NRA

*National Rivers Authority*

*Anglian Region*

# A FLOOD ALLEVIATION STRATEGY FOR BROADLAND

REPORT OF TASK GROUP

BINNIE & PARTNERS
CONSULTING ENGINEERS

*in association with*

OAKWOOD ENVIRONMENTAL
*Consultants in Environmental Management*

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# A FLOOD ALLEVIATION STRATEGY FOR BROADLAND

## REPORT OF TASK GROUP

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### Introduction

S1. This report presents the findings of the Task Group established following the meeting of the Norfolk and Suffolk Local Flood Defence Committee on 27 July 1992 to evaluate two schemes for alleviating flooding in Broadland and Great Yarmouth. The Task Group included nominees from the Broads Authority with representatives from the National Rivers Authority and their main consultant for the study, Binnie & Partners.

### Background

S2. The flood alleviation study was begun in May 1991 by Binnie & Partners in association with Oakwood Environmental. They assessed six options and ten sub-options, concluding that either of two schemes would provide effective defence but that there was insufficient information available to choose between them.

S3. The two schemes and their principal components are:

**Scheme 1 - Barrier on the Yare above Haven Bridge**

- a barrier near the Haven Bridge,
- strengthening the Great Yarmouth floodwalls and raising them seaward of the barrier,
- strengthening and raising the Broadland floodbanks.

**Scheme 2 - Barrier on the Bure and washland at Haddiscoe Island**

- a barrier near the mouth of the Bure,
- a washland at Haddiscoe Island,
- strengthening the Great Yarmouth floodwalls,
- strengthening and raising the Broadland floodbanks.

S4. Both schemes will require a commitment to regular raising of floodbanks and floodwalls to guard against settlement and sea level rise. This will be in addition to normal maintenance needs, which include the continuing need to provide and repair

erosion-protection-works.

**Issues raised and additional information needed**

S5. The Task Group identified a total of 13 key issues which could be affected by one or other of the two schemes and therefore need to be taken into account when choosing between them.

(i) Standard of defence
(ii) Great Yarmouth
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S6. On reviewing the information available the Task Group determined that additional information was required concerning saline intrusion in Broadland rivers and how this would be affected by each scheme, the nature conservation opportunities provided by a washland and how it could be managed to realise these opportunities and the effects of each scheme on the port of Great Yarmouth and on inland navigation.

S7. The studies required to obtain the additional information needed were carried out and are described in the report.

**Comparison of options**

S8. The Task Group compared the two schemes against each of the 13 key issues that had been identified. Scheme 2 was found to provide a substantial improvement to the standard of defence for all currently defended areas. It has significant advantages

over Scheme 1 in terms of cost, saline intrusion and nature conservaiton and has no major effect on the port. In other respects both schemes have broadly similar effects. On the basis of this comparison it was concluded that Scheme 2, comprising a barrier on the Bure, a washland at Haddiscoe Island and strengthening and raising the existing defences in Broadland and Great Yarmouth, should be implemented.

**Recommendations**

S9. The recommendations of the Task Group may be summarised as follows:

| | | |
|---|---|---|
| A. | Proposed defence strategy | implement Scheme 2 as described above. |
| B. | Immediate actions | - submit proposed strategy to MAFF for approval,<br>- arrange for further studies to be undertaken and Planning Application submissions to be prepared. |
| C. | Further studies | - carry out further studies including hydraulic modelling, environmental studies, and site investigations,<br>- prepare outline designs and Environmental Statement. |
| D. | Planning procedures | - submit Outline Planning Application,<br>- prepare for Public Inquiry. |
| E. | Management | - establish study group to identify environmental enhancement opportunities,<br>- establish comprehensive monitoring programme,<br>- investigate complementary strategies for control of saline intrusion |

S10. The costs of these recommendations are estimated to be:

| | |
|---|---|
| Total engineering cost of scheme (over 50 years) | £115.7M undiscounted<br>£45.1M discounted at 6% |
| Cost of scheme during construction (5 years) | £37.6M undiscounted |
| Cost of further studies | £500,000 |
| Cost of Public Inquiry | £500,000 |

The costs of the further studies and the Public Inquiry are not included in the scheme costs.

# 1. INTRODUCTION

1.1 On 25 March 1991 the Anglian Region of the National Rivers Authority (NRA) appointed Binnie & Partners in association with Oakwood Environmental to develop a strategy for the alleviation of flooding in Broadland. The area of the study is shown in Figure 1 and covers all the low-lying land adjacent to the tidal reaches of the rivers in the Yare basin, including land in Great Yarmouth.

1.2 Following an assessment of six flood alleviation options and ten sub-options, two schemes were selected for more detailed consideration. The consultants found, however, that existing information was inadequate to choose between these two schemes. This was reported to the Norfolk and Suffolk Local Flood Defence Committee (LFDC) at a meeting on 27 July 1992 when they agreed to the study being extended and to a Task Group being established to evaluate the two schemes in more detail.

1.3 In view of the significance of the impacts each scheme would have on Broadland the LFDC further agreed that nominees from the Broads Authority should be invited to sit on the Task Group with representatives from the NRA and the consultants.

1.4 The Task Group was convened on 7 September 1992 and has met on 6 occasions subsequently. This report, which is agreed unanimously by the members, describes the additional work commissioned by the group, the results of this work and the conclusions reached by the group in the light of the additional information obtained.

## 2. BACKGROUND

2.1 The work carried out before the Task Group was established is described in a Briefing Note prepared for the July 1992 LFDC meeting. The main points are outlined below.

### Existing defences

2.2 Flooding in Broadland is caused by high sea levels or by high river flows. The most damaging events are associated with high sea levels since much of the flooding is then saline. Saltwater also penetrates further up the rivers than usual, damaging the ecology of normally freshwater reaches and occasionally causing heavy fish kills.

2.3 Broadland contains some 240 km of floodbank defending about 21,300 ha of land. Many of these have settled, by an average of about 20mm/year, since they were last improved and over much of the area are at risk of being overtopped by floods with return periods of 5 years or less. Great Yarmouth is defended by floodwalls which have recently been raised to levels which prevent overtopping by floods with return periods of 100 years or more.

### Scope of study

2.4 The work undertaken included:

- **hydraulic modelling**, of the river system and the areas flooded,
- **engineering assessment**, of the existing defences and possible options,
- **cost-benefit analysis**, of each option,
- **environmental assessment**, again of each option.

A contingent valuation study was undertaken by the University of East Anglia to assess Broadland's landscape and amenity value. The views of a wide range of statutory consultees, other interest groups and the general public were obtained and were taken into account when the options were assessed.

## Options considered

2.5 The study concentrated on providing protection against flooding caused by high sea levels rather than by high river flows. Six basic options were considered:

1. **Do nothing**

2. **Sustain existing defences**. Strengthening the defences at their present level and raising them to guard against future settlement/sea level rise were examined.

3. **Raise embankments**. Raising by up to 1m or more to provide a general 1:20 year standard against saline flooding and 1:50 year for Halvergate Triangle.

4. **Bure barrier**. One site near the mouth of the Bure was considered.

5. **Yare barrier**. Five sites, three seaward of the Bure mouth and two upriver of this point were considered.

5. **Washlands**. Three sites, one on the Bure and two on the Yare were examined.

The use of barrages, suggested by a number of consultees, was also considered but ruled out because of the water quality and sedimentation problems and the wholesale ecological changes that would occur.

## Preferred options

2.6 The results of the contingent valuation study showed substantial support for maintaining the existing character of Broadland by improving the defences rather than allowing it to deteriorate by doing nothing. Following an initial screening of the other options two schemes were selected for more detailed assessment. These are described in more detail below. The reasons for eliminating the other options are summarised in Tables 1, 2 & 3.

**Scheme 1 - Barrier on the Yare above Haven Bridge**

2.7 The principal components of this scheme are:

- a barrier located at the site shown on Figure 2 which is closed to prevent water entering Broadland when sea levels are predicted to be higher than a predetermined level,

- raising and strengthening the Great Yarmouth floodwalls seaward of the barrier to guard against the higher water levels that will occur there when the barrier is closed, and

- raising and strengthening the existing floodbanks in Broadland as necessary to prevent breaching and overtopping when the barrier is not closed.

2.8 The barrier, shown in Figure 3, will provide a very high standard of protection to all Broadland when it is closed. The frequency of closure will depend on the crest level of the Broadland floodbanks but is unlikely to be much greater than six times each year on average for flood defence purposes. This is because any additional settlement of the floodbanks will lead to an unacceptably large increase in the frequency of closure needed to prevent overtopping. To prevent this happening the study assumed that all floodbanks will be raised at intervals of 15 years, so guarding against the effects of both settlement and sea level rise. The duration of closure will normally be less than 24 hours but on rare occasions may be two or even three days.

**Scheme 2 - Barrier on the Bure and washland at Haddiscoe Island**

2.9 The principal components of this scheme are:

- a barrier located at the site shown on Figure 2 which is closed to prevent water entering the Bure and its tributaries when sea levels are predicted to be higher than a pre-determined level,

- a washland at Haddiscoe Island (see Figure 1) designed to flood when water levels rise more than 0.3 to 0.5m above normal high spring tide level, so restricting further rises in water level and therefore protecting the land adjacent to the Yare and the Waveney.

- raising and strengthening the existing floodbanks in Broadland as necessary to prevent breaching and overtopping along the Bure when the barrier is not closed and, in conjunction with the washland, to provide target standards of protection to the land by the Yare and the Waveney.

2.10 The barrier, shown in Figure 4, will provide the same high standard of protection to land adjacent to the Bure and its tributaries as the Scheme 1 barrier will provide to all Broadland. The frequency of closure is again unlikely to be much greater than about six times each year on average for flood defence purposes, for the reasons given in Para 2.8 above.

2.11 The washland, shown in Figure 5, will provide a general 1 in 20 year standard of protection against saline flooding and a 1 in 50 year standard for Halvergate Triangle. Water will enter the washland over weirs set in the floodbanks with a total length of 4 km and will be pumped off the land once river levels have receded. The frequency of flooding will be no more than 2 or 3 times each year on average and the pumps are designed to evacuate the area fully in no more than 6 days.

## 3. ISSUES RAISED AND ADDITIONAL INFORMATION NEEDED

3.1 The Terms of Reference of the Task Group required it to:

- define the requirements of any flood defence strategy within the overall management objectives of the Broads Plan,
- identify the additional information needed to determine which of the two preferred schemes should be recommended for selection,
- assess the additional and existing information, taking particular note of the environmental and recreational opportunities and consequences of each scheme, and
- recommend which of the two preferred schemes should be implemented and set out the programme for implementation, identifying any additional data needs.

3.2 By considering the objectives of the Broads Plan together with the NRA's statutory duties the Task Group identified certain key issues which could be affected by one or both of the two options being considered and therefore need to be taken into account when choosing between them. These issues are discussed below.

**Key issues**

(i) **Standard of defence**

3.3 The NRA 's corporate flood defence aim is to provide effective defence for people and property against flooding from rivers and the sea. To assist in the preliminary assessment of flood defence schemes the Anglian Region of the NRA have established target standards of defence which depend on the land use in the area protected. The targets applicable to Broadland are shown in Figure 6. They are for guidance only, however; if detailed assessment shows they cannot be justified a lower standard is to be adopted. Similarly a higher standard may be selected with appropriate justification.

(ii) Great Yarmouth

3.4 The target standard of defence for urban areas such as Great Yarmouth is 1 in 200 years (that is, the defences should not be overtopped by events with return periods of 200 years or less). The existing floodwalls have recently been raised to meet the target standard. In many areas, however, the floodwalls are supported by timber or steel piling which will need replacement as it deteriorates. Seepage of water through the ground occurs at a number of points when sea levels are high and this needs to be remedied to secure the long-term integrity of the defences.

(iii) **Defended areas of Broadland**

3.5 The majority of Broadland is defended by floodbanks which were originally constructed several hundred years ago and have been periodically raised or improved since then. They are subject to settlement however (see below) and the current standard of protection in some areas is estimated to be 1:5 years or less. This is well below the NRA's target standard of 1:20 years for areas subject to saltwater flooding (1:50 years for the Halvergate Triangle due to its important road and rail links) although acceptable for marsh grazing land subject to flooding by fresh water.

3.6 Flooding has occurred on a number of occasions in recent years, generally as a result of overtopping at low points in the floodbanks. This overtopping has restricted the rise of water levels in the rivers so preventing flooding elsewhere; if the existing low points are raised the flooding will be moved to the next lowest points.

3.7 Much more serious flooding would have occurred if a floodbank had breached. Most of the existing floodbanks have narrow crests and steep sides and so the risk of breaching is relatively high, particularly if they are overtopped. They are also subject to seepage and are difficult to inspect and maintain.

3.8 In parts of Broadland the floodbanks are threatened by toe erosion due to boat wash (exacerbated in places by deterioration of the reed rands between the bank and the river channel). Erosion protection works will be needed to secure the defence in these areas. In addition existing protection works will need replacement as they reach the end of their useful life.

(iv) **Undefended properties in Broadland**

3.9 Both residential and commercial properties have been built on the floodplain outside the existing defences in a number of areas of Broadland, particularly at Brundall, St Olaves and Potter Heigham (as shown on Figure 7). Residential properties are generally seasonally occupied riverside holiday cottages while commercial properties are generally associated with boatyards. Some of the more substantial buildings have piled foundations but the majority do not and are therefore prone to settlement.

3.10 Many of these properties are subject to regular flooding which will get progressively worse as settlement continues. Some are designed to be raised at regular intervals to overcome this problem. Other measures are also taken, such as removing furniture or equipment during the winter months when the most serious flooding occurs and the properties are unoccupied, or storing materials and equipment above the general flood level. This level is largely controlled by the level of the floodbanks along the river and will rise if these banks are raised. Any settlement of these banks will limit the increase in flooding caused by settlement of the properties.

3.11 Although the flooding of undefended properties causes inconvenience, distress and loss of working time it is not generally life-threatening as most properties are close to high ground or to defended land allowing ready escape to safety. Economic losses are limited by the avoiding measures described above.

(v) **Settlement and sea level rise**

3.12 The poor soil on which the floodbanks (and many properties) in Broadland are founded leads to very high rates of settlement, between 6mm and 30mm/year having been measured with an average of just under 20mm/year. This settlement will continue, indeed is likely to increase for some years if the load on the ground is increased by widening or raising the banks. If the increase in load is too great the stability of the bank and its foundations will be threatened.

3.13 The effect of settlement is exacerbated by the effect of sea level rise, currently estimated to be about 7mm/year although this may increase in the future. For the present study these two effects were considered together, allowance being made for a combined effect of 25mm/year. The sensitivity of this assumption was tested by

considering combined effects of 15mm and 35mm/year also.

(vi) **Scheme costs**

3.14 It is important that comprehensive and well-founded cost estimates for each scheme considered should be available. In addition to the initial costs of construction, these estimates need to include the costs of purchasing any land required, of any disruption or loss caused (either during construction or subsequently) and the costs of subsequently operating and maintaining the scheme.

3.15 Although the costs should be comprehensive it is also important that they should be sub-divided so that costs common to both schemes being considered can be taken out when the detailed assessment takes place. The costs of the toe protection works to the floodbanks and the maintenance and replacement of the Great Yarmouth defences in particular fall into this category; these are major costs which will be the same whichever scheme is implemented and so do not affect the choice of scheme.

3.16 When assessing flood defence schemes the Ministry of Agriculture, Fisheries and Food considers the total cost over the assumed life of the scheme (50 years for the present study) discounted at the Treasury Rate of 6%. This cost represents the amount of money which, if invested now at 6% interest, would just cover all the anticipated costs over the life of the scheme. It is important to consider also, however, the immediate funding requirements of each scheme and how they may be phased.

(vii) **Port and related industry**

3.17 The port of Great Yarmouth sustains a large proportion of the local industry with up to 8,000 people being directly or indirectly employed in port-related activities. Originally a fishing port, its principal current activity is concerned with servicing the southern North Sea gas fields but it also retains a significant import/export trade. Although a difficult harbour to enter or leave, it has the advantage of being accessible at all states of the tide. It is believed that this is the main reason for it having been able to survive competition from other east coast and continental ports.

3.18 Access to the port has improved in recent years with the dualling of the A11 and the A47 and this is planned to continue. Two major enhancement schemes have been proposed in recent years, a third river crossing (at a site about one third the way up the Haven from the harbour mouth) and an outer harbour. It has not been possible to raise finance for either, however, and the chance of them being implemented in the foreseeable future seems remote.

(viii) **Agriculture**

3.19 In the 1970's much of Broadland was drained and large areas of traditional grazing marsh converted to arable farming. This process attracted considerable opposition from conservation groups and ceased in the 1980's, aided by MAFF's designation of Broadland as an Environmentally Sensitive Area (ESA) and the provision of grants to encourage landowners to revert to traditional marshland grazing regimes. The success of the ESA scheme, which is voluntary, is demonstrated by its recent renewal and extension for a further 10 year period. Significant areas of land, nevertheless, are still arable, particularly along the left bank of the lower Bure and by the middle Yare.

3.20 Farmers wishing to enter the ESA scheme are required to use farming practices which will enhance the environment. There are currently three tiers in the scheme, higher tiers providing greater environmental benefits and attracting greater payments. Tier 1 is intended simply to maintain the grassland landscape while Tier 2 involves higher summer water levels in the ditches and restricts grazing to the summer months. Tier 3 in addition requires wet winter and spring conditions to benefit waders and wildfowl.

3.21 A reliable freshwater supply to the marsh dykes is critical for the success of the ESA scheme, to provide summer drinking water for stock and to maintain the dyke flora. In many parts of Broadland farmers rely on water from the rivers to supplement rainwater and spring supplies, particularly during periods of dry weather. Saline intrusion in the rivers restricts the opportunity to do this and can lead to the seepage of saline water through the banks, contaminating the water in the dykes. This can, in severe cases, cause toxicity problems for cattle and deterioration of marsh dyke communities.

3.22 Part of the land in the ESA scheme is grazed by the owners themselves and part is let out to others on one-year leases. The system is complex and, at best, the returns are marginal. Indeed in the current economic climate for agriculture it appears likely that it will become increasingly difficult in the future to ensure that stocking rates on all ESA land are kept at the required level.

### (ix) Tourism and recreation

3.23 An estimated 1 million people visit the area each year, providing direct employment to some 6,000 people locally and indirect employment to a further 3,000. The visitors are involved in both land-based activities,including sight-seeing and walking, and water-based activities, including fishing, sailing and boating.

3.24 The amenity value of Broadland has been demonstrated by the results of the contingent valuation study, which indicates that visitors would be willing to pay at least £6M each year to avoid the extensive and long drawn-out changes that would occur if nothing is done to the flood defences.

3.25 Coarse fishing is an important component of recreation in Broadland, being the principal reason for visiting the area for a significant number of people and being attempted at least once by many more during their stay. The quality of the fishing is on occasion affected by saltwater intruding further up the rivers than normal, particularly during periods when fresh water flows are low. Several fish kills, some involving large numbers of fish, have occurred when the intrusion has been extensive. Not all kills are related to intrusion from the sea however: a significant proportion appear to have been caused by the build up of the toxic algae *Prymnesium parvum*.

3.26 Two water-based activities that are becoming increasingly popular are water skiing and wind surfing. This is recognised in the Broads Plan which has identified a need for areas which can be set aside to accommodate these activities without interrupting the peace and tranquillity which is sought by the majority of other Broadland visitors.

### (x) Inland navigation

3.27 The importance of boating activities within Broadland indicates the need to maintain and, where possible, improve inland navigation routes. An important route is the one

from the Yare and the Waveney, where many of the boat hire yards are located, through Great Yarmouth to the popular boating areas in the upper reaches of the Bure, the Ant and the Thurne. Since many boats are hired on a weekly or fortnightly basis, being collected and returned on Saturday, this route tends to be particularly heavily used at the start and end of the week.

3.28 The holiday boating season has increased in length in recent years and now extends from the beginning of April until the end of October. School holidays are naturally particularly popular, with peaks of activity occurring at Easter, Whitsun, in July and August and at the half-term break in October. September is also a very popular month.

### (xi) Natural resources

3.29 The Broadland area is recognised as being a wetland of international importance for nature conservation. As in most wetlands there has been intensive use of natural resources through history, leading to some deterioration of wildlife habitats through pollution, over-exploitation and neglect. National and international concern led to the establishment of the Broads Authority in 1988 to manage the land and water activities in the area and at the same time to co-ordinate the conservation and restoration of the natural environment.

3.30 The importance of Broadland's natural resources lie in their diversity, encompassing grazing marshes (drained marshland), fens (undrained peatland, alder carr and reedswamp), intertidal areas (saltmarsh and mudflat) and aquatic habitats (rivers, broads, and marsh dyke systems) ranging from freshwater to brackish. Three major restoration programmes are underway; the enhancement of the grazing marshes (through the ESA); the restoration of valley fens (in conjunction with English Nature) and the restoration of aquatic life in the rivers and broads (in conjunction with the NRA).

3.31 It is important that the full diversity of Broadland and the investment in restoration programmes should be protected. Possible threats include long-term changes to the regular pattern of river flows or water levels altering existing patterns of flushing on reed rands or leading to reduced flushing of off-river broads, increased nutrient enrichment or increased sedimentation. A matter of particular concern is the

possibility of increased saline intrusion as this has extremely damaging effects if it extends into broads or river reaches that are normally fresh.

(xii) **Landscape**

3.32 Broadland contains a range of distinctive landscapes, from the enclosed privacy of some of the smaller broads to the broad sweep of the traditionally managed open grazing marsh. The ESA scheme is intended to safeguard and restore the latter and it is important that this aim should not be compromised by whichever scheme is selected, either during construction or during subsequent operation or maintenance. The impact of any structures on the landscape, either in the countryside or in the town, therefore needs to be given most careful consideration.

(xiii) **Saline intrusion**

3.33 The significance of saline intrusion in the Broadland rivers has been highlighted above; it affects agriculture, particularly the security of the ESA scheme, through contamination of the freshwater dyke systems due to seepage through the floodbanks and by restricting the opportunities for topping up the dykes with fresh water; it affects fishing by causing fish mortality and by excluding fish from reaches where they are normally to be found; and it affects the natural resources of the area, particularly the flora and fauna found in normally fresh water reaches of the rivers or off-river broads or in the fresh water dyke systems. Particularly extreme events could threaten restoration work carried out by the Broads Authority and other organisations in some of the more sensitive broads in the upper Bure, the Ant and the Thurne.

3.34 It must be realised, however, that Broadland is not a wholly freshwater system. Much of its environmental value comes from the diversity of habitats found there, due in large part to the change from fresh to brackish to wholly saline conditions found in its rivers. To prevent the extreme events which cause extensive damage to normally fresh water reaches is a desirable aim but to attempt to exclude salt water completely would diminish the importance of the area significantly.

### Scheme appraisal

3.35 It is inevitable that a major part of the scheme appraisal process will depend on the comparison of the economic costs and benefits of the two options. It is therefore important that these costs and benefits should be defined as comprehensively and robustly as possible. It is equally important, however, to realise that not all impacts (costs or benefits) can be expressed in strict economic terms and to ensure that the appraisal process considers these intangible impacts also.

### Additional studies

3.36 Having identified the key issues raised by the flood alleviation strategy the Task Group reviewed the information available from the work carried out prior to its establishment. This indicated that further information was needed in three areas to allow a full assessment of the two schemes to be made. These areas were:

- saline intrusion, in particular how the salinity regime is affected by river flow and sea level variations at present and how this would be changed by each scheme;

- washlands, both the opportunities that construction of a washland would provide for creation of desirable habitats and the way it would need to be operated to ensure its long-term sustainability,

- navigation, the effects that each scheme would have on navigation and related matters in the port of Great Yarmouth and on inland navigation.

3.37 The studies that were carried out to obtain this information and the results of these studies are described in the following chapters.

## 4. SALINE INTRUSION STUDIES

4.1 The purposes of the saline intrusion studies were:

- to examine the existing salinity regime in the Bure, Yare and Waveney and how it is affected by variations in freshwater flow and sea level;

- to determine the effect that each of the two schemes would have on saline intrusion if they were operated simply for flood defence purposes;

- to determine whether either scheme could be operated to improve the salinity regime in Broadland and what other effects the changed operating rules would have on the area.

4.2 Existing river flow and tide level records are reasonably comprehensive but useful salinity data are very sparse, the first continuous recorder only having been installed in July 1991. Prior to this the data consist largely of spot readings, generally with no note of the time they were taken. Accordingly the hydraulic model developed for the earlier studies was used to examine existing salinity conditions in some detail, as well as to examine the effects of the two preferred schemes on these conditions. Care was taken to confirm that the model results for existing conditions compared reasonably with the limited salinity data available.

**Existing salinity regime in Broadland**

4.3 The model was used to determine the limit of intrusion (the distance from the mouth reached by water of a given salinity) that would occur in each river with different combinations of freshwater flow at the tidal limit and tide at Great Yarmouth. The tides examined included a normal spring-neap cycle and the same cycle with marine surges of varying severity superimposed.

4.4 The results of the model tests show that, in each river, the intrusion increases as the high tide level at Great Yarmouth increases and as the freshwater flow decreases. In the southern rivers (the Yare and the Waveney), the intrusion on any tide is related to the high water level and freshwater flow at the time. In the northern rivers, however, (the Bure, Ant and Thurne) the intrusion is related to preceding conditions as well.

4.5 The reasons for the difference are the much larger surface area of the broads and fens in the northern rivers, which act as a reservoir and even out the freshwater flow in the lower reaches, and the high bed levels round the Bure Loop which restrict the flow of saltwater into and out of the system on each tide. One result of this is that during periods of low flow salt water can build up in the northern river system leading to progressively increasing intrusion. Another result is that following a major event caused by particularly high sea levels it can take some considerable time for all the salt water to be flushed out and conditions to return to normal. Such conditions are likely to occur very infrequently in the southern rivers.

4.6 The model test results were used to derive empirical relationships between high tide level, freshwater flow and saline intrusion for the Bure, the Yare and the Waveney. These relationships were then used with the historic river flow and tide records to determine the probable frequency of salinity greater than 0.5 g/l intruding past certain key points in each river; Acle Bridge and Thurne Mouth on the Bure, Reedham and Rockland Broad on the Yare and St Olaves and Oulton Broad on the Waveney. The results are shown in Table 4. Salt water frequently intrudes beyond Reedham and St Olaves (in the Yare and the Waveney respectively) but does not often reach as far as Rockland and Oulton Broads. On the Bure, salt water is estimated to pass Acle Bridge on about 14 tides during an average year and to extend beyond Thurne Mouth more than twice.

4.7 Conditions in the Bure were examined in more detail. It was found that severe intrusion was caused either by relatively infrequent low flows coinciding with normal high tides or by relatively infrequent high tides coinciding with normal river flows. The former combination tended to occur in summer (May-August) and the latter in winter (November-February). Both combinations occurred in autumn (September, October) while severe intrusion due to either combination was very rare in spring (March, April).

4.8 The results of the analysis are given in Table 5. The upper part of the table shows the frequency of intrusion irrespective of the flow in the river while the lower part shows the frequency excluding occasions when the flow is less than $1.0m^3/s$. The results indicate that on average salt water will intrude beyond Acle Bridge 13.6 times each year and on all but 1.4 of these the river flow will be less than $1.0m^3/s$. Such

flows, which occur about 2% of the time, therefore are associated with about 90% of the intrusion events. It may be noted that the model suggests that intrusion beyond Acle Bridge will not occur with a flow of 1.0m³/s unless the tide level at Great Yarmouth is more than +1.2m OD whereas levels as low as +0.65m OD will cause intrusion in combination with the very low flows that can occur.

**Effect of barriers**

4.9 The effects of a barrier in the Yare between the Haven Bridge and the mouth of the Bure and one in the Bure near the old railway bridge were examined in the model. In both cases the barrier was tested against a surge event in which the water level at Great Yarmouth reached a peak of +3.0m OD. The effect of closing the barrier when the water had reached levels of +0.9m and +1.2m OD and keeping it closed until the surge was past and water levels on either side of the barrier had equalised once more were examined.

4.10 The saline intrusion occurring in both the Bure and the Yare with each condition is compared with that occurring without a barrier (but assuming the floodbanks are built up to prevent overtopping) in Table 6. The results for the Yare were as expected, with the Yare barrier leading to a significant reduction in intrusion, particularly when closed early, but the Bure barrier having little effect. The results for the Bure showed that the Bure barrier would be more effective at reducing intrusion than the Yare barrier.

4.11 The reason for this is the presence of Breydon Water just up river of the mouth of the Bure. When the Yare barrier is closed Breydon is full of saltwater and, unless the closure is very early indeed, the water level there is higher than the level in the upper reaches of the Bure. Salt water therefore flows from Breydon Water into the Bure throughout the whole of the period the barrier is closed, causing the intrusion noted. The Bure barrier, however, cuts the Bure off from Breydon Water so that once it is closed no further intrusion occurs. The example shown is for a relatively short duration surge; the effect is more pronounced as the duration of the surge increases.

### Effect of washland

4.12 The effect of the proposed washland at Haddiscoe Island on saline intrusion was examined for the same event as the barriers, both during the surge and afterwards when water is being pumped out from the washland back into the Yare and the Waveney at a rate of 14m$^3$/s each.

4.13 The test showed that the washland filled with salt water but despite this had little overall effect on saline intrusion in the Yare and none noticeable in the Bure, compared with existing conditions. Pumping the washland out had the effect of maintaining higher salinities in the rivers by the pumping stations at low tide but had little effect on conditions at high tide. There would be, as a result, no adverse conditions upstream.

### Conclusions

4.14 The main findings of the saline intrusion studies are:

- in all rivers saline intrusion increases as the high tide level at Great Yarmouth increases and as the freshwater flow decreases,

- salinity is generally flushed from the Yare and the Waveney fairly rapidly following an intrusion but takes longer to be removed from the Bure and the other northern rivers,

- the majority of intrusion events in the Bure occur in the summer and autumn at times when the river flow is less than 1m$^3$/s,

- when the flow in the Bure is 1m$^3$/s or greater the lowest high water level at Great Yarmouth likely to cause intrusion is +1.2m OD,

- a Bure barrier is very effective at preventing saline intrusion in the Bure and has negligible effect on the Yare,

- A Yare barrier near the Haven Bridge has some effect on saline intrusion in the Yare but relatively little in the Bure.

a washland at Haddiscoe Island has little effect on saline intrusion in the Yare or the Waveney, either during operation or while it is being pumped out subsequently.

4.15 It should be noted that these conclusions are preliminary and require to be confirmed by further studies in due course. While these further studies may affect the details given above they are unlikely to alter the general pattern of behaviour described.

## 5. WASHLAND STUDIES

5.1 The purposes of the washland studies were:

- to determine the types of habitat that would be acceptable and sustainable on Haddiscoe Island, given the flooding regime anticipated.

- to assess the engineering and other implications of establishing these habitats and to determine whether they would have a significant impact on the cost estimates.

- to consider means of managing the area to achieve the desired aims.

5.2 The studies assumed that the washland would be generally as shown on Figure 5. When operating, water would flow into the washland over weirs with a total length of 4 km located near the northern end of the island. The weir crests would be set initially at a level of about +1.4m OD and so would be overtopped on average about once a year. They would settle with time but would be made up to the original level once they had fallen to +1.2m OD (at which level they would be overtopped 2 or 3 times each year on average). The washland would be divided into two compartments by a bank with its crest set slightly below the inflow weir crest. The northern compartment would be expected to flood every time the weirs overtop and the southern compartment during events with return periods of about 10 years or more (which is higher than the standard of protection given by the present defences). Pumping stations would be provided to evacuate the whole area from full over a period of 6 days.

### Possible habitat types

5.3 Preliminary consideration of the Broads Plan objectives and the known views of other organisations led to the following criteria for selecting possible habitat types:

- as far as possible the existing landscape (open grazing marsh and associated features) should be maintained.

- the most effective way of maintaining this landscape would be to continue to use it for grazing under conditions as similar as possible to the present;

- if grazing the land is not possible then alternative uses which would enhance the nature conservation value of the island by creating habitats considered desirable in the Broadland context should be adopted.

5.4 The relative infrequency of flooding in the southern area suggests that the existing grazing regime there should be sustainable subject to availability of freshwater for the dyke system. The northern area will be flooded more frequently, however, and there is concern among the farming community that any form of grazing will be unsustainable there. A number of alternative land uses were therefore considered, including:

- upper saltmarsh
- middle and lower saltmarsh
- reedbed and open water

The possibility of creating an area of shallow open water and providing facilities for recreation such as wind surfing or water skiing was raised but dismissed as inappropriate in this location due to the area's high landscape value.

5.5 Middle and lower saltmarsh would require a quasi-tidal flooding regime which would be difficult to maintain and these options were therefore discarded. The possibility of developing and sustaining an upper saltmarsh habitat was examined by collecting information on other sites in the UK and on the continent subjected to salt water flooding of similar flooding frequencies and durations expected on Haddiscoe Island. More than fifteen such sites were found. Information on developing reedbeds was obtained locally.

5.6 Following from these investigations it was concluded that either a wet grassland (containing salt tolerant species found in upper saltmarsh) or a reedbed environment could be sustained under the flooding conditions anticipated. Both these environments would provide significant conservation benefits provided water levels in the dykes are kept higher than they are at present. The greatest benefit would be obtained by allowing a mixture of grassland and reed with some open water to

develop as this would increase the diversity of habitats in the area and so improve conditions for birds, in particular for breeding waders and wildfowl.

5.7 The salt-tolerant wet grassland may be expected to develop from the existing sward, which already contains salt-tolerant species, but could be promoted by sowing if necessary. Areas that are to remain as grassland would need to be grazed as otherwise they would gradually be colonised by reed and eventually revert to a natural reedbed environment. This process could be accelerated by planting in areas where reed is desired.

5.8 It was concluded, therefore, that if Haddiscoe Island is used as a washland then the existing grazed freshwater marsh should be maintained in the southern part of the island and a mixture of grazed saltwater marsh and reed allowed to develop in the northern part. The infrastructure and management arrangements needed for this to happen are discussed below.

**Infrastructure and engineering aspects**

5.9 The principal infrastructure requirement will be to review the existing dyke network, in both the northern and southern parts of the island, and modify it to provide the ability to control water levels and water movements with the degree of precision needed. It is likely that improved fresh water intake structures and drainage arrangements will be needed as part of this exercise.

5.10 Although it may often be possible to flush salt water out of the dykes in the northern area after a flood this cannot be guaranteed. If the northern area is to be grazed, therefore, a separate fresh water supply system will be needed to ensure the stock can drink.

5.11 If the grazing regime on the southern part of the island follows the current Tier 2 ESA requirements the risk of stock being on the land when the area is flooded will be very low. However the northern part could get flooded towards the end of the grazing season (during September and October). The provision of raised areas to provide refuge for the stock when this occurs was considered but found to be expensive and unsightly and it is therefore assumed that stock will be removed from the northern part of the island at the end of August.

5.12 Other matters to be considered in the design of the washland are the need to maintain or protect the traditional building on the island and the need for the washland structures to be as unobtrusive as possible. The pumphouses, in particular, will need careful design to achieve this, noting that they will be visible from both the land and the river.

**Management aspects**

5.13 At present the land on Haddiscoe Island falls within Tier 2 of the ESA scheme set up by MAFF to promote traditional agricultural practices in Broadland. This sets out a number of requirements, the most important being that summer water levels in the dykes should be kept high and that grazing should be restricted to the summer months. In return MAFF pays an annual grant to the farmer. The owners of the land on the island graze some of it themselves but rent out the remainder to graziers on annual leases (which are, in effect, subsidised by the MAFF grant). This system works well at present since the quality of the grass in the area is well known and graziers are assured of a reasonable return on their investment.

5.14 If the island is developed as a washland part of the area could become reedbed and part remain as grazed grassland. The conditions in the grassland areas would be closer to those set out for Tier 3 of the ESA scheme, which requires water levels to be kept high during winter and spring as well as the summer. The land would be subject to regular flooding by salt water, however, and the water in the dykes is therefore likely to be much more saline than at present.

5.15 Three matters need to be addressed if the washland development is to be successful:

- whether the existing methods of managing the area will be suitable, bearing in mind the greater degree of both day-to-day and long-term control needed if the full landscape and nature conservation benefits are to be achieved,

- whether MAFF will continue in principle to support landscape and nature conservation in the area, either through the ESA scheme or through alternative arrangements.

- whether sufficient graziers willing to put their stock on the grassland areas can be found, bearing in mind that they are likely to have less confidence in the quality of grass that may have been flooded the previous winter and that there is generally a surplus of grazing land available for rent within Broadland.

These matters need to be discussed in detail with MAFF and the present land owners, occupiers and graziers. A possible solution for managing the area would be for the NRA to buy all the land on the island and enter into a management agreement with a single party. This party would then be responsible for establishing an acceptable mix of habitats within the area and for subsequently maintaining it, negotiating as necessary with other interested groups.

**Conclusions**

5.16 The principal conclusions of the washland studies are:

- the development of a washland with the proposed arrangement at Haddiscoe Island would enhance the nature conservation value of the site and benefit Broadland as a whole.

- the existing grassland grazing regime could be maintained in the southern part of the washland and a mix of grassland grazing (with salt-tolerant species) and reed with some open water in the northern part.

- improvements to the infrastructure of the island would be needed.

- discussions with MAFF, local landowners and other interested parties would be needed to agree the way the area should be managed.

## 6. PORT AND NAVIGATION STUDIES

6.1 The aims of the port and navigation studies were:

- to examine the effect of the Yare barrier on port operations and activities,
- to examine the effect of the Bure barrier and the Haddiscoe Island washland on inland navigation.

In both cases the effect of operating the barrier solely for flood defence and additionally to prevent saline intrusion were considered.

**Effects on port operations and activities**

6.2 During discussion with the Great Yarmouth Port Authority it became apparent that their main concerns are related to the Yare barrier scheme and that they have little comment on the Bure barrier and washland scheme. Their concerns about the Yare barrier are:

- it would affect navigation when closed, particularly of vessels entering and leaving the port,
- it would affect the hydraulic and sediment regime of the Haven,
- the threat of interrupted navigation resulting from its presence would affect the confidence of port operations and so affect trade.

6.3 The Authority believe that the barrier would significantly alter the flow patterns at the mouth of the harbour when closed, to the extent that it would be physically impossible for ships to enter or leave safely on these occasions. Furthermore they do not believe that training the pilots and ships' captains with licences to use the port would help; the problem would not be lack of familiarity with the conditions but the conditions themselves. As a result the Authority believe it would be necessary to close the port whenever the barrier is operated.

6.4 With regard to the hydraulic and sediment regime the Authority's main concern is that the presence of the barrier could lead to increased sedimentation in the harbour. This would require an increase in their dredging commitment, which is currently very low. There is also some concern that the actual closure of the barrier could cause a reflected wave high enough to overtop the floodwalls.

6.5 The threat to trade (and therefore to the port's prosperity), arises because the port's main advantage compared with its competitors on the east coast is perceived to be its flexibility; ships can enter and leave it at all times. If this flexibility is reduced, even marginally, as is believed would happen if the Yare barrier is built, then the confidence of the port users would be affected and some would be attracted elsewhere. Of particular concern are the companies servicing the gas fields in the southern North Sea as many of these have bases in Dutch ports which they could switch to relatively easily.

6.6 The present studies have addressed some of the concerns raised by the port. The difficulty of navigating the entrance is evident and it is apparent that the barrier will significantly alter the conditions there when it is closed. What is not clear is whether the changes will restrict the navigation as claimed. Further studies including detailed model tests would be needed to confirm this. Model tests would also be needed to show the effect the barrier would have on the sediment regime, although preliminary assessment suggests this is unlikely to be very great. Barrier closure will cause a reflected wave but tests in the existing model indicate that this can be controlled. The threat to trade caused by the presence of the barrier is difficult to quantify since it depends largely on confidence. The position of the port as a major contributor to the local economy means that this threat must be addressed seriously and further studies will be required to do this if the Yare barrier scheme is to go ahead.

**Effects on inland navigation**

6.7 Meetings were arranged with representatives from the Broads Authority Navigation Committee and other groups with inland navigation interests. During these meetings it became apparent that the main concern was with the Bure barrier because it would interrupt traffic between the northern and southern river systems when closed and with the washland because of the possible danger to boats when it operates. There was very little concern about the Yare barrier as it would not interrupt inland

navigation and few private boats would wish to put to sea on the occasions it is closed.

6.8 To determine the effect of the Bure barrier the study addressed the following points:

- existing restrictions to navigation in the reach where the barrier would be located,

- how often and for how long the barrier would be closed if operated for flood defence or to prevent saline intrusion,

- the increased restriction caused by the barrier's operation.

6.9 The main restriction to navigation at present is understood to be provided by the old railway bridge and the adjacent road bridge near the mouth of the Bure, both of which have a soffit level of about +3.17m OD. The effect of this is shown on Table 7, which gives the water level at the bridge that would prevent craft of various heights passing beneath the bridges, the equivalent water level at the mouth of the harbour and the percentage of tides each year that exceed this level.

6.10 The table shows that craft requiring 12 ft (3.66m) clearance will only be able to pass the bridges when the tide is low and that craft requiring 7 ft (2.13m) will be obstructed when the high water level is +1.2m OD or greater. It is understood that more than 80% of Broads craft fall within this range.

6.11 The barrier would be closed for flood defence purposes when the water level at Great Yarmouth (at the harbour mouth) is predicted to exceed a given critical level. The number of closures each year will depend on the critical level selected, as shown on Table 7. In practice a predicted level of about +1.8m OD at Great Yarmouth would be selected as the criterion for closure, giving an average (based on 10 years of record) of 2.4 closures per year of which 75% would be in winter (November to February) and the remainder in autumn (September, October) and spring (March, April). Allowing for false alarms and maintenance this could increase to a total of perhaps 6 times/year. Apart possibly from the maintenance closures (which would normally be of short duration) navigation would anyway be interrupted when the barrier is closed as the water level would then be higher than +1.2m OD.

6.12 The salinity studies described in Section 4 showed that saline intrusion in the Bure could be caused by a combination either of relatively low river flows ($<1.0 m^3/s$) and normal tides or normal river flows and relatively high tides (>+1.2m OD). The first combination occurs mostly in the summer and would be very difficult to control with a barrier, requiring it to be closed for long periods of time which would be unacceptable not only because of the effect on navigation but also because of the environmental consequences. The number of the second combination of events estimated to occur during a period of 10 years is shown in Table 9, which also gives the number of those occasions when the water level would be greater than +1.8m OD (the occasion when a Bure barrier would be closed anyway for flood defence purposes). The table indicates that the barrier would need to be closed on about 2 additional occasions each year to restrict saline intrusion in the Bure associated with tides greater than +1.2m OD. These tides would anyway interfere with navigation and the additional closures would therefore cause little additional restriction.

6.13 In general, therefore, the barrier will not increase navigation restrictions to the majority of Broad's crafts. There will, nevertheless, be occasions when craft will have to wait to pass the site (as they do at present). There are a number of moorings available upstream of the barrier site but very few on the other side, which could cause difficulties if the barrier had to be closed at a time when traffic is heavy. It is recommended, therefore, that additional moorings are provided seaward of the barrier as a safety measure.

6.14 The study also examined the effect of the washland on inland navigation. Two matters were considered, the filling of the washland from the river and the discharge to the river when it is being pumped dry. Neither of these are considered to be of particular concern; the weirs used for filling are very long so that the depth of water over them (and therefore the cross-current experienced by passing vessels) will be relatively small while the effects of the discharge can be mitigated by design. Warning notices and chains would provide adequate safeguard.

## Conclusions of navigation studies

6.15 The principal conclusions of the navigation studies are:

- the Yare barrier will have a significant effect on port operations when it is closed but the impact of this effect on the economy of the port and the surrounding area is difficult to assess,

- it is possible that the Yare barrier could affect sedimentation patterns in the Haven when closed but further studies are required to show this,

- a reflected wave will occur when the Yare barrier is closed but the rise in water levels can be adequately controlled,

- navigation between the southern and northern parts of Broadland is affected at present by the low clearance below the road and old railway bridges at the mouth of the Bure,

- the Bure barrier will be closed only on tides which at present would interrupt navigation for at least 90% of Broadland craft,

- nevertheless additional temporary moorings should be provided seaward of the barrier site,

- the washland will have no significant impact on inland navigation.

## 7. COMPARISON OF OPTIONS

7.1 To assist in selecting which scheme to recommend for implementation, the impacts of each were assessed in terms of the key issues identified in Section 3. These assessments are compared in outline in Table 10 and discussed in more detail below. The table lists only the issues that are affected differently by the two schemes since it is these differences that need to be considered when making the selection.

7.2 The principal components of the two schemes are described in Section 2 but for convenience are summarised here also:

**Scheme 1 - Yare Barrier above Haven Bridge**

- barrier on the Yare, closed when high sea levels are predicted,
- Great Yarmouth floodwalls strengthened to prevent foundation failure and seepage and raised seaward of the barrier,
- Broadland floodbanks strengthened and raised as necessary,
- floodwalls and floodbanks raised in future to allow for settlement and sea level rise.

**Scheme 2 - Bure Barrier and Haddiscoe Island washland**

- barrier on the Bure, closed when high sea levels are predicted,
- washland at Haddiscoe Island, flooded when water levels in the Yare and Waveney are high,
- Great Yarmouth floodwalls strengthened to prevent foundation failure and seepage,
- Broadland floodbanks strengthened and raised as necessary.

- floodwalls, floodbanks and washland weirs raised in future to allow for settlement-and-sea level rise.

Both schemes will require a continued commitment to maintain floodwall and floodbank levels to guard against future settlement and sea level rise.

**Comparison of impacts on key issues**

**(i) Standard of defence**

7.3 Both schemes will provide and maintain the NRA's target standards of protection to all the currently defended areas of Broadland; the actual standards provided are discussed in more detail below. The question of whether these standards are justifiable will need to be discussed in detail with MAFF whichever scheme is selected. Some modifications to the recommended scheme may be required as a result of these discussions.

**(ii) Great Yarmouth**

7.4 The standard of defence to Great Yarmouth with either scheme will be no different from that provided at present. The security of the defence should be increased, however, as both schemes allow for the continued replacement of defective sheet piling and the prevention of seepage.

**(iii) Defended areas of Broadland**

7.5 Scheme 1 will protect all the defended areas of Broadland against events with return periods of up to 200 years or more. Scheme 2 will provide the same standard of protection to land adjacent to the Bure, Ant and Thurne and the NRA's target standards to the land adjacent to the Yare and Waveney. These standards give protection against events with return periods of up to 50 years for the Halvergate Triangle, 20 years for land subject to saline flooding and 5 years for land subject to freshwater flooding.

7.6 Both schemes allow for the existing flood banks to be strengthened, reducing seepage and the risk of breaching. It should be noted that in Scheme 2 it is this reduction in

the risk of breaching, rather than the washland, that provides the greater part of the improved security to land by the Yare and the Waveney. When the defences are over-topped, either at present or if a washland is built, the area of land flooded will be relatively limited provided the flood banks are not breached.

7.7 Both schemes allow for the continued protection of the flood banks against erosion.

**(iv) Undefended properties in Broadland**

7.8 Undefended properties in Broadland could be protected either directly, by providing floodbanks or walls to prevent water reaching them, or indirectly by preventing water levels in the rivers from rising. Neither scheme will provide direct protection to any currently undefended property nor will they have any effect on water levels caused by high river flows.

7.9 With Scheme 1 the barrier will be closed when water levels at Great Yarmouth are predicted to be higher than a critical level, probably about +1.8m OD, which occurs some 2 or 3 times each year. However the maximum levels within Broadland that can occur during more severe events than this are less than 0.4m higher than those that would occur when the critical level is just not reached (and the barrier is not closed). Therefore the barrier will not cause a large reduction in the maximum levels reached in Broadland although it will reduce the frequency of these levels occurring. Many undefended properties suffer from settlement and the security of these properties may be expected to deteriorate whether the Scheme 1 barrier is built or not. The barrier will not provide any security against future rises in sea level to undefended properties.

7.10 Scheme 2 will provide the same degree of security against flooding to properties beside the Bure, Ant and Thurne as Scheme 1. Water levels along the Yare and the Waveney will rise slightly higher during major events than the highest levels that would occur with Scheme 1 but will be up to 0.1m lower than the levels that would occur at present. As with Scheme 1, the additional security thus provided will be countered by any future settlement of the undefended properties. Scheme 2 will also provide no security against future rises in sea level.

### (v) Settlement and sea level rise

7.11 Both schemes will require regular raising of the floodbanks to guard against the effects of future settlement and sea level rise. A combined effect of up to about 40mm/yr can be accommodated in this way. If the effect is much greater than this either the interval between successive raisings will be unrealistically short or the height of raising on each occasion will be greater than the banks can safely sustain.

7.12 Future rises in sea level will lead to salt water penetrating further up the Broadland rivers than at present. This increased intrusion will occur uniformly on all tides and therefore neither scheme will be able to control it without completely altering the tidal regime within Broadland.

### (vi) Scheme costs

7.13 The total costs of each scheme over 50 years, undiscounted and discounted at 6%, are given in Table 11. These costs include maintenance, periodic raising of flood banks to allow for settlement and sea level rise, the effect on the port and other ongoing works. These works (erosion protection to the flood banks and replacement of the Great Yarmouth defences) are itemised separately. The economic costs and benefits of each scheme are summarised in Table 12.

7.14 The costs of each scheme during construction (assumed to take 5 years) are given in Table 13. These costs include both the cost of the construction work itself and the costs of purchasing land and compensation for loss of crops.

### (vii) Port and related industry

7.15 Scheme 1 will have a considerable effect on the port and port-related activities as the barrier will prevent the passage of vessels upstream and alter flow patterns at the mouth of the Haven when it is closed. The raised floodwalls seaward of the barrier will make loading and unloading of vessels more difficult on certain quays. Any activities upstream of the Haven Bridge will suffer considerable disruption during the construction period, to the extent that the one operator with a quay in this area may prefer to move to one of the unoccupied quays further downstream. The reach from the Haven Bridge to the Breydon Bridge will be more difficult to navigate.

7.16 It is extremely difficult to determine the impact of the these effects on the economy of the port and the surrounding area. A relatively conservative view, taking only the direct costs to the port into account, gives a figure of between £6m and £7m over the 50 year life of the scheme, equivalent to about £3.6m when discounted at 6%. The more pessimistic view taken by the Port Authority, which assumes that all oil and gas-related trade and associated industry will immediately be lost, gives an annual loss of about £280m with a discounted value of about £4700m over 50 years. The true figures are probably somewhere between these limits but the more conservative (lower) ones have been used in the cost estimates given in Tables 11 and 12.

7.17 The impact of Scheme 2 on the port and port-related activities is negligible.

**(viii) Agriculture**

7.18 Apart from Haddiscoe Island, the effect of both schemes on agriculture in Broadland will be very similar. The principal effect will be the avoidance of flood damage due to the greatly reduced risk of breaching. The difference in standard between the two schemes has a relatively small effect on the value of the damage avoided; over 50 years this difference in value is estimated to total about £5.7m, equivalent to about £1.4m when discounted. In practice these figures over-estimate simple agricultural losses since they include damage to property and infrastructure.

7.19 The other important effect will be the reduction in seepage through the banks and, in some areas, the separation of the soke dyke from the internal water distribution system that will result from the bank strengthening work that is carried out. This will reduce the quantity of salt entering the dykes and so improve the potability of the water used for drinking by the stock on the land.

7.20 Scheme 1 will have no effect on agriculture in Haddiscoe Island but Scheme 2 may reduce the area of land available for grazing. There will be a drop in the quality of the grazing in part of the remaining area due to the frequency of flooding with salt water, although the studies carried out to date indicate that this is likely to be relatively small.

### (ix) Tourism and recreation

7.21 Neither of the two schemes is likely to have a significant impact on tourism or recreation in Broadland. Both schemes will, however, require large volumes of material to strengthen the floodbanks and the borrow pit from which this material is obtained could provide opportunities for recreation once the work has been completed.

7.22 Scheme 2 will give better control of saline intrusion in the Bure during surge events which could prevent some fish kills and therefore improve angling. As discussed below it will not, however, be able to prevent the intrusions due to low river flows that occur during the summer and early autumn.

### (x) Inland navigation

7.23 The impact of Scheme 1 on inland navigation will be negligible.

7.24 Scheme 2 will have a limited effect on boats passing between the northern rivers (the Bure, Ant and Thurne) and the southern ones (the Yare and the Waveney) when the Bure barrier is closed. This is because few boats are currently able to pass under the road and railway bridges at the barrier site when water levels are as high as they will be at the times the barrier is closed. Nevertheless for safety reasons the scheme allows for the construction of temporary moorings seaward of the barrier for use when it is closed since there are very few available in this area at present.

### (xi) Natural resources

7.25 Neither scheme will cause any long-term changes to the pattern of river flows or water levels and so will not threaten the diversity of Broadland's natural resources. Both schemes will provide the opportunity for a review of the habitats by each floodbank as part of the detailed design process and the potential for modifying these habitats, in the soke dyke, on the bank itself and on the rand, when the banks are strengthened. Both schemes will reduce the seepage of salt water through the floodbanks which will protect existing freshwater dyke systems.

7.26 Scheme 2 will be considerably more effective at reducing saline intrusion caused by high water levels in the Bure system, where the majority of the resources threatened by such intrusion are located, than Scheme 1. Scheme 2 will also provide an opportunity to create in Haddiscoe Island an area which will be secured against future changes in ownership and managed to promote its conservation interest. This will enhance the environmental diversity of Broadland.

**(xii) Landscape**

7.27 Both schemes will affect the landscape of Broadland as a result of the bank strengthening and raising that will be carried out. Both schemes will also affect the townscape in Great Yarmouth although the large structure of the Yare barrier of Scheme 1, with its vertical lift gate, will have a much greater impact than the smaller and lower Bure barrier of Scheme 2.

7.28 The diversity of the landscape in Haddiscoe Island will be increased by the washland of Scheme 2 although its overall character will be maintained. All possible steps will be taken to reduce the visual impact of the overflow weirs and pumping stations associated with the washland.

**(xiii) Saline intrusion**

7.29 The saline intrusion studies demonstrated clearly that Scheme 2 will be more effective than Scheme 1 at controlling saline intrusion on the Bure, where it is of greatest concern. In practice, however, this control can only be used to restrict intrusion caused by relatively high sea levels. It cannot be used to restrict intrusion caused by very low river flows as this would require the barrier to be closed on successive tides for relatively long periods of time, not only interfering with inland navigation but also reducing the natural water level variations in the river and therefore adversely affecting the inundation of inter-tidal vegetation and the flushing of off-river broads.

**Scheme appraisal**

7.30 On the basis of the comparisons described above and summarised in Table 10, Scheme 2 provides considerably more advantages than does Scheme 1. It provides

an acceptable standard of protection throughout Broadland and although this standard is not as high by the Yare and the Waveney as that provided by Scheme 1 the flooding that will result during major events will not be extensive. It has no impact on the port or port-related activities and limited impact on agriculture, tourism and recreation. It provides an opportunity for the development of an area of potentially high conservation interest on Haddiscoe Island while retaining the greater part of the existing grazing there and can be used to control saline intrusion in the Bure caused by relatively high sea levels. It has little impact on inland navigation. Finally, it will cost some £9m less during the initial 5 year construction period and about the same over the 50 year life of the scheme (whether the figures are discounted or not). This may be compared to the £5.7m (£1.4m when discounted) estimated as the increase in the damage due to flooding that will result if Scheme 2 rather than Scheme 1 is implemented.

7.31 The Task Group therefore has therefore concluded that of the two schemes given to it to study, Scheme 2 should be selected for implementation.

## 8. CONCLUSIONS

8.1 The conclusions of the Task Group's studies may be summarised as follows:

1. There is a serious risk to people and property from flooding in Broadland.

2. There is a serious risk to areas of conservation and agricultural interest from flooding and saline intrusion in Broadland rivers.

3. The most appropriate means of providing cost-effective and technically and environmentally acceptable protection from flooding is to raise and strengthen the existing embankments and at the same time construct a barrier across the Bure, and a washland at Haddiscoe Island.

4. The barrier on the Bure should be operated to restrict saline intrusion in this river during severe events but not to prevent long-term regime changes. Further complementary measures (including low flow and river management) would be needed for this. The costs of these complementary measures would not be attributable to flood defence.

# 9. RECOMMENDATIONS

9.1 The recommendations of the Task Group are as follows:

A. **Proposed defence strategy**

1. Construct a surge exclusion barrier across the Bure and a washland scheme at Haddiscoe Island.
2. Raise and strengthen the existing flood embankments in Broadland.
3. Continue to replace and extend the works needed to limit erosion of the riverbanks.
4. Continue to repair and replace the existing hard defences to Great Yarmouth.

The costs of these works are summarised on page 41.

B. **Immediate actions**

1. Submit proposed defence strategy to MAFF for approval.
2. Establish the strategy to be followed to obtain planning approval.
3. Arrange for further studies to be undertaken and Planning Application and Public Inquiry submissions to be prepared.

C. **Further studies**

1. Carry out hydraulic model studies to examine:

   - water movements and sediment patterns local to the barrier (physical model),
   - sediment movements in the lower reaches of the Yare and Bure and through the Haven (existing 1-D mathematical model, extended and modified as necessary),
   - water levels and saline intrusion throughout the tidal reaches of Broadland to determine detailed design parameters and acceptable barrier operating rules.

2. Carry out environmental studies to examine:

- impact of proposed barrier operating rules and the resulting changes in saline intrusion on the ecology of the Bure system.
- impact of proposed washland design and operation on the ecology of the Yare and the Waveney systems.
- impact of embankment construction work on the Broadland environment and to set guidelines for identifying enhancement opportunities during detailed design,
- methods of managing saline washland areas to meet differing agricultural and conservation aims.

3. Determine surge tide warning criteria needed for safe operation of the barrier and identify any changes to the existing Flood Emergency Procedures required.

4. Carry out site investigations for the major structures proposed (barrier, washland overflow weirs, washland pumping stations).

5. Prepare outline designs and Environmental Statement for all works proposed for inclusion in submission to Public Enquiry.

The cost of these studies is estimated to be £500,000.

D. **Planning procedures**

1. Prepare and submit Outline Planning Application.
2. Brief counsel and decide strategy for Public Inquiry.
3. Undertake further consultations as necessary.
4. Prepare submission for and attend Public Inquiry.

The cost of the Public Inquiry is estimated to be £500,000.

E. Management

1. Establish study group to ensure that feasible environmental enhancement opportunities are identified during outline and detailed design.
2. Review existing inspection, monitoring and maintenance procedures and establish comprehensive monitoring programme.
3. Investigate complementary strategies for control of saline intrusion in Broadland, including low flow and river management.

9.2 The engineering costs of the recommended scheme are estimated to be:

| | | Total cost over 50 years | |
|---|---|---|---|
| | Cost of new works | Undiscounted | Discounted at 6% |
| Barrier | 3.4 | 4.7 | 3.0 |
| Washland | 9.1 | 15.6 | 8.5 |
| Floodbanks | 22.3 | 95.4 | 33.6 |
| Great Yarmouth defences | | 66.7 | 20.0 |
| Erosion protection | | 107.7 | 33.5 |
| TOTAL | 37.6 | 290.1 | 98.6 |

Note that the cost of the new works are for an assumed 5 year construction period. The costs of the further studies and the Public Inquiry are additional.

## TABLE 1

## SCHEMES DEFENDING ALL BROADLAND

| Reference | Name | Reasons for elimination |
|---|---|---|
| Option 2.1 | Sustain existing defences | Failure inevitable as no allowance for future settlement/sea rise |
| Option 2.2 | Sustain existing standards | Existing standards considered inadequate |
| Option 3 | Raise embankments | Doubts about engineering feasibility due to poor foundation conditions<br><br>Water levels raised during floods, increasing damage to undefended properties, eg Brundall, Wroxham<br><br>Landscape implications of extensive raising |
| Option 5.1 | Yare barrier - harbour mouth | High cost<br><br>Impact on port activities during construction<br><br>Complete closure of port during operation |
| Option 5.2 | Yare barrier - ferry crossing | High cost<br><br>Impact on port activities during construction<br><br>Closure of most operating wharfs during operation |
| Option 5.3 | Yare barrier - Haven Bridge | Selected for further consideration |

## TABLE 2

## SCHEMES DEFENDING BURE, ANT AND THURNE

| Reference | Name | Reasons for elimination |
|---|---|---|
| Option 4 | Bure barrier | Selected for further consideration |
| Option 6.1 | Washland - Bure | More expensive than Option 4 (Bure barrier)<br><br>Less effective at preventing saline intrusion<br><br>Land cannot continue to be used for arable agriculture<br><br>Lower standard of protection than Option 4 (Bure barrier) |

## TABLE 3

## SCHEMES DEFENDING YARE AND WAVENEY

| Reference | Name | Reasons |
|---|---|---|
| Option 5.4 | Yare barrier - East Breydon Water | More expensive than Option 6.3<br>Impact on tidal conditions in Breydon Water |
| Option 5.5 | Yare barrier - West Breydon Water | More expensive than Option 6.3<br>Landscape implications<br>Extensive bank raising needed by Breydon Water |
| Option 6.2 | Washland - South Breydon Water | More expensive than Option 6.3<br>Increased velocities through Haven |
| Option 6.3 | Washland - Haddiscoe Island | Selected for further consideration |

## TABLE 4

## SALINE INTRUSION IN BROADLAND RIVERS

| | Intrusion of 0.5 g/l salinity beyond given location | |
|---|---|---|
| Location | Frequency (% of tides) | Number occasions each year |
| Bure | | |
| Acle Bridge | 1.9 | 13.6 |
| Thurne Mouth | 0.03 | 2.2 |
| Yare | | |
| Reedham | 68 | 478 |
| Rockland Broad | 1.4 | 10 |
| Waveney | | |
| St Olaves | 57 | 406 |
| Oulton Broad | 3.4 | 24 |

## TABLE 5

## SALINE INTRUSION IN BURE

| | | Intrusion of 0.5 g/l beyond | | | |
|---|---|---|---|---|---|
| | | Acle Bridge | | Thurne Mouth | |
| Season | No of tides | Frequency (% of tides) | No occasions each year | Frequency (% of tides) | No occasions each year |
| Considering all flows | | | | | |
| Spring | 118.1 | 0.16 | 0.2 | 0 | 0 |
| Summer | 238.1 | 3.18 | 7.6 | 0.43 | 1.0 |
| Autumn | 118.1 | 3.69 | 4.4 | 0.90 | 1.1 |
| Winter | 232.3 | 0.61 | 1.4 | 0.06 | 0.1 |
| TOTAL | 706.6 | | 13.6 | | 2.2 |
| Excluding flows less than 1.0m$^3$/s | | | | | |
| Spring | 118.1 | 0.12 | 0.1 | 0 | 0 |
| Summer | 238.1 | 0 | 0 | 0 | 0 |
| Autumn | 118.1 | 0.17 | 0.2 | 0.07 | 0.1 |
| Winter | 232.3 | 0.47 | 1.1 | 0.06 | 0.1 |
| TOTAL | 706.6 | | 1.4 | | 0.2 |

## TABLE 6

## EFFECT OF BARRIERS ON SALINE INTRUSION

| | Saline intrusion (0.5 g/l) during typical surge (km) | |
|---|---|---|
| | In Bure | In Yare |
| With no barrier | 34.0 | 28.2 |
| With Yare barrier | | |
| Closed at +0.9m OD | 22.6 | 22.6 |
| Closed at +1.2m OD | 23.8 | 24.5 |
| With Bure barrier | | |
| Closed at +0.9m OD | 19.5 | 28.2 |
| Closed at +1.2m OD | 21.5 | 28.2 |

Notes: Saline intrusion measured as km upstream of the barrier site in each river. Corresponding distances are:

| | |
|---|---|
| Acle Bridge | 18.5 km upstream of Bure barrier |
| Thurne Mouth | 22.8 km upstream of Bure barrier |
| Reedham | 24.2 km upstream of Yare barrier |
| Rockland Broad | 28.2 km upstream of Yare barrier |

## TABLE 7

## EXISTING NAVIGATION RESTRICTIONS ON BURE

| Boat air draft | | Water level preventing passage under bridges | Equivalent water level at harbour mouth | High tides exceeding this level |
|---|---|---|---|---|
| (ft) | (m) | (mOD) | (mOD) | (%) |
| 7 | 2.13 | 1.04 | 1.24 | 5 |
| 8 | 2.44 | 0.73 | 0.93 | 25 |
| 12 | 3.66 | -0.49 | -0.29 | 99.9 |

Note: Soffit level of road and rail bridges at mouth of Bure assumed to be +3.17m OD

## TABLE 8

## BURE BARRIER
## FREQUENCY OF CLOSURE FOR FLOOD DEFENCE PURPOSES

| | Number of closures in 10 year record | | | | |
|---|---|---|---|---|---|
| Critical level (mOD) | Spring | Summer | Autumn | Winter | Total |
| +1.6 | 7 | 1 | 11 | 54 | 73 |
| +1.7 | 3 | 1 | 9 | 31 | 44 |
| +1.8 | 2 | 0 | 4 | 18 | 24 |
| +1.9 | 2 | 0 | 2 | 14 | 18 |

Note: Data obtained from water level records for period 1982-1992

## TABLE 9

## BURE BARRIER
## FREQUENCY OF CLOSURE FOR SALINE INTRUSION PURPOSES

| | Number of saline intrusion events in 10 year record associated with tides given level | | | | |
|---|---|---|---|---|---|
| Tide level (mOD) | Spring | Summer | Autumn | Winter | Total |
| +1.2 | 2 | 6 | 12 | 14 | 34 |
| +1.8 | 1 | 0 | 3 | 12 | 16 |
| Difference | 1 | 6 | 9 | 2 | 18 |

Notes:
1. Data obtained by combining probability of given river flow with probability of given tide level.
2. All combinations of river flow and tide level included.
3. Saline intrusion events defined as occasions when hydraulic model predicts salinity >0.5 g/l extending upstream of Acle Bridge.

## TABLE 10

## COMPARISON OF SCHEMES

| Issue | Scheme 1<br>Barrier at Haven Bridge | Scheme 2<br>Bure barrier & Haddiscoe Island washland |
|---|---|---|
| (i) Standard of defence | Achieves target standard | Achieves target standard |
| (ii) Great Yarmouth | Standard as at present<br>Security increased | Standard as at present<br>Security increased |
| (iii) Defended areas of Broadland | By Bure : 1 in 200 year standard<br>By Yare : 1 in 200 year standard | By Bure : 1 in 200 year standard<br>By Yare : Target standards, ie<br>Freshwater flooding 1 in 5 years<br>Saltwater flooding 1 in 20 years<br>Halvergate Triangle 1 in 50 years |
| (iv) Undefended properties in Broadland | Peak levels reduced by <0.4m<br>Frequency of peak levels reduced<br>Effects of settlement, sea level rise unchanged | Peak levels reduced by <0.2m<br>Effects of settlement, sea level use unchanged |
| (v) Settlement and sea level rise | Will accommodate combined rate of 40mm/year | Will accommodate combined rates of 40mm/year |
| (vi) Scheme costs | Total engineering costs over 50 years : £304.4M<br>Discounted at 6% : £110.0M<br>Cost of new works in first 5 years : £45.0M | Total engineering costs over 50 years : £294.8M<br>Discounted at 6% : £101.2M<br>Cost of new works in first 5 years : £37.6M |
| (vii) Port and related industry | Major impact on port during and after construction | Negligible impact on port |
| (viii) Agriculture | Value of flood damage avoided over 50 years<br>Undiscounted : £232.4<br>Discounted at 6% : £90.4 | Value of flood damage avoided over 50 years<br>Undiscounted : £227.7<br>Discounted at 6% : £89.0 |
| (ix) Tourism and recreation | Negligible impact | Negligible impact |
| (x) Inland navigation | Negligible impact | Negligible additional restriction as barrier closed only when existing bridges affect navigation anyway |
| (xi) Natural resources | Small impact on freshwater dykes and banks<br>Small reduction in saline intrusion in Bure | Small impact on freshwater dykes and banks<br>Significantly greater reduction in saline intrusion in Bure<br>Improved diversity by creation of washland |
| (xii) Landscape | Major impact on Great Yarmouth<br>Limited impact in Broadland | Limited impact on Great Yarmouth<br>Limited impact on Broadland<br>Increased diversity in Haddiscoe Island |
| (xiii) Saline intrusion | Small reduction in Bure | Significantly greater reduction in Bure |

## TABLE 11

## COMPARISON OF COSTS OVER 50 YEARS

| | Scheme 1 - Barrier at Haven Bridge | | | | Scheme 2 - Bure barrier & washland at Haddiscoe Island | | | |
|---|---|---|---|---|---|---|---|---|
| | £ million (undiscounted) | | £ million (discounted at 6%) | | £ million (undiscounted) | | £ million (discounted at 6%) | |
| | Item | Total | Item | Total | Item | Total | Item | Total |
| Engineering costs of proposed scheme | | | | | | | | |
| Embankments | 92.31 | | 31.50 | | 95.41 | | 33.62 | |
| Barriers | 26.90 | | 17.79 | | 4.74 | | 2.99 | |
| Washlands | .00 | | .00 | | 15.53 | | 8.54 | |
| Great Yarmouth (see Note 1) | .66 | 119.87 | 2.13 | 51.42 | - | 115.68 | -.04 | 45.11 |
| Non-engineering costs of proposed scheme | | | | | | | | |
| Agricultural land purchase | .48 | | .19 | | 2.00 | | 1.39 | |
| Farm relocation | .00 | | .00 | | .08 | | .07 | |
| Agricultural disruption | 2.51 | | .89 | | 2.51 | | .89 | |
| Urban land purchase | .38 | | .30 | | .19 | | .15 | |
| Port disruption | .99 | | .26 | | - | | - | |
| Loss of trade | 5.75 | 10.11 | 3.37 | 5.01 | - | 4.78 | - | 2.50 |
| Other programmed engineering costs | | | | | | | | |
| Erosion protection to embankments | 107.67 | | 33.53 | | 107.67 | | 33.53 | |
| Replacement of Great Yarmouth defences | 66.71 | 174.38 | 20.04 | 53.57 | 66.71 | 174.38 | 20.04 | 53.57 |
| TOTAL | 304.36 | 304.36 | 110.00 | 110.00 | 294.84 | 294.84 | 101.18 | 101.18 |

Note:

1. Discounted Great Yarmouth costs show effect of bringing forward (Scheme 1) or delaying (Scheme 2) the programmed replacement work
2. Costs revised to take account of Task Group conclusions

## TABLE 12

## SUMMARY OF COSTS AND BENEFITS

| | Scheme 1 | | Scheme 2 | |
|---|---|---|---|---|
| | Undiscounted | Discounted (6.0%) | Undiscounted | Discounted (6.0%) |
| Considering Broadland only | | | | |
| Losses if nothing done (Option 1) | 233.55 | 91.42 | 233.55 | 91.42 |
| Losses with this option | 1.21 | 1.06 | 5.88 | 2.41 |
| Benefit of this option | 232.34 | 90.36 | 227.67 | 89.01 |
| Engineering costs of scheme | 119.87 | 51.42 | 115.68 | 45.11 |
| Non-engineering costs of scheme | 10.11 | 5.01 | 4.78 | 2.50 |
| Erosion protection to embankments | 107.67 | 33.53 | 107.67 | 33.53 |
| Cost of this option | 237.65 | 89.96 | 228.13 | 81.14 |
| Ratio of benefit : cost | .98 | 1.00 | 1.00 | 1.10 |
| Considering Broadland & Great Yarmouth | | | | |
| Losses if nothing done (Option 1) | 842.24 | 222.49 | 842.24 | 222.49 |
| Losses with this option | 1.21 | 1.06 | 5.88 | 2.41 |
| Benefit of this option | 841.03 | 221.43 | 836.36 | 220.08 |
| Costs of Broadland defences | 237.65 | 89.96 | 228.13 | 81.14 |
| Costs of Great Yarmouth defences | 66.71 | 20.04 | 66.71 | 20.04 |
| Cost of this option | 304.36 | 110.00 | 294.84 | 101.18 |
| Ratio of benefit : cost | 2.76 | 2.01 | 2.84 | 2.18 |

Note: Amenity benefits from contingent valuation study not included in table above. They are estimated to have a total value of £228M and a discounted value of £49M over the 50 years

| Including recreation and amenity benefits | Scheme 1 | | Scheme 2 | |
|---|---|---|---|---|
| | Undiscounted | Discounted (6.0%) | Undiscounted | Discounted (6.0%) |
| Considering Broadland only | | | | |
| Ratio of benefit : costs | 1.94 | 1.55 | 2.00 | 1.70 |
| Considering Broadland & Great Yarmouth | | | | |
| Ratio of benefit : cost | 3.51 | 2.46 | 3.61 | 2.66 |

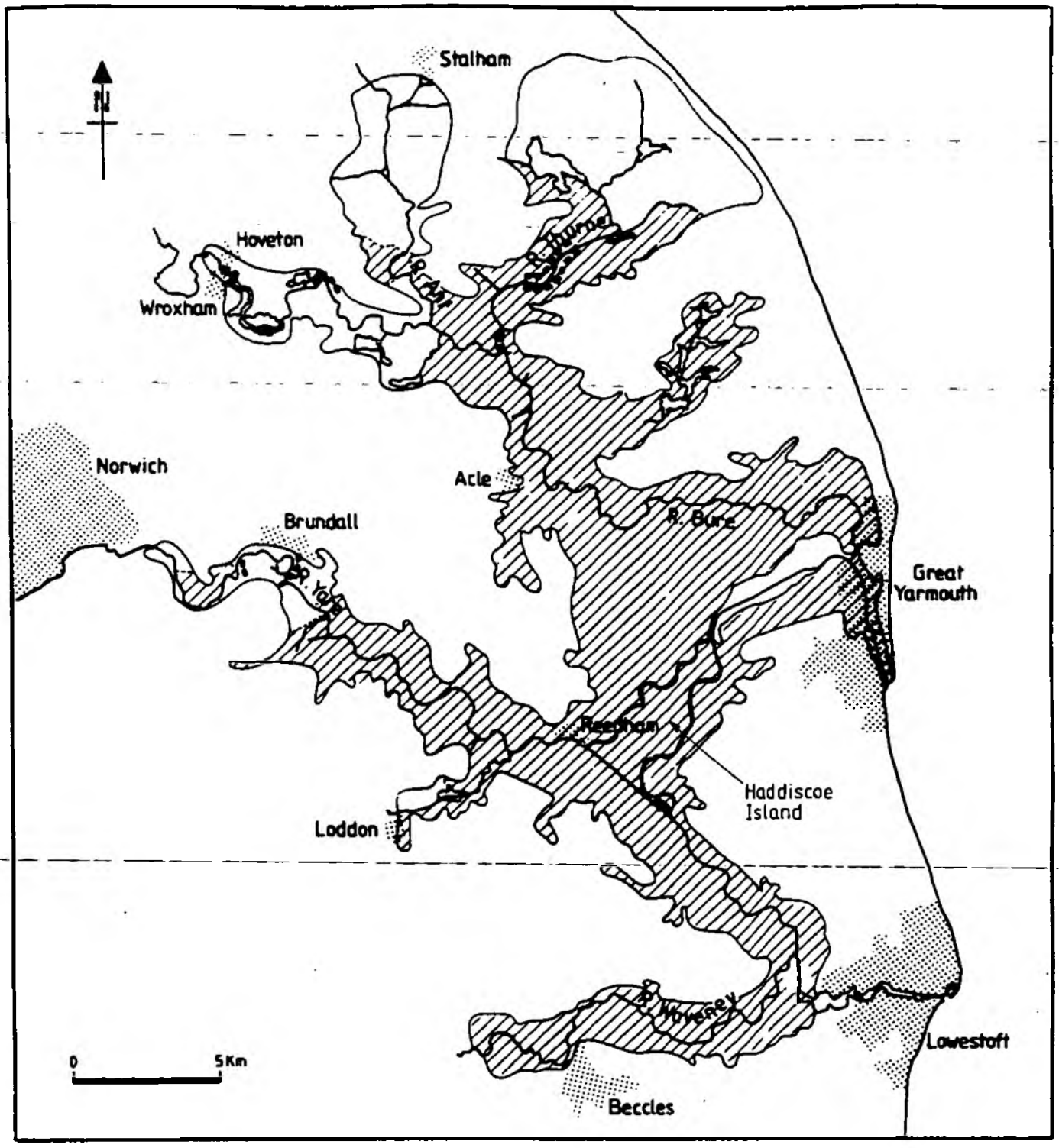
## TABLE 13

## COMPARISON OF COSTS DURING 5 YEAR CONSTRUCTION PERIOD

| Item | Scheme 1 (£M) | Scheme 2 (£M) |
|---|---|---|
| Engineering costs | | |
| Embankments | 19.8 | 22.3 |
| Barrier | 21.2 | 3.4 |
| Washland | - | 9.1 |
| Great Yarmouth | 2.6 | - |
| Other direct costs | | |
| Land purchase | 0.6 | 1.9 |
| Land-owner compensation | 0.8 | 0.9 |
| TOTAL | 45.0 | 37.6 |

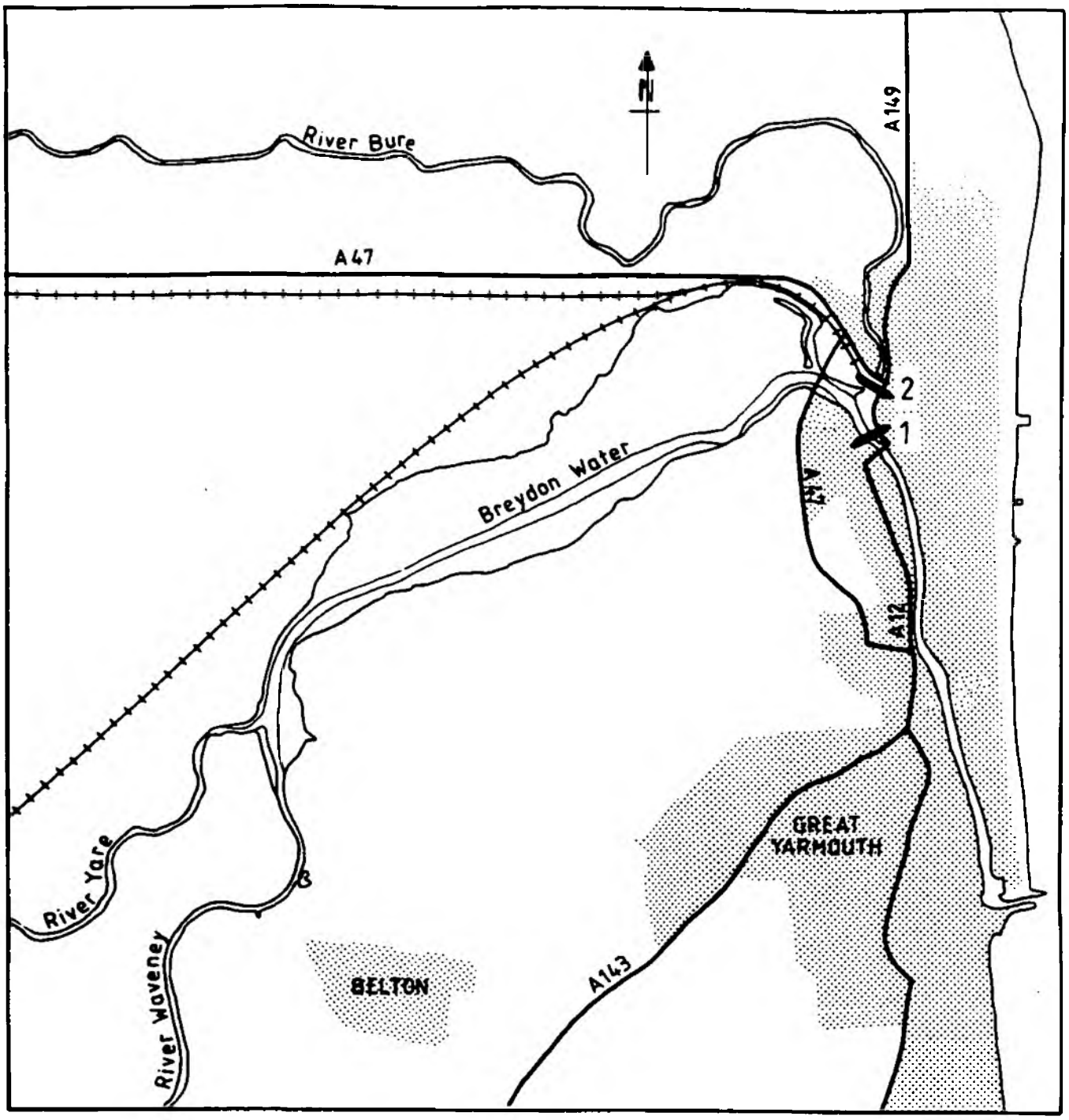
Notes:

1. Construction period of 2 years assumed for barriers and 5 years for embankments raising
2. Ongoing costs (eg bank erosion costs, maintenance of Great Yarmouth defences) not included
3. No allowance included for disruption to port operations
4. All costs at 1992 prices
5. Costs revised to take account of Task Group conclusions



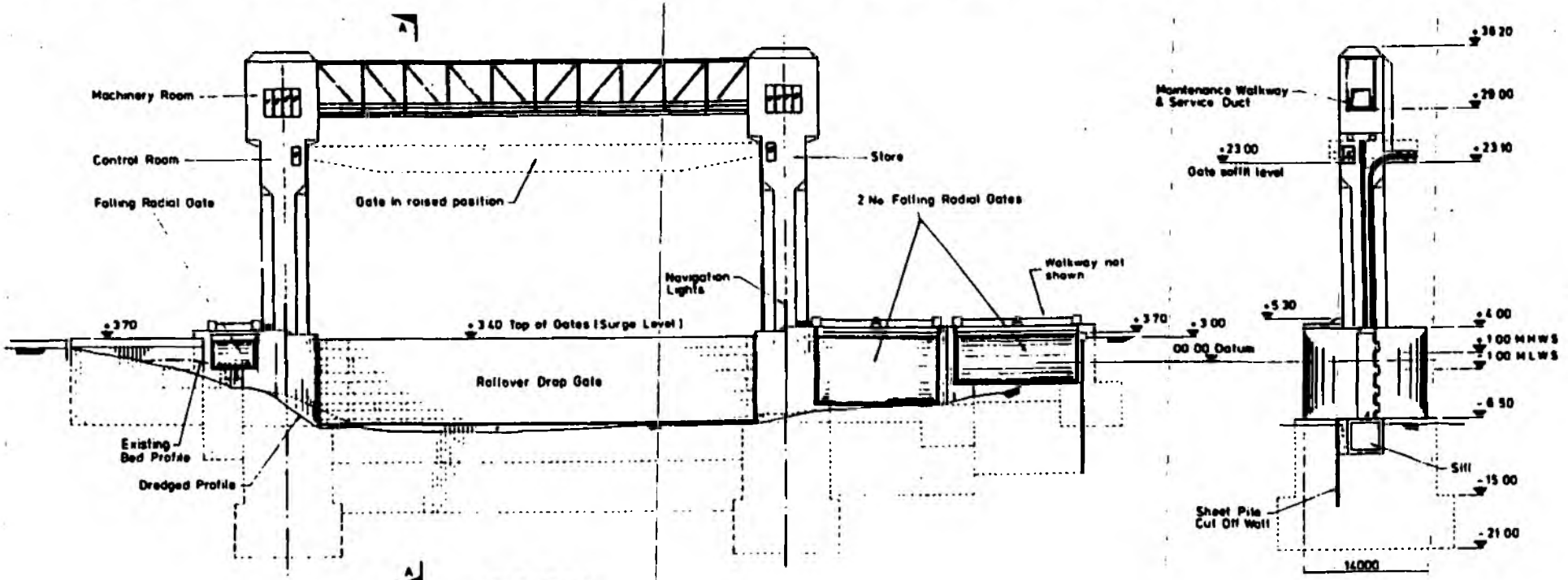

THE STUDY AREA

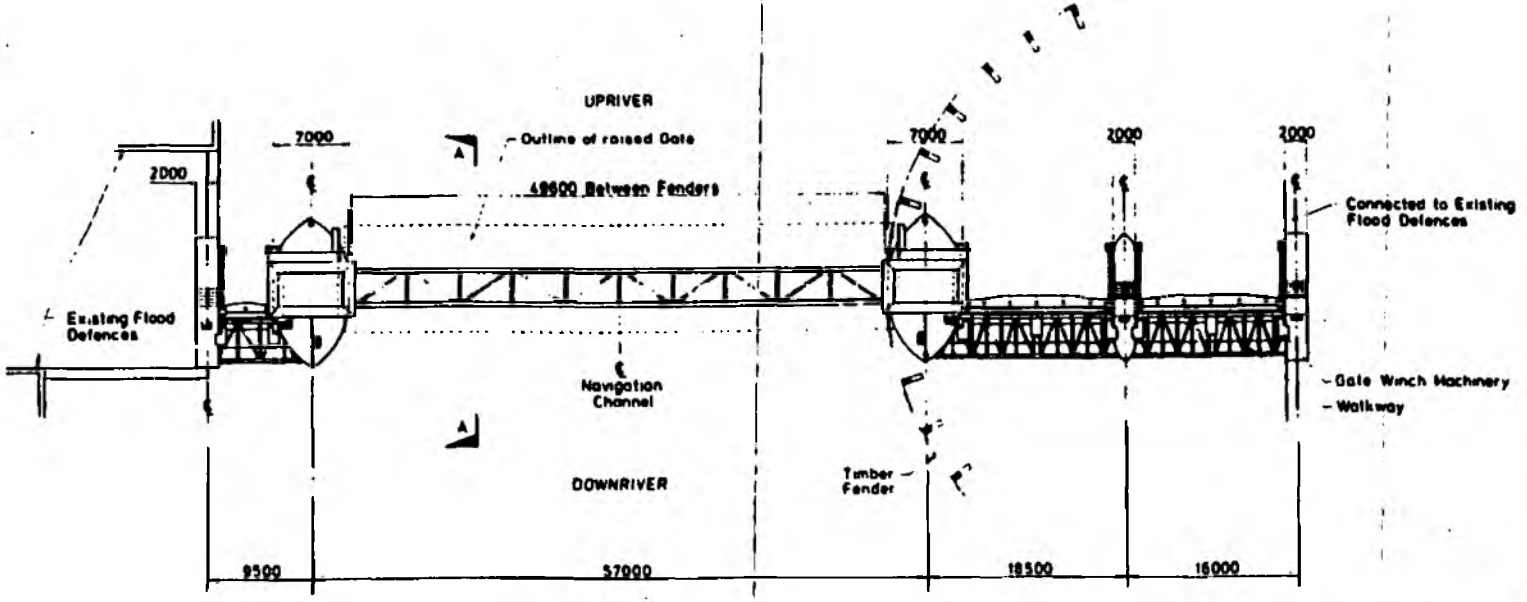
Figure 1




Scheme 1 – Yare barrier
Scheme 2 – Bure barrier

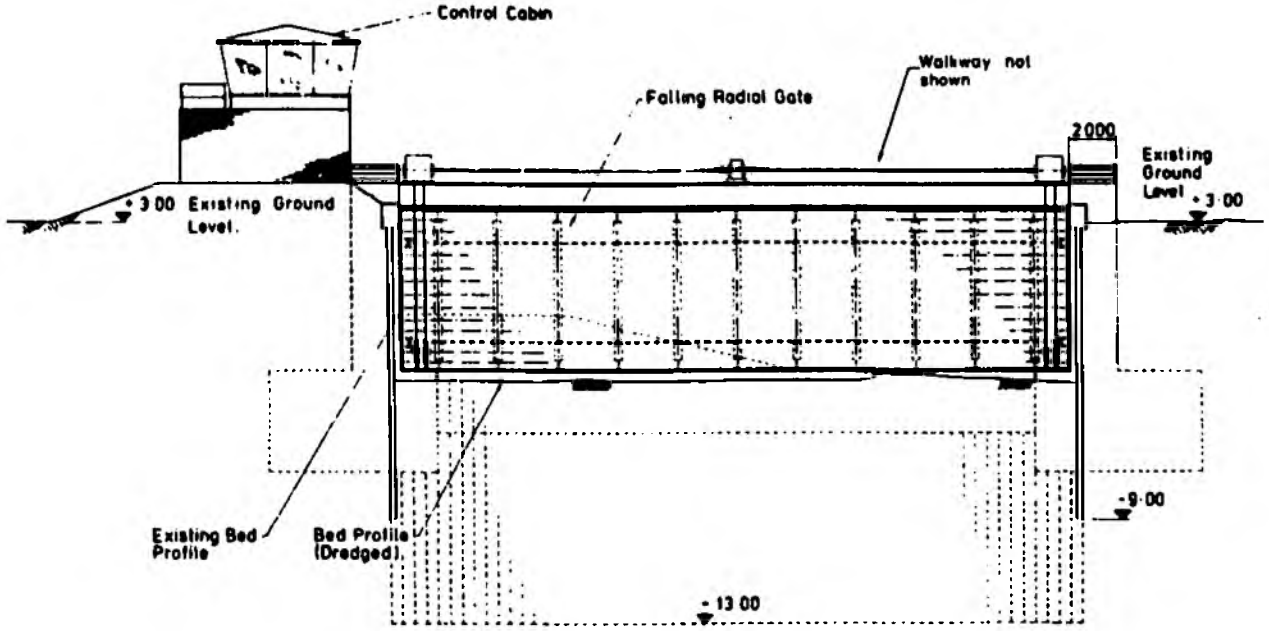
BARRIER LOCATIONS
Figure 2



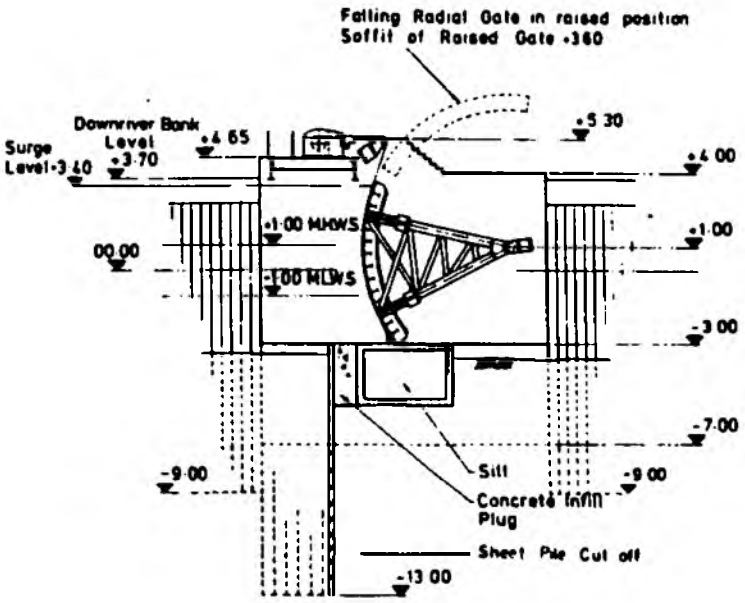




NOT TO SCALE

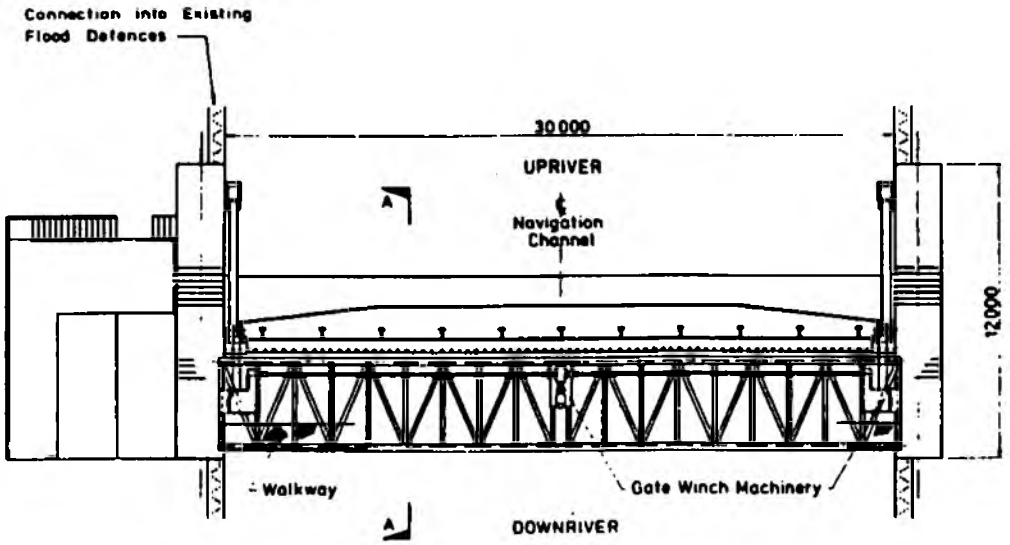
SCHEME 1
YARE BARRIER
GENERAL ARRANGEMENT
Figure 3




ELEVATION



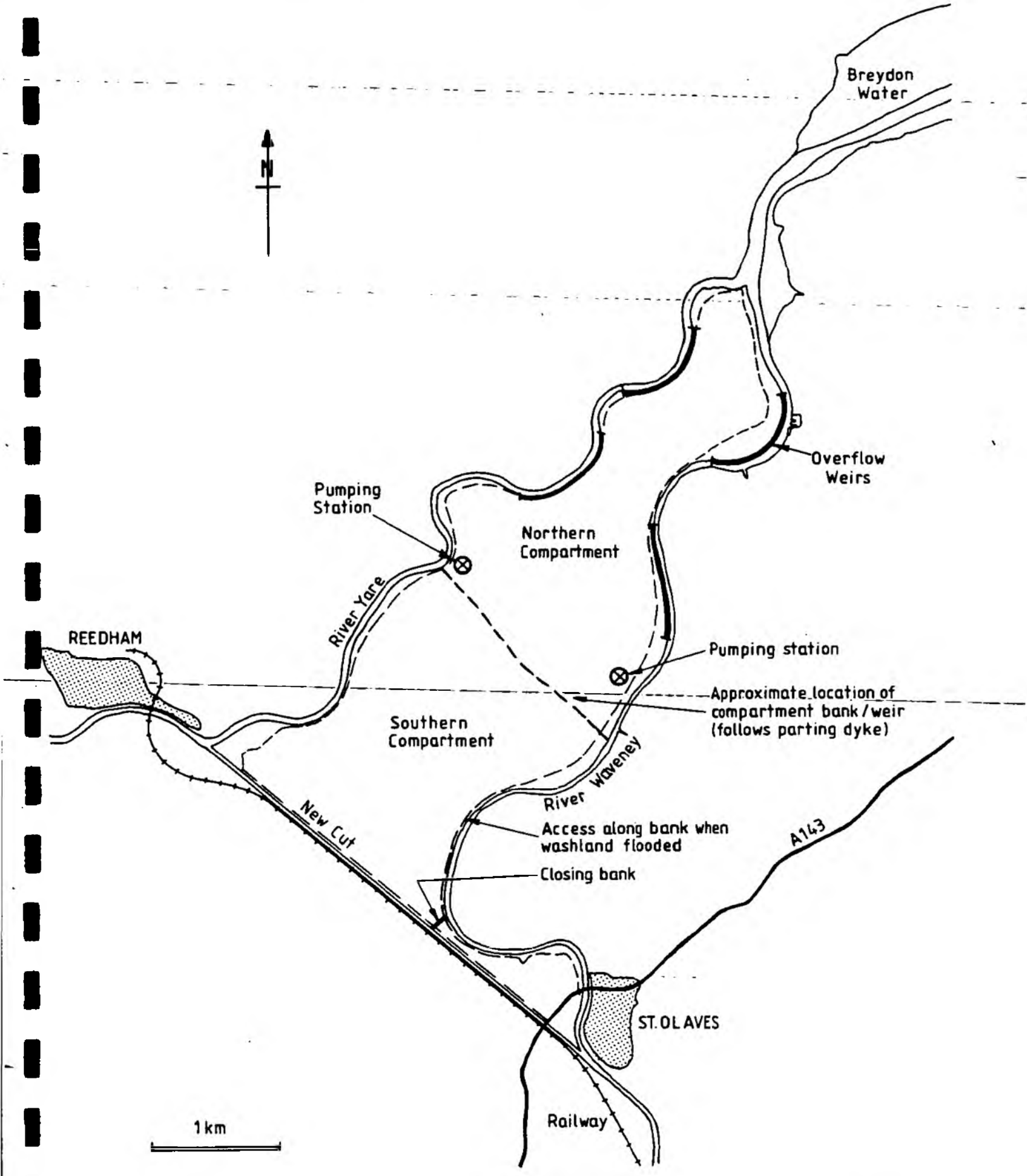

SECTION A-A



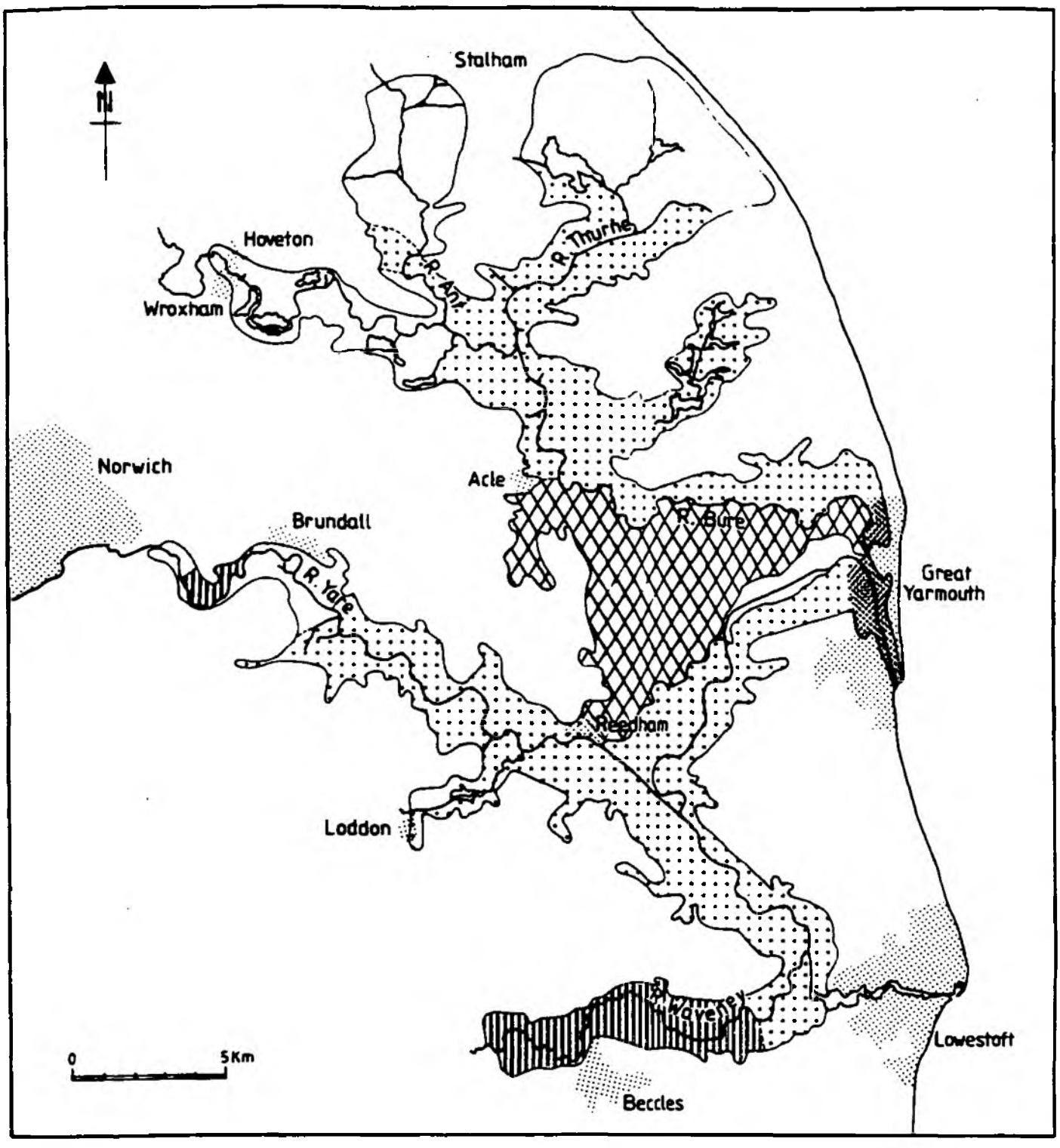

PLAN

NOT TO SCALE

SCHEME 2
BURE BARRIER
GENERAL ARRANGEMENT
Figure 4




SCHEME 2
HADDISCOE ISLAND WASHLAND
Figure 5



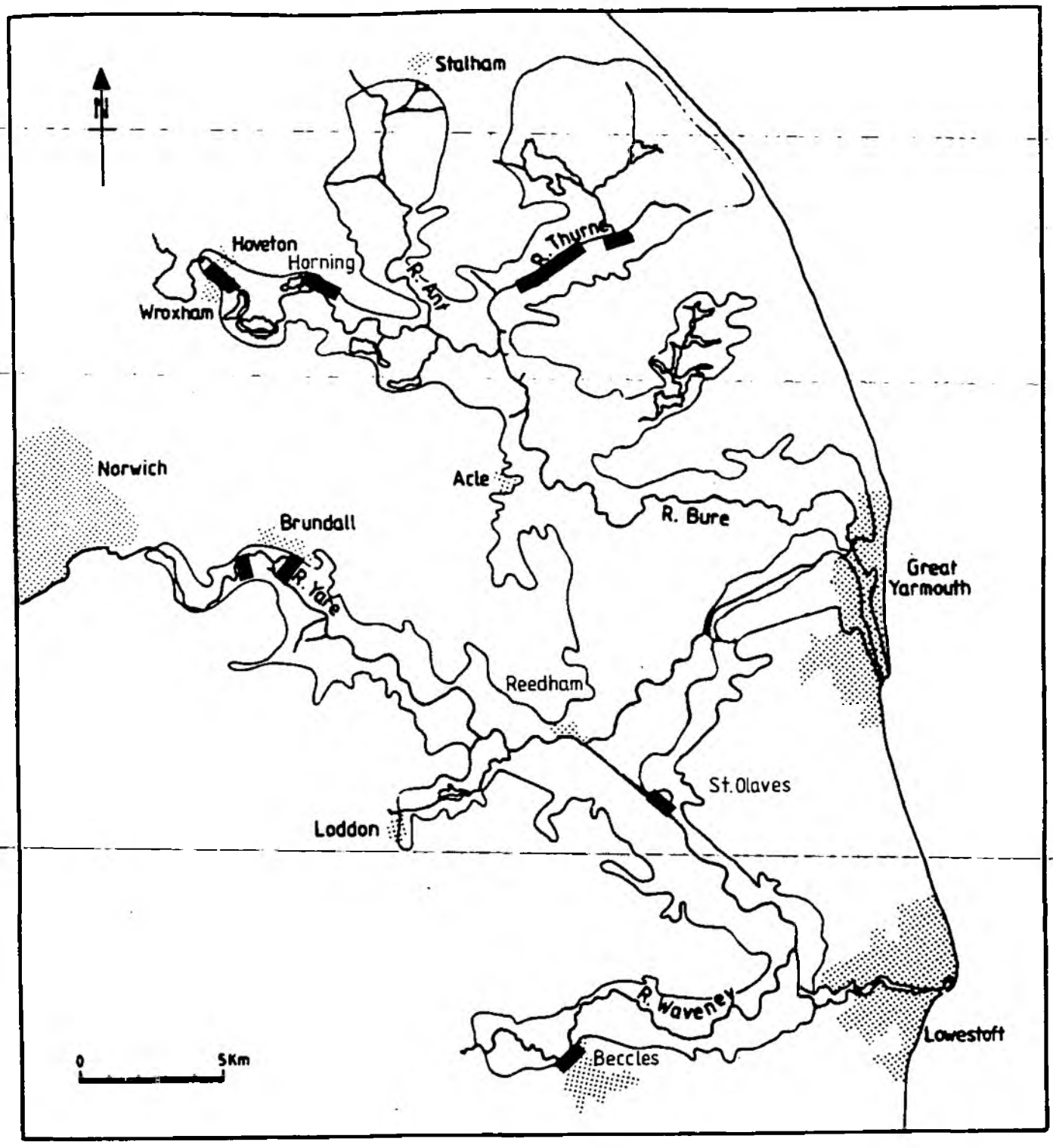

Study boundary (land below 3·0m OD)

TARGET STANDARDS OF DEFENCE (within study boundary)

| | | |
|---|---|---|
| Freshwater flooding | 1 in 5 | years |
| Saline flooding | 1 in 20 | years |
| Saline flooding | 1 in 50 | years |
| Urban areas | 1 in 200 | years |

TARGET STANDARDS OF DEFENCE

Figure 6




Study area (land below 3·0 m OD)

Undefended properties

LOCATIONS OF
UNDEFENDED PROPERTIES

**Figure 7**