FINAL REPORT

# A Flood Management High Level Review for the Broads Climate Partnership

October 2016

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# Introduction

## 1.1 Background

Flood and Coastal Risk Management (FCRM) in the eastern half of Norfolk incorporates three major flood defence systems: Eccles to Winterton (coastal), Great Yarmouth (tidal) and the Broads (tidal and fluvial), see Figure 1.1. In recent years several £million per annum has been spent on maintaining and improving these defences, in line with three separate FCRM strategies. These were all initiated over 20 years ago and, while those for Eccles to Winterton and for Great Yarmouth have been reviewed since that time, the principles of the original strategies remain, e.g. to hold the lines and to improve the defences where appropriate.

The current strategies have been successful in progressing delivery of the FCRM objectives. However those strategies have, to some degree, set artificial boundaries that do not facilitate a true long term approach for the larger area. It is therefore necessary to investigate the interrelationships between the three separate strategies for Eccles to Winterton, the Broads and Great Yarmouth to identify the most appropriate long term approach to FCRM across the area. This could be through the development of one single overarching integrated strategy that can reflect the fundamental importance of flood defence management decisions from all of these areas upon the wider Broadland environment and economy.

Discussion on the way forward began in 2010, when it was agreed that a partnership approach including the Environment Agency, Natural England, the Broads Authority, other key stakeholders and the Broadland community, was the correct way to proceed. However, for a variety of reasons, notably that the revised Shoreline Management Plan (SMP) was only approved in 2012 and the public consultation on the Broads Climate Adaptation Plan only concluded in 2015, development of a wider strategy has not yet been undertaken.

## 1.2 Purpose of this review

This area has been very heavily influenced by natural processes (erosion and flooding) and human intervention for several hundred years. It is a man-made environment that has changed over the years, and has an environment and economy which are dependent upon flood defences. An integrated approach will need to take a fresh look at a strategy in this wider context and take account of changes in circumstance since previous strategies were set. This includes changes in funding and contributions to schemes which sets new challenges but also creates opportunities, and predicted changes in climate which may change perceptions of risk, damage, opportunities, and thus the basis for decisions previously taken.

To initiate this thinking and taking the next step, this report provides a collation and appraisal of the current state of knowledge which:

- delivers a succinct summary of that knowledge and appreciation of the present situation;
- identifies the key areas of interrelationships between the individual strategies and issues/questions that will require investigation and resolution for a strategy to be produced; and
- outlines requirements for consideration of a tidal barrier within Great Yarmouth, which might be a potential option for any future strategy to consider.

This is based upon the existing body of information contained in previous studies rather than any additional studies being undertaken at this point. However, in addition to those a high level estimate of the potential order of magnitude costs of delivering flood defence to the area in line with the present strategies, together with the levels of partnership funding contributions that are now likely to be required to deliver those, has been calculated.

This document is necessarily a technical report, aimed specifically at informing the Broads Climate Partnership on the issues associated with providing flood defence management, which will need to be taken into account going forward when developing plans for the production of a longer term and wider flood risk management strategy. These findings should however also provide a useful starting point and basis for discussion and engagement with the key stakeholders and communities about future defences and funding.

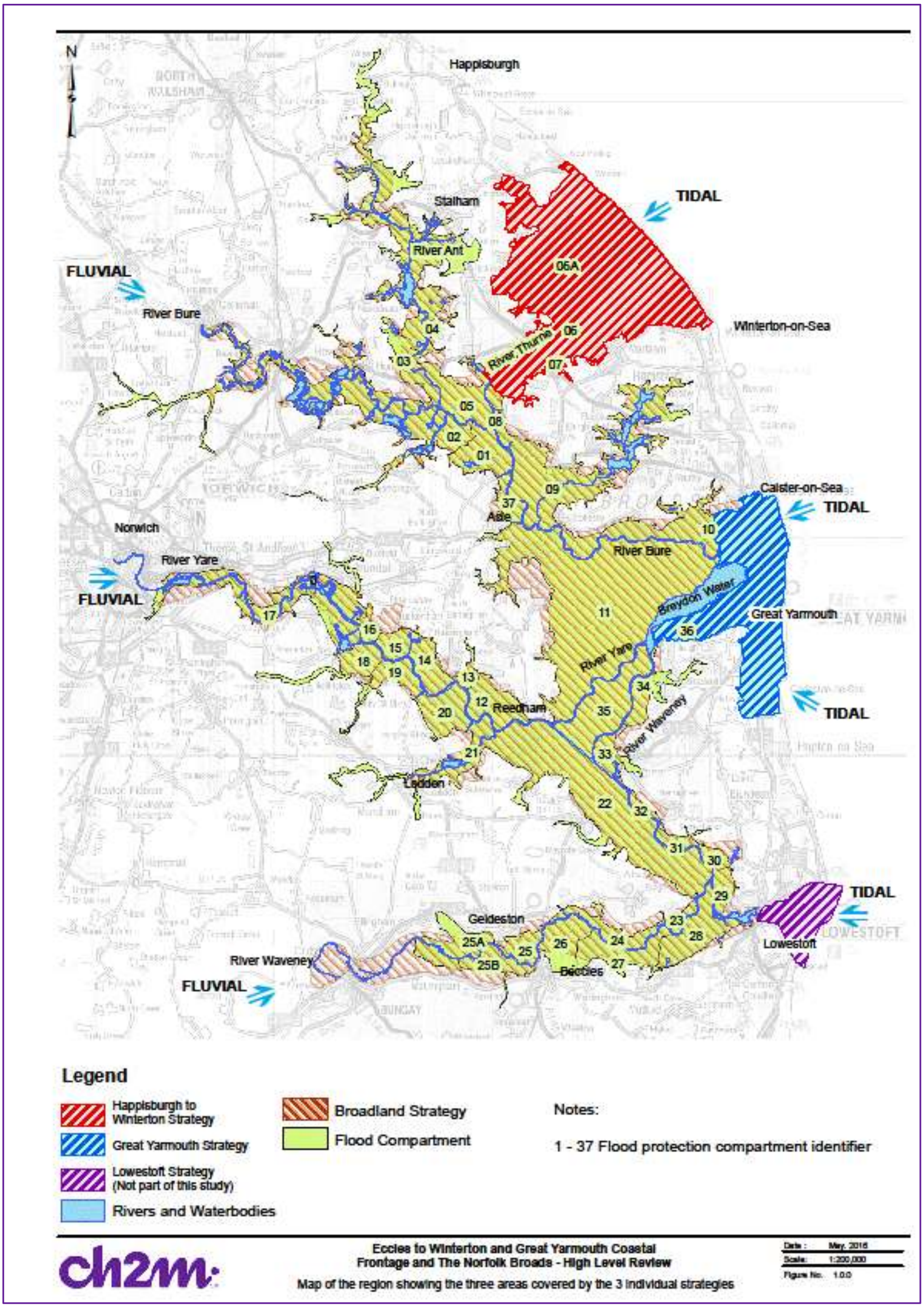



**Figure 1.1 Areas covered by the three strategies**

# Overview of current strategies

A clear route map is required to provide confidence that there is a deliverable plan for the longer term. To inform this it is important to understand the existing strategies and their status for each of the three areas, which are summarised in the sections below.

## 2.1 Eccles (Happisburgh) to Winterton

### 2.1.1 Introduction

The sea defences along the 14km coastline between Cart Gap, Eccles and Beach Road, Winterton protect a low-lying hinterland of up to 3,600 hectares which includes several hundred residential and commercial properties, internationally designated habitats, agricultural land, and help support an important tourism industry.

This area is a naturally eroding frontage with a history of flooding prior to the introduction of the current sea defences and coastal management regime; floods have been recorded here since 1287. The worst recorded coastal flood in this area in modern times occurred in 1938 when 3,000 hectares flooded following a breach in the dunes, which had previously been strengthened with brushwood faggots and timber groynes in response to erosion. Following the 1938 flood the first 'hard' defences were built, comprising a sea wall of concrete filled sand bags at Horsey and Eccles. Major flooding and loss of life in 1953 led to the construction of a more substantial concrete seawall, built in stages between 1953 and 1989, which runs almost the entire length of the frontage. Another breach in the defences would cause extensive damage and risk to life in the immediate hinterland and parts of the Broads.

The integrity of the seawall is dependent on its foundations being protected from wave attack under storm conditions by a beach. The maintenance of adequate beach levels is therefore essential to continued sea defence. The beach in front of the seawall has a history of erosion as there is a natural deficit between the supply of sediment from the north and the sediment that leaves the frontage to the south. The beaches here are known for their volatility, when large volumes of sand can be removed from the frontage during storm events, which has the potential to undermine the structure of the seawall. During the late 1980s, the stability of this wall was threatened by dramatic erosion of the beach and foreshore (as illustrated by the photo in Figure 2.1, c1990), which led to the development and implementation of the current strategy.

### 2.1.2 Shoreline management plan policy

The Kelling to Lowestoft Ness Shoreline Management Plan (SMP6 – adopted 2012) description of the long term management policy for this length of coastline has been the subject of an ongoing debate since 2004, although all parties have given full support to the present '*hold the existing defence line*' policy for the short and medium term (up to 2055).

The longer-term SMP6 policy option is for "*conditional hold the line, with an investigation into the potential for managed realignment, as and when it is confirmed that it is no longer sustainable to defend*", pointing out that this is likely to become more difficult and expensive as the impacts of climate change increase.

**Figure 2.1 Eccles to Winterton strategy frontage**

## 2.1.3 Strategy and implementation status

The initial 50-year sea defence strategy was adopted in 1992, and was subsequently fully reviewed in 1996 and 2002. The sea defence strategy included reef and groyne construction through a series of phases, together with a number of beach recharge campaigns. A subsequent review of the strategy in 2002 recommended continuation of the approach of beach recharge and groyne replacement.

Those works, which have helped to stabilise beach volumes, have altogether included:

- Stage 1 – The construction of four offshore reefs (numbers '5' to '8') between 1993 and 1995.
- Stage 2 – Beach recharge and construction of five more offshore reefs ('9' to '13') in 1997.
- Intermediate works to ensure the integrity of existing defences where beach loss has occurred in areas not defended by the reefs (2000).
- Stage 3A – Beach recharge, the construction of a rock revetment south of Reef 13, and the replacement/construction of rock groynes between Cart Gap and Bramble Hill in 2002 and 2004.

A further full review of the strategy planned for 2007/08 did not proceed for reasons including the delayed adoption of the updated SMP. The 2002 Strategy therefore remains the present approach, i.e. undertaking beach management through recharge and groynes.

In line with this, the requirement for further works prompted the development of a Project Appraisal Report (PAR) in 2008 by the Environment Agency, which was approved for a stand-alone scheme of groyne construction and sand recharge ahead of any further strategy review. The initial work undertaken comprised:

- Stage 3B Phase 1 – beach recharge plus some recycling, construction of further rock groynes, and strengthening of the existing rock revetment (2008-2009).

Approval for this work included further activity (Stage 3B Phase 2), with various measures of a similar nature originally planned for 2011 onwards. This was not implemented, due to less erosion than anticipated and some sediment accumulation at the site. Beach profile monitoring has continued and beach volumes remained relatively consistent between 2011 and 2015. More recently however the requirement for some of the Phase 2 works has arisen, including the full and partial replacement of dilapidated timber and steel groynes with rock, undertaken in late-2015/early-2016. It is anticipated that periodic beach recharge, recycling and further groyne refurbishment may continue to be necessary between 2016 and 2020.

### 2.1.4 Further considerations

A full review of the Eccles to Winterton strategy has not yet taken place. However, other than more recent beach profiles, there will be little change in the baseline data since the 2002 review, so the current position remains valid. It is important to note however that beyond 2055 the SMP policy is only 'conditional' and that there is a need for better evidence to inform the long term decisions, and thus the choices made up to that point too.

The Action Plan within the SMP proposed a number of specialist studies to address the main areas of uncertainty, particularly the technical and environmental implications of holding or retiring the present defence line beyond 2055. Within the site there are areas of internationally significant dune habitat and extensive dune heath. These are designated both for the habitats that they support and for their morphological interest, which in part is dependent upon a dynamic system; one of the SMP Biodiversity Targets is to allow natural processes to operate. When the strategy is reviewed there needs to be consideration of uncertainties with respect to how the dunes may respond if the seawall were retained or lost, and also to the mechanisms of Winterton Ness dune evolution and any linkages between that and the offshore bank systems. These studies remain outstanding and would need to be incorporated within a forthcoming wider strategy.

## 2.2 Great Yarmouth Tidal Walls

### 2.2.1 Introduction

Much of urban Great Yarmouth is low lying and at risk from flooding. There are approximately 13km of floodwalls along the Rivers Yare and Bure protecting in total approximately 7,000 residential and commercial properties. Following serious flooding in 1953 which took the lives of 10 people, with 10,000 more evacuated and unable to return to their homes for several weeks, many of the then existing defences were raised. However, by the 1980's many of the walls had again been noted to be sub-standard due to inadequate height, poor state of repair, or excessive seepage through the flood defence. Again in 2007 another 3000 people were evacuated, although the tide (estimated to have a 1:40 year return period) did not ultimately overtop the defences on that occasion.

There are over 130 different sections of flood defence that form integral defences to Great Yarmouth. These vary considerably in type of construction but can be broadly categorised as:

- Low level steel sheet pile quay walls, with concrete flood walls constructed on top of the quay wall or in some cases several metres back.
- High level steel sheet piled quay walls, usually including a concrete coping, to provide a flood wall.
- Embankments, fronted by steel sheet pile quay walls.
- Retired line reinforced concrete flood walls with floodgates for quay access (although these still generally rely on the quay wall for their stability).

A major issue for provision of flood defence throughout Great Yarmouth is that the majority of the flood walls rely upon the quays for support, but these structures are in poor condition and in need of replacement. It is that work to the quay walls which constitute the major cost element in respect of any works required. Whilst a function of the quay walls is in part to support flood prevention it is not their sole purpose and it had been accepted in the past that a substantial proportion of the cost of replacing old quays should lie with the quay owner or user.

### 2.2.2 Strategy

Following various *ad hoc* works to raise and upgrade defences following the 1953 flooding, a more comprehensive investigation into the adequacy of flood defences at Great Yarmouth was carried out in 1985. This proposed a series of works to raise the flood defence standard to a consistent 1 in 100 year standard through the construction and improvement of walls throughout Great Yarmouth. The study also included a comprehensive condition survey of the defences and established the concept of 8 separate flood protection compartments 'A' to 'J' (there is no compartment 'D' or 'I'), the referencing to which has been widely used since and remains today; see Figure 2.2.

Further inspection in 1997/8 showed that many defences were still in a poor condition, concluding that many could be expected to come to the end of their effective life within 30 years, and that some defence levels were lower than required to provide the 1 in 100 year target standard of protection. This led to the development of a Strategy Review (2002-4) concluding a preferred strategy to 'hold the line' through extensive raising and replacement of floodwalls on the existing defence line to a common 1 in 300 year standard throughout. The programme of replacement works were stated to remain flexible to meet the time scales and funding opportunities with individual frontage owners, but not to the extent where that would compromise the risk to flood defence.

Although the Strategy Review identified priorities for the first five years spend, it also recommended the re-inspection of assets and the production of Project Appraisal Reports (PAR), noting that all assets identified as being at risk of failure within the first 10 years and any other areas of concern will be inspected again and used to further develop the implementation plan and the economic assessment of the business case.


**Figure 2.2 Great Yarmouth flood compartments and tidal walls**

### 2.2.3 Implementation status

Works are planned in Compartment A over the next 15 years. Walls have been prioritised by condition for each compartment.

As part of the initial work on Compartment C, the area with the greatest number of properties to be defended, a subsequent condition survey as part of a strategy implementation status review (2007) indicated that the piles had since deteriorated even more significantly as a result of accelerated low water corrosion (ALWC). This concluded that a higher expenditure than set out in the strategy would need to be prioritised for works in Compartment C, and that is therefore where most works have since been focussed. Those works have though primarily been replacement, i.e. rebuilding quay walls with new longer piles. A scheme to renew approximately 660m of anchored steel sheet piled quay wall and supported flood defence wall in Compartment C was approved in 2013 and undertaken from 2014 to 2016, together with continued maintenance and minor repairs proposed elsewhere.

A considerable amount of work and investment is still needed to deliver the strategy requirements throughout all of Great Yarmouth (indeed even to complete Compartment C) as other than A and C, the remaining compartments have received limited attention.

### 2.2.4 Further considerations

The status review of strategy implementation in 2007 identified a number of changes in circumstance in the intervening period. Other factors have also altered since the strategy was originally published, which would need to be considered in the forthcoming wider strategy.

Accelerated low water corrosion of the quay walls in Great Yarmouth, in combination with sea level rise and the lack of space to build cheaper, sloping, flood defences does call into question the future viability of continuing to improve defence at the water's edge. The identification of ALWC in Compartment C is also likely to be an issue for other frontages too; this could mean that the effective lifespan of considerable lengths of quay wall are even less than previously estimated, requiring action at a much earlier point in time, e.g. no later than the 2020's, to ensure stability.

Estimates of climate change have been revised, and in addition the timescales for considering strategies have lengthened. The 2007 report states that both these factors increase the attractiveness of a barrier option over raising/replacing tidal defences over long distances. The desire to restrict saltwater intrusion and high surge events entering the Broads has also since become stronger from a number of stakeholders. This has implications in terms of considering alternative approaches to providing flood protection to Great Yarmouth.

The construction of the Outer Harbour has altered the situation too, and could potentially mean refocussed priorities for the Port Authority with respect to the inner harbour and associated funding to maintain the quay walls. That could in turn give rise to potential redevelopment or regeneration plans, and with that offer opportunities to look at different ways to manage flood risk in the town.

Any updated and broader strategy will need to consider more fully the wider range of options than previously taken into account. In doing so, the following will need to be appraised:

- It will not be possible to complete a competent business case for flood defence in Great Yarmouth without consideration of a barrier option and what that might provide.
- In the context of that, what works would then be required to ensure flood protection standards were achieved.

Other options including retired lines for flood walls have been considered and dismissed previously but may now need to be re-evaluated: partner funded contributions have never reached the levels required.

## 2.3 The Broads

### 2.3.1 Introduction

The River Yare and its three principal tributaries the Wensum, the Waveney and the Bure, drains around 350,000 hectares of land in Norfolk and northern Suffolk. All of these rivers outfall to the sea at Great Yarmouth and are influenced by tidal conditions to points 40 to 50 kilometres inland.

These reaches pass through Broadland which comprises a network of lowland rivers, shallow lakes or broads and adjoining areas of low lying marshland. Around 30,000 hectares of land within Broadland are susceptible to flooding, of which about 21,300 hectares are protected by 240 kilometres of existing flood defences. Within this there are around 1,700 properties considered at risk of flooding of which around a fifth have no formal defences, key road and rail infrastructure and utilities including a major gas pipeline, high voltage pylons, sewage treatment works, etc. Much of this low lying land is divided into 40 flood protection compartments (Figure 2.3). These are discrete areas bordered by high ground or flood walls so that if flooding occurs it is likely to be contained within the compartment. These rely on pumped drainage to control water levels through the marsh dykes, and are predominately operated by the local Internal Drainage Boards (IDBs).

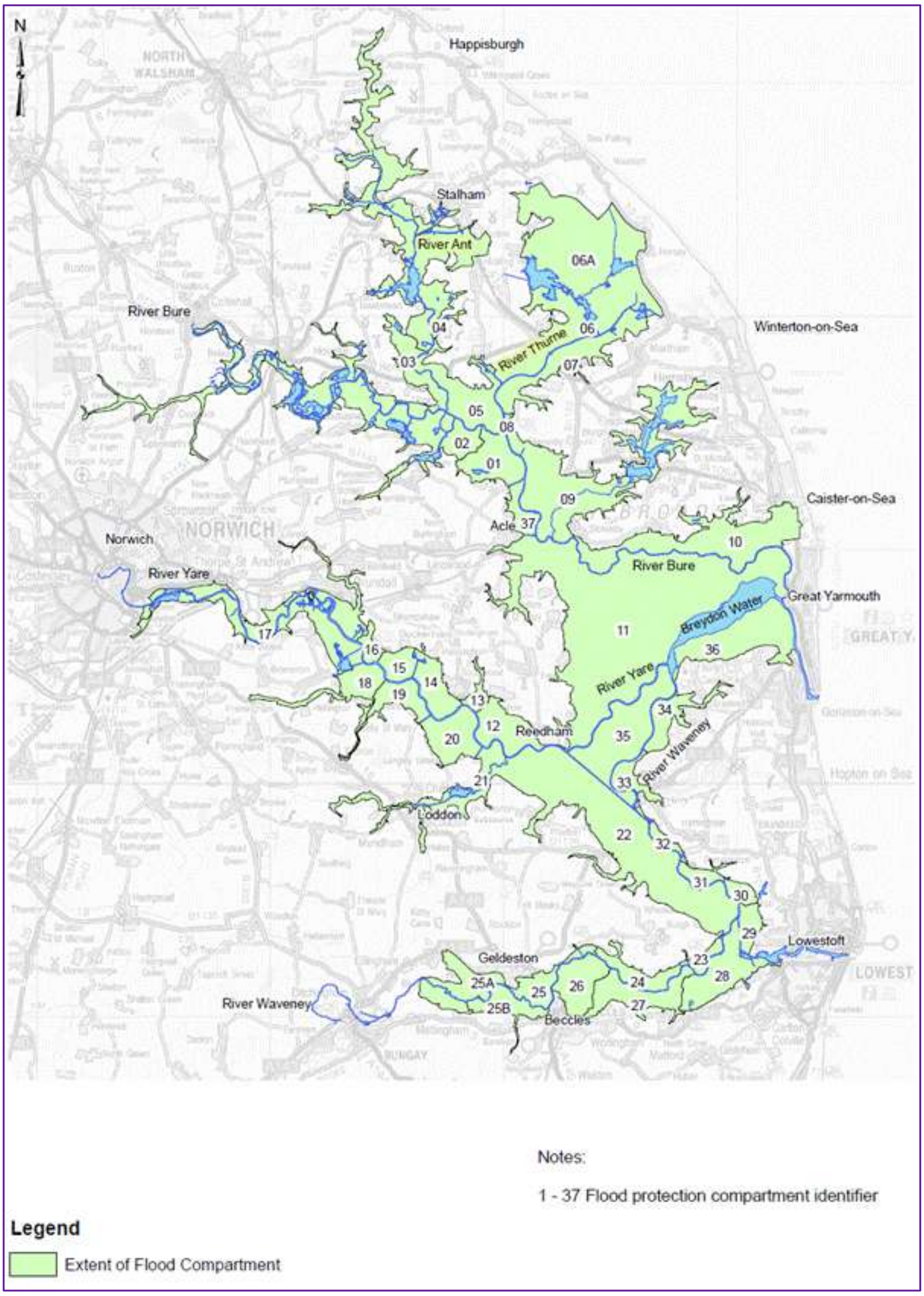



**Figure 2.3 Broadland flood protection compartments**

### 2.3.2 Strategy

In the early 1990s, concerns about the poor condition of these embankments prompted a major study to develop a Flood Alleviation Strategy for Broadland. The study investigated a range of technically feasible options for mitigating the impacts of flooding on the natural and developed environment, including washlands and tidal barriers.

A 1994 report on the study findings recommended an extensive programme of embankment strengthening and river bank erosion protection works. It concluded that the high additional cost involved in constructing a tidal barrier was not then economically justified. It did, however, recognise the likelihood that the case for a Yare Barrier would have to be re-examined in the future as it becomes more difficult to increase the height of the embankments to counter the combined effects of settlement and sea level rise.

The strengthening and erosion protection works were estimated to take 10 years to complete with raising planned to begin 5 years after the initial cycle to guard against settlement and sea level rise. This would again take 10 years and be repeated on a 15 year cycle.

In 2001 the Environment Agency entered into a 20-year contract with Broadland Environmental Services Ltd (BESL), a joint venture between BAM Nuttall and Halcrow (now CH2M), to improve and maintain the flood defences in Broadland. These embankment strengthening and erosion protection works are currently being implemented under a Public/Private Partnership project known as the Broadland Flood Alleviation Project (BFAP).

BESL’s overarching responsibility is for designing, constructing and maintaining works to provide and maintain a specified flood defence service level, re-establish and maintain (as far as reasonably practicable) the overtopping regime and satisfy the requirements for residual life taking into account sea level rise and settlement. In essence BESL are to ‘sustain’ the existing flood defences for the duration of that agreement; that is improve and subsequently maintain their condition without raising the long-term standard of protection they provide. This is to make them more resilient to breach but not to the extent that they may not still experience some level of overtopping under surge events.

### 2.3.3 Implementation status

The strategy is now in year 15 of 20, has completed all the improvement works and is progressing with the on-going maintenance requirements, which are typically local crest raising and erosion protection.

The defence bank heights have been maintained to levels that ensure that flooding elsewhere in other compartments is not made worse, which has been determined by means of hydraulic modelling and year-on-year monitoring of the flood bank crest. Because the banks within Broadland are continuously settling, BESL have an annual yearly crest raising programme which addresses sections of bank which are approaching service level requirements or have been subject to unpredicted settlement. Works to mitigate any adverse impacts also include a number of first time defences to previously undefended settlements, and setting back of banks to increase overall channel capacity.

Improvement works have all been undertaken such that subject to subsequent maintenance the flood defences will meet the contract residual life requirements in 2021. BESL will also prepare an ongoing maintenance schedule which will allow this residual life requirement to be met through until 2027. Wherever possible BESL have removed the need for hard defences, primarily steel sheet or timber piling, by setting the bank back inland and creating a soft reeded rand. This has therefore reduced the on-going long term liability for these. Where this has not been possible new sheet piling has been installed but in many cases having also retired the line of the bank to reduce its dependency on the piling for support.

In 2013 the Broadland banks were tested by the biggest flood event since 1953 (Figure 2.4). Although they sustained rear face erosion due to the depth of overtopping, and several compartments were flooded there were no major breaches in the defences and no properties flooded.

**Figure 2.4 Flood event 2013**

### 2.3.4 Further considerations

There have been a number of significant developments over the 16 years since the Flood Alleviation Strategy was developed including:

- Updated Climate Change predictions
- Revised guidance on scheme Economic Appraisal
- Experience of fish kills and detrimental effects on designated wetland habitats caused by salt water intrusion
- Further questions over the potential for a barrier structure at Great Yarmouth to help manage flood risk within the Broads

The Broads Plan 2004 has also since been reviewed by the Broads Authority, with associated public consultation. The Authority made climate change a cross cutting theme in the updated Plan, and included a draft objective for the Environment Agency to 'develop a flood risk management strategy for the Broads, by assessing advantages and disadvantages of various engineering options'. However, with low property counts it is unlikely that the Environment Agency will have the business case to be able to justify significant Flood Defence Grant in Aid (FDGiA) expenditure, except where key infrastructure or European Habitat regulation require it. This would likely see more than half the compartments at increased risk of flooding.

To inform the flood management approach to this requires a collective vision across all three strategy areas and across all organisations involved including the Broads Authority and the other key statutory bodies such as Natural England, NFU, RSPB, etc. Clear and agreed objectives may necessitate defining, for example, what is considered 'practicable' in terms of seeing the Broads remaining as a freshwater environment for as long as possible? Equally, there is the question of what alternatives to that might be? With the Broads currently being a tidally dominated system increased sea level rise will only see a more brackish environment move up river, and even with a barrier in place there will still be a change in that; maintaining the status quo may not be a viable option, so what might be acceptable? These are a mixture of financial, technical and political considerations, so direction on such matters is necessary for a flood defence management strategy to be developed. This should link to the climate change scenarios and cover the short, medium and long term.

# Strategy interrelationships

There are well recognised interrelationships and overlaps between the three areas despite the development up until now of three individual strategies. Those relationships have been explored and are discussed here.

## 3.1 Coastal processes

Coastal processes have previously been studied in considerable detail through a range of projects and initiatives including, but not exclusively, the Anglian Sea Defence Management Study, the Southern North Sea Sediment Study, the Kelling to Lowestoft Shoreline Management Plans, and various individual schemes along the Norfolk coastline, including those at different stages of the Happisburgh (now Eccles) to Winterton Ness Strategy.

Those studies have identified that net sediment drift is in a southerly direction and that there is a long term sediment transport feed from cliff erosion in North Norfolk to beaches as far south as Great Yarmouth (and potentially Lowestoft), although the time taken for sediment to travel from 'source' to 'sink' has been estimated to take several decades.

Consequently, there is a potential inter-relationship between any activities that alter the sediment transport regime along the Eccles to Winterton frontage, and frontages further south. However, that would not affect the inner harbour at Great Yarmouth or the Broads in any way as they are not dependent upon, nor detrimentally impacted by, any shoreline sediment transport. One potential influence could have been a change in sedimentation across the mouth of the river, but construction of the Great Yarmouth Outer Harbour (2007 to 2009) now prevents that from occurring.

The relationship with areas to the north are also necessary to understand. Previous modelling for the 2002 strategy calculated the annual loss of sediment from the Eccles to Winterton frontage to vary considerably, by between 50,000 to 250,000m$^3$/yr, but overall the sediment input is insufficient to maintain the system with an annual shortfall of 150,000m$^3$/yr on average. Recent 'SCAPE' geomorphological modelling of the shore between Cromer and Eccles for North Norfolk District Council (2013) considered the release of sediment from cliff erosion if and when defences there fail, e.g. as a result of 'do-nothing' or from implementing SMP policy. This offered a conclusion that there may in future be a reduced need to artificially nourish the beaches south of Cart Gap along the Eccles to Winterton strategy frontage. Clearly, with more sediment entering the system that statement makes sense, but it is important to look at this in context. Although the values presented in that report show the potential supply to the strategy area approximately doubling by the 2050's, the upper and lower bounds of the predicted rates are quoted to be approximately +/- 100% higher or lower than the mid-point of the range, so this is far from definitely accurate. Furthermore the change between the present day and the 2020's is a change in sediment input of less than 10%, which given the high annual variability can be considered to be inconsequential with respect to any need to reconsider requirements in the near term. In summary, that work does not at this time support a need to further consider any fundamental change in current strategic direction for the Eccles to Winterton frontage.

Notwithstanding this, any proposals for dramatically different approaches to coastal management elsewhere that could have a major influence on wider coastal processes do need to be taken into account, as the potential to increase or decrease the rate of sediment supply to this frontage could be a consequence that has significant implications for this strategy.

The other potential mechanism for interaction with Great Yarmouth and thus the Broads might come through any changes to the nearshore bank system, resulting from changes in sediment supply to those banks, having the potential to possibly alter their configuration and thus the tidal flow regime in and out of the inner harbour. Recent work commissioned by Bourne Leisure Ltd (2016) has looked at the changes in the nearshore bank system south of Winterton Ness over the last 40 years. This concluded that the presence of Winterton Ness, where there is a sharp change in alignment of the coast, will exert some influence on how those banks behave, so that could be important to understand. However, it also concludes that the extremely high volume of material entering the bank system annually at the northern end of that system is far in excess of any material that could come from the shoreline and therefore must be dominated by feed from other offshore sources, notably other bank systems to the north. Therefore it is highly improbable that any activities that alter the sediment regime along the Eccles to Winterton frontage would directly affect the behaviour of the bank system.

## 3.2 Flood risk

The individual strategy areas have their own direct flood risks, e.g. both the hinterland of Eccles to Winterton and urban areas of Great Yarmouth are at risk of tidal flooding if not defended. But those risks also extend to the Broadland area and cannot therefore be considered in isolation.

To fully understand the extent of flood risk it is useful to look back at the history of the Broadland area and its interaction with the coast. Although there has been considerable changes over time, with Broads having been dug, river courses altered, the coastline eroded and sea levels altered, the general topography of the area is still similar to that shown on the first mapping in Roman times (Figure 3.1). Historically the sea could enter the low lying areas inland via gaps in the high ground in the vicinity of Great Yarmouth and between Eccles to Winterton; the major difference now is that defences constructed in those sections have restricted that and been instrumental in reclaiming the land.

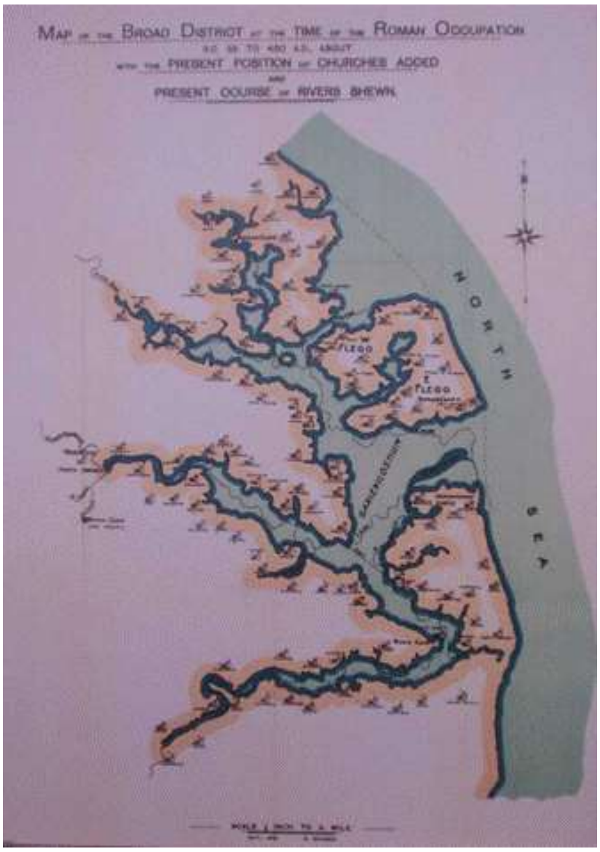
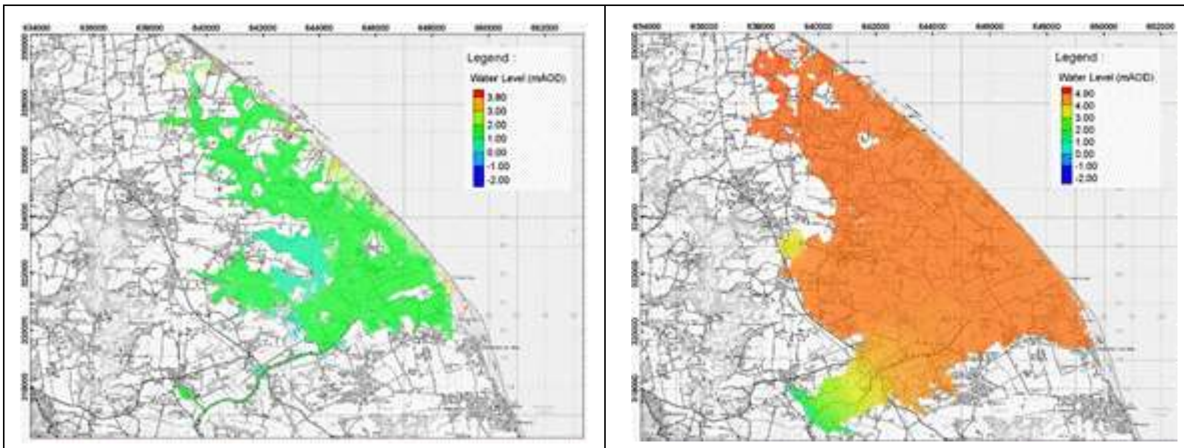



**Figure 3.1 Map of the area in Roman times (source unknown)**

Any changes to the nature, position and standard of the defences along the Eccles to Winterton frontage will potentially impact on flood risk to the Broads. The Broadland Modelling and Mapping Study demonstrated the extent of penetration of flood water into the hinterland from breaching of the coastal defences, as Figure 3.2 illustrates.

The Broadland Rivers Catchment Flood Management Plan looked at the potential impact of climate change on flood risk due to tidal surges via Great Yarmouth, adopting a total sea level rise by the year 2100 of 800 mm. That level of rise would see the entire Broads area flooded. Coupled with this would be the decrease in the time for water to be able to flow freely back to the sea (tide locking) which would push the flood risk further up the river system. Sustaining flood defences to the necessary height using conventional earth banks would be extremely problematic given the soft sub-soil and associated settlement.




(a) Present day condition
(depth of inundation from 1 in 200 year event)

(b) With sea level rise
(depth of inundation from 1 in 200 year event)

**Figure 3.2 Tidal flooding of Broads via Eccles to Winterton**

Likewise any intervention that seeks to change the hydrology of the Broads will potentially have an impact on river flows and therefore on flood risk in Great Yarmouth, and vice versa. Withdrawing maintenance from the flood defences in Broadland presents its own issues. Recent modelling work on the impact of mitigating flood risk through the use of managed and unmanaged washlands could have the likely impact of reducing normal water levels and impact designated sites as well as navigation.  This scenario is indicative of the likely outcome if the banks were neglected, or maintenance was reduced. At present the relatively low bank levels around Broadland result in the banks overtopping at extreme water levels and this in turn offers protection to the surrounding villages and infrastructure. Such consequences of changes need to be understood and evaluated in greater detail.


The 2002-04 Strategy Review for Great Yarmouth identified it to be potentially at risk from three sources of flooding: directly via tidal surge within The Haven, and indirectly via coastal frontages and from Broadland. Flooding in Broadland could impact upon flooding within parts of Great Yarmouth should water enter via the Broadland defence frontages, e.g. within Breydon Water, and thus outflanking the riverside defences in those compartments (Figure 3.3) Potential flooding from coastal frontages along the South Denes Peninsula was also identified as a risk for certain compartments, but investigation of overtopping found this to not be significant. Surface water drainage will be another consideration for any future assessment of flooding risk.

**Figure 3.3 Potential backdoor flooding to Great Yarmouth**

In developing any future strategies, there will be options and choices for the three areas that will challenge the long term appropriateness of continuing with the current strategies of maintaining and improving the existing flood defences as they presently stand.  Such options, while offering the opportunity to develop a new sustainable strategy for FCRM in the area, could also have potentially wider ranging impacts. This further reinforces the need for an integrated strategic approach to the area.

## 3.3 Water management

Water management is crucial to the maintenance of the Broads as a valued landscape and important area for biodiversity, tourism, recreation, farming and as a place for people to live. These aspects will all be affected by the increased risk of flooding, coastal erosion and associated changes in salinity, excess nutrients, land use, and beach profiles, that will occur as a result of sea level rise and climate change.

Coastal defences and the embankments along the Broadland rivers prevent inundation of the low-lying marshes. Permanent or regular flooding will compromise current farming activities as well as change the habitats and species that an area is able to support. However, occasional short-lived flood events can also have a detrimental impact due to the fact that the water will usually be highly saline (from a tidal event) and/or have high nutrient levels. Some parts of Broadland, notably in the upper reaches of the rivers, are not embanked and there is direct connectivity with the watercourses. These 'undefended' areas tend to comprise a mixture of reedswamp, fen, wet woodland and broads. Water quality also affects the status of these habitats.

Within the defended areas water level management, which seeks to balance the needs of agriculture and the environment, is managed by the IDBs through the use of pumping stations and various water control structures. Most of the time the pumps will be evacuating excess surface water originating from direct rainfall, springs on the valley sides and run-off from the wider catchment. Occasionally there will be input directly from the rivers either through overtopping during a major flood event or seepage through the banks. Due to the generally poor quality of river water (high nutrients and /or saline levels) this input can have an adverse impact on both the natural environment and farming practices. Following major flood events it is often necessary to also 'flush' the dyke network with fresh water, especially where the flood water has been saline.

Within the upper Thurne area there is a particular issue with the fact that there is a pathway for salt water to get into the marshes from the sea, under the coastal frontage and into the groundwater. This has a number of consequences. Firstly, Hickling Broad, Horsey Mere and the other waterbodies in the area are all naturally brackish and this is reflected in some of the species that are found there. Secondly, the soils in these marshes are high in sulphates and lacking in calcium carbonate, which means that when they are deep-drained for arable cultivation the water and soils become more acidic. This means that drainage activities result in large volumes of poor quality water being discharged into the broads and watercourses in the Thurne via the IDB pumps.

## 3.4 Natural environment/biodiversity

The study area includes a number of designated nature conservation sites, many of which support freshwater habitats and species that are dependent upon the protection provided by the flood defences (see Maps 2 and 3). This includes those that are located very close to the coast such as the Upper Thurne Broads and Marshes SSSI as well as those further inland but are still vulnerable to the effects of saline flooding via the tidal river system. Additionally, some stretches of the coastal frontage (Horsey to Winterton and Great Yarmouth North Denes) are designated and their boundaries incorporate the foreshore as well as the dunes and marsh that lie behind the flood wall. The estuary at Breydon Water is designated separately and is bordered by defences that are currently maintained.  Consequently, flood risk management has a crucial part to play in the future of all these sites and their features, both through seeking to maintain extent and quality in the short to medium term but also addressing the likely need for adaptation.

Continued maintenance of the Broadland and coastal flood defences are necessary to comply with the biodiversity objectives and obligations in the short to medium terms. An increase in frequency and extent of saltwater penetration into the Broads would be damaging to ecology both in the short term (for example the high tide in November 2006 led to an estimated 138,000 fish fatalities) and for the long term (putting sites at risk that have been designated under the Habitats Directive). Minimising the risk of the area becoming inundated by saline water either from the coastline between Eccles and Winterton, or via The Haven at Great Yarmouth will need to remain a priority if this situation is to remain, as should seeking to reduce the volume and /or salinity levels of sea water infiltrating the groundwater.

### 3.4.1 Upper Thurne Broads and Marshes SSSI (component site of the Broads SAC, Broadland SPA and Broadland Ramsar site)

The 14km of frontline defences between Eccles and Winterton protect the Broads from flooding directly from the North Sea. Occasional overtopping can introduce saline water into the headwaters of the River Ant. A greater threat exists further south where the sea has broken through on several occasions historically, often close to the former outfall of the Hundred Stream (e.g. in 1938) and subsequently the 1953 breach at Sea Palling. This resulted in widespread, deep flooding over an area of approximately 3,000ha including the whole of the Upper Thurne and is indicative of the area threatened if the current defences were to fail. Flooding from the sea therefore represents the most significant threat to natural habitats in this particular part of the Broads.

Although much of the Upper Thurne is embanked and has been subject to recent strengthening and crest raising the consequences of flooding from the rivers and other watercourses are not as significant as that from the sea directly. Saline intrusion via a surge through The Haven is not usually a problem this far up the river system at present, rarely penetrating beyond Potter Heigham bridge. However, this could be exacerbated in the future with greater penetration and more frequent events as a consequence of sea level rise and climate change.  There are other water quality issues in the Upper Thurne as a consequence of the ochre that is pumped into the broads from the marshes and the elevated salinity levels that encourage the growth of the algal *Prymesium parvum*, which can cause mass fish-kills.

### 3.4.2 Broadland

In addition to the Upper Thurne Broads and Marshes there are over 20 other SSSIs that together form the Broads SAC, Broadland SPA and Broadland Ramsar sites. Whilst some of the component SSSIs are undefended or directly connected to the rivers the majority are protected by flood defences and it is currently possible to minimise the duration of flooding by pumping the water off the marshes once river levels drop, thereby reducing the impacts on the freshwater features. Through the current strategy all of the flood defences have been strengthened and in places have constructed new setback banks. Although some allowance has been made for sea level rise when designing the improved banks, it is uncertain how long the current level of protection can be maintained in view of the likelihood of increased frequency of surge events and a range of issues associated with water quality. Two key issues would be lower river flows and/or increases in tidal levels which would allow saline water to penetrate further up the system and the effect of tide-locking which could cause an increase in fluvial flooding with poor quality water as a result of run-off from urban areas and farmland.

With respect to flood risk management the Site Improvement Plan for the Broads SAC and Broadland SPA (Natural England, 2014[1]) identifies climate change, hydrological changes and inappropriate coastal management as key issues. The listed actions relate to the need for further research to understand the implications for freshwater features and to produce both short-term and longer term adaptation strategies. The report acknowledges and supports the SMP policy to hold the line in the short to medium term which, in combination with the work already being undertaken, will provide a level of protection that will maintain the whole system as predominantly freshwater.

### 3.4.3 Breydon water

Breydon Water SSSI comprises the estuary whereas the SPA and Ramsar site extend onto parts of the adjoining Halvergate Marshes SSSI, which is within the defended area. The main issue within the estuary, where the important habitats are mudflat and to a lesser extent saltmarsh, is whether sea level rise and an increase in storm/flood events will cause erosion which could affect the availability of suitable feeding and roosting sites for birds. Within the grazing marsh part of the site an increased risk of saline flooding which would exacerbate the existing problem of an insufficient volume of fresh water that is available to bird and other features within the wider Halvergate marshes complex.

### 3.4.4 Horsey-Winterton and Great Yarmouth North Denes

These sites extend either side of the hard defences where present. Some parts of the Horsey-Winterton SSSI are in unfavourable condition due to the presence of the sea wall which means that coastal processes are compromised. The Site Improvement Plan for the SAC (Natural England, 2014[2]) acknowledges that this is a difficult problem to solve given the current hold the line policy of the SMP and the fact that any removal and realignment of the defence here would result in adverse impacts on the Upper Thurne Broads and Marshes SSSI. This illustrates the dilemma of individual classifications and not looking at the wider area.

## 3.5 Social/Human Environment

Clearly much of the land in the region is low lying, giving rise to widespread flood risk as well as issues of land drainage and water level management, having a strong influence on agricultural practices and conservation. Any un-planned increase in tidal and/or fluvial flooding would impact upon the existing environment and consequently affect the attractiveness of the area to tourists as well as reduce farming viability.

The existence and legacy of coastal defences, first installed in the aftermath of the 1953 floods, have had a strong influence on current FCRM policy and on people’s expectations. People have lived and worked in the area for centuries and the ongoing maintenance of the Broadland and coastal flood defences will have given security and confidence to landowners, land managers and statutory bodies that water level management practices can be sustained in the short to medium terms.

The Broads are unique in terms of their landscape, recognised by the fact that they have a status equivalent to that of the National Parks in England and Wales, and thus have huge appeal for recreation and tourism (Map 4). The maintenance of these landscape features, in both extent and quality, is dependent upon a range of factors including the approach to flood management. Changes in flood risk or flood management to Broadland could be direct or indirect, i.e. affected by strategic decisions for Eccles to Winterton or Great Yarmouth, and if this is unplanned for could impact upon present tourism interests with consequences for the regional economy. Due to the importance of the tourist industry, both along the coast and within the Broads, many jobs and businesses are either wholly or partly dependent upon the continued ability of the area to attract visitors. The open beaches and dunes plus the waterways of the broads and rivers are the basis for this attraction. It is likely that those basing their holiday in the Broads will visit the coast at some time during their stay and vice versa.

Whilst some tourism attractions may be adaptable, e.g. wildlife, walking, others will be less so. An example of this is boating, with the Broads offering over 190km of navigable waterway including the ability to move from the northern rivers to the southern rivers via Breydon Water as well as out into the North Sea via The Haven at Great Yarmouth (and to a lesser extent via Mutford Lock at Lowestoft). Many visitors to the area will come on a boating holiday or hire day boats and canoes whilst staying. Exposure of the waterways to more frequent storm surges may also reduce the amount of time that people could spend on the rivers and broads in any one year. Whilst siltation is another threat to navigation a change in water quality will also affect the wildlife and landscape; it needs to be understood whether that would affect people’s enjoyment and could deter them from visiting? The Broads is also a nationally important coarse fishery and many holidaymakers, including those who hire boats, come mainly for this reason. Would a change in water quality, including that caused by increasing salinity, have an impact on this?

Farming represents the main land use and other important economic activity within the Broadland area (see Map 5). Farming in the floodplain is highly dependent on flood protection, the supply of sufficient, good quality water and the ability to manage water levels. It is likely that the available area of farmland, certainly for arable but also for some grazing regimes, will reduce over time if changes in exposure to tidal flooding and salinity reduces the viability of current farming practices close to the coast and along the tidal rivers.

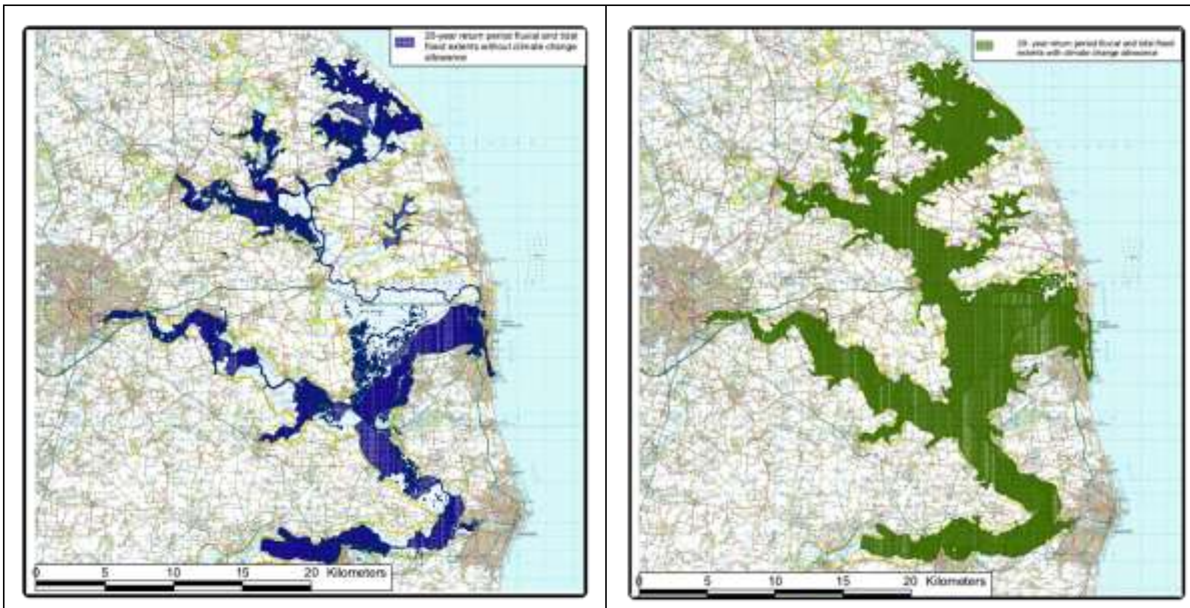
Many town and village communities lie within the study area, providing residences for those working across the area and businesses that are aligned with the local characteristics of the area, all contributing to the economy of the region. Critical infrastructure is shown ion Map 6. The aforementioned risks of flooding and changes to the nature of the area would have significant consequences upon them irrespective of source, so cannot be considered in isolation.

## 3.6 Climate change

Climate change itself, and the possible future strategies to adapt to climate change, could produce major impacts on the local economy, communities, land use planning and on the wider environment, i.e. landscape, socio economics, archaeology etc., as well as on conservation.

Various high level plans have highlighted the challenges posed by climate change. The Kelling to Lowestoft Ness Shoreline Management Plan highlighted that maintaining the coastline in its present position "*may not be technically or economically sustainable in the long term*", and the Broadland Rivers Catchment Flood Management Plan states that "*climate change presents a significant challenge for protection of people, property and the environment of the Broads for which there are no easy solutions*". 'Responding to the impacts of climate change on the natural environment: the Broads', published by Natural England in March 2009, states that "*The scale of the potential impacts in the Broads…..means that it is particularly vulnerable to the impacts of climate change*". Figure 3.4 illustrates the differences in flood extents from just a 1 in 20 year event.

Therefore the range and significance of climate change impacts on future FCRM policy will require fundamental re-thinking, and in the widest context, i.e. taking a holistic view of the whole area covered by the strategies, addressing the inter-relationships discussed in this report, and considering the full range of potential climate change outcomes.




(a) Present day condition (1 in 20yr event)

(b) With sea level rise (1 in 20 year event)

**Figure 3.4 Fluvial and tidal flood extents with climate change**

## 3.7 Legislation, Political Relationships and Responsibilities

The main bodies involved with flood and coastal management and policy in England include Defra, the Environment Agency, the Lead Local Flood Authorities (LLFA), the Internal Drainage Boards (IDBs), Regional Flood and Coastal Committees (RFCC), and Department for Communities and Local Government (DCLG). Map 1 shows the administrative boundaries of the local authorities that include the coastal frontage of the study area.

Key legislative drivers relevant to the approach taken when implementing FCRM and considering an integrated strategy are set out in Appendix B, along with relevant local and other plans administered by the three local planning authorities.

Although the structure is in place, a joined-up approach to FCRM between planning communities, engineering, funding streams, politics and the environment can sometimes be lacking with no overarching consistent and clear direction which takes account of planning, infrastructure, economy and the environment. Different organisations also have different perspectives and therefore various interpretations and drivers may result. Given the interrelationships that exist across this area, there is a need for consistency between the different planning authorities in relation to FCRM and the timing and scope of any management or adaptation strategy.

# Tidal Barrier

There are several factors that will have a bearing on the future decisions for the area, but one of the single biggest factors will be whether or not a tidal barrier is provided at Great Yarmouth.

This has been considered previously but not progressed, albeit acknowledging that this would need to again be examined at a future date. This planned review provides an appropriate point in time at which to consider doing so, taking into account there have also been changes since previous assessments were conducted that warrant such re-consideration, including:

- Increased levels of information and data on hydrodynamics and defence assets;
- Revisions to sea level rise predictions indicating levels rising at a faster rate than previously estimated;
- Condition assessments and works since carried out to flood defences across Broadland and Great Yarmouth;
- Construction of the Great Yarmouth Outer Harbour, altering the use of the Haven especially for larger vessels;
- The increased potential for environmental damage within Broadland caused by tidal flooding, for example fish kills as a result of saline intrusion, and the potential for this to affect our ability to meet legal obligations to protect designated sites;
- Potential changing attitudes with respect to flood risk, environmental management, and the provision of a Barrier;
- Advances in technology with respect to the design, construction and operation of barriers;
- The economic criteria for obtaining FDGiA and for finding partnership funding contributions.

Consequently, this high level review has re-examined previous assessments for a barrier and outlined what steps would need to be taken to progress this option, so that a well informed and considered decision on its viability can be developed.

## 4.1 Previous considerations

### 4.1.1 Options

The construction of a tidal barrier within the Haven at Great Yarmouth (the 'Yare' Barrier) has been the subject of various studies and assessments over the past 40 years. The barrier options and their locations previously considered were as follows (see also Figure 4.1):

- Barriers at the west end of Breydon Water and across the mouth of River Bure (5.4 + 4);
- Barriers at the east end of Breydon Water at Breydon Viaduct (excluding or in combination with the road bridge which is now the route of the A12) and across the mouth of River Bure (5.4);
- Barrier between Haven Bridge and mouth of River Bure (5.3);
- Barrier opposite Queens Road (5.2);
- Barrier at the Lower Ferry Crossing (not shown);
- Barrier at the mouth of the Haven. (5.1).
- The previous studies considered from both a technical and economic perspective what a barrier might provide, in conjunction with other work in Great Yarmouth and Broadland, to:
- reduce the risk of tidal flooding to people and property both in Broadland and in Great Yarmouth;

- reduce the impact from increased saltwater intrusion into the Broads.

These considerations remain the same primary focus for any further evaluation of a tidal barrier as part of a wider combined strategy.

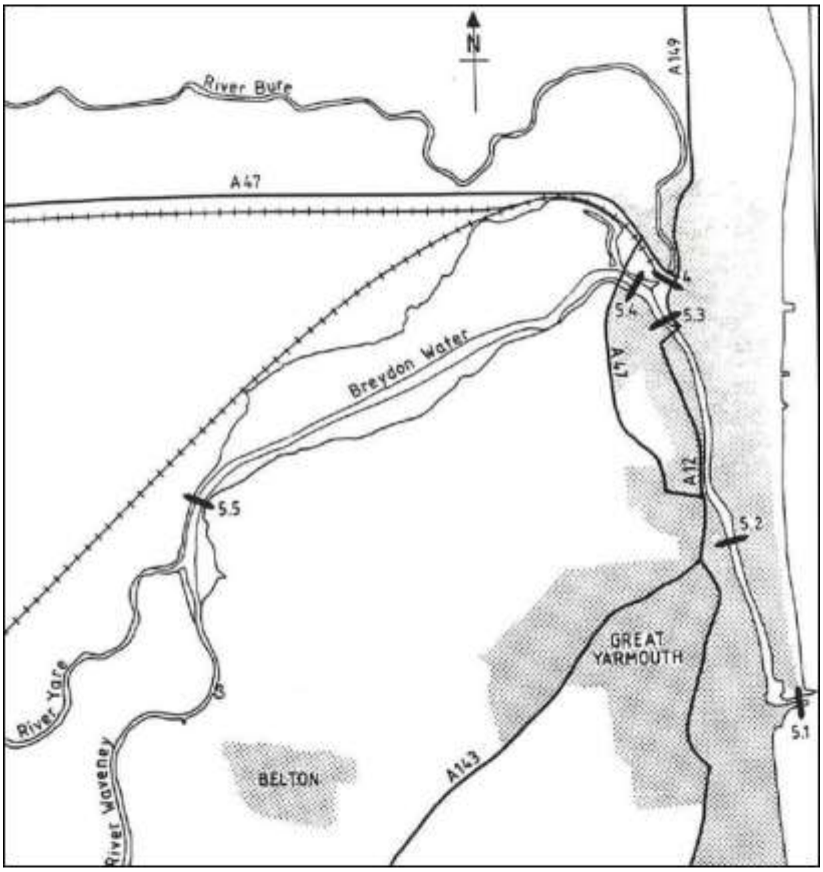



**Figure 4.1: Previously considered barrier locations (taken from 1994 Yare Barrier report)**

### 4.1.2 Assessments

The key studies conducted previously were those by Rendel Palmer and Tritton '*Yare Basin Flood Control Study*' in 1977 (with an update in 1983) for Anglian Water Authority, and '*A Flood Alleviation Strategy for Broadland – Yare Barrier*' by Binnie and Partners in 1994 on behalf of the National Rivers Authority. Key issues considered in previous studies with respect to the design and construction of the barrier, and observations made then that may remain relevant to decisions today are outlined in Appendix A2, and summarised below.

#### 4.1.2.1 Tidal flood risk

A Barrier will reduce the highest water levels experienced in Broadland compared to those at present, by an amount that will depend upon the operating rules adopted and, in particular, on the frequency of operation. Taking prediction uncertainties into account, reductions of 0.1m to 0.2m may be expected with an operating frequency of 5 to 10 times per year, and 0.2m to 0.4m with a frequency of 30 to 40 times per year (based upon 1994 water levels). Flooding of undefended property in Broadland is likely to be less frequent and not as deep as at present if the Barrier was built, but it would not be eliminated unless other remedial measures were taken.

Closure of a Barrier could result in water levels downstream being higher than if a barrier were not there. For a calculated 1:200 year surge event (in 1994), it was estimated that peak water levels would be about 0.3m higher at the barrier site, reducing to zero at the Haven mouth, and that downstream defences would need to raised and improved to suit.

***These provide a useful initial guide on potential effectiveness and impacts, but new assessments utilising more recent data and modelling capabilities would still be required to re-establish these***

***effects and this operating criteria for a range of circumstances, based upon agreed objectives and overall costs for defence options.***

#### 4.1.2.2 Salt water intrusion

The operation of a Barrier would reduce the intrusion of salt water into Broadland when sea levels are high but would not control intrusion caused by low river flows. *This remains particularly pertinent when considering sea level rise.*

This reduction would be most effective if a Barrier is closed around mid-tide level, but the duration of closure could be several hours, varying between 5 and 20 hours, with longer durations during neap tides. ***Again useful in considering viability, but further analysis utilising more recent data and modelling capabilities will be necessary to better determine the effectiveness and practicalities of various operating rules, including objectives and effects on navigation.***

#### 4.1.2.3 Barrier configuration

Previous studies were based upon requirements to accommodate the size and type of shipping present at that time, including a proposed Ro-Ro terminal upstream, and a navigable clear width of up to 50m was considered necessary. ***However, these requirements may have altered and a narrower navigable width could potentially be acceptable.***

The river width at Breydon Viaduct is more than double that Haven Bridge, so would require a greater number of secondary spans and more complex and costly operations system. Location also influences the gate type. At Haven Bridge, a high level vertical lift (or drop) gate arrangement was preferable as a rising sector gate would result in blocking the river whilst it was exposed above water for maintenance and a balanced swing gate would require a middle pier in the river which would be a navigation obstruction. ***This is similar to the Hull Barrier.***

At Breydon Viaduct, a balanced swing gate and high level structure were considered technically feasible, with the high level structure recommended on grounds of greater reliability, ease of maintenance and costs.

Figure 4.2 shows examples of some of these barrier gate types.

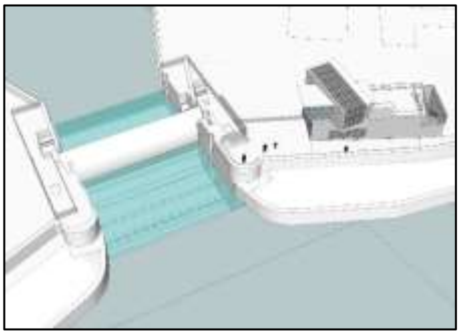
The appearance of a gate would impact on the townscape of Great Yarmouth, and defined by the type of gate proposed and width of the navigational opening. A vertical lift gate would require a structure with a height approximately 36m above mean water level. ***In comparison, side hung mitre gates would only have a height of approximately 6m above high water level.***

In addition to river width, a number of other factors contribute to the cost considerations. At Haven Bridge the maximum depth of the river bed level and thus sill levels compared to Breydon Viaduct could result in a more costly barrier gate at Haven Bridge. However, suitable foundation conditions are expected to be encountered at a lower level at Breydon Viaduct, affecting the invert levels and thus costs of construction. Tidal current velocities, which are significantly higher at Haven Bridge could though have an influence on construction methodologies.

***The above assessments provide a useful baseline to begin discussion on points of viability, but are all aspects that require re-evaluation in the context of more recent knowledge and gate technology, construction methods etc, and also with objectives for flood management, saline intrusion and navigation being re-freshened.***

**Hull Barrier, UK**: Vertical lift gate – 30m wide. *Photo : Environment Agency*

**Ijssel Barrier, Rotterdam, Netherlands**: Vertical lift gates – 80m wide. *Photo : Rijkswaterstaat*



**Ipswich Barrier, UK**: Rising sector gate – 20m wide

**Lake Borgne Barrier, IHNC, New Orleans**: Vertically hinged horizontal sector gate – 46m wide *Photo : USACE*

**Figure 4.2 Example barriers and gates**

#### 4.1.2.4 Navigation

When closed a Barrier could cause oscillations of the water surface in the channel to seaward, affect the pattern of water movement, and hence increase the difficulties of vessels using or entering/leaving The Haven. ***More detailed modelling would be needed to determine the severity of these issues and whether they could be overcome by particular Barrier operating procedures.***

Existing port traffic and operations would be affected more by barrier locations downstream of Haven Bridge than at Breydon Viaduct. Recreational navigation traffic was considered to be more affected by a Barrier at Breydon Water as most pass this point, with very few heading downstream into the Haven channel. ***The current level of commercial navigation traffic passing through Haven Bridge has however changed significantly since 1994.***

#### 4.1.2.5 Sedimentation

The presence of a Barrier was unlikely to have a significant effect on the hydraulic or sediment regimes in the Haven channel on the basis that the existing channel cross sectional area would be not be significantly reduced. There may be some localised erosion of the bed caused by the piers and possibly some accretion if zones of low currents occur in the immediate vicinity of a barrier structure. The amount of sand entering the port may be reduced due to the reduction in flow velocities into and out of the Haven when the barrier is closed.

The effect of an open barrier in Broadland and the Haven was considered small and, as a result, unlikely to have any significant impact on overall sediment movements.

***Although matters to be re-evaluated for any options taken forward, these are again useful conclusions regarding potential impacts of the barrier that can be used to help initially inform decisions.***

### 4.1.3 Previous conclusions

In all of the previous studies a Barrier at the Haven Bridge site was considered to be the preferred location primarily because: its overall cost was estimated to be less than the others, with a greater cost benefit ratio; it was located up-river of the active commercial wharves within the Haven and hence would have less impact on the operation of the port, and; its construction would have less impact on navigation traffic than the other option locations.

However it was also noted in the 1994 report, '*A Flood Alleviation Strategy for Broadland*' that as it was necessary to replace a proportion of the quay walls in order to maintain the necessary flood protection for Great Yarmouth; that "*The only engineering alternative to reconstruction of the quay walls, would be to relocate the proposed surge barrier at a site below the Lower Ferry Crossing at South Denes*".

As outlined in the preceding sub-sections, there are a number of assessments previously made that help to inform initial consideration of the viability of a Barrier. But several criteria used and assumptions made previously have since altered, as has information and understanding of issues such as climate change, and any future options need to be reappraised in the context of those and with a re-assessment of what the objectives and criteria for a Barrier might now be.

## 4.2 Barrier costs

### 4.2.1 Previous cost estimates

The most recent barrier cost estimate was that provided in the March 1994 report with an estimated total capital cost in the first 10 years of £21.2 million and a whole life cash cost over 50 years of £34.7 million (December 1993 prices). This was based on a 10 year implementation phase for the construction of the barrier and an average annual operation and maintenance cost over the following 40 years of circa £0.35 million per annum (December 1993 prices).

The above capital cost excluded the costs of further studies and a Public Inquiry which were estimated to be £1.5 million (December 1993 prices). This cost estimate was based on the construction of a 50m wide vertical lift gate type barrier in combination with 3 smaller falling radial type gates of varying size either side.

The above equates to an estimated present day capital cost estimate over the first 10 years of circa £53 million and a whole life cash cost over 50 years of circa £84 million (December 2015 prices using the Construction Output Price Index).

### 4.2.2 Benchmark cost estimates

#### 4.2.2.1 Hull Barrier

The closest benchmark to the above type of barrier is the Hull Barrier, constructed in 1980, which although only 30m wide, is similar in size, type and configuration.

Its equivalent present day capital cost over the first 10 years is estimated at circa £25 to £30 million (December 2015 prices).

From the perspective of long term maintenance costs the Hull Barrier underwent a major £10 million refurbishment in 2013 to sustain its operation for the next 30 years.

#### 4.2.2.2 Ipswich Barrier

The construction cost for the Ipswich Barrier, which is a 20m wide rising sector gate, and which is due for completion in 2018, is £21 million with an overall capital cost over the delivery period of £33 million.

The estimated whole life cash cost for the barrier scheme over the 100 year appraisal period to 2109 is £78 million.

### 4.2.3 Summary

Based on the above bench mark information a capital cost for the Yare Barrier in the order of £50 - £55 million (December 2015 prices) is a reasonable high level estimate at this stage.

A whole life cash cost in the order of £80 - £85 million over 50 years is also a reasonable high level estimate at this stage for a barrier (noting this is not including costs for any other defence raising works).

It should be noted that a reduction in the barrier width required for navigation is likely to result in some reduction in capital cost. Conversely a significant increase in the frequency of barrier operation to manage saline intrusion is likely to result in increased whole life operation and maintenance (O&M) costs.

## 4.3 Future considerations for a barrier scheme

In undertaking any future evaluation of options for a barrier it will be necessary to establish and confirm more precisely what the actual objectives for any barrier would be, as well as the current physical conditions and constraints, the construction as well as future operational and maintenance requirements, the potential environmental and other impacts and likely mitigation, and future development plans in the area.

Some of the topic areas that will need to be evaluated to establish the most appropriate location for, and type of, barrier are set out in Appendix A1. Not all of these factors will require determination at strategy stage to the level of detail listed therein, but they will have a bearing upon the viability or otherwise of a barrier as a strategic approach and therefore need to be considered when assessing potential options.

### 4.3.1 Scheme implementation

When considering the process that would need to be followed when looking at the future implementation of a barrier scheme, there are a number of elements which will be key to the delivery of such a scheme.

#### 4.3.1.1 Transport and Works Act Order

To secure the necessary powers to enable the construction of a barrier across the navigation channel, there will be a need to prepare a Transport and Works Act Order (TWAO) for submission to either the Department for Transport (DfT) or Department for Environment, Food and Rural Affairs (Defra) for approval

The primary outputs to support the TWAO application include:

- An appraisal providing technical, economic, social and environmental evidence;
- Comprehensive consultation and stakeholder engagement to secure support for the preferred barrier scheme and reduce the risk of objection;
- Environmental Impact, Habitat Regulations and Water Framework Directive assessments;
- Legal agreements with third parties affected by the scheme e.g. landowners, port authority, etc.

Based on the experience from the Ipswich and Boston Barrier schemes, deemed planning approval and the necessary Marine Licence would be sought in conjunction with the TWAO application.

At this strategic stage allowances should be made from a cost and programme perspective for holding a public inquiry to deal with any substantive objections to the TWAO application and making of the Order.

#### 4.3.1.2 Assurance

In developing a barrier scheme the necessary technical and economic assurance will be required to support its implementation.

The need for a barrier could be established in an approved combined overarching strategy (or Strategic Outline Case) as recommended elsewhere, which would allow further more detailed appraisal work to support the business case and hence funding for the construction and long term maintenance of the barrier.

Approval of the scheme would be achieved by submitting a business case for review, through the Environment Agency's Large Projects Review Group (LPRG).

It is likely that the business case would need to be delivered in two stages, pre and post the TWAO approval with additional management milestones seeking LPRG 'assurance to proceed' to prepare and submit the TWAO.

#### 4.3.1.3 Programme

Based on the recent experience from the implementation of the Ipswich and Boston Barrier schemes, a period of 6 to 8 years should be allowed from strategy approval to construction completion.

This could be longer should the necessary capital and long term operation and maintenance funding prove problematical to obtain.

### 4.3.2 Key Considerations Going Forward

There are a number of specific key barrier considerations related to flood risk management and the problem of saline incursion that will need to be addressed going forward. For example, depending upon the form of any barrier and how it is operated it will have quite different implications for how saline intrusion and tidal surges are managed within Broadland, including the future viability of current pumping operations, and whether some parts of the Broads will need to adapt differently to others. Indeed there are multiple permutations of options with numerous potential outcomes at the present time, which need to be reduced to a more manageable number for detailed consideration.

A pre-strategy definition of some of these matters would help develop a better understanding of the extent and scale of these issues and hence guide the scope and efficient delivery of the strategy development. These considerations might include:

- What will a barrier be used for, what are the expectations and extent to which is will address flood risk, or/and saline incursion?
- From a Broads perspective where do the saltwater incursion problems actually lie?
- What is the likely frequency of barrier operation necessary for managing flood risk and saline intrusion (noting that these are significantly different requirements)?
- What are the navigation requirements and constraints which a barrier scheme will need to accommodate – and how would any plans for use of the Outer Harbour affect those?
- How would a barrier scheme be potentially funded – capital cost and long term Operation & Maintenance costs? Are there re-generation aspirations/opportunities for Great Yarmouth that could influence this?
- Is there a potential future need for other features, e.g. locks and/or fish passes?

# Headline economics

## 5.1 Flood defence costs

The costs of providing flood defence across the whole area have been estimated from information provided by previously completed studies for each of the three areas. These estimates are high level approximations only, as the basis for some of those costs will have changed during the intervening years and requirements going forward may be different from assumptions made at that time. Such assumptions, which can affect the expenditure profile and thus present value (PV) calculations include the nature and timing of works. Another important factor is the ongoing annual cost associated with operation and maintenance of those works. For these reasons it is important to emphasise that the costs presented here as part of this high level review are simply providing an order of magnitude approximation based upon past assumptions; they are not the result of detailed and precise calculation which would necessitate a level of information and knowledge beyond that available at this stage.

The potential costs for implementation of a tidal barrier at Great Yarmouth have also been accounted for in these estimates, based upon the information presented in Section 4.2, assuming a corresponding potential reduction of expenditure on other flood defences within Broadland and Great Yarmouth, and potential differences in timing of works. Here again there could be considerable variation in those other costs (and benefits), depending for example where in Great Yarmouth any such barrier was located.

It is also prudent to allow for the risks relating to uncertainty and unforeseen expenditures, although within the original cost estimates used here there will already be some allowance for such risks made within those previous strategies. But for the purposes of this appraisal, and to assess the sensitivity of the subsequent economic calculations, an 'upper bound' estimate has been developed, which equates to a level of 20-30% on top of the initial total cash cost estimates, and with works 'front-end' loaded.

Potential costs are shown in Table 5.1 for two different example expenditure profiles (lower level of expenditure but requiring earlier investment, slower investment but higher total spend), along with discounted Present Value costs (PVc), based upon a 50 year appraisal period.

| YEARS | HIGHER EARLY SPEND COST ESTIMATES | | LOWER EARLY SPEND COST ESTIMATES | | UPPER BOUND COST ESTIMATE (WITH ALLOWANCE FOR RISK) | |
|---|---|---|---|---|---|---|
| | CASH | PVc | CASH | PVc | CASH | PVc |
| 1 to 10 | 135 | 108 | 95 | 76 | 210 | 168 |
| 10 to 20 | 75 | 45 | 80 | 48 | 110 | 66 |
| 20 to 30 | 65 | 26 | 120 | 48 | 75 | 30 |
| 30 to 40 | 50 | 15 | 70 | 21 | 60 | 18 |
| 40 to 50 | 65 | 13 | 60 | 12 | 55 | 11 |
| Total | 390 | 207 | 425 | 205 | 510 | 293 |

**Table 5.1 Indicative costs (£ Million) for flood defence across all three strategy areas**

Present Value (PV) costs are calculated to make direct comparisons between different options. Although this is primarily to facilitate option appraisal, which is not being conducted here, it is also important to calculate in order to compare costs with benefits, and thus derive the likely level of partnership funded contributions that will be required.

Table 5.1 illustrates that despite some different derivations of the cost estimates, the PVc is similar at just over £200 Million. Allowing for risks and uncertainty, the upper bound PVc could be closer to £300M.

## 5.2 Review of flood defence benefits

There are approximately 6,500 residential properties located in the flood risk area that may at least partially benefit from defences during extreme flood events. In addition there are a further 600 commercial premises including; schools, shops, restaurants, garages etc, and approximately 20,000 hectares of agricultural land.

For the purposes of this high level economic appraisal an assumption of level of risk has also been made, with properties banded into risk categories based upon annual probability of flooding. The standard Environment Agency flood risk mapping shows the total extent of potential flood for a given return period, indicating the 0.5% and 0.1% (annual probability) extents, commonly referred to as the 1 in 200 and 1 in 1000 year flood risk areas. However properties within the total extent can have dramatically different risks depending on ground levels and property threshold levels. For the purposes of this high level appraisal it has been assumed that 10% of properties are at 'very significant' risk, 40% at 'significant', 40% at 'moderate' and 10% at 'low' risk. Although highly improbable, an (extreme) test of the economic sensitivity has also been undertaken for a scenario with all properties at 'very significant' risk, which is included in Section 5.3.

The economic benefits of providing flood defences can vary considerably depending upon the nature and timing of those works, of which there are multiple permutations (including barriers). Therefore, to make a broad brush assessment of the total potential benefits of providing flood defence, the total damages arising from not defending are calculated. This 'do-nothing' scenario assumes that the defences fail and breach, and no actions are then taken to repair those. This will not necessarily occur immediately, so assumptions of defence failures after 10 years or 20 years have been adopted for this high level assessment.

Table 5.2 below represents a summary of the present value those do-nothing tangible damages. Some very broad assumptions have been made regarding the value attributed to each of the affected asset types, but this does provide the order of magnitude level of benefits that would be obtained from providing flood defences across the area.

| Affected assets and value | | | | PV total loss (£ Million) | |
|---|---|---|---|---|---|
| Asset type | | Value assumed | Value | Year 10 | Year 20 |
| Residential Properties (6487 No) | | £200k each | £1,300M | £921M | £653M |
| Commercial Properties (624 No) | | £100k each | £62M | £44M | £31M |
| Agricultural Land | (Grade 1) | £15k /acre | £25M | £18M | £13M |
| | (Grade 2) | £10k /acre | £29M | £21M | £15M |
| | (Grades 3 & 4) | £7.5k/ acre | £345M | £245M | £173M |
| **Total** | | | **£1,761M** | **£1,249M** | **£885M** |

**Table 5.2 Summary of tangible damages associated with do-nothing**

In addition to the above, the Broads area provides a huge amount of economic intangible benefits both locally and to the nation as a whole. Tourism and recreation, including boating and angling, are significant activities that presently benefit from flood defence infrastructure. Under a do-nothing scenario there could be significant economic losses for these and other activities. Recent studies looking at the value of the Norfolk and Suffolk Broads established that there were over 8 million visitors to the Broads area in 2013, with an economic impact (direct and indirect expenditure) of tourism to the Broads being approximately £786 Million and supporting 9,452 FTE jobs.

Establishing a robust economic valuation for this benefit in a form that could be related to different flood defence management approaches is beyond the current study, but will be an important piece of analysis as part of the strategy development to compare options and also beneficiaries for partnership funding purposes. This also has to look beyond the present day; for example, in terms of a potential tidal barrier these activities already exist and thrive in the current environment without a barrier in place, but this situation would alter significantly with climate change. For the purposes of that appraisal an assessment would be made of the potential damages for different levels and frequencies of tidal surges and tide locking events, and the additional benefit a barrier would bring.

## 5.3 Potential flood defence grant and other contributions

The total costs of providing flood defence across the whole area is expected to be of the order of £400 Million to £500 Million, with a PVc of £200 Million to £300 Million. The total value of land and property in the flood risk area is in excess of £1700 Million, with the potential benefits (PVb) of damages averted by defences being between approximately £900 Million and £1200 Million. The benefit to cost ratio (BCR) is therefore between 1:3 and 1:6 across the whole area, although this will vary considerably for individual flood compartments and different combinations of defence options.

In addition to any eligibility for central government funding (FDGiA), all flood defence schemes must also be partially funded with contributions from other sources; generally referred to as Partnership Funding (PF). The rules on the levels of any FDGiA and other contributions are established and can be calculated using standardised methods (available from https://www.gov.uk/guidance/flood-and-coastal-defence-funding-submit-a-project). A PF score of 100% is the absolute minimum required to attract Flood Defence Grant in Aid funding. A higher score may be required to secure funds once the project is added to the national programme of flood and coastal erosion risk management schemes.

The results of this high level analysis of potential FDGiA and contributions that will be required (in PV terms) are presented in Table 5.3. The PF Score is shown as a percentage and represents the approximate amount of FDGiA that the project is eligible for. These figures are based upon some broad assumptions regarding overall costs and benefits, so calculations are included for extreme assumptions on costs and flood risk to provide a more robust determination of sensitivity. This does though provide a good indication of the range in the level of funding that may be needed.

| Flood defence | 50 year PVc | PF score low | Contribution (PV) | PF score high | Contribution (PV) |
|---|---|---|---|---|---|
| Including property flood damage assumptions (see Section 5.2) | | | | | |
| Lower bound | £205-207M | 31% | £140-142M | 42% | £120M |
| Upper bound | £293M | 22% | £229M | 30% | £206M |
| Sensitivity with all property at 'very significant' flood risk | | | | | |
| Lower bound | £205-207M | 49% | £104-106M | 60% | £82-84M |
| Upper bound | £293M | 35% | £192M | 42% | £170M |

**Table 5.3 Results of indicative economic analysis using all property at high flood risk**

The analysis shows that, based upon this broad brush economic analysis, a PV funding contribution of between £80 Million and £230 Million might be required to implement all works required across the area. The lowest level of contribution (PV £80 Million to £100 Million) calculated is based on a sensitivity assumption that all properties are at 'very significant' risk, which is probably unlikely.

Contributions in the range of £120 Million to £200 Million (PV) are more likely to be required to continue to deliver and operate/maintain flood defence to the extents and standards as presently set out in previous strategies. The sources for these contributions will depend upon the likely beneficiaries, which may vary depending upon the approach taken to flood risk management. Depending upon the time that those contributions might be found (i.e. what proportion now or future decades), this will also influence the approach that can be taken to flood risk management, and the actual cash value of those contributions (which could be as high as £250 Million to £350 Million depending upon when that money is secured). In turn, those contributors will also have an opportunity to define that approach to flood risk management. That may include the nature of the options that are implemented and the extents of flood defence provided.

# Conclusions

Flood risk management across this area has up until now been covered by three separate strategies for the Eccles to Winterton coastal frontage, Broadland, and Great Yarmouth. Despite the successful implementation of each of these strategies to date, there will continue to be an ongoing requirement involving a considerable amount of work in maintaining defences to manage the risk of inundation over the decades to come. Within these existing strategies there are also several key issues that need to be addressed, including:

- Eccles to Winterton – The SMP policy to hold the line is only currently 'conditional' from 2055 onward. There will be various options with different implications, some of which have not yet been considered, and a need to obtain better evidence to inform the long term decisions here.
- Great Yarmouth Tidal Walls – If the present line of defence is to remain, then the requirement to provide flood defence also requires considerable investment to address the issue of the poor and continually deteriorating state of quay walls, and issues over how to fund those works need to be addressed.
- The Broads –the present BESL contract concludes in 5 years' time and there is no current plan in place on what is to follow. Decisions on that will be highly dependent upon what is technically and financially practical, and assessments of those factors need to commence now to be in time to be able to inform those decisions.

A review and update of all three current strategies is overdue and it is evident that they cannot be treated independently, and consideration of the above points needs to be carried out strategically, not ad hoc or in isolation from wider considerations and any possible consequences and opportunities.

A tidal barrier at Great Yarmouth is an option that might still be considered for providing part of a future flood defence system, but there are still many aspects relating to this that need to be examined and evaluated. There are a range of different aspirations, assumptions, and requirements regarding what a barrier can provide, which are not all going to be compatible and mean that it may not be able to deliver all things to all people. Given the level of partnership funding contributions needed to deliver flood defence across the whole area, including that required to provide a barrier, resolution of these points is essential to align with appropriate potential funding sources and fully assess its viability as an appropriate and affordable potential strategic option.

This high level review concludes that there is a clear need for a single strategic overview of the policies in the area that not only considers flood and coastal risk management and the inter-relationship between the tidal and fluvial flood risk to the large area of low-lying land in this region, but also wider concerns and issues that will determine how the area is to utilised by those living, visiting, and working there. It would therefore be more appropriate to produce one single overarching strategy, which includes FCRM, and takes account of associated issues across all three areas.

Although existing high level plans such as the SMP advocate maintaining the status quo for the short to medium term, it is in the medium to long term when sustainability and appropriateness of the present management practices are expected to become a greater issue, particularly with the increasing impacts of climate change. Although such changes may be some years away, the size of investments required for FCRM and the consequences of management activities instigated now will extend over decades. Therefore it is necessary to consider now what the outcomes and requirements will be over a suitably long time scale and take into account what those changes might be.

That strategy will need to consider the full range of economic, social, planning, technical and environmental aspects. For example, Issues of water abstraction and large-scale infrastructure may also need to be drawn in to the decision-making process. The possible interactions between features of the different strategies may also require a fresh appraisal of approaches that have been previously rejected but may now become attractive when linkages between the areas are taken into account; it is likely to be necessary to challenge previous assumptions.

The economic benefits of protecting land and properties from flood risk is estimated to have a present value (PVb) of between £900 Million and £1,200 Million. In addition, approximately £800 Million of revenue is generated by tourism across the area each year. The total costs of continuing to protect these assets is likely to be between £400 Million and £500 Million over the next 50 years, with a present value (PVc) of £200 Million to £300 Million. Under current funding eligibility rules, central government grant aid (FDGiA) will not meet all of that cost and it is estimated that between £120 Million and £200 Million (PV) will need to be found through partnership contributions (which could equate to a non-discounted cash value in excess of £300 Million depending upon when works are undertaken). The level and sources of those contributions will be of key importance to determining the nature of the strategy and options to be implemented.

In taking forward development of any future strategy there are several points to consider that could have a major bearing upon the direction that the strategy ultimately takes and thus the approach to be considered to developing that. These illustrate that we are not yet in a position to make firm decisions for the longer term, as the inter-relationships require more detailed analysis and joint objectives established. Indeed, there are multiple permutations of flood management options with numerous possible outcomes at the present time, which need to be reduced to a more manageable number for detailed consideration.

In the meantime, Broadland continues to be managed through the existing contract up to 2021, but elsewhere it may be necessary to carry out interim works along the Eccles to Winterton and Great Yarmouth tidal walls frontages to prevent failures and consequential damages, albeit at a level that maintains the status quo rather than altering it, at least until the future strategy for the wider area is determined. Assessments based upon the information presented in this report demonstrate that the progression of any flood defence works in the short term (up to 2021) between Eccles to Winterton and along Great Yarmouth tidal walls, can proceed without compromising any longer term wider strategy.

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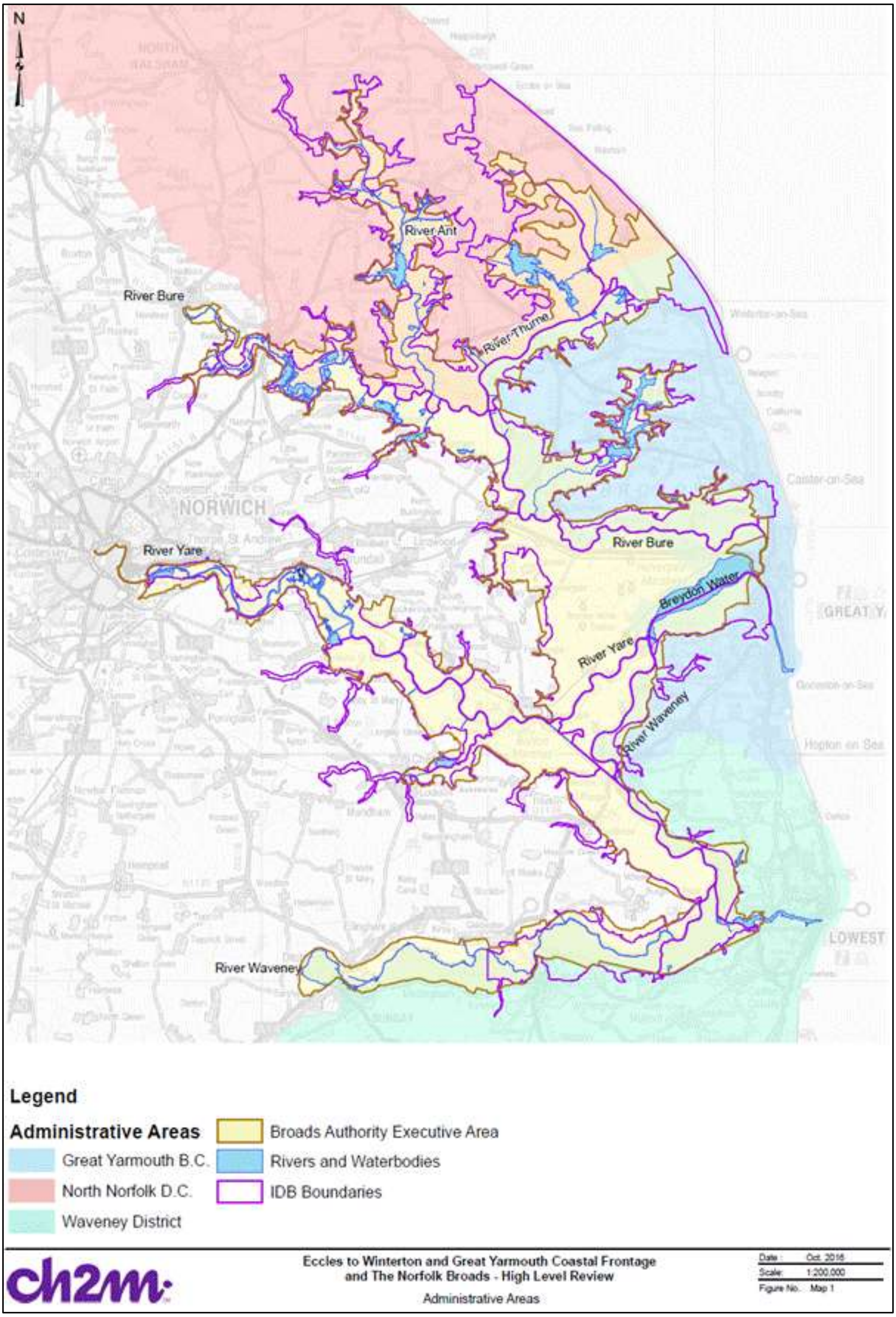
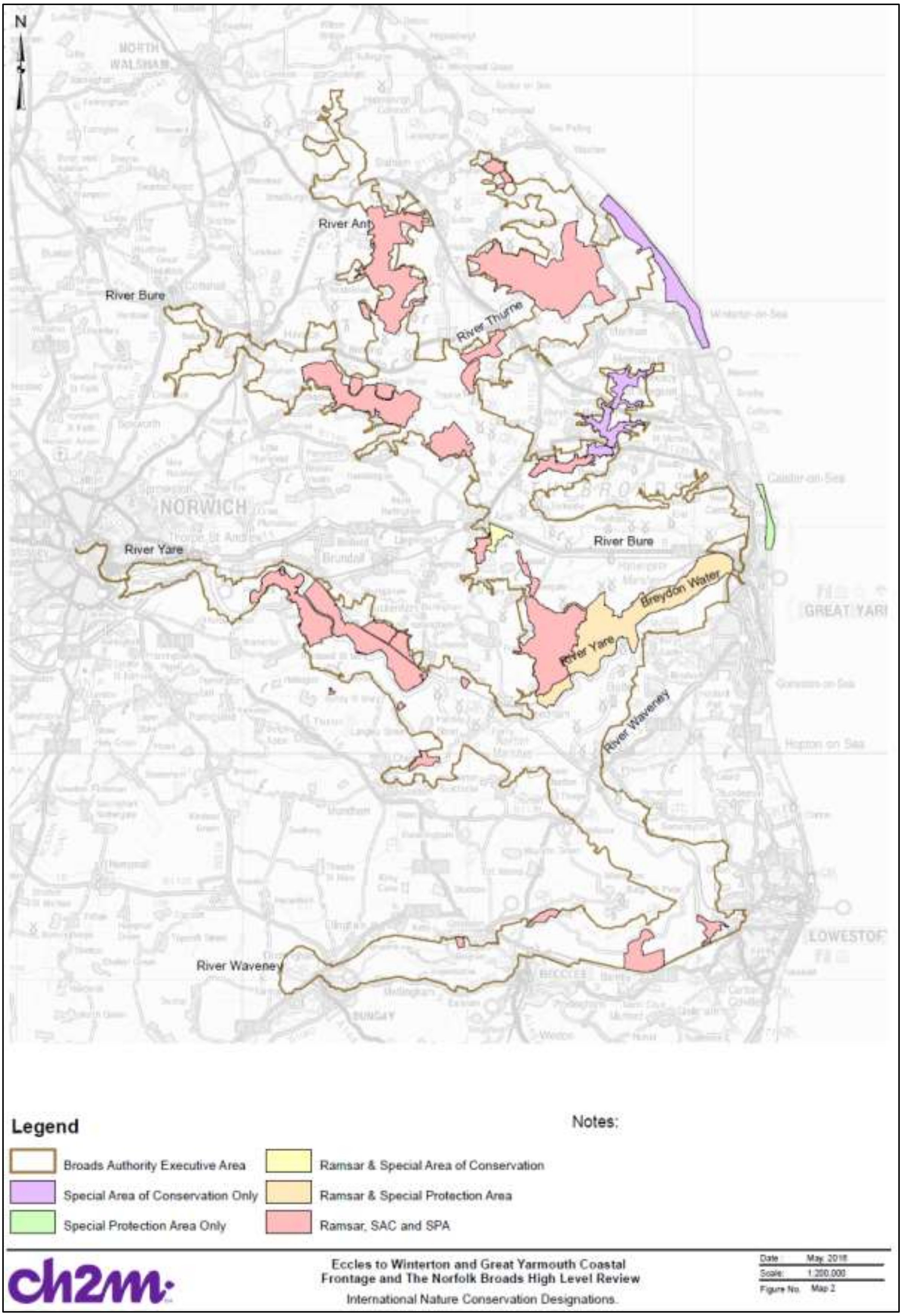
# Maps

# Maps

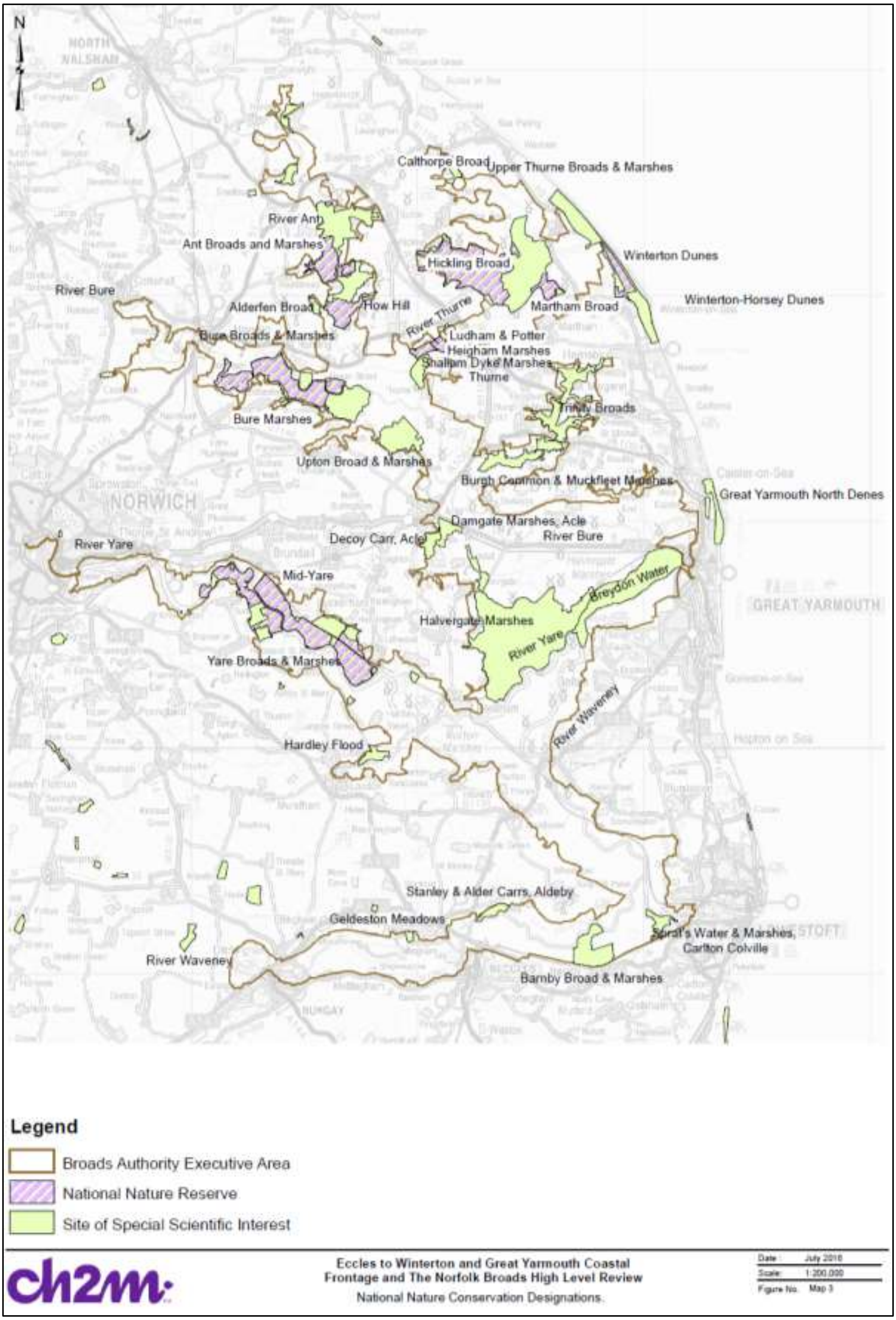
**MAP 1 Administrative Areas**



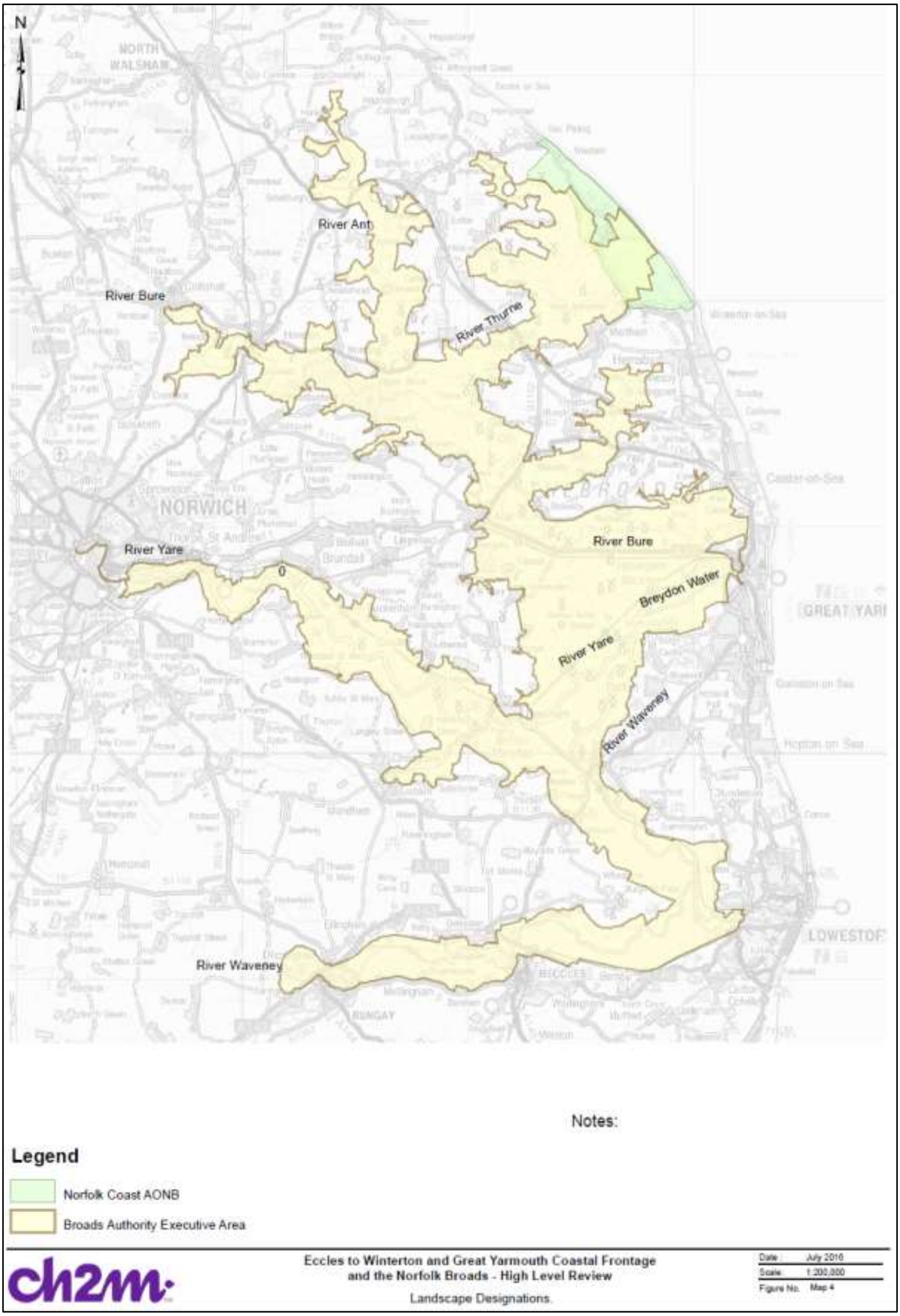
## MAP 2 International Nature Conservation Designations



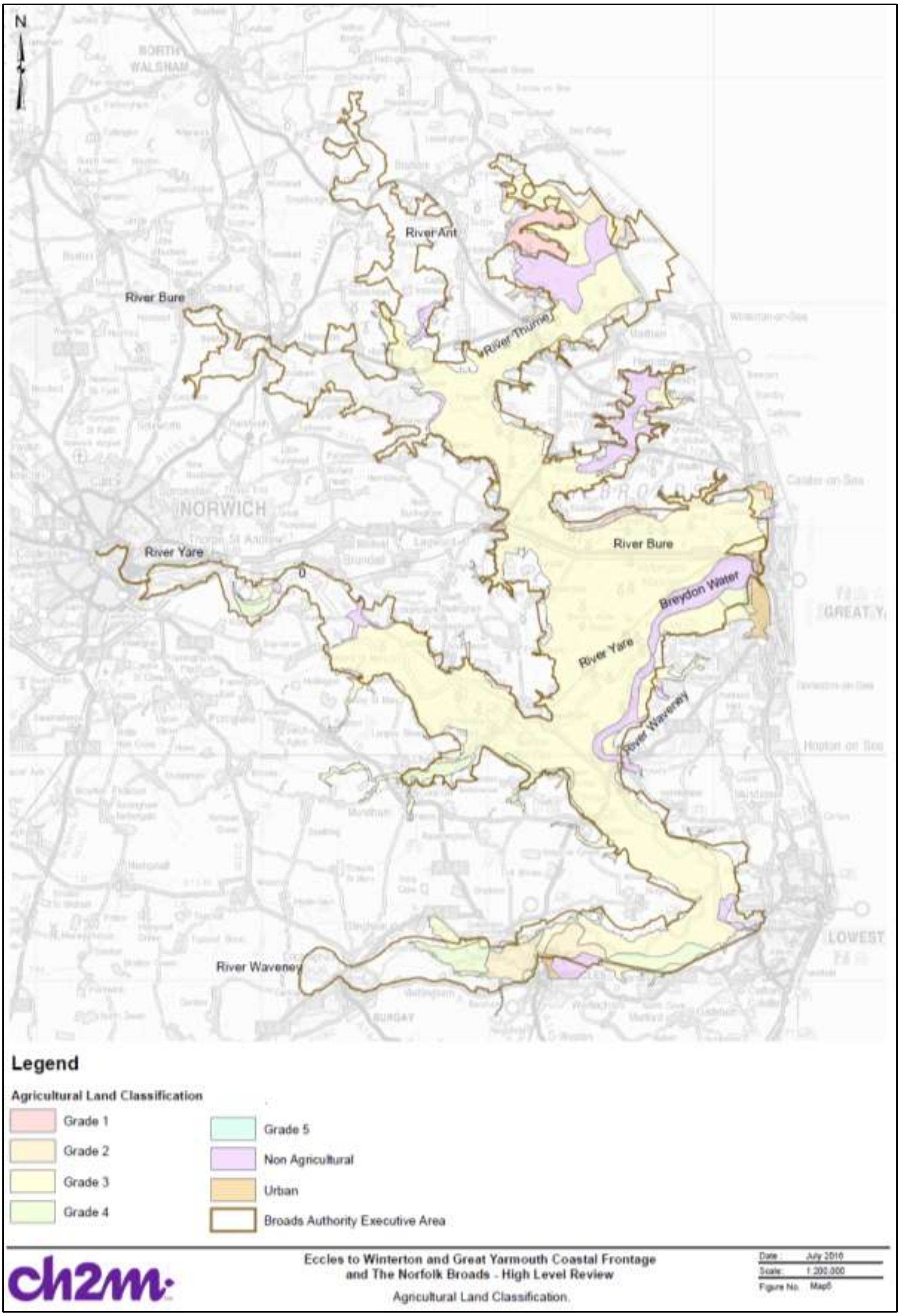
## MAP 3 National Nature Conservation Designations



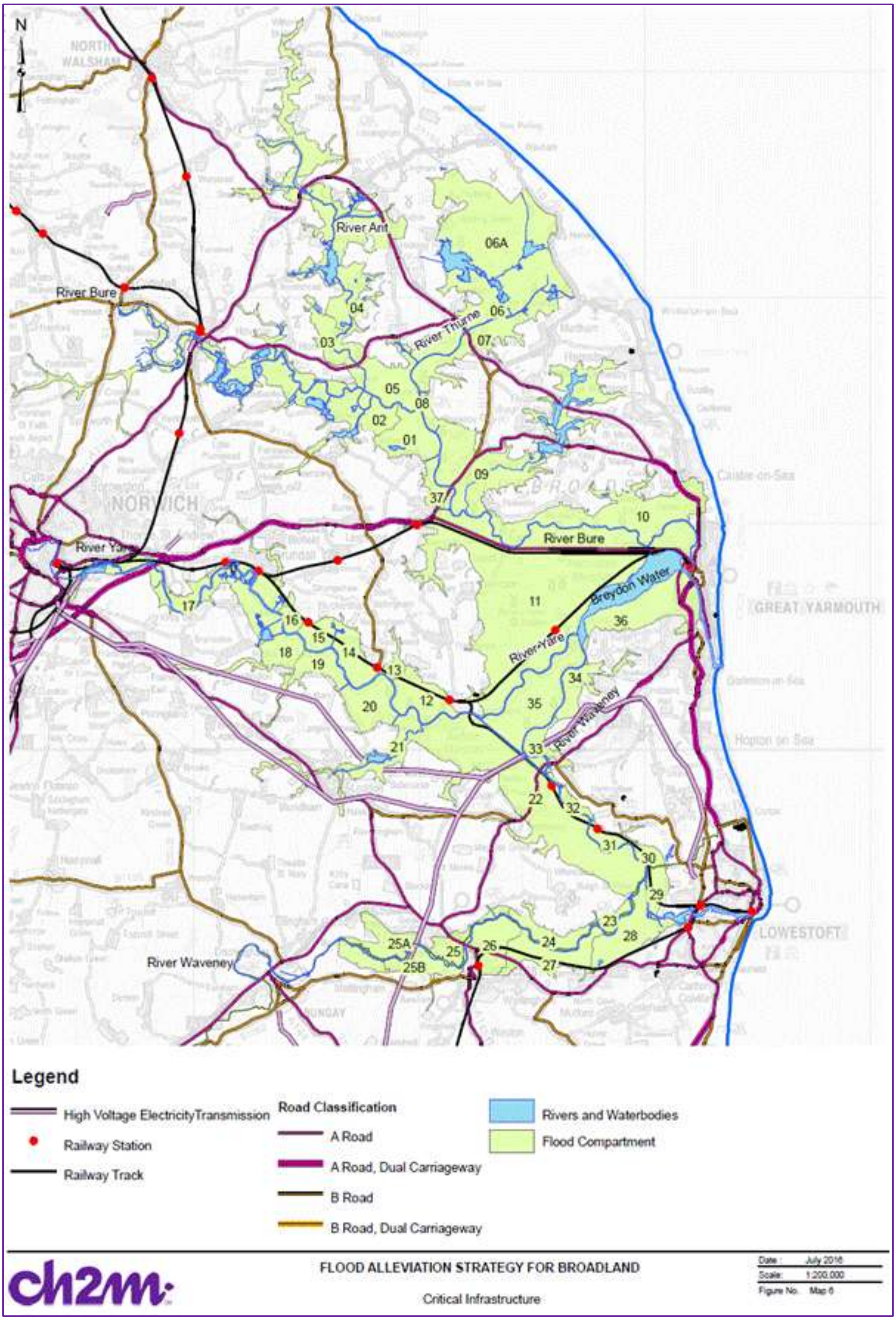
## MAP 4 Landscape Designations



## MAP 5 Agricultural Land Classification



**MAP 6 Critical Infrastructure**



# Appendix A
# Tidal Barrier Considerations

# A Tidal Barrier Considerations

## A1 Barrier Location/Type Option Appraisal

| | |
|---|---|
| Flood Risk Management | ➢ Standards required and associated extents and levels<br>➢ Operating criteria (range of scenarios), now and in future with sea level rise<br>➢ Downstream implications (defence raising/strengthening) |
| Hydrology and Hydraulics | ➢ Operating criteria (range of scenarios) to manage saline intrusion now and in future with sea level rise – thresholds for Broadland<br>➢ Interrelationship between Yare and Bure catchments<br>➢ Flows and velocities – tidal and fluvial<br>➢ Upstream storage<br>➢ Land drainage impacts |
| Port And Quayside Operations and Requirements | ➢ Commercial navigation traffic (now and future)<br>➢ Recreational navigation traffic (now and future)<br>➢ Outer Harbour – impact on Haven traffic |
| Navigation Requirements | ➢ Vessel dimensions – beam/draft/height/tonnage<br>➢ Line of sight and vessel maneuverability with respect to river channel<br>➢ Protective measures (vessel impact)<br>➢ Mooring facilities – permanent or temporary |
| Waterfront Development | ➢ Long term plans (regeneration?)<br>➢ Opportunities created (funding?) |
| Environmental Impacts | ➢ Fisheries<br>➢ Ecology<br>➢ Biodiversity<br>➢ Archaeology and heritage<br>➢ Landscape/visual |
| Geomorphological Impacts | ➢ Sediment accretion/erosion/scour in Haven channel<br>➢ Increased dredging requirements |
| Operation and Maintenance Requirements | ➢ Outline control philosophy<br>➢ Frequency of operation – now and in the future with sea level rise + maintenance<br>➢ Responsible organisation<br>➢ Access (operations and maintenance) |
| Barrier Gate Type and Configuration | ➢ Functionality required – future flexibility/adaptability<br>➢ Constraints<br>➢ Channel width<br>➢ Single or multiple gates<br>➢ Gate reliability<br>➢ Level of maintenance |
| Services | ➢ Provisions for barrier<br>➢ Diversions required |
| Ground Conditions | ➢ Contaminated ground – river channel sediments and adjacent land<br>➢ Foundation depths<br>➢ Ground and site investigation works required |
| Costs | ➢ Buildability<br>➢ Capital and whole life<br>➢ Funding requirements – immediate + long term + future maintenance<br>➢ Affordability |

# A2 Previous Assessments

## A2.1 'Yare basin Flood Control Study' (1977)

The following are key points identified from review of the **'Yare Basin Flood Control Study, Final Report, Volume 2' carried out in 1977 by Rendel Palmer and Tritton on behalf of Anglian Water Authority**.

The report noted that from Phase 1 of the works, 8 potential schemes were considered which consisted of embankments, barrages and barriers. Of the eight, the following barrier schemes were considered:

- Scheme B – barrier at Queens Road
- Scheme C – barrier between Haven Bridge and mouth of River Bure
- Scheme D – Barrier at Breydon Viaduct (excluding road bridge) and across mouth of River Bure
- Scheme E – Barriers at west end of Breydon Water and across mouth of River Bure

Based on a uniform rate of agricultural development [conversion from marsh land], none of the eight schemes were viable at Treasury Test Discount Rate of 10%. Using a more optimistic rate of development, Scheme C became viable with Scheme D as the second option. Both options were taken forward to Phase 2.

The Phase 2 study considered an embankment option, Haven Bridge Barrier (previously Option C), Breydon Viaduct barrier (previously Option D) and a combined road bridge/barrier at Breydon Viaduct.

The barriers are located between the Haven Bridge and the mouth of the River Bure, and the site of the old railway viaduct across Breydon Water (now the route of the A12).

The report considers three principal aspects:

- The effect of a barrier on existing port traffic and operations
- The effect on future port development
- The number of spans required and types of barrier gate which would be suitable

Existing port traffic and operations would have been affected more by the Haven Bridge location than Breydon Viaduct. Approximately half of the existing commercial traffic passing through Haven Bridge was destined to/from J Lee Barbour's quay at Bowling Green Wharf, the remainder was destined to/from the Port of Norwich, plus an increase in numbers of vessels during the sugar beet processing season serving British Sugars refinery at Cantley.

Pleasure traffic would be more affected by a barrier at Breydon Water as most pass this point, with very few heading downstream.

It was estimated that 50m of quay space would become sterile on both sides of the river, adjacent to the Haven Bridge option. No sterilisation of existing facilities was considered to occur from Breydon Water Barrier, although a subsidiary structure on the River Bure would reduce Bowling Green Wharf slightly.

Two types of gates were considered on the River Yare:

- A rising sector gate; and
- A balanced swing gate.

At Haven Bridge, both options were rejected in favour of a high level drop gate, as the rising sector gate would have resulted in blocking the river whilst it was exposed above water for maintenance; and the balanced swing gate would require a middle pier in the river which would be a navigation obstruction, but also require a constant bed level over which the gate could sweep.

At Breydon Viaduct, the balanced swing gate and high level structure were considered technically feasible, with the high level structure recommended on grounds of greater reliability, ease of maintenance and costs.

Navigation between the Haven Bridge and Bure mouth is difficult due to bends in the river and strong tidal currents that occur. An additional structure situated in this location would be likely to increase the navigation difficulties, but it was considered that correctly located, with adequate navigational width, this should be acceptable. A distance of 300m should be provided between the Haven Bridge and the barrier, placing the new structure opposite the River Commissioners boatyard on one side and Horsley Smith's timber yard (formerly Jewson's) on the other.

To accommodate the (then) present size and type of shipping a main span navigable width of 42 to 45m would need to be considered. However a Ro-Ro container terminal development at Vauxhall Station was being considered and a navigable width of 50m clear between fenders was deemed appropriate.

At Breydon Viaduct, the size and types of vessels would require a main span width of 20m. Lead in dolphins would have to be provided up and downriver to protect the side spans from damage from vessels. The main span towers would also provide guide markers for shipping and assist navigation in this area.

A closure of the barrier was considered appropriate when water levels reach +1.8m ODN at the harbour mouth. Anything lower would become disruptive to port traffic and higher levels than this. A level of +2.1m ODN (which was the current 1977 danger level for Great Yarmouth) would be an infrequent event. For the +1.8m ODN level the barrier would operate on average once per month (not including testing and maintenance operation), with closure of the barrier commencing when water levels reach +1.55m ODN (i.e. 0.25m below this water level). It was noted that adequate warning times and systems/methods would need to be developed to provide both the port operator and barrier operations adequate time to allow for barrier closures.

The river width is approximately 255m at Breydon Viaduct compared to approximately 100m at Haven Bridge, resulting in Breydon Viaduct having a greater number of secondary spans and more complex and costly operations system.

There would be greater interference with existing commercial traffic at Haven Bridge, although limited pleasure boat impacts. Breydon Viaduct may be considered a hazard to pleasure craft during the summer months.

Sill levels were determined by the existing river bed levels. At Haven Bridge the maximum depth of the river bed level is -7.0m compared to -5m at Breydon Viaduct, resulting in a more costly barrier gate at Haven Bridge.

Suitable foundation conditions are generally encountered at a higher level at Haven Bridge compared to Breydon Viaduct. Whilst not affecting the foundation type, this would affect the invert levels and cost of construction of the foundations at each location.

Tidal current velocities at Haven Bridge were 0.84m/s (Flood) and 1.05m/s (Ebb), which are significantly higher than at Breydon Viaduct (0.70m/s Flood and 0.91m/s Ebb) due to difference in channel width.

For both schemes the design level for flood defences downriver is based on a freeboard of 0.25m above the 100year surge level of +3.15m. Hence the design level is +3.4m. Except towards the downriver end of the Haven, the existing defences are not to this height, thus necessitating some raising.

Upstream, the worst case condition occurs if the barrier is not operated but the peak surge level just fails to reach the barrier closure level. This would necessitate some upstream bank raising to prevent localised flooding on the Rivers Waveney, Bure and Yare.

Tables 4.6 and 4.7 of that report present cost estimates.

***Table 4.6 Cost Estimates for Barrier Structures[a] (£ million)***

| Structure | Construction Costs | | | | Annual Maintenance | Annual Operating |
|---|---|---|---|---|---|---|
| | Civil | Gate | Machinery | Total | | |
| Haven Bridge | 3.56 | 0.94 | 1.18 | 5.68 | 0.023 | 0.020 |
| Breydon Viaduct<br>Bure Mouth | 5.47<br>0.48 | 0.54<br>0.23 | 0.57<br>0.12 | 6.58<br>0.83 | 0.026 | 0.027 |
| Structures Total | 5.95 | 0.77 | 0.69 | 7.41 | | |

[a] Based on December 1976 prices.

***Table 4.7 Associated Bank Works (£ million)***

| Scheme | Upriver Bank Works [b] | Downriver Bank Works [c] |
|---|---|---|
| Haven Bridge Barrier | 1.25 | 0.46 |
| Breydon Viaduct and Bure Mouth Barriers | 1.25 | 0.56 |

A combined road bridge and barrier at Breydon Viaduct were considered as part of the Phase 2 works of the above report. At the time of report, Norfolk County Council and Department of Transport (DTp) had Breydon Viaduct crossing identified as the new road crossing. It was estimated however that the normal process of public consultation etc for the road would take in the order of 8 to 12 years before construction of the road crossing could commence.

Based on an implementation programme of construction commencing in 1980 with the barrier complete in 1982, the following capital and operating costs for each option are shown in Table 5.13.

***Table 5.13 Phase 2 Capital, Maintenance and Operating Costs of Alternative Schemes 1978-2001 (£'000) [a]***

| Year | Embankment Schemes | | | Barrier Schemes | |
|---|---|---|---|---|---|
| | Full | Slowly [b] Implemented | Reduced Height | Haven Bridge | Breydon Viaduct |
| 1978 | - | - | - | - | - |
| 79 | - | - | - | - | - |
| 1980 | 3,372 | 1,365 | 1,752 | 2,956 | 3,672 |
| 81 | 3,373 | 1,365 | 1,753 | 2,956 | 3,672 |
| 82 | 3,372 | 1,365 | 1,752 | 1,478 | 1,836 |
| 83 | 3,373 | 1,771 | 1,753 | 43 | 53 |
| 84 | 810 | 1,770 | 360 | 43 | 53 |
| 85 | 810 | 1,771 | 360 | 43 | 53 |
| 86 | 810 | 1,770 | 360 | 43 | 53 |
| 87 | 810 | 1,771 | 360 | 43 | 53 |
| 88 | 810 | 1,770 | 360 | 43 | 53 |
| 89 | | 1,770 | | 43 | 53 |
| 1990 | | 405 | | 43 | 53 |
| 91 | | 405 | | 43 | 53 |
| 92 | | 405 | | 43 | 53 |
| 1993-2001 | | | | 43 | 53 |
| Total Capital Cost | 17,540 | 17,704 | 8,810 | 7,390 [c] | 9,180 [c] |

[a] Excluding bank maintenance costs, but including upriver and downstream bank raising.
[b] Extending the implementation of the full embankment scheme would increase the cost because of the need to provide temporary counterwalls during construction
[c] Excluding recurring costs 1983 - 2001

Indirect costs which result from barrier closures from 1983 onwards were predicted to be:

- Haven Bridge: £2,000/year due to commercial vessels delay costs; delays for pleasure craft insignificant.
- Breydon Viaduct: delay costs from commercial vessels approximately £1,000/annum plus £2,000/annum from pleasure craft.

Ultimately the Haven Bridge barrier scheme remained the most attractive of the options considered.

### A2.2 'Yare Basin Flood Control Study' (1983)

The subsequent **'Yare Basin Flood Control Study' July 1983 by Rendel Palmer and Tritton on behalf of Anglian Water Authority** provided an update and refinement of the 1977 report. In the main the report concentrates on changes to benefits to the scheme, and also updates some cost.

In the intervening period, anticipated agricultural improvement (main source of benefit in 1977 report) had proceeded on a significant scale, and the HM Treasure Test Discount Rate had reduced from 10 to 5%. In additional environmental policies and interest for the Broads has also increased/changed.

The location of the proposed barrier, 300m upstream of Haven Bridge affords no protection to properties downstream. In 1977 it was considered that the these areas were adequately protected by the existing flood defences which could be raised by small amounts necessary to allow for increased downstream flood levels which would result from barrier closure. However, it was noted that the downstream defences consist of quay walls with concrete flood walls constructed on top of them. A number of existing structures were in poor condition, deteriorated due to lack of maintenance and nearing the point where it would become unsafe to rely on them to form part of the existing Great Yarmouth flood protection. It was now considered that the flood protection previously provided by the existing downstream quay walls would be likely to be lost within the following 5 years and therefore necessary to replace a proportion of the quay walls in order to maintain the necessary flood protection.

The report notes "The only engineering alternative to reconstruction of the quay walls, would be to relocate the proposed surge barrier at a site below the Lower Ferry Crossing, at South Denes". However, no further consideration or information is provided with regard to this option.

### A2.3 'A Flood Alleviation for Broadland – Yare Barrier' (1994)

The following are key points identified from review of the **'A Flood Alleviation Strategy for Broadland – Yare Barrier' carried out in 1994 by Binnie and Partners on behalf of the National Rivers Authority**.

The report examines the case for a scheme to construct a barrier across the River Yare near Haven Bridge in Great Yarmouth. It draws on results from two previous studies by Binnie's between May 1991 and October 1993, The Flood Alleviation Strategy Study (FASS) and Norfolk Broadland Erosion Protection Scheme (BEPS).

Key issues relating to design and construction of the barrier are identified as being:

- Location of barrier and its impact on Great Yarmouth Port;
- Navigation through the barrier;
- The barriers appearance;
- Effect on hydraulic conditions in the river system;
- Disruption caused by the construction of the barrier and any associated works.

During the FASS, three potential barrier locations were considered: the mouth of the Haven; at Ferry Crossing; and at the seaward mouth of the Bure near the Haven Bridge. The barrier at the Haven bridge site was preferred because:

- its overall cost was estimated to be less than the others, with a greater cost benefit ratio;
- its location up-river of the active commercial wharves creates less impact on the operation of the port;
- construction at either of the other two sites would be more disruptive due to impact on boat movements.

The preferred location is the same as that proposed by Rendel, Tritton and Palmer (RTP) in 1977.

To allow navigation through the barrier, a 50m wide main gate was proposed (based on RTP 1977 report), but it was noted that further modelling is required to confirm this figure. Based on this assumption then the vertical lift gate is the most appropriate solution. If further modelling demonstrated that a narrower width could safely accommodate navigation, than other alternatives may be more economically competitive.

The appearance of the gate will impact on the townscape of Great Yarmouth. The appearance will be largely controlled by the type of gate proposed and therefore the width of the navigational opening. The 50m wide opening vertical lift gate would be stored approx. 25m above water level, with support structures approx. 5m x 5m. The maximum height of the structure would be approx. 36m above mean water level. If a narrower /alternative arrangement were considered then this could be reduced significantly (estimated that side hung mitre gates, normally stored in gate piers would only have a height of approx. 6m above mean water level).

The navigational opening would be flanked by supplementary sluices, resulting in a flow of approx. 85.5% of the channel section at low tide; the overall obstruction considered less than the existing Haven Bridge. The effect of an open barrier in Broadland and the Haven was considered small, and as a result unlikely to have any significant impact on overall sediment movements, or salinity distribution or water quality. There may be some localised erosion of the bed to compensate for blockages caused by the piers and possibly some accretion if zones of low currents occur in the immediate vicinity of the structure.

Closure of the barrier would result in water levels seaward to be higher than if the barrier were not there. For a 1:200 year design event, peak water levels would be about 0.3m higher at the barrier site (reducing to zero at the haven mouth) and defences would need to raised and improved to suit. Consequently loading on the defences upstream of the barrier would be reduced and therefore the maintenance programme for these may be able to be reduced.

Although the location of the barrier will have the least impact on port activities, it would still impact on commercial vessels using the upstream active wharf or those travelling to Cantley or Norwich, plus any leisure craft wishing to pass this point.

Closure of the barrier was anticipated to occur when the water level is about +0.3m to+0.6m to most effectively minimise saline incursion, but it was noted that there may not always be sufficient warning time for this to happen. Duration of closure could vary between 5 and 20 hours, with longer durations during neap tides.

Too rapid a closure of the gate could cause large water surface oscillations in the Haven (causing problems to shipping and overtopping of defences). Further studies would be required on final configuration and operation of the gate.

It was considered that the amount of sand entering the port may be reduced due to the reduction in flow velocities into and out of the Haven when the barrier is closed (but would need further studies to confirm). The Port Authority had concerns about the reduction in velocities and resulting changes in flow patterns at the mouth of the harbour and within the Haven when the barrier is closed, which may make navigational manoeuvres more difficult (further modelling is required to confirm).

Operating rules of the barrier would affect the water levels in the Broadland – the more frequent the barrier is operated in general the lower the water levels and hence defence levels required upstream.  However ongoing settlement of defences and sea level rise also needs to be considered. It was noted however that if the combined rate of flood bank settlement and sea level rise is greater than about 50mm/year then it would not be possible to raise the banks fast enough to sustain the situation, and operation of the barrier would be required much more frequently, potentially operating on every tide.

The following additional information was identified as being required:

- more detailed study of operating rules for the barrier;
- ability of the Storm Tide Warning Service to provide required water level and surge height information;
- impact of closure of the barrier on sediment movement in the Haven;
- impact of closure on port activities, particularly on boats entering and leaving the harbour and manoeuvring in the Haven;
- prevention of water oscillations following closure;
- the effect of barrier operation on undefended properties within Broadland.

The economic case for the barrier however only provided a cost benefit ratio of 0.09.  The construction of the barrier would only be viable if a narrower navigation opening was acceptable, no loss of trade to the port is encountered, and no work to the embankments is undertaken for 15 years while benefits are double what was estimated.

It was considered that the only way that a barrier would become economically viable is if the net effect of sea level rise and settlement become too great that it is impossible to raise the embankments within the Broads to keep up with this impact.

# Appendix B
# Legislation, Political Relationships and Responsibilities

# B Legislation, Political Relationships and Responsibilities

## B1 FCRM Responsibilities

The main bodies involved with flood and coastal management and policy in England include Defra, the Environment Agency, the Lead Local Flood Authorities (LLFA), Regional Flood and Coastal Committees (RFCC), and Department for Communities and Local Government (DCLG).

- Defra is responsible for policy and regulations on environmental, food and rural issues, has overall national responsibility for policy on FCRM, and provides funding for flood risk management authorities through grants to the Environment Agency and local authorities.
- The Environment Agency is responsible for taking a strategic overview of the management of all sources of flooding and coastal erosion. The Environment Agency also has operational responsibility for managing the risk of flooding as well as being a coastal erosion risk management authority.
- LLFAs are responsible for developing, maintaining and applying a strategy for local flood risk management in their areas and for maintaining a register of flood risk assets. District, Borough and Unitary Councils in coastal areas also act as coastal erosion risk management authorities.
- IDBs are responsible for managing drainage and water levels within their respective districts, in particular to agricultural land. They have a key role to play in providing a link to landowners, and especially the farming community.
- RFCCs are responsible for ensuring coherent plans are in place for identifying, communicating and managing flood and coastal erosion risks across catchments and shorelines. The committees provide a link between Flood and Coastal Erosion Risk Management Authorities and other bodies, and promote targeted investment in flood and coastal erosion risk management.
- DCLG through Local Planning Authorities have a key role in the planning process to ensure that flood risk and coastal change is appropriately taken into account in the planning process. The National Planning Policy Framework was published in 2012 sets out the government's planning policies for England, replacing the previous Planning Policy Statements.

## B2 Legislation

Key legislative drivers relevant to the approach taken when implementing FCRM and considering an integrated strategy are set out below:

**Conservation of Habitats and Species Regulations 2010 (as amended in 2012)**

The Regulations transpose into law the requirements of the EC Habitats Directive and Wild Birds Directive.

The Water Environment (Water Framework Directive) (England and Wales) Regulations 2003

The Regulations require measures to be taken to encourage the sustainable use of water and to protect and improve inland surface waters, groundwater and coastal waters with the aim of achieving good status.

**Climate Change Act 2008**

The Climate Change Act 2008 provides a legally-binding long-term framework to cut greenhouse gas emissions and a framework for building the UK's ability to adapt to a changing climate.

**The Flood and Water Management Act 2010**

One of the main provisions of the Act is for the production of a national flood and coastal erosion risk strategy for England, to be reviewed every five years. The first one was published in 2011 and built on previous approaches by promoting the use of a wide range of measures to manage risk.

There are other legislative requirements that are also pertinent, in particular:

- the Town and Country Planning Act 1990 (as amended) and Town and County Planning (Environmental Impact Assessment) Regulations 2011 (as amended) with respect to schemes that require planning consent.
- at the local level the Norfolk and Suffolk Broads Act and Great Yarmouth Port Act are relevant to the way that the Broads Authority and Port Authority, respectively, undertake their functions.

## B3 Local Planning Authorities

The study area is administered by three local planning authorities: North Norfolk District Council; Great Yarmouth Borough Council; and The Broads Authority.

Each of the planning authorities has its own set of statutory documents that comprise the Local Plan (Development Plan Documents) and are used to guide future development and land use within their areas.

**Broads Local Plan**

The Broads Local Plan necessarily has much more focus on the management of the natural and historic environment, tourism and recreation compared to the other two local authority Plans. Key strategic objectives contained in the Core Strategy are:

*S03 - To protect the natural resources of the Broads from development or activities which would be detrimental to its value or integrity, to promote enhancement and restoration of fragmented and degraded habitats, to increase biodiversity, to promote the development of replacement habitats to plan for climate change and increased sea levels, and to promote sustainable resource use and management.*

*S05 - To develop the Broads as a more naturally functioning flood plain of extensive and connected habitats, accommodating the longer-term impacts of climate change and social and economic influences over the next 100 years.*

**Great Yarmouth Core Strategy**

The Great Yarmouth Core Strategy has a specific policy (CS13) on protecting areas at risk of flooding and coastal change. It acknowledges the importance of monitoring and maintaining the defences including those around Breydon Water as there are flood pathways into the town if the estuary embankments overtop or are breached. It also sets out the approach to dealing with anticipated coastal change including the identification of Coastal Change Management Areas.

**North Norfolk District Council Core Strategy and Development Control Policies**

The North Norfolk District Council Core Strategy and Development Control Policies pre-dates the most recent issue of the SMP. Relevant policies are *EN1: Protecting the character of the Norfolk Coast AONB and The Broads*, and *EN10: Development and flood risk*. There is currently no relevant publically available information on the emerging North Norfolk Local Plan.

FCRM objectives and individual schemes need to accord with Local Plan policies and vice versa. The risk of tidal and fluvial flooding is a major issue for the area so it is important that the respective Local Plans are consistent in their approach as well as the three individual strategies. At present there is consistency during the short-term because the objective is to hold the line and maintain the status quo i.e. retain the current line and standard of defences on the coast, through Great Yarmouth and along the Broadland rivers. But the local plans only cover the first 20-yer period whereas, due to the levels of investment required for FCRM it is necessary to consider flood defence strategy for several decades ahead.

There is clearly a need for consistency between the three planning authorities in relation to FCRM and the timing and scope of any management or adaptation measures. This needs to be reflected not only in their Local Plan reviews but also in working with the Environment Agency to consolidate the relevant parts of the SMP, Great Yarmouth Strategy and Broadland FAS into one consistent strategy.

## B4 Other Key Plans

The Broads Climate Adaptation Plan (2015) identifies the need to address the risk of flooding and saline incursion as the main priority. Consultation with stakeholders during the plan development concluded that there is a strong desire to maintain the Broads as a predominantly freshwater system until such time as it becomes unfeasible to do so because of economic, environmental or technical reasons.

This approach is consistent with both the SMP and the Broadland FAS as well as the current Broads Plan (2011-16). The latter is a strategic management plan for the Broads area which is produced by the Broads Authority but is supported and implemented by a range of partner organisations. It is currently being revised for the next 5-year period and the first draft has recently been subject to public consultation (February-April 2016). With respect to managing flood risk and water resources the aspiration is to "*Develop an integrated long-term flood risk management strategy for the Broads and interrelated coastal frontage, and improve water capture and water efficiency across the Broads catchment*". The associated action is to produce a strategy for the period post 2021 when the current BESL contract comes to an end.

The Broadland Rivers Catchment Flood Management Plan aims to improve the water environment and provide wider benefits for people and nature at a catchment scale, but particularly focussing on the impacts within the Broads' floodplain due to input of sediment and nutrients arriving via the wider catchment. This is an approach encouraged by Government with the publication of a policy document in 2013.

The following graphic, taken from 'Flood and Coastal Erosion Risk Management appraisal guidance' (Environment Agency, 2010), puts into context how any strategy relates to other plans in the area.