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Planning for the rising tides: the Humber Estuary Shoreline Management Plan

P.J.S. Winn[a], R.M. Young[b], A.M.C. Edwards[c,*]

[a]*Environment Agency, Phoenix House, Global Avenue, Leeds, LS11 8PG, UK*
[b]*RYE Consultancy Providence Cottage, Common Road, Lingfield, Surrey, RH7 6BZ UK*
[c]*Environment Agency, 1 Viking Close, Great Gutter Lane (East), Willerby, Hull, HU10 6DE, UK*

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Abstract

The Humber Estuary Shoreline Management Plan provides the framework for investment in defences to reduce the risk of flooding to people, property and the environment. A key issue is the rise in sea level, which is reducing the standard of protection provided and is increasing erosion. The plan is developed from detailed geomorphological and ecological studies, and extensive consultation with interested organisations and the community. It takes into account the urban and industrial development on the floodplain, high-grade agricultural land, the historic environment and the Humber's status as an outstanding site for wildlife, which is protected under the Habitats Directive. A key aim is wherever possible to work with natural processes. Another is to ensure that there is no net loss of protected inter-tidal habitat. The options investigated include changes to the existing alignment of the embankments. The overall strategy provides for a continuing line of defence around the estuary and tidal rivers but with the use of managed retreat in some places. The creation of new inter-tidal habitat by this means is to gain more stable and cost-effective defences, and to offset the loss of protected sites, including by coastal squeeze. Further studies are in progress to appraise potential managed retreat sites.

Keywords: Estuary management; Flood defence; Sea level rise; Wildlife; Habitats; Managed retreat; Humber; Trent; Yorkshire Ouse

1. Introduction

The Humber Estuary Shoreline Management Plan provides the framework for long-term investment in defences to reduce the risk of tidal flooding to people, property and environmental assets. The Humber is one of the principal estuaries of the North Sea. It is of international importance for wildlife, particularly birds, and maritime trade, and is of national importance for the UK's economy and historic environment. The aim of the plan is to provide justified and affordable defences against flooding, particularly in relation to the relative rise in sea level, in a manner that is sustainable and compatible with the other important uses of the Humber. This paper summarises

*Corresponding author. Tel.: +91-44-2351-269x226; fax: +91-44-235-2870.
E-mail address: tony.edwards@environment-agency.gov.uk (A.M.C. Edwards).

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the issues considered and the plan (Environment Agency, 2000a).

Estuaries form a transition zone between rivers and the open sea. The interfaces between land and water, and between fresh and saline water, along with the continual tidal action, make estuaries particularly diverse and complex features. The trapping and recycling of sediments and nutrients make estuaries amongst the most fertile and productive ecosystems in the world. In many places they also provide sheltered harbours and sites for industrial, urban and leisure development. Estuaries face competing pressures between nature conservation and economic growth. The UK Government emphasises the need for integrated management of the coastal zone and an improvement of the links between the different interests and managers of this environment (Department of the Environment, 1995).

A shoreline management plan is a document which sets out the long-term, sustainable strategy for coastal defence for a specific length of coast taking account of natural processes, and human and other environmental influences (Ministry of Agriculture, Fisheries and Food, 1995). A sustainable policy is based on harmony between society, the environment and the economy so that the quality of life is improved, both now and in the future without placing an unacceptable burden on the environment (Department of the Environment, Transport and the Regions, 1999). Initially plans were prepared for 11 open coast 'sediment cells' around England and Wales. The large size and complexity of the Humber's tidal environment led to the extension of the shoreline management concept to the estuary.

The Humber has a catchment area of 24,472 km^2, a fifth of the area of England, in which live nearly 11 million people. The tidal waters have a length of 317 km, of which the Humber itself is 62 km from the confluence of the Trent and Yorkshire Ouse to the North Sea. The study area for the shoreline management plan is the tidal floodplain (land below 5 m OD), which has an area of 90,000 ha (Fig. 1). The geology, geomorphology and ecology of the Humber is described in Jones (1998), while water management issues affecting the estuary and its catchment are the subject of Environment Agency (1999a) and Edwards et al. (1997) and Edwards (2001). This area was the focus of much of the research on the fluxes of water, solutes and sediments of the Land Ocean Interaction Study (Huntley et al., 2001) and the information presented in this publication is both of UK and Europe-wide significance on the water quality management of a major input to the North Sea. The LOIS programme was also of importance for understanding the sediment dynamics and geomorphology of the estuary and, thus, contributed to the shoreline management plan studies.

2. Objectives

The Humber Estuary Shoreline Management Plan was developed from objectives based on the Environment Agency's statutory responsibilities and the views of partner organisations. The overall objectives are:

To develop a coherent and realistic plan for the estuary's flood defences that is:

- Compatible with natural estuary processes;
- Compatible with adjacent developments, including preferred options for adjoining lengths of frontage;
- Sustainable, taking into account future changes in the environment (human, built or natural), in sea levels and in the climate.

To ensure that all proposals are:

- Technically feasible;
- Economically viable;
- Environmentally appropriate;
- Socially acceptable.

The 13 detailed objectives given in Table 1 reflect the range of interests in the Humber and its floodplain.

3. Methodology

Coastal and estuary flood defences must be seen in the context of an extremely variable environment, where modification of one part can have serious consequences both locally and on other areas some distance away. The key principles for

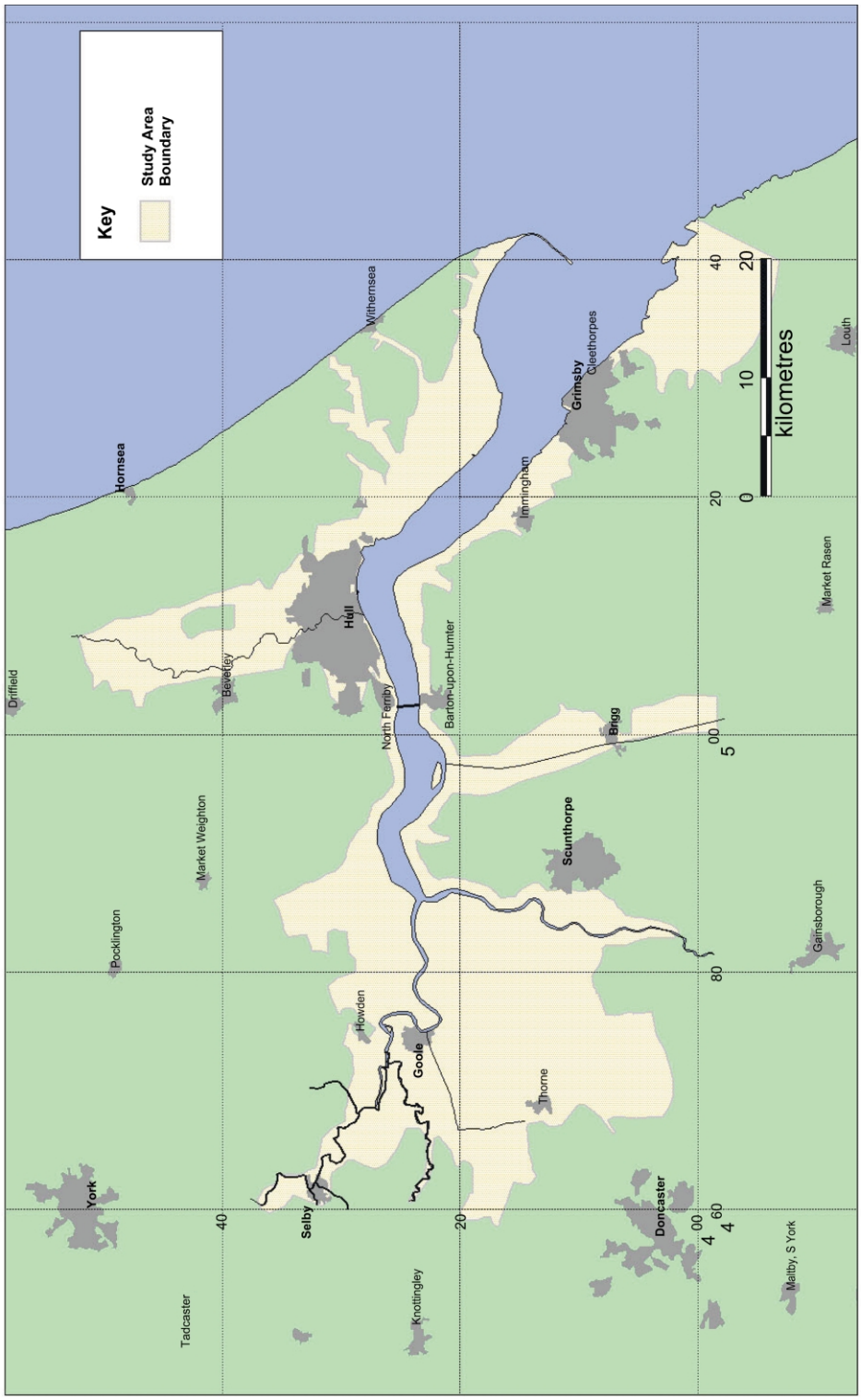

Fig. 1. The Humber Estuary Shoreline Management Plan study area.

Table 1
Detailed objectives for the Humber Estuary Shoreline Management Plan

Flood defence –To reduce the risk to people, property and the environment from flooding and erosion. *Land use and planning* –To provide standards of protection that are consistent with existing land use while permitting future development where appropriate. –To encourage the recognition of flood risk as an issue in regional planning guidance and in structure and local plans. *Industry and commerce* –To provide appropriate protection for industry and commerce and encourage future industrial and commercial development in suitable locations. *Navigation and port development* –To avoid adversely affecting navigation in the estuary or opportunities for its development. *Fisheries* –To avoid adversely affecting fisheries (inland or in the estuary) or the fishing industry. *Agriculture* –To protect, where appropriate high quality agricultural land by the estuary. –To minimise the impact of natural processes on land drainage to the estuary. *Community interests* –To protect the overall interests of people living near the estuary.	*Sport, recreation and access* –To maintain and, where possible, improve the provision of sporting and recreational facilities by the estuary. *Tourism* –To allow for the importance of tourism to the local economy. *Heritage and cultural resources* –To avoid actions that adversely affect the estuary's heritage and cultural resources. –To comply with all statutory obligations arising from national and local designations and related legislation. –To protect, where necessary, the estuary's heritage and cultural resources against erosion. *Landscape* –To protect and, where possible, enhance the estuary's existing landscape character. –To complement the objectives of the Heritage Coast Management Strategies. *Estuary processes* –To build an understanding of the natural processes taking place within the estuary and work with these processes. –To respond to future climate change and sea level rise. *Nature conservation* –To comply with all statutory obligations arising from national and international designations and related legislation. –To encourage habitat development that contributes to the UK Biodiversity Action Plan. –To create areas of new habitat in compensation for any habitat lost.

the development of shoreline management plans accordingly are:

- Defences should be based on a scientific understanding of natural processes;
- Such works should only disrupt natural processes where life or important natural or man-made assets are at risk.

A basic requisite of making management decisions within estuaries is, thus, a sound understanding of their physical and ecological functioning (EMPHASYS Consortium, 2000).

Many of the problems in the Humber and other estuaries are related to flood risk, erosion and loss of habitat result from reclamation and other engineering works in the past, which have not taken into account the estuary morphology and dynamics. The morphology of the outer Humber evolved during the Holocene period with the rise in sea level. Over the last 1000 years or so, land reclamation by drainage and sediment entrapment ('warping') has greatly reduced the inter-tidal area. For example, over 200 years up to the beginning of the twentieth century, over 2000 ha of land around Sunk Island were reclaimed for agriculture (de Boer, 1988).

The aim is to have effective flood defences that have long-term stability and enhance wildlife and natural resources. Embankments, floodwalls and other structures may, however, change estuary

dynamics and lead to erosion or siltation problems elsewhere in the system. With rising sea levels, an estuary will attempt to broaden out. When confined within hard defences 'coastal squeeze' will occur leading to a loss of valuable inter-tidal habitat and the potential under-mining of the structures. The stability of embankments thus benefits from having saltmarsh and mudflats in front of them to dissipate wave energy and so protect against erosion (Moller et al., 2001). In the 1990s 'managed retreat' was investigated as a soft engineering technique for coastal management in the UK (Burd, 1995). The setting back of flood defences results in a wider inter-tidal profile, which is more able to respond to coastal processes and reduce the effect of coastal squeeze.

The Humber Estuary Shoreline Management Plan is as a result based on extensive Geomorphological Studies (Environment Agency, 2000b). A consortium of Binnie Black and Veatch, ABP Research and Consultancy, British Geological Survey, H.R. Wallingford and the Universities of Durham and Newcastle undertook this work. The mathematical modelling tools used were broadly classified into 'bottom-up' and 'top-down'. The former are process-based morphological models which can provide estimates of general trends in erosion and accretion but require detailed knowledge of environmental conditions to provide better predictions. Bottom-up models are best suited to modelling local impacts of schemes where changes in bed levels are likely to be greater than natural variability (Norton and Townend, 2000). The top-down regime approach develops empirical relationships between the dimensional features of the estuarine topography and measures of tidal flow. It is aimed at predicting the long-term physical response of an estuary to changes in forcing factors such as: sea level rise; and changes in morphology, such as dredging, reclamation or other engineering works. The main lines of investigation of physical and ecological processes influencing the Humber are summarised in Table 2.

The Environment Agency consulted widely during the preparation of the plan. This work was guided by a Steering Group formed of representatives of key stakeholders including: other agencies; local authorities; business interests; agriculture; and conservation and recreation organisations. The aim of these consultations was to give all those affected by the plan opportunities to voice their concerns, learn about the issues, understand the options and comment on the conclusions. Consultation took place in a three-step process:

- To tell people about the plan and ask them for any relevant information (October 1997);
- To discuss the issues and enable people to express their concerns and aspirations (April 1999); and
- To allow people to comment on the options (November 1999).

During the third stage, over 3000 copies of the consultation document (Environment Agency, 1999b) were issued and approximately 20 meetings were held, with individual organisations and groups and with the general public. A large number of points were raised at the meetings and nearly 100 written responses were received and made valuable contributions to the final plan.

4. Land use and development

The estuary's flood defences protect nearly 90,000 ha of land; approximately 85% of this area is farmed and approximately 3% is used for other commercial or industrial purposes. Housing and other urban areas occupy some 8% while the balance is used for a variety of other activities including recreation and nature conservation. More than 300,000 people live within the project area, mostly in the urban areas.

The Humber's catchment has been described by Jarvie et al. (1997). The land by the Humber Estuary is among the best and most productive in the country. Most of the holdings around the estuary are mixed or arable in nature and many are run intensively, with cropping patterns, farm operations and supporting industries geared closely to the area and type of land available.

The two main areas of industry on the Humber are in Hull and nearby at Salt End on the north bank and between Grimsby and North Killingholme on the south bank. British Aerospace has a major facility at Brough that includes Brough airport. Other concentrations of industry are found

Table 2
Technical studies undertaken to development the Humber Estuary Shoreline Management Plan

Existing conditions in estuary These were examined using existing data and predictive models to determine how the estuary behaves at present, providing a baseline to assess how it will respond to change.	*Sensitivity and management tests* The predictive models were used to examine different ways of managing the defences in the Humber and elsewhere including: –Moving back the defences in different parts of the estuary; –Reducing channel movements in the upper estuary.
Past response to sea level rise Recent studies were reviewed of sea level changes in the Humber area over the last 10,000 years of the Holocene period and geological data was examined to determine how the estuary has responded.	*Review of biodiversity information* The information on the conservation designations, from the Agency's biological monitoring and assembled with the intention of producing the Local Biodiversity Action Plan for the Humber Estuary were assessed to determine baseline ecological conditions.
Channel migration in the upper estuary A review was carried out of historic records of the rapid channel movements that occur in the upper estuary (between Trent Falls and the Humber Bridge) to determine their cause.	*Coastal squeeze* An assessment was made of the inter-tidal areas (mudflat, saltmarsh) that could be lost as a result of sea level rise if the estuary bed levels remain unchanged as a result of the constraint of flood banks on Humber.
Estuary bathymetry Historic records were reviewed of bed and water levels in the estuary to determine how these have changed over the last 150 years, taking into account the sea level rise over the period.	*Habitat migration* This assessed constraints affecting the creation of inter-tidal habitats in the estuary and of the habitats likely to occur if the defences were moved back.
Sediment movements This reviewed sources of sediment and modelled movement of sediment into, around and out of the estuary. The estuary's sediment dynamics are critically important for both the navigation and the ecology. A large amount of modelling has been done on the response of the sediments and inter-tidal area to changes in sea level, river flows, reclamation and the possible re-alignment of embankments.	*Archaeology review* Initial information was assembled on archaeological and historic interest around the Estuary.

beside the Ouse and the Trent, particularly at Goole and Flixborough. The port facilities in the Humber are of prime importance because of the wealth and employment they give and the attraction they provide for other industries to locate in the area. The ports of Goole, Grimsby, Hull and Immingham are operated by Associated British Ports (ABP) Ltd, and there are smaller independent operations at various locations throughout the estuary.

Guidance on planning issues in coastal regions is provided by the Department of the Environment (1992) in Planning Policy Guidance Note (PPG) 20 on Coastal Planning and in areas at risk of flooding in Department of the Environment Food and Rural Affairs (2001) PPG 25 on Development and Flood Risk. This document advises that the vulnerability of land to flooding is a material planning consideration and emphasises the role of the Agency in providing strategic advice on flood issues. It also suggests that developers should contribute towards the cost of flood defences required because of the development.

New structure plans around the Humber are in preparation for East Riding of Yorkshire/Kingston upon Hull City Councils, and North and North East Lincolnshire Councils. These will have to take into account the need for land for housing and industry as well as flood risks, nature conservation, archaeology and other issues. The Regional Economic Strategy for Yorkshire and the Humber

(Yorkshire Forward, 1999) has policies for a Humber Trade Zone to capitalise on the sub region's ports and infrastructure for economic development.

Any land in the floodplain is liable to be flooded, whatever standard of protection is provided, since there is always a risk that an event capable of overwhelming the defences will occur. Current legislation does not (except in special circumstances relating to the Habitats Directive) require the Environment Agency either to provide or to maintain a particular standard of protection. As a result, there is no general provision for compensating anyone whose land or property is affected either by flooding or by erosion. Compensation arising from the construction of flood defence works is available in some circumstances.

The land by the Humber Estuary contains assets that are of fundamental importance both to the well-being of the local population and to the national economy. The loss or forced re-location of any significant proportion of these assets would have implications that cannot be fully estimated.

A combination of increased crop yields and strong overseas competition means that the incentive to keep agricultural land in production is no longer as high as it once was. Nevertheless, much of the land near the Humber is so versatile and of such quality that taking large areas of it permanently out of production is unlikely to be acceptable nationally. The ability to sustain productive agriculture here depends on the land having an adequate standard of protection. The loss of small areas of land, either by setting back the defences or by lowering the standard of protection, may be acceptable although removing part of a holding could be difficult if it involves re-organising a well balanced operation.

Any new development in the floodplain will affect the value of the property in the area and so could have implications on the standard of protection that is appropriate there. When considering such developments, the flood risk should be taken into account on the assumption that the standard of protection is not altered. Any proposals for new allocations of land for development that would require the standard of protection to be increased should be subject to a rigorous sustainability appraisal covering economic, environmental and social issues.

5. Flood defence standards

There are approximately 235 km of flood defences in the area covered by the plan. Most are simple earth embankments, varying between 2 and 5 m in height. Many of the banks have stone or concrete protection on their seaward faces and in some places wave walls have been built on top to improve the standard of protection. By urban areas many of the defences include vertical reinforced concrete or sheet piled walls.

The defences are surveyed regularly to check their condition. The most recent surveys show that many are in 'good' or 'fair' condition overall, although there are problems with individual parts of the structure in places, such as where the foundation is being undermined by erosion. The Environment Agency is responsible for most of the defences but a significant length at Sunk Island is owned by the Crown Estate and lengths elsewhere are the responsibility of Associated British Ports, Kingston-upon-Hull City Council and North East Lincolnshire Council.

The standard of protection is determined by comparing the height of the defences with the water levels and wave heights that are expected to occur during extreme events. The standard of protection needed in each area reflects the value of the damage that would be caused if flooding occurs. This is generally related to the value of the assets protected and hence on the land use. Ministry of Agriculture Fisheries and Food (MAFF) (1999) provides guidance on the standards that are appropriate in the form of a range of return periods for different land use bands (Table 3). The Environment Agency has no legal duty to provide these standards, which have to be justified using cost benefit analysis (MAFF, 1999).

Approximately 70% of the land beside the estuary is currently provided with a standard of protection equal to or greater than the indicative standard. If the defences are not raised, the standard provided will fall as sea levels rise. Assuming an average rise of 6 mm per year, sea levels in 50 years will be 300 mm higher than at present and

Table 3
Indicative standards of protection for property around tidal areas

Current land use	Indicative standard		
	Guideline return period in years	Selected return period in years	Annual probability of failure
Typically intensively developed urban areas at risk from flooding and/or erosion.	100–300	200	0.50%
Typically less intensive urban areas with some high-grade agricultural land and/or environment.	50–200	150	0.67%
Typically large areas of high-grade agricultural land and/or environmental assets of national significance requiring protection with some properties also at risk, including caravans and temporary structures.	10–100	50	2%
Typically mixed agricultural land with occasional, often agriculturally related, properties at risk. Agricultural land may be prone to flooding, waterlogging or coastal erosion. May also apply to environmental assets of local significance.	2.5–20	20	5%
Typically low-grade agricultural land, often grass, at risk from flooding, impeded land drainage or coastal erosion, with isolated agricultural or seasonally occupied properties at risk, or environmental assets at little risk from frequent inundation.	<5	5	20%

less than 40% of the land will be provided with the indicative standard unless the defences are raised (Table 3).

The overall cost of continuing to provide acceptable standards of defence is likely to be of the order of £200–300 million over the next 50 years. This is a major investment that needs full and proper justification.

6. Estuary processes

The upper estuary to the west of the Humber Bridge is of considerable geological antiquity while to the east it has developed since the end of the last glaciation. The main physical features of the estuary are:

- Spurn Head, which is connected to the shore by a bank of sand and shingle and fed by sediment moving south along the Holderness shoreline;
- The narrows at Grimsby, which were formed by the development of Sunk Island (originally as a natural shoal and then by reclamation);
- The Chalk of the Lincolnshire and Yorkshire Wolds, which provides the foundations for the Bridge and prevents the estuary from widening at this point; and
- Trent Falls, where the estuary divides into the tidal reaches of the rivers Ouse and Trent.

The form of Spurn Head, the narrows at Grimsby and the confluence at Trent Falls have all been strongly influenced by human intervention. This activity has changed the natural processes of accretion and sedimentation in the Humber (Pethick, 1998). The flood defences by the estuary are a major constraint, canalising the rivers above Trent Falls and fixing the high water line from there to the sea. The River Don once had outfalls into the Aire and Trent. A single channel, the Dutch River, was constructed to the River Ouse and the marshes were drained in the 17th century (Environment Agency, 1997). In the 1930s, the channels near Trent Falls were stabilised by training works built to improve navigation. Historically, much of the

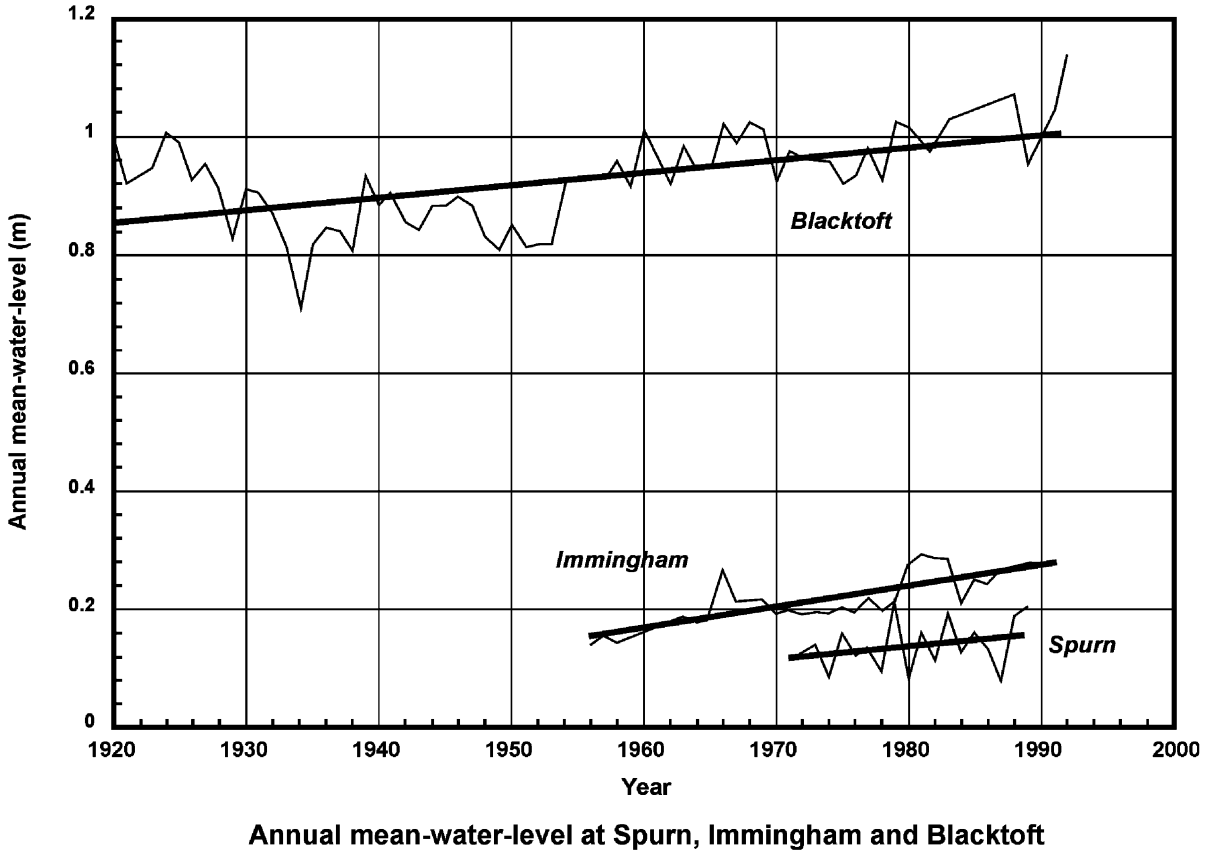

Fig. 2. Annual mean water levels and linear trend at Spurn, Immingham and Blacktoft.

land beside the upper estuary was subject to warping, the practice of flooding land with sediment-laden water at high tide and allowing the sediment to be deposited. This has led to as much as 1 m of material being accumulated in a year on top of the old land surface. In the lower estuary, the land around Sunk Island, opposite Grimsby, was drained during the 18th and 19th centuries (de Boer, 1988).

Both the tidal range and high tide levels vary along the estuary. The high water level at Goole on a spring tide is more than 1 m above the level at Spurn. During extreme events, water levels can be up to 3 m above normal levels. Waves up to 4 m high can occur in the outer estuary between Cleethorpes and Donna Nook on the south bank and near Hawkins Point on the north bank, but reduce to little more than 1 m high upstream of Hull.

Historically sea levels have been rising relative to land levels at an average rate of approximately 1 mm per year over the last 4000 years. The rate of rise over the last 100 years has been between 2 and 2.5 mm per year, as shown in Fig. 2 (Environment Agency, 1999c). These rates take the isostatic lowering of the land into account. The present rate of sea level rise is superimposed on a number of cyclical changes, one of which has a period of some 18 years and an amplitude of approximately 50 mm.

Approximately 6 million tonnes (dry solid weight) of sediment enter the estuary each year, most of it either as background material from the North Sea or from erosion of the Holderness coast

and only a small proportion (less than 3%) from the rivers. Much of the marine material returns to the North Sea on the subsequent tide but some remains in the estuary, moving upstream along the shoreline and either accumulating there or entering the channels and being carried back towards the sea. The soft cliffs of glacial material at the southern end of Holderness are retreating at an average rate of 2 m per year (de Boer, 1996). Approximately three million tonnes of sediment are dredged each year from the docks, port approaches and the main shipping channel. All dredged material is returned to the estuary, generally close to the point from which it was removed. Dredging also takes place off the coast and this may affect the supply of sediment to the estuary.

The overall volume of the water contained by the estuary appears to have been approximately constant over the last 150 years, implying that the supply of sediment has been adequate to meet the demand imposed by rising sea levels over this period. Localised accretion and erosion occurs however, near Hawkins Point for example and near Immingham, where it is threatening to undermine the defences. This, and other evidence, suggests that the estuary may respond to sea level rise by accreting and eroding in different parts so that it seems to rise and move landward, or 'roll over'.

Foreshore erosion is also occurring elsewhere in the estuary, particularly upstream of the Humber Bridge. Here, erosion is due to the channel movements rather than to a general fall in foreshore levels, and may have been accentuated by reclamations at Broomfleet and by river training works at Trent Falls.

The studies show that the estuary can be divided into four main 'process' units: outer; middle; inner; and the tidal river sections. The boundaries between these units mark the places where either the nature of the processes taking place or the impact of these processes on the rest of the estuary change significantly.

The outer estuary extends from Spurn Head to a line across the estuary between Grimsby and Hawkins Point. The middle estuary extends as far as the Humber Bridge but is divided into two just downstream of Hull. It leads to the inner estuary that extends to Trent Falls but again is divided into two near Whitton Ness. The two river sections, the Ouse and the Trent, are inland from Trent Falls. The processes taking place in the outer estuary are significantly different from those occurring elsewhere and suggest that this unit behaves more as a coastal inlet or bay than as part of an estuary. More typical estuary behaviour begins at the middle estuary boundary.

Global warming is expected to become more pronounced in the future and to cause the rate of sea level rise to increase. The magnitude and timing of this increase are uncertain at present and MAFF recommend that for planning purposes an average rate of 6 mm per year (including land settlement) should be assumed for the next 50 years. This is more than twice times the rate that has occurred over the last 50 years (between 2 and 3 mm per year) and implies that sea levels will rise by a total of 300 mm relative to land levels over the period. As a result, the flood defences beside the estuary will, in effect, be 300 mm lower than in 50 years time than they are at present, significantly increasing the risk of flooding in all areas.

The estuary's response to sea level rise is likely to be that of 'roll over'—its overall volume will be unchanged but the foreshore in the outer estuary may erode further as it attempts to widen and move inland (Environment Agency, 2000b). This assumes the supply of sediment remains sufficient to meet the demand. In this context it is important that the sea-borne sediment supply in particular, much of which comes from the Holderness Coast, continues at a steady rate. If it does not, more extensive erosion may occur, probably in the outer part of the middle estuary, adding to any erosion taking place there due to the 'roll over' process and further threatening the defences.

The estuary's ability to 'roll over' may be limited by natural features, such as the local geology, and by the presence of the defences. In particular, the defences in the inner estuary and the river sections will prevent any significant landward movement of the shoreline. The implications of this are not clear, but one possibility is that foreshore levels in the inner estuary might rise faster than sea levels, which could affect channel behaviour (and hence navigation), amongst other

things. Setting back the defences could reduce the rise in foreshore levels but further studies are needed to examine this.

A further effect of sea level rise is that if foreshore levels do not rise by the same amount, the inter-tidal area in front of the defences (taking this as the area between the defence line and the mean low water spring line) will decrease. The magnitude of this effect, known as 'coastal squeeze', is difficult to estimate but a preliminary assessment suggests it could lead to the total inter-tidal area in the estuary being reduced by approximately 700 ha over the next 50 years, or just under 7% of the present inter-tidal area. In practice, this is likely to be an upper bound to the loss.

Global warming may also lead to weather that is increasingly stormy. This could result in extreme events, such as marine surges and high waves, occurring more frequently than at present, so increasing the risk of flooding. The evidence for this is increasing but as yet there are no firm conclusions and so at present no allowance has been included in the plan. Research progress in this area of work will be carefully monitored, however, and the plan amended once the implications are known. The effect of increased storminess will be to bring forward the date when works to raise the standard of the defences will be required.

Setting back the flood defences in the estuary will allow space for 'roll over' to take place and may postpone the effect of erosion at the toe of the defences. It will also provide inter-tidal habitat. Setting back in the outer estuary or in the outer part of the middle estuary (effectively seaward of Hull) will have little other effect, either locally or elsewhere in the system. Setting back in the inner part of the middle estuary (from seaward of Hull to the Humber Bridge) could raise water levels further inland. Setting back in the inner estuary, however, could lower water levels there without affecting them significantly elsewhere. This effect is enhanced if the setback takes place in the rivers.

The scale of the effect depends strongly on the size, level and location of the setback. Preliminary studies suggest that an area of approximately 400 ha in the river sections could reduce water levels locally by up to 300 mm. Several such sites may be needed over the 50-year duration of the present plan. Further studies are needed to examine these dependencies and to confirm that the results are sustainable.

Foreshore erosion in the outer and middle estuary is currently threatening the stability of the defences in places, particularly on the South Bank between Grimsby and North Killingholme where repairs are needed urgently. If the erosion is linked to sea level rise, it will become more serious as the rate of rise increases, threatening more of the defences and increasing the expenditure needed to keep them in an acceptable condition. Ultimately, the difficulty of maintaining the defences could become so great that it will be necessary to set them back to a new line or carry out other works elsewhere which will achieve the same effect.

The timing of this will depend mostly on the rate of sea level rise and the estuary's response to this rise. Although some progress has been made, a clear link between foreshore levels and sea level rise has not yet been established.

7. Natural environment

The inter-tidal area of the Humber Estuary (taken as the area above the mean low water spring tide line) is currently estimated to be approximately 12,000 ha, although earlier estimates are rather higher. Of this area, more than 90% is mudflat and sandflat and the remainder is largely saltmarsh. There are approximately 200 ha of reedbed near the estuary, some in front of the defences (in the upper estuary and the rivers) but mostly to landward, particularly in the disused claypits near Barton. There are beaches and sand dunes at Spurn and from Cleethorpes to Donna Nook. There are also several saline lagoons with a total area of approximately 120 ha.

Between 140,000 and 170,000 waterfowl visit the estuary each year to roost and feed there, mainly during the winter months (Archer, 2000). These numbers place it among the top 10 European estuaries in order of importance for birds and among the top five estuaries in the UK. The estuary's importance for wildfowl and wading birds has led to much of the inter-tidal habit being designated an Special Protection Area (SPA) under EC Directives, implemented in the UK as the

Conservation (Natural Habitats etc.) Regulations (1994). The whole estuary is a candidate for being a Special Area of Conservation (SAC). It is also designated a Ramsar site, reflecting its international importance as a wetland area. The designated areas have legal safeguards, which require any development (including flood defence works) that may affect them to be examined rigorously. If the development is shown to affect the conservation status of the designated sites adversely, the regulations require that an acceptable alternative be sought. If no acceptable alternative is found, the development will be refused unless there is an over-riding public interest, in which case there will be a need to compensate for the habitat lost.

In parts of the estuary, the simplest way of maintaining or improving existing defences or of building new defences may result, directly or indirectly, in some loss of foreshore. This could affect the conservation status of designated sites in the Humber, whether the scheme is located beside these sites or elsewhere in the estuary. If there is a reduction in this status, then the proposed works must be modified so that the overall effect is to leave the status unchanged and preferably enhanced.

When assessing the impacts of a flood defence scheme, it is often necessary to consider what happens beyond the designated site boundary as well as inside it, since developments elsewhere in the estuary may equally affect the overall aim of supporting bird life. In addition, natural estuary processes can change erosion and accretion patterns and so affect the area of inter-tidal habitat found in the estuary. The response to sea level rise, in particular, could lead to significant losses of inter-tidal habitats. English Nature, Environment Agency and Centre for Coastal and Marine Science (2000) have developed the methodology for Coastal Habitat Management Plans (CHaMP).

An initial CHaMP report has been prepared for the Humber (Environment Agency, 2001) and a full CHaMP will be produced as the shoreline management plan is refined. This will provide a framework for considering the potential gains and losses of inter-tidal habitat in line with the conservation objectives for the estuary. The principle adopted is that there should be no net habitat loss. There will, thus, be a need to create new habitat in the future to compensate for losses due to developments in the estuary and to natural processes.

Consideration of habitat creation opportunities around the Humber shows that inter-tidal habitats can only be produced by setting back the defence line as there is little currently undefended land which does not already support a valuable habitat. It also suggests that ground levels round much of the estuary are too low for saltmarsh to develop naturally if a managed realignment takes place. In most setback areas, mud or sand flats will develop, at least initially, and only by raising ground levels could saltmarsh be created. This would generally require major earthworks but could occur naturally, over a period of time, as the area accretes.

8. Historic environment

The estuary and its floodplain contain a complex array of historic buildings, settlements, landscapes and archaeological sites that are a fundamental component of the regional identity and an important focus for education, tourism and recreation. The archaeological resource, both seaward and landward of the shoreline, is particularly valuable because of its widespread wetland component where the waterlogged conditions can limit the decay of organic materials and so help preserve organic archaeological remains (Ellis and Van de Noort, 2000).

The Humber has sites of archaeological and historic value from the earliest times to the present day, including prehistoric artefacts and Bronze Age boats found on the foreshore. There are Iron Age, Roman, Anglo-Saxon and Viking settlements. The estuary has been an important trade route since early times and there are important features associated with the navigation and ports. There are also military installations of interest from the two World Wars.

Some of the more important features of the historic environment are covered by statutory designations and actions that would have an adverse effect on such designated features will normally be refused unless there is an over-riding justification. Many of the known or potential archaeolog-

ical sites are in areas that are threatened by erosion, by the development or re-alignment of the flood defences. It is therefore important to establish procedures for surveying sites where works are proposed and for evaluating, preserving or recording new discoveries when they are found.

9. Options considered

The four main options for managing the flood defences by the Humber Estuary were investigated in detail. Other options, such as tidal barrages, were considered at an early stage and rejected on the grounds of environmental impact, disruption to navigation and cost.

9.1. (i) Monitor and review

In this case no actions are planned but the situation is monitored so that should circumstances change the decision can be reviewed. Any flood defences will no longer be maintained and so will deteriorate and, in due course, fail. In general, this option is not considered appropriate for the Humber Estuary.

9.2. (ii) Retreat the line

The defence line is deliberately moved back from the estuary, either to a new line of defences or to high ground at the edge of the floodplain. The land between the old and new lines will no longer be protected against flooding and most of it will revert to mudflat or saltmarsh. This will have major impacts on the landowners and farming community, although there are potential flood defence or nature conservation benefits that could make it worthwhile at selected sites in the estuary if land can be acquired or grants secured for habitat creation.

The estuary process studies indicate that retreating the line beside the rivers upstream of Trent Falls, and possibly beside the inner estuary (between Trent Falls and the Humber Bridge), will have the effect of lowering water levels locally. If so, any crest raising work needed nearby as a result of sea level rise may be postponed. Retreating the line elsewhere will have no overall effect on the estuary although it will provide compensation for any loss of inter-tidal habitat locally. It will also counter the effect of foreshore erosion, if this is occurring, by moving the defence away from the problem.

9.3. (iii) Maintain the line

The defence line will remain where it is at present and will continue to be maintained in the future. The standard of protection may change if, for example, the defence crest is not raised in line with sea level rise. Maintaining the line in the middle and outer estuary will have no impact on estuary processes elsewhere in the system, although it could be difficult and expensive to do where the defences are threatened by erosion or falling foreshore levels, and it could exacerbate coastal squeeze. Maintaining it in the inner estuary and beside the rivers may restrict the estuary's ability to 'roll-over' in response to sea level rise, possibly causing a net rise in bed levels there and so affecting navigation.

9.4. (iv) Advance the line

The defence line is moved towards the estuary to a new line of defences. The land between the new and old lines is protected against flooding and can be used for any function consistent with local planning policy. Advancing the line may affect estuary processes and will result in loss of inter-tidal habitat. Generally the effects on estuary processes are unlikely to be beneficial as the estuary is already constrained by the presence of the existing defences. Overall, there are no flood defence reasons for adopting this option anywhere in the estuary.

10. The overall strategy

The shoreline management plan has been developed to meet the objectives listed in Section 2 taking into account the issues discussed in Sections 4–8 and the options examined. It is based on the best current knowledge of the system and the processes operating, and it takes into account developments currently envisaged over the next 50

years, including sea level rise. It is intended to be sustainable in the sense that it will meet today's needs without compromising the needs of future generations, although more work is required on this aspect.

The number of people and the value of property within the floodplain mean it is essential to continue to provide a line of defences around the estuary. It may be worthwhile moving the line locally, however, if this will provide benefits (such as reduced costs). The overall flood defence strategy therefore has three main features, as follows.

(i) Hold the line of the existing defences where there is no justification for moving them.

Beside the greater part of the estuary the existing defences are satisfactory and the overall costs of moving them, taking economic, social and environmental considerations into account, would be greater than any resulting benefits. Where this is so, the existing line will be maintained. In some places, however, keeping the line where it is may not be sustainable in the future if the foreshore continues to erode. The time when this occurs will depend on the long-term rate of erosion and also on the rate of sea level rise. Developing the land immediately behind the defences in these places could make realignment difficult line if it becomes necessary. The inclusion in planning guidance of advice, that future development near the defences should allow for this by providing a buffer strip, will be sought.

(ii) Identify sites where moving the defences will provide flood defence benefits, taking social, environmental and economic issues into account, and establish a programme for moving these defences.

(a) Sites where moving the defences will provide flood defence benefits directly.

The defences are inspected regularly and standard maintenance works are carried out as required. More extensive works may be needed where the structure is deteriorating, the foreshore is eroding or defence levels are low. Sites requiring immediate attention have been identified and works will be needed at other sites in the future as conditions change. Before these works are carried out, their costs will be assessed; taking into account any raising needed to allow for sea level rise and any other changes that might be made. Moving the defences may lead to savings if the new line is cheaper to build or maintain, for example if it is shorter, lower or avoids the need for costly erosion protection measures. Any decision to move the line will take into account the loss of land or property that will result and the need to provide compensation for habitat losses due to flood defence works elsewhere in the Humber.

(b) Sites where moving the defences will provide flood defence benefits by reducing the effects of sea level rise.

The estuary process studies indicate that setting back the defences at sites beside the inner estuary (west of the Humber Bridge) and the rivers leading to it may reduce the effects of sea level rise and lower water levels locally during extreme events. Further studies will be carried out to confirm the results are sustainable, to identify suitable sites and draw up a programme for setting back the defences there. The re-aligned defences will continue to provide adequate protection to people and property. Sites will be chosen taking into account the resulting loss of land or property, the condition of the existing defences and the net cost of the works (including any savings from lowering extreme water levels locally). These factors will also be considered when the programme is drawn up, together with sea level changes and any need to provide inter-tidal habitat in compensation for habitat lost because of flood defence works elsewhere in the Humber.

(iii) Support the creation of new inter-tidal habitat to maintain the estuary's conservation status.

The estuary is important for nature conservation, both in general terms and in terms of the number and variety of birds it supports. There are legal implications stemming from the Habitats Regulations and obligations that arise from the UK's commitment to the conservation of inter-tidal habitats, which will be expressed in due course in English Nature's conservation objectives. The Agency recognises these obligations, which are likely to require the creation of new inter-tidal habitat to compensate for losses due to coastal squeeze. The CHaMP will be prepared to provide

a framework for managing the flood defences and ensuring that damage to designated sites in response to natural changes is prevented.

The Humber Estuary Shoreline Management Plan (Environment Agency, 2000a) divides the land around the estuary into eight management units and provides more detail on the implications of the plan for each unit. Fig. 3 summarises the broad strategy. The defence line will be held in front of the main urban centres of Cleethorpes/Grimsby and Hull. The banks in front of the heavily industrialised zone on the South Bank are being undermined by erosion, a process that will intensify as sea level rises. Chemical works and other installations are built right up against the flood defences and there is a presumption against further encroachment onto the mud flats, which are part of the Special Protection Area.

The retreat of some embankments in the part of the estuary east of the Bridge will not reduce extreme high water levels. Set backs may, however, be undertaken to gain a more stable line or to create new habitat to compensate for other losses. Upstream of the Bridge managed retreat should result in a decrease in the magnitude of the highest water levels, particularly in the tidal rivers and, thus, will have direct flood defence benefits. This is being investigated further with more mathematical modelling.

11. The next steps

A fundamental component of the shoreline management plan is that the flood defences in certain areas should be set back and farmland turned into inter-tidal habitat. The present plan does not, however, identify where this should happen either now or in the future. To allow these sites to be identified, a further development phase of the plan is being carried out during the period 2001/2003. The components of the work are:

- Further geomorphology studies concerned particularly with the estuary's likely response to changes (including sea level rise and climate variability) over the next 20–50 years and on the short- and long-term implications of setting back the defences at specific sites in the estuary. These studies will benefit from the work on modelling estuary morphology and processes by the Estuaries Review Group, which is funded by the Environment Agency, English Nature and Department for the Environment Food and Rural Affairs (EMPHASYS Consortium, 2000).
- Setback site selection studies, identifying potential sites and collecting the detailed information (engineering, economic, ecological, historic and social) needed to assess the costs and benefits of setting back and so draw up a programme for implementing setback schemes. The assessment will draw heavily on the results of the geomorphology studies to confirm that any perceived benefits are sustainable in the long term.
- Consultation with those affected by or interested in the setback schemes, in particular those who own, occupy or are employed on land or property that will be affected.

The study will also have a fourth component, to be undertaken once the other three are completed. This will be to draw the results of all the studies together, revise the CHaMP and produce a refined Humber Estuary Shoreline Management Plan to:

- Re-state the flood defence strategy for the estuary;
- Establish the need to set back the defences locally;
- Identify the sites where the setback will take place; and
- Set out a programme for implementing the setback schemes and other flood defence works.

Both the estuary's flood defence requirements and the need to meet national commitments to compensate for habitat losses will be taken into account when establishing the need to set back the defences. Once the refined Humber plan has been drafted, a further round of consultations will be undertaken to ensure that all those potentially affected by the revised proposals will have the opportunity to learn about and comment on them.

It should be noted that The Conservation (Natural Habitats, etc.) Regulations 1994 require a 'scheme of management' to be produced for Eur-

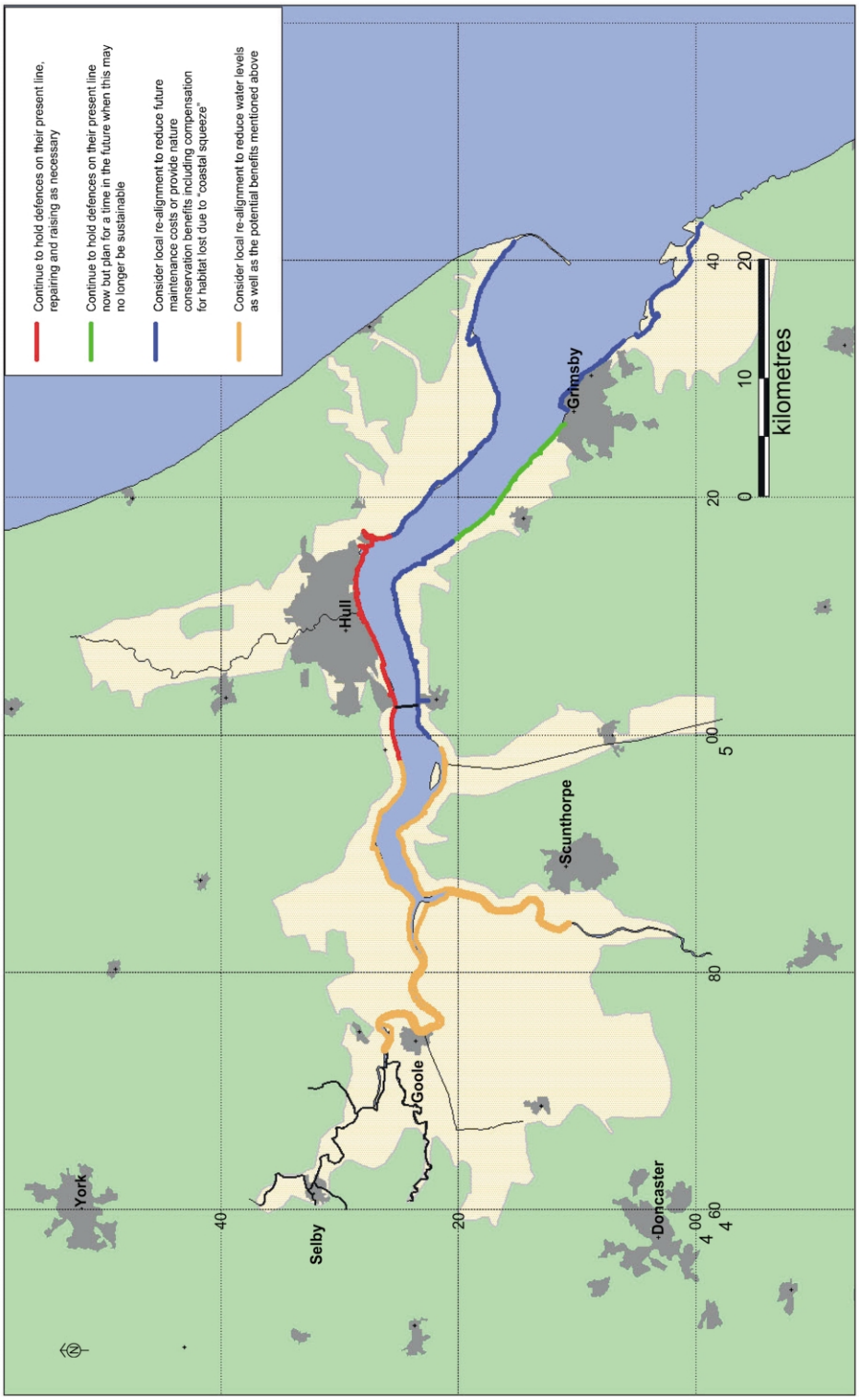

Fig. 3. The broad strategy of the Humber Estuary Shoreline Management Plan.

opean marine sites by 'relevant authorities'. These are organisations with statutory functions in relation to the management of the land and water in or adjacent to the site, including the Environment Agency, English Nature, local authorities, harbour authorities and internal drainage boards. A scheme for the Humber is in preparation and will draw together how the authorities will exercise their functions so that they are compatible with the requirements of the Habitats Directive.

Predictions over 50 years are inevitably uncertain and the plan will need to be reviewed regularly and updated at approximately 5-yearly intervals. Monitoring of the condition of flood defence structures, residential and industrial development trends, sea level and the state of the environment will provide information on whether the assumptions on which the plan was made have changed so that it can be modified as necessary. Projects to improve the standard of service will then be undertaken as the need arises and in accordance with the plan so that statutory obligations are met, and the economic, environmental and community benefits are realised.

The Humber Estuary Shoreline Management Plan is a major contribution to the sustainable management of the Humber. It is being developed from a good scientific understanding of the system, the legal framework and extensive consultation with stakeholders. It is of particular importance as solutions are being sought that meet the need for investment for the protection from flooding of a large population along with industry and agriculture, while also complying with the statutory requirements of the European Habitats Directive. The goal is, thus, to protect and enhance the environment, and to have a thriving local economy and community. The Humber is a large and complex estuary system, which is providing a test case for practical sustainable management of relevance to other estuaries in the UK and Europe, and elsewhere in the world.

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