finest examples of Jurassic strata in the world. Through faulting and folding these exposures present tremendous potential for erosion and the creation of unstable slopes. Past engineering developments around the UK's coast have not fully understood the geological stability/instability of some areas and consequently risk and hazard assessments find their way increasingly into the domain of local authorities and planning. The magnitude of the requirements necessary for 'fuller control' of the environment direct attention to more creative strategies; strategies to minimise the impact of hazards that could have financial implications as well as involving the possible loss of human life.

The history of UK coastal regulations is complex and has culminated in responsibilities being centred on small authorities. Legislation is in need of reform but the scale of the task is large and political will is unlikely to challenge the task in its entirety. The element of co-operation seen in this initial report indicates that first steps to address many issues are being taken.

The extent of academic study and research is expanding as the implications of climate change become more apparent to communities, the scientists and politicians and with this expansion of interest follows the onus of responsibility for applying some degree of control.

Literature Review

Climate Change

A significant part of this study must relate to climate change and scenarios based on different CO^2 and other emission levels[4]. Numerous resources examine the issues from political and sociological angles but a detailed scientific resource is found in the UKCIP02 Scientific report[5] which itself is the culmination of collaborative projects between DEFRA[6], the Tyndale[7], and Hadley Centres[8]. This collective approach has only emerged in recent years following the last decade's (1990-2000) designation as the 'International Decade for Natural Disaster Reduction'[9] Scenarios represented in the UKCIP98 report used a coarser cell structure, lower anticipated carbon emissions, higher sulphur emissions and wider ranges of climate responses,[10] resulting in lower temperature predictions than the more recent UKCIP02 report. However it was a significant collective attempt to represent which conditions might prevail in the future. It is clear from the Hadley Centre research that temperatures have been rising steadily for some years and whilst patterns to 1970 can be accounted for by natural global fluctuations, the recent changes can only be accommodated by inclusion of human activity/emissions. (Appendix Page 2 - Chart 1)

In the South East, the South East Climate Change Partnership[11] reviews relevant parts of UKCIP02[12] for those regional organisations affected.
Additional research is initiated by SCOPAC[13] – The 'Standing Conference on Problems Associated with the Coastline', a Hampshire organisation comprising UK authorities concerned with coastal issues and interested parties along the South coast. This group covers the Isle of Wight and coast between Shoreham and Lyme Regis. Its association with Halcrow[13a] resulted in "Preparing for the Impacts of Climate Change" [14] and included remarkable conclusions regarding potential reversal of longshore drift (from net East to a net West vector) along the South coast (p. 383 para 1). If this reversal were to occur the sources and sinks[15] illustrated in SCOPAC's[15] detailed maps would dramatically alter with implications for communities currently at risk of flooding from predicted sea level rise[16] Detailed study of these currents and submarine bedforms has been published [17] and a comparatively thorough understanding of sediment movement obtained. It is alarming to consider the suggested current reversal and consequent introduction of a completely revised dynamic sediment system with equally alarming implications for existing defences.

The Land Ocean Interaction Study (LOIS); an initiative attempting to bridge the gap between research and management (1992-1998)[18] –sited on the North Norfolk coast and estuaries; examined issues associated with environment and habitat at the land / sea interface. Conclusions and data (2000) - were distributed on CD-media to laboratories and research institutes. Issues of remote sensing and monitoring were raised in the study[19] the results of which are reviewed by

Neal et al (2003),[20] and which also considered dredging, coastal reclamation and erosion patterns.

Observations of how climate change might affect landslide frequency have been undertaken, as in Collison, et al. (2000)[21] report covering the Hythe area of Lower Greensand escarpment. (appendix page 7 – Fig 15) The report's findings balance anticipated increased precipitation with increased evaporation and conclude little change in frequency or scale of scarp movement but does not take into account the predicted *extremes* – predictions that have only been revised as climate-modelling becomes more detailed.

Coastal Management and Regional authority

Historically, control of UK coastal zones has been the province of several agencies acting under complex piecemeal legislation dating back to the middle ages.[22] (Appendix Page 3 - table 2)[23] – agencies not directly concerned with issues outside their own area. River and associated flooding risks have been the responsibility of the National Rivers Authorities (NRA) whilst shorelines have been the concern of MAFF (now replaced by DEFRA). Erosion of coastal-land areas is primarily a concern of local councils managed and reviewed within regional shoreline-management schemes.

This fractured approach has caused significant co-ordination problems and experience has demonstrated that the arrangement has been illogical and inefficient.[24] A variety of papers have reviewed this issue – from the efficiency perspective[25] and by comparison with other countries – notably New Zealand – where a large scale reorganisation was implemented in October 1991.[26] Associated with issues of development in coastal zones are issues of insurance and risk assessment. The risk aspects are addressed by Downing, Olsthoorn and Tol's book "Climate, Change and Risk"[27] The issue of soils prone to clay-shrinkage subsidence in the UK, is reviewed in detail.

Geological strata, shoreline morphology and landslide classification

Geological strata of sections of coast under review have been accessed. Norfolk and Suffolk[28], Essex,[29] Kent[30] Sussex,[31] Hampshire[32], Dorset[33], and are well documented with geological histories and illustrative mapping. Norfolk's low-lying[34] concerns, characteristics,[35] and geological structure[36], and the isostatic-compensation effects on the South East, contrive to accentuate the anticipated effects of a possible sea-level rise of 79 cm by 2080[37], more usually quoted as between 0.4 and 0.9 metres[38]

'Green awareness' (and recent instances of flooding) have elevated public concern - drawing heightened funding and focus into planning and management strategies.[39] Regional sectioning of the coast has resulted from heightened concerns[40] and is evident in regional sensitivity to proposed development (and aggregate removal[41]) as part of planning strategies for Norfolk. Sections of Norfolk and Essex coasts have been lost to the sea[42] whilst other sections have been drained over several hundred years and with the trend towards re-establishment of Salt marshes as a sea defence[43] gaining ground - if one can use that phrase in the circumstances - detailed assessment of specific localities is now seen to be occurring[44].

Landslide dynamics are categorised and analysed to identify causal factors, (Table 4 – Appendix – Page 5) many of which are embraced within lithologies of the Southern UK. The clay, sandstone, chalk lithologies are covered under several sections of Table 1 within "*Landslide causal factors and landslide remedial options*"[45] (Popescu (2002). This paper expands on the criteria of categorisation used by the UNESCO Working party on World Landslide Inventory – that of Varnes (1978)[46] - which grouped movement into falls, flows, slides, spreads and topples. Further remedial options are considered in Crozier (1984)[47]

Some of Varnes' (1978)[46] characteristics can easily be recognised in lithologies of the SE and are briefly listed here:

Table : A

Characteristic	**Zone / Concern**
Plastic / weak materials	Wealden clays, Gault, Lower Greensand Kimmeridge clays, Glacial tills
Jointed, fissured and sheared materials	Dorset / Hampshire faulting and folding zones and ancient landslides (Isle of Wight)
Contrast in Permeability	Sandstones, clays, muds and chalks e.g Bagshot sands / Claygate Beds & London Clay [48], Tills
Gypsum dissolution	High Weald – Jurassic sections
Isostatic rebound from glacial covering (Geo-isostacy)	Sheerness (relative rate of rising sea-level) – increased exposure to wave effects – Generally the SE
Wave and storm erosion of the slope toe Mechanical excavation of slopes and toe of slides	Much of the coastline of the SE and developments as recession is experienced and beach slopes increase [49] Aggregate removal along many parts of the coast – both recent and historic [50]
Erosion of lateral margins (Isle of Wight - Erosion around many emplacements)	Following falls and slides – unloading of adjacent material. Changes in dynamic env.
Artificial vibration	Many sites with roads and paths sited along cliff edges
Hydrological changes	Intense – short period rainfalls or prolonged precipitation - UKCIP98 and UKCIP02 – increase in pore water pressures. Wave force
Shrink and swell weathering of expansive soils	Wave attack on cliffs – boundaries between lithologies. Plastic & shear values (Bell [50a]) Characteristics of London clays
Loading of the slope at crest	Roads – Coastal cliff top development – changing relation between cliff top developments and defined edge of cliff

Popescu (2002), includes an additional table of remedial measures / techniques (Appendix – pages 5/6 – (tables 4 and [remedial measures] table 5)

Offshore morphological changes following removal of aggregate for building from beaches and offshore has occurred in several places. This can potentially contribute to several criteria listed above.[51]

Aggregate is used as bulk material for beach feeding (e.g.. replenishing the eroding spit on which Dungeness Nuclear Power station is sited[52]) and for other shoreline defence strategies despite experience demonstrating the inadvisability of *steepening* beach slopes, (as can happen when beach aggregate is added) or otherwise intentionally or inadvertently facilitating 'natural' steepening[52b]. Wave dynamics dictate their destructive potential; in deeper water the mass of the wave imparts its momentum into the face onto which it moves. It follows that in shallower water, waves will have dissipated most energy before breaking.[53]

Fred Bell 1999 ("Geological Hazards" – Chapter: Coastal Erosion) cites the period of *destructive* waves as being around 4 seconds whilst higher frequency waves, (approx 7 second period) can be constructive.[54] Bell also identifies zones of net erosion and deposition in a schematic section of beach[55] The same wave dynamics will alter lower slopes of beaches through the circulatory movement of water beneath breaking waves. The erosion caused by this effect during storms could effectively remove toe support from unstable (landward and submarine) slopes. It will only be through the total absorption of all such knowledge that a fuller understanding of processes will be achieved.

Understanding, observations and learning from experience

Cornelia Dean, in reviewing the destruction of beach properties on America's (particularly eastern seaboard) coasts (in "Against The Tide")[56] identifies several case studies in which a lack of understanding has led developers into ill-conceived construction exercises. These include the building of Galveston[57] on its 33 mile sand spit with a mean elevation of less than 2 metres and the dramatic rebuilding of the town following the September storm of 1900 in which 20,000 people died. The application of accrued knowledge might be expected to be applied in new developments[58].

Mapping and Imaging

Besides an understanding of processes the management of shorelines must be the result of careful recording followed by monitoring. Canfield and Morang (1996)[59], in their papers produced for the US Army Corps of Civil Engineering research, conclude that a major deficiency in registering coastal assessment images is the lack of control-point features. Given the responsibility for management of coastal environments it will be *necessary* for regional authorities to effectively monitor their zones. The technology facilitating this is rapidly improving as the needs of government and authorities gives 'technology push' to new techniques[60]. Geomorphology is evolving – stereo-imaging of coasts is being replaced with satellite images, LIDAR, IKONOS, and high altitude photography,[61] using a range of frequencies and with the aid of GPS referencing, a national resource of data may be developed.

The integrated mapping of UK marine and coastal zones through projects such as the MAFF / CEFAS (Centre for Environment, Fisheries and Aquaculture Science) 'Marine and Coastal Mapping Project'[62] may allow referencing of land movement and even prediction within areas of known concerns.

'Interferometry'[63] has already been used in detecting ground movements associated with tectonics and igneous processes and is seeing increased use in sedimentological studies. As a tool for recording topographic[64] coastal changes the system currently lacks the large-scale database of coastal regions.

(appendix - page 9).

A number of papers examine the remote sensing potential[65]. Many look at the sociological aspect of urban growth – an area of study of which coastal development is just one facet. Mapping techniques progressed during the Mars Orbiter programme on board 'Mars Global Surveyor' (1997-2001) when a 10Hz pulsed Infra-red-ranging device was used. This has been named the Mars Orbiter Laser Altimer (MOLA) and ultimately gave an accuracy of vertical resolution[65] of +/-1 metre. The resultant DEMs[66] have given the potential for another means of accurate morphological recording. Geomagnetic analysis using geophysics-sensing can also be used and to reveal water content in strata.[67]

Storms and waves – Flooding risk and hydrological effect on sediments

A significant feature of the southern North Sea (Norfolk, Kent and Essex coasts) is the increased exposure to storm surges through current dynamics originating in the North Atlantic. The storm-elevated sea surface sweeps through the North sea's 'northern entrance', rising onto the continental shelf and shallower water. The surge builds to a greater height which under the coriolis force (moving the vector clockwise) forces elevated waves and tides onto UK shores - continuing to rotate and elevating still further so representing a greater threat to German, and especially low lying Dutch coasts[68]. This process contributed to the (3 metres surge-elevation[69]) catastrophic 1953 East Coast flooding[70] [71]

Managed Relocation – the last resort

A suitable point to end this review might be the resort of 'final retreat'. '*Managed relocation'* has to be a final admission that we should always be at one with our environment. A recent UK example of technological application to resolve the issue of property safety and cliff erosion lay not in the control of the 100 metre high chalk cliff on which the property stood but in the moving of the 850 ton Belle lighthouse [72] 74 metres away from the cliff edge over a period of 3 months. It had taken from 1834 to the time of moving (1998) for the cliff to erode to within 3-4 metres of the lighthouse. This situation is unlikely to happen in Carolina USA [73] as the 1960's building regulations require that coastal houses should be on raised piles – removing flooding susceptibility and allowing relocation.

The surest facts must be Orrin Pilkey's "Truths of the Shoreline" [74] that includes the statement "The interest of the beach property owners should not be confused with the natural interest."

One might as easily replace 'beach' with 'coastal' and 'natural' with 'national'. The principle would be the same.

Report

Climate, Risk and Losses

There has been a noticeable alteration in climate in the past few decades in the south-eastern UK and modelled scenarios of climate-change[1] outline conditions that may lead to elevated extremes of temperature and precipitation

(**Report appendix - Fig 1**),

In 1990 climate induced storm damage cost insurers $15 billion, whilst damage through drought resulting from the last major dry spell of 1975-76 cost British Insurers £100 million. Additionally, drought damage between 1989 and 1996 totalled £2 billion[2] The scale of these climate induced losses has focused insurers and authorities on examining the means by which climatic changes and associated hazards can be understood. A scientific understanding is essential to the assessment of the risks associated with the potential hazards that such changes in the environment, as predicted in the UKCIP scenarios, would cause. The frequency and scale of coastal landslips and erosion may well change and thus dramatically change the risks of flooding.

A 'hazard' has been defined as "*a threatening event, the probability of the occurrence of a potentially damaging phenomenon within a time period and area… and with the potential to damage some aspect of human welfare*" [2], and by this definition clearly has a human perspective.

With the prospect of loss of life, property and amenities resulting from erosion and landslips, a significant series of geological-hazard risks exist.

Urbanisation of the coastal zone

The sea is the major force affecting coastal land movement and various engineering solutions for manipulating this force have been developed.
UK coastal defences have been installed over hundreds of years to meet demands for stabilising and occupying coastal zones but without human intervention the dynamic coastline will retreat under transgressive conditions, or when sediment supply is low, and advance as sea level falls, or sediment supply increases [3]. (**Report appendix - Fig 2**), The human perspective that perceives the landward change as a problem has labelled it 'coastal erosion'. It arises when the natural cycle cannot occur because the coastal zones have been occupied and defended with permanent structures. The situation becomes more anthropocentric when employment and economic concerns are overlaid on those associated with simply preserving the structures of the coastal zone.

One half of the UK manufacturing industry is located near coasts along with half of the UK power generating stations and perhaps significantly, *all* petrol refineries.[4] A significant percentage of the UK population live within 30 miles of the coastline [5] and a brief look at the maps produced by the Environment Agency shows the level of flooding risk to the population, particularly of the south and eastern counties of England, if breaks in either natural or artificial defences were to occur and the sea were to flood the land. [6] (**Report appendix - Fig 3**),

Erosion of the coastline

Sea-level rise, droughts, land movement, storm surges and coastal inundation can all be associated with scenarios of climate-changes and given the proximity of communities within coastal zones and the continuing practice of building on land at risk to flooding, it may prove particularly difficult and costly in the short term, and impossible in the long term, to maintain our current level of coastal 'defences'.

(An analysis of land use in Norfolk by the Norfolk Coastal Management group (200 km coastline) shows approximately 50 % being used for residential, industrial, commercial, public or leisure use and a further 37 % for agriculture. [7])

(**Report appendix - Fig 4**)

Brunsden and Ibsen (1993) [8] provided figures relating to rates of coastal retreat along the western part of the South coast. These highlighted a 25metre yr^{-1} rate at Budleigh Salterton between1981-85 and an average rate of retreat of 2.4m yr^{-1} at Charmouth, Dorset between 1914-1970. Many other locations suffer less than a metre a year but such apparently minor losses accumulate over time and threaten coastal zone developments. On the East coast similar rates are seen but here there is a significantly greater exposure to flooding risk should the sea gain access to the low-lying flat tracts of Norfolk, Essex and Suffolk.

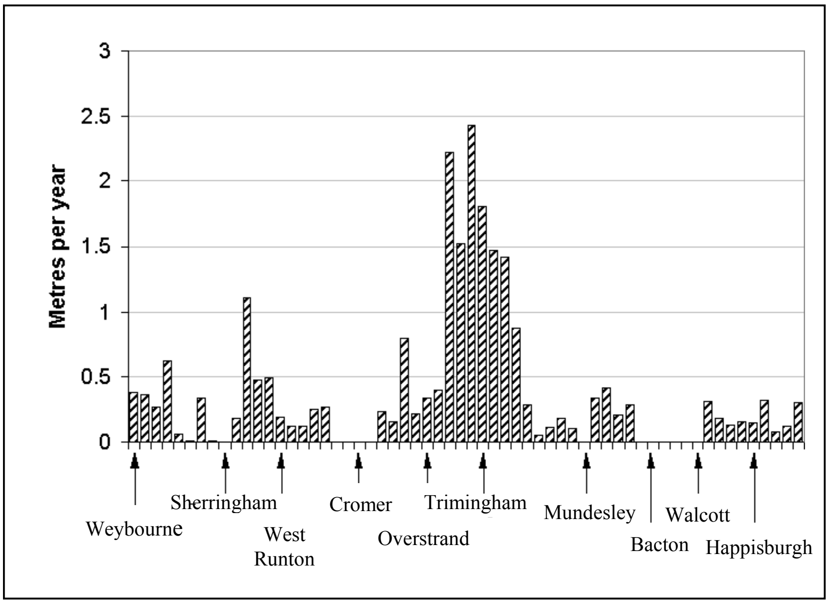


Table 1

Chart showing differential erosion rates for sections of the Norfolk coast as influenced by lithology [9]
Source : http://www.northnorfolk.org/coastal/doc1.html

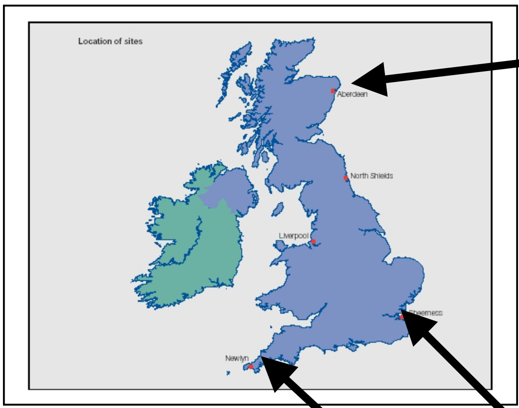
The lithology of the Norfolk coast and its susceptibility to erosion

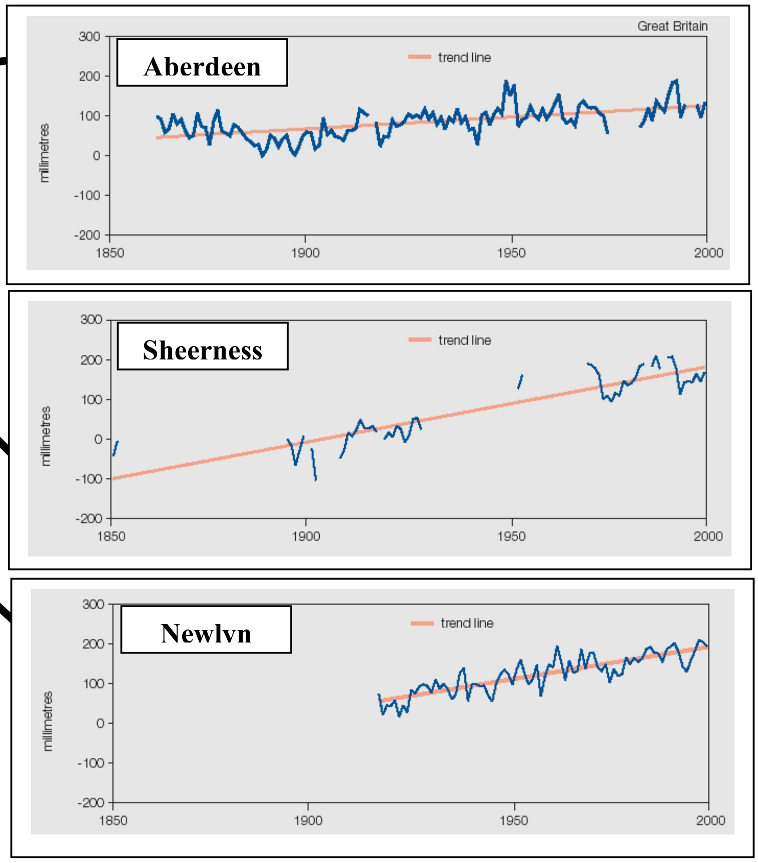
Photo courtesy: Martin Warren. Norfolk Museum/Archaeology

The 220 km of Norfolk coast is composed of Pleistocene gravels and sand deposited during the advance and retreat of major ice sheets [10]. Northernmost sections dating from the Anglian (300,000-250,000 BP – the Cromer Till), North-western sections from the

Wolstonian (200,000-150,000 BP - the 'Basement till') and eastern, southern and superficial tills from the late Devensian. (25,000 – 10,000 BP). (**See Figs 5 and 6 – Report Appendix** The cliffs are between 20 and 75 metres but all are unconsolidated and consequently exceptionally prone to undercutting by hydraulic action of incoming wave fronts and corrasion, producing gravity falls, slumps and slips. The translational failure that follows allows slumps and slips to develop into landslides supported by a 'toe' of the fallen material. (**See Fig 7 – Report Appendix**) The 'toe' is then itself eroded by further wave action removing support from the remaining material. In this way erosion and recession of cliffs along their length takes place. All unconsolidated sediments along the East Anglian coastline are additionally prone to saturation in periods of heavy rain. Excess water content (elevated pore water pressure) allows the development of slip surfaces at levels within the strata where permeability or cohesive strengths are slightly different. Bell (2001) showed that with glacial Norfolk sediments and as little as 2 ~ 2.5% additional water, on overall reduction in residual strength of 70-75% followed. [12] The combined situation of unconsolidated sediment, rising sea level and extremes of both storm frequency and magnitude, along with extremes of climate from desiccation to waterlogging (UKCIP02), could only be worsened if the whole area were to be tilting gently downward to meet the sea .

Isostatic readjustment, attributable to the removal of Northern ice sheets (glacio-isostacy) is creating exactly this situation in the South-East where, as the North experiences upward tilting, the South moves downward.





Charts showing an historic rise in sea level in the Southern areas of the UK. Between 1850 and 2000

Source :

NERC Proudman Oceanographic Laboratory [13]

The charts show a significant slope of relative sea-level rise for the southern locations when compared to the slope for Aberdeen.

North-east Norfolk and the sediment budget

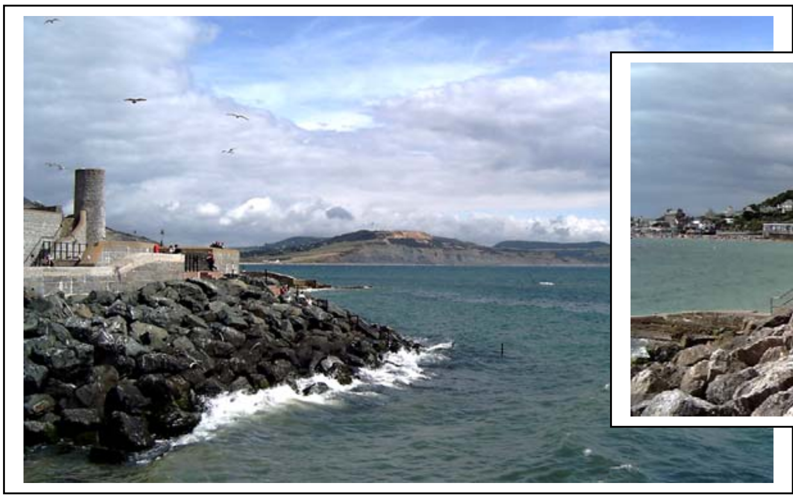
The vulnerable North-eastern section is comprised of Wolstonian glacial tills, sands, clay [14] and silt with no hard rocks present. These deposits lie on a chalk and flint bed, a bed gradually being dissolved at any interface with the sea. The sandy till sediment from the erosive processes is re-deposited as offshore sandbars, and in some places, barrier islands (e.g. Scott Head island). This type of 'bar and barrier island' coastline is uncommon in the UK but frequently found elsewhere, including Denmark, Holland and along the eastern USA. However satellite images (Baars, 2003)[15] show that plumes of Norfolk sediment are carried towards the Southern Bight and the Dutch coast and there is therefore a net loss from the area. [16] This concurs with an assessment of the sediment budget for Norfolk, (McCave, I.N.) whose paper [17] identified sinks and sources around the Norfolk coastline and quantified supply as being dominantly from the erosion of Northern and North-eastern cliffs[17a], of Coverhithe, Dunwich and Walton (approx 800,000 tonnes a^{-1}) with deposition of sediment in the Norfolk area of only 100,000 tonnes a^{-1}. (see appendix Fig 9 [table 1] & Fig 10) Silting in the Norfolk marshes accounted for a further 100,000 tonnes, but whilst reclamation projects undertaken since Roman times increased the usable land area, much of it is below sea-level [18] and at risk of flooding. Only the rapidly eroding North-eastern coastal features protect these low-lying areas.

Defending the coast

Of the UK's 18,000 km coastline, 750 km comprise the East Anglian coast, within which there are many 'defended' sections depriving the sea of sediment to redistribute along other coastline lengths. A 1998 report[17a] estimated that of 1000km of actively eroding coast in 1900 only 200 km now remained with no hard defences. There is therefore an impasse in that the sea is not allowed to rework parts of the coast and so adjacent 'undefended' areas are starved of the possibility of accretion. In consequence they frequently erode at an increasingly progressive rate, removing small hamlets and isolated properties as well as undeveloped coasts that ironically are often the most aesthetically pleasing environments.

Isolated cliff top properties and small communities frequently do not see the resultant benefit of coastal defence structures and may in fact ultimately be destroyed *because* of defence structures elsewhere.

Along exposed coastlines, particularly those of unconsolidated sediments, considerable natural protection can be gained from broad shallow-shelving beaches onto which the force of breaking waves and storms can be dissipated.[19] Observations of similar coastlines in the USA (with bars and barriers), has shown that beach dunes build during storms and surges, providing material for re-working in future swell periods when the material is removed and deposited in bars and islands, again to be later removed and returned to the dunes when stormy conditions return. This natural cycle is broken by coastal urbanisation. Without the protection of beaches and dunes the force of the sea directly confronts coastal-zone development and any remaining beaches are quickly removed as the beach slope steepens,[21] leaving few further options for defences. The frequently used traditional main defence of the sea-wall ultimately begins to fail. Following the 1953 storm in the North Sea, (see appendix fig 22) defences were built and it is now estimated that 60 % of these urgently need repair[21a]. This repair frequently takes the form of the addition of rock 'rip-raps'



Photos : W. Richmond

Rock 'rip-rap' placed to protect the sea wall at Lyme Regis, Dorset provide an unsightly last defence against winter storms when any remaining beach has disappeared through erosion.

Past attempts at protecting fragile coastal environments and manipulating rates of change positioned groynes, sea-walls and revetments [22] along the coast.

It might be argued that the understanding of coastal dynamics has still not been achieved as interference has exacerbated erosion, and through the application of economic and 'political pressures' the UK authorities and coastal inhabitants now find themselves defending property and assets in locations that cannot realistically be protected. It is understandable that coastal property owners have their own viewpoint when new sea-defence issues are raised but the impacts on adjacent coastal areas seem frequently to be of less concern.

Dixon and Pilkey in "The Corps and the Shore" [23] detail the frequent instigation of projects on the Eastern USA coasts, politically driven projects which purport to benefit communities in coastal regions but more often result in benefiting property owning individuals [24]. Only in recent years have some US states required that new coastal zone buildings must be designed to be moveable [25] and that following individual property damage of greater than 50% the property should not be rebuilt [26]. Several areas on the eastern coast of the USA have a similar 'beach, sandbar and barrier island' structure to that of Norfolk [27] and reference to those areas is therefore relevant. Engineering solutions used in the USA to stabiles coasts have clearly been studied and implemented around the Norfolk coastal environment.

Off-shore breakwaters might be considered more benign in being designed to allow a continuation of sediment movement in longshore currents whilst dissipating onshore wave energy and limiting beach and dune material loss. The design depends on reducing currents to allow sediment deposition from transport-suspension facilitating prograding of beaches. Similar breakwaters are now controversially being used along the coast of Norfolk at Sea Palling [28]

The formation of tombolos indicates that whilst accretion is taking place, erosion must be occurring downdrift through sediment starvation.

Tombolos forming behind offshore breakwaters at Sea Palling, Norfolk.

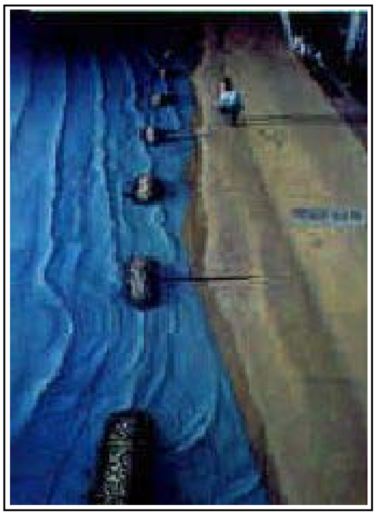
"The project functions by reducing incident wave energy that reaches the shore thereby reducing sand losses and hence erosion" [30]

Far from 'reducing sand losses' along the coast at Sea Palling, accretion is occurring. If accretion occurs to join breakwaters to the shore - no longer allowing a long-shore current, then sediment starvation must be occurring elsewhere and the breakwater cannot function as intended.

Pictures: 'Quarrying Today' – (Quarry Products Association) - Spring 2001 Issue 9 p.6
Aerial view : source Multimap – Sea Palling breakwaters Norfolk

A similar structure producing accretionary tombolos (at Presque Isle, Lake Eerie Pennsylvania) drew the verdict that the structure had been "too successful" [30] in its effects. Despite its failure to wholly meet its design-function it went on to win coastal engineering merit-awards.

Presque Isle shoreline erosion project. – (Model and Installation) Lake Eerie , Pennsylvania. **US Army Engineering Corps.**



An alternative, but expensive solution would be that of beach feeding, in which the protective beach-slope is recreated . This has been practiced along the Norfolk coast and replaces lost material with suitable sediment from elsewhere. The sourcing of suitable sediment is a problem and has traditionally come from deep-water aggregate dredged off shore. A combination of dredging, North Sea oil removal and natural processes has resulted in lowering the bed level of the North Sea, inadvertently creating deeper water and more dynamic wave-action along the coast. Rising sea level and storm surges do not help the situation. Dredging is therefore considered undesirable in many places and the stability of the re-created beach is not guaranteed. In the USA, Ocean City beach was replenished at a cost of $ 2.5 million and remained in place for only two months. Between 1962-95 the same beach was renewed 22 times, costing $83.1 million[55]

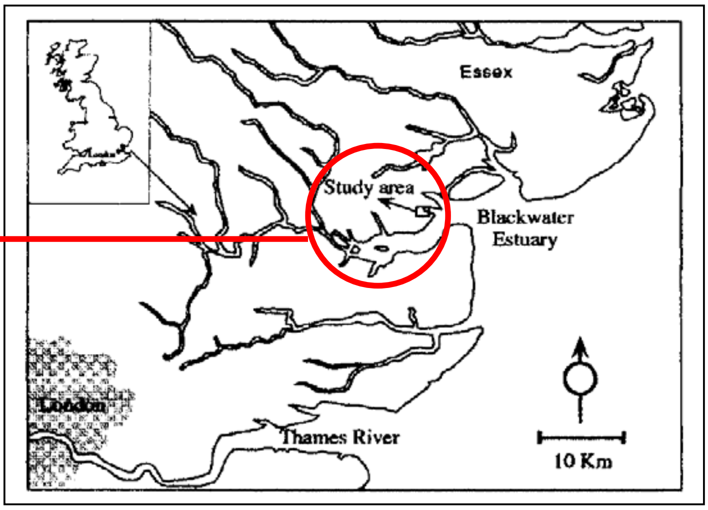
Muds, salt-marsh and shingle beaches

Around the coasts of Essex, Suffolk and Sussex many estuaries and marshes trap fine muds and silts but as sea level rises, unconsolidated materials unbound by vegetation are the most easily removed. Muds are easily retaken into suspension so that with heightened sea level and increasing storm strength, marshlands will undoubtedly disappear along with unconsolidated cliffs.

The height of seawalls required to negate the power of incoming waves is reduced in an almost linear relationship with the width of a slat-marsh between land and the sea's edge [31]. Salt-marshes and mudflats therefore have a significant value as natural sea-defences.

The coast of Suffolk and Essex, experiences a mean tidal range of 4.5 metres, [32] and the convoluted estuaries could not realistically be protected in a 'hard-engineering' way [33]. For this reason the practice of 'Managed Retreat'[33] has been introduced. Since 1973, parts of the Blackwater Estuary salt-marshes have been lost to erosion and in 1995 the old (operative) sea wall, built in the late 1700's was deliberately allowed to be breached after a new defence had been constructed [34] This was an experimental attempt to re-establish the marshes and followed observations of

Picture sources: Multimap and Reference 34 (Fig 1)



Mashes naturally reflooded by the sea as long as 100 years ago - in places like the Medway estuary. [34a]

Within 2 years the marsh area had increased in size [35] and the approach at the Tollesbury site was seen to be a viable defence option. With marsh-losses running (1973-1998) at 23% on the Orwell estuary, 28% on the Stour and 10% on the Blackwater, a significant benefit might be gained from a successful outcome.

The same geological processes dominated by water depth, wave action and sediment supply are seen along the UK's shingle beaches. Slapton Sands, (with a very limited future)(Pethick, J. 2002) [36]. (see appendix Fig 14,15,16), Chesil beach [37] and the shingle beach of Dungeness[38] (see appendix Fig 17,18) all protect developments in the extreme front-line of the coastal zone and in gradually narrowing show fragility, despite their substantial appearance. The proximity of buildings along beaches shows an historic failure to understand natural dynamic coastal processes.

Slapton Sands with Slapton Ley (SSSI) behind the shingle beach. The road between Torcross and Dartmouth has recently (2001) been realigned and will need similar treatment in the future if the system does not fail completely in the comparatively near future. " the system as described… is in the ultimate breakdown stage.." Pethick (2002) [36]

Dungeness and the nuclear power station [39] sited there would seem to be a most extreme example of 'confident coastal engineering' . The consultant engineering company Halcrow[40] produced costings for post-development management [41] in the late 1950's when the station was built and depended on beach feeding, (a unique idea at that time [42]) Although a comprehensive schedule of costs and volumes of shingle were prepared those figures are now being exceeded and with rising sea level will certainly require further revision. Should the suggested reversal of mean current direction along the south coast occur as discussed in Hosking, McGuinness (2002) [43] then Dungeness' strategic plan will be based on parameters that have no further relevance and a drastic, undoubtedly expensive solution will be required.

Summary and conclusion

It has been remarked that scientists attempt to understand a system whilst engineers attempt to manipulate it [44]. Whatever the level of truth in the statement it is clear that we must fully utilise the understanding we have. Climate change has been an additional burden added to our apparent inability to comfortably co-exist with the planet   It might also be seen that an ability to act on the understanding we have with regard to allowing coastlines to retreat or prograde as changes in sea-level and storms dictate, is something we are reluctant to do. With so much coastal occupation, so much physical environmental change and heightened public 'green awareness', we are slowly beginning to acknowledge that we must change our attitude to the coasts.

However as more people seem to find the coastal zone a desirable place to be, more building work is undertaken as close to the coast as possible. When disaster strikes there is therefore no room for retreat, and undertaking retreat before disaster strikes effectively reduces the value of coastal-zone properties *before* they are damaged. A strategy for reducing building in the coastal zone and for abandoning those properties damaged or destroyed might seem an economically prudent option. The cost of defence structures is high[45] and a simple policy of compensation might be more in the national interest than maintaining long-term unsustainable policies of structural defence and maintenance work.

In the UK and even in the United states there is currently no effective database of property damage[46] caused by earthquakes, landslides and the like, and therefore no way of quantifying the cost of a change in strategy compared with maintaining the current policy line. The successor theme for the decade of “International Decade for Natural Disaster Reduction” (1990-1999) is the “International Strategy for Disaster Reduction” and ideally requires that something positive should come from international momentum. Two questions might be asked:

1. How much is scientific knowledge lacking and how much does lack of knowledge influence inadequate policy ?
2. How much knowledge is available, but is either inaccessible or simply not used ?

It seems likely that in the UK, as in the USA, economic growth and heightened exposure to hazards is linked (White et al 2001[47]) but the occurrence of disaster is low compared to national wealth. The prospect of legal action following attempts to apportion blame for the consequences of erosion may seem likely but in the USA this is infrequent (Pilkey 2003 – personal communication[54]) and in the UK a high court action brought by the Holbeck Hotel against Scarborough Council [48] became a web of counter legal-action. There seems therefore little real political reason for a large-scale programme that would reduce what is a comparatively low *relative* level of loss. As long as this situation exists there will be no reason for the current system of regional coastal management cells (see appendix Fig 20) undertaking their piecemeal strategies [49] to be changed. Government policy continues to permit development of floodplains whilst apparently ignoring flooding risk, [50] ironically at the same time as 'Coastal Relocation' [51] strategies are seen to move large structures inland away from the edges of cliffs.

Moving the Belle Tout lighthouse away from the edge of the eroding chalk cliff (Beachy Head, Southern UK)- at an approximate cost of £300,000.

Constructed 35 metres from the edge 164 years before the move it was within 4 metres when the move took place.

McGlashan, Derek J., (August 2002)
"Managed relocation : an assessment of its feasibility as a coastal management option""

With no likelihood of a large-scale policy change, Geoscientists might consider the establishment of a comprehensive, universally, *freely* accessible, and frequently updated database of high resolution images showing the UK coastal zone. Equally important might be a central database of relevant research of use to all coastal management authorities. These would be of great benefit in planning and monitoring changes interactively between coastal management zones. High resolution monitoring with good vertical and horizontal accuracy is becoming more of a possibility with the use of LIDAR [52] and GIS [53], but political commitment to funding will be the limiting factor. The level of understanding gained through the elevation in research of recent years, and the application of policies making full use of this knowledge and data, remains firmly in the political arena.

List of Photographs

Acknowledgements with photographs

Appendix

See separate Appendix document (19 pages)

References

See separate Reference (pdf) document (9 pages)

List of figures - Literature Review

Figures

Tables

List of tables