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ENVIRONMENT AGENCY
Anglian Region

# SUFFOLK ESTUARINE STRATEGIES

## RIVER BLYTH

## STRATEGY REPORT
## Volume 2 Appendices

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**ENVIRONMENT AGENCY**

**SUFFOLK ESTUARINE STRATEGIES**

**PHASE II – REPORT A**

**BLYTH ESTUARY**

**Volume 2 - Appendices**

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# APPENDIX A

# DISCUSSION OF DEFENCE OPTIONS FOR INDIVIDUAL FLOOD COMPARTMENTS AND ZONES

## GENERAL

Various options and combination of options are considered zone by zone. Slightly different approaches are taken for each zone depending on the nature of the zone or upon the degree of interaction between the individual FCs within each zone. In some cases this has led to an assessment being made for each FC, in effect, independently, only drawing the option for the zone together at the end. In other cases, it is essential that two or more FCs are considered together, reflecting the manner in which each interacts with the other.

In each case there is a logical progression in considering the options. This excludes, by common-sense, certain options or combination of options. The intent is to ensure that options are compatible and to reduce the number of options actually in need of examination to those that reflect a sensible alternative approach in strategic terms. The rational behind which options have been considered and the options themselves are discussed in this appendix, together with the implications these options have as to the use, interest and economic outcome for the zone and for the estuary as a whole.

The manner in which the economic analysis has been derived is discussed and the values determined are tabulated for each zone. Further details of the economic appraisal are given in Appendix D1.

## ZONE 1. UPPER REACH
## Blyford Bridge to Blythburgh Bridge

### Discussion of Management Options in Zone 1.

Seven options have been considered combining various individual options for each FC. Table A.1 provides a summary of the economic analysis undertaken for this zone. Not every combination of options are considered. Those that are, aim to examine the sensitivity of certain general approaches to the zone, honing in on the critical factors influencing the management policy for this area and the potential impact this may have on the estuary as a whole. The "zone options" are discussed below together with a discussion of the rational behind selecting solely these options for consideration.

1) **Do nothing throughout the zone.** Potential present value of damages £2,035k. The loss of assets would have a severe adverse effect on the present balance of use of the estuary. In addition there would be a loss of existing pasture habitat. While there is the potential for some minor benefit to the natural environment through the creation of new salt marsh around the fringe of the estuary, this habitat would still suffer damage in the long term as rising water levels squeeze the marginal salt marsh against the relatively steeply rising hinterland.

   There would be a significant increase in tidal volume in this critical upper reach of the estuary. Flows through the Blythburgh bridge would be increased to such an extent that structural damage is likely to occur. The increase in tidal volume will effect flow in all reaches further down the estuary, increasing discharge by over 50% at Southwold and Walberswick Harbour.

   This approach to the defences within the zone does not assist in maintaining the use and balance within the estuary. It would, in fact, result in increasing the burden of defence elsewhere and could potentially result in a major re-alignment of the estuary and a substantial re-configuration at the estuary mouth. When considered in the context of its impact on the estuary as a whole, this option may be seen to be contrary to the overall aim set out in Section *3* of the strategy report.

   The approach does, however, minimise dependence on defence expenditure and as such provides a baseline for further comparison.

2) **Hold the Line throughout the zone.** Potential present value cost £2,740k. Hold the Line is the existing policy and maintains the existing use and balance within this section of the estuary. However, based on the current estimate of the condition of defences and the assessment of maintaining and eventually replacing these works, Hold the Line for each FC cannot be justified economically at a local level overall. The option has an NPV of -£-705k[1]. This option fails to comply with the overall strategy aim due to the dependence on high local defence expenditure.

   The option minimises the impact on the physical regime of the estuary but fails to create any significant opportunity as far as creation of habitat or enhancement in the use of the estuary.

These first two options examine the extreme scenarios of minimum and maximum expenditure and minimum and maximum protection of assets. Neither is truly compatible with the strategic aim. Other options are, therefore, examined.

[1] The short fall in value of assets which would be loss under the Do Nothing option compared to the cost required to maintain the defences. £2,740k - £2,035k = £705k (see table A.1)

3) **No longer protect the FCs adjacent to the river but continue defend FC 18.** It is recognised that there are significant assets in FC18 with a present value of the order of £367k. Because the FC is set back from the front line of defence and because of the relatively short length of defence needed to defend the frontage, the present value cost of defence is of the order of £257k. Regardless of policies elsewhere in the zone, there is economic justification in defending FC18. This option, as a whole, would still result in a significant increase in tidal volume and, not withstanding the interests protected within FC18, would only be a marginal improvement in maintaining the balance of use of the estuary when compared to option 1.

Having isolated a positive benefit in protecting FC18 there is even less economic benefit in defending the other FCs within the zone.

4,5 & 6) **Testing the economic sensitivity of maintaining defences in the short term but with the intention of Doing Nothing to defences when maintenance is no longer viable.** Option 4 considers this Delay Do Nothing (DDN) for all FCs. Option 5 considers solely Delay Do Nothing on the southern bank (FC17 and 18). Option 6 examines whether there is benefit in maintaining FC17 in the short term before retreating to defend only FC18.

In economic terms option 6 demonstrates a significantly better NPV than either options 4 or 5, and demonstrates benefit in comparison with option 3. In effect option 6 demonstrates the cost of maintaining FC17 for as long as possible is economically justified by allowing the capital expenditure on FC18 to be delayed. However, as soon as there is a need for more major works the justification for holding FC17 is lost. The economic case for maintaining FC17 in the short term is only sustainable if the defences on the opposite side of the channel are abandoned, thereby, reducing pressure on the banks defending FC17.

Despite the delay before totally abandoning the defence of this zone, option 6 must realistically be seen as merely a variation of Do Nothing. This option would still result in a substantial increase in tidal volume and when considered in the context of the estuary as a whole, this option may still be seen to be contrary to the overall aim set out in Section 3. Most significant is the increased cost this option would have on the defence of zones further down the estuary. The option is, however, viable and is economically justified in comparison with a strict Do Nothing approach.

Although at a local level there is a strong argument for Doing Nothing to defences, either immediately or in the future to most of this zone, the impact on the rest of the estuary is large. None of the options would in this respect assist in achieving the strategy aim. However the cost of Holding the Line is equally large and therefore equally hard to justify. One final option is examined as a means of reducing the impact and costs.

7) **Maintain the present level of defence but excluding the tide with a sluice at Blythburgh Bridge.** Tidal flow into the area is substantially greater than fluvial flow. It would therefore, be of significant benefit in terms of maintaining defences if the tide were excluded from the zone. Flooding, which could still occur, would no longer be saline and this would reduce the scale of damage to the current use of the adjacent FCs. The option would provide a sluice at the Blythburgh Bridge, excluding salt water from entering the zone. There would be a need to improve the defence alongside the A12 to the north of Blythburgh bridge. These costs are included within the costs set out in Table 4.1.

The costs of Holding the Line are significantly reduced by taking this approach and as a consequence the NPV is greater for this option than the NPV for a direct Hold the Line option (option 2). Even so, the NPV is still negative.

This option would slightly reduce the existing tidal volume of the estuary and would clearly avoid the massive increase in volume which would otherwise be generated by a Do Nothing approach. This reduction in future tidal volume would result in a reduction in the cost of defending FCs down stream.

In addition to this economic benefit, in excluding the tide, this option creates a fresh water environment within the upper reach of the estuary. This would provide the opportunity, if so required, to recreate specific fresh water habitat under generally more sustainable conditions at a relatively low cost.

Therefore, while having no economic justification at a local level, the opportunities potentially created for better overall management of the estuary, and the possible reduction on the cost of defence further downstream makes this option well worthy of further consideration when assessing options for other zones.

**Table A.1 Summary of Zone 1 Economic Assessments**

| Option | | 1[3] | 2 | 3[3] | 4[3] | 5[3] | 6[3] | 7 |
|---|---|---|---|---|---|---|---|---|
| Flood Compartments | 10 | DN | HTL | DN | DDN | DN | DN | HTL[2] |
| | 11 | DN | HTL | DN | DDN | DN | DN | HTL[2] |
| | 12 | DN | HTL | DN | DDN | DN | DN | HTL[2] |
| | 17 | DN | HTL | DN | DDN | DDN | DDN[1] | HTL[2] |
| | 18 | DN | HTL | HTL | DDN | DDN | HTL | HTL[2] |
| Associated Options | None | | | | | | | |
| PVc Costs £ x1000 | | 0 | 2740 | 257 | 566 | 283 | 427 | 2139 |
| PVd Damages £ x1000 | | 2035 | 0 | 1668 | 1377 | 1500 | 1255 | 42 |
| PVb Benefits £ x1000 | | 0 | 2035 | 367 | 658 | 535 | 780 | 1993 |
| NPV £ x1000 | | 0 | -705 | 110 | 92 | 252 | 353 | -146 |

Notes
1. No appreciable increase in maintenance due to Do Nothing on opposite bank.
2. Hold the line associated with construction of barrage at the A12 Blythburgh Bridge
3. Increase in tidal volume of estuary, damages allow for cost of repair to A12 bridge.

## ZONE 2. CENTRAL REACH
## Angel and Bulcamp Marshes

### Discussion of Management Options in Zone 2

Because of the nature of the zone each FC may be considered separately. Only in the case of FC15 would the consequence of the defence management have any significant impact further down the estuary. FC15 abuts FC14 (in Zone 3), and therefore, the policy for FC15 will influence the assessment, particularly of this other FC. FC15 (part of Tinkers Marsh) forms part of the internationally designated Minsmere-Walberswick heaths and marshes SPA and Ramsar Site. The loss of this area would have a significant impact on the estuary as a whole. Defence decisions with relation to FC9 or FC16 are of little strategic importance to the estuary as a whole.

Only on FC15 are decisions upstream (Zone 1) likely to be material

Because of the independence of each FC, the options considered in table A.2 may be divided into three groups relating to each FC. In the case of FC9 and 16 the options are either Do Nothing or Hold the Line. In the case of FC15, five options are considered, taking into account the possible consequence of options in Zone 1 and the possibility of delaying Do Nothing. The various options are discussed below.

**Flood Compartment 9**

1) **Do Nothing in FC9** (irrespective of options for other FCs). Potential present value of damages £242k. The loss is principally with respect to the loss of Bulcamp House. The option has little or no impact beyond the immediate area with little scope for creation of new habitat due to the relatively steep rise of the land behind and the limited width of the compartment. Should the defence of the area be abandoned, then the area would tend to revert to mud flat with a narrow saltmarsh fringe.

2) **Hold the Line in FC9** (irrespective of options for other FCs). Potential present value cost of defence £123k. The costs allow for some minor maintenance and more substantial reconstruction and raising of defences in the future. Hold the Line is the existing policy and maintains the existing use and balance of the estuary. There would, in time, be some squeeze of high intertidal habitat against the defence line, resulting in some loss to the estuary as a whole. However, maintaining this frontage, slightly in advance of the adjacent high land to the north, creates a small niche in the line of the shore capable of retaining higher levels of mud in the future. This is a local issue and should be considered as part of future detailed appraisal of this Hold the Line option. There is an NPV of £119k in favour of holding the line. Defence costs need to be monitored and a more detailed analysis undertaken of the economics before this policy could be confirmed.

**Flood Compartment 16**

3) **Do Nothing in FC16** (irrespective of options for other FCs) . Potential present value damages would amount to £98k, relating principally to the property in the area. The option has little or no impact beyond the immediate area with little scope for creation of new habitat due to the relatively steep rise of the land behind and the limited width of the compartment. Should the defence of the area be abandoned then the area would tend to revert to mud flat with a narrow saltmarsh fringe.

4) **Hold the Line in FC16** (irrespective of options for other FCs). Potential present value cost of defence £72k. The costs allow for some minor maintenance and more substantial reconstruction and raising in the future. Hold the line is the existing policy and maintains the existing use and balance of the estuary. There would in time be some squeeze of high intertidal habitat against the defence line, resulting in some loss to the estuary as a whole. This option has an NPV of £26k, which in terms of the anticipated defence costs is quite reasonable. The future cost of defence needs to be monitored and a detailed appraisal carried out to confirm this option.

**Flood Compartment 15**

5) **Do Nothing in FC15** (associated with Do Nothing in Zone 1). Potential present value of damages £151k. Far more significant would be the loss of the important freshwater marsh habitat. The loss of this area would result in a substantial reduction in favourable conservation status of the SPA. The land defended is generally well below high water neap tide. Flooding of the area would tend to encourage development of mud flats, adding to the relatively large area of mud flat within this zone. There might be some saltmarsh development at the fringe of the FC but this would be narrow and subject to squeeze against the relatively steeply rising land behind. The change in habitat would have a significant and strategic impact on the estuary as a whole.

The defences are at present suffering from erosion. Do Nothing in Zone 1 would increase the chance of these defences failing. Failure of the defences would result in an increase in tidal volume further downstream, which although not highly significant in itself, would have a cumulative impact on flows and on pressure on defences. The abandonment of the FC15 defences would increase the cost of defending FC14.

This option would not maintain nor significantly add to the overall balance of interests in the estuary. In this regard, at a local level, it fails to address the aim of the strategy. However, there is a recognition in the principals upon which the strategy is developed that where opportunity presents to relocate assets to a more suitable environment, reducing the overall dependence on defence, then this should be taken. At a broader level this option may be acceptable if, within the area of the estuary, the balance of critical habitat can be maintained.

This option must be considered further in assessing options for other zones. In making this assessment the possible physical and economic impact particularly on the defences of FC14 must be taken into account, together with the need for the opportunity for habitat creation.

6) **Hold the Line in FC15** (associated with Do Nothing in Zone 1). Potential present value cost of defence is £507k. The costs allow for initial minor maintenance, increasing with the increasing pressure on the defence, due to the associated policy in Zone 1, and then a more substantial reconstruction in the future. Due to the proximity of the low water channel to the defence, and due to the level of the land behind, raising the banks in line with the anticipated rise in sea level would be a relatively major and expensive operation. The NPV is negative and of the order of -£356k.

7) **Hold the Line in FC15** (associated with Hold the Line in Zone 1). Potential present value cost of defence is £415k. The costs allow for a period of maintenance followed by more major reconstruction. The difference in estimated cost of this option and that of option 6 are attributable to Holding the Line throughout Zone 1; the associated lower tidal volume this generates and the consequential reduction in maintenance

costs and the reduced urgency and scope of the reconstruction work. The NPV is still, however, negative, with a value of -£264k.

In effect, maintaining defences in Zone 1 would result in a decrease of the order of £100k in the cost of defence of FC15. Even so, the cost of defending FC15 could not be justified in economic terms. Option 5 and 6 warrant further consideration in assessing the options for FC 14.

8) **Delay Do Nothing in FC15** (associated with Hold the Line in Zone 1). This option would delay the loss of assets giving a present value residual damage of £54k (an economic benefit of £97k in comparison with Do Nothing, option 5). However, this would still be at a present value cost of maintaining the defences in the short term of £74k. The option has a positive NPV of £23k. At this strategic level of analysis such a result is economically marginal and other factors such as allowing time to implement decisions elsewhere in the estuary may be more significant.

9) **Delay Do Nothing in FC15** (associated with Do Nothing in Zone 1). As a result of the increased tidal volume from Zone 1, and associated increased rate of deterioration of defences of FC15, the period of delay before Doing Nothing to FC15 would be shorter than in the case of option 8 above. The present value cost of maintenance would be less (£63k), but the residual damages would be higher (£72k). The NPV for this option is as a consequence still marginal and less than option 8 (NVP of £16k).

Options 8 and 9 have a similar impact on the rest of the estuary as option 5 (Do Nothing). Generally in assessing options for elsewhere within the estuary these options for FC15 are interchangeable. Options 8 and 9 do provide some opportunity in respect to the implementation of a strategy in that they allowing time for establishing compensatory habitat. This time would be in effect bought at a cost of the negative NPV of either option. The difference between option 8 and 9 being of the order of £7k, reflecting the difference between Holding the Line or Do Nothing in Zone 1.

**Table A.2 Summary of Zone 2 Economic Assessments**

| Option | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Flood Compartments** | **9** | **DN** | **HTL** | | | | | | | |
| | **16** | | | **DN** | **HTL** | | | | | |
| | **15** | | | | | **DN** | **HTL** | **HTL** | **DDN**[1] | **DDN**[2] |
| **Associated Options** | **Zone 1** | **DN** | **DN** | **DN** | **DN** | **DN** | **DN** | **HTL** | **HTL** | **DN** |
| **PVc Costs** £ x1000 | | **0** | **123** | **0** | **72** | **0** | **507** | **415** | **74** | **63** |
| **PVd Damages** £ x1000 | | **242** | **0** | **98** | **0** | **151** | **0** | **0** | **54** | **72** |
| **PVb Benefits** £ x1000 | | **0** | **242** | **0** | **98** | **0** | **151** | **151** | **97** | **79** |
| **NPV** £ x1000 | | **0** | **119** | **0** | **26** | **0** | **-356** | **-264** | **23** | **16** |
| **Notes** | **1** | Based on delay of 10 years | | | | | | | | |
| | **2** | Based on delay of 5 years | | | | | | | | |

## ZONE 3.
## The Reydon and Tinkers Marshes

### Discussion of Management Options in Zone 3

The channel is in effect canalised through this zone. Velocities are relatively high and this is reflected in the general pattern of erosion to either bank. Short groynes have been introduced along areas of the Reydon defences in an attempt to hold the flow away from the banks. There has been slippage of the bank in places and the defences have been reinforced by steel sheet piling. On the Tinkers marsh side of the river there is a narrow width of saltmarsh in front of a thin clay bank. The saltmarsh is eroding and in places the bank is being exposed. The defences are under considerable pressure. Any increase in tidal volume upstream will result in this pressure increasing. Due to the curve in the channel attempts to resist erosion along one frontage can, and is resulting in an increased pressure on the opposite bank; not necessarily at a location immediately opposite.

In assessing the possible options there is a need to consider the possible impacts of increasing flow by allowing defences upstream, particularly those in Zone 1, to fail. At the same time there is a need to consider that if one side of the estuary is held what increase in cost will there be on defence of the opposite bank.

The assessment of the zone has been undertaken in two stages. First, considering the economic case, and other factors, which influence the need for defence of the northern bank. There are four FCs along this frontage. Secondly, the justification for defence along the southern side, where there is just the one large FC of Tinkers Marsh. In each stage the influence of policies on the opposite shore is examined to test what additional burden or relief may be derived. In both stages the impact of policies upstream is also tested.

**The northern bank of Zone 3.** There are 8 options considered in total. The first three test the basic economic viability of defending the four northern FCs.

1) **DN for all compartments (FC8, 7, 6 & 5).** In total present value damages would amount to some £1.2M. This assumes that a Do Nothing option is taken in Zone 1 and along the opposing bank in FC14; tidal flows would be increased but some of the constraint would be relaxed due to Doing Nothing to the defence opposite. There might be some environmental benefit from the development of salt marsh against the higher ground at the fringe of the compartments but this would be at the expense of loosing a significant part of the agricultural land in the estuary, loosing archaeological interest and increasing pressure on the Squire's Hill Pipe bridge. In addition the road across Wolsey Bridge may become unusable and the impact on the next zone of the estuary would be substantial. This option does not meet with the aims of the strategy.

2) **HTL to FC8 but DN elsewhere.** It is recognised that, in economic terms, FC FC8 may distort the case for defence of the northern frontage, due to the fact that it contains a substantial amount of assets and has a relatively short defence length. This option, where only this FC is defended gives an NPV of £160k.

3) **HTL along the northern bank..** If all compartments are defended then the NPV for this option is £252k; an increase of £92k over option 2. Even though FC8 provides the bulk of the justification in defending the frontage as a whole, this option demonstrates that there is still significant economic justification in defending the other compartments. The costs associated with this option recognises the need for, and the difficulty of raising the defences in the future to maintain the current defence standard in a response to sea level rise.

These options consider the case where, although there is a considerable increase in tidal flow due to the policy in Zone 1, the pressure on defences is reduced due to Do Nothing to FC14.

4) **HTL along the northern bank.** (With DN for Zone 1 and FC15 but HTL FC14). This option tests the impact of holding the existing width of the channel by Hold the Line to the opposite bank (FC14). The NPV of this option is negative with a value of -£109k. The value of this option in comparison with that for option 3 is reduced by some £361k; the additional burden placed on the cost of defending the northern frontage by maintaining the existing channel width under these circumstances.

The main pressure on the northern frontage is along the defence to FC6. Releasing this area would reduce the impact that Holding the Line to FC14 would have and reduce the pressure on FC14 itself. However, Do Nothing along FC6 would mean that the internal defences between he FCs on this northern side would have to be strengthened. This is considered as option 5.

5) **DN to FC6 but HTL elsewhere.** (With DN for Zone 1 and FC15 but HTL FC14). The NPV of this option is again negative with value of -£302k. The option could potentially create the potential for salt marsh creation within the enclosed area created. However, the additional cost in defending the long lengths of adjacent compartments would mitigate strongly against such an approach.

6) **DN to FC6 and FC5 but HTL elsewhere.** (With DN for Zone 1 and FC15 but HTL FC14). This option takes option 5 one step further where the defence of FC5 as well as FC6 are abandoned. This takes advantage of the partial defence already in place between FC5 and FC4, considerably reducing costs. Even so the NPV of this option is still negative, with a value of -£109k. In comparison to option 3, this option shows an economic disadvantage of some -£361k in terms of NPV.

The above options demonstrate that there is a good economic case for holding the line to this northern section of defences even under the condition where the flow through the estuary has been considerably increased by a policy in Zone 1. They also demonstrate that attempting to hold the line to both sides of the channel through the zone under such conditions does not make economic sense at the local level. The following two options consider the benefit to the zone in Holding the Line in Zone 1 and thereby reducing the increase in tidal volume.

7) **HTL along the northern bank** (With DN in FC15 but HTL to Zone 1 and FC14). Reducing the flow by Holding the Line in Zone 1 brings the scenario back to existing conditions. In this case, even if FC14 is held there is a case for defending the northern frontage. The NPV of this option is -£185k.

8) **HTL along the northern bank** (With DN in FC15 and FC14, but HTL to Zone 1). Under the same scenario as above but Doing Nothing to the defence of Tinkers Marsh the NPV increases by £124k, to £309k. This option provides the most economically advantageous approach but relies on reducing the tidal volume and releasing the pressure caused by the Tinkers marsh defences.

The various options above are detailed in Table A.3a together with the the results of the economic assessment.

**The southern bank of Zone 3.** The next stage of the zone assessment examines the case for defence to the southern section. The seven options are considered starting as above with the Do Nothing case.

1) **DN to FC14** (With DN for Zone 1, FC15, and the northern side of Zone 3) The damages in economic terms of Doing Nothing to this defence would amount to a present value of the order of £399k. This takes into account the need to defend the sewer pipe to the Squires Hill pipe bridge and the need for some protection to the bridge itself. This option would result in the loss of the existing important habitat within Tinkers Marsh. FC14 forms part of the internationally designated Minsmere-Walberswick heaths and marshes SPA and Ramsar Site. The loss of this area could reduce the favourable conservation status of the SPA and would lead to the loss of nationally important freshwater grazing marsh habitat. If this option were to be adopted it is likely that it would only be acceptable if an equivalent habitat could be generated elsewhere in the estuary.

2) **HTL to FC14** (With DN for Zone 1, the northern side of Zone 3 but HLT to FC15). Retaining FC15, so as to minimise costs in the defence of FC14, Doing Nothing to the defences of Zone 1 but compensating locally for the additional flow by Doing Nothing to the defence of the northern section of the zone, the NPV of Holding the Line to FC14 would be -£331k.

3) **HTL to FC14** (With DN only along the northern shore of Zone 3, HLT to Zone 1 and FC15). Further improving the scenario by reducing the future flow in the river while still relieving the pressure on FC14 by Doing Nothing to the defence of the northern section of the zone would still only increase the NPV by £151k, still resulting a negative NPV of -£180k. This is in addition to the negative NPV for Hold the Line to FC15 in Zone 2 of -£264k.

The above demonstrates that, whereas with respect to the northern section of the zone either holding the line in Zone 1 or Doing Nothing to the defence of FC14 can give rise to a positive economic outcome for defence of the northern section, in the case of FC14, even under the most favourable scenario the NPV remains negative. The following options, therefore, consider ways in which a more favourable outcome may be achieved.

4) **DDN to FC14** (With DN along the northern side of Zone 3, HTL in Zone 1 and DDN to FC 15). By undertaking minor maintenance, the defences may be sustained for a further ten years. This not only provides a positive (if marginally so) NPV of £37k but also allows time to examine how and to re-create equivalent habitat elsewhere. The option still results in damage to the interest of the estuary.

Options 5, 6 and 7 examine how this damage may be minimised locally by retreating the line of the defence so that the eastern area of Tinkers Marsh at least can be maintained. This would provide protection to the sewer and pipe bridge, in addition to retaining the valuable and unique (for this estuary) transition in habitat created by the more gradual rise in the land to Walberswick Common.

5) & 6)**Managed Re-alignment FC14** (With either Doing Nothing to or Holding the northern section.). In this scenario Holding the Line on the northern bank has little impact, indeed the impact may be beneficial in that holding the Reydon Marsh would not increase the tidal volume and flow within the estuary. However, these options have NPVs of -£110k and -£106k respectively and would, therefore, be hard to justify.

7) **Managed Re-alignment FC14** (With DN to FC15, but HLT to in Zone 1 and the northern side of Zone 3). Under this option, holding the line in Zone 1 would result in savings of around £50k. Under these more favourable conditions the scheme NPV would be marginally negative. It would, however, save an important element of the existing SSSI and would assist in reducing the cumulative impact of increasing tidal volume resulting from abandoning defences within the estuary.

**Table A.3a Summary of Zone 3N Economic Assessments – Northern bank only.**

| Option | | 1 | 2[1] | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| Flood Compartments | 8 | DN | HTL | HTL | HTL | HTL | HTL | HTL | HTL |
| | 7 | DN | DN | HTL | HTL | HTL | HTL | HTL | HTL |
| | 6 | DN | DN | HTL | HTL | DN | DN | HTL | HTL |
| | 5 | DN | DN | HTL | HTL | HTL | DN | HTL | HTL |
| Associated Options | Zone 1 | DN | DN | DN | DN | DN | DN | HTL | HTL |
| | FC15 | DN | DN | DN | DN | DN | DN | DN | DN |
| | FC14 | DN | DN | DN | HTL | HTL | HTL | HTL | DN |
| PVc Costs £ x1000 | | 0 | 108 | 865 | 1224 | 1320 | 488 | 987 | 863 |
| PVd Damages £ x1000 | | 1172 | 904 | 57[2] | 57[2] | 154 | 793 | 0 | 0 |
| PVb Benefits £ x1000 | | 0 | 268 | 1115 | 1115 | 1018 | 379 | 1172 | 1172 |
| NPV £ x1000 | | 0 | 160 | 252 | -109 | -302 | -109 | 185 | 309 |
| Notes | 1 | Increases tidal volume by 680M $m^3$ due to contribution from northern FCs and a further 570M $m^3$ due to contribution from FC14 and 15. Total 1250M $m^3$. | | | | | | | |
| | 2 | Additional protection required to maintain the bridge. | | | | | | | |

**Table A.3b Summary of Zone 3S Economic Assessments – Southern bank only.**

| Option | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| Flood Compartments | 14 | DN | HTL | HTL | DDN[1] | R[2] | R[2] | R[2] |
| Associated Options | Zone 1 | DN | DN | HTL | HTL | DN | DN | HTL |
| | Zone 3N | DN | DN | DN | DN | DN | HTL | HTL |
| | FC15 | DN | HTL | HTL | DDN | DN | DN | DN |
| PVc Costs £ x1000 | | 0 | 730 | 579 | 120 | 315 | 315 | 260 |
| PVd Damages £ x1000 | | 399[3] | 0 | 0 | 242[3] | 194[4] | 190[4] | 194[4] |
| PVb Benefits £ x1000 | | 0 | 399 | 399 | 157 | 205 | 209 | 205 |
| NPV £ x1000 | | 0 | -331 | -180 | 37 | -110 | -106 | -55 |
| Notes | 1 | Maintain defences for ten years | | | | | | |
| | 2 | Retreat to defend the eastern section of Tinkers Marsh only. | | | | | | |
| | 3 | Loss of important habitat and increase in tidal volume by 570M $m^3$ | | | | | | |
| | 4 | Loss of important habitat and increase in tidal volume by 530M $m^3$. Safeguards habitat unique to estuary. | | | | | | |

## ZONE 4 LOWER REACH
### Southwold and Walberswick Harbour.

### Discussion of Management Options in Zone 4

The channel through this zone of the estuary is relatively straight, although the corner under the pipe bridge is quite sharp. Under present ebb tide conditions the flow is forced against the northern side of the channel downstream of the bridge. Flows accelerate through the entrance to the estuary on both flood and ebb. The flow into and out of the estuary is constrained more by the cross sectional area of the channel rather than by the way in which the banks constrain its direction.

There is, therefore a conflict between defence of the two sides of the river, which is becoming more apparent. A symptom of this is the scour of the channel walls just inside the estuary mouth. This conflict is likely to be more evident as the tidal volume of the estuary increases with sea level rise, or if the tidal volume of the estuary is increased substantially by Doing Nothing to defences further upstream. The defence of both sides of the river would be put under extreme strain if there were a wholesale retreat from defences further up the estuary. More modest abandonment would increase flow and velocities and, while defences of this lower reach would still be technically feasible it would require increased investment, a greater level of maintenance and would result in defences either failing or requiring more major work sooner. In assessing the economic case for defence of the zone, the difference in investment, and in NPV, is determined to a degree by the time scale for expenditure.

The economic case for defending the northern side and the southern side of the estuary within this zone is considered separately; although, within these assessments, the impact of a policy for one side of the estuary is considered in examining options for the other side. Table A.4a presents a summary of the options for the northern frontage, taking into account the implications of options for Zone 1, 2 and 3 as well as the implications of options for the southern frontage. Table A.4b presents a summary of the options for the southern side of the estuary, taking into account the implications of options for Zone 1, 2 and 3 and for the northern frontage of this zone.

**The Northern Frontage**
The first four options consider Do Nothing to the northern section of Zone 4 examining the difference different scenarios upstream have on the economics of this.

1) **Do Nothing. (While Holding the Line solely in the northern section of Zone 3)** This option sets out the worst realistic case with respect to additional flow down the estuary. In not holding the line to the southern bank of Zone 4, the extreme pressure through the harbour reach is not fully developed. The present value damages amount to some £3.7 million

Under the do nothing scenario, several strategically important assets would be lost. These would include the sewage works to Southwold and Walberswick, located in Botany Marsh (FC4). Regular flooding would result to the Woodsend Marsh and the Town Marshes changing the environmental interest as well as in effect destroying the infrastructure and access to the harbour. There would also be the loss of the caravan park and amenity assets of FC1 as well as housing in this area. The regular flooding of Havenbeach may result in damage to the frontline dune sea defence, resulting potentially loss of this area.

There would also be a significant impact on the coastal processes due to the considerable increase in flow through the harbour entrance. Do Nothing along this frontage would clearly not meet the aims of the estuary. It does however provide the basis for comparison of other options.

2) **Do Nothing (Holding the Line to the southern section of the Zone).** If the southern section of defences to Robinson's Marsh and Walberswick are maintained then the increased constriction of flow will result in defences on the northern side suffering greater damage, with damages amounting to £4.1M due to failure of defences occurring sooner. This gives this option a negative NPV of -£320k.

3) **Do Nothing (Holding the Line to Zone 1 and Zone 3N).** If the defences at the head of the estuary are maintained (HTL in Zone 1), reducing the flow in the channel, then damages would be reduced giving an NPV of £522k.

4) **Do Nothing (Holding the line to all but the southern section of Zone 3)** In this option flows are reduced but the constraint on the channel through Zone 4 is maintained. The NPV of this option is reduced to £158k.

The above options highlight the possible impact various options upstream may have on the zone. The next two options, considered together below, examine the value of treating the northern section of Zone 4 as one or the potential of Doing Nothing to individual FCs.

5 & 6 **Hold the Line to FC4 and Hold the Line to Zone 4 north.** FC4, at the western end of Zone 4 and extending around to the northern side of Southwold, contains the Southwold sewage works. The sewage works potentially distorts the economic argument for the defence of this frontage. Option 5 examines the benefit of defending just this frontage and assumes that the defence is taken back to the narrow section in front of Botany marshes. This gives an NPV of the order of £984k. Holding the Line over the whole northern frontage (option 6), however, gives an NPV of the order of £2,585k. Therefore, despite the important value of FC4 it is considerably more effective to protect the whole area. A similar analysis (not presented) indicates that it is more cost effective to Hold the Line over the full frontage rather than attempting to hold only individual FCs. This is not surprising given that to defend individual FCs would require enhancing the defence works between the compartments. Hold the Line for FCs 1, 2, 3 and 4 may be seen to be worthwhile and, in that this would avoid the disruption identified under Do Nothing, assists in meeting the aim for the strategy.

By comparison with option 6, options 7, 8, 9 and 10 test the impact the defence option for other zones have on the NPV for Holding the Line along the northern side of the estuary channel. As in options 1 to 4, the two main variables are the volume of water moving through the estuary, dictated by the defence of FCs upstream, and the constraint imposed in attempting to hold both the northern and southern sides of the channel within Zone 4.

7) **Hold the Line to both sides of the channel with high tidal volume.** The NPV of this option is £2,340k, some £245k less effective than option 6 due to the additional constraint on the channel.

8) **Hold the Line with reduced tidal volume and no constraint.** The NPV of this option is £3,064k, an improvement in economic terms of £479k as a direct result of Holding the Line in Zone 1 (option 6).

9) **Hold the Line with reduced tidal volume but constricting the future development of the channel.** The NPV of this option is £2,846k, indicating that the defence of FC13 would impose some £218k burden on the defence of the northern frontage.

10) **Hold the Line with reduced tidal volume and retreating FC13 some as to release pressure on the northern frontage.** The NPV of this option is £3,036k, reducing the burden on the northern side of the zone to a mere £28k.

One of the significant damages which would occur if FC1, 2, 3, 4 (the northern side) and FC13 (the southern side) were both held, is the loss of moorings along the frontage. If Zone 1 were abandoned and the channel through Zone 4 maintained at its present width then velocities could double, maintenance of the smaller moorings would become difficult and the potential for bank erosion would result in their actual loss.

**The Southern Frontage**

As with the northern frontage defence of FC13 on the southern frontage is sensitive to the options adopted elsewhere within the estuary. The eight options set out below examine the impacts first if a Do Nothing policy is adopted for FC13, then under a Hold the Line policy and finally if part of the FC is retreated.

1) **Do Nothing with maximum flow through the zone and the northern section abandoned.** The present value of damages for this option is £708k. A substantial proportion of these damages are associated with the moorings along the channel and with damage to, or loss of property in the village of Walberswick.

2) **Do Nothing minimising flow through the zone and still Doing Nothing to the northern section.** This option has a slightly reduced level of damages with an NPV of £75k.

3) **Hold the Line with maximum flow through the zone and the northern section abandoned.** Under this option the NPV is marginally positive with a value of £2k. The high cost being attributable to the high level of flow through the zone.

4) **Hold the Line with minimum flow through the zone and the northern section abandoned.** The NPV of this option is £126k benefiting from both a reduction in the flow and from the release of pressure from the opposite bank allowing the channel to respond to sea level rise by increasing its width to the north.

5) **Hold the Line with maximum flow through the zone but the northern section held.** The restriction in width of the channel means that there is an additional burden on defences. Furthermore, because of the increased volume of the estuary and the anticipated rise in sea level with the accompanying increase in velocities it must be assumed that the moorings to this side of the river will be lost. The NPV of this option becomes negative reducing to -£185k

6) **Hold the Line with minimum flow through the zone but the northern section still held.** This option in effect equates to the present situation. Damage to the moorings would be reduced but there would still be a significant increase in expenditure on defence in response to sea level rise. The NPV of this option would be marginally positive with a value of £2k.

The main concentration of assets is around Walberswick, there is potentially good justification in retreating the defence to concentrate on this area. This would relieve some of the pressure on the width of the channel but would clearly result in the loss of most of the south bank moorings. The final two options consider the Managed Re-alignment option while increasing the flow through the zone (DN in Zone 1) or minimising the flow (HTL Zone 1).

7) **Managed Re-alignment with maximum flow through the zone but the northern section held.** This option results in an NPV of £233k, an improvement in NPV of some £418k over the equivalent HTL option (option 5).

8) **Managed Re-alignment with minimum flow through the zone but the northern section held** This option has an NPV of £380k, an improvement in NPV of some £378k over the equivalent HTL option (option 6) and of some £147k in comparison to Doing Nothing to the defence of Zone 1 (option 7).

Hold the Line is only economically worthwhile if the opposite bank of the channel is allowed to erode (option 4; DN for FC1, 2, 3 and 4) and the increase in flow through the estuary is minimised through holding the line in Zone 1. Considering solely the economic analysis for Zone 4, it is only economically sensible to Hold the northern bank, or the southern bank. The NPV for holding the northern defences are an order of magnitude greater than that for holding the defence of FC13.

If the tidal volume through the estuary is maintained at a minimum by holding the defences of the upper estuary then the NPV of holding FC13 is only in the order of £2k. However, this would still result in the loss of moorings along this southern FC as the tidal volume due to sea level rise has a greater impact.

An alternative approach would be to retreat FC13, allowing the land upstream of Walberswick to be flooded but defending the village itself. This would provide some benefit in releasing the pressure on the northern defences. Moorings on the southern side of the channel would still be lost, as would the agricultural use of the flood plain. However, of the order of £603k of assets would be protected. There would be some increase in the flow through the entrance channel and this would increase the need to address the problems of the quay on the northern side of the estuary. If this approach were adopted then there would be of the order of £147k improvement in NPV if the area to the west of the A12 (Zone 1) were defended.

**Table A.4a Summary of Zone 4N Economic Assessments – northern bank only.**

| Option | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Flood Compartments | 1 | DN | DN | DN | DN | DN | HTL | HTL | HTL | HTL | HTL |
| | 2 | DN | DN | DN | DN | DN | HTL | HTL | HTL | HTL | HTL |
| | 3 | DN | DN | DN | DN | DN | HTL | HTL | HTL | HTL | HTL |
| | 4 | DN | DN | DN | DN | HTL | HTL | HTL | HTL | HTL | HTL |
| Year of failure /construction [1] | | 7[2] | 5[2] | 10[3] | 8[2] | 7[2] | 15[2] | 10[2] | 20/25[3] | 18/23[2] | 20/25[2] |
| Associated Options | Zone 1 | DN | DN | HTL | HTL | DN | DN | DN | HTL | HTL | HTL |
| | Zone 3N | HTL | HTL | HTL | HTL | HTL | HTL | HTL | HTL | HTL | HTL |
| | Zone 3S | DN | DN | DN | DN | DN | DN | DN | DN | DN | DN |
| | FC13 | DN | HTL | DN | HTL | DN | DN | HTL | DN | HTL | R |
| PVc Costs £ x1000 | | 0 | 0 | 0 | 0 | 396 | 1052 | 1201 | 678 | 791 | 706 |
| PVd Damages £ x1000 | | 3742 | 4062 | 3190 | 3584 | 2362 | 105[4] | 201[5] | 0 | 105[4] | 0 |
| PVb Benefits £ x1000 | | 0 | -320 | 552 | 158 | 1380 | 3637 | 3541 | 3742 | 3637 | 3742 |
| NPV £ x1000 | | 0 | -320 | 552 | 158 | 984 | 2585 | 2340 | 3064 | 2846 | 3036 |

Notes

1. The residual life of defences or the period during which the existing defences can be maintained depends, to a large degree, on the tidal volume of the estuary and the degree of constraint imposed by maintenance of both sides of the channel. Increased tidal volume or increased constraint increases the cost of maintenance and decreases the time that maintenance may be sustained.
2. The general residual life of structures is given. The need for works to safeguard the quay in FC1 is taken as 5 years.
3. The general residual life of structures is given. The need for works to safeguard the quay in FC1 is taken as 7 years.
4. Partial loss of moorings due to increased flows and erosion of the frontage.
5. Loss of moorings due to increased flows and erosion of the frontage

**Table A.4b Summary of 4S Economic Assessments – Southern bank only.**

| Option | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| FCs | 13 | DN[1] | DN[1] | HTL | HTL | HTL [2] | HTL [2] | R [3] | R [3] |
| Associated Options | Zone 1 | DN | HTL | DN | HTL | DN | HTL | DN | HTL |
| | Zone 3N | HTL | HTL | HTL | HTL | HTL | HTL | HTL | HTL |
| | Zone 3S | DN | DN | DN | DN | DN | DN | DN | DN |
| | Zone 4N | DN | DN | DN | DN | HTL | HTL | HTL | HTL |
| PVc Costs [5] £ x1000 | | 0 | 0 | 654 | 582 | 789 | 654 | 253 | 163 |
| PVd Damages [5] £ x1000 | | 708 | 633 | 52 [4] | 0 | 104 | 52 [4] | 222 | 165 |
| PVb Benefits £ x1000 | | 0 | 75 | 656 | 708 | 604 | 656 | 486 | 543 |
| NPV £ x1000 | | 0 | 75 | 2 | 126 | -185 | 2 | 233 | 380 |

Notes

1. Loss of the embankment is assumed to occur in seven years.
2. Reconstruction costs are assumed to be needed in years 10 and 15 for options 5 and 6 respectively.
3. Managed Re-alignment would occur in year 5 or in year 10 for option 7 and 8 reflecting the difference in tidal volume between the two options. Managed Re-alignment would be to the defence of the village of Walberswick.
4. Damages are the loss of moorings due either to the excessive increase of tidal volume or due to constrain of the channel.
5. Neither costs nor damages take into account the additional cost or damage associated with coastal defence due to estuary options.

## APPENDIX B

## 'HYDRAULIC AND SEDIMENT REGIME OF THE BLYTH, ALDE/ORE AND DEBEN ESTUARIES'

## HR WALLINGFORD 1999

# Suffolk Estuarine Strategies

## Hydraulic and sediment regime of the Blyth, Alde/Ore and Deben Estuaries

Report EX 3983
January 1999

HR Wallingford

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## Contract

This report describes work commissioned by Posford Duvivier, whose representative was Mr G Guthrie. This report forms part of a larger project, "Suffolk Estuarine Strategies", carried out by Posford Duvivier and HR Wallingford for the Environment Agency, Anglian Region, whose representative was Mr C Flanders. The HR Wallingford project manager was Dr W Roberts. The work was carried out under job number DDR2504 in the Ports and Estuaries Group of HR Wallingford.

Prepared by ........B W Roberts........ *(name)*

........SENIOR SCIENTIST........ *(Title)*

Approved by ........M P Dearnaley........ *(name)*

........Principal Scientist........ *(Title)*

Date ....20 January.... 1999

# Summary

Suffolk Estuarine Strategies

Hydraulic and sediment regime of the Blyth, Alde/Ore and Deben Estuaries

Report EX 3983
January 1999

This report forms part of the output from the Suffolk Estuarine Strategies project, carried out jointly by Posford Duvivier and HR Wallingford, for the Environment Agency, Anglian Region. The aim of the project was to assess the options for long-term (50 years) flood defence strategy in the Blyth, Alde/Ore and Deben estuaries, with particular reference to the anticipated rise in sea level. The purpose of this report is to identify and explain the important aspects of the physical processes governing the hydraulic and sediment behaviour in the estuaries, to provide background understanding for the consideration of specific management options.

Estuary regime theory has been used in this project as a simple and robust tool for making approximate predictions of the response of estuaries to sea level rise and to engineering schemes, such as managed retreat or abandonment of flood defences. The interaction of the estuary mouths with the coast has been examined, to provide supporting information to consideration of the link between the estuary flood defence management strategy and the coastal Shoreline Management Plan. Also, extreme water levels have been calculated for the estuaries, based on water level measurements in the estuaries and POL data for coastal water level extremes.

The hydraulic and morphological effects of a number of specific proposed managed retreat and channel realignment schemes have been considered, using the regime based methodology developed in the report.

The study concludes that the result of sea level rise is expected to be erosion of the middle and outer reaches and accretion in the inner estuaries. In cases where there is limited capacity for the estuaries to increase their width, due to the presence of flood protection embankments, this is likely to cause erosion adjacent to these embankments and a consequential increase in the cost of maintaining them. Increasing tidal volume, as a result of sea level rise and/or managed retreat schemes will interact with the coastline by causing expansion of the ebb delta shoal at the estuary mouths, with the potential to influence littoral drift patterns.

Based on the calculated extreme water levels, a rise in sea level of 0.5m will increase the frequency of occurrence of a given extreme water level by approximately 20-25 times. Thus the present 1:100 year water level would be expected to occur approximately once every five years, following this magnitude of sea level rise.

# Contents

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# 1. INTRODUCTION

The purpose of this report is to identify and explain the important aspects of the physical processes governing the hydraulic and sedimentological behaviour of the Blyth, the Alde/Ore and Deben Estuaries and then to apply this understanding to determine how different sections of the estuaries will respond to sea level rise and to possible management strategies. Using this approach, it is possible to identify the interaction between different parts of the estuary systems and to develop a method to determine the impact of possible management schemes.

The report also includes an assessment of the interaction of changes in the estuary with the coastline, which should be considered in any future integration of estuary and shoreline management plans.

Extreme water levels for the estuaries have been estimated from the available data and the results are presented in Chapter 7.

Location plans for the three estuaries are shown in Figures 1, 2 and 3.

# 2. OVERVIEW OF THE ESTUARIES

## 2.1 Geographical and Historical Setting

The shapes of all three estuaries have been greatly altered by historical reclamations of marshland, substantially reducing the high water area of the estuaries, and hence the tidal volume and the maximum length of wave fetch. The Blyth and Alde/Ore both have long narrow channels, restricted in width at High Water by the flood embankments, opening out into wider basins in their upper reaches. In the Blyth, the upper part of the estuary, from Bulcamp Marshes to Blythburgh Bridge, was previously constrained by flood protection, which was breached during the 1953 flood, partially repaired, breached again in the 1960s and then abandoned, so that now a substantial part of the tidal volume of the estuary lies in its upper reaches. Seaward of Bulcamp marshes, the channel is narrow and in recent years the narrow strip of salt marsh lining the flood embankments has been suffering erosion, leading in places to significant erosion of the base of the wall by tidal currents, threatening its stability. Salt marsh areas in south-eastern England generally have been suffering from erosion in recent decades and the causes of this erosion are not entirely clear, possibly being different in different areas. However in the Blyth it appears that the increase in tidal volume following the flooding of Bulcamp and Angel Marshes has led to faster currents through the constrained section of channel and hence a tendency for this channel to widen and deepen, causing pressure on the flood embankments.

At the same time as responses to man-made changes to the estuaries, they will have been changing gradually as a result of natural changes, such as sea-level rise, changing weather patterns and changing supplies of sediments. It is often convenient to consider the idea of an equilibrium morphology of an estuary, when the shape of the estuary, its sediment and vegetation composition and the forcing factors, such as waves and currents, are all in balance. This idea is used later in the application of regime approaches. Although it seems likely that such equilibrium conditions can exist in principle, the constantly changing external circumstances, principally engineering works and sea level rise, mean that the equilibrium condition towards which the estuary form is 'heading' will also be changing. This 'moving target' may mean that the estuary never actually reaches an equilibrium state, but the concept of the estuary tending towards such an equilibrium can still be a useful tool to understanding its behaviour.

## 2.2 Tidal Properties

The propagation of the tidal wave through the southern North Sea is such that the tidal range increases with distance southward along the East Anglian coast, with a mean spring range of 1.9m at Lowestoft, rising to 5.9m at Tilbury in the Thames Estuary. Thus the Blyth has the smallest tidal range of the three Suffolk

Estuaries under examination and the Deben has the largest. The mean spring and mean neap tidal ranges are as follows:

**Table 1 Tidal range of the Suffolk Estuaries**

| | Mean spring tidal range (m) | Mean neap tidal range (m) |
|---|---|---|
| Blyth (Southwold) | 2.1 | 1.3 |
| Alde/Ore (Orford Haven) | 2.9 | 1.5 |
| Deben (Woodbridge Haven) | 3.2 | 1.9 |

The three estuaries modify the tide in different ways as it propagates along them. In the Blyth, the range in the upper estuary is smaller than that at the mouth. This is likely to be a result of the long narrow channel in the lower estuary, which constrains the flow and leads to a throttling of the tidal flows by frictional effects. This is a mild example of the behaviour seen in many channel-lagoon systems, where the restricted flows through the channel mouth mean that the water level in the large volume internal part cannot respond quickly enough to the changing external water level.

The Alde/Ore is a much longer estuary and the tidal propagation is complex. High water levels in the upper estuary are similar to those at the mouth, with a central section of the estuary where the high water level is slightly lower.

The Deben exhibits a mild amplification of the tidal range with distance up the estuary, so that the tidal range at Woodbridge is 3.6m, with a mean high water spring water level of 4.0m CD, in comparison to MHWS of 3.7m CD at the mouth. This is very similar behaviour to the Orwell and Stour Estuaries, a few kilometres to the south, except that the tidal range is slightly higher still in these estuaries.

## 2.3 River Inflow

The fresh water flow to each of the estuaries is small in comparison with tidal influences. The Phase I reports give the mean fresh water inputs and mean tidal flows at the estuary mouths as follows:

**Table 2 Comparison of fresh water and tidal flows**

| | Mean river flow ($m^3/s$) | Mean tidal flow at mouth ($m^3/s$) |
|---|---|---|
| Blyth | 0.38 | 200 |
| Alde/Ore | 0.62 | 1500 |
| Deben | 0.6 | 1700 |

During occasional river flood events, the influence of fresh water may be temporarily more significant, but for the majority of the time, it will be restricted to the uppermost parts of the estuaries. Over the middle and lower parts of the estuaries the salinity is close to the value found in the open sea.

Fischer (1979) presents an 'estuarine Richardson Number', which relates the potential energy associated with the density differences arising from the presence of fresh water from the river and the kinetic energy associated with the tidal currents:

$$R = \left(\frac{\Delta\rho}{\rho}\right)\frac{gQ_f}{WU_t^3} \qquad (1)$$

where $\Delta\rho$ is the difference in density between river and sea water, $Q_f$ is the river discharge, $W$ is the channel width and $U_t$ is the root mean square tidal velocity. The value of $\Delta\rho/\rho$ is approximately 0.025. Taking approximate values for the three estuaries (widths taken at mean water) gives the following results:

Table 3 Estuarine Richardson Number

| | $Q_f$ (m³/s) | $W$ (m) | $U_t$ (m/s) | $R$ |
|---|---|---|---|---|
| Blyth | 0.38 | 60 | 0.70 | 0.0047 |
| Alde/Ore | 0.62 | 200 | 0.63 | 0.0032 |
| Deben | 0.6 | 250 | 0.77 | 0.0015 |

The transition from well-mixed to stratified estuaries occurs at values of the estuary Richardson number in the approximate range 0.08 – 0.8. Thus it can be seen that in all of these estuaries, the influence of fresh water is extremely small and can be neglected. During times of high fresh water flow, when $Q_f$ may be 20 times higher, then the effect of salinity may start to be felt, but will still not lead to strong stratification. However, even in a well-mixed estuary, a longitudinal salinity gradient can cause a residual circulation, enhancing the strength of near-bed flows during the flood tide and enhancing near-surface flows on the ebb. This encourages landward movement of sediment, because sediment concentrations are generally higher near the bed than the surface. This is likely to be a weak effect in these estuaries.

## 2.4 Waves

The effect of waves is less important in the Blyth, Alde/Ore and Deben than in many other estuaries, because of the form of the estuary mouths which exclude most of the swell wave energy formed in the North Sea, and because of the narrow sinuous form of the estuaries, which limits the length of fetches for local generation of waves. The position and width of the mouth of the Blyth have been fixed by the construction of breakwaters, whereas the Alde/Ore and Deben are in a dynamic balance with littoral movement of the shingle beaches, but all have narrow mouths, which severely restrict the penetration of offshore waves. Although locally generated waves are small in all three estuaries, they should not be entirely neglected, because of their importance in resuspending weak muddy sediment deposits from intertidal areas, and in erosion of salt marsh cliffs and even flood embankments themselves during extreme events.

One of the areas highlighted by local Environment Agency representatives as being particularly susceptible to waves is the reach of sea wall to the south of Hazlewood Marshes, at the east end of the wide upper part of the Alde. None of the wave gauges deployed in the Phase I studies was close to this area, so these reportedly larger waves were not recorded.

Interpretation of the measured wave heights and their implications for flood defence levels is presented in Chapter 7.

## 2.5 Sediment Types

A small number of samples of bed material were collected from each estuary during the Phase I studies. In the Blyth, the sediments of the upper and mid sections of the estuary are characterised by typical estuarine mud, comprising a mixture of clays and silts, with a small amount of fine sand. Near the estuary mouth, from the foot bridge seaward, the sediments begin to coarsen, with a sample of silty gravel obtained adjacent to the breakwaters.

The sediments collected from the Alde/Ore were similar to those of the Blyth: predominantly silt, with a few samples of sandier material and one sample of gravel near the mouth.

In the Deben, the same pattern is followed again, with samples of silt or silty sand in the upper and middle reaches and a sample of gravel near the mouth. The proportion of sand in the Deben samples is possibly a little greater than in the samples from the other estuaries, but substantial variability in the composition of bed materials is common and no firm conclusion can be drawn from this.

The movement of coarse sediments tends to be strongly dominated by the direction of the fastest currents which occur during the course of the tide. In all three of the estuaries in this study, the fastest currents occur during the ebb phase of the tide, which means that sandy sediments tend to be expelled from the main part of the estuaries. Exceptions to this occur close to sources of sandy material within the estuaries, for example where cliffs are eroded by wave action, leading to sandy upper foreshores. In these areas, the current speeds are too slow to lead to significant movement of sand, which is instead moulded by waves into small beach-like formations. Thus the bed of the estuary channels consists mainly of mud and gravel. The current speeds are rarely fast enough to cause movement of the gravelly sediments. Transport of gravel in tidal situations, like sand, is strongly dominated by the direction of the fastest currents, but the current speed at the threshold of motion is much higher. Most of the gravel in the estuaries is thus relatively immobile.

The behaviour of muddy sediments is slightly different. The threshold of motion current speed can vary from a very low value for fresh unconsolidated deposits to a value comparable with medium sand for more consolidated muds. As with coarser sediments, the transport rate is strongly dependent on the current speed, so ebb-dominated currents (i.e. fastest current speed occurring on the ebb phase of the tide) tend to lead to ebb-dominated sediment transport. However, the settling velocity of mud is much lower than for sand. The rate of transport of sand tends to be roughly in equilibrium with the local current speed (and hence the amount of energy available for maintaining sediment in suspension as well as for carrying it along). This is not the case for mud. When the current speed drops, so that the capacity of the flow for transporting sediment decreases, it can take a long time (tens of minutes to several hours) for the sediment to settle through the water column and deposit. This leads to the phenomenon of settling lag, which leads to the movement of muddy sediments into areas of low current speed. Muddy water will move along the estuary in the landward direction during the flood phase of the tide. As current speeds drop as the high water slack period begins, the sediment will start to settle out, but will continue to be advected forward by the continuing slow currents and some of the material will deposit some distance landward from the point at which current speeds dropped below the threshold value for deposition. This will often be in a location where current speeds are always very slow, for example in shallow intertidal areas. Thus mud settling in this area is unlikely to be resuspended by the action of currents and requires also the action of waves to be brought into motion once more. The net effect of this can be a residual motion of fine sediment towards the head of the estuary and towards the estuary margins. A balance of erosion and deposition is established in intertidal areas between deposition during calm periods and erosion during windy (and hence wavy) periods.

# 3. ESTUARY HYDRODYNAMICS AND MORPHOLOGY

## 3.1 Introduction

This chapter presents the important principles of estuarine dynamics and how these manifest themselves in the three Suffolk Estuaries. Also discussed are theories which have been developed by various authors to explain aspects of estuary behaviour and how these theories can be applied to understand possible future development of the estuaries.

## 3.2 Tidal currents

The main driving force behind the currents in estuaries is of course the rise and fall of the tide. In relatively short estuaries such as the Suffolk estuaries, there is a small difference in tidal phase from the mouth of the estuary to the head. This is smallest in the Deben Estuary, which is the widest of the three and thus presents relatively little resistance to the tidal flow. In both the Blyth and the Alde/Ore, the narrow sections of channel cause more resistance and hence a longer phase lag. This is more pronounced in the Alde/Ore because of its greater length. Note that this means that there can be a substantial head difference across the narrow spit at Slaughden, because the tidal phase in the estuary lags that in the open sea by approximately 1.5 hours. At some stages of the tide this could correspond to approximately a metre in tidal height.

**Table 4 Tidal phase lag**

| | High Water phase lag (hrs) | Low water phase lag (hrs) |
|---|---|---|
| Blyth – A12 Bridge | 1.4 | 0.8 |
| Blyth – Blyford Bridge | 1.4 | 1.8 |
| Alde/Ore – Aldeburgh Marshes | 1.3 | 1.1 |
| Alde/Ore – Snape Maltings | 2.0 | 2.3 |
| Deben – Methersgate Quay | 0.4 | 0.4 |
| Deben – Woodbridge | 0.5 | 1.4 |

**Table 5 Flood and ebb duration**

| | flood duration (hrs) | ebb duration (hrs) |
|---|---|---|
| Blyth – mouth | 6.1 | 6.6 |
| Blyth – Blyford Bridge | 5.6 | 7.1 |
| Alde/Ore – mouth | 5.9 | 6.3 |
| Alde/Ore – Snape Maltings | 5.3 | 6.9 |
| Deben – mouth | 5.9 | 6.3 |
| Deben – Woodbridge | 5.0 | 7.2 |

A good first approximation to the behaviour of tidal currents can be made by considering the tidal volume of the estuaries and the wet area at different water levels. Thus if at a certain time the water level is z and the wet area landward of the location of interest, P, is $A_s$, then the volume of water which must pass the estuary cross section in the following short time interval $\delta t$ can be estimated as follows:

$$V = \delta t \frac{\partial z}{\partial t} A_s \qquad (2)$$

If the cross-sectional area at level z at P is equal to $A_x$, then the average current speed through the section is

$$u = \frac{V}{A_x \delta t} = \frac{\partial z}{\partial t} \frac{A_s}{A_x} \qquad (3)$$

Short term changes to current patterns caused by changes in the estuary geometry or hydrodynamic forcing can be considered using this simple equation. For example, a managed retreat of sea defences upstream of a cross-section will increase the wet surface area $A_s$ at most states of the tide, without affecting the cross-sectional area $A_x$, thus causing an increase in current speed at the cross-section.

This type of simple physical argument, combined with observations from real estuaries and inlets is the basis of the regime theory of estuarine morphology, which is discussed in the next section.

## 3.3 Regime theory

Estuaries with a small amount of fresh water inflow, such as the Blyth, Alde/Ore and Deben can be treated in many respects as tidal inlets and hence can be analysed using a number of techniques developed for tidal inlets. Other approaches have been developed with estuaries in particular in mind. This section summarises the main contributions to regime analysis of estuaries and discusses how such techniques could be applied to the Suffolk Estuaries.

The main principle of regime theory is that an estuary, under constant forcing, will reach an equilibrium form and this form can be described by relationships between the channel geometry and key features of the hydrodynamics. The channel is typically described by its width and depth, giving the cross-sectional area, and the hydrodynamic effect is typically characterised by the tidal volume or the mean discharge, or alternatively the peak discharge.

Much of the work on regime theory has been based on observations and analysis of rivers. For example, Leopold and Maddock (1953) proposed the following relationships for rivers, rather than tidal estuaries:

$$U \propto Q^m \qquad (4)$$
$$B \propto Q^b$$
$$D \propto Q^f$$
$$S \propto Q^z$$

where $Q$ is the mean discharge in the channel, $U$ is the current speed, $B$ is the channel width, $D$ is the channel depth and $S$ is the water surface slope. They derived the following values for the coefficients $m$, $b$, $f$ and $z$ (again for rivers):

$m \approx 0.1$ (5)
$b \approx 0.5$
$f \approx 0.4$
$z$ between –0.5 and –1.0.

Myrick and Leopold (1963) applied this approach to measurements in a tidal estuary and obtained:

m = 0.00 (6)
b = 0.77
f = 0.23
no determination of z

(Note that because the discharge is given by the product of the velocity, the width and the depth of the channel, the coefficients must satisfy $m+b+f=1.0$).

A key difference between tidal estuaries and rivers is that the tidal discharge is a dependent variable (i.e. dependent on the channel size and shape), whereas the river discharge is an independent one, being determined by catchment size and rainfall, etc. This is possibly the explanation for the coefficients for these type of relationships for estuaries being different to those for rivers.

Langbein (1963) stated that "an analogy with entropy production in a steady state system leads to a statement that the geometry of natural waterways is governed by two opposing influences:

i.e. a) equal work per unit area of bed
and b) minimum work done in the system as a whole."

He used this hypothesis to develop relationships between the different exponents and hence derive theoretical values for them, as follows:

m = 0.05 (7)
b = 0.71
f = 0.24
z = -0.12

Note that these coefficients, derived by application of physical arguments, are very similar to those of Myrick and Leopold, obtained through observation.

O'Brien (1930) observed morphological relationships in tidal inlets and put forward the following relationship between cross-sectional area of the mouth of the inlet, A, and the mean tidal volume, Ω, contained within the inlet (i.e. the difference in the volume of water contained inside the entrance at mean high water and mean low water):

$$A \propto \Omega^{0.85} \quad (8)$$

De Jong and Gerritsen (1984) analysed data from the Western Scheldt Estuary and found a good correlation between maximum discharge and cross-sectional area at peak discharge, i.e.

$$A \propto \Omega \quad (9)$$

Different authors have preferred either tidal volume (also known as tidal prism) or maximum discharge as the key parameter in their regime relationships. However these parameters are closely related and it is relatively unimportant which is used. In an estuary with a sinusoidal tide, the peak discharge $Q_{max}$ and the tidal volume $\Omega$ are related as follows:

$$Q_{max} = \frac{\pi\Omega}{T} \quad (10)$$

where $\pi = 3.14$ as usual and T is the tidal period. For real tidal inlets, Keulegan (1951) found that

$$Q_{max} = \frac{\pi k\Omega}{T} \quad (11)$$

where k is a constant of proportionality, found to take values between 0.81 and 1.0.

## 3.4 Intertidal areas

The intertidal areas of the estuaries are of prime ecological importance and also play a key role in the estuary hydrodynamics.

Beardall et al (1991) give the following figures for the area of salt marsh and mudflat in the three estuaries:

**Table 6 Areas of salt marsh and mudflat – Beardall (1991)**

| | Salt marsh (ha) | Mudflat (ha) | Total intertidal area (ha) |
|---|---|---|---|
| Blyth | 55 | 276 | 331 |
| Alde/Ore/Butley | 341 | 536 | 877 |
| Deben | 251 | 447 | 698 |

Analysis of the bathymetric cross-sections which were surveyed as part of the Phase I studies yields the following approximate values for estuary areas. The spacing between cross-sections was too large to be ideal for this type of spatial analysis, but useful information can still be deduced from these surveys.

Table 7 Intertidal areas and volumes estimated from cross-section surveys

| | Area at MHWS (ha) | Area at MLWS (ha) | Intertidal area (ha) | Intertidal volume ($Mm^3$) |
|---|---|---|---|---|
| Blyth | 290 | 40 | 250 | 2.75 |
| Alde/Ore/Butley | 1100 | 540 | 560 | 9.55 |
| Deben | 900 | 310 | 590 | 8.95 |

The values derived from the cross-section data give smaller values of total intertidal area than Beardall et al. As mentioned above, data of this type are not ideal for making spatial calculations so there may be some inaccuracy. Also, the data in the Table 7 are based on a mean spring tide, whereas the definition of intertidal area in the Beardall data is the combined area of salt marsh and mudflat. Salt marsh will generally extend above the MHWS level, so encompassing a larger area than the mean spring intertidal area. Furthermore, it is not clear at what level the division between low-lying mudflats and subtidal areas was chosen.

Although mudflats and salt marsh differ in many of their properties, they are nonetheless strongly interlinked with each other, in terms of sediment movements and their interaction with tidal and wave energy (Pethick, 1992, Toft et al, 1995). Therefore morphological change in an estuary will tend to affect both types of intertidal area, perhaps changing the balance between them.

The hydrodynamic forcing on mudflats can be divided into forcing by currents and forcing by waves. The forcing by currents can be subdivided into long-shore (or shore parallel) currents and cross-shore currents (Roberts and Whitehouse, 1997). As discussed earlier, the three Suffolk Estuaries are well sheltered from penetration by offshore waves, and their narrow sinuous form limits fetch lengths for local wave generation, with the exception of the basin type areas at the head of the Blyth and Alde/Ore. In these areas, waves are still generally small but can be large enough to be the main cause of sediment resuspension. Upper mudflats (and salt marshes – see next section) are dry for much of the tide and so the influence of waves is dependent on the coincidence of strong winds and high water levels.

The influence of cross-shore currents on mudflats is only significant when the average cross-shore slope of the mudflat is very small – i.e. the mudflat is wide. In this case the water's edge must move a significant distance between low water and high water which in some cases can generate current speeds high enough to mobilise sediments. This type of mudflat only tends to occur either in the upper parts of estuaries, particularly when the head of the estuary has been artificially shortened as in the case of the Alde and Blyth, or in the middle or lower parts of estuaries when a natural or artificial spit or headland blocks the along-shore currents.

Over most of the three Suffolk estuaries, the mudflats are dominated by shore parallel currents and are strongly influenced by the regime cross-sectional area considerations discussed in Section 3.3. The factors controlling the cross-sectional shape of the mudflat (for a given cross-sectional area) are not fully understood at present, although Dronkers (1986, 1998) and Speer and Aubrey (1985) have examined the relationship between the low water channel and intertidal flats and how the changing average depth affects tidal propagation. High mudflats and a deep low water channel leads to enhanced ebb-dominance of the tide, whereas low mudflats and a shallow low water channel enhances flood-dominance. Because the degree of flood or ebb dominance affects the input and output of sediment from the estuary, this could lead to an equilibrium where the mudflat shape and the tidal propagation influence on sediment transport are in balance. This type of effect has been considered for the Stour Estuary by Roberts et al (1998).

## 3.5 Salt marshes

Higher elevation intertidal areas are often vegetated. Different salt marsh plant species can tolerate different frequencies of immersion and have a varying resistance to damage or removal through the action of tidal currents or waves. Salt marsh forms in areas reasonably sheltered from waves. Key factors affecting salt marsh are: sediment supply, tidal regime, wind-wave climate and the movement of relative mean sea level (Allen and Pye, 1992).

For vegetation of an area to begin, the level of the bed must reach a certain minimum level, usually around the level of mean high water on neap tides. Once initiated, vegetation can accelerate accretion by trapping sediment. Salt marshes are highly effective in dissipating wave energy and relatively extreme wave events are required to cause erosion of the marsh surface. Because of the high elevation of salt marshes, the probability of a large wave event occurring at the same time as high water on a spring tide is low and so erosion events are rare. Between these events, slow accretion creates an approximate overall balance. This is discussed by Pethick (1992).

The effect of rising sea level on salt marshes is discussed in Section 4.4, which concentrates on the changing frequency of inundation as the mean sea level rises. In addition, the strength of waves and currents to which the salt marsh is exposed also increases with rising sea level.

## 3.6 Meandering channels

All three estuaries follow a meandering course. In the Blyth and Alde/Ore particularly, the location of the flood embankments has closely followed the path of the low water channel, with a relatively small ratio of high water width to low water width over the middle and lower reaches. In the Deben, there is a larger value of this ratio, because the flood embankments are some distance back from the low water channel and the mudflats and salt marsh allow a more natural cross-section to form. It has been established, mainly through research into river channel geometry, that channel width, meander radius and meander length are functions of the channel discharge. A small stream has a meander length of a few tens of metres whereas a large estuary can have meander lengths on the order of 10km. This effect is clearly seen in the path of the low water channel of the Deben for example, with meander length increasing from about 500m at Woodbridge to 3-4km in the lower estuary, as the peak tidal discharge increases. This may be an important issue in the constrained sections of the estuaries if future changes in the Suffolk Estuaries affect the volume and speed of water flow. This is addressed in more detail for the Deben Estuary in Section 9.3.1. Attempts by the river channels to change their form may bring them into conflict with the positions of the sea walls. Well developed meanders in rivers are characterised by an approximately constant ratio of channel width to radius of curvature. Chang (1984) proposed that the minimum meander radius of curvature (i.e. the radius of the channel centre line at the apex of the bend) is directly proportional to the channel width, with a constant of proportionality typically taking a value of around 3 in rivers. The situation is more complex in tidal rivers, because of the changing width through the tidal cycle, but the principle remains valid. Regime analysis of both rivers and estuaries show that the channel width is related by a power law to the discharge in the channel. Therefore increasing tidal volume in an estuary will increase the discharge, thus increasing both the channel width and the meander radius. This assumes that the bed material is uniform and makes no prediction of how long it will take the river or estuary to reach the equilibrium shape.

Thus if the tidal volume of the estuary increases, the tidal discharge will increase, the width and depth of the channel will increase and so the meander radius will increase. This requires a change in the path of the channel. It is difficult to predict exactly how this change in the channel position will occur. The greatest energy available for erosion of the channel banks occurs on the outside of the bends, and it is in these areas where initial pressure for channel movement is likely to be seen.

At Slaughden in the Alde Estuary, the river channel bends very sharply. The approximate radius of curvature at the apex of the Slaughden bend is around 400m, with a channel width at low water of around 300m, suggesting that the presence of the beach is constraining the channel course and there will be pressure on the outside of that bend for erosion.

## 3.7 Application of Regime Theory to the Suffolk Estuaries

Regime theory is a useful technique for making an approximate prediction of the long-term response of the Suffolk Estuaries to changes in sea level rise and man-made changes in the estuary shape.

The following assumptions will be made:

- the peak discharge and the tidal volume are related by equation (10)
- tidal volume (and peak discharge) are related to the cross-sectional area at peak discharge by equation (9)
- the width and depth of the channel are related to the peak discharge by the Myrick and Leopold relationships: $B \propto Q^{0.77}$, $D \propto Q^{0.23}$.
- The minimum radius of curvature on each meander bend is proportional to the channel width.

These can be used as a guide to predict relative changes in the channel properties. Local conditions in different parts of the estuaries lead to different coefficients of proportionality in the above relationships. For example if the bed sediments are particularly resistant to erosion, then cross-sectional areas of the channel will tend to be smaller.

# 4. EFFECT OF SEA LEVEL RISE

## 4.1 Effect on hydrodynamics

Estimates of the rate of relative mean sea level rise vary: the Phase I studies proposed consideration of a rise of 0.5m over the next 50 years. This is at the high end of the range of predicted sea level rise in the literature. A brief review of current guidelines, actual trends in recent data and IPCC assessments suggests that a future rate of rise of about 6mm per year is the most commonly accepted value, in other words about 0.3m over 50 years. For consistency with the Phase I studies, and in order to consider potentially the worst case, this study will continue to assume a possible rise of 0.5m over 50 years.

This rise in level will have an influence on the hydraulic forces on the estuaries. Consideration of the geometry of the estuaries shows how these effects occur.

The implications of these hydraulic changes on the flood defences and on intertidal habitats include the following:

- firstly, the obvious effect that high water levels will be higher, with a greater risk of exceeding the height of the defences
- lower current speeds will tend to cause accretion in the upper parts of the estuaries and a pressure for the channel to deepen and widen in the lower estuaries; this could increase pressure on sea walls by erosion of the toe of the embankment in areas where the channel runs close to the defences
- the frequency of inundation at different elevations will increase, affecting the type of habitat which can exist.
- a pressure for realignment of the channel in areas where the channel is already curved

These four effects are discussed in the next four sections.

## 4.2 Risk of overtopping

The risk of the water level reaching the embankment height increases as sea level rises, assuming the embankment level remains constant. Chapter 7 gives estimates of the extreme water levels for events of different frequencies, assuming present day mean sea levels. If the sea level rises by 0.5m, an estimate of the future extreme levels can be made by simply adding 0.5m to the values quoted in Tables 17 to 19. This will increase the frequency of a given water level being attained. For example at Reydon in the Blyth the changes are as follows:

Table 8 Extreme water levels at Reydon (metres above ODN)

| | Return period (years) | | | |
|---|---|---|---|---|
| Scenario | 0.1 | 1 | 10 | 100 |
| Present day | 1.30 | 1.50 | 1.88 | 2.26 |
| 0.5m sea level rise | 1.80 | 2.00 | 2.38 | 2.76 |

It can be seen that for this example, at any given water level, the frequency of that event is increased by a factor of more than 10. Following the sea level rise, the once a year extreme level is higher than the present once every 10 years level and the future 10 year event is higher than the present 100 year event. Thus the risk of overtopping of the defences is increased by a factor of more than 10 times.

## 4.3 Changes in channel cross-section

To apply the regime relationships explained in Chapter 3 to determine the behaviour of a particular channel cross-section, the following procedure can be followed:

- Calculate the change in tidal volume landward of the cross-section
- Calculate the change in cross-sectional area of the channel caused directly by the increase in sea level
- Calculate the change in cross-section predicted by regime theory for the new tidal volume
- Determine whether the new cross-sectional area (following sea level rise) is bigger than the regime cross-section or smaller than the regime cross-section and consider the erodibility of sediment in the area and the supply of suspended sediment to decide whether to expect erosion or accretion.

*Change in tidal volume*

An increase in mean sea level will almost always cause an increase in intertidal volume. The only exception to this is the case where the estuary is bounded on both sides by vertical walls and the whole estuary cross-section is wet at low water and high water. In that very artificial limiting case, a rise in sea level leaves the intertidal volume unchanged. However, the similar but less extreme case of a steep sided channel with narrow intertidal areas at each side is quite common in the Blyth and Alde/Ore and in this type of area, the increase in tidal volume caused by sea level rise is relatively small. It is areas with wide intertidal flats which experience the biggest change in intertidal volume. The water level rises, so that the intertidal flats are exposed for a shorter period on each tide and the average depth at high water is greater.

It is estimated that 0.5m of sea level rise could increase the intertidal volume of the Blyth Estuary from approximately 2.75$Mm^3$ at present, on a mean spring tide, to approximately 4.1$Mm^3$, a factor of 1.49. These figures are based on analysis of the surveyed channel cross-sections produced as part of the Phase 1 studies. Widely spaced cross-sections are not ideal for making tidal volume estimations and a more detailed survey would be useful for improving the accuracy of calculations of this type.

In the Alde/Ore analysis of the cross-section data shows that a sea level rise of 0.5m would increase the estuary tidal volume from approximately 9.55$Mm^3$ to approximately 12.3$Mm^3$, a factor of 1.29.

In the Deben, sea level rise of 0.5m would increase the estuary tidal volume from approximately 8.95$Mm^3$ to 11.9$Mm^3$, a factor of 1.33.

*Change in cross-sectional area*

An increase in mean sea level will always cause an increase in the cross-sectional area of the estuary. The regime relationships described above relate the tidal volume to cross-sectional area at the water level corresponding to peak discharge. This generally occurs around or slightly above mean water level. The increase in cross-sectional area depends on the channel width at this water level and the proportional increase in cross-sectional area depends also on the mean water depth at this water level.

For example, near the mouth of the Blyth, in the Southwold Harbour area, the cross-sectional area at mean water level is about $135m^2$. The width of the river at mean water level at present is approximately 60m. Therefore a 0.5m rise in sea level will increase the cross-sectional area to $165m^2$, a factor of 1.22.

Near the mouth of the Alde/Ore, a sea level rise of 0.5m would increase the cross-sectional area at mean sea level from about $1224m^2$ to $1386m^2$, a factor of 1.13 (assuming that the bed remained unchanged).

Near the mouth of the Deben, the cross-section area would increase from around $1576m^2$ to $1742m^2$, a factor of 1.11.

*Regime cross-sectional area*

The regime cross-sectional area is proportional to the tidal volume, $\Omega$. The channel width increases as $\Omega^{0.77}$ and the channel depth increases as $\Omega^{0.23}$.

So for example in the Blyth, the anticipated increase in tidal volume for the whole estuary corresponds to an increase by a factor of 1.49. This would then require a similar increase in the cross-sectional area of the estuary at the mouth, made up of an increase by a factor of 1.36 in width (i.e. 36% increase) and a factor of 1.09 in depth. At cross-sections further up the estuary, the proportional change in tidal volume could be different. The largest proportional change in upstream tidal volume will occur around Reydon Marshes, at the downstream limit of the wide area of the Blyth.

*Erosion or accretion*

To determine whether erosion or accretion is expected at a channel cross-section, the proportional increase in cross-sectional area due to sea level rise must be compared with the proportional increase in the regime channel cross-section. If the actual increase is bigger than the regime increase, accretion is expected. If the actual increase is smaller than the regime increase, erosion is expected. The rate at which accretion occurs depends on the supply of sediment. The rate at which erosion occurs depends on the type and strength of bed material at the cross-section.

Taking the example of the section in the lower Blyth, the previous sub-section gives the increase in cross-sectional area due to sea level rise to be a factor of 1.22. This is less than the regime increase, so it is predicted that there will be pressure for deepening and widening of the river at this point.

In the upper part of the Blyth, the actual increase in cross-sectional area is larger than the increase regime cross-sectional area, so it is to be expected that accretion will occur.

In the Alde/Ore and Deben, similar behaviour could be expected because the proportional increase in tidal volume as a result of sea level rise exceeds the proportional increase in cross-sectional area at the mouth due to sea level rise. Therefore to achieve a new regime, deepening and widening of the mouth by erosion is likely to occur.

Note that regime theory predicts a certain ratio of width to depth. This is proportional to $\Omega^{0.54}$ and so large channels associated with large volumes of flow tend to be wider in comparison to their depth than smaller channels. For steep sided channels such as are found along much of the length of the Blyth and Alde/Ore, the effect of sea level rise is to increase depth more than width. Therefore even if the new channel capacity is found to be adequate for the new volume, there may be a tendency for erosion at the channel sides and siltation at the channel bottom, to gradually alter to a more stable width to depth ratio.

Over much of the length of the Blyth and Alde/Ore, the channel sides and bottom are composed of consolidated but erodible muddy material. Adjustment of such cross-sections is unlikely to be rapid, but the strength is not sufficient to prevent long-term erosion. Where the channel abuts flood defences, the resistance to erosion may be higher. In this case the channel cross-section is not so easily able to expand, but if the channel is constricted speeds will increase under ongoing sea level rise until erosion of the embankment can occur, usually through the mechanism of undercutting of the embankment toe followed by slumping. The Deben Estuary has more extensive intertidal areas. In this case, an increase in cross-sectional area can occur through erosion of the lower intertidal mudflats, providing a source of material which can contribute to accretion in the upper parts of the estuaries. The sediments in these areas are relatively soft and adjustment of the Deben to a new equilibrium may take place more quickly than for the other estuaries.

## 4.4 Frequency of inundation

The frequency of inundation is one of the most important criteria in determining the suitability of an estuarine area for growth of salt marsh plants. Salt marsh vegetation usually exists between the levels of high water on neap tides and high water on spring tides. Below the level of high water neap, pioneer marsh gives way into mudflat and above high water springs, salt marsh vegetation gradually gives way to terrestrial species. These water levels are as follows for the three estuaries:

**Table 9 High water levels – neap and spring tides (m above ODN)**

| | MHWN | MHWS |
|---|---|---|
| Blyth (Southwold) | 0.90 | 1.20 |
| Alde/Ore (Orford Haven) | 0.94 | 1.54 |
| Deben (Woodbridge Haven) | 0.97 | 1.77 |

It can be seen that if the sea level were to rise by 0.5m and ground levels remain unchanged, all of the land presently suitable for salt marsh plants in the Blyth would be below the future level of MHWN and thus inundated on almost every tide. In the Alde/Ore, a small proportion of the present salt marsh areas will continue to be viable, whereas in the Deben a larger proportion of existing salt marsh areas might survive, although the mixture of species at a given location may undergo gradual change.

Accretion may take place in parts of the estuary which will reduce the impact of the sea level rise on frequency of inundation. If accretion can keep pace with sea level rise, then the proportions of sub-tidal areas, intertidal mudflats and salt marshes could remain constant. If accretion cannot keep pace with sea level rise, then outward expansion of the estuary is necessary to maintain the area of mudflat and salt marsh. The changing hydrodynamics will tend to cause erosion of the lower part of the estuaries and accretion in the upper parts. Thus it seems extremely probable that intertidal areas in the lower part of the estuary will be affected unless lateral expansion is possible. In the upper estuary, the supply of sediment and mechanisms for transporting that sediment to the upper estuary must be examined to determine the relative rates of accretion and sea level rise. If the upper estuary can accrete at the same rate as sea level increases, then the increasing tidal volume effect is removed, and the lower estuary can also become an accretion zone.

The change in the total amount of intertidal area then depends on the bed slopes around the low water and high water marks. If the high water level abuts the flood embankment, or a natural cliff, then increase in high water level leads to a very small lateral movement of the top of the intertidal area. Typically, the bed slope near low water is much flatter, which means that the low water line is moved towards the high water line and the total intertidal area decreases.

## 4.5 Changes in channel alignment

As described above, sea level rise will lead to an increase in tidal volume, causing initially an increase in flow velocities, which will develop into an increase in channel width and depth and, ultimately, a return of flow velocities to close to their original values. The greater channel discharge will create a pressure for the radius of curvature of meanders to increase and hence realign themselves. This will manifest itself initially in erosion of the channel bank on the outside of bends.

## 5. EFFECT OF ENGINEERING SCHEMES

A similar procedure can be applied to consider the effect of engineering schemes. The main types of engineering schemes are as follows:

- managed retreat schemes. The principal effect on the estuary as a whole is an increase in tidal volume. In addition there will be local effects at the 'entrance' to the scheme.
- channel realignment schemes. Here, the channel cross-section and bending radius should be considered.

### 5.1 Managed retreat schemes

Managed retreat schemes consist of abandoning or deliberately breaching a section of the sea defence, flooding an area of low-lying land behind the defence, with retreat of the high water line, either to existing high ground, or to a new flood defence embankment. A scheme of this type increases the tidal volume of the estuary. The amount of this increase depends upon the area of the scheme and the ground elevation of the newly flooded area.

Application of the regime-based approach involves the following steps.

- Evaluate the tidal volume of the breached area.
- Evaluate the increase in peak discharge at cross-sections further down the estuary.
- Calculate the increase in the regime width and depth.
- Consider the erodibility of the sediments in the area and the proximity of any hard structures to estimate future erosion.
- Consider possible realignments of the channel arising from the increased flow speed and/or increased channel width.

In addition to the above estuary-wide considerations, the future behaviour of the breached area itself should be considered, in particular:

- cross-section of the breach itself
- rate of accretion or erosion of sediments in the breached area.

An example of this type of effect was the breaching of the defences in the upper Blyth in the 1960s. This led to flooding of the Bulcamp Marshes and a substantial increase in the tidal volume of the upper part of the Blyth. This has created large intertidal mudflats, dry at low water and covered at high water. The average level of these flats is between OD and 1m above OD. High water on spring tides is 1.2m above OD and low water is about 0.7m below OD.

The additional tidal volume of these flats is quite substantial, assuming an average depth of 0.75m at High Water over an area of approximately 2.0 million $m^2$, gives a tidal volume increase of the order of 1.5 million $m^3$, constituting about 55% of the existing total tidal volume. Thus at the time of the breaching, the tidal volume of the Blyth more than doubled. If the narrow channel section of the Blyth was 'in regime' before this event, then the increase in tidal volume will have caused a strong pressure for expansion of the channel. Taking a cross-section in the lower part of the estuary, the tidal volume above that section would be increase by a factor of 2.2 Using the regime relationships, this would require an increase in channel width by a factor of 1.8 and an increase in channel depth by a factor of 1.2, to regain the regime. No data on changing channel cross-sections is available, although it is clear that there are erosion related problems in maintaining the embankments along some sections of the Blyth. It is probable that the response to that change is still ongoing. The alterations of the estuary towards a new regime involve accretion in the low energy intertidal areas as well as erosion of the main channel. This intertidal accretion in the upper part appears to be proceeding very slowly. This could be linked to a low supply of sediment, arising mainly from marine sources. The ebb-dominated hydrodynamics of the estuary are not conducive to rapid sediment ingress. John French of UCL comments that the remains of the old embankment are being eroded from the back by locally generated waves at high water, and this may provide a small source of sediment for accretion elsewhere in the estuary.

For managed retreat schemes, where the breaching of the embankments is engineered, the elevation of the land behind the breach has a strong influence on its future behaviour. As seen in the case of the Blyth and also in the managed retreat experiment at Tollesbury, the rate of accretion in the retreat areas is rather slow. If it is desired that the retreated areas should be suitable for salt marsh growth, then the ground elevation should ideally be engineered by sediment placements or sediment redistribution before breaching, so that the inundation frequency is suitable.

The increased flow speeds in the channel cause a pressure for increasing meander radius, which is achieved by erosion of the outside of the channel bends. This will contribute to the observed erosion problems in the Reydon Marshes area.

### 5.2 Channel realignment schemes

Schemes of this type may be beneficial in areas where there is presently erosion pressure on the flood defences, for example on the outside of bends. Increases in tidal volume due to sea level rise and/or managed retreat schemes are likely to worsen such problems and engineering works to realign the channel away from the worst erosion problems may offer a solution.

Examples of areas where such schemes could be considered are at Slaughden in the Alde and around Reydon Marshes on the Blyth. At Slaughden, a new cut could be made through the narrow spit of land at the north end of Home Reach, opposite Slaughden. At Reydon Marshes, no single realignment solution stands out, but some loss of land would be necessary, either on the Reydon side or from Tinkers Marsh.

## 6. INTERACTION OF ESTUARY MOUTHS WITH COAST

### 6.1 Possible effects on the coast of works within an estuary

This section considers the following question:

> Can flood defence schemes within an estuary affect the open coastline either side of its mouth?

In the present study, which considers three particular estuaries in Suffolk, this general question can be answered in a similar way because of the similarities of the estuary entrances. In all three cases, these entrances cut through shingle beaches, whose character is dominated by wave action from the North Sea. At all three entrances, the coastline has a nett southward longshore drift, with sand and shingle crossing the estuary mouth via an 'ebb delta shoal'. Figure AB1, adapted from Dean (1988), shows this general configuration. The details of each of the three entrances differ somewhat, but in each case, the coastline on at least one side of the estuary is of the 'barrier beach' type, with either low-lying land at risk of flooding or part of the estuary immediately behind it. It should be noted that the ebb shoal delta is usually a very dynamic part of the seabed, changing shape almost continually as a result of the action of waves, tidal currents and longshore drift processes. As the delta changes shape, so the position and depths of channels connecting the estuary and the open sea also alter, although it is not generally possible to say whether the change in one causes or follows the other. In the three estuaries presently being considered, there is also a transfer of beach sediment across the estuary mouth, from north to south. Many of the individual grains of sand and shingle will, temporarily, settle on and form part of the ebb shoal delta, before completing their crossing of the estuary mouth.

Within a kilometre either side of the estuary mouths, the beaches are dominated by wave action. Flood defence works inside the estuaries will not affect waves from the North Sea reaching these beaches. Because of this, any changes that such works cause will, at least initially, be localised to the area at and either side of the entrance itself. Left unchecked, however, such changes could eventually extend both up- and down-drift, and affect the coastline for a considerable distance.

There are three possible mechanisms through which flood defence works within any of these three Suffolk estuaries could affect the open coast, namely:

- Alteration of the existing nett balance of the import or export of sediments through the estuary mouth.
- Changes in the volume of water entering or leaving the estuary, which in turn will affect the currents and sediment transport through its entrance.
- Changes in the currents and morphology within the estuary that might provoke the formation of a new estuary entrance (either replacing or in addition to the existing entrance).

For the first of these bullet points, the main interest in the present study would be the nett influx or outflow of sand and shingle. While there may well be an alteration in the present exchanges between estuary and open sea of finer-grained sediments (clay, mud) this is most unlikely to have any repercussions on the character of the shingle beaches along the open coast of Suffolk.

For these three estuaries there is no significant volume of sand or shingle entering from upstream, and travelling out to the open coast. The first of the above points thus reduces to consideration of the interchange of sediment between the open coast and the main part of estuary itself, particularly its lower reaches. Therefore the most likely way that changes in the present sediment exchange process will occur is as a consequence of changes in the hydrodynamic and sediment–transport regimes of the estuary entrance, discussed next.

Turning then to the second bullet point, changes in currents, sediment transport processes and morphology at the mouth of an estuary have been a subject of numerous studies and treatises in the past (see for example Dean, 1988, Bruun and Gerritsen, 1960). These studies, however, have typically concentrated on the management and manipulation of the mouths of estuaries and tidal inlets to allow safe navigation through them. The major concerns in such studies have been the maintenance of adequate water depths, preserving a stable channel position and preventing or mitigating erosion of the coastline down-drift of the entrance.

Fewer studies have considered the consequences of changes in the estuary on the entrance and adjacent stretches of coastline. However, these possible problems still remain, especially that of erosion of the open coast, usually down-drift from the entrance.

The key issue is the possible change in the ebb shoal delta. When the volume of water entering leaving an estuary decreases, e.g. as a result of reclamation of inter-tidal flats, then the ebb shoal delta typically diminishes in size. The reduced size of the shoal will allow larger waves to reach the shoreline on either side of the estuary mouth, potentially leading to beach erosion. In addition, the sediment in the ebb delta shoal can be transported further into the estuary by the more vigorous wave action. It is not clear whether this latter process would be a 'one off' adjustment reflecting the change in the regime of the estuary and its mouth, or whether the process of transfer of sediment into the estuary via the reduced ebb shoal delta would continue indefinitely.

In the converse situation, i.e. where the tidal volume of the estuary is increased, then the ebb shoal delta will typically become larger. It is likely that the extra sediment needed to increase the volume of the delta will be obtained from the longshore drift of sand and shingle across the estuary mouth, rather than from within the estuary itself. This will result, at least in the short term, in a reduction in sediment arriving on the down-drift beaches. However, the increase in size of the delta will also provide more shelter to the coastline to the landward. This may perhaps lead to deposition of beach material near the estuary entrance.

Thus, changes in the tidal volume of any of the three estuaries will lead to changes in their ebb shoal delta, and hence in the topography of the shoreline on either side of their entrance. The likely scale of such changes will depend on the magnitude of the changes in the peak ebb tide velocity. If these changes are small, i.e. less than a few percent, then it is unlikely that the changes in morphology of the delta or the coastline could be discriminated from the changes caused by variations in wave conditions. If larger changes in peak ebb current speeds are predicted to occur as a result of works inside the estuary, then the changes at the entrance may be more noticeable. For all three estuaries, it is likely that the changes on the southern side of the entrance will be of greatest potential concern, since these areas stand the greatest risk of erosion following disruption of the longshore drift across the estuary entrance.

However, it will always be very difficult to predict these changes with any degree of accuracy. Models of morphological changes at the mouths of estuaries are still the province of research workers rather than part of a coastal engineer's tool-kit. The wide range of tidal and wave conditions that can occur in multiple combinations and sequences make predicting long-term trends a very daunting task, and at present it is only possible to indicate the likelihood of short-term changes, i.e. over a few days or weeks. A comprehensive and long-term survey programme would need to be established to investigate the present dynamic behaviour of the estuary mouths, and hence provide data to verify such models of morphological change. Even then, there would still be considerable difficulties and substantial cost in then using them to confidently predict the effects of a change in the capacity of the estuary in the short ream, let alone many years hence.

The final bullet point is particularly relevant to the Ore/Alde estuary, and perhaps the Deben estuary as well. Changes in the tidal volume of an estuary (by reclamation or managed re-alignment) will inevitably bring about changes in currents, most noticeably in the vicinity of the works carried out. In the case of managed re-alignment of flood defences, it is also likely that the wave activity within that part of the estuary will also be increased (because of the increase in fetch lengths within it). Usually, these changes will only be an 'internal' concern, i.e. limited to within the estuary itself. Typical examples would be effects on adjacent stretches of flood defence embankments or erosion of saltmarsh, even dry land, around the margins of the estuary.

However, where an estuary is only separated from the sea by low-lying land and a narrow beach, the possibility of erosion forming a completely new entrance needs to be considered. If this were to occur, then the subsequent impacts on the open coastline (as well as the estuary itself) might be very dramatic. This possibility is returned to in the discussion of the individual estuaries below.

## 6.2 Blyth

The Blyth estuary has a very narrow and constrained entrance. Unless changes in the estuary seaward of the old railway bridge (about 1500m upstream from the end of the North Pier) are being contemplated, then it is very unlikely that any changes in the channel position through the entrance will occur. There is a marked change in alignment of the main channel at this point. It seems inconceivable that any 'internal' estuary management works upstream of this area would result in the estuary forming a new entrance to the sea. The main effects on the open coast of such schemes will therefore occur as a result of changes in the tidal currents through the entrance between the piers.

Note however that managed re-alignment schemes in the vicinity of this bridge, or downstream of it may have much greater effects on the open coast. In particular that a scheme which increased flows and wave action within Busscreek Marshes might eventually lead to the possibility of a breach in the shingle beach north of Southwold Pier. Cliff protection works have already been installed at the northern end of the seawall protecting Easton Marshes, but this remains a 'weak point'. Wave action within Easton Marshes would add to the present erosion problems in this area.

The existing northern training wall/ groyne, together with the constricted and hence accelerated flows into and out from the estuary, has been disrupting the natural longshore drift processes for many years. As a consequence, the beaches to the south have been deprived of some of the sand and shingle that would otherwise have travelled over the ebb shoal delta to them from the north. There has been occasional breaching of the shingle barrier beach in front of Westwood Marshes, which probably has been caused, at least in part, by the disruption to the natural drift of beach material. As well as these short-term events, there has also been a long history of erosion along this southern frontage. The shoreline at Corporation Marsh has retreated over 100 metres since 1884 (SMP, p4/2/4), with lower rates of retreat further south.

Because of the artificially constrained entrance, it is unlikely that any major changes in the channel could occur, although the South Pier is known to be in a poor state of repair, and hence may be vulnerable to any increase in currents and hence scour at its foundations. Also, to the south of the entrance, a flood-wall protects the village of Walberswick itself. As pointed out in the Shoreline Management Plan (Halcrow, 1998) this defence will need to be maintained, and probably enhanced as the years pass, to prevent the risk of serious economical and social damage here. Walberswick is therefore also at some potential risk arising from changes at the estuary mouth.

In view of the foregoing, there is a need for careful monitoring of the estuary entrance, the South Pier and of the beach immediately south of entrance (Walberswick) before and after any major works within the estuary of the Blyth. Erosion of the beaches can be mitigated by artificially by-passing shingle across the estuary entrance to compensate for changes in the existing natural drift processes, or alternatively by importing such material from elsewhere.

## 6.3 Alde/Ore

The Alde/Ore estuary also has a very narrow entrance, Orford Haven, with major shingle banks across its mouth (the ebb delta shoal). The coastline here has changed shape considerably over the years, with the entrance having migrated a considerable distance south, under the influence of the southward shingle transport. In addition the beach to the north has been accreting at about one metre/ year (Halcrow, 1998).

In contrast, the village of Shingle Street, just south of the entrance, is more vulnerable, being on low-lying land and is protected from flooding by a clay embankment fronted by a shingle beach. The coastal lagoons at Shingle Street are of international conservation importance (pSAC) and there is a requirement to preserve their integrity. While at present there seems no problem of erosion in this area, changes in the estuary regime may conceivably change this situation, requiring some form of intervention.

The effects at and either side of the estuary mouth following possible changes in the ebb shoal delta are as for the Blyth. There will need to be careful monitoring of the coastline, especially south of the entrance, with the option of shingle nourishment to mitigate against any problems of erosion at Shingle Street.

For this estuary, however, there is also the possible problem of significant changes in the meandering main channel that runs just behind the shingle ridge between the estuary mouth and Aldeburgh. Changes in the estuary hydrodynamics, for example as a consequence of a managed re-alignment scheme, may provoke changes in the plan-shape of this main channel, and possibly scour of the western side of the coastal shingle ridge, for example at Slaughden. It should be possible to predict significant changes in currents by numerically modelling any proposed management schemes within the estuary. Increases in current speeds close to the landward side of these barrier beaches, e.g. at Slaughden south of the Martello Tower, would be well worth avoiding.

In addition, the most vulnerable areas of this ridge will need careful monitoring to identify and mitigate any tendency for such erosion that otherwise might lead to a weakening of the ridge. In extreme cases, this might allow a breach to be formed by large storm waves; while in most cases such a breach would probably 'self-heal', the possibility of a permanent breach, leading to a greatly changed position of the estuary mouth, cannot be ruled out. This in turn would probably lead to significant changes in (extreme) tidal levels in some parts of the estuary, as well as dramatic changes of the coastline in the vicinity of the new entrance.

## 6.4 Deben

The Deben Estuary has the widest entrance of the three considered in this report. The position of the main channel through this entrance (Woodbridge Haven) has varied over the years, and presently runs along the south-western, i.e. Felixstowe Ferry shoreline. The deep water and fast currents close to the shoreline have caused erosion and the need for flood defence works to be installed. However, the groynes and sheet-steel pile wall on the other side of the entrance, alongside the Bawdsey Manor frontage bear witness to similar problems there in the past.

The position of the channel is linked to the ebb shoal delta, which here also incorporates an inter-tidal 'bar' of sand and shingle, oriented SSE and springing from the Bawdsey Manor frontage. As this bar alters its shape, for example in response to severe waves or storm surges, so the currents and channels further into the estuary entrance will alter, in a complex and unpredictable manner. Changes in the estuary capacity, either from reclamation or managed re-alignment schemes, will further alter the existing, volatile behaviour of the bar and channels.

The main possibilities for changes along the open coastline here are as follows:

Re-positioning of the main channel through the entrance to the north side of Woodbridge Haven. This would perhaps bring about an increased tendency for erosion and damage to coastal defences along the Bawdsey Manor frontage (and possibly further into the estuary, i.e. in front of Bawdsey Marshes). However, the Bawdsey Manor frontage has a sheet-steel pile seawall, which should limit the erosion. On the more positive side, such a change in the channel position would probably reduce the present erosion problems along the Felixstowe Ferry shoreline, and hence the danger of flooding of Felixstowe Marshes to the landward.

Erosion of the shoreline south of Woodbridge Haven, along the Golf Links frontage, i.e. between the Martello Tower, at about Nat. Grid co-ordinates 329373, and the main coastal protection works at Felixstowe about 3000m further south. The frontage, including the area known as 'The Dip', has had its coastal defences improved in recent years, in part by the importation of shingle to supplement the diminishing natural beach. Changes in the ebb shoal delta which lead to a reduction in the transfer of shingle across the mouth of the Deben, or which reduce the shelter to the beaches on the south side of the entrance, would increase the tendency for erosion along this shoreline.

Finally, careful consideration should be given to any schemes in the lower reaches of the estuary that might, in time, lead to the formation of a new entrance to the Deben. The most likely point for a new entrance is probably through the narrow 'neck' of land near Manor Dairy. There is also a possibility of a new entrance forming further north, near the old gun emplacement at East Lane, Bawdsey, where the beaches are eroding, and the land behind is low-lying. South of the estuary entrance, a breach could perhaps occur in the vicinity of the golf links club-house, north of The Dip. Here too the beach is narrow and vulnerable to erosion. Large scale managed re-alignment schemes within the Deben estuary could result in wave attack and erosion on the western sides of the barrier beaches at any of these locations, thus requiring a greater effort to protect their seaward sides.

# 7. EXTREME WATER LEVELS

## 7.1 Estimation of extreme water levels

Extreme water levels were estimated in the rivers Blyth, Alde and Deben, with reference to different sources of information. A little over one year's worth of measured data (1/4/95 –30/4/96) was available at a number of different locations within each river. The data and full details of the measuring instruments and locations are given in Cambridge/UCL (1996a, 1996b, 1996c). Reference to POL (1997) provided a guide to extreme water levels at the coastal boundaries of each of the rivers.

Extreme water levels were calculated from the measured data. The highest measured value at each location was assigned a return period of one year. Then, a lower threshold was selected and the number of records exceeding the threshold counted. Thus a lower return period estimate was made.

Extreme value distributions are often of the form $y=e^{-x}$ (where y is the environmental variable, and x is the probability of exceedence). Therefore plotting return period, on a log scale, against water level allows a linear extrapolation of water level to higher return periods. This type of extrapolation was carried out for each of the sites where measurements were made. The results are shown in Tables 10–12. The consistency of the 0.1 and 1 year return period values gives some confidence in their accuracy. However, manual extrapolation of only one year of data introduced considerable uncertainty to the 10 and 100 year values.

**Table 10 Extreme water levels (m above ODN) in the river Blyth (from measured data)**

| Blyth | Return period (years) | | | |
|---|---|---|---|---|
| Location | 0.1 | 1 | 10 | 100 |
| Blythburgh | 1.35 | 1.4 | 1.5 | 1.55 |
| Bulcamp | 1.5 | 1.55 | 1.6 | 1.65 |
| Reydon | 1.3 | 1.5 | 1.75 | 1.95 |
| Southwold | 1.5 | 1.6 | 1.75 | 1.85 |

**Table 11 Extreme water levels (m above ODN) in the river Alde (from measured data)**

| Alde | Return period (years) | | | |
|---|---|---|---|---|
| Location | 0.1 | 1 | 10 | 100 |
| Snape | 1.85 | 2.05 | 2.25 | 2.5 |
| Iken | 1.9 | 2.05 | 2.3 | 2.5 |
| Slaughden | 1.85 | 2.0 | 2.25 | 2.4 |
| Orford | 1.9 | 2.0 | 2.15 | 2.3 |
| Butley River | 1.95 | 2.0 | 2.05 | 2.1 |
| Flybury | 1.9 | 1.95 | 2.0 | 2.1 |
| Orford Haven | 2.0 | 2.25 | 2.5 | 2.75 |

**Table 12 Extreme water levels(m above ODN) in the river Deben (from measured data)**

| Deben | Return period (years) | | | |
|---|---|---|---|---|
| Location | 0.1 | 1 | 10 | 100 |
| Woodbridge | 2.25 | 2.7 | 3.1 | 3.5 |
| Woodringfield | 2.2 | 2.6 | 2.95 | 3.3 |
| Ramsholt | 2.1 | 2.4 | 2.7 | 3.2 |
| Felixstowe Ferry | 2.2 | 2.55 | 2.85 | 3.1 |

POL (1997) is the latest in a series of publications detailing extreme water levels around the coast of the UK. The results are extrapolated from a combination of measured water level data and a numerical tidal flow model. The tidal flow model data consists of synthetic hourly sea levels, with corresponding tidal and surge levels for 39 years between 1955 and 1993. The data are available at 2964 locations on a regular grid of resolution 36 by 36km over the North West European continental shelf. The model uses meteorological data to generate the synthetic surge data. Physical laws generate the tidal component. The results at the coastal boundaries of the three rivers have been extracted and are given in Table 13.

**Table 13 Extreme water levels (m above ODN) at the coastal boundaries of the rivers Blyth, Alde and Deben**

| River | Return Period (years) | | | | |
|---|---|---|---|---|---|
| | 1 | 10 | 25 | 50 | 100 |
| Blyth Estuary | 2.35 | 2.87 | 3.08 | 3.21 | 3.42 |
| Alde Estuary | 2.60 | 3.10 | 3.31 | 3.44 | 3.64 |
| Deben Estuary | 2.69 | 3.19 | 3.40 | 3.53 | 3.73 |

The one year extreme values shown in Table 13 for the Blyth, Alde and Deben can be compared with results shown in Tables 10, 11 and 12, for Southwold, Orford Haven and Felixstowe Ferry respectively. The POL estimates are higher at all three locations, with the greatest difference (0.75m) at Southwold and least difference at Felixstowe Ferry (0.14m).

Like any numerical model not all physical effects are accurately accounted for in the POL tidal flow model. Additionally, the nearest measuring/calibration station may be some way from the location of interest. For these reasons POL (1997) recommend that if ***sufficient*** measured data at the site of interest is available, this should be incorporated into the extremes analysis. The suggested approach, applied here, is to use the one year value from the measured data and add the quoted amount for each higher return period. The results are shown in Tables 14, 15 and 16.

**Table 14 Extreme water levels (m above ODN) for measuring stations in the river Blyth (POL adjustments)**

| Blyth | Return period (years) | | | | | |
|---|---|---|---|---|---|---|
| Location | 0.1 | 1 | 10 | 25 | 50 | 100 |
| Blythburgh | 1.35 | 1.4 | 1.92 | 2.13 | 2.26 | 2.47 |
| Bulcamp | 1.5 | 1.55 | 2.07 | 2.28 | 2.41 | 2.62 |
| Reydon | 1.3 | 1.5 | 2.02 | 2.23 | 2.36 | 2.57 |
| Southwold | 1.5 | 1.6 | 2.12 | 2.33 | 2.46 | 2.67 |

**Table 15 Extreme water levels (m above ODN) for measuring stations in the river Alde (POL adjustments)**

| Alde | Return period (years) | | | | | |
|---|---|---|---|---|---|---|
| Location | 0.1 | 1 | 10 | 25 | 50 | 100 |
| Snape | 1.85 | 2.05 | 2.55 | 2.76 | 2.89 | 3.09 |
| Iken | 1.9 | 2.05 | 2.55 | 2.76 | 2.89 | 3.09 |
| Slaughden | 1.85 | 2 | 2.50 | 2.71 | 2.84 | 3.04 |
| Orford | 1.9 | 2 | 2.50 | 2.71 | 2.84 | 3.04 |
| Butley River | 1.95 | 2 | 2.50 | 2.71 | 2.84 | 3.04 |
| Flybury | 1.9 | 1.95 | 2.45 | 2.66 | 2.79 | 2.99 |
| Orford Haven | 2 | 2.25 | 2.75 | 2.96 | 3.09 | 3.29 |

**Table 16 Extreme water levels (m above ODN) for measuring stations in the river Deben (POL adjustments)**

| Deben | Return period (years) | | | | | |
|---|---|---|---|---|---|---|
| Location | 0.1 | 1 | 10 | 25 | 50 | 100 |
| Woodbridge | 2.25 | 2.7 | 3.21 | 3.42 | 3.55 | 3.75 |
| Woodringfield | 2.2 | 2.6 | 3.11 | 3.32 | 3.45 | 3.65 |
| Ramsholt | 2.1 | 2.4 | 2.91 | 3.12 | 3.25 | 3.45 |
| Felixstowe Ferry | 2.2 | 2.55 | 3.06 | 3.27 | 3.40 | 3.60 |

Although this approach has been adopted, there remain questions: is one year of data sufficient from which to accurately estimate the one year return period value? If the measured data is exactly representative of the long term variation in water levels, the highest recorded value would provide a good estimate of the one year return period water level. The analysis of longer periods of water level measurements in this area would enable the measured data used in this project to be put in context with the longer term trend. However, such a study is beyond the scope of this project. There is therefore some doubt regarding the accuracy of the one year extreme value estimated from the measured data.

The results in Tables 14, 15 and 16 show results at each measuring location within each river. In deriving these results it has been assumed that the increase in water level at the coast (from POL (1997)) will be exactly reproduced at every location considered. This assumption is probably over conservative. One would expect the influence of the surge to diminish with distance up river, where the tidal influence is less evident. The extent to which an extreme surge propagates up river could be investigated with further runs of the existing tidal flow models.

Taking the above comments into account, the best estimates for each of the locations have been calculated by averaging the extreme estimates directly extrapolated from the measured data, with the estimates based on POL (1997), with the one year value taken from the measurements. The results are shown in Tables 17, 18 and 19.

**Table 17 Best estimates of extreme water levels (m above ODN) in the river Blyth**

| Blyth | Return period (years) | | | |
|---|---|---|---|---|
| Location | 0.1 | 1 | 10 | 100 |
| Blythburgh | 1.35 | 1.40 | 1.71 | 2.01 |
| Bulcamp | 1.5 | 1.55 | 1.83 | 2.13 |
| Reydon | 1.3 | 1.50 | 1.88 | 2.26 |
| Southwold | 1.5 | 1.60 | 1.93 | 2.26 |

Table 18 Best estimates of extreme water levels (m above ODN) in the river Alde/Ore

| Alde | Return period (years) | | | |
|---|---|---|---|---|
| Location | 0.1 | 1 | 10 | 100 |
| Snape | 1.85 | 2.05 | 2.40 | 2.80 |
| Iken | 1.9 | 2.05 | 2.43 | 2.80 |
| Slaughden | 1.85 | 2.00 | 2.38 | 2.72 |
| Orford | 1.9 | 2.00 | 2.33 | 2.67 |
| Butley River | 1.95 | 2.00 | 2.28 | 2.57 |
| Flybury | 1.9 | 1.95 | 2.23 | 2.55 |
| Orford Haven | 2 | 2.25 | 2.63 | 3.02 |

Table 19 Best estimates of extreme water levels (m above ODN) in the river Deben

| Deben | Return period (years) | | | |
|---|---|---|---|---|
| Location | 0.1 | 1 | 10 | 100 |
| Woodbridge | 2.25 | 2.70 | 3.15 | 3.62 |
| Woodringfield | 2.2 | 2.60 | 3.03 | 3.47 |
| Ramsholt | 2.1 | 2.40 | 2.80 | 3.32 |
| Felixstowe Ferry | 2.2 | 2.55 | 2.95 | 3.35 |

## 7.2 Summary

Best estimates of extreme water levels have been calculated at a total of 15 locations in the rivers Blyth Alde and Deben. Two different sources of data were used: one year of measured data at each of the fifteen locations; POL (1997) giving details of extreme water levels for the entire coast of the UK. Extremes were calculated directly from the measured data using an intuitive approach. Additive adjustments for higher return periods from POL (1997) were applied to the one year extremes from the measured data to provide give an alternative set of extremes. The best estimates were calculated by averaging the results from these two approaches

The accuracy of the results could be improved by measuring water levels in the estuaries over a longer period. Simulation of a surge tide in a numerical model of flow in the estuaries could provide information on how the surge water level at the estuary mouths is modified as it propagates landward.

## 7.3 Wave measurements

The gauges record variations in sub-surface pressures as waves pass over on the surface. For very long period waves the pressure transmitted is equal to the hydrostatic pressure, so that the change in pressure (in terms of centimetres of water) is the same as the change in surface elevation. However, at lower wave periods the sub-surface pressure variation can be very much less. The ratio depends on the water depth and on the wave period, but roughly it begins to take effect at periods below about eight seconds and becomes very high at periods below about three seconds. Our own experience is that the pressure variation produced by waves below about two seconds in period cannot be distinguished from system noise. This would appear to be the case for these gauges, since the lowest mean wave period reported is about two seconds. This is not a problem in the open sea, where the proportion of energy at periods below two seconds is very low, but it can be significant in smaller bodies of waters such as rivers and reservoirs.

During the course of the study, observations of waves were made from the Bawdsey to Felixstowe ferry on a windy day in August 1998. At the downwind (Bawdsey) side choppy waves with a significant wave height of about 0.1m and a mean wave period of about one second were observed. The height reduced gradually to almost zero at the upwind (Felixstowe) side. These wave conditions were just about limited by the maximum possible wave steepness before breaking occurs. Presumably on windier days in Winter larger steepness-limited waves with periods still less than two seconds could be generated locally within the river.

Assuming that locally generated waves of up to 0.15m or so in height are not recorded by the pressure gauges, it is likely that wave height will be under-reported. If such waves occurred in conjunction with reported significant wave heights of, say, 0.1, 0.2 or 0.3m, then the true values could be closer to 0.18, 0.25 or 0.34m, but the most extreme waves would be less affected.

## 7.4 Joint probability

Correlation can be expressed as a factor to relate it to either the dependent or independent case. It is this type of approach that is suggested for this study and is described briefly here. For a full description of this method see CIRIA (1996, section 3.5.3).

If wave conditions were independent of water level, the joint probability of a given water level occurring at the same time as a given wave height, is simply the product of the probability of occurrence of the specified wave height and the specified water level. If the two events are dependent the joint probability is equal to the probability of occurrence of either of the two events. The independent joint probability can be either divided by the correlation factor, or the dependent product can be multiplied by the correlation factor to find the actual joint probability.

A conservative correlation factor of 100 ('well correlated' CIRIA (1996)) is recommended for use in this study. This leads to joint probability combinations with a return period of 100 years having a marginal return period product of 14. For example, a one year wave condition could be combined with a 14 year water level or alternatively a 1 year water level could be combined with a 14 year wave height. Thus a range of combinations of wave heights and water levels can be calculated each with a return period of one hundred years.

Alternatively, a simple approach that could be applied for this study would be to combine the 100 year water level with the highest recorded (1 year) wave height. Although this may seem overly conservative at first, given the above comments regarding the probable under measurement of wave conditions, this approach would give reasonable results.

# 8. REVIEW OF DOMINANT PROCESSES OCCURRING AT EACH ESTUARY SECTION

## 8.1 Blyth

(i) Upstream of the A12

This area is characterised by a narrow river channel with relatively low embankments. During periods of high river flow, the water in this area may be mainly fresh, although during low flow, saline water will still penetrate. Tidal volumes are low, but flow speeds can still be significant. The defences restrict the capacity and the alignment of the channel, but as it lies above Bulcamp Marshes, where most of the intertidal area is situated, the rise in sea level will have a relatively small effect on flows. Indeed it is likely that the actual cross-section area will increase more than the regime cross-section as a result of sea level rise and so some accretion may be expected in this area. In the uppermost parts, the channel form will be dominated by fresh water flow and the change in sea level will have little effect.

(ii) A12 bridge to Reydon Marshes

In this section of the estuary, the bulk of the intertidal area is located. Sea level rise will greatly increase the tidal volume and cross-sectional areas in this part of the estuary. Slow accretion is anticipated on the intertidal flats as a result of sea level rise. There will be pressure for a widening of the low water channel, but it is relatively unconstrained and this is not likely to be a major problem. Only at the lower end of Bulcamp Marshes, where the meandering channel links into the Reydon Marshes reach, the channel is constrained by its capacity and alignment and there is likely to be erosion close to the embankment on the right (southern) bank.

(iii) Reydon Marshes and Tinkers Marsh

In this area the channel is constrained in capacity and alignment. Sea level rise or managed retreat upstream will create potentially serious pressure for the channel to widen, and for the radius of curvature of bends to increase. The channel is probably still responding to the large increase in tidal volume which occurred in the 1960s and present difficulties in maintaining the flood defences are expected to worsen.

(iv) Southwold Harbour

This reach is constrained to some extent in its capacity, although no serious alignment related problems are experienced or anticipated. There will be pressure in the future for the channel to widen, with potential damage to the flood embankments.

(v) Harbour entrance

This area is constrained by capacity. There will be increased pressure in future for deepening and widening. The width of the channel is fixed by the breakwaters, so the additional tidal discharge will cause deepening. Attention should be paid to potential structural problems for the breakwaters. The increased tidal flows will lead to expansion of the ebb delta shoals (see Chapter 6) with the potential for temporary interruption of the southward net littoral drift as extra beach material is drawn into the larger shoal. During this period of adjustment, interruption of littoral drift could cause erosion of the Walberswick frontage.

## 8.2 Alde/Ore

(i) Upper Alde – Snape Maltings area

As in the Blyth, a stretch of the old flood embankments has been breached and abandoned in the upper section of the Alde. The additional intertidal area reintroduced to the system by this breaching is smaller than that in the Blyth. The tidal limit lies just above Snape Bridge. Increasing sea level is likely to cause slow accretion in this area.

(ii) Long Reach

A large part of the intertidal area of the Alde lies in this reach, which is wide with extensive mud flats and generally low current speeds. Sea level rise will lead to slow accretion on these intertidals, which will probably be unable to keep pace with the rate of sea level rise, thus leading to net loss of intertidal area. Threats to sea defences will arise only through increased sea level and hence increased risk of overtopping. The length of wave fetch will increase slightly with the higher water levels and this could cause erosion of embankments at the exposed east end of this reach through wave attack.

(iii) Barbers Point to Short Reach

The alignment of this meandering stretch of river is partially fixed by the high ground on the left bank at Round Hill and further downstream on the right bank at Cowton. The disused jetty on the left bank, just east of Round Hill appears to have a local influence in preventing erosion and may contribute to fixing the position of the river. Sea level rise will increase the tidal volume in the Long Reach area and this will cause pressure for widening in this reach. There is limited scope for realignment of this stretch of river, but erosion is likely on the outside of bends and could cause erosion of the southern part of the salt marsh at Cob Island.

(iv) Slaughden

This is one of the potentially troublesome reaches on the Alde. It is constrained in capacity and alignment. There will be increasing pressure for erosion on the Slaughden (left) bank, where the river bends abruptly. It could become steadily more difficult to prevent breaching of the gravel spit in this area, because of pressure both from the sea and from the river side.

(v) Slaughden to Orford

This reach is characterised by very narrow intertidal areas and hence steep banks. Sea level rise will increase the tidal volume by more than the cross-section increases and so there will be pressure for the channel to widen, but probably no strong tendency for changes in alignment.

(vi) Orford and Havergate Island

The channel divides to flow around Havergate Island, with the northern branch being the larger. The increase in tidal volume as a result of sea level rise will cause a pressure for both parts of the channel to widen. The influence of the Butley on the northern branch is likely to cause greater changes in the northern branch than in the southern branch.

(vii) Ore and Butley confluence

The discharge of both the Alde/Ore and the Butley will be increased by sea level rise, causing pressure for widening of the channels. It is possible that the relative changes in each estuary will be different leading to some realignment of the confluence.

(viii) Lower Butley

Sea level rise is likely to cause widening and deepening of the channel in this area.

(ix) Upper Butley

Sea level rise is likely to cause accretion in this area.

(x) Mouth of Ore

As explained in Chapter 6, the increase in tidal volume will cause an expansion of the ebb delta shoal, which will require net input of material from the beach transport system. The channel mouth may widen, but this is unlikely to cause any problems. Temporary partial interruption of littoral transport as the delta expands may cause erosion of the beach to the south. Widening of the lowest part of the River Ore may cause Orford Beach to become narrower and more prone to breaching by waves. Any such breach will probably 'self-heal'. Past behaviour has shown occasional movements in the location of the mouth of the Ore. Such changes are unlikely to have serious adverse effects on the estuary or the surrounding area.

## 8.3 Deben

(i) Upper

In the upper part of the Deben, increased cross-sectional area due to sea level rise will out-weigh increased tidal volume and slow accretion is expected. Despite this, there will be a net loss in intertidal area, unless the high water line of the estuary is allowed to expand outwards.

(ii) Lower

In the lower part of the Deben, the increase in tidal volume as a result of sea level rise, will have a greater effect than the increase in cross-section and this will lead to widening and deepening of the estuary channel. This will take place mainly by erosion of the lower intertidal flats. In some areas, erosion on the outside of channel bends will lead to erosion of salt marsh, for example in the vicinity of Hemley.

(iii) Mouth

As with the other estuaries, the increase in sea level will cause expansion of the ebb delta shoal and a temporary effect in trapping a proportion of the net southerly littoral drift, possibly causing some erosion of the beach to the south. The mouth of the Deben at Felixstowe Ferry will attempt to widen, possibly enhancing erosion difficulties in the area.

# 9. CONSIDERATION OF SPECIFIC MANAGEMENT OPTIONS IN THE ESTUARIES

This chapter considers a series of potential management options for the three estuaries, involving retreat or realignment of the flood defences in certain areas of the estuaries. A preliminary discussion of the likely effects of such schemes on the estuary hydraulics and morphology is presented.

## 9.1 Blyth Estuary

Three schemes have been put forward:

(i) Removal of all defences upstream of the A12 bridge
(ii) Flooding of Reydon and Tinkers Marshes
(iii) Flooding the Marshes adjacent to Southwold Marshes

These schemes will clearly cause major changes in sediment and ecological conditions within the areas flooded. In addition there will be changes throughout the estuary caused by the increase in tidal volume. The most important influences of each scheme are seaward of the scheme itself, because of the inflow and outflow of the additional tidal volume. These can be assessed by using the regime approach, explained in Section 3.7.

The existing tidal volume of the Blyth on a mean spring tide is approximately 2.75Mm$^3$. The additional tidal volume associated with each scheme has been estimated to be the following:

| | | |
|---|---|---|
| West of A12: | 2.0Mm$^3$ | |
| Reydon and Tinkers Marshes | 1.3Mm$^3$ | |
| Marshes at Southwold Harbour | 1.25Mm$^3$ | (Town Marshes and Robinson's Marshes) |

These volumes assume that the tidal range within the flooded areas will be similar to that in the existing estuarine channel adjacent to them. If the entrances to these areas are narrow enough to present a significant restriction to the flow, there may be a reduction in the tidal range within the flooded areas due to the time required for filling and emptying. This is only likely to be an issue for the area above the A12, where very rapid flows could occur under the existing A12 bridge. If the tidal volume west of the A12 becomes around $2Mm^3$, the peak tidal discharge will be approximately $140m^3/s$, applying the above formula. This will cause erosion of the channel under the bridge which could lead to some structural damage.

Assuming that the constriction presented by the bridge reduces the tidal range west of the A12 and hence reduces the tidal volume to $1.5Mm^3$, say, then the effect of the additional tidal volume at the estuary mouth can be calculated.

The total estuary tidal volume will increase from 2.75 to 4.25 $Mm^3$, a factor of 1.55. This means that the regime width of the estuary mouth will increase by a factor of 1.4 and the depth by a factor of 1.1. Note that this is the increase in the *regime* width, and if the estuary was unconstrained by embankments or training walls or geological hard-points, then the estuary could be expected to evolve gradually towards this new regime over a long period. However, the estuary mouth is not free to evolve in this way. Nonetheless, this calculation gives useful information about the expected response to such a change. The peak discharge at the mouth will increase by approximately the same proportion as the tidal volume, i.e. 1.55. The accelerated current speed will cause some erosion of the bed, thus increasing the depth and some erosion of the banks of the present channel in places where they consist of sediment or marsh. In places where the banks consist of hard structures, no lateral movement of the channel will be possible in the short term and the extra current speed will tend to cause additional deepening of the channel in order to attain a larger overall cross-section. This may have implications for the stability of certain structures if their foundations are exposed.

Flooding of the marshes west of the A12 would increase the volume of flow passing through the Bulcamp Marshes area. This will cause an increase in the width of the low water channel through the marshes and may cause some erosion of the lower parts of the intertidal. However, it would also increase the tidal excursion in the lower part of the estuary and hence increase the distance which turbid coastal water can penetrate into the estuary, leading to a small increase in the average suspended sediment concentrations in this area. This might increase the rate of accretion of the mid to upper parts of the intertidal flats in Bulcamp Marshes.

The Reydon and Tinkers Marshes scheme increases the tidal volume at the mouth from 2.75 to $4.05Mm^3$, a factor of 1.47. The regime width increases by a factor of 1.34 and the depth by 1.09.

The Town and Robinson's Marshes scheme increases the volume from 2.75 to $4.0Mm^3$, a factor of 1.45. The regime width increases by a factor of 1.33 and the depth by 1.09.

Breaches in the flood embankments to flood these marshes should be designed such that the current speed through the breach are not too large, to avoid excessive erosion close to the breach and the bottom level of the breach should be low enough in elevation to allow full drainage of the new intertidal area behind.

The flooded areas will accrete slowly following breaching. Evidence from Bulcamp Marshes suggests that the supply of sediment is small and so accretion since the 1960s breaching has been very slow. Similar behaviour can be expected for the proposed managed retreat areas. If it is desired that the flooded areas become suitable for particular flora and fauna types it may be necessary to engineer the land levels prior to flooding to attain the desired frequency of tidal inundation. If this is carried out, then adaptation to the desired estuarine (as opposed to land-based) ecosystem can occur more quickly. Accurate estimates of the rate of accretion following breaching are hard to make without more observations of suspended sediment concentration in the estuary, but it is likely that it would be restricted to a few centimetres per year. The flooded areas near the mouth will probably accrete more rapidly than those further landward due to higher suspended sediment concentrations in the estuary channel.

## 9.2 Alde/Ore Estuary

(i) Potential retreat areas in upper Alde

Two possibilities are being considered: breaching of defences of Hazlewood Marshes and Iken Marshes. The approximate flooded areas would be:

| | |
|---|---|
| Hazlewood Marshes | $0.6Mm^2$ |
| Iken Marshes | $1.6Mm^2$ |

If an average depth of 1m at high water is assumed, then the tidal volume of these areas is $0.6Mm^3$ and $1.6Mm^3$ for Hazlewood and Iken respectively.

The total tidal volume of the Alde/Ore is approximately $9.5Mm^3$. The tidal volume above Slaughden is approximately $5.3Mm^3$. Therefore flooding of Hazlewood marshes represents a 6% increase in the total tidal volume and an 11% increase in the tidal volume of the estuary above Slaughden. The larger site at Iken Marshes constitutes a 17% increase in the total tidal volume and a 30% increase above Slaughden.

Using the regime coefficients described in the report, the changes in regime width and depth can be calculated. The potentially most important changes may occur at the bend in the river at Slaughden. Here, the increase in regime width as a result of the Hazlewood scheme is a factor of 1.08 and, for the Iken scheme, a factor of 1.22. Pressure for river widening will be strongest on the outside of the bend, which at present lies against the jetties of Slaughden yacht club. Deepening of the channel through this bend can be expected, with the potential to cause erosion at the toe of bank protection structures around the outside of the bend.

The effect of sea level rise will exacerbate this effect.

(ii) Reshaping bend at Slaughden in the Alde

A possible scheme would be to alter the alignment of the channel bend at Slaughden to reduce the pressure on the present defences, with the aim of reducing costs and reducing the risk of breaching of the narrow spit in this area. Re-routing the channel bend to cut through the narrow spit may run the risk of moving the area of greatest pressure further to the south, where the present bank protection is of a lower standard than at Slaughden. Therefore, possible disbenefits of this scheme should be considered very carefully. Possible alternative measures to reduce the pressure on the outside of the Slaughden bend could include widening on the inside of the bend, possibly combined with short groynes or other structures on the outside of the bend. Again, possible long term effects of this type of approach should be carefully considered and would depend on the detailed flow patterns produced. More detailed design studies are required to address this issue.

(iii) Boyton Marshes

A further possibility is to stop defending Boyton Marshes, at the western side of the confluence of the Butley and Ore. The approximate area to be flooded would be $0.5Mm^2$. The increase in tidal volume associated with this change is relatively small, as it lies near the mouth of the Alde/Ore system. Significant changes in regime would tend to be local and would depend on where the breach or breaches in the defences occurred. The present alignment of channels at the entrance is unlikely to change significantly. If all of the defences were removed, there could be flow across the marsh area around high water, but at low to medium water levels, the flow would take the present route following the deepest water.

The most likely reason for the shape of the Butley/Ore confluence, with the Butley entering the main channel in an upstream direction, is related to tidal phasing. The Butley, a small estuary with relatively slow speeds has less momentum than the much larger Alde/Ore and so the flow reversal from the flood to ebb direction occurs sooner after High Water in the Butley. Thus the Butley is starting to ebb while the Ore is still flooding weakly. This will tend to deflect the entrance of Butley to the east.

## 9.3 Deben Estuary

This section considers both the general issue of change to the form of the channel meanders in the Deben as a result of sea level rise, and the specific issues associated with three potential managed retreat schemes.

### 9.3.1 Channel Meanders in the Deben Estuary

The Deben Estuary exhibits distinct meanders from its tidal limit north-east of Woodbridge to the mouth. Over most of the length of the estuary, the flood defence embankments follow the meandering path of the low water channel. Therefore, if the form of these meanders changes as a result of sea level rise or managed retreat areas, then there could be consequential effects on defence embankments in other parts of the estuary.

There is a body of research work on the properties of meanders in rivers, but very little published work on meandering of estuaries. Chang (1984) proposes a theory for river meanders, whereby the width, depth and slope of the channel adjust to satisfy continuity of the water and sediment fluxes in such a way that the dissipation of energy is minimised. This typically leads to a channel slope which is less steep than the valley slope and so the equilibrium form of the channel is a meandering one. Allen (1985) comments that river meanders tend to evolve by slowly increasing their amplitude and migrating downstream.

Meandering of the low water channel is a common feature of estuaries, but the properties of the meanders are not generally the same as in rivers. The source of energy for flows in estuaries is dominated by the rise and fall of the water level at the estuary mouth. The discharge varies rapidly with distance along the estuary channel because it is dominated by the tidal volume capacity of the estuary, rather than the inflow from the river. In common with rivers, the radius of curvature of estuary channels appears to increase as the width of the channel increases. Chang proposes that in rivers the radius of curvature at the apex of the bend increases linearly with the width of the channel. Estuary regime theory indicates that the width of the estuary channel increases as the discharge to the power of approximately 0.77. The exact coefficient differs according to different authors, and perhaps in different estuaries, but the values are consistently less than 1.

It can therefore be expected that the radius of curvature of the bends in an estuary channel will increase towards the estuary mouth. Analysis of the plan-form shape of the Deben thalweg (low water channel) shows that the length along the thalweg of each meander increases approximately linearly with the distance along the thalweg from the head of the estuary (denoted "distance from the tidal limit" in Figures 4 and 5). A similar relationship exists between radius of curvature and distance from the tidal limit, although there is more scatter in these data, partly because of the few nearly straight sections in the upper part of the estuary. Calculating the best linear fit to these data suggests that the angle through which each bend turns is approximately constant along the estuary at an average value of 73°. (See Figures 4 and 5).

To answer the question of how the estuary might change in the future, an understanding of the mechanism determining the meander shape is required, and this is not well understood in estuaries in general.

The Suffolk Estuarine Strategies Phase 1 Report on the Deben Estuary comments that chart and map analysis shows that in the 19$^{th}$ and 20$^{th}$ century there has been little movement of the high and low water marks, suggesting that the pattern of meanders has been stable, or at least slowly varying. Therefore there has been little noticeable response to any rise in sea level over that period.

Future sea level rise, or increased flooding of marsh areas caused by retreat or abandonment of defences, will tend to increase the tidal volume of the Deben Estuary. This will have the effect of increasing the width and depth of the channel. If there is a direct link between the width of the channel and/or the estuary discharge and the radius of curvature and length of meanders, then it can be expected that there will be a tendency for the route followed by the channel thalweg to change. The way in which this occurs depends on what is most important in determining the form of the channel meandering and the present state of scientific knowledge about estuaries does not provide a sure guide to this.

Although long term changes are difficult to predict, it is clear that increasing tidal volume will increase the current speeds in the existing estuary, causing it to adjust its form. The greatest capacity for erosion will often occur on the outside bank at the apex of channel bends. Problematic areas will be those where the deep water channel lies close to the flood embankments.

Methersgate Quay appears to be an example of a structure influencing the path of the estuary channel. It is situated at the outside of a slight bend in the channel, but the angle of deflection of the channel through that bend is much smaller than for most other bends in the channel, suggesting that, if unconstrained, the channel might take a path further to the east.

### 9.3.2 Effect of specific schemes in the Deben Estuary

For economic reasons, the following locations are under consideration as retreat or 'do nothing' areas. The potential influence of changes in these areas on the channel morphology is considered below.

(i) West bank, south of the confluence of Martlesham Creek with the main estuary
Deterioration of defences in this area is unlikely to have any significant effect on other parts of the estuary. There would be a small increase in tidal volume of the estuary and a small drainage creek or creeks will form through the marsh adjacent to the present defences. It would allow the possibility of the main estuary channel along 'Troublesome Reach' to migrate southward, although if that were to occur, there are no obvious adverse effects for other parts of the estuary.

(ii) Stonner Point, on the east bank opposite Waldringfield
In this area, the main estuary channel lies close to the west bank, at Waldringfield. There is a smaller secondary channel to the east side of the estuary, drying at around low water spring tide level, with an area of salt marsh lying between the two channels, covering at around high water spring tide level. The survey of bathymetric cross-sections undertaken for the Phase 1 Studies shows a somewhat more substantial channel than that indicated by the Admiralty Chart. This is confirmed by the aerial photographs of the area. The secondary channel is most defined to the south of Stonner Point, shallowing and widening to the north of the salt marsh island. No measurements of current speeds are available in this area.

This is the largest flood compartment of the three discussed here and the filling and emptying of the area through a breach or breaches in the embankment would either lead to the enlargement of existing creeks through the intertidal area, or the formation of new creeks, depending on the breach location. It is possible that the change to the current patterns would encourage more flow through the secondary channel past Stonner Point. If this occurred, it may lead to loss of depth in the present main channel adjacent to Waldringfield. More detailed studies would be required to predict this type of effect more accurately.

(iii) East bank near Ramsholt Lodge
This area lies on the inside of a bend in the river channel and is fronted by 100-150m of salt marsh. No salt marsh exists at the north side of the bend. It appears that at present there is relatively little pressure of erosion on this area of the flood embankment and so deterioration of the embankment under a do-nothing policy is likely to be slower than in other more exposed parts of the estuary. Flooding of the small area of low-lying land protected by this stretch of embankment would cause formation of a creek or creeks through the existing salt marsh. The tidal volume of the area would be small and its effects on other parts of the estuary would also be small.

## 10. SUMMARY AND CONCLUSIONS

### 10.1 Morphological change in the estuaries

The most important aspects of estuary hydraulics and sediment transport have been summarised, with particular reference to the Blyth, Alde/Ore and Deben. A methodology for assessing the gross impacts of sea level rise or engineering works has been formulated, based on the simple but well-established regime approach. This method is not well-suited to predicting the time scale or fine detail of morphological change: both of these aspects require a combination of more intensive data collection and modelling, but it provides a practical approach to understanding the overall estuary behaviour.

The main impact of sea level rise in the estuaries is predicted to be erosion of the middle and outer reaches and accretion in the inner estuaries. In cases where there is limited capacity for the estuaries to increase their width, due to the presence of flood protection embankments, this is likely to cause erosion adjacent to these embankments and a consequential increase in the cost of maintaining them. Sea level rise will cause an increase in tidal volume of the estuaries. The amount of this change will depend on the rate at which sediment input can keep pace with the rising sea level.

Managed retreat of flood defences will increase the area of the estuaries and the tidal volume. This will enhance the tidal flow through the parts of the estuaries seaward of any such scheme, which could have similar effects to sea level rise in terms of erosion of flood embankments.

### 10.2 Estuary-coastline interaction

The principal mechanism of interaction between the estuary and the coastline is via the ebb delta shoal which exists at the mouth of all three of the estuaries. Beach material moving along the coast under the influence of waves effectively passes through the delta. An increase in tidal volume of the estuary increases the size of its ebb delta, so there will be a period when a proportion of the littoral drift is trapped in the delta as its size increases. Because the direction of net drift is southward, this could cause erosion of the coast to the south of each estuary mouth, because of the decrease in transport rate.

### 10.3 Extreme water levels

Extreme water levels have been predicted for each estuary based on the monitoring data obtained during the Phase I studies, combined with POL data for extreme coastal water levels. The local data cover a period of approximately one year, which is too short a period for reliable extrapolation to infrequent extreme events, such as the once in ten year or once in one hundred year event. Although the POL data is calculated on a relatively coarse spatial grid around the coast, and so does not provide accurate local detail, it is more reliable for longer term behaviour. Therefore the approach used has taken into account both sources of information.

The best estimate of extreme water levels in each of the three estuaries is given in Tables 17 to 19 for return periods 0.1 year, 1 year, 10 years and 100 years. A rise in sea level of 0.5m would greatly increase the frequency of occurrence of a given water level, by a factor of around 20-25 times.

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# *Figures*

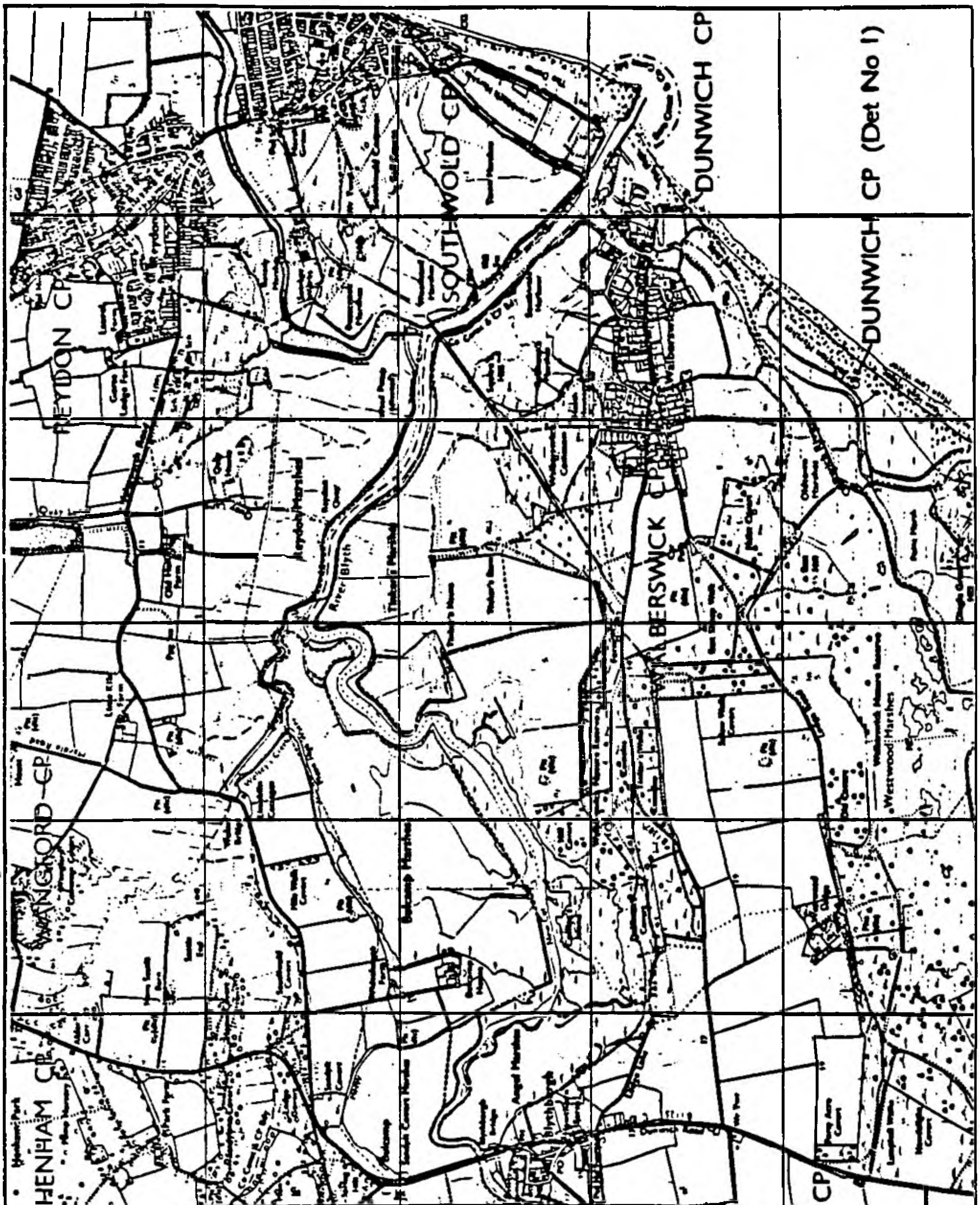



**Figure 1 Blyth Estuary location plan.**

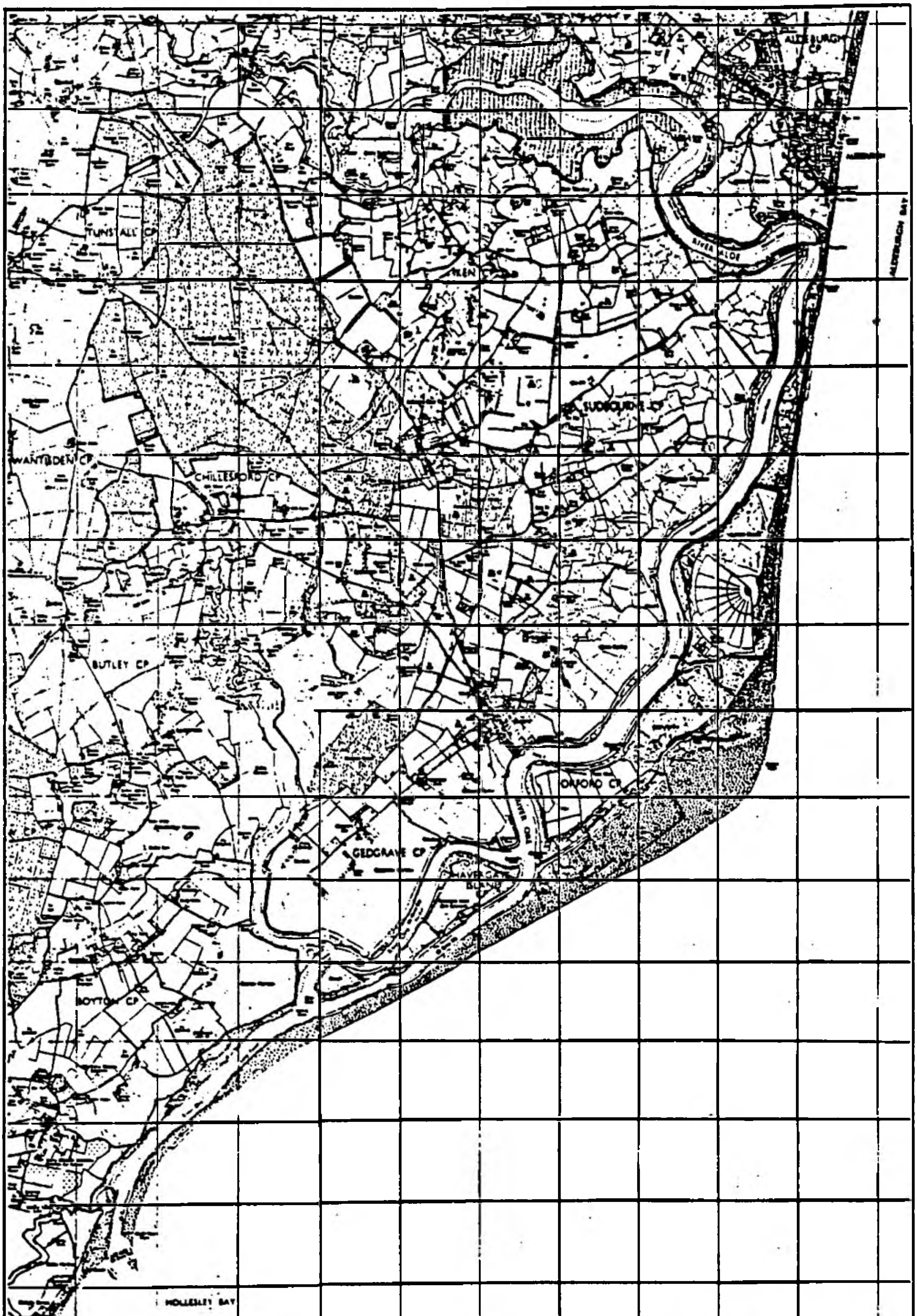



**Figure 2  Alde/Ore Estuary location plan.**

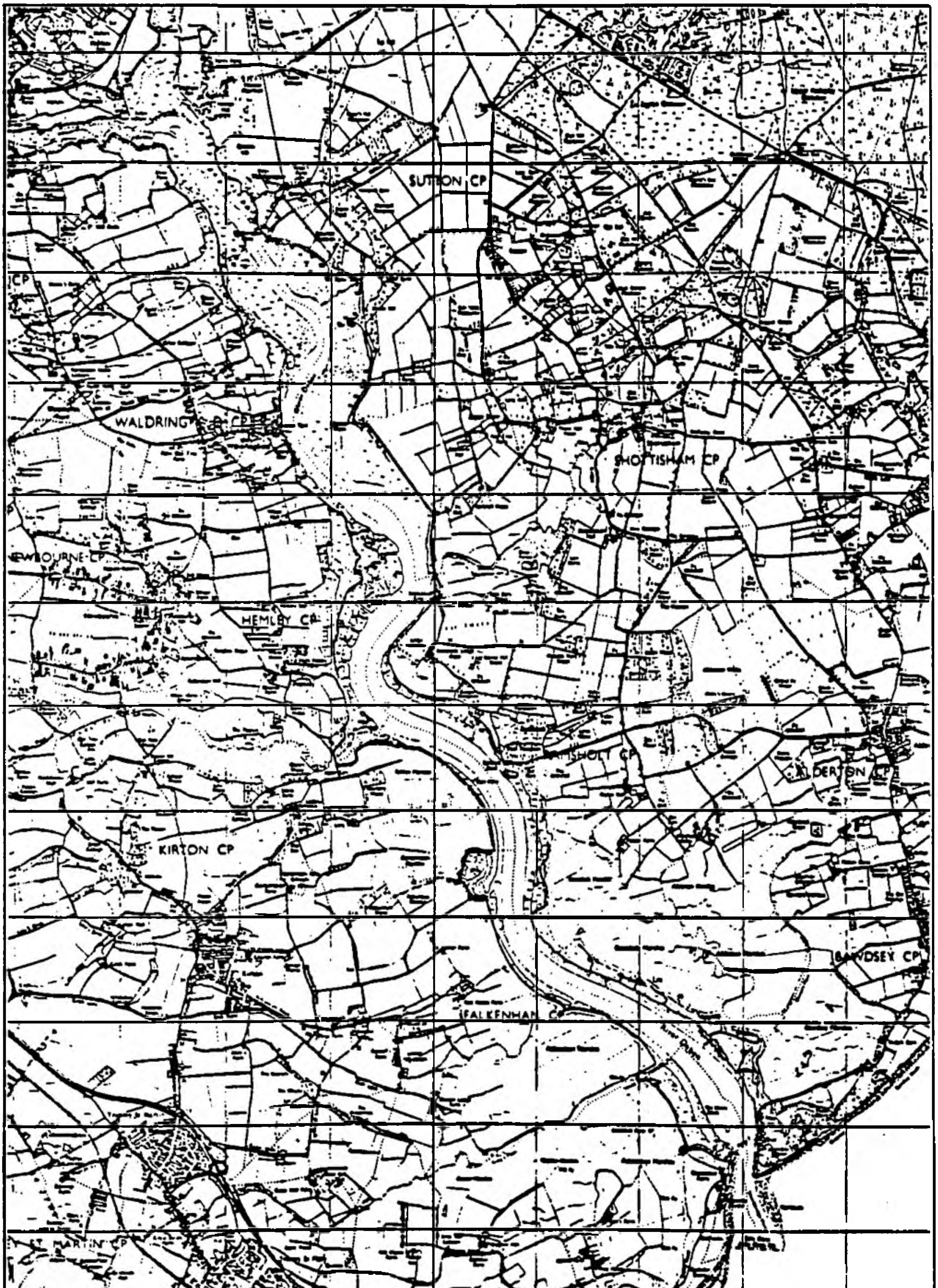



**Figure 3 Deben Estuary location plan.**

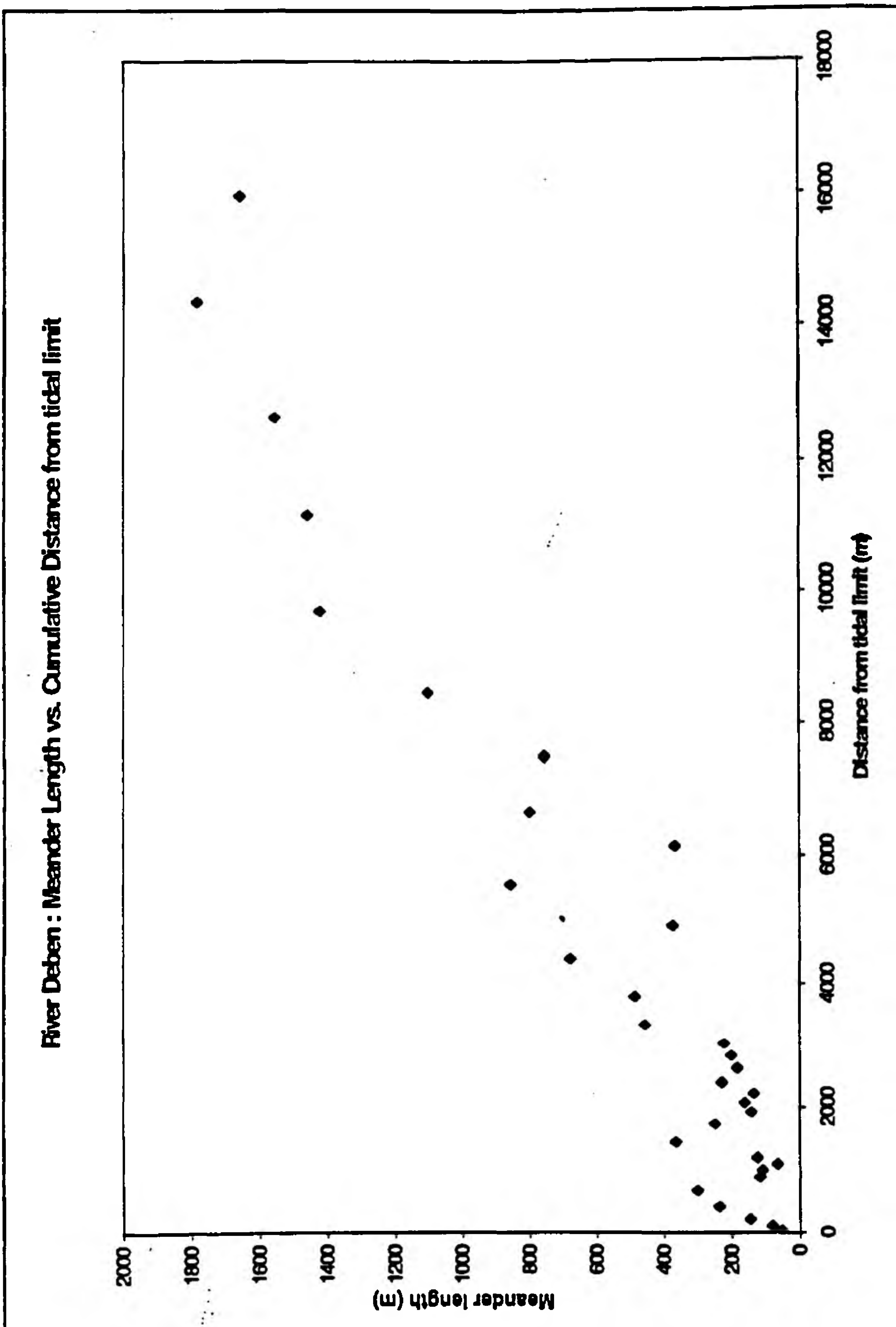
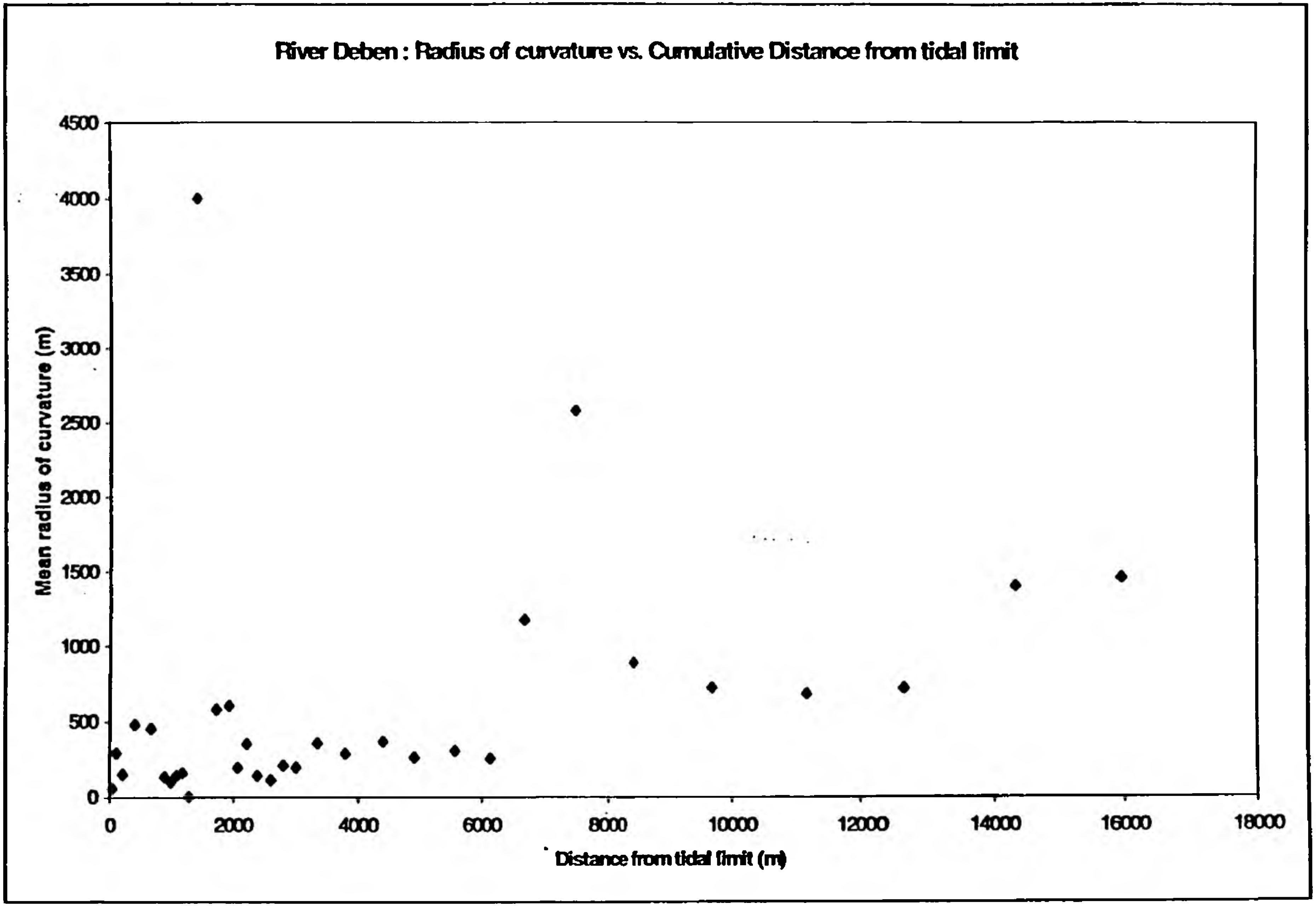



**Figure 4** Length of Deben channel meanders as a function of distance down the estuary

Figure 5 Radius of curvature of the Deben Channel as a function of distance down the estuary.



## APPENDIX C

## FLOOD DEFENCES

CONTENTS

## C1. INTRODUCTION

The aim of this current study is to provide a long term strategy for the estuaries. Inherent to this is the need to examine the defences throughout the estuaries, and changes thereof over a 50 year period for a number of different scenarios. This appendix discusses the development of the defence database, and the key issues in assessing the defences and their performance.

## C2. NEED FOR DATABASE

The strategy for a particular FC considers four potential future flood defence options:

- 'Do Nothing' - abandoning the existing defences
- 'Hold the Line' - maintaining and rebuilding the existing defences
- 'Managed Re-alignment' - replacing the existing defences with new set-back defences
- 'Delay Do Nothing' - maintaining the existing defences, but not rebuilding them

The impacts and timing of each of these options will depend a number of factors relating to the defences, principally those identified below:

- Construction type,
- Standard of protection provided,
- Condition of defence,
- Residual life of defence.

The assessment of these factors, for incorporation into the estuary strategies, is discussed in the following sections.

## C3. SCOPE OF SURVEYS

The estuary strategies, and data taken from various defence surveys, cover the tidal reaches of the three estuaries.

For the River Blyth the tidal limit was taken as the road bridge at Blythford Bridge; for the River Alde/Ore it was taken as the road bridge at Snape; and for the River Deben it was taken as the railway bridge to the northeast of Melton.

## C4. DATA COLLATION

The information used to produce the defence database was obtained from the following sources:

- 1992 Sea Defence Survey, and various updates, giving details of defence type, standard and condition,
- Annual inspections carried out by the Environment Agency, reviewing the overall condition of lengths of defence,
- Discussions held with The Environment Agency's Engineers, regarding specific issues and recent maintenance and capital works,
- Photographs taken and notes made during informal inspections of defences.

## C5. DISCUSSION OF DEFENCE DETAILS

A number of factors have been identified as influencing the performance and cost of a defence. These are discussed below:

### C5.1 Construction Type

#### Earth embankments

The majority of the man made defences in the three estuaries are in the form of earth embankments. This is one of the simplest forms of defence, requiring little specialist machinery or technique. The cost of construction and maintenance can, however, vary greatly, depending on the source of material. Typically such banks were initially constructed using material won locally from the soke dyke to the rear.

The presence of these soke dykes does, however, mean that significant raising of crest levels, such as may be required to account for sea level rise or the need to increase defence standards, can be difficult. This can lead to the re-alignment of the dyke and the subsequent loss of land.

Earth embankments often require regular 'topping up' as the material settles or consolidates in time. This is in addition to any maintenance work required due to erosion. The limitations highlighted above, regarding the amount of crest raising possible, means that the potential to 'top up' may also be restricted. It is estimated that increases to crest level in this manner should probably not be greater than 500mm. Beyond this, the bank may become unstable. As settlement and consolidation may be on-going processes, it is clear that continual 'topping up' is not possible, and therefore major repair work reconstruction will, at some point, be necessary.

In addition to minor maintenance as discussed above, further major repair work to earth embankments will also be required, to protect against erosion and increase stability. Typically this takes the form of the placement of stone or block revetments on the front face, although lengths of sheet piling are also frequently constructed. Although not strictly reconstruction, such works have the purpose of extending the residual life of a defence by up to 20 or 30 years, and so are considered as reconstruction works.

#### Other Defence Types

Throughout the estuaries there are also isolated lengths of sheet pile walls and concrete or masonry walls. These are typically located along the more populated reaches such as the frontages of Southwold Harbour in the Blyth, The Maltings and Slaughden in the Alde/Ore, and Woodbridge in the Deben.

In general these defences require less short term maintenance, but the costs of reconstruction will be greater.

### C5.2 Standard of Defence

The standard of defence is defined as the return period of the water level that the defences are able to provide protection against. The water levels and return periods for each estuary have been investigated by HR Wallingford, and are discussed in more detail in Appendix B. The crest levels of the defences, which are compared against the water levels to produce a return period, were primarily obtained from the Sea Defence Survey and confirmed through discussions held with the Environment Agency and review of the annual inspection reports.

It must be recognised that these return periods, or standards of defence, will change with time. It has been estimated that over the 50 year life span of the strategy sea level rise will result in a reduction in standard by a factor of ten, even if the level of defence remains constant. For example, a defence with a standard of 1 in 50 years in 1999 will have a standard of 1 in 5 years in 2049.

### C5.3 Condition of Defence

This was principally concerned with the front face of the defence, being exposed to the forces of the river. The general categories of 'good', 'fair' or 'poor' give an indication of both the residual life of the defence and the extent of repair or reconstruction necessary.

### C5.4 Residual Life

The residual life of a defence is the number of years that it is likely to remain intact and performing at a satisfactory level. It is, by necessity, an estimation, based on site inspection and the use of engineering judgement. A knowledge of past performance and rates of deterioration of similar defences is also used.

The estimation and use of the residual life of a structure significantly influences the outcome of an economic assessment of the structure. A clear definition is therefore required before the assessment takes place. For this study, two residual life values are considered as follows:

- STANDARD Residual life for Do Nothing:

The length of time which the structure would prevent significant damage to the hinterland if NO FURTHER MAINTENANCE OR REPAIR WORK is carried out – i.e the structure is allowed to deteriorate and fail.

- EXTENDED Residual life with routine maintenance:

The length of time which the structure would prevent significant damage to the hinterland if ROUTINE MAINTENANCE AND REPAIR WORK is carried out. Such repair work would include raising local low points in banks, or replacing damaged sections of blockwork protecting the front face of the bank.

It must be recognised that, whilst routine maintenance and repairs will EXTEND the residual life of a structure, they will not prevent the necessity for major capital works (rebuilding the banks), only delay it. Furthermore, it must be recognised that the residual life is possibly the area of greatest uncertainty, based as it is on the judgement of the condition of the defence and upon the actual occurrence of more extreme conditions. Consistency in the approach taken for each length of defence is essential. In this way, even though residual life is only estimated, the comparison of options relative to one another may be considered reasonably robust.

## C6. DEFENCE DATABASE

Data from the various available sources was collated to form a single database, in a consistent format, covering all three estuaries. This was then used in assessing physical processes and economic impacts throughout the estuaries. The database is shown in Figure C1.

**SUFFOLK ESTUARINE STUDIES**

**River Blyth**

**Flood Defences**

| Comp't | Reference no. | | Location | Length element | sub-element | Existing Defences Type (no.) | (description) | Crest level actual | effective | 1992 Sea Defence Survey Overall Condition | | Residual Life | | Priority 1 hi - 5 low | Urgency 1 hi - 3 low | EA Tidal Bank Inspections I.D | 1996 Tidal Bank Inspections | 1997 Tidal Bank Inspections 1997 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BLYTH North bank of estuary | | | | | | | | | | | | | | | | | |
| | 1300 | 001 | Southwold | 170 | | E | Clay embankment | 3.30 | 3.00 | F | Fair | A | > 5 | 5 | 3 | | | |
| | | 002 | | | 170 | C | Concrete wall | | | F | Fair | A | > 5 | 5 | 3 | | | |
| | 1301 | 001 | Southwold | 750 | | E | Clay embankment | 3.00 | 2.70 | F | Fair | A | > 5 | 5 | 3 | | | |
| | | 002 | | | 150 | C | Concrete wall | | | F | Fair | A | > 5 | 5 | 3 | | | |
| | | 003 | | | 110 | R | Block revetment | | | P | Poor | A | > 5 | 5 | 3 | | | |
| | | 004 | | | 110 | C | Concrete wall | | | F | Fair | A | > 5 | 5 | 3 | | | |
| | 1302 | 001 | Town Marshes | 520 | | E | Clay embankment | 2.50 | 2.30 | F | Fair | A | > 5 | 5 | 3 | | | |
| | | 002 | | | 120 | S | Sheet piling | | | F | Fair | A | > 5 | 5 | 3 | | | |
| | | 003 | | | 130 | C | Concrete wall | | | F | Fair | A | > 5 | 5 | 3 | | | |
| | 1303 | 001 | Buss Creek | 120 | | E | Clay embankment | 2.50 | 2.30 | G | Good | A | > 5 | 5 | 3 | | | |
| | | 002 | | | 120 | P | Stone pitching | | | F | Fair | A | > 5 | 5 | 3 | | | |
| | 1304 | 001 | Reydon | 1150 | | E | Clay embankment | 2.50 | 2.30 | P | Poor | A | > 5 | 5 | 2 | Reydon Marsh | Mostly in fair condition except @ pump - large slips into river & marsh. Recent repairs stillmoving/cracking. Timber piles sinking & falling apart. Whole section V.overgrown - should be cut | ditto |
| | | 002 | | | 90 | C | Concrete wall | | | F | Fair | A | > 5 | 5 | 2 | | | |
| | | 003 | | | 90 | S | Sheet piling | | | F | Fair | A | > 5 | 5 | 2 | | | |
| | | 004 | | | 150 | S | Sheet piling | | | F | Fair | A | > 5 | 5 | 2 | | | |
| | 1305 | 001 | Reydon | 1630 | | E | Clay embankment | 2.30 | 2.10 | P | Poor | A | > 5 | 5 | 2 | | | |
| | | 002 | | | 230 | N | Concrete revetment | | | P | Poor | A | > 5 | 5 | 2 | Lime Kilne | Fair condition throughout. | ditto |
| | | 003 | | | 430 | Q | Stone revetment | | | F | Fair | A | > 5 | 5 | 2 | | | |
| | 1306 | 001 | Wolsey Bridge | 60 | | S | Sheet piling | 2.90 | 2.90 | F | Fair | A | > 5 | 5 | 3 | | | |
| | - | | Bulcamp House | 4400 | | - | N/A | - | - | - | - | - | - | - | - | | | |
| | 1322 | 001 | Blythburgh | 290 | | E | Clay embankment | 2.50 | 2.50 | F | Fair | A | > 5 | 5 | 3 | Blythburgh Marshes U/S of A12 | V.poor condition throughout - piling collapsed, numerous low points which overtop @ high water. Also some cracking on new works. Clay washed out from behind wing walls @ Beaumers Sluice. Whole section V.overgrown | ditto. Also large holes in new works @ Beaumers allowing water in - presence of footpath means public danger |
| | 1307 | 001 | Blythburgh # | 710 | | E | Clay embankment | 1.70 | 1.50 | P | Poor | B | 2 - 5 | 4 | 3 | | | |
| | | 002 | | | 220 | Q | Stone revetment | | | P | Poor | B | 2 - 5 | 4 | 3 | | | |
| | | 003 | | | 60 | S | Sheet piling | | | F | Fair | A | > 5 | 5 | 3 | | | |
| | 1308 | 001 | Blythburgh # | 780 | | E | Clay embankment | 1.50 | 1.30 | P | Poor | A | > 5 | 5 | 3 | | | |
| | | 002 | | | 60 | S | Sheet piling | | | F | Fair | A | > 5 | 5 | 3 | | | |
| | - | | Blythburgh # | 175 | | - | N/A | - | - | - | - | - | - | - | - | | | |
| | 1309 | 001 | Union Farm # | 270 | | E | Clay embankment | 1.70 | 1.50 | P | Poor | A | > 5 | 5 | 3 | | | |
| | 1310 | 001 | Bulcamp # | 800 | | E | Clay embankment | 1.50 | 1.20 | P | Poor | A | > 5 | 5 | 3 | | | |
| | - | - | Blyford # | 800 | | - | N/A | - | - | - | - | - | - | - | - | | | |
| | North bank Source South bank | | | | | | | | | | | | | | | | | |
| | - | | Wennaston # | 900 | | - | N/A | - | - | - | - | - | - | - | - | | | |
| | 1311 | 001 | Blyford # | 60 | | S | Sheet piling | 2.00 | 2.00 | F | Fair | A | > 5 | 5 | 3 | Blythburgh Marshes U/S of A12 | V.poor condition throughout - piling collapsed, numerous low points which overtop @ high water. Also some cracking on new works. Clay washed out from behind wing walls @ Beaumers Sluice. Whole section V.overgrown | ditto. Also large holes in new works @ Beaumers allowing water in - presence of footpath means public danger |
| | 1312 | 001 | Wenhaston # | 140 | | E | Clay embankment | 1.40 | 1.20 | P | Poor | A | > 5 | 5 | 2 | | | |
| | 1313 | 001 | Blowers Common # | 160 | | E | Clay embankment | 1.70 | 1.50 | P | Poor | A | > 5 | 5 | 2 | | | |
| | 1314 | 001 | Blowers Common # | 2020 | | E | Clay embankment | 1.50 | 1.30 | P | Poor | A | > 5 | 5 | 2 | | | |
| | 1315 | 001 | Blythburgh # | 530 | | E | Clay embankment | 1.80 | 1.60 | P | Poor | A | > 5 | 5 | 2 | | | |
| | 1321 | 001 | Blythburgh | 260 | | E | Clay embankment | 2.20 | 2.00 | F | Fair | A | > 5 | 5 | 3 | | | |
| | | 002 | | | 190 | G | Gabions | | | F | Fair | A | > 5 | 5 | 3 | | | |
| | - | | Hill Covert | 3500 | | - | N/A | - | - | - | - | - | - | - | - | | | |
| | 1316 | 001 | Tinkers Marshes | 2080 | | E | Clay embankment | 2.20 | 2.00 | P | Poor | A | > 5 | 5 | 3 | | | U/S end of wall some erosion around groynes, & large holes in them |
| | | 002 | | | 310 | R | Block revetment | | | F | Fair | A | > 5 | 5 | 3 | | | |
| | 1317 | 001 | Tinkers Marshes | 580 | | E | Clay embankment | 2.00 | 1.80 | P | Poor | A | > 5 | 5 | 3 | | Whole section V.overgrown. Fairly poor condition, thin, uneven, low in places. Saltings generally eroding, especially @ C.S 18. Clay washed out behind wing walls @ Tinkers Marsh Sluice. Large hole D/S of groynes. | |
| | 1318 | 001 | Walberswick | 180 | | E | Clay embankment | 2.40 | 2.20 | P | Poor | A | > 5 | 5 | 3 | Tinkers Marsh | | ditto |
| | 1319 | 001 | Walberswick | 680 | | E | Clay embankment | 2.40 | 2.20 | F | Fair | A | > 5 | 5 | 2 | | | |
| | 1320 | 001 | Walberswick | 420 | | E | Clay embankment | 2.70 | 2.50 | F | Fair | A | > 5 | 4 | 3 | | | |
| | - | | Walberswick | 525 | | - | N/A | - | - | - | - | - | - | - | - | | | |
| | South bank of estuary | | ***# denotes outside estuary limits*** | | | | | | | | | | | | | | | |

**Priority** based on assessment of Purpose, Level of Service (or Residual Life), and Benefit / Cost ratio

**Urgency** based on effective standard of protection offered by existing defence

## APPENDIX D

## ECONOMIC ASSESSMENT

CONTENTS

## D1. INTRODUCTION

The aim of this current study is to provide a long term strategy for the estuaries. Inherent to this is the need to examine the potential costs of defence and possible loss of assets over a 50 year period for a number of different scenarios. This appendix sets out the basic premise upon which the economic analysis is undertaken. It discusses the factors involved, and their evaluation.

The strategy for a particular FC considers four potential future flood defence options:

- 'Do Nothing' - abandoning the existing defences
- 'Hold the Line' - maintaining and rebuilding the existing defences
- 'Managed Re-alignment' - replacing the existing defences with new set-back defences
- 'Delay Do Nothing' - maintaining the existing defences, but not rebuilding them

Each of these options will result in either damage to assets within the compartment, maintenance and / or rebuilding works, or a combination thereof. This, in turn, will incur an economic cost which must be evaluated as part of the strategy development.

A number of factors have been identified as having an influence on this evaluation, and these can be split into two basic categories:

- Assets: Land type, level and area
  Property type, level and number

- Defences: Defence length, type, standard, condition and residual life

Costs of damage to assets for an option within a flood compartment and, of defence works necessary to avoid that damage, can be evaluated economically, and compared to assess the appropriateness of the option.

This appendix discusses the methodology of evaluating the assets, and carrying out the economic assessment. Defence type, standard, condition and residual life are discussed in Appendix C of this report.

## D2. ASSET EVALUATION

The assets generally comprise the inherent value of the land within the flood plain, specific assets such as individual properties and, in some cases, the added economic value of land supported by irrigation using freshwater supplies within the flood zone. A detailed identification of assets has been undertaken on a field by field basis. However, average values have been used in attributing value.

The value of assets within a flood plain, and their calculation, is dependant on the type of asset concerned and on the likely frequency or degree of inundation. Within the Suffolk it is assumed that, in the event of defences failing, assets within a particular flood compartment will be permanently lost. The methods of evaluating these assets is discussed below:

Agricultural land:

This category includes land which is, or may potentially in the future be, used for agricultural production. It has been assessed in accordance with MAFF guidance notes (PAGN – Annex G). Damage caused by **frequent flooding or surrender** of land is calculated using prevailing market prices of agricultural land of a similar quality to that at risk, obtained from the Farm Management Pocket Book (Nix), adjusted by a factor of 0.4 in accordance with PAGN.

Properties:

In the case of **frequent flooding or surrender**, it is assumed that the property is written off. A valuation is then based on typical property values obtained from local land valuers and landowners.

From the above assessments, a value or range of values was obtained for each of the categories. This is summarised in Table D.1:

**Table D.1 Valuation of Assets**

| Degree of flooding / Asset | Occasional | Frequent flooding OR surrender of land |
|---|---|---|
| **Land** | | |
| Agricultural | £ 370 / Ha | £ 3,225 / Ha |
| Forest, scrub or woodland | - | £ 3k / Ha |
| Residential or industrial | - | Up to £ 10k / Ha |
| **Properties** | | |
| Residential or public | Up to £ 26k / property | £ 96k / property |
| Industrial | Up to £ 63k / property | £ 100k / property |
| Agricultural | Up to £ 26k / property | £ 144k / property |
| Other | Up to £900k / property | Up to £ 1,850k / structure |

Using these evaluations an assessment of assets within each estuary was made, on a flood compartment basis.

## D3. DEFENCE COSTS

In all cases, apart from the case of "Do Nothing", the cost of defence includes an element of maintenance and an element of reconstruction. Reconstruction may be required because maintenance has become too onerous, because the pressure on the defence is such that more substantial defences would be required or because the level of the defence will need to be raised to match sea level rise.

The derived costs are based on discussion with the Environment Agency's operational staff and upon recent works undertaken within the region. They are, however, necessarily averaged over a period of time for each defence length.

The cost of future works carried out on existing defences is largely dependant on the form of these defences. For the purposes of this assessment it is envisaged that defences will be replaced 'like with like' at the end of their residual life, unless changes in estuarine processes would make this impractical.

It is recognised that, in reality, entire lengths of defence are unlikely to be totally reconstructed or be the subject of minor repairs. A more realistic scenario at the end of a residual life will involve the building up or reinforcement of discrete lengths of the existing defence. Similarly, maintenance is more likely to occur at different discrete locations each year. For the purposes of this study, however, both of these costs can be equated to values per metre run of defence.

For the majority of the Suffolk Estuaries the primary flood defence consists of earth embankments. There are also short lengths of blockwork, concrete wall and sheet piling throughout the estuaries. Standard costs have therefore been developed for each of these types of construction, based on typical values taken from a number of recent projects and schemes of a similar nature.

It is recognised that variations to the cost of defence re-construction and maintenance may also occur, depending on the forces against which such a structure must be designed. Reducing the pressure on an embankment will result in less onerous design requirements on future works, allowing a relative reduction in capital costs. Similarly, an increase in pressure will necessitate higher capital costs. A range of costs for specific structures has been determined. The costs calculated are summarised in Table D.2:

**Table D.2 Typical Defence Re-construction and Maintenance Costs**

| | Re-construction | | Maintenance | |
|---|---|---|---|---|
| Defence Type | Standard Costs (£ per m run) | Range of Costs | Standard Costs (£ per m run) | Range of Costs |
| Earth embankment | 500 | 300 – 900 | 10 | 5 – 20 |
| Concrete wall | 1000 | - | 10 | - |
| Sheet pile wall | 900 | - | 10 | - |

## D4. APPLICATION OF COSTS

The cost of damage to assets and of rebuilding defences is incurred at the end of the residual life of the defence. The estimation and use of the residual life of a structure therefore significantly influences the outcome of an economic assessment of the structure. A clear definition is therefore required before the assessment takes place. For this study, two residual life values are considered as follows:

- STANDARD Residual life for Do Nothing:

The length of time which the structure would prevent significant damage to the hinterland if NO FURTHER MAINTENANCE OR REPAIR WORK is carried out – i.e the structure is allowed to deteriorate and fail.

- EXTENDED Residual life with routine maintenance:

The length of time which the structure would prevent significant damage to the hinterland if ROUTINE MAINTENANCE AND REPAIR WORK is carried out. Such repair work would include raising local low points in banks, or replacing damaged sections of blockwork protecting the front face of the bank.

It must be recognised that, whilst routine maintenance and repairs will EXTEND the residual life of a structure, they will not prevent the necessity for major capital works (rebuilding the banks), only delay it. Furthermore, it must be recognised that the residual life is possibly the area of greatest uncertainty, based as it is on the judgement of the condition of the defence and upon the actual occurrence of more extreme conditions. Consistency in the approach taken for each length of defence is essential. In this way, even though residual life is only estimated, the comparison of options relative to one another may be considered reasonably robust.

There are three elements to the economic assessment which need to be considered:

- Maintenance costs;
- Capital costs (rebuilding);
- Damages – avoided and caused (residual).

Estimated annual maintenance costs are considered as an annuity, over the period between year 0 and the EXTENDED residual life of the structure. At this stage in the strategy development, ongoing minor maintenance such as grass cutting on clay embankments has been omitted from the assessment.

Estimated capital costs are considered as single sums occurring at the end of the EXTENDED residual life of the structure.

Damage is considered as a single sum, or series of sums, occurring at the end of the STANDARD residual life of the structure. It is envisaged that the existing maintenance programme for the estuary will be continued in the near future

Damages with a scheme are always related to the damages which would occur for the Do Nothing case, and so the cost of a defence scheme may be compared with the value of damages avoided.

Some damage to assets behind the defences may also occur before the end of the existing structure's residual life. This is dependant on the standard of the existing defence. For the purposes of this strategy it is assumed that water will overtop a defence with a 1 in 10 year standard every ten years. It is recognised that this is not a true depiction of the probability of return periods. However, for an estuary-wide wide approach it is considered acceptable.

For the purposes this assessment, it is assumed that currently active farmland will only become un-workable, and currently occupied properties will only become uninhabitable at the end of the residual life. Damage occurring before this time is deemed to be temporary. "Do Nothing" damages may, therefore, consist of a series of discounted single sums representing loss of, or damage to, land, crops or property.

## D5. NET PRESENT VALUES

The normal approach to the initial comparison of options, set out in MAFF guidance notes (PAGN), is through their respective benefit cost ratios. This does not, however, reflect the fact that increased investment may result in substantially better benefits and hence the need to consider incremental benefit cost analysis (PAGN decision rule step III) especially when examining whole life strategies. Nor does the benefit cost ratio provide a simple means identifying the transfer of cost, which is fundamental in taking an integrated view of the estuary defences.

The approach, therefore, adopted is to compare options on the basis of their Net Present Value (NPV). This is both a measure of incremental benefit and highlights the deficit or overall economic benefit which may be derived from a specific approach to defence. For each option considered, the NPV is a measure of either the economic advantage or disadvantage in adopting that option compared to a Do Nothing approach.

The calculation of Net Present Values for each option in each FC involves the following stages:

1. Evaluation of actual value of asset
2. Assessment of residual life of defence, delaying the costs
3. Calculation of discount factors
4. Calculation of Present Values
5. Calculation of Net Present Values

$$NPV = PV_{(\text{damage avoided})} - [\, PV_{(\text{capital costs})} + PV_{(\text{maintenance costs})} + PV_{(\text{residual damage caused})}]$$

For a scheme to be economically viable, the NPV must be greater than zero.

The calculation of NPV for FCs is contained in Annex D1.

The economic assessment of options, however, provides only one facet of the overall strategy decision making process. The strategy also takes into account other factors such as the environment, impact on the community and legislation.

## D6. ESTUARY-WIDE STRATEGY

In the development of a strategy for the entire estuary, it may be necessary to select a non economically viable option for an individual area for a number of valid reasons:

- economic impacts - on the whole estuary
- environmental interests & limitations - within the area under investigation
  - in the whole estuary
- impact on or effect of physical process - on the area under investigation
  - on the whole estuary

However, this approach can only be economically justified if the overall NPV is greater than the other options considered. In this way, a management strategy beneficial to the whole estuary is achievable.

## ECONOMIC ASSESSMENT

**ZONE 1 : OPTION 1**

| Flood Compartment | 10 | 11 | 12 | 17 | 18 | |
|---|---|---|---|---|---|---|
| **1/ Defences** | | | | | | |
| Defended length | 2000 | 350 | 1500 | 3850 | 0 | m |
| Residual life for Do Nothing | 3 | 3 | 3 | 3 | 3 | years |
| Residual life if maintained | 10 | 10 | 10 | 10 | 10 | |
| Maintenance costs | 0 | 0 | 0 | 0 | 0 | £/m/yr |
| discount factor F1 | 7.36 | 7.36 | 7.36 | 7.36 | 7.36 | |
| discounted maintenance costs | £0 | £0 | £0 | £0 | £0 | Present Value |
| Reconstruction costs | 0 | 0 | 0 | 0 | 0 | £/m |
| discount factor F2 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 | |
| discounted reconstruction costs | £0 | £0 | £0 | £0 | £0 | Present Value |
| Maintenance of new def | 0 | 0 | 0 | 0 | 0 | £/m/yr |
| discount factor F3 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | |
| discounted maintenance costs | £0 | £0 | £0 | £0 | £0 | Present Value |
| TOTAL DISCOUNTED COSTS | £0 | £0 | £0 | £0 | £0 | Present Value of scheme |
| | TOTAL DISCOUNTED COSTS | | | £0 | | |
| **2/ Assets** | | | | | | |
| Current value | 199,413 | 14,190 | 223,815 | 1,476,774 | 436,995 | £ |
| discount factor F4 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | |
| Discounted assets WRITTEN OFF | **£168,000** | **£12,000** | **£188,000** | **£1,240,000** | **£367,000** | |
| Residual damages | £107,000 | | | | | |
| year occuring | £10 | | | | | |
| discount factor F5 | 0.56 | | | | | |
| discounted residual damages | **£60,000** | | | | | |
| TOTAL DISCOUNTED DAMAGES | **£2,035,000** | | | | | |

**3/ Assessment of Costs**

| | | Do Nothing |
|---|---|---|
| **Costs** | | |
| Maintenance costs (existing) | PVe | 0 |
| Scheme Costs | PVc | 0 |
| Maintenance costs (new) | PVm | 0 |
| Total Costs | PVtc | 0 |
| **Damages** | | |
| Flood damages | PVd | £1,975,000 |
| Residual damages | PVrd | £60,000 |
| Total Damages | PVtd | £2,035,000 |
| **Damages Avoided** | | |
| (Benefits) | PVb | 0 |
| **Net Present Value** | NPV | 0 |

**ECONOMIC ASSESSMENT**

**ZONE 1 : OPTION 2**

| **Flood Compartment** | 10 | 11 | 12 | 17 | 18 | |
|---|---|---|---|---|---|---|
| **1/. Defences** | | | | | | |
| Defended length | 2000 | 350 | 1500 | 3850 | 0 | m |
| Residual life for Do Nothing | 3 | 3 | 3 | 3 | 3 | years |
| Residual life if maintained | 10 | 10 | 10 | 10 | 10 | |
| | | | | | | |
| Maintenance costs | 10 | 10 | 10 | 10 | 10 | £/m/yr |
| discount factor F1 | 7.36 | 7.36 | 7.36 | 7.36 | 7.36 | |
| discounted maintenance costs | £147,200 | £25,760 | £110,400 | £283,360 | £0 | Present Value |
| | | | | | | |
| Reconstruction costs | 500 | 500 | 500 | 500 | 500 | £/m |
| discount factor F2 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 | |
| discounted reconstruction costs | £560,000 | £98,000 | £420,000 | £1,078,000 | £0 | Present Value |
| | | | | | | |
| Maintenance of new def | 1 | 1 | 1 | 1 | 0 | £/m/yr |
| discount factor F3 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | |
| discounted maintenance costs | £4,200 | £4,200 | £4,200 | £4,200 | £0 | Present Value |
| | | | | | | |
| TOTAL DISCOUNTED COSTS | **£711,000** | **£128,000** | **£535,000** | **£1,368,000** | **£0** | Present Value of scheme |
| | TOTAL DISCOUNTED COSTS | | | **£2,740,000** | | |
| **2/ Assets** | | | | | | |
| Current value of assets | 0 | 0 | 0 | 0 | 0 | £ |
| discount factor F4 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | |
| Discounted assets WRITTEN OFF | **£0** | **£0** | **£0** | **£0** | **£0** | |
| | | | | | | |
| Residual damages | £50,000 | (habitat management) | | | | |
| year occuring | 3 | | | | | |
| discount factor F5 | 0.84 | | | | | |
| discounted residual damages | **£42,000** | | | | | |
| | | | | | | |
| TOTAL DISCOUNTED DAMAGES | **£42,000** | | | | | |

**3/ Assessment of Costs**

| | | **Do Nothing** | **Scheme (HTL)** |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £567,000 |
| Scheme Costs | PVc | 0 | £2,156,000 |
| Maintenance costs (new) | PVm | 0 | £17,000 |
| Total Costs | PVtc | 0 | £2,740,000 |
| **Damages** | | | |
| Flood damages | PVd | £1,975,000 | 0 |
| Residual damages | PVrd | £60,000 | 0 |
| Total Damages | PVtd | £2,035,000 | 0 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 2,035,000 |
| **Net Present Value** | NPV | 0 | **-£705,000** |

**ECONOMIC ASSESSMENT**

**ZONE 1 : OPTION 3**

| Flood Compartment | 10 | 11 | 12 | 17 | 18 | |
|---|---|---|---|---|---|---|
| **1/ Defences** | | | | | | |
| Defended length | 2000 | 350 | 1500 | 3850 | 500 | m |
| Residual life for Do Nothing | 3 | 3 | 3 | 3 | 3 | years |
| Residual life if maintained | 10 | 10 | 10 | 10 | 0 | |
| Maintenance costs | 0 | 0 | 0 | 0 | 0 | £/m/yr |
| discount factor F1 | 7.36 | 7.36 | 7.36 | 7.36 | 1 | |
| discounted maintenance costs | £0 | £0 | £0 | £0 | £0 | Present Value |
| Reconstruction costs | 0 | 0 | 0 | 0 | 500 | £/m |
| discount factor F2 | 0.56 | 0.56 | 0.56 | 0.56 | 1 | |
| discounted reconstruction costs | £0 | £0 | £0 | £0 | £250,000 | Present Value |
| Maintenance of new def | 1 | 1 | 1 | 1 | 1 | £/m/yr |
| discount factor F3 | 8.4 | 8.4 | 8.4 | 8.4 | 14.76 | |
| discounted maintenance costs | £0 | £0 | £0 | £0 | £7,380 | Present Value |
| TOTAL DISCOUNTED COSTS | £0 | £0 | £0 | £0 | £257,000 | Present Value of scheme |
| | TOTAL DISCOUNTED COSTS | | | £257,000 | | |

| **2/ Assets** | 10 | 11 | 12 | 17 | 18 | |
|---|---|---|---|---|---|---|
| Current value of assets lost | 199,413 | 14,190 | 223,815 | 1,476,774 | 0 | £ |
| discount factor F4 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | |
| Discounted assets WRITTEN OFF | **£168,000** | **£12,000** | **£188,000** | **£1,240,000** | **£0** | |
| Residual damages | £107,000 | | | | | |
| year occuring | £10 | | | | | |
| discount factor F5 | 0.56 | | | | | |
| discounted residual damages | **£60,000** | | | | | |
| TOTAL DISCOUNTED DAMAGES | **£1,668,000** | | | | | |

**3/ Assessment of Costs**

| | | Do Nothing | Scheme (HTL) |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £0 |
| Scheme Costs | PVc | 0 | £250,000 |
| Maintenance costs (new) | PVm | 0 | £7,000 |
| Total Costs | PVtc | 0 | £257,000 |
| **Damages** | | | |
| Flood damages | PVd | £1,975,000 | £1,608,000 |
| Residual damages | PVrd | £60,000 | £60,000 |
| Total Damages | PVtd | £2,035,000 | 1,668,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 367,000 |
| **Net Present Value** | NPV | 0 | **£110,000** |

**ECONOMIC ASSESSMENT**

**ZONE 1 : OPTION 4**

| Flood Compartment | 10 | 11 | 12 | 17 | 18 | |
|---|---|---|---|---|---|---|
| **1/ Defences** | | | | | | |
| Defended length | 2000 | 350 | 1500 | 3850 | 0 | m |
| Residual life for Do Nothing | 10 | 10 | 10 | 10 | 10 | years |
| Residual life if maintained | 10 | 10 | 10 | 10 | 10 | |
| Maintenance costs | 10 | 10 | 10 | 10 | 0 | £/m/yr |
| discount factor F1 | 7.36 | 7.36 | 7.36 | 7.36 | 7.36 | |
| discounted maintenance costs | £147,200 | £25,760 | £110,400 | £283,360 | £0 | Present Value |
| Reconstruction costs | 0 | 0 | 0 | 0 | 0 | £/m |
| discount factor F2 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 | |
| discounted reconstruction costs | £0 | £0 | £0 | £0 | £0 | Present Value |
| Maintenance of new def | 1 | 1 | 1 | 1 | 1 | £/m/yr |
| discount factor F3 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | |
| discounted maintenance costs | £0 | £0 | £0 | £0 | £0 | Present Value |
| TOTAL DISCOUNTED COSTS | **£147,000** | **£26,000** | **£110,000** | **£283,000** | **£0** | Present Value of scheme |
| | TOTAL DISCOUNTED COSTS | | | **£566,000** | | |
| **2/ Assets** | | | | | | |
| Current value of assets lost | 199,413 | 14,190 | 223,815 | 1,476,774 | 436,995 | £ |
| discount factor F4 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 | |
| Discounted assets WRITTEN OFF | **£112,000** | **£8,000** | **£125,000** | **£827,000** | **£245,000** | |
| Residual damages | £107,000 | | | | | |
| year occuring | £10 | | | | | |
| discount factor F5 | 0.56 | | | | | |
| discounted residual damages | **£60,000** | | | | | |
| TOTAL DISCOUNTED DAMAGES | **£1,377,000** | | | | | |

**3/ Assessment of Costs**

| | | Do Nothing | Scheme (HTL) |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £567,000 |
| Scheme Costs | PVc | 0 | £0 |
| Maintenance costs (new) | PVm | 0 | £0 |
| Total Costs | PVtc | 0 | £567,000 |
| **Damages** | | | |
| Flood damages | PVd | £1,975,000 | £1,317,000 |
| Residual damages | PVrd | £60,000 | £60,000 |
| Total Damages | PVtd | £2,035,000 | 1,377,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 658,000 |
| **Net Present Value** | **NPV** | **0** | **£91,000** |

## ECONOMIC ASSESSMENT

**ZONE 1 : OPTION 5**

| Flood Compartment | 10 | 11 | 12 | 17 | 18 | |
|---|---|---|---|---|---|---|
| **1/ Defences** | | | | | | |
| Defended length | 2000 | 350 | 1500 | 3850 | 0 | m |
| Residual life for Do Nothing | 3 | 3 | 3 | 10 | 10 | years |
| Residual life if maintained | 10 | 10 | 10 | 10 | 10 | |
| Maintenance costs | 0 | 0 | 0 | 10 | 0 | £/m/yr |
| discount factor F1 | 7.36 | 7.36 | 7.36 | 7.36 | 7.36 | |
| discounted maintenance costs | £0 | £0 | £0 | £283,360 | £0 | Present Value |
| Reconstruction costs | 0 | 0 | 0 | 0 | 0 | £/m |
| discount factor F2 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 | |
| discounted reconstruction costs | £0 | £0 | £0 | £0 | £0 | Present Value |
| Maintenance of new def | 1 | 1 | 1 | 1 | 1 | £/m/yr |
| discount factor F3 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | |
| discounted maintenance costs | £0 | £0 | £0 | £0 | £0 | Present Value |
| TOTAL DISCOUNTED COSTS | £0 | £0 | £0 | £283,000 | £0 | Present Value of scheme |
| | TOTAL DISCOUNTED COSTS | | | £283,000 | | |
| **2/ Assets** | | | | | | |
| Current value of assets lost | 199,413 | 14,190 | 223,815 | 1,476,774 | 436,995 | £ |
| discount factor F4 | 0.84 | 0.84 | 0.84 | 0.56 | 0.56 | |
| Discounted assets WRITTEN OFF | £168,000 | £12,000 | £188,000 | £827,000 | £245,000 | |
| Residual damages | £107,000 | | | | | |
| year occuring | £10 | | | | | |
| discount factor F5 | 0.56 | | | | | |
| discounted residual damages | £60,000 | | | | | |
| TOTAL DISCOUNTED DAMAGES | £1,500,000 | | | | | |

**3/ Assessment of Costs**

| | | Do Nothing | Scheme (HTL) |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £283,000 |
| Scheme Costs | PVc | 0 | £0 |
| Maintenance costs (new) | PVm | 0 | £0 |
| Total Costs | PVtc | 0 | £283,000 |
| **Damages** | | | |
| Flood damages | PVd | £1,975,000 | £1,440,000 |
| Residual damages | PVrd | £60,000 | £60,000 |
| Total Damages | PVtd | £2,035,000 | 1,500,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 535,000 |
| **Net Present Value** | NPV | 0 | £252,000 |

**ECONOMIC ASSESSMENT**

**ZONE 1 : OPTION 6**

| **Flood Compartment** | 10 | 11 | 12 | 17 | 18 | |
|---|---|---|---|---|---|---|
| **1/ Defences** | | | | | | |
| Defended length | 2000 | 350 | 1500 | 3850 | 500 | m |
| Residual life for Do Nothing | 3 | 3 | 3 | 10 | 10 | years |
| Residual life if maintained | 10 | 10 | 10 | 10 | 10 | |
| Maintenance costs | 0 | 0 | 0 | 10 | 0 | £/m/yr |
| discount factor F1 | 7.36 | 7.36 | 7.36 | 7.36 | 7.36 | |
| discounted maintenance costs | £0 | £0 | £0 | £283,360 | £0 | Present Value |
| Reconstruction costs | 0 | 0 | 0 | 0 | 500 | £/m |
| discount factor F2 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 | |
| discounted reconstruction costs | £0 | £0 | £0 | £0 | £140,000 | Present Value |
| Maintenance of new def | 1 | 1 | 1 | 1 | 1 | £/m/yr |
| discount factor F3 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | |
| discounted maintenance costs | £0 | £0 | £0 | £0 | £4,200 | Present Value |
| TOTAL DISCOUNTED COSTS | **£0** | **£0** | **£0** | **£283,000** | **£144,000** | Present Value of scheme |
| | TOTAL DISCOUNTED COSTS | | | **£427,000** | | |
| **2/ Assets** | | | | | | |
| Current value of assets lost | 199,413 | 14,190 | 223,815 | 1,476,774 | 0 | £ |
| discount factor F4 | 0.84 | 0.84 | 0.84 | 0.56 | 0.56 | |
| Discounted assets WRITTEN OFF | **£168,000** | **£12,000** | **£188,000** | **£827,000** | **£0** | |
| Residual damages | £107,000 | | | | | |
| year occuring | £10 | | | | | |
| discount factor F5 | 0.56 | | | | | |
| discounted residual damages | **£60,000** | | | | | |
| TOTAL DISCOUNTED DAMAGES | **£1,255,000** | | | | | |

**3/ Assessment of Costs**

| | | **Do Nothing** | **Scheme (HTL)** |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £283,000 |
| Scheme Costs | PVc | 0 | £140,000 |
| Maintenance costs (new) | PVm | 0 | £4,000 |
| Total Costs | PVtc | 0 | £427,000 |
| **Damages** | | | |
| Flood damages | PVd | £1,975,000 | £1,195,000 |
| Residual damages | PVrd | £60,000 | £60,000 |
| Total Damages | PVtd | £2,035,000 | 1,255,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 780,000 |
| **Net Present Value** | NPV | 0 | £353,000 |

## ECONOMIC ASSESSMENT

### ZONE 1 : OPTION 7

| Flood Compartment | 10 | 11 | 12 | 17 | 18 | barrier | |
|---|---|---|---|---|---|---|---|
| **1/ Defences** | | | | | | | |
| Defended length | 2000 | 350 | 1500 | 3850 | 0 | 1 | m |
| Residual life for Do Nothing | 3 | 3 | 3 | 3 | 3 | 3 | years |
| Residual life if maintained | 10 | 10 | 10 | 10 | 10 | 10 | |
| Maintenance costs | 5 | 5 | 5 | 5 | 0 | 0 | £/m/yr |
| discount factor F1 | 7.36 | 7.36 | 7.36 | 7.36 | 7.36 | 7.36 | |
| discounted maintenance costs | £73,600 | £12,880 | £55,200 | £141,880 | £0 | £0 | Present Value |
| Reconstruction costs | 300 | 300 | 300 | 300 | 300 | 1000000 | £/m |
| discount factor F2 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 | |
| discounted reconstruction costs | £336,000 | £58,800 | £252,000 | £646,800 | £0 | £560,000 | Present Value |
| Maintenance of new def | 1 | 0 | 0 | 0 | 0 | 0 | £/m/yr |
| discount factor F3 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | 8.4 | |
| discounted maintenance costs | £2,520 | £0 | £0 | £0 | £0 | £0 | Present Value |
| TOTAL DISCOUNTED COSTS | £412,000 | £72,000 | £307,000 | £788,000 | £0 | £560,000 | Present Value of scheme |
| | TOTAL DISCOUNTED COSTS | | | £2,139,000 | | | |
| **2/ Assets** | | | | | | | |
| Current value of assets | 0 | 0 | 0 | 0 | 0 | £ | |
| discount factor F4 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | | |
| Discounted assets WRITTEN OFF | £0 | £0 | £0 | £0 | £0 | | |
| Residual damages | £50,000 | (habitat management) | | | | | |
| year occuring | 3 | | | | | | |
| discount factor F5 | 0.84 | | | | | | |
| discounted residual damages | £42,000 | | | | | | |
| TOTAL DISCOUNTED DAMAGES | £42,000 | | | | | | |

**3/ Assessment of Costs**

| | | Do Nothing | Scheme (HTL) |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £283,000 |
| Scheme Costs | PVc | 0 | £1,854,000 |
| Maintenance costs (new) | PVm | 0 | £3,000 |
| Total Costs | PVtc | 0 | £2,140,000 |
| **Damages** | | | |
| Flood damages | PVd | £1,975,000 | £0 |
| Residual damages | PVrd | £60,000 | £42,000 |
| Total Damages | PVtd | £2,035,000 | 42,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 1,993,000 |
| **Net Present Value** | NPV | 0 | -£147,000 |

**ECONOMIC ASSESSMENT**

**ZONE 2 : OPTION 1**

| | | |
|---|---|---|
| **Flood Compartment** | 9 | |
| **1/ Defences** | | |
| Defended length | 500 | m |
| Residual life for Do Nothing | 15 | years |
| Residual life if maintained | 25 | |
| | | |
| Maintenance costs | 0 | £/m/yr |
| discount factor F1 | 12.78 | |
| discounted maintenance costs | £0 | Present Value |
| | | |
| Reconstruction costs | 0 | £/m |
| discount factor F2 | 0.23 | |
| discounted reconstruction costs | £0 | Present Value |
| | | |
| Maintenance of new def | 0 | £/m/yr |
| discount factor F3 | 2.98 | |
| discounted maintenance costs | £0 | Present Value |
| | | |
| TOTAL DISCOUNTED COSTS | £0 | Present Value of scheme |
| | | |
| **2/ Assets** | | |
| Current value | 575,853 | £ |
| discount factor F4 | 0.42 | |
| Discounted assets WRITTEN OFF | £242,000 | |
| | | |
| Residual damages | £0 | |
| year occuring | £0 | |
| discount factor F5 | 1 | |
| discounted residual damages | £0 | |
| | | |
| TOTAL DISCOUNTED DAMAGES | £242,000 | |

**3/ Assessment of Costs**

| | | Do Nothing |
|---|---|---|
| **Costs** | | |
| Maintenance costs (existing) | Pve | 0 |
| Scheme Costs | PVc | 0 |
| Maintenance costs (new) | PVm | 0 |
| Total Costs | PVtc | 0 |
| **Damages** | | |
| Flood damages | PVd | £242,000 |
| Residual damages | PVrd | £0 |
| Total Damages | PVtd | £242,000 |
| **Damages Avoided** | | |
| (Benefits) | PVb | 0 |
| **Net Present Value** | NPV | 0 |

## ECONOMIC ASSESSMENT

### ZONE 2 : OPTION 4

| | | |
|---|---|---|
| **Flood Compartment** | 9 | |
| **1/ Defences** | | |
| Defended length | 500 | m |
| Residual life for Do Nothing | 15 | years |
| Residual life if maintained | 25 | |
| Maintenance costs | 10 | £/m/yr |
| discount factor F1 | 12.78 | |
| discounted maintenance costs | £63,900 | Present Value |
| Reconstruction costs | 500 | £/m |
| discount factor F2 | 0.23 | |
| discounted reconstruction costs | £57,500 | Present Value |
| Maintenance of new def | 1 | £/m/yr |
| discount factor F3 | 2.98 | |
| discounted maintenance costs | £1,490 | Present Value |
| TOTAL DISCOUNTED COSTS | £123,000 | Present Value of scheme |
| **2/ Assets** | | |
| Current value of assets | 0 | £ |
| discount factor F4 | 0.42 | |
| Discounted assets WRITTEN OFF | **£0** | |
| Residual damages | £0 | |
| year occuring | £0 | |
| discount factor F5 | 1 | |
| discounted residual damages | **£0** | |
| TOTAL DISCOUNTED DAMAGES | **£0** | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £64,000 |
| Scheme Costs | PVc | 0 | £58,000 |
| Maintenance costs (new) | PVm | 0 | £1,000 |
| Total Costs | PVtc | 0 | £123,000 |
| **Damages** | | | |
| Flood damages | PVd | £242,000 | £0 |
| Residual damages | PVrd | £0 | £0 |
| Total Damages | PVtd | £242,000 | 0 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £242,000 |
| **Net Present Value** | NPV | 0 | £119,000 |

**ECONOMIC ASSESSMENT**

**ZONE 2 : OPTION 2**

| | | |
|---|---|---|
| **Flood Compartment** | 16 | |
| **1/ Defences** | | |
| Defended length | 260 | m |
| Residual life for Do Nothing | 15 | years |
| Residual life if maintained | 20 | |
| Maintenance costs | 0 | £/m/yr |
| discount factor F1 | 11.47 | |
| discounted maintenance costs | £0 | Present Value |
| Reconstruction costs | 0 | £/m |
| discount factor F2 | 0.31 | |
| discounted reconstruction costs | £0 | Present Value |
| Maintenance of new def | 0 | £/m/yr |
| discount factor F3 | 4.29 | |
| discounted maintenance costs | £0 | Present Value |
| TOTAL DISCOUNTED COSTS | £0 | Present Value of scheme |
| **2/ Assets** | | |
| Current value | 233,400 | £ |
| discount factor F4 | 0.42 | |
| Discounted assets WRITTEN OFF | **£98,000** | |
| Residual damages | £0 | |
| year occuring | £0 | |
| discount factor F5 | 1 | |
| discounted residual damages | £0 | |
| TOTAL DISCOUNTED DAMAGES | **£98,000** | |

**3/ Assessment of Costs**

| | | Do Nothing |
|---|---|---|
| **Costs** | | |
| Maintenance costs (existing) | Pve | 0 |
| Scheme Costs | PVc | 0 |
| Maintenance costs (new) | PVm | 0 |
| Total Costs | PVtc | 0 |
| **Damages** | | |
| Flood damages | PVd | £98,000 |
| Residual damages | PVrd | £0 |
| Total Damages | PVtd | £98,000 |
| **Damages Avoided** | | |
| (Benefits) | PVb | 0 |
| **Net Present Value** | NPV | 0 |

## ECONOMIC ASSESSMENT

**ZONE 2 : OPTION 5**

**Flood Compartment** 16

**1/ Defences**

| | | |
|---|---|---|
| Defended length | 260 | m |
| Residual life for Do Nothing | 15 | years |
| Residual life if maintained | 20 | |
| | | |
| Maintenance costs | 10 | £/m/yr |
| discount factor F1 | 11.47 | |
| discounted maintenance costs | £29,822 | Present Value |
| | | |
| Reconstruction costs | 500 | £/m |
| discount factor F2 | 0.31 | |
| discounted reconstruction costs | £40,300 | Present Value |
| | | |
| Maintenance of new def | 1 | £/m/yr |
| discount factor F3 | 4.29 | |
| discounted maintenance costs | £2,145 | Present Value |
| | | |
| TOTAL DISCOUNTED COSTS | £72,000 | Present Value of scheme |

**2/ Assets**

| | | |
|---|---|---|
| Current value of assets | 0 | £ |
| discount factor F4 | 0.42 | |
| Discounted assets WRITTEN OFF | £0 | |
| | | |
| Residual damages | £0 | |
| year occuring | £0 | |
| discount factor F5 | 1 | |
| discounted residual damages | £0 | |
| | | |
| TOTAL DISCOUNTED DAMAGES | £0 | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £30,000 |
| Scheme Costs | PVc | 0 | £40,000 |
| Maintenance costs (new) | PVm | 0 | £2,000 |
| Total Costs | PVtc | 0 | £72,000 |
| **Damages** | | | |
| Flood damages | PVd | £98,000 | £0 |
| Residual damages | PVrd | £0 | £0 |
| Total Damages | PVtd | £98,000 | 0 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £98,000 |
| **Net Present Value** | NPV | 0 | £26,000 |

**ECONOMIC ASSESSMENT**

**ZONE 2 : OPTION 3**

**Flood Compartment** 15

**1/ Defences**

| | | |
|---|---|---|
| Defended length | 1000 | m |
| Residual life for Do Nothing | 2 | years |
| Residual life if maintained | 10 | |
| | | |
| Maintenance costs | 0 | £/m/yr |
| discount factor F1 | 7.38 | |
| discounted maintenance costs | £0 | Present Value |
| | | |
| Reconstruction costs | 0 | £/m |
| discount factor F2 | 0.56 | |
| discounted reconstruction costs | £0 | Present Value |
| | | |
| Maintenance of new def | 0 | £/m/yr |
| discount factor F3 | 8.4 | |
| discounted maintenance costs | £0 | Present Value |
| | | |
| TOTAL DISCOUNTED COSTS | £0 | Present Value of scheme |

**2/ Assets**

| | | |
|---|---|---|
| Current value | 170,175 | £ |
| discount factor F4 | 0.89 | |
| Discounted assets WRITTEN OFF | **£151,000** | |
| | | |
| Residual damages | £0 | |
| year occuring | £0 | |
| discount factor F5 | 1 | |
| discounted residual damages | **£0** | |
| | | |
| TOTAL DISCOUNTED DAMAGES | **£151,000** | |

**3/ Assessment of Costs**

| | | **Do Nothing** |
|---|---|---|
| **Costs** | | |
| Maintenance costs (existing) | Pve | 0 |
| Scheme Costs | PVc | 0 |
| Maintenance costs (new) | PVm | 0 |
| Total Costs | PVtc | 0 |
| **Damages** | | |
| Flood damages | PVd | £151,000 |
| Residual damages | PVrd | £0 |
| Total Damages | PVtd | £151,000 |
| **Damages Avoided** | | |
| (Benefits) | PVb | 0 |
| **Net Present Value** | **NPV** | **0** |

## ECONOMIC ASSESSMENT

**ZONE 2 : OPTION 7**

| | | |
|---|---|---|
| **Flood Compartment** | 15 | |
| **1/ Defences** | | |
| Defended length | 1000 | m |
| Residual life for Do Nothing | 2 | years |
| Residual life if maintained | 5 | |
| Maintenance costs | 12 | £/m/yr |
| discount factor F1 | 4.21 | |
| discounted maintenance costs | £50,520 | Present Value |
| Reconstruction costs | 600 | £/m |
| discount factor F2 | 0.75 | |
| discounted reconstruction costs | £450,000 | Present Value |
| Maintenance of new def | 1 | £/m/yr |
| discount factor F3 | 11.55 | |
| discounted maintenance costs | £6,930 | Present Value |
| TOTAL DISCOUNTED COSTS | £507,000 | Present Value of scheme |
| **2/ Assets** | | |
| Current value of assets | 0 | £ |
| discount factor F4 | 0.89 | |
| Discounted assets WRITTEN OFF | £0 | |
| Residual damages | £0 | |
| year occuring | £0 | |
| discount factor F5 | 1 | |
| discounted residual damages | £0 | |
| TOTAL DISCOUNTED DAMAGES | £0 | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £51,000 |
| Scheme Costs | PVc | 0 | £450,000 |
| Maintenance costs (new) | PVm | 0 | £7,000 |
| Total Costs | PVtc | 0 | £508,000 |
| **Damages** | | | |
| Flood damages | PVd | £151,000 | £0 |
| Residual damages | PVrd | £0 | £0 |
| Total Damages | PVtd | £151,000 | 0 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £151,000 |
| **Net Present Value** | NPV | 0 | -£357,000 |

**ECONOMIC ASSESSMENT**

**ZONE 2 : OPTION 6**

| | | |
|---|---|---|
| **Flood Compartment** | 15 | |
| **1/ Defences** | | |
| Defended length | 1000 | m |
| Residual life for Do Nothing | 2 | years |
| Residual life if maintained | 10 | |
| | | |
| Maintenance costs | 10 | £/m/yr |
| discount factor F1 | 7.36 | |
| discounted maintenance costs | £73,600 | Present Value |
| | | |
| Reconstruction costs | 600 | £/m |
| discount factor F2 | 0.56 | |
| discounted reconstruction costs | £336,000 | Present Value |
| | | |
| Maintenance of new def | 1 | £/m/yr |
| discount factor F3 | 8.4 | |
| discounted maintenance costs | £5,040 | Present Value |
| | | |
| TOTAL DISCOUNTED COSTS | £415,000 | Present Value of scheme |
| | | |
| **2/ Assets** | | |
| Current value of assets | 0 | £ |
| discount factor F4 | 0.89 | |
| Discounted assets WRITTEN OFF | **£0** | |
| | | |
| Residual damages | £0 | |
| year occuring | £0 | |
| discount factor F5 | 1 | |
| discounted residual damages | **£0** | |
| | | |
| TOTAL DISCOUNTED DAMAGES | **£0** | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £74,000 |
| Scheme Costs | PVc | 0 | £336,000 |
| Maintenance costs (new) | PVm | 0 | £5,000 |
| Total Costs | PVtc | 0 | £415,000 |
| **Damages** | | | |
| Flood damages | PVd | £151,000 | £0 |
| Residual damages | PVrd | £0 | £0 |
| Total Damages | PVtd | £151,000 | 0 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £151,000 |
| **Net Present Value** | NPV | 0 | -£264,000 |

## ECONOMIC ASSESSMENT

**ZONE 2 : OPTION 8**

**Flood Compartment** 15

### 1/ Defences

| | | |
|---|---|---|
| Defended length | 1000 | m |
| Residual life for Do Nothing | 10 | years |
| Residual life if maintained | 10 | |
| | | |
| Maintenance costs | 10 | £/m/yr |
| discount factor F1 | 7.36 | |
| discounted maintenance costs | £73,600 | Present Value |
| | | |
| Reconstruction costs | 0 | £/m |
| discount factor F2 | 0.56 | |
| discounted reconstruction costs | £0 | Present Value |
| | | |
| Maintenance of new def | 1 | £/m/yr |
| discount factor F3 | 8.4 | |
| discounted maintenance costs | £0 | Present Value |
| | | |
| TOTAL DISCOUNTED COSTS | £74,000 | Present Value of scheme |

### 2/ Assets

| | | |
|---|---|---|
| Current value of assets LOST | 96,000 | £ |
| discount factor F4 | 0.56 | |
| Discounted assets WRITTEN OFF | £54,000 | |
| | | |
| Residual damages | £0 | |
| year occuring | 0 | |
| discount factor F5 | 1 | |
| discounted residual damages | £0 | |
| | | |
| TOTAL DISCOUNTED DAMAGES | £54,000 | |

### 3/ Assessment of Costs

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £74,000 |
| Scheme Costs | PVc | 0 | £0 |
| Maintenance costs (new) | PVm | 0 | £0 |
| Total Costs | PVtc | 0 | £74,000 |
| **Damages** | | | |
| Flood damages | PVd | £151,000 | £54,000 |
| Residual damages | PVrd | £0 | £0 |
| Total Damages | PVtd | £151,000 | £54,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £97,000 |
| **Net Present Value** | NPV | 0 | £23,000 |

**ECONOMIC ASSESSMENT**

**ZONE 2 : OPTION 9**

| | | |
|---|---|---|
| **Flood Compartment** | **15** | |
| **1/ Defences** | | |
| Defended length | 1000 | m |
| Residual life for Do Nothing | 5 | years |
| Residual life if maintained | 5 | |
| Maintenance costs | 15 | £/m/yr |
| discount factor F1 | 4.21 | |
| discounted maintenance costs | £63,150 | Present Value |
| Reconstruction costs | 0 | £/m |
| discount factor F2 | 0.75 | |
| discounted reconstruction costs | £0 | Present Value |
| Maintenance of new def | 1 | £/m/yr |
| discount factor F3 | 11.55 | |
| discounted maintenance costs | £0 | Present Value |
| TOTAL DISCOUNTED COSTS | £63,000 | Present Value of scheme |
| **2/ Assets** | | |
| Current value of assets LOST | 96,000 | £ |
| discount factor F4 | 0.75 | |
| Discounted assets WRITTEN OFF | £72,000 | |
| Residual damages | £0 | |
| year occuring | 0 | |
| discount factor F5 | 1 | |
| discounted residual damages | £0 | |
| TOTAL DISCOUNTED DAMAGES | £72,000 | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £63,000 |
| Scheme Costs | PVc | 0 | £0 |
| Maintenance costs (new) | PVm | 0 | £0 |
| Total Costs | PVtc | 0 | £63,000 |
| **Damages** | | | |
| Flood damages | PVd | £151,000 | £72,000 |
| Residual damages | PVrd | £0 | £0 |
| Total Damages | PVtd | £151,000 | £72,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £79,000 |
| **Net Present Value** | NPV | 0 | £16,000 |

## ECONOMIC ASSESSMENT

**ZONE 3 : OPTION 1**

| **Flood Compartment** | 5 | 6 | 7 | 8 | |
|---|---|---|---|---|---|
| **1/ Defences** | | | | | |
| Defended length | 1000 | 500 | 1200 | 0 | m |
| Residual life for Do Nothing | 3 | 3 | 10 | 10 | years |
| Residual life if maintained | 10 | 10 | 20 | 10 | |
| | | | | | |
| Maintenance costs | 0 | 0 | 0 | 0 | £/m/yr |
| discount factor F1 | 7.36 | 7.36 | 11.47 | 7.36 | |
| discounted maintenance costs | £0 | £0 | £0 | £0 | Present Value |
| | | | | | |
| Reconstruction costs | 0 | 0 | 0 | 0 | £/m |
| discount factor F2 | 0.56 | 0.56 | 0.31 | 0.56 | |
| discounted reconstruction costs | £0 | £0 | £0 | £0 | Present Value |
| | | | | | |
| Maintenance of new def | 0 | 0 | 0 | 0 | £/m/yr |
| discount factor F3 | 8.4 | 8.4 | 4.29 | 8.4 | |
| discounted maintenance costs | £0 | £0 | £0 | £0 | Present Value |
| | | | | | |
| TOTAL DISCOUNTED COSTS | £0 | £0 | £0 | £0 | Present Value of scheme |
| TOTAL DISCOUNTED COSTS | | | £0 | | |
| | | | | | |
| **2/ Assets** | | | | | |
| Current value | 471,390 | 115,455 | 132426 | 543,897 | £ |
| discount factor F4 | 0.84 | 0.84 | 0.56 | 0.56 | |
| Discounted assets WRITTEN OFF | £396,000 | £97,000 | £74,000 | £305,000 | |
| | | | | | |
| Residual damages | £600,000 | | | | |
| year occuring | £12 | | | | |
| discount factor F5 | 0.5 | | | | |
| discounted residual damages | £300,000 | | | | |
| | | | | | |
| TOTAL DISCOUNTED DAMAGES | £1,172,000 | | | | |

**3/ Assessment of Costs**

| | | Do Nothing |
|---|---|---|
| **Costs** | | |
| Maintenance costs (existing) | Pve | 0 |
| Scheme Costs | PVc | 0 |
| Maintenance costs (new) | PVm | 0 |
| Total Costs | PVtc | 0 |
| | | |
| **Damages** | | |
| Flood damages | PVd | £872,000 |
| Residual damages | PVrd | £300,000 |
| Total Damages | PVtd | £1,172,000 |
| | | |
| **Damages Avoided** | | |
| (Benefits) | PVb | 0 |
| | | |
| **Net Present Value** | NPV | 0 |

**ECONOMIC ASSESSMENT**

**ZONE 3 : OPTION 2**

| **Flood Compartment** | **5** | **6** | **7** | **8** | |
|---|---|---|---|---|---|
| **1/ Defences** | | | | | |
| Defended length | 1000 | 500 | 1200 | 500 | m |
| Residual life for Do Nothing | 3 | 3 | 3 | 15 | years |
| Residual life if maintained | 10 | 10 | 20 | 15 | |
| | | | | | |
| Maintenance costs | 0 | 0 | 0 | 0 | £/m/yr |
| discount factor F1 | 7.36 | 7.36 | 11.47 | 9.71 | |
| discounted maintenance costs | £0 | £0 | £0 | £0 | Present Value |
| | | | | | |
| Reconstruction costs | 0 | 0 | 0 | 500 | £/m |
| discount factor F2 | 0.56 | 0.56 | 0.31 | 0.42 | |
| discounted reconstruction costs | £0 | £0 | £0 | £105,000 | Present Value |
| | | | | | |
| Maintenance of new def | 0 | 0 | 0 | 1 | £/m/yr |
| discount factor F3 | 8.4 | 8.4 | 4.29 | 6.05 | |
| discounted maintenance costs | £0 | £0 | £0 | £3,025 | Present Value |
| | | | | | |
| TOTAL DISCOUNTED COSTS | **£0** | **£0** | **£0** | **£108,000** | Present Value of scheme |
| | TOTAL DISCOUNTED COSTS | | **£108,000** | | |
| **2/ Assets** | | | | | |
| Current value of assets | 471,390 | 115,455 | 132426 | 0 | £ |
| discount factor F4 | 0.84 | 0.84 | 0.84 | 0.42 | |
| Discounted assets WRITTEN OFF | **£396,000** | **£97,000** | **£111,000** | **£0** | |
| | | | | | |
| Residual damages | £600,000 | | | | |
| year occuring | £12 | | | | |
| discount factor F5 | 0.5 | | | | |
| discounted residual damages | **£300,000** | | | | |
| | | | | | |
| TOTAL DISCOUNTED DAMAGES | **£904,000** | | | | |

**3/ Assessment of Costs**

| | | **Do Nothing** | **With Scheme** |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £0 |
| Scheme Costs | PVc | 0 | £105,000 |
| Maintenance costs (new) | PVm | 0 | £3,000 |
| Total Costs | PVtc | 0 | £108,000 |
| **Damages** | | | |
| Flood damages | PVd | £872,000 | 604,000 |
| Residual damages | PVrd | £300,000 | £300,000 |
| Total Damages | PVtd | £1,172,000 | 904,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 268,000 |
| **Net Present Value** | NPV | **0** | **£160,000** |

## ECONOMIC ASSESSMENT

**ZONE 3 : OPTION 3**

| Flood Compartment | 5 | 6 | 7 | 8 | |
|---|---|---|---|---|---|
| **1/ Defences** | | | | | |
| Defended length | 1000 | 500 | 1200 | 500 | m |
| Residual life for Do Nothing | 5 | 5 | 10 | 15 | years |
| Residual life if maintained | 15 | 10 | 15 | 15 | |
| | | | | | |
| Maintenance costs | 10 | 10 | 10 | 0 | £/m/yr |
| discount factor F1 | 9.71 | 7.36 | 9.71 | 9.71 | |
| discounted maintenance costs | £97,100 | £36,800 | £116,520 | £0 | Present Value |
| | | | | | |
| Reconstruction costs | 500 | 500 | 500 | 0 | £/m |
| discount factor F2 | 0.42 | 0.56 | 0.42 | 0.42 | |
| discounted reconstruction costs | £210,000 | £140,000 | £252,000 | £0 | Present Value |
| | | | | | |
| Maintenance of new def | 1 | 1 | 1 | 0 | £/m/yr |
| discount factor F3 | 6.05 | 8.4 | 6.05 | 6.05 | |
| discounted maintenance costs | £3,025 | £4,200 | £3,025 | £0 | Present Value |
| | | | | | |
| TOTAL DISCOUNTED COSTS | **£310,000** | **£181,000** | **£372,000** | **£0** | Present Value of scheme |
| TOTAL DISCOUNTED COSTS | | | £863,000 | | |
| | | | | | |
| **2/ Assets** | | | | | |
| Current value of assets | 0 | 0 | 0 | 0 | £ |
| discount factor F4 | 0.75 | 0.75 | 0.56 | 0.42 | |
| Discounted assets WRITTEN OFF | **£0** | **£0** | **£0** | **£0** | |
| | | | | | |
| Residual damages | £135,000 | | | | |
| year occuring | £15 | | | | |
| discount factor F5 | 0.42 | | | | |
| discounted residual damages | **£57,000** | | | | |
| | | | | | |
| TOTAL DISCOUNTED DAMAGES | **£57,000** | | | | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £250,000 |
| Scheme Costs | PVc | 0 | £602,000 |
| Maintenance costs (new) | PVm | 0 | £10,000 |
| Total Costs | PVtc | 0 | £862,000 |
| **Damages** | | | |
| Flood damages | PVd | £872,000 | 0 |
| Residual damages | PVrd | £300,000 | £57,000 |
| Total Damages | PVtd | £1,172,000 | 57,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 1,115,000 |
| **Net Present Value** | NPV | 0 | £253,000 |

**ECONOMIC ASSESSMENT**

**ZONE 3 : OPTION 4**

| **Flood Compartment** | 5 | 6 | 7 | 8 | |
|---|---|---|---|---|---|
| **1/ Defences** | | | | | |
| Defended length | 1000 | 500 | 1200 | 500 | m |
| Residual life for Do Nothing | 5 | 5 | 10 | 15 | years |
| Residual life if maintained | 10 | 10 | 15 | 15 | |
| | | | | | |
| Maintenance costs | 15 | 15 | 10 | 0 | £/m/yr |
| discount factor F1 | 7.36 | 7.36 | 9.71 | 9.71 | |
| discounted maintenance costs | £110,400 | £55,200 | £116,520 | £0 | Present Value |
| | | | | | |
| Reconstruction costs | 700 | 1000 | 500 | 0 | £/m |
| discount factor F2 | 0.56 | 0.56 | 0.42 | 0.42 | |
| discounted reconstruction costs | £392,000 | £280,000 | £252,000 | £0 | Present Value |
| | | | | | |
| Maintenance of new def | 1 | 1 | 1 | 0 | £/m/yr |
| discount factor F3 | 8.4 | 8.4 | 6.05 | 6.05 | |
| discounted maintenance costs | £5,880 | £8,400 | £3,025 | £0 | Present Value |
| | | | | | |
| TOTAL DISCOUNTED COSTS | **£508,000** | **£344,000** | **£372,000** | **£0** | Present Value of scheme |
| | TOTAL DISCOUNTED COSTS | | **£1,224,000** | | |

| | | | | | |
|---|---|---|---|---|---|
| **2/ Assets** | | | | | |
| Current value of assets | 0 | 0 | 0 | 0 | £ |
| discount factor F4 | 0.75 | 0.75 | 0.56 | 0.42 | |
| Discounted assets WRITTEN OFF | **£0** | **£0** | **£0** | **£0** | |
| | | | | | |
| Residual damages | £135,000 | | | | |
| year occuring | £15 | | | | |
| discount factor F5 | 0.42 | | | | |
| discounted residual damages | **£57,000** | | | | |
| | | | | | |
| TOTAL DISCOUNTED DAMAGES | **£57,000** | | | | |

**3/ Assessment of Costs**

| | | **Do Nothing** | **With Scheme** |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £282,000 |
| Scheme Costs | PVc | 0 | £924,000 |
| Maintenance costs (new) | PVm | 0 | £17,000 |
| Total Costs | PVtc | 0 | £1,223,000 |
| | | | |
| **Damages** | | | |
| Flood damages | PVd | £872,000 | 0 |
| Residual damages | PVrd | £300,000 | £57,000 |
| Total Damages | PVtd | £1,172,000 | 57,000 |
| | | | |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 1,115,000 |
| | | | |
| **Net Present Value** | **NPV** | **0** | **-£108,000** |

## ECONOMIC ASSESSMENT

**ZONE 3 : OPTION 5**

| **Flood Compartment** | 5 | 6 | 7 | 8 | |
|---|---|---|---|---|---|
| **1/ Defences** | | | | | |
| Defended length | 1400 | 500 | 1600 | 500 | m |
| Residual life for Do Nothing | 5 | 3 | 10 | 15 | years |
| Residual life if maintained | 10 | 10 | 10 | 15 | |
| Maintenance costs | 10 | 0 | 10 | 0 | £/m/yr |
| discount factor F1 | 7.36 | 7.36 | 7.36 | 9.71 | |
| discounted maintenance costs | £103,040 | £0 | £132,480 | £0 | Present Value |
| Reconstruction costs | 600 | 0 | 600 | 0 | £/m |
| discount factor F2 | 0.56 | 0.56 | 0.56 | 0.42 | |
| discounted reconstruction costs | £470,400 | £0 | £604,800 | £0 | Present Value |
| Maintenance of new def | 1 | 0 | 1 | 0 | £/m/yr |
| discount factor F3 | 8.4 | 6.4 | 8.4 | 6.05 | |
| discounted maintenance costs | £5,040 | £0 | £5,040 | £0 | Present Value |
| TOTAL DISCOUNTED COSTS | £578,000 | £0 | £742,000 | £0 | Present Value of scheme |
| | TOTAL DISCOUNTED COSTS | | £1,320,000 | | |
| **2/ Assets** | | | | | |
| Current value of assets LOST | 0 | 115,455 | 0 | 0 | £ |
| discount factor F4 | 0.75 | 0.84 | 0.56 | 0.42 | |
| Discounted assets WRITTEN OFF | £0 | £97,000 | £0 | £0 | |
| Residual damages | £135,000 | | | | |
| year occuring | £15 | | | | |
| discount factor F5 | 0.42 | | | | |
| discounted residual damages | £57,000 | | | | |
| TOTAL DISCOUNTED DAMAGES | £154,000 | | | | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £236,000 |
| Scheme Costs | PVc | 0 | £1,075,000 |
| Maintenance costs (new) | PVm | 0 | £10,000 |
| Total Costs | PVtc | 0 | £1,321,000 |
| **Damages** | | | |
| Flood damages | PVd | £872,000 | 97,000 |
| Residual damages | PVrd | £300,000 | £57,000 |
| Total Damages | PVtd | £1,172,000 | 154,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 1,018,000 |
| **Net Present Value** | NPV | 0 | -£303,000 |

## ECONOMIC ASSESSMENT

**ZONE 3 : OPTION 6**

| **Flood Compartment** | 5 | 6 | 7 | 8 | |
|---|---|---|---|---|---|
| **1/ Defences** | | | | | |
| Defended length | 1400 | 500 | 1800 | 500 | m |
| Residual life for Do Nothing | 3 | 3 | 10 | 15 | years |
| Residual life if maintained | 10 | 10 | 20 | 15 | |
| | | | | | |
| Maintenance costs | 0 | 0 | 10 | 0 | £/m/yr |
| discount factor F1 | 7.36 | 7.36 | 11.47 | 9.71 | |
| discounted maintenance costs | £0 | £0 | £206,460 | £0 | Present Value |
| | | | | | |
| Reconstruction costs | 0 | 0 | 500 | 0 | £/m |
| discount factor F2 | 0.56 | 0.56 | 0.31 | 0.42 | |
| discounted reconstruction costs | £0 | £0 | £279,000 | £0 | Present Value |
| | | | | | |
| Maintenance of new def | 0 | 0 | 1 | 0 | £/m/yr |
| discount factor F3 | 6.4 | 6.4 | 4.29 | 6.05 | |
| discounted maintenance costs | £0 | £0 | £2,145 | £0 | Present Value |
| | | | | | |
| TOTAL DISCOUNTED COSTS | **£0** | **£0** | **£488,000** | **£0** | Present Value of scheme |
| | TOTAL DISCOUNTED COSTS | | **£488,000** | | |

| **2/ Assets** | 5 | 6 | 7 | 8 | |
|---|---|---|---|---|---|
| Current value of assets LOST | 471,390 | 115,455 | 0 | 0 | £ |
| discount factor F4 | 0.84 | 0.84 | 0.56 | 0.42 | |
| Discounted assets WRITTEN OFF | **£396,000** | **£97,000** | **£0** | **£0** | |
| | | | | | |
| Residual damages | £600,000 | | | | |
| year occuring | £12 | | | | |
| discount factor F5 | 0.5 | | | | |
| discounted residual damages | **£300,000** | | | | |
| | | | | | |
| TOTAL DISCOUNTED DAMAGES | **£793,000** | | | | |

### 3/ Assessment of Costs

| | | **Do Nothing** | **With Scheme** |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £206,000 |
| Scheme Costs | PVc | 0 | £279,000 |
| Maintenance costs (new) | PVm | 0 | £2,000 |
| Total Costs | PVtc | 0 | £487,000 |
| | | | |
| **Damages** | | | |
| Flood damages | PVd | £872,000 | 493,000 |
| Residual damages | PVrd | £300,000 | £300,000 |
| Total Damages | PVtd | £1,172,000 | 793,000 |
| | | | |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 379,000 |
| | | | |
| **Net Present Value** | NPV | **0** | **-£108,000** |

**ECONOMIC ASSESSMENT**

**ZONE 3 : OPTION 7**

| Flood Compartment | 5 | 6 | 7 | 8 | |
|---|---|---|---|---|---|
| **1/ Defences** | | | | | |
| Defended length | 1000 | 500 | 1200 | 500 | m |
| Residual life for Do Nothing | 5 | 3 | 10 | 15 | years |
| Residual life if maintained | 10 | 7 | 10 | 15 | |
| Maintenance costs | 10 | 10 | 10 | 0 | £/m/yr |
| discount factor F1 | 7.36 | 5.58 | 7.36 | 9.71 | |
| discounted maintenance costs | £73,600 | £27,900 | £88,320 | £0 | Present Value |
| Reconstruction costs | 500 | 500 | 500 | 0 | £/m |
| discount factor F2 | 0.56 | 0.67 | 0.56 | 0.42 | |
| discounted reconstruction costs | £280,000 | £167,500 | £336,000 | £0 | Present Value |
| Maintenance of new def | 1 | 1 | 1 | 0 | £/m/yr |
| discount factor F3 | 8.4 | 10.18 | 8.4 | 6.05 | |
| discounted maintenance costs | £4,200 | £5,090 | £4,200 | £0 | Present Value |
| TOTAL DISCOUNTED COSTS | £358,000 | £200,000 | £429,000 | £0 | Present Value of scheme |
| TOTAL DISCOUNTED COSTS | | | £987,000 | | |
| **2/ Assets** | | | | | |
| Current value of assets | 0 | 0 | 0 | 0 | £ |
| discount factor F4 | 0.75 | 0.84 | 0.56 | 0.42 | |
| Discounted assets WRITTEN OFF | £0 | £0 | £0 | £0 | |
| Residual damages | £0 | | | | |
| year occuring | £0 | | | | |
| discount factor F5 | 1 | | | | |
| discounted residual damages | £0 | | | | |
| TOTAL DISCOUNTED DAMAGES | £0 | | | | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £190,000 |
| Scheme Costs | PVc | 0 | £784,000 |
| Maintenance costs (new) | PVm | 0 | £13,000 |
| Total Costs | PVtc | 0 | £987,000 |
| **Damages** | | | |
| Flood damages | PVd | £872,000 | 0 |
| Residual damages | PVrd | £300,000 | £0 |
| Total Damages | PVtd | £1,172,000 | 0 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 1,172,000 |
| **Net Present Value** | NPV | 0 | £185,000 |

## ECONOMIC ASSESSMENT

**ZONE 3 : OPTION 8**

| **Flood Compartment** | **5** | **6** | **7** | **8** | |
|---|---|---|---|---|---|
| **1/ Defences** | | | | | |
| Defended length | 1000 | 500 | 1200 | 500 | m |
| Residual life for Do Nothing | 5 | 5 | 10 | 15 | years |
| Residual life if maintained | 15 | 10 | 15 | 15 | |
| Maintenance costs | 10 | 10 | 10 | 0 | £/m/yr |
| discount factor F1 | 9.71 | 7.36 | 9.71 | 9.71 | |
| discounted maintenance costs | £97,100 | £36,800 | £116,520 | £0 | Present Value |
| Reconstruction costs | 500 | 500 | 500 | 0 | £/m |
| discount factor F2 | 0.42 | 0.56 | 0.42 | 0.42 | |
| discounted reconstruction costs | £210,000 | £140,000 | £252,000 | £0 | Present Value |
| Maintenance of new def | 1 | 1 | 1 | 0 | £/m/yr |
| discount factor F3 | 6.05 | 8.4 | 6.05 | 6.05 | |
| discounted maintenance costs | £3,025 | £4,200 | £3,025 | £0 | Present Value |
| TOTAL DISCOUNTED COSTS | **£310,000** | **£181,000** | **£372,000** | **£0** | Present Value of scheme |
| TOTAL DISCOUNTED COSTS | | | **£863,000** | | |
| **2/ Assets** | | | | | |
| Current value of assets | 0 | 0 | 0 | 0 | £ |
| discount factor F4 | 0.75 | 0.75 | 0.56 | 0.42 | |
| Discounted assets WRITTEN OFF | **£0** | **£0** | **£0** | **£0** | |
| Residual damages | £0 | | | | |
| year occuring | £0 | | | | |
| discount factor F5 | 1 | | | | |
| discounted residual damages | £0 | | | | |
| TOTAL DISCOUNTED DAMAGES | **£0** | | | | |

**3/ Assessment of Costs**

| | | **Do Nothing** | **With Scheme** |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £250,000 |
| Scheme Costs | PVc | 0 | £602,000 |
| Maintenance costs (new) | PVm | 0 | £10,000 |
| Total Costs | PVtc | 0 | £862,000 |
| **Damages** | | | |
| Flood damages | PVd | £872,000 | 0 |
| Residual damages | PVrd | £300,000 | £0 |
| Total Damages | PVtd | £1,172,000 | 0 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 1,172,000 |
| **Net Present Value** | **NPV** | **0** | **£310,000** |

**ECONOMIC ASSESSMENT**

**ZONE 3 south : OPTION 1**

| | | |
|---|---|---|
| **Flood Compartment** | 14 | |
| **1/ Defences** | | |
| Defended length | 1625 | m |
| Residual life for Do Nothing | 5 | years |
| Residual life if maintained | 10 | |
| | | |
| Maintenance costs | 0 | £/m/yr |
| discount factor F1 | 7.36 | |
| discounted maintenance costs | £0 | Present Value |
| | | |
| Reconstruction costs | 0 | £/m |
| discount factor F2 | 0.56 | |
| discounted reconstruction costs | £0 | Present Value |
| | | |
| Maintenance of new def | 0 | £/m/yr |
| discount factor F3 | 8.4 | |
| discounted maintenance costs | £0 | Present Value |
| | | |
| TOTAL DISCOUNTED COSTS | £0 | Present Value of scheme |
| | | |
| **2/ Assets** | | |
| Current value | 332,607 | £ |
| discount factor F4 | 0.75 | |
| Discounted assets WRITTEN OFF | **£249,000** | |
| | | |
| Residual damages | £268,000 | |
| year occuring | £10 | |
| discount factor F5 | 0.56 | |
| discounted residual damages | **£150,000** | |
| | | |
| TOTAL DISCOUNTED DAMAGES | **£399,000** | |

**3/ Assessment of Costs**

| | | Do Nothing |
|---|---|---|
| **Costs** | | |
| Maintenance costs (existing) | Pve | 0 |
| Scheme Costs | PVc | 0 |
| Maintenance costs (new) | PVm | 0 |
| Total Costs | PVtc | 0 |
| | | |
| **Damages** | | |
| Flood damages | PVd | £249,000 |
| Residual damages | PVrd | £150,000 |
| Total Damages | PVtd | £399,000 |
| | | |
| **Damages Avoided** | | |
| (Benefits) | PVb | 0 |
| | | |
| **Net Present Value** | NPV | 0 |

**ECONOMIC ASSESSMENT**

**ZONE 3 south : OPTION 2**

| | | |
|---|---|---|
| **Flood Compartment** | 14 | |
| **1/ Defences** | | |
| Defended length | 1625 | m |
| Residual life for Do Nothing | 5 | years |
| Residual life if maintained | 10 | |
| Maintenance costs | 15 | £/m/yr |
| discount factor F1 | 7.36 | |
| discounted maintenance costs | £179,400 | Present Value |
| Reconstruction costs | 600 | £/m |
| discount factor F2 | 0.56 | |
| discounted reconstruction costs | £546,000 | Present Value |
| Maintenance of new def | 1 | £/m/yr |
| discount factor F3 | 8.4 | |
| discounted maintenance costs | £5,040 | Present Value |
| TOTAL DISCOUNTED COSTS | £730,000 | Present Value of scheme |
| **2/ Assets** | | |
| Current value of assets | 0 | £ |
| discount factor F4 | 0.75 | |
| Discounted assets WRITTEN OFF | £0 | |
| Residual damages | £0 | |
| year occuring | £0 | |
| discount factor F5 | 1 | |
| discounted residual damages | £0 | |
| TOTAL DISCOUNTED DAMAGES | £0 | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £179,000 |
| Scheme Costs | PVc | 0 | £546,000 |
| Maintenance costs (new) | PVm | 0 | £5,000 |
| Total Costs | PVtc | 0 | £730,000 |
| **Damages** | | | |
| Flood damages | PVd | £249,000 | £0 |
| Residual damages | PVrd | £150,000 | £0 |
| Total Damages | PVtd | £399,000 | £0 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £399,000 |
| **Net Present Value** | NPV | 0 | -£331,000 |

## ECONOMIC ASSESSMENT

**ZONE 3 south : OPTION 3**

| | | |
|---|---|---|
| **Flood Compartment** | 14 | |
| **1/ Defences** | | |
| Defended length | 1625 | m |
| Residual life for Do Nothing | 5 | years |
| Residual life if maintained | 10 | |
| Maintenance costs | 10 | £/m/yr |
| discount factor F1 | 7.36 | |
| discounted maintenance costs | £119,600 | Present Value |
| Reconstruction costs | 500 | £/m |
| discount factor F2 | 0.56 | |
| discounted reconstruction costs | £455,000 | Present Value |
| Maintenance of new def | 1 | £/m/yr |
| discount factor F3 | 8.4 | |
| discounted maintenance costs | £4,200 | Present Value |
| TOTAL DISCOUNTED COSTS | £579,000 | Present Value of scheme |
| **2/ Assets** | | |
| Current value of assets | 0 | £ |
| discount factor F4 | 0.75 | |
| Discounted assets WRITTEN OFF | £0 | |
| Residual damages | £0 | |
| year occuring | £0 | |
| discount factor F5 | 1 | |
| discounted residual damages | £0 | |
| TOTAL DISCOUNTED DAMAGES | £0 | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £120,000 |
| Scheme Costs | PVc | 0 | £455,000 |
| Maintenance costs (new) | PVm | 0 | £4,000 |
| Total Costs | PVtc | 0 | £579,000 |
| **Damages** | | | |
| Flood damages | PVd | £249,000 | £0 |
| Residual damages | PVrd | £150,000 | £0 |
| Total Damages | PVtd | £399,000 | £0 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £399,000 |
| **Net Present Value** | NPV | 0 | -£180,000 |

**ECONOMIC ASSESSMENT**

**ZONE 3 south : OPTION 4**

| | | |
|---|---|---|
| **Flood Compartment** | 14 | |
| **1/ Defences** | | |
| Defended length | 1625 | m |
| Residual life for Do Nothing | 10 | years |
| Residual life if maintained | 10 | |
| | | |
| Maintenance costs | 10 | £/m/yr |
| discount factor F1 | 7.36 | |
| discounted maintenance costs | £119,600 | Present Value |
| | | |
| Reconstruction costs | 0 | £/m |
| discount factor F2 | 0.56 | |
| discounted reconstruction costs | £0 | Present Value |
| | | |
| Maintenance of new def | 0 | £/m/yr |
| discount factor F3 | 8.4 | |
| discounted maintenance costs | £0 | Present Value |
| | | |
| TOTAL DISCOUNTED COSTS | £120,000 | Present Value of scheme |
| | | |
| **2/ Assets** | | |
| Current value of assets | 332,607 | £ |
| discount factor F4 | 0.56 | |
| Discounted assets WRITTEN OFF | **£186,000** | |
| | | |
| Residual damages | £100,000 | |
| year occuring | £10 | |
| discount factor F5 | 0.56 | |
| discounted residual damages | **£56,000** | |
| | | |
| TOTAL DISCOUNTED DAMAGES | £242,000 | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £120,000 |
| Scheme Costs | PVc | 0 | £0 |
| Maintenance costs (new) | PVm | 0 | £0 |
| Total Costs | PVtc | 0 | £120,000 |
| **Damages** | | | |
| Flood damages | PVd | £249,000 | £186,000 |
| Residual damages | PVrd | £150,000 | £56,000 |
| Total Damages | PVtd | £399,000 | £242,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £157,000 |
| **Net Present Value** | NPV | 0 | £37,000 |

## ECONOMIC ASSESSMENT

**ZONE 3 south : OPTION 5**

| | | |
|---|---|---|
| **Flood Compartment** | 14 | |
| **1/ Defences** | | |
| Defended length | 800 | m |
| Residual life for Do Nothing | 5 | years |
| Residual life if maintained | 10 | |
| Maintenance costs | 7 | £/m/yr |
| discount factor F1 | 7.36 | |
| discounted maintenance costs | £41,216 | Present Value |
| Reconstruction costs | 600 | £/m |
| discount factor F2 | 0.56 | |
| discounted reconstruction costs | £268,800 | Present Value |
| Maintenance of new def | 1 | £/m/yr |
| discount factor F3 | 8.4 | |
| discounted maintenance costs | £5,040 | Present Value |
| TOTAL DISCOUNTED COSTS | £315,000 | Present Value of scheme |
| **2/ Assets** | | |
| Current value of assets LOST | 207,656 | £ |
| discount factor F4 | 0.75 | |
| Discounted assets WRITTEN OFF | **£156,000** | |
| Residual damages | £50,000 | (habitat management) |
| year occuring | 5 | |
| discount factor F5 | 0.75 | |
| discounted residual damages | **£37,500** | |
| TOTAL DISCOUNTED DAMAGES | £193,500 | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £41,000 |
| Scheme Costs | PVc | 0 | £269,000 |
| Maintenance costs (new) | PVm | 0 | £5,000 |
| Total Costs | PVtc | 0 | £315,000 |
| **Damages** | | | |
| Flood damages | PVd | £249,000 | £156,000 |
| Residual damages | PVrd | £150,000 | £37,500 |
| Total Damages | PVtd | £399,000 | £193,500 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £205,500 |
| **Net Present Value** | NPV | 0 | -£109,500 |

**ECONOMIC ASSESSMENT**

**ZONE 3 south : OPTION 6**

| | | |
|---|---|---|
| **Flood Compartment** | 14 | |
| **1/ Defences** | | |
| Defended length | 800 | m |
| Residual life for Do Nothing | 5 | years |
| Residual life if maintained | 10 | |
| | | |
| Maintenance costs | 7 | £/m/yr |
| discount factor F1 | 7.36 | |
| discounted maintenance costs | £41,216 | Present Value |
| | | |
| Reconstruction costs | 600 | £/m |
| discount factor F2 | 0.56 | |
| discounted reconstruction costs | £268,800 | Present Value |
| | | |
| Maintenance of new def | 1 | £/m/yr |
| discount factor F3 | 8.4 | |
| discounted maintenance costs | £5,040 | Present Value |
| | | |
| TOTAL DISCOUNTED COSTS | £315,000 | Present Value of scheme |
| | | |
| **2/ Assets** | | |
| Current value of assets LOST | 207,656 | £ |
| discount factor F4 | 0.75 | |
| Discounted assets WRITTEN OFF | **£156,000** | |
| | | |
| Residual damages | £50,000 | (habitat management) |
| year occuring | £7 | |
| discount factor F5 | 0.67 | |
| discounted residual damages | **£33,500** | |
| | | |
| TOTAL DISCOUNTED DAMAGES | **£189,500** | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £41,000 |
| Scheme Costs | PVc | 0 | £269,000 |
| Maintenance costs (new) | PVm | 0 | £5,000 |
| Total Costs | PVtc | 0 | £315,000 |
| **Damages** | | | |
| Flood damages | PVd | £249,000 | £156,000 |
| Residual damages | PVrd | £150,000 | £33,500 |
| Total Damages | PVtd | £399,000 | £189,500 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £209,500 |
| **Net Present Value** | NPV | 0 | -£105,500 |

## ECONOMIC ASSESSMENT

**ZONE 3 south : OPTION 7**

| | | |
|---|---|---|
| **Flood Compartment** | 14 | |
| **1/ Defences** | | |
| Defended length | 800 | m |
| Residual life for Do Nothing | 5 | years |
| Residual life if maintained | 15 | |
| Maintenance costs | 7 | £/m/yr |
| discount factor F1 | 9.71 | |
| discounted maintenance costs | £54,376 | Present Value |
| Reconstruction costs | 600 | £/m |
| discount factor F2 | 0.42 | |
| discounted reconstruction costs | £201,600 | Present Value |
| Maintenance of new def | 1 | £/m/yr |
| discount factor F3 | 6.05 | |
| discounted maintenance costs | £3,630 | Present Value |
| TOTAL DISCOUNTED COSTS | £260,000 | Present Value of scheme |
| **2/ Assets** | | |
| Current value of assets LOST | 207,656 | £ |
| discount factor F4 | 0.75 | |
| Discounted assets WRITTEN OFF | £156,000 | |
| Residual damages | £50,000 | (habitat management) |
| year occuring | 5 | |
| discount factor F5 | 0.75 | |
| discounted residual damages | £37,500 | |
| TOTAL DISCOUNTED DAMAGES | £193,500 | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £54,000 |
| Scheme Costs | PVc | 0 | £202,000 |
| Maintenance costs (new) | PVm | 0 | £4,000 |
| Total Costs | PVtc | 0 | £260,000 |
| **Damages** | | | |
| Flood damages | PVd | £249,000 | £156,000 |
| Residual damages | PVrd | £150,000 | £37,500 |
| Total Damages | PVtd | £399,000 | £193,500 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £205,500 |
| **Net Present Value** | NPV | 0 | -£54,500 |

**ECONOMIC ASSESSMENT**

**ZONE 4 : OPTION 1**

| **Flood Compartment** | **1** | **2** | **3** | **4** | |
|---|---|---|---|---|---|
| **1/ Defences** | | | | | |
| Defended length | 500 | 800 | 300 | 100 | m |
| Residual life for Do Nothing | 5 | 7 | 7 | 7 | years |
| Residual life if maintained | 10 | 25 | 20 | 20 | |
| | | | | | |
| Maintenance costs | 0 | 0 | 0 | 0 | £/m/yr |
| discount factor F1 | 7.36 | 12.78 | 11.47 | 11.47 | |
| discounted maintenance costs | £0 | £0 | £0 | £0 | Present Value |
| | | | | | |
| Reconstruction costs | 0 | 0 | 0 | 0 | £/m |
| discount factor F2 | 0.56 | 0.23 | 0.31 | 0.31 | |
| discounted reconstruction costs | £0 | £0 | £0 | £0 | Present Value |
| | | | | | |
| Maintenance of new def | 0 | 0 | 0 | 0 | £/m/yr |
| discount factor F3 | 8.4 | 2.98 | 4.29 | 4.29 | |
| discounted maintenance costs | £0 | £0 | £0 | £0 | Present Value |
| | | | | | |
| TOTAL DISCOUNTED COSTS | £0 | £0 | £0 | £0 | Present Value of scheme |
| TOTAL DISCOUNTED COSTS | | | £0 | | |
| | | | | | |
| **2/ Assets** | | | | | |
| Current value of assets LOST | 1,426,560 | 1,194,760 | 734,454 | 2,060,318 | £ |
| discount factor F4 | 0.75 | 0.67 | 0.67 | 0.67 | |
| Discounted assets WRITTEN OFF | **£1,070,000** | **£800,000** | **£492,000** | **£1,380,000** | |
| | | | | | |
| Residual damages | £0 | | | | |
| year occuring | £0 | | | | |
| discount factor F5 | 1 | | | | |
| discounted residual damages | **£0** | | | | |
| | | | | | |
| TOTAL DISCOUNTED DAMAGES | **£3,742,000** | | | | |

**3/ Assessment of Costs**

| | | **Do Nothing** |
|---|---|---|
| **Costs** | | |
| Maintenance costs (existing) | Pve | 0 |
| Scheme Costs | PVc | 0 |
| Maintenance costs (new) | PVm | 0 |
| Total Costs | PVtc | 0 |
| | | |
| **Damages** | | |
| Flood damages | PVd | £3,742,000 |
| Residual damages | PVrd | £0 |
| Total Damages | PVtd | £3,742,000 |
| | | |
| **Damages Avoided** | | |
| (Benefits) | PVb | 0 |
| | | |
| **Net Present Value** | NPV | **0** |

## ECONOMIC ASSESSMENT

**ZONE 4 : OPTION 2**

| Flood Compartment | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|
| **1/ Defences** | | | | | |
| Defended length | 500 | 800 | 300 | 100 | m |
| Residual life for Do Nothing | 5 | 5 | 5 | 5 | years |
| Residual life if maintained | 10 | 25 | 20 | 20 | |
| Maintenance costs | 0 | 0 | 0 | 0 | £/m/yr |
| discount factor F1 | 7.36 | 12.78 | 11.47 | 11.47 | |
| discounted maintenance costs | £0 | £0 | £0 | £0 | Present Value |
| Reconstruction costs | 0 | 0 | 0 | 0 | £/m |
| discount factor F2 | 0.56 | 0.23 | 0.31 | 0.31 | |
| discounted reconstruction costs | £0 | £0 | £0 | £0 | Present Value |
| Maintenance of new def | 0 | 0 | 0 | 0 | £/m/yr |
| discount factor F3 | 8.4 | 2.98 | 4.29 | 4.29 | |
| discounted maintenance costs | £0 | £0 | £0 | £0 | Present Value |
| TOTAL DISCOUNTED COSTS | £0 | £0 | £0 | £0 | Present Value of scheme |
| TOTAL DISCOUNTED COSTS | | | £0 | | |
| **2/ Assets** | | | | | |
| Current value of assets LOST | 1,426,560 | 1,194,760 | 734,454 | 2,060,318 | £ |
| discount factor F4 | 0.75 | 0.75 | 0.75 | 0.75 | |
| Discounted assets WRITTEN OFF | **£1,070,000** | **£896,000** | **£551,000** | **£1,545,000** | |
| Residual damages | £0 | | | | |
| year occuring | £0 | | | | |
| discount factor F5 | 1 | | | | |
| discounted residual damages | £0 | | | | |
| TOTAL DISCOUNTED DAMAGES | **£4,062,000** | | | | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | PVe | 0 | £0 |
| Scheme Costs | PVc | 0 | £0 |
| Maintenance costs (new) | PVm | 0 | £0 |
| Total Costs | PVtc | 0 | £0 |
| **Damages** | | | |
| Flood damages | PVd | £3,742,000 | £4,062,000 |
| Residual damages | PVrd | £0 | £0 |
| Total Damages | PVtd | £3,742,000 | £4,062,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | -320,000 |
| **Net Present Value** | NPV | 0 | -£320,000 |

## ECONOMIC ASSESSMENT

**ZONE 4 : OPTION 3**

| Flood Compartment | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|
| **1/ Defences** | | | | | |
| Defended length | 500 | 800 | 300 | 100 | m |
| Residual life for Do Nothing | 7 | 10 | 10 | 10 | years |
| Residual life if maintained | 10 | 25 | 20 | 20 | |
| | | | | | |
| Maintenance costs | 0 | 0 | 0 | 0 | £/m/yr |
| discount factor F1 | 7.36 | 12.78 | 11.47 | 11.47 | |
| discounted maintenance costs | £0 | £0 | £0 | £0 | Present Value |
| | | | | | |
| Reconstruction costs | 0 | 0 | 0 | 0 | £/m |
| discount factor F2 | 0.56 | 0.23 | 0.31 | 0.31 | |
| discounted reconstruction costs | £0 | £0 | £0 | £0 | Present Value |
| | | | | | |
| Maintenance of new def | 0 | 0 | 0 | 0 | £/m/yr |
| discount factor F3 | 8.4 | 2.98 | 4.29 | 4.29 | |
| discounted maintenance costs | £0 | £0 | £0 | £0 | Present Value |
| | | | | | |
| TOTAL DISCOUNTED COSTS | **£0** | **£0** | **£0** | **£0** | Present Value of scheme |
| TOTAL DISCOUNTED COSTS | | | **£0** | | |
| | | | | | |
| **2/ Assets** | | | | | |
| Current value of assets LOST | 1,426,560 | 1,194,760 | 734,454 | 2,060,318 | £ |
| discount factor F4 | 0.67 | 0.56 | 0.56 | 0.56 | |
| Discounted assets WRITTEN OFF | **£956,000** | **£669,000** | **£411,000** | **£1,154,000** | |
| | | | | | |
| Residual damages | £0 | | | | |
| year occuring | £0 | | | | |
| discount factor F5 | 1 | | | | |
| discounted residual damages | **£0** | | | | |
| | | | | | |
| TOTAL DISCOUNTED DAMAGES | **£3,190,000** | | | | |

### 3/ Assessment of Costs

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £0 |
| Scheme Costs | PVc | 0 | £0 |
| Maintenance costs (new) | PVm | 0 | £0 |
| Total Costs | PVtc | 0 | £0 |
| | | | |
| **Damages** | | | |
| Flood damages | PVd | £3,742,000 | £3,190,000 |
| Residual damages | PVrd | £0 | £0 |
| Total Damages | PVtd | £3,742,000 | £3,190,000 |
| | | | |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 552,000 |
| | | | |
| **Net Present Value** | NPV | 0 | **£552,000** |

## ECONOMIC ASSESSMENT

**ZONE 4 : OPTION 4**

| Flood Compartment | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|
| **1/ Defences** | | | | | |
| Defended length | 500 | 800 | 300 | 100 | m |
| Residual life for Do Nothing | 5 | 8 | 8 | 8 | years |
| Residual life if maintained | 10 | 25 | 20 | 20 | |
| Maintenance costs | 0 | 0 | 0 | 0 | £/m/yr |
| discount factor F1 | 7.36 | 12.78 | 11.47 | 11.47 | |
| discounted maintenance costs | £0 | £0 | £0 | £0 | Present Value |
| Reconstruction costs | 0 | 0 | 0 | 0 | £/m |
| discount factor F2 | 0.58 | 0.23 | 0.31 | 0.31 | |
| discounted reconstruction costs | £0 | £0 | £0 | £0 | Present Value |
| Maintenance of new def | 0 | 0 | 0 | 0 | £/m/yr |
| discount factor F3 | 8.4 | 2.98 | 4.29 | 4.29 | |
| discounted maintenance costs | £0 | £0 | £0 | £0 | Present Value |
| TOTAL DISCOUNTED COSTS | **£0** | **£0** | **£0** | **£0** | Present Value of scheme |
| TOTAL DISCOUNTED COSTS | | | £0 | | |

| **2/ Assets** | | | | | |
|---|---|---|---|---|---|
| Current value of assets LOST | 1,426,560 | 1,194,760 | 734,454 | 2,060,318 | £ |
| discount factor F4 | 0.75 | 0.63 | 0.63 | 0.63 | |
| Discounted assets WRITTEN OFF | **£1,070,000** | **£753,000** | **£463,000** | **£1,298,000** | |
| Residual damages | £0 | | | | |
| year occuring | £0 | | | | |
| discount factor F5 | 1 | | | | |
| discounted residual damages | £0 | | | | |
| TOTAL DISCOUNTED DAMAGES | **£3,584,000** | | | | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £0 |
| Scheme Costs | PVc | 0 | £0 |
| Maintenance costs (new) | PVm | 0 | £0 |
| Total Costs | PVtc | 0 | £0 |
| **Damages** | | | |
| Flood damages | PVd | £3,742,000 | £3,584,000 |
| Residual damages | PVrd | £0 | £0 |
| Total Damages | PVtd | £3,742,000 | £3,584,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 158,000 |
| **Net Present Value** | **NPV** | **0** | **£158,000** |

**ECONOMIC ASSESSMENT**

**ZONE 4 : OPTION 5**

| **Flood Compartment** | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|
| **1/ Defences** | | | | | |
| Defended length | 500 | 800 | 300 | 1000 | m |
| Residual life for Do Nothing | 5 | 7 | 7 | 5 | years |
| Residual life if maintained | 10 | 25 | 20 | 7 | |
| Maintenance costs | 0 | 0 | 0 | 10 | £/m/yr |
| discount factor F1 | 7.36 | 12.78 | 11.47 | 5.58 | |
| discounted maintenance costs | £0 | £0 | £0 | £55,800 | Present Value |
| Reconstruction costs | 0 | 0 | 0 | 500 | £/m |
| discount factor F2 | 0.56 | 0.23 | 0.31 | 0.67 | |
| discounted reconstruction costs | £0 | £0 | £0 | £335,000 | Present Value |
| Maintenance of new def | 0 | 0 | 0 | 1 | £/m/yr |
| discount factor F3 | 8.4 | 2.98 | 4.29 | 10.18 | |
| discounted maintenance costs | £0 | £0 | £0 | £5,090 | Present Value |
| TOTAL DISCOUNTED COSTS | **£0** | **£0** | **£0** | **£396,000** | Present Value of scheme |
| TOTAL DISCOUNTED COSTS | | | **£396,000** | | |
| **2/ Assets** | | | | | |
| Current value of assets LOST | 1,426,560 | 1,194,760 | 734,454 | 0 | £ |
| discount factor F4 | 0.75 | 0.67 | 0.67 | 0.75 | |
| Discounted assets WRITTEN OFF | **£1,070,000** | **£800,000** | **£492,000** | **£0** | |
| Residual damages | £0 | | | | |
| year occuring | £0 | | | | |
| discount factor F5 | 1 | | | | |
| discounted residual damages | £0 | | | | |
| TOTAL DISCOUNTED DAMAGES | **£2,362,000** | | | | |

**3/ Assessment of Costs**

| | | **Do Nothing** | **With Scheme** |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £56,000 |
| Scheme Costs | PVc | 0 | £335,000 |
| Maintenance costs (new) | PVm | 0 | £5,000 |
| Total Costs | PVtc | 0 | £396,000 |
| **Damages** | | | |
| Flood damages | PVd | £3,742,000 | £2,362,000 |
| Residual damages | PVrd | £0 | £0 |
| Total Damages | PVtd | £3,742,000 | £2,362,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 1,380,000 |
| **Net Present Value** | **NPV** | **0** | **£984,000** |

## ECONOMIC ASSESSMENT

### ZONE 4 : OPTION 6

| Flood Compartment | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|
| **1/ Defences** | | | | | |
| Defended length | 500 | 800 | 300 | 100 | m |
| Residual life for Do Nothing | 5 | 7 | 7 | 5 | years |
| Residual life if maintained | 5 | 15 | 15 | 15 | |
| Maintenance costs | 20 | 20 | 20 | 10 | £/m/yr |
| discount factor F1 | 4.21 | 9.71 | 9.71 | 9.71 | |
| discounted maintenance costs | £42,100 | £155,360 | £58,260 | £9,710 | Present Value |
| Reconstruction costs | 1000 | 750 | 900 | 500 | £/m |
| discount factor F2 | 0.75 | 0.42 | 0.42 | 0.42 | |
| discounted reconstruction costs | £375,000 | £252,000 | £113,400 | £21,000 | Present Value |
| Maintenance of new def | 1 | 1 | 1 | 1 | £/m/yr |
| discount factor F3 | 11.55 | 6.05 | 6.05 | 6.05 | |
| discounted maintenance costs | £11,550 | £4,538 | £5,445 | £3,025 | Present Value |
| TOTAL DISCOUNTED COSTS | **£429,000** | **£412,000** | **£177,000** | **£34,000** | Present Value of scheme |
| TOTAL DISCOUNTED COSTS | | | £1,052,000 | | |
| **2/ Assets** | | | | | |
| Current value of assets LOST | 0 | 0 | 0 | 0 | £ |
| discount factor F4 | 0.75 | 0.67 | 0.67 | 0.75 | |
| Discounted assets WRITTEN OFF | £0 | £0 | £0 | £0 | |
| Residual damages | £300,000 | | | | |
| year occuring | £18 | | | | |
| discount factor F5 | 0.35 | | | | |
| discounted residual damages | £105,000 | | | | |
| TOTAL DISCOUNTED DAMAGES | £105,000 | | | | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £265,000 |
| Scheme Costs | PVc | 0 | £761,000 |
| Maintenance costs (new) | PVm | 0 | £25,000 |
| Total Costs | PVtc | 0 | £1,051,000 |
| **Damages** | | | |
| Flood damages | PVd | £3,742,000 | £0 |
| Residual damages | PVrd | £0 | £105,000 |
| Total Damages | PVtd | £3,742,000 | £105,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 3,637,000 |
| **Net Present Value** | NPV | 0 | £2,586,000 |

**ECONOMIC ASSESSMENT**

**ZONE 4 : OPTION 7**

| **Flood Compartment** | **1** | **2** | **3** | **4** | |
|---|---|---|---|---|---|
| **1/ Defences** | | | | | |
| Defended length | 500 | 800 | 300 | 100 | m |
| Residual life for Do Nothing | 5 | 7 | 7 | 5 | years |
| Residual life if maintained | 5 | 10 | 10 | 10 | |
| | | | | | |
| Maintenance costs | 20 | 20 | 20 | 10 | £/m/yr |
| discount factor F1 | 4.21 | 7.36 | 7.36 | 7.36 | |
| discounted maintenance costs | £42,100 | £117,760 | £44,160 | £7,360 | Present Value |
| | | | | | |
| Reconstruction costs | 1000 | 900 | 900 | 500 | £/m |
| discount factor F2 | 0.75 | 0.56 | 0.56 | 0.56 | |
| discounted reconstruction costs | £375,000 | £403,200 | £151,200 | £28,000 | Present Value |
| | | | | | |
| Maintenance of new def | 1 | 1 | 1 | 1 | £/m/yr |
| discount factor F3 | 11.55 | 8.4 | 8.4 | 8.4 | |
| discounted maintenance costs | £11,550 | £7,560 | £7,560 | £4,200 | Present Value |
| | | | | | |
| TOTAL DISCOUNTED COSTS | **£429,000** | **£529,000** | **£203,000** | **£40,000** | Present Value of scheme |
| | TOTAL DISCOUNTED COSTS | | **£1,201,000** | | |
| | | | | | |
| **2/ Assets** | | | | | |
| Current value of assets LOST | 0 | 0 | 0 | 0 | £ |
| discount factor F4 | 0.75 | 0.67 | 0.67 | 0.75 | |
| Discounted assets WRITTEN OFF | **£0** | **£0** | **£0** | **£0** | |
| | | | | | |
| Residual damages | £300,000 | | | | |
| year occuring | £7 | | | | |
| discount factor F5 | 0.67 | | | | |
| discounted residual damages | **£201,000** | | | | |
| | | | | | |
| TOTAL DISCOUNTED DAMAGES | **£201,000** | | | | |

**3/ Assessment of Costs**

| | | **Do Nothing** | **With Scheme** |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | PVe | 0 | £211,000 |
| Scheme Costs | PVc | 0 | £957,000 |
| Maintenance costs (new) | PVm | 0 | £31,000 |
| Total Costs | PVtc | 0 | £1,199,000 |
| **Damages** | | | |
| Flood damages | PVd | £3,742,000 | £0 |
| Residual damages | PVrd | £0 | £201,000 |
| Total Damages | PVtd | £3,742,000 | £201,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 3,541,000 |
| **Net Present Value** | **NPV** | **0** | **£2,342,000** |

## ECONOMIC ASSESSMENT

### ZONE 4 : OPTION 8

| Flood Compartment | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|
| **1/ Defences** | | | | | |
| Defended length | 500 | 800 | 300 | 100 | m |
| Residual life for Do Nothing | 5 | 7 | 7 | 5 | years |
| Residual life if maintained | 7 | 25 | 20 | 20 | |
| Maintenance costs | 20 | 5 | 10 | 10 | £/m/yr |
| discount factor F1 | 5.58 | 12.78 | 11.47 | 11.47 | |
| discounted maintenance costs | £55,800 | £51,120 | £34,410 | £11,470 | Present Value |
| Reconstruction costs | 1000 | 500 | 700 | 500 | £/m |
| discount factor F2 | 0.67 | 0.23 | 0.31 | 0.31 | |
| discounted reconstruction costs | £335,000 | £92,000 | £65,100 | £15,500 | Present Value |
| Maintenance of new def | 1 | 1 | 1 | 1 | £/m/yr |
| discount factor F3 | 10.18 | 2.98 | 4.29 | 4.29 | |
| discounted maintenance costs | £10,180 | £1,490 | £3,003 | £2,145 | Present Value |
| TOTAL DISCOUNTED COSTS | £401,000 | £145,000 | £103,000 | £29,000 | Present Value of scheme |
| | TOTAL DISCOUNTED COSTS | | £678,000 | | |
| **2/ Assets** | | | | | |
| Current value of assets LOST | 0 | 0 | 0 | 0 | £ |
| discount factor F4 | 0.75 | 0.67 | 0.67 | 0.75 | |
| Discounted assets WRITTEN OFF | £0 | £0 | £0 | £0 | |
| Residual damages | £0 | | | | |
| year occuring | £0 | | | | |
| discount factor F5 | 1 | | | | |
| discounted residual damages | £0 | | | | |
| TOTAL DISCOUNTED DAMAGES | £0 | | | | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £153,000 |
| Scheme Costs | PVc | 0 | £508,000 |
| Maintenance costs (new) | PVm | 0 | £17,000 |
| Total Costs | PVtc | 0 | £678,000 |
| **Damages** | | | |
| Flood damages | PVd | £3,742,000 | £0 |
| Residual damages | PVrd | £0 | £0 |
| Total Damages | PVtd | £3,742,000 | £0 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 3,742,000 |
| **Net Present Value** | NPV | 0 | £3,064,000 |

## ECONOMIC ASSESSMENT

**ZONE 4 : OPTION 9**

| Flood Compartment | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|
| **1/ Defences** | | | | | |
| Defended length | 500 | 800 | 300 | 100 | m |
| Residual life for Do Nothing | 5 | 7 | 7 | 5 | years |
| Residual life if maintained | 5 | 23 | 18 | 18 | |
| Maintenance costs | 20 | 10 | 15 | 10 | £/m/yr |
| discount factor F1 | 4.21 | 12.256 | 10.83 | 10.83 | |
| discounted maintenance costs | £42,100 | £98,048 | £48,735 | £10,830 | Present Value |
| Reconstruction costs | 1000 | 500 | 700 | 500 | £/m |
| discount factor F2 | 0.75 | 0.262 | 0.35 | 0.35 | |
| discounted reconstruction costs | £375,000 | £104,800 | £73,500 | £17,500 | Present Value |
| Maintenance of new def | 1 | 1 | 1 | 1 | £/m/yr |
| discount factor F3 | 11.55 | 3.504 | 4.93 | 4.93 | |
| discounted maintenance costs | £11,550 | £1,752 | £3,451 | £2,465 | Present Value |
| TOTAL DISCOUNTED COSTS | **£429,000** | **£205,000** | **£126,000** | **£31,000** | Present Value of scheme |
| TOTAL DISCOUNTED COSTS | | | **£791,000** | | |
| **2/ Assets** | | | | | |
| Current value of assets LOST | 0 | 0 | 0 | 0 | £ |
| discount factor F4 | 0.75 | 0.67 | 0.67 | 0.75 | |
| Discounted assets WRITTEN OFF | **£0** | **£0** | **£0** | **£0** | |
| Residual damages | £300,000 | | | | |
| year occuring | £18 | | | | |
| discount factor F5 | 0.35 | | | | |
| discounted residual damages | **£105,000** | | | | |
| TOTAL DISCOUNTED DAMAGES | **£105,000** | | | | |

### 3/ Assessment of Costs

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £200,000 |
| Scheme Costs | PVc | 0 | £571,000 |
| Maintenance costs (new) | PVm | 0 | £19,000 |
| Total Costs | PVtc | 0 | £790,000 |
| **Damages** | | | |
| Flood damages | PVd | £3,742,000 | £0 |
| Residual damages | PVrd | £0 | £105,000 |
| Total Damages | PVtd | £3,742,000 | £105,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | 3,637,000 |
| **Net Present Value** | NPV | 0 | **£2,847,000** |

## ECONOMIC ASSESSMENT

**ZONE 4 : OPTION 10**

| Flood Compartment | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|
| **1/ Defences** | | | | | |
| Defended length | 500 | 800 | 300 | 100 | m |
| Residual life for Do Nothing | 5 | 7 | 7 | 5 | years |
| Residual life if maintained | 5 | 25 | 20 | 20 | |
| Maintenance costs | 20 | 5 | 10 | 10 | £/m/yr |
| discount factor F1 | 4.21 | 12.78 | 11.47 | 11.47 | |
| discounted maintenance costs | £42,100 | £51,120 | £34,410 | £11,470 | Present Value |
| Reconstruction costs | 1000 | 500 | 700 | 500 | £/m |
| discount factor F2 | 0.75 | 0.23 | 0.31 | 0.31 | |
| discounted reconstruction costs | £375,000 | £92,000 | £65,100 | £15,500 | Present Value |
| Maintenance of new def | 1 | 1 | 1 | 1 | £/m/yr |
| discount factor F3 | 11.55 | 2.98 | 4.29 | 4.29 | |
| discounted maintenance costs | £11,550 | £1,490 | £3,003 | £2,145 | Present Value |
| TOTAL DISCOUNTED COSTS | £429,000 | £145,000 | £103,000 | £29,000 | Present Value of scheme |
| | TOTAL DISCOUNTED COSTS | | £706,000 | | |
| **2/ Assets** | | | | | |
| Current value of assets LOST | 0 | 0 | 0 | 0 | £ |
| discount factor F4 | 0.75 | 0.67 | 0.67 | 0.75 | |
| Discounted assets WRITTEN OFF | £0 | £0 | £0 | £0 | |
| Residual damages | £0 | | | | |
| year occuring | £0 | | | | |
| discount factor F5 | 1 | | | | |
| discounted residual damages | £0 | | | | |
| TOTAL DISCOUNTED DAMAGES | £0 | | | | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £139,000 |
| Scheme Costs | PVc | 0 | £548,000 |
| Maintenance costs (new) | PVm | 0 | £18,000 |
| Total Costs | PVtc | 0 | £705,000 |
| **Damages** | | | |
| Flood damages | PVd | £3,742,000 | £0 |
| Residual damages | PVrd | £0 | £0 |
| Total Damages | PVtd | £3,742,000 | £0 |
| **Damages Avoided** (Benefits) | PVb | 0 | 3,742,000 |
| **Net Present Value** | NPV | 0 | £3,037,000 |

## ECONOMIC ASSESSMENT

**ZONE 4S : OPTION 1**

**Flood Compartment** 13

**1/ Defences**

| | | |
|---|---|---|
| Defended length | 1500 | m |
| Residual life for Do Nothing | 5 | years |
| Residual life if maintained | 15 | |
| | | |
| Maintenance costs | 0 | £/m/yr |
| discount factor F1 | 9.71 | |
| discounted maintenance costs | £0 | Present Value |
| | | |
| Reconstruction costs | 0 | £/m |
| discount factor F2 | 0.42 | |
| discounted reconstruction costs | £0 | Present Value |
| | | |
| Maintenance of new def | 0 | £/m/yr |
| discount factor F3 | 6.05 | |
| discounted maintenance costs | £0 | Present Value |
| | | |
| TOTAL DISCOUNTED COSTS | £0 | Present Value of scheme |

**2/ Assets**

| | | |
|---|---|---|
| Current value | 944,230 | £ |
| discount factor F4 | 0.75 | |
| Discounted assets WRITTEN OFF | **£708,000** | |
| | | |
| Residual damages | £0 | |
| year occuring | £0 | |
| discount factor F5 | 1 | |
| discounted residual damages | **£0** | |
| | | |
| TOTAL DISCOUNTED DAMAGES | £708,000 | |

**3/ Assessment of Costs**

| | | Do Nothing |
|---|---|---|
| **Costs** | | |
| Maintenance costs (existing) | Pve | 0 |
| Scheme Costs | PVc | 0 |
| Maintenance costs (new) | PVm | 0 |
| Total Costs | PVtc | 0 |
| **Damages** | | |
| Flood damages | PVd | £708,000 |
| Residual damages | PVrd | £0 |
| Total Damages | PVtd | £708,000 |
| **Damages Avoided** | | |
| (Benefits) | PVb | 0 |
| **Net Present Value** | **NPV** | **0** |

**ECONOMIC ASSESSMENT**

**ZONE 4S : OPTION 2**

| | | |
|---|---|---|
| **Flood Compartment** | 13 | |
| **1/ Defences** | | |
| Defended length | 1500 | m |
| Residual life for Do Nothing | 7 | years |
| Residual life if maintained | 15 | |
| | | |
| Maintenance costs | 0 | £/m/yr |
| discount factor F1 | 9.71 | |
| discounted maintenance costs | £0 | Present Value |
| | | |
| Reconstruction costs | 0 | £/m |
| discount factor F2 | 0.42 | |
| discounted reconstruction costs | £0 | Present Value |
| | | |
| Maintenance of new def | 0 | £/m/yr |
| discount factor F3 | 6.05 | |
| discounted maintenance costs | £0 | Present Value |
| | | |
| TOTAL DISCOUNTED COSTS | £0 | Present Value of scheme |

| | | |
|---|---|---|
| **2/ Assets** | | |
| Current value | 944,230 | £ |
| discount factor F4 | 0.67 | |
| Discounted assets WRITTEN OFF | **£633,000** | |
| | | |
| Residual damages | £0 | |
| year occuring | £0 | |
| discount factor F5 | 1 | |
| discounted residual damages | **£0** | |
| | | |
| TOTAL DISCOUNTED DAMAGES | **£633,000** | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £0 |
| Scheme Costs | PVc | 0 | £0 |
| Maintenance costs (new) | PVm | 0 | £0 |
| Total Costs | PVtc | 0 | £0 |
| | | | |
| **Damages** | | | |
| Flood damages | PVd | £708,000 | £633,000 |
| Residual damages | PVrd | £0 | £0 |
| Total Damages | PVtd | £708,000 | £633,000 |
| | | | |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £75,000 |
| | | | |
| **Net Present Value** | NPV | 0 | £75,000 |

**ECONOMIC ASSESSMENT**

**ZONE 4S : OPTION 3**

| | | |
|---|---|---|
| **Flood Compartment** | 13 | |
| **1/ Defences** | | |
| Defended length | 1500 | m |
| Residual life for Do Nothing | 7 | years |
| Residual life if maintained | 15 | |
| Maintenance costs | 10 | £/m/yr |
| discount factor F1 | 9.71 | |
| discounted maintenance costs | £145,650 | Present Value |
| Reconstruction costs | 800 | £/m |
| discount factor F2 | 0.42 | |
| discounted reconstruction costs | £504,000 | Present Value |
| Maintenance of new def | 1 | £/m/yr |
| discount factor F3 | 6.05 | |
| discounted maintenance costs | £4,840 | Present Value |
| TOTAL DISCOUNTED COSTS | £654,000 | Present Value of scheme |

| | | |
|---|---|---|
| **2/ Assets** | | |
| Current value of assets PROTECTED | 0 | £ |
| discount factor F4 | 0.67 | |
| Discounted assets WRITTEN OFF | £0 | |
| Residual damages | £92,500 | |
| year occuring | £10 | |
| discount factor F5 | 0.56 | |
| discounted residual damages | £52,000 | |
| TOTAL DISCOUNTED DAMAGES | £52,000 | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £146,000 |
| Scheme Costs | PVc | 0 | £504,000 |
| Maintenance costs (new) | PVm | 0 | £5,000 |
| Total Costs | PVtc | 0 | £655,000 |
| **Damages** | | | |
| Flood damages | PVd | £708,000 | £0 |
| Residual damages | PVrd | £0 | £52,000 |
| Total Damages | PVtd | £708,000 | £52,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £656,000 |
| **Net Present Value** | NPV | 0 | £1,000 |

## ECONOMIC ASSESSMENT

**ZONE 4S : OPTION 4**

| | | |
|---|---|---|
| **Flood Compartment** | 13 | |
| **1/ Defences** | | |
| Defended length | 1500 | m |
| Residual life for Do Nothing | 7 | years |
| Residual life if maintained | 15 | |
| Maintenance costs | 5 | £/m/yr |
| discount factor F1 | 9.71 | |
| discounted maintenance costs | £72,825 | Present Value |
| Reconstruction costs | 800 | £/m |
| discount factor F2 | 0.42 | |
| discounted reconstruction costs | £504,000 | Present Value |
| Maintenance of new def | 1 | £/m/yr |
| discount factor F3 | 6.05 | |
| discounted maintenance costs | £4,840 | Present Value |
| TOTAL DISCOUNTED COSTS | £582,000 | Present Value of scheme |

| | | |
|---|---|---|
| **2/ Assets** | | |
| Current value of assets PROTECTED | 0 | £ |
| discount factor F4 | 0.67 | |
| Discounted assets WRITTEN OFF | £0 | |
| Residual damages | £0 | |
| year occuring | £0 | |
| discount factor F5 | 1 | |
| discounted residual damages | £0 | |
| TOTAL DISCOUNTED DAMAGES | £0 | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | PVe | 0 | £73,000 |
| Scheme Costs | PVc | 0 | £504,000 |
| Maintenance costs (new) | PVm | 0 | £5,000 |
| Total Costs | PVtc | 0 | £582,000 |
| **Damages** | | | |
| Flood damages | PVd | £708,000 | £0 |
| Residual damages | PVrd | £0 | £0 |
| Total Damages | PVtd | £708,000 | £0 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £708,000 |
| **Net Present Value** | NPV | 0 | £126,000 |

**ECONOMIC ASSESSMENT**

**ZONE 4S : OPTION 5**

| | | |
|---|---|---|
| **Flood Compartment** | 13 | |
| **1/ Defences** | | |
| Defended length | 1500 | m |
| Residual life for Do Nothing | 7 | years |
| Residual life if maintained | 10 | |
| Maintenance costs | 10 | £/m/yr |
| discount factor F1 | 7.36 | |
| discounted maintenance costs | £110,400 | Present Value |
| Reconstruction costs | 800 | £/m |
| discount factor F2 | 0.56 | |
| discounted reconstruction costs | £672,000 | Present Value |
| Maintenance of new def | 1 | £/m/yr |
| discount factor F3 | 8.4 | |
| discounted maintenance costs | £6,720 | Present Value |
| TOTAL DISCOUNTED COSTS | £789,000 | Present Value of scheme |

| | | |
|---|---|---|
| **2/ Assets** | | |
| Current value of assets | 0 | £ |
| discount factor F4 | 0.67 | |
| Discounted assets WRITTEN OFF | **£0** | |
| Residual damages | £185,000 | |
| year occuring | £10 | |
| discount factor F5 | 0.56 | |
| discounted residual damages | **£104,000** | |
| TOTAL DISCOUNTED DAMAGES | **£104,000** | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | PVe | 0 | £110,000 |
| Scheme Costs | PVc | 0 | £672,000 |
| Maintenance costs (new) | PVm | 0 | £7,000 |
| Total Costs | PVtc | 0 | £789,000 |
| **Damages** | | | |
| Flood damages | PVd | £708,000 | £0 |
| Residual damages | PVrd | £0 | £104,000 |
| Total Damages | PVtd | £708,000 | £104,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £604,000 |
| **Net Present Value** | NPV | 0 | -£185,000 |

## ECONOMIC ASSESSMENT

**ZONE 4S : OPTION 6**

| **Flood Compartment** | 13 | | |
|---|---|---|---|
| **1/ Defences** | | | |
| Defended length | 1500 | m | |
| Residual life for Do Nothing | 7 | years | |
| Residual life if maintained | 15 | | |
| | | | |
| Maintenance costs | 10 | £/m/yr | |
| discount factor F1 | 9.71 | | |
| discounted maintenance costs | £145,650 | Present Value | |
| | | | |
| Reconstruction costs | 800 | £/m | |
| discount factor F2 | 0.42 | | |
| discounted reconstruction costs | £504,000 | Present Value | |
| | | | |
| Maintenance of new def | 1 | £/m/yr | |
| discount factor F3 | 6.05 | | |
| discounted maintenance costs | £4,840 | Present Value | |
| | | | |
| TOTAL DISCOUNTED COSTS | £654,000 | Present Value of scheme | |
| | | | |
| **2/ Assets** | | | |
| Current value of assets | 0 | | £ |
| discount factor F4 | 0.67 | | |
| Discounted assets WRITTEN OFF | **£0** | | |
| | | | |
| Residual damages | £92,500 | | |
| year occuring | £10 | | |
| discount factor F5 | 0.56 | | |
| discounted residual damages | **£52,000** | | |
| | | | |
| TOTAL DISCOUNTED DAMAGES | £52,000 | | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £146,000 |
| Scheme Costs | PVc | 0 | £504,000 |
| Maintenance costs (new) | PVm | 0 | £5,000 |
| Total Costs | PVtc | 0 | £655,000 |
| **Damages** | | | |
| Flood damages | PVd | £708,000 | £0 |
| Residual damages | PVrd | £0 | £52,000 |
| Total Damages | PVtd | £708,000 | £52,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £656,000 |
| **Net Present Value** | NPV | 0 | £1,000 |

**ECONOMIC ASSESSMENT**

**ZONE 4S : OPTION 7**

| | | |
|---|---|---|
| **Flood Compartment** | 13 | |
| **1/ Defences** | | |
| Defended length | 500 | m |
| Residual life for Do Nothing | 5 | years |
| Residual life if maintained | 5 | |
| Maintenance costs | 10 | £/m/yr |
| discount factor F1 | 4.21 | |
| discounted maintenance costs | £21,050 | Present Value |
| Reconstruction costs | 600 | £/m |
| discount factor F2 | 0.75 | |
| discounted reconstruction costs | £225,000 | Present Value |
| Maintenance of new def | 1 | £/m/yr |
| discount factor F3 | 11.55 | |
| discounted maintenance costs | £6,930 | Present Value |
| TOTAL DISCOUNTED COSTS | £253,000 | Present Value of scheme |
| **2/ Assets** | | |
| Current value of assets | 245,080 | £ |
| discount factor F4 | 0.75 | |
| Discounted assets WRITTEN OFF | **£184,000** | |
| Residual damages | £50,000 | (habitat management) |
| year occuring | 5 | |
| discount factor F5 | 0.75 | |
| discounted residual damages | **£37,500** | |
| TOTAL DISCOUNTED DAMAGES | **£221,500** | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £21,000 |
| Scheme Costs | PVc | 0 | £225,000 |
| Maintenance costs (new) | PVm | 0 | £7,000 |
| Total Costs | PVtc | 0 | £253,000 |
| **Damages** | | | |
| Flood damages | PVd | £708,000 | £184,000 |
| Residual damages | PVrd | £0 | £37,500 |
| Total Damages | PVtd | £708,000 | £221,500 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £486,500 |
| **Net Present Value** | NPV | 0 | £233,500 |

## ECONOMIC ASSESSMENT

**ZONE 4S : OPTION 8**

| | | |
|---|---|---|
| **Flood Compartment** | 13 | |
| **1/ Defences** | | |
| Defended length | 500 | m |
| Residual life for Do Nothing | 10 | years |
| Residual life if maintained | 10 | |
| | | |
| Maintenance costs | 5 | £/m/yr |
| discount factor F1 | 7.36 | |
| discounted maintenance costs | £18,400 | Present Value |
| | | |
| Reconstruction costs | 500 | £/m |
| discount factor F2 | 0.56 | |
| discounted reconstruction costs | £140,000 | Present Value |
| | | |
| Maintenance of new def | 1 | £/m/yr |
| discount factor F3 | 8.4 | |
| discounted maintenance costs | £4,200 | Present Value |
| | | |
| TOTAL DISCOUNTED COSTS | £163,000 | Present Value of scheme |

| | | |
|---|---|---|
| **2/ Assets** | | |
| Current value of assets PROTECTED | 245,080 | £ |
| discount factor F4 | 0.56 | |
| Discounted assets WRITTEN OFF | **£137,000** | |
| | | |
| Residual damages | £50,000 | (habitat management) |
| year occuring | 10 | |
| discount factor F5 | 0.56 | |
| discounted residual damages | **£28,000** | |
| | | |
| TOTAL DISCOUNTED DAMAGES | **£165,000** | |

**3/ Assessment of Costs**

| | | Do Nothing | With Scheme |
|---|---|---|---|
| **Costs** | | | |
| Maintenance costs (existing) | Pve | 0 | £18,000 |
| Scheme Costs | PVc | 0 | £140,000 |
| Maintenance costs (new) | PVm | 0 | £4,000 |
| Total Costs | PVtc | 0 | £162,000 |
| **Damages** | | | |
| Flood damages | PVd | £708,000 | £137,000 |
| Residual damages | PVrd | £0 | £28,000 |
| Total Damages | PVtd | £708,000 | £165,000 |
| **Damages Avoided** | | | |
| (Benefits) | PVb | 0 | £543,000 |
| **Net Present Value** | NPV | 0 | £381,000 |

## APPENDIX E

## ENVIRONMENT AND PLANNING

CONTENTS

## E1 OVERVIEW OF THE BLYTH ESTUARY

The Blyth is the smallest and perhaps the least estuary-like of the Suffolk estuaries. This is largely due to the history of land reclamation that has been undertaken around the estuary. In the lower part of the valley, the Blyth is closely contained in a narrow channel by the flood defences that protect Southwold Town Marshes, Reydon Marshes and Tinker's Marsh. Upstream of Tinker's Marsh the estuary suddenly opens out into a large expanse of mudflats, the result of inundation of former reclaimed agricultural land following collapse of the flood defences. In its upper reaches (upstream of the A12 bridge) the tidal Blyth River is contained in a narrow channel flanked by grazing marshes.

The Blyth is located within the Suffolk Coast and Heaths Area of Outstanding Natural Beauty and is a designated Heritage Coast. The Blyth estuary is also contained within the Minsmere-Walberswick SSSI, which is a Special Protection Area and Ramsar site. This internationally important site comprises a mosaic of coastal, wetland and heathland habitats that support a very diverse flora and fauna, including many nationally scarce and rare species. Counts of overwintering waterfowl on the estuary over the past decade confirm that the Blyth is now nationally important for overwintering black-tailed godwit and pintail and in some winters internationally important for overwintering avocet. Tinker's Marsh is an important area of grazing marsh and one of the best localities in Suffolk for breeding waterfowl.

Agricultural land predominates around the Blyth with arable production, grazing and outdoor pig rearing being the main activities. A large area of the inter-tidal mudflats and saltmarsh, together with heathland and grazing marsh (Tinker's Marsh) on the southern side of the estuary, forms part of the Walberswick National Nature Reserve and is managed by English Nature.

Recreational activity is largely limited to the coastal end of the estuary, centred on Southwold and Walberswick. Southwold Harbour is used for a mix of inshore fishing and sailing boats which tie up to jetties along both sides of the river. Waveney District Council manages the harbour through a users committee. Traditionally there has been little recreation activity upstream of the Bailey Bridge, but water skiing takes place and there is occasional use by jet skis and canoeists.

## E2 HUMAN AND BUILT ENVIRONMENT

### E2.1 Land Use

As with much of the Suffolk coast, the land surrounding the Blyth is largely undeveloped and uncommercialised lending the estuary and its environment an isolated and relatively undisturbed feel. Agricultural land use dominates with large open arable fields sweeping down to the reclaimed drained marshland of the valley floor. Mixed farming predominates with grazing and arable on the valley floor and arable and outdoor pigs on the slopes. The agricultural landscape is interrupted by the wooded slopes and heathland along the southern side of Angel Marshes and Bulcamp Marshes, which form part of the Walberswick National Nature Reserve.

Development has been restricted to spurs or promontories of land, the location of which provided protection from flooding. Examples of these include. Blythburgh at the head of the estuary, and Southwold and Walberswick at the mouth of the estuary.

### E2.2 Residential Development and Industry

The main residential areas are the historic settlements of Southwold and Walberswick, situated towards the mouth of the estuary on the north and south banks respectively. Southwold particularly acts as a service centre for the local population. The only other residential area is the village of Blythburgh, situated approximately 5 km from the estuary mouth at the foot of the A12 road bridge.

In addition to these settlements there are numerous farm houses and cottages located on the slopes overlooking the estuary.

Apart from agriculture, industrial and commercial activity on and around the estuary is restricted to the fishing industry and small-scale light works such as boat building at Southwold Harbour. The Harbour is considered to be an important local economic asset to the town of Southwold, providing employment for fishermen, boat builders and associated activity, and the Harbour Inn.

### E2.3 Recreation and Tourism

Compared with the other Suffolk estuaries recreational activity on the Blyth is relatively low-key. Activities centred on the estuary include water sports such as sailing, canoeing and yachting, along with wildfowling, walking and birdwatching from the estuary shores. There is a sailing club located at the harbour. Unlike the other Suffolk estuaries, however, the Blyth has no swinging moorings. Due to the relatively narrow channel and presence of old flood walls, navigation in the upper part of the estuary is difficult, which tends to restrict boating activity to the lower estuary or more generally the open sea. Some waterskiing and jet skiing takes place in the lower part of the estuary between Southwold and Reydon. There are, however, occasional problems with jetskis moving into the upper part of the estuary, where disturbance to roosting and feeding birds as well as erosion of estuary vegetation can result. The secluded and calm nature of the Blyth make it popular with canoeists and is well used all year round by novices and very experienced sea and inland paddlers, including touring canoeists.

The footpath network in the area is relatively extensive, is well used and is an important recreational resource. The flood defences on either side of the estuary form the main footpath routes, except in the upper estuary where breach of the flood walls has effectively destroyed the original route. The footpaths on either side of Southwold Harbour (via the Bailey Bridge) form part of the Suffolk Coast long distance path. The paths across Southwold Town Marshes are particularly well used by birdwatchers and local walkers.

The historic and picturesque settlements of Southwold and Walberswick are popular tourist destinations. Much of their appeal is centred on their attractive setting alongside the estuary and the sandy beaches on the open coast. Southwold Harbour, with its traditional waterside character is a well visited area, although access and car parking can be problematic. The maintenance of a high quality environment, both natural and human, is viewed as of great importance to the tourism industry. Tourist facilities immediately adjacent to the estuary are limited. There is a camping and caravan park at Havenbeach Marshes on the Southwold side of the estuary. This is the main site for the area and makes an important contribution towards the local economy. A restricted use (summer only) campsite occupies part of The Flats amongst the dunes and grassland at the eastern end of Walberswick.

### E2.4 Commercial and Recreational Fishing

There are shellfish layings in the Blyth, for which the council has issued approval under the Shellfish Directive (91/492/EEC). There is a small but thriving Pacific oyster (*Crassostrea gigas*) fishery at Wolsey Creek, where the shellfish are grown in trestles and purified in tanks prior to marketing. There is limited cultivation of the Pacific oyster near Bulcamp Marshes, and evidence of historical mussel and native oyster cultivation in the area.

Fishing activity comprises pleasure angling and some commercial netting for bass and mullet by small fishing vessels. Eel fishing also takes place in the river, notably by line fishing. Approximately 30 licensed inshore vessels are based at Southwold and Walberswick, although only half of these are currently considered to be active. The existence of a right to fish in tidal waters means that most angling takes place on an informal basis. This occurs from the shore in almost any location where access is possible. The extensive saltings and mudflats that occur along the estuarine areas can, however, inhibit access at low water.

Many different types of fish are caught by recreational anglers fishing on the estuaries and the coast. Flatfish such as plaice, dab, flounder and sole are regularly caught by beach anglers. Cod and whiting are commonly caught in autumn in winter, whereas bass tend to be caught in the summer and autumn.

### E2.5 Agriculture and Forestry

Agricultural land use dominates the slopes surrounding the Blyth estuary. The free-draining and acidic soils of the area are developed from glacial sands and gravels overlying Crag sands and pebble beds. These soils are relatively infertile giving rise to agricultural land which, without irrigation is largely unproductive (classified as Grade 4). The light sandy soils are, however, conducive for the raising of outdoor pigs.

Grazing marsh predominates on the valley floor. This land represents former intertidal estuary mudflats and saltmarsh which has been reclaimed and drained. The majority of reclamation took place in the 16th and 17th centuries. By 1842, 1100 ha of agricultural land had been reclaimed from the Blyth, resulting in the estuary being confined to a narrow meandering channel in the centre of the valley. Following the exceptional coastal flooding of 1953 a large area of the Blyth was submerged and lay neglected for a number of years. The floods provided the impetus to begin large-scale agricultural improvement with strengthening of the flood walls, field levelling and under-drainage taking place. Further breaches of the flood defences in the upper part of the estuary (Angel Marshes and Bulcamp Marshes) in the 1960s have since returned some 250 ha of grazing marsh to mudflat. Most of the grazing marsh is improved and semi-improved for cattle and sheep grazing.

All of the agricultural land surrounding the Blyth is included within the Suffolk River Valleys Environmentally Sensitive Area (ESA).

There are only small areas of woodland and wooded hedgerows on the valley slopes surrounding the Blyth. The largest woodland block is an area of coniferous plantation (Hill Covert) on the southern side of the estuary which forms part of the Walberswick National Nature Reserve. There are no designated areas of ancient woodland near the Blyth.

### E2.6 Historic and Archaeological Heritage

The archaeological resource of the Suffolk estuaries is relatively unknown. From survey work in similar situations e.g. the Essex estuaries, it is clear that over the past 4000 years the sheltered interface between the land and the sea found along estuary shores has provided an important area for settlement and food gathering. The estuaries have also provided safe havens for ships and their cargoes for at least two thousand years. No systematic survey has been undertaken of the archaeological interest of the estuaries, but there is no reason to doubt their importance given the significant finds that have been made from the Essex estuaries. Near the Blyth, dredging work at Buss Creek in 1990 led to the chance discovery of the remains of two 10th century boats.

The Royal Commission on the Historical Monuments of England has identified only one charted foul which is situated at the mouth of the estuary. However, considering its past maritime influence, it is likely that there are more wrecks in the area which remain undiscovered.

There are several Grade II listed buildings situated adjacent to the estuary. These comprise the Harbour Inn at Southwold Harbour, an old water tower to the east of Southwold, and the Blackshore wind pump at Reydon Marshes.

Three Scheduled Ancient Monuments occur in the immediate area. These are the remains of an Augustinian Priory at Blythburgh (TM 4520 7540) and two round barrows near Tinker's Walks (TM 4710 7480 and TM 4700 746).

### E2.7 Water Quality

Water quality targets can be divided into those that are statutory and non-statutory. Statutory standards in the East Suffolk Local Environment Agency Plan (LEAP) Consultation Report (Environment Agency, 1997) are set by the following EC Directives: the EC Freshwater Fish Directive (78/659/EEC), the EC Bathing Waters Directive (76/160/EEC), the Shellfish Waters Directive (79/923/EEC) and the EC Dangerous Substances directive (79/464/EEC).

The best indication of estuarine water quality is provided by the CEWP Target Classes for Saline Waters. This incorporates both biological and chemical parameters. In 1995, this system classified 7km of the Blyth estuary as Class A (Good), with no stretches of the estuary classified as Class B to D. Traditionally estuaries have been used for the dilution of domestic sewage derived from adjacent towns and villages. There are currently two sewage outfalls that discharge into the Blyth, located at Blythburgh Hospital, approximately 2km upstream of the A12 bridge and the final effluent from the Sewage Treatment Works at Southwold.

Blooms of suspended microscopic algae can occur in estuaries rivers and may impact on the dissolved oxygen levels in the estuary waters. During periods of prolific algal growth the reduced levels can result in fish mortality. Factors which interact to result in the formation of algal blooms are numerous and complex, but it is known that algal growth is promoted by high levels of nutrients, in particular nitrogen and phosphorus. The principal source of these is often sewage treatment works (point source discharges) and run-off from agricultural land (diffuse inputs). Suspended algal populations are determined on some watercourses by the concentration of *chlorophyll a* in the water. *Chlorophyll a* monitoring is regularly carried out on the Blyth estuary, although the estuary is not classified as a candidate Sensitive Area (Eutrophic) under the Urban Waste Water Treatment Directive (91/271/EEC).

## E3 NATURAL ENVIRONMENT

### E3.1 Geology and Geomorphology

The solid geology of the Suffolk Coast is comparatively simple and is dominated by rocks formed by sedimentary processes. These soft, generally undisturbed rocks are responsible for creating the area's gently rolling landscape. North of the Deben estuary the solid geology is dominated by shelly marine sands and clays, known as Crags. These were deposited under shallow marine conditions during the late Pliocene to Pleistocene, some 2 million years ago. Around the Blyth, and throughout East Suffolk, much of the Crag outcrop is overlain by a series of sands and gravels deposited as outwash material as the last ice sheet retreated from Britain. These sediments give rise to the deep, free-draining acidic soils characteristic of the area.

In geological terms the Suffolk estuaries are of recent origin having formed as sea-level rose following the end of the last Ice Age approximately 7k years ago. Coupled with the subsidence of the North Sea Basin this rise in sea-level flooded the river valleys of east Suffolk. All of the Suffolk estuaries, with the exception of the Ore, have been formed by this process. The calm conditions that prevailed in the newly formed estuaries allowed sediment to settle and formed extensive areas of intertidal mudflat fringed by salt tolerant vegetation.

The present day morphology of the Blyth estuary largely reflects human influence over the last three hundred years. The original intertidal area of the Blyth was in the region of 1300ha. By 1842 the extent of reclamation was such that approximately 1100ha of the intertidal zone had been converted to agricultural land, restricting the estuary to a thin channel extending 10 km inland to Blyford Bridge. Today, due to a series of breaches in the defences during this century, 250ha have been returned to the intertidal zone.

## E3.2 Landscape

The landscape of the Blyth, more than perhaps any of the other Suffolk estuaries, documents a history of reclamation and marshland drainage. The present estuary occupies about a third of its former (pre-reclamation) valley floodplain. In general, the valley of the Blyth is relatively uniform in width (700-1000m) with gently sloping sides up to the surrounding plateau surface at 5-10m OD.

Above Blythburgh the upper reaches of the estuary consist of a narrow tidal channel enclosed by flood banks and flanked by extensive grazing marshes. Downstream of the A12 at Blythburgh as far as Reydon, the estuary fully occupies the valley floor, with extensive inter-tidal mudflats extending up to the break in slope. The course of the main channel across the mudflats is in places marked by former river walls which originally constrained the estuary until they were breached during the 1950's. The tributary valley of the River Wang enters the Blyth at Wolsey, downstream of which the estuary is again contained within a relatively narrow channel to its mouth at Southwold Harbour. Along this section the channel is flanked by treeless grazing marshes and arable land, rising to the north to form the low hill on which Southwold is located and to the south to form the low promontory on which the village of Walberswick is situated. Between the two, at the mouth of the estuary, Southwold harbour is characterised by wooden-built jetties which line either side of the channel and a variety of huts and sheds which reflect the general informal and uncommercialised character of this section of the coast.

## E3.3 Habitats and Species

### E3.3.1 Saltmarsh and Mudflats

The intertidal area of the Blyth represents the most significant habitat type within the study area and is particularly important as a feeding and roosting area for waterfowl. The mudflats regularly support large flocks of avocet (*Recurvirostra avosetta*), with up to 400 being recorded in recent winter months. Significant populations of pintail (*Anas acuta*), avocet and black-tailed godwit (*Limosa limosa*) have wintered on the Blyth only during the past ten years, during which time numbers have generally increased annually. The Blyth now supports nationally important populations of these species and at times internationally important numbers of avocet.

Thirteen saltmarsh and two swamp communities have been identified (Suffolk Wildlife Trust, 1993) on the Blyth estuary covering a total of 86 ha. The majority of the saltmarsh fringes the southern side of Bulcamp Marshes and Angel Marshes. There has been very limited development of saltmarsh on the main bulk of the mudflats and northern side of these areas following breach of the estuary defences in the 1950-1960s. This suggests that the inundated land was at a low-level relative to mean high water and that, in addition, the overall rate of sediment accumulation is low.

Saltmarsh vegetation can be split into four basic community types, each with a suite of different species adapted to varying tidal and substrate conditions. Pioneer saltmarsh accounts for approximately 13% of the total habitat, a relatively high component compared with the other estuaries. Low-marsh communities make up about 29% on the Blyth and is dominated by extensive stands of rayed sea aster (*Aster tripolium*) particularly on the southern side of the mid-estuary. These stands are species-poor, having an underlayer of glasswort (*Salicornia* spp.) and cordgrass (*Spartina anglica*) and are comparable to those growing along the mid section of the Deben estuary. One notable difference is that the stands on the Blyth are apparently more stable and do not show the extensive erosion seen in the stands on the Deben. Low-mid and mid-marsh communities make up the bulk of the well-established saltmarsh blocks, comprising 37% of the total. This is often a complex community comprising a variety of species, but on the Blyth tends to be dominated by species such as common saltmarsh grass (*Puccinellia maritima)* and sea lavender (*Limonium vulgare)*. The upper marsh community comprises various grass species, notably sea couch (*Elytrigia atherica)*. This species generally occurs on old flood banks and often forms a strip between the lower communities and the vegetation of higher ground. On the Blyth it is prevalent on the northern side of Bulcamp Marshes where there are no flood defences, forming a fringe between the mudflats and the neighbouring agricultural land.

Survey work undertaken by Suffolk Wildlife Trust in 1993 indicates that saltmarsh erosion along the seaward-edge is relatively widespread throughout the estuary, particularly on the southern side of Bulcamp Marshes. There are some very small areas where accretion appears to be taking place. The overall loss of this habitat on the Blyth is difficult to estimate, but has been put at about 0.5-1% annually of the total area (i.e. 0.4-0.8ha).

### E3.3.2 Vegetated Shingle

There are no significant areas of this habitat present within the Blyth estuary. On the open coast at Southwold Denes, immediately to the north of the estuary mouth, a linear strip of partially vegetated shingle occurs fronting the sand dune system.

### E3.3.3 Grazing Marsh

Grazing marsh occupies much of the original estuary valley floodplain, particularly on both the northern and southern side of the channel between the estuary mouth and Wolsey Bridge. Upstream of the A12 extensive areas of grazing marsh occupy the floodplain of the Blyth. The majority of the marshes are improved and semi-improved cattle grazing with some areas of unimproved grazing located upstream of the A12 and at Tinkers Marshes. Botanically these areas are generally species-poor with very few "pockets" of diversity. The internal dyke systems are often of more interest particularly if the cycle of dyke management has not been too harsh. Slightly brackish dyke systems are characteristic of many of the coastal grazing marshes, often showing a transition to freshwater along their more landward stretches. These salinity variations provide a range of habitat niches and often support rich aquatic communities as at Tinkers Marshes and Southwold Town Marshes.

Where water levels within the internal dyke systems are raised to near surface level, the marshes support important breeding and overwintering bird populations. Tinker's Marsh on the southern side of the Blyth is particularly important and represents one of the more important wet grassland wader and waterfowl breeding sites in Suffolk. The Suffolk Wildlife Trust survey in 1997 recorded 23 pairs of redshank (*Tringa totanus*), 20 pairs of lapwing (*Vanellus vanellus)* and notably 8 pairs of avocet. In contrast only three pairs of oystercatcher (*Haematopus ostralegus*) were recorded from the larger block of Reydon Marshes on the northern side of the estuary. These differences reflect the specific management of Tinkers Marshes for its wildlife interest and the improved and drier nature of the marshes at Reydon.

Historically Southwold Town Marshes has been an important breeding site for waterfowl although in recent years the number of pairs of species such as lapwing and redshank has markedly declined. The Marshes are, however, an important overwintering and landfall site for waterfowl.

### E3.3.4 Reedbeds

Reedbeds are an important habitat for a number of rare birds and invertebrates. In Suffolk, there are 550 hectares of reedbed remaining, which amounts to almost 25% of the national resource. Large reedbeds have developed on the coast either in estuaries or on former coastal grazing marshes and their dykes, or fringing brackish lagoons. The large brackish coastal reedbeds, tend to be species-poor plant communities almost entirely composed of common reed (*Phragmites australis*). Approximately 12ha of reedbed occurs on the Blyth, the vast majority of it occurring along the southern shore of

Angel Marshes. This area supports a small colony of the nationally rare marsh sowthistle (*Sonchus palustris*).

### E3.4 Conservation Designations

The Suffolk coast is recognised nationally and internationally as an area of unique landscape, wildlife and historic interest. This is reflected in the large number of statutory and non-statutory designations that have been applied to the area. Further information regarding theses designations is provided in Section E5.

The Blyth and surrounding land falls within the Suffolk Coast and Heaths Area of Outstanding Natural Beauty (AONB). The primary purpose of the designation is to conserve and enhance the natural beauty of the area and to protect its flora, fauna, geological interest and landscape features. However, in pursuing the primary purpose account should be taken of the needs of agriculture, forestry and the economic and social needs of local communities.

The Blyth estuary is also contained within the Suffolk Heritage Coast (designated in 1973). The 1992 Heritage Coast Policy sets national targets for all Heritage Coasts, namely the provision of a semi-natural strip along the coast accommodating a coastal path, the clearance of eyesores and meeting standards for water and beach cleanliness.

A large part of the intertidal estuary, the grazing marshes and wetlands of the River Hen and lower part of the Wang valley, Southwold Town Marshes and significant areas of grazing marsh and heathland to the south of the estuary are contained within the Minsmere to Walberswick Heaths and Marshes Site of Special Scientific Interest (SSSI). The main estuary channel east of Tinkers Marshes and the extensive grazing marshes upstream of Blythburgh are not included within the SSSI. The SSSI (apart from Southwold Town Marshes) is also a designated Special Protection Area (SPA) and Ramsar Site for its internationally important breeding bird populations. Heathland on the southern side of the Blyth, notably Walberswick Common, is included within the Minsmere-Walberswick Special Area of Conservation (SAC). In addition, Tinkers Marshes and Angel Marshes, together with heathland and woodland on the southern side of the estuary, form part of Walberswick National Nature Reserve (NNR). The boundaries of the SSSI, SPA and SAC are shown in Map 5 of the Atlas.

Buss Creek, Busscreek Marshes, Southwold Denes, the shingle and saltmarsh to the west of Walberswick, the grazing marshes of the River Wang, Blythburgh Marshes and marshland on the northern side of the river near Blyford are all County Wildlife Sites (CWS). The Suffolk Wildlife Trust own an area of wet woodland and grazing marsh upstream of Wolsey Bridge (the Norman Gwatkin Nature Reserve). In addition, the Suffolk Wildlife Trust is in the process of acquiring a 37 ha site alongside its current 10 ha landholding to create a new reedbed as part of a European Union project to create and manage reedbeds for bittern and other wetland fauna and flora.

The entire estuary and much of its hinterland is contained within the Suffolk River Valleys Environmentally Sensitive Area (ESA), which was designated in 1988 and extended in 1993 by MAFF.

## E4 PLANNING AND LEGISLATION

### E4.1 Introduction

A major task of the Strategies is to balance the management of flood defence requirements in the estuaries with the interests of organisations and individuals involved in the area. Planning departments, amenity groups, and conservation organizations, amongst others, have a diverse range of interests, concerns and policies which need to be fully considered in developing a strategy for sustainable flood and coastal defence. To this end, this section identifies some of the existing management plans, policies and legislation that influence the final management objectives and policies put forward in the Strategy for each estuary.

## E4.2 Statutory Plans and Policies

Although the individual estuary Strategies are not Shoreline Management Plans, their establishment and production is founded on similar principles and objectives. With respect to this MAFF (1995) have, in their SMP guidance, provided the following definition: "*a Shoreline Management Plan is a document which sets out a strategy for coastal defence for a specified length of coast taking account of natural coastal processes and human and other environmental influences and needs*". The local planning authorities are responsible for the type and control of development within their areas of jurisdiction and this is enforced primarily through the preparation of plans and the granting of planning permission. Additionally, the information contained in the adopted planning documents can be expected to provide an indication of "human and environmental influences and needs" (MAFF, 1995).

The Suffolk Estuarine Strategies is not a statutory document, but must put forward a strategy which is consistent with the adopted policies and objectives already established through the statutory planning framework (e.g. Planning Policy Guidance and other Ministry advice, sites designations, Structure Plans and Local Plans). Conversely, the Strategies also has a role in informing and directing future policies and objectives with regard to activities and development within the estuaries and along the coast, if this could potentially impact upon estuarine processes. In terms of planning permission (i.e. adherence to Structure and Local Plans), new flood defence and coast protection capital works normally require planning permission (MAFF, 1995).

## E4.3 National Planning Policy Guidance

The National Planning Policy Guidance Notes (PPG's) detail Government guidelines on implementation of national planning policies at the regional and local level. The PPG's provide primary guidance to all relevant authorities on how they should execute their responsibilities with regard to wider public interest. This guidance therefore is used to guide the development of county structure plans and local authority plans. The following PPG's are particularly relevant to the development of the Strategies:

- PPG 7, The Countryside and the Rural Economy
- PPG 9, Nature Conservation
- PPG 14, Coastal Hazards
- PPG 15, Planning and Historic Environment
- PPG 16, Archaeology and Planning
- PPG 17, Sport and Recreation
- PPG 20, Coastal Planning
- PPG 21, Tourism.

## E4.4 Structure Plan Policies

The entire area is covered by the Suffolk County Structure Plan, which is the approved statutory Strategic Development Plan for the whole of the County. The County Council has also published a Suffolk Structure Plan Review Consultation Draft (April 1998).

The structure plan provides a planning framework for the entire study area. The plan sets out the County Council's overall land use strategy with regard to the quality of the County's environment and its conservation; the development and other use of land; and the movement of people and goods.

A number of policies from the structure plan are relevant to the SMP in as much as they provide protection for designated areas such as SSSIs and SAMs. These encompass agriculture, conservation, development, tourism and recreation issues among others.

The County Structure Plan, however, does not deal directly with flood protection issues.

### E4.5 Local Plans

There are two Local Plans within area the covered by the Strategies. The majority of the Suffolk coast falls under the authority of the Suffolk Coastal District Council. Waveney District Council covers the northern part of the Suffolk coast from Walberswick northwards. This area includes Southwold Harbour, the eastern end of the Blyth Estuary and the northern bank of the estuary as far upstream as Wolsey Bridge.

The above planning documents were reviewed as part of the collation and analysis of issues for the Strategies. The relevant policies that potentially may influence the Strategy objectives for the Blyth have been identified and are summarised in Table E4.5(a),(b) and (c) below:

**Table E4.5(a) Suffolk Coastal Local Plan (First Alteration)**

| Planning Issue | Summary | Local Plan Policy |
|---|---|---|
| *Countryside-Protection* | The landscape quality and character of the countryside will be protected for its own sake by generally restricting development to that which is essential for the efficient operation of agriculture, forestry and horticulture or is otherwise permitted by other policies in the Local Plan. | LP8A |
| Management Plans | The District Council will actively encourage the implementation of the Suffolk Coast and Heaths Management Plan and the Greenways Project Management Plan. | LP10A |
| Agriculture and Commercial Woodland | When considering proposals for development the District Council will pay particular regard to the need to minimise irreversible loss of commercial woodlands and the best and most versatile agricultural land, and the need to minimise the severance and disruption of viable farms and commercial woodland. Best and most versatile land includes Grades 1,2 and 3a. | LP10.1 |
| Area of Outstanding Natural Beauty | To safeguard landscape quality within the AONB development will be strictly controlled and no planning permission will be given unless there is an overriding national need for such development. | LP11A |
| Special Landscape Areas | The valleys and tributaries of the Alde, Blyth, Deben, Ore are designated as Special Landscape Areas. No development shall take place that will detract the special landscape quality of the areas. | LP13A |
| | Development will not be permitted if it would result in: | |

| Planning Issue | Summary | Local Plan Policy |
|---|---|---|
| Wildlife and Habitats | i) the loss or significant alteration of important habitats including heathland, woodland, dunes, water meadows, permanent pasture, parkland, marshes, saltmarshes, vegetated shingle, mudflats, streams, ponds, reedbeds, green lanes, trees and hedges.<br>ii) The threat to rare or vulnerable species, especially those protected by law. | LP13A |
| Designated Areas and Habitats | Development which would adversely affect NNRs, SSSIs, SPAs, SACs and Ramsar sites will not be permitted unless it has been demonstrated that there is an overriding national need for such development in that particular location and no alternative site is available. The potentially adverse effects of development on CWSs and LNRs will be a material planning consideration. | LP14A |
| Trees, Hedgerows and Woodlands | The retention, improvement and management of existing trees, hedgerows and woodlands will be encouraged | LP16A |
| Tourism | The District Council will encourage tourist facilities, accommodation and attractions, particularly those which:<br>i) extend the tourist season and the range of tourist attractions<br>ii) provide employment | LP57A |
| Areas at Risk from Flooding | Development will not be permitted where it is likely to impede materially the flow or storage of flood water or increase the risk of flooding elsewhere or increase the number of people or properties at risk from flooding unless the development includes appropriate measures to prevent these occurring. | LP75A |
| Sea Defences | In the interests of marine and coastal habitats, particularly along the Heritage Coat the DC will expect the use of soft sea defences … thus providing the opportunity to maximise nature conservation benefits rather than the installation or raising of sea walls using material such as concrete. The protection of sites of archaeological importance will also be relevant to the design of the sea defences. | LP80A |
| Loss of Playing Pitches and Other Sports Grounds | Proposals involving the loss of existing playing pitches and grounds for outdoor sports use will be judged against the overall needs of the community, adopted standards of provision and the availability of provisions elsewhere. | LP82A |

**Table E4.5(b) Suffolk Coastal Local Plan (October 1991)**

| Planning Issue | Summary | Local Plan Policy |
|---|---|---|
| Listed Building Consent | The District Council will only consent to alterations or extensions to buildings Listed as being of special architectural or historic interest, where it can satisfactorily be demonstrated that they will not prejudice the special character of the building or setting. | LP5 |
| Development of Archaeological Sites | There will be a presumption against development that would adversely affect SAMs and other nationally important archaeological sites and their setting. | LP7 |
| Local Nature Reserves | Where the Council already has an interest in the land it will declare appropriate sites of wildlife interest as Local Nature Reserves. | LP15 |
| Footpaths and Bridleways | The DC will endeavour to safeguard the existing public footpath and bridleway network and encourage its maintenance. It will also support the provision, in appropriate locations, of the creation of additional public, or permissive, rights of way, particularly if such provision is compatible with the objectives for recreation within the AONB. | LP86 |

**Table E4.5(c) The Waveney Local Plan**

| Planning Issue | Summary | Local Plan Policy |
|---|---|---|
| *The Natural Environment* | The District Council will secure the conservation and enhancement of the natural beauty of the Suffolk Coast and Heaths AONB, including the Heritage Coast, by favouring the conservation of the landscape in development control decisions and by positive measures of management and enhancement | ENV1 |
| | Development which would, directly or indirectly, would have a material adverse impact on existing SSSI, SPAs, SACs, Ramsar sites and NNRS will not be permitted | ENV5 |
| | Development which, directly or indirectly, is likely to result in the destruction of or significant damage to CWSs, LNRs or sites proposed for such designations will not be permitted | ENV6 |
| | All development proposals should make provision for the protection of semi-natural features. Development which would have a material adverse impact on sites supporting species protected by the Wildlife and Countryside Act 1981 and other nationally rare species will not be permitted | ENV7 |
| | Proposals which are likely to lead, directly or indirectly, to an increase in coastal erosion or flooding will not be permitted | ENV13 |
| | Proposals likely to establish or increase the need for coastal protection measures will not be permitted | ENV14 |
| | Development within flood risk areas (including washlands and floodplains), either from tidal or fluvial situations, or development which would place existing development at risk will not be permitted | ENV16 |
| | Development which poses an unacceptable risk to the quality of groundwater will not be permitted | ENV17 |
| The Built Environment | To protect the character of the conservation area and to ensure that new buildings, alterations of other developments, preserve or enhance them, the District Council will, through the control of development within or affecting conservation areas, have regard to the following design criteria | ENV20 |
| | Planning permission for development | |

| Planning Issue | Summary | Local Plan Policy |
|---|---|---|
| | affecting scheduled ancient monuments or other sites of national archaeological importance will not be permitted. | ENV31 |
| | On sites of local archaeological importance and in areas of regional importance, the local planning authority will not approve planning applications unless the archaeological aspects of development proposals has demonstrated that particular sites and monuments will be satisfactorily preserved on site or by record | ENV32 |
| Recreation | The District Council, in conjunction with the County Council, will seek to safeguard and extend the existing footpath and bridleway network, particularly through the creation of circular footpath routes starting and finishing at or near suitable parking areas or public transport stops | OS7 |
| Southwold | The District Council will continue to carry put essential safety work at the Harbour as and when resources allow | S4 |
| | An area for additional moorings has been identified on the northern shore of the River Blyth. Outside this area permission for new moorings will not be permitted on either side of Southwold Harbour | S5 |
| | Replacement moorings will be permitted in an identified area on the proposals maps (northern bank of the River Blyth) provided that all reasonable works of maintenance and repair have been carried out to prolong the life of the stages | S6 |

### E4.6 Other Relevant Plans and Non-statutory Designations

There are a number of different types of voluntary management plans and designations that are relevant to the management of the estuaries. These are listed below together with a summary of relevant policies, objectives and management issues. There can be an overlap between the different plans, but in general each has a particular remit.

### E4.7 The East Suffolk Local Environment Agency Plans (LEAP)

LEAPs focus on main river catchments, which include estuaries and coastal waters, and provide a strategic framework within which the following demands can be integrated: flood defence; water resources; navigation; conservation; fisheries, and pollution. LEAPs have been produced by the Environment Agency to replace the original Catchment Management Plans. The East Suffolk LEAP, produced in 1997, sets out a programme of actions which the Environment Agency and partner organisations intend to undertake over the next five years to protect and enhance the local environment of East Suffolk, including the estuaries of the Deben, Alde-Ore and Blyth. A summary of relevant issues if given in Table E4.7.

**Table E4.7 Summary of Relevant Issues in East Suffolk Local Environment Agency Plan (LEAP)**

| Issue | Concern/Action |
|---|---|
| A1 | Impacts on the environment arising from land use in parts of the Sandlings area |
| A4 | Flows in the River Deben decline to an environmentally unacceptable level during the summer period |
| A5 | Concern over the potential impact of declining flows of small streams running across intertidal areas within SPAs |
| A6 | There is a lack of habitat diversity both within rivers and their floodplains |
| A7 | Ensure that the Environment Agency activities comply with the new and existing EU Directives concerning nature conservation |
| A9 | There is a need to assess and where appropriate protect the ecological status of the headwaters of rivers |
| A10 | Operation of Blyford Water Control Structure has implications for the upstream ecology, fishery and water quality impacts |
| B2 | Requirement to provide estuarial, coastal and fluvial flood protection |
| C3 | The presence of toxic and persistent chemicals disposed of on Orford Ness have had an adverse impact on the groundwater and local ecosystem |
| C4 | Concern regarding eutrophication of the freshwater environment of the River Deben |
| C5 | Concern over nutrient loadings to the Deben estuary and the frequent occurrence of algal blooms |

## E4.8 Suffolk Coast and Heaths Management Plan

The coastline of Suffolk from Kessingland in the north to the Stour Estuary in the south together with the heathland, coniferous forests and surrounding agricultural land of the coastal strip forms the Suffolk Coast and Heaths Area of Outstanding Natural Beauty. The primary purpose of the designation is to conserve and enhance the natural beauty of the area and to protect its flora, fauna, geological interest and landscape features. AONBs are designated by the Countryside Commission under the *National Parks and Access to the Countryside Act 1949*.

The management plan outlines an integrated approach for the management of the AONB area ensuring that activities do not conflict with the purposes of designation, and wherever possible contribute towards them. It sets the context for management, defines strategic objectives, highlights issues and formulates management policy in relation to them. Management plan objectives relevant to the production and implementation of the Suffolk Estuarine Strategies are summarised below under four main headings:

### (i) Conservation

**Objectives:** To conserve and enhance the natural beauty of the area in particular the varied landscape, wildlife and historic value. To take account of the needs of agriculture, forestry, tourism, other industry and of the economic and social needs of local communities. Particular regard should be given to promoting environmentally sustainable forms of social and economic activity.

| Assessment | Policy No. | Management Policy |
|---|---|---|
| *Landscape and Wildlife Designations* | C1 | Maximise opportunities to enhance the landscape and character and resist changes which undermine it |
| | C2 | Seek the inclusion of the Stour estuary and its south shore within the Suffolk Coast and Heaths AONB. |
| | C3 | Monitor landscape change within the AONB |
| | C4 | Promote the designation, protection, enhancement and re-creation of the areas nationally important landscape and wildlife character. |
| | C5 | Promote awareness and sensitive management of CWSs with landowners. |
| Development | C6 | Encourage all agencies to pay particular regard to restricting inappropriate development in AONB. |
| | C7 | Proposed major developments in or adjacent to the AONB must be in the national interest and with no alternative location. They should be accompanied by appropriate amelioration of benefit to the landscape and wildlife value of the area. |
| | C12 | Implement a programme to remove, relocate or reduce the visual impact of prominent coastal eyesores. |
| Estuaries | C20 | Prevent further loss of intertidal areas. |
| | C21 | Integrate environmentally sustainable recreation and commercial activity with the conservation of estuarine landscape and wildlife. |
| | C22 | Encourage the preparation of integrated management plans for estuaries. |
| Heathland | C23 | All remaining heathland should be brought into effective management |
| | C24 | Promote the re-creation of heathland, targeted at areas that were historically heathlands or adjacent to existing heathlands. |
| Archaeology and Built Heritage | C29 | Identify and promote the protection and management of historic and archaeological sites, and where appropriate make management agreements with landowners. |
| | C32 | Conduct surveys of archaeological sites under threat of coastal erosion and in intertidal areas of estuaries. |
| | C34 | Prepare a management strategy for coastal archaeology. |
| Coastal Defence | C41 | Ensure that high regard is paid to visual and environmental considerations in the planning and design of coastal defence works. |
| | C42 | Seek the use of natural coast defence processes and soft engineering solutions wherever possible. |
| | C43 | Seek the creation of areas of landscape and wildlife interest in planning for sea level rise. |
| | C44 | Seek the re-routing of public rights of way which are made impassable as a result of sea erosion. |
| | C45 | Support the Environment Agency, District Councils and MAFF in developing an integrated approach to coastal defence and the preparation of SMPs. |

### (ii) Recreation

**Objective:** To facilitate the quiet enjoyment of the area insofar as is consistent with conservation of natural beauty and wildlife significance and the needs of agriculture and forestry.

| Assessment | Policy No. | Management Policy |
|---|---|---|
| *Tourism* | R3 | Provide opportunities for leisure and tourism interests to make direct contributions to conservation and recreation initiatives. |
| *Visitor Management* | R6 | Carefully monitor and evaluate recreation activity to assist the application of appropriate management measures. |
| Countryside Access | R14 | Target all public rights of way to be legally defined, properly maintained and suitably publicised by 2000. |
| | R16 | Develop, extend and maintain the Suffolk Coast Path and the Essex Way. |
| | R17 | Promote routes with high standards of accessibility, maintenance and publicity for walkers, cyclists and horseriders and the less able. |
| | R19 | Develop sites and facilities where appropriate, for informal countryside recreation. |
| | R21 | Support land acquisition where public access is compatible with conservation or where positive management would reduce conflict. |
| | R22 | Develop appropriate recreational use of the coastal forests and ensure that public access is safeguarded. |
| Water-based Recreation | R24 | Monitor water based recreation activity and facilities. |
| | R26 | To further explore sites suitable for use by Personal Water Craft and measures to control use in inappropriate places. |
| | R27 | Co-ordinate use of waterspace and integrate with conservation management on all estuaries. |
| | R29 | Establish estuary forums of user and other interests to pursue integrated management of all the main estuaries. |

### (iii) Awareness

**Objectives:** To promote understanding of the area and the need for its conservation. To promote co-ordinated management amongst all users which makes the best use of resources and minimises conflict. To encourage local participation in the management of the area.

| Assessment | Policy No. | Management Policy |
|---|---|---|
| *Raising Awareness* | A1 | Promote greater awareness and increased understanding among local people, local authorities, the main agencies and key decision makers, in order to encourage greater commitment to the conservation of the AONB. |
| | A5 | Support the work of estuary associations and user groups and to provide a more co-ordinated approach to management. |

**(iv) Management Zones**

| Management Zone | Relevant Management Priorities |
|---|---|
| Blyth Valley | Manage the rich wildlife interest of the Minsmere, Walberswick Heath and Marshes SSSI and other heaths. |
| | In association with users prepare and implement environmental improvements for Southwold Harbour with regard to access, jetties, car parking and other facilities and the use of the Blyth estuary |

### E4.9 Suffolk Heritage Coast

Heritage Coast is a non-statutory designation agreed between local authorities and the Countryside Commission to assist with planning and management of the coastline. Areas selected for designation must have at least 1 mile of coastline of exceptionally fine scenic quality, generally undeveloped and with features of special significance and interest.

The basis of Heritage Coast designation (defined by the Countryside Commission in 1970 and retained in the 1992 policy document is "the finest stretches of undeveloped coast". The designation originally referred to landscape quality but was revised in 1992 to include flora and fauna (terrestrial, littoral and marine) and heritage features of architectural, historical and archaeological interest, as well as environmental quality (e.g. water quality).

Broadly, the aims can be described as:

- the conservation and enhancement of characteristic heritage features – landscape, geology, wildlife, archaeology, history.
- the enjoyment of the area by the public in ways that do not damage or degrade its heritage characteristics.

The coastline, including the estuaries (apart from the upper half of the Deben) from Kessingland in north Suffolk to Felixstowe has been designated as the Suffolk Heritage Coast. Objectives relating to its management are effectively covered by the Suffolk Coast and Heaths Management Plan for the AONB in which the Heritage Coast is contained.

### E4.10 Suffolk River Valleys Environmentally Sensitive Area (ESA)

A large part of the Suffolk coast and the valleys of the main rivers including the estuaries of the Deben, Alde/Ore and Blyth fall within the Suffolk River Valleys ESA. Within this area, designated by the Ministry of Agriculture, Fisheries and Foods (MAFF) in 1988 and extended in 1993, farmers can voluntarily enter into an agreement in which they receive payments for adopting or maintaining traditional management practices which will help to conserve and enhance the landscape, wildlife and historic interest of the area. The ESA is administered through the Farming and Rural Conservation Agency.

### E4.11 County Wildlife Sites

Most English counties have a non-statutory system of County Wildlife Sites (CWS), generally established by the local County Wildlife Trust. Trusts own, lease and manage reserves. These sites are increasingly recognised by the statutory development plans and accorded some degree of protection under the planning system. Locally they may be known by other names such as Sites of Nature Conservation Importance (SNCI). A large number of sites on the Suffolk coast have been classified as CWSs by the Suffolk Wildlife Trust.

## E5 LEGISLATION

### E5.1 Overview

As well as the plans and strategies described above, the establishment of flood protection or defence measures must also adhere to current legislation. The main items of legislation that are relevant to the use of this Estuarine Strategy are the following EC Directives, UK Acts and Conventions:

- Environment Act, 1995
- Food and Environment Protection Act, 1985
- The Coast Protection Act, 1949
- The Land Drainage Act, 1991
- The Ramsar Convention
- The Wildlife and Countryside Act 1981
- The Birds Directive (79/409/EEC)
- The Habitats Directive (92/43/EEC)
- The Conservation (Natural Habitats etc.) Regulations, 1994
- The Convention on Biodiversity, 1994.

Future works must also take into account current water quality legislation including:

- Dangerous Substances Directive (76/464/EEC)
- Bathing Water Directive (76/160/EEC)
- Shellfish Waters Directive (79/923/EEC)
- Urban Waste Water Treatment Directive (91/271/EEC).

### E5.2 Environment Act

Within England and Wales the principle legislation regulating the environmental protection of coastal and estuarine waters is the Environment Act 1995. The objective of this Act is to form the legal basis for the EA and as such, it modified the previous objectives and aims of the NRA, HMIP and the WRCs (as identified by the Water Resources Act, 1991). The overall aim of the EA is to protect and enhance the whole environment (land, air and water) as part of the international goal of sustainable development. This is defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The Minister of State has set seven objectives to guide the EA to work toward sustainable development. These are:

- An integrated approach toward environmental protection and enhancement, taking into consideration the impact of all activities and natural resources
- Delivery of environmental goals without imposing disproportionate costs on industry or society as a whole
- Clear and effective procedures for serving its customers, including the development of single points of contact with the EA
- High professional standards, using the best possible information and analytical methods
- Organization of its own activities to reflect good environmental and management practice, and provision of value for money for those who pay its charge, as well as for taxpayers as a whole
- Provision of clear and readily available advice and information on its work
- Development of a close and responsive relationship with the public, including Local Authorities, other representatives of local communities and regulated organisations.

The Environment Agency has statutory powers that affect estuarine waters and interests, including responsibilities for issues such as flood defence, water quality and fisheries, etc.

### E5.3 Food and Environment Protection Act (FEPA)

Under the FEPA 1985 (as amended), MAFF has a statutory duty to control the deposition of certain articles or materials in the sea or in tidal waters. FEPA requires that a licence be obtained from MAFF to deposit any articles or substances in the sea or under the seabed. Such articles or substances include materials used during offshore construction as well as waste materials that are dumped at sea, where the deposit or placement may affect the hydrology, other marine activities or impact on the sea bed and marine flora and fauna, with implications for designated conservation areas.

### E5.4 The Coast Protection and Land Drainage Acts

The Coast Protection Act 1949 and the Land Drainage Act 1991 define the general powers of the coast protection and flood defence authorities. The implementation of the Strategies will be governed, therefore, by the responsibilities of the managing agencies (the Environment Agency and coastal authorities) defined under these Acts.

### E5.5 The Ramsar Convention (Wetlands of International Importance)

Ramsar sites are statutory areas designated by the UK Government under the *International Ramsar Convention* (the Convention on Wetlands of International Importance especially as Waterfowl Habitat). This requires signatory states to designate wetlands of international importance and promote their conservation and wise use. Ramsar sites are designated for their waterfowl population, plant and animal assemblages, wetland interest or a combination of these. Sites designated as Ramsar sites may also be designated separately as Special Protection Areas.

### E5.6 The National Parks and Access to the Countryside Act and Wildlife and Countryside Act

The 1949 Act introduced the concept of National Nature Reserves (NNRs) and Sites of Special Scientific Interest (SSSI). SSSI are designated by English Nature as being "of special interest by reason of flora, fauna, or geological or physiographical features". They represent the areas of greatest significance to nature conservation in Britain, a collective national total of protected areas sufficient to guarantee the survival of Britain's wildlife and physical features. It should be noted that some SSSI may be of biological interest, geological interest or both. SSSI designated for their biological interest may be divided into Nature Conservation Review (NCR) sites (essentially those which are most important in national terms) and non-NCR sites. All geological sites are Geological Conservation Review sites. SSSI can include terrestrial and intertidal habitats, but not the subtidal zone

National Nature Reserves (NNRs) can be designated under Section 35 of the *Wildlife and Countryside Act 1981* (previously designated under Section 19 of the *National Parks and Access to the Countryside Act 1949*). They represent examples of Britain's best areas of natural or semi-natural habitat and have to be designated SSSI's. They are designated by English Nature but, unlike other SSSI, they are managed primarily in the interests of nature conservation. NNRs may be owned and managed by English Nature or by arrangement with other approved organisations.

The 1981 Act strengthened the protection for SSSIs and restricted the killing, taking from the wild and disturbance of various species.

### E5.7 The Birds and Habitats Directives

The Blyth Estuary forms part of the Minsmere - Walberswick Special Protection Area (SPA) and part of the tidal floodplain is included in the Walberswick candidate Special Area of Conservation (cSAC). Both designations bestow particular responsibilities on the Environment Agency and relevant coastal authorities.

**Special Protection Areas (SPAs)**

SPAs are designated under the EU Directive on the *Conservation of Wild Birds* (79/409/EEC). This requires member states to take conservation measures to protect certain rare or vulnerable species and migratory birds. This is achieved by the statutory protection afforded to a site by being designated as an SPA. The designation is implemented through the *Conservation (Natural Habitats, etc.) Regulations 1994* and the *Wildlife and Countryside Act 1981*. All SPAs have to be first notified as a Site of Special Scientific Interest (SSSI). In addition, the Habitats Directive amends the Birds Directive by applying the same requirements for protection from damage as applied to Special Areas of Conservation.

**Special Areas of Conservation (SAC)**

SAC are designated under the EU Directive on the *Conservation of Natural Habitats and Wild Fauna and Flora* (92/43/EEC). This requires member states to designate areas as SACs to protect important wildlife habitats or listed species and to provide measures that will maintain or restore those interests to a "favourable conservation status". The SAC designation is implemented in the UK by the *Conservation (Natural Habitats etc.) Regulations 1994*. *Planning Policy Guidance Note 9* (PPG 9) also gives detailed information on the requirements of the Habitats Directive. In addition, MAFF have published guidelines with particular reference to the implications of SAC designation on flood and coastal defence, these guidelines also apply to SPAs (MAFF, 1995).

The MAFF guidelines on SMPs (of direct relevance to the Strategies) state that:

*"Shoreline Management Plans which include such sites will need to reflect the special protection afforded to the habitats or species for which they are identified as being of international importance. Damage to these sites is only permissible for 'imperative reasons of overriding public interest' and where there is no reasonable alternative option or different practicable approach available which would have less impact"* (MAFF, 1995).

## E5.8 The Conservation (Natural Habitats etc.) Regulations

*The Conservation (Natural Habitats etc.) Regulations 1994* transpose the Habitats Directive into UK law. The Regulations require "competent authorities" when carrying out works, which are likely to affect SPAs and SACs, to have regard to the requirements of the Habitats Directive in exercising their functions.

The Environment Agency as a competent and relevant authority has an obligation to ensure that all of the works and activities it undertakes in or near to designated sites will not adversely affect their integrity. This includes activities undertaken through General Development Orders (GDO), such as maintenance works to flood defences. If, through consultation with English Nature (and the local planning authority in respect of GDO's), it is considered that proposed EA works or activities would have an adverse impact upon the integrity of an SPA or SAC then the works cannot be undertaken, unless there are imperative reasons of overriding public interest.

If it is determined that a plan or project is likely to have a significant effect on the habitats or species for which a SAC or a SPA was designated, then an appropriate assessment must be carried out by the competent authority (coastal protection authority, EA, etc.

Where an appropriate assessment shows that a proposed development will have an adverse impact on the integrity of a SPA or a SAC or priority habitat, MAFF have produced the following criteria for determining if the development may proceed.

For sites which **do not** host a priority habitat or species a development will proceed if:

- there are no alternative solutions, and
- there are imperative reasons of over-riding public interest, including those of a social or economic nature.

For sites which **do** host a priority habitat or species a development may proceed if:

- there are no alternative solutions, and
- there are imperative reasons of over riding national public interest relating to human health and safety or beneficial consequences of primary importance to the environment (unless, on application, the European Commission is of the opinion that there are other imperative reasons of over-riding national public interest which could justify the development).

Within the estuaries, which are all designated SPAs, there are particular issues concerning the predicted loss of saltmarsh and freshwater grazing marsh habitat. Given the potential losses of saltmarsh habitat from the estuaries that could occur through "coastal squeeze" by maintaining the existing line of defence it could be argued that not only would this constitute a significant effect under the Conservation Regulations (thereby requiring an appropriate assessment to be undertaken) but, that it would also have an adverse affect on the integrity of the SPAs (i.e. each of the estuaries). Therefore, either defences could not be maintained or saltmarsh habitat would need to be created to compensate for losses if they were. There are several caveats to this, such as whether saltmarsh loss affect bird populations which utilise the estuaries, but in general terms it can be seen that this is a very significant issue with potentially far reaching consequences. It has to be said that at the present time there is still debate as to whether maintaining existing defences within SPA/SAC designated estuaries constitutes significant effect, and until this question has been fully debated the actual overall responsibility of the EA and requirements to deal with the situation remains unresolved.

### E5.9 The Biodiversity Convention and Agenda 21

In January 1994, the UK government published an Action Plan in response to the Convention on Biological Diversity. The Action Plan has established principles and objectives, which are relevant to the SMP.

The Action Plan provides a list of objectives to conserve and, where practicable, enhance wild species and wildlife habitats. The objectives taken from the *Biodiversity - The UK Action Plan* (HMSO, 1994), which are relevant to the SMP are listed below:

- create mechanisms for effective protection and management of key wildlife areas in the marine environment in the UK;
- ensure that development control conforms to Government policies for the conservation of biodiversity;
- continue to implement new approaches to coastal flood defence and coast protection which manipulate, and work with, natural processes;
- undertake further research to assess the scope for habitat creation through managed retreat of the coast, linking research projects around a full scale trial;
- incorporate environmental principles, including biodiversity, in their policies and programmes.

The statement of principles and objectives in the UK Action Plan aims to integrate environmental concerns with human activities. The goal of sustainable development is reflected within the 1995 MAFF SMP guidelines, which state that "*in preparing a Shoreline Management Plan the aim is to arrive at sustainable coastal defence policies which take account of the inter-relationships with other defences, developments and processes within a catchment or coastal sediment cell or sub-cell, and which avoid as far as possible tying future generations into inflexible and expensive options for defence*" (MAFF, 1995).

An underlying principle of the UK Government's approach is that the precautionary principle should guide management of decisions. This principle advises that, if the eventual outcome of a course of action cannot be predicted with confidence, then that course of action should not be undertaken.

A biodiversity plan for Suffolk is currently being produced.

### E5.10 Water Quality Legislation

In addition, of relevance to the Strategies, is legislation governing Water Quality. Any development adjacent to or located within the catchment of the estuary may potentially affect the contaminant loading or microbiological standard of the water. The control of water quality and effluent discharges is legislated for in four main Directives.

The Dangerous Substances Directive seeks to protect water quality by eliminating discharges containing toxic, persistent and bioaccumulative substances in List I, commonly known as the "Black List" and by reducing pollutants from substances contained in List 2, the "Grey List".

The Bathing Water Directive defines microbiological (coliform bacteria) and physico-chemical standards that designated bathing waters should achieve. The main objective of this Directive is to improve or maintain the quality of bathing water for amenity use and public health reasons.

The Shellfish Waters Directive sets water quality standards for areas designated to support shellfish.

Under the Urban Waste Water Treatment Directive, except in "high natural dispersion areas", all significant sewage discharges to coastal waters, where the outfalls serve populations >10k (roughly equivalent to 1,800m$^3$ per day), and to estuaries, where they serve populations >2k (roughly 360m$^3$ per day), will require at least secondary treatment, to be phased in by 2005.

In England, the primary statute to control discharges to the aquatic environment is the Water Resources Act 1991. The responsibility for the control of discharges and the maintenance of water quality lies with the Environment Agency who authorise sewage discharges to the sea by issuing "consents", with MAFF as a consultee to safeguard fishery interests. Trade effluent discharges, including hazardous substances, are also authorised by the Environment Agency under the Environmental Protection Act 1990.

## E6 COASTAL SQUEEZE, HABITAT LOSS AND THE HABITATS DIRECTIVE

Burd (1989) in her study of East Anglian estuaries recorded significant losses of salt marsh vegetation from the estuaries of North Essex and south Suffolk over the period 1973-1988. On the Orwell there was a 33% recorded loss. Although she did not study the Deben, Alde-Ore and Blyth estuaries it is assumed that a similar scale of loss has occurred on these three estuaries. Much of the recorded loss has been attributed to the impact of coastal squeeze where, in response to sea-level rise, salt marsh is not able to maintain its position within the tidal frame due the presence of static defences preventing lateral migration. With no scope for compensatory development landwards, the width of saltmarsh is becoming progressively narrower as the seaward edge of the marsh is eroded.

The extent of saltmarsh loss from the Suffolk estuaries has not been considered in detail.

Beardall and Casey (1995) provide the overall estimate of 1% loss of saltmarsh area/year (including the effects of sea-level rise, erosional processes etc) for the Suffolk estuaries. For the three estuaries this equates to:

Deben 237 ha = 2.4 ha/yr (over 50 years = 120 ha)

Alde-Ore 310 ha = 3.1 ha/yr (50 = 155ha)

Blyth 86 ha = 0.8 ha/yr (50 = 40ha)

Further to this study, Beardall (pers. Comm.) suggests that about 13ha of saltmarsh/yr is being lost from the Suffolk estuaries (including the Orwell). If this is the case, and it is assumed that about 1ha/yr is being lost from the Orwell, then 12ha/yr is being lost from the Deben/Alde-Ore/Blyth which, over 50 years equates to 600 ha, or all of the existing saltmarsh habitat. Until detailed figures are available it is considered that in the order of 200-600 ha of saltmarsh could be lost from the estuaries over the duration of the strategy. There would also be losses of inter-tidal mudflat due to sea-level rise, although these would be more than offset by the additional amount of mudflat created due to the loss of salt marsh vegetation.

Where flood defences are in effect preventing saltmarsh migration, they are to all intents and purposes causing damage to this habitat. This has important consequences with respect to estuaries, such as the Deben, Alde-Ore and Blyth, that are EC designated sites of international nature conservation importance (SPA, SAC).

In addition, and directly relevant to this issue, is the fact that the EA is a key player in shaping and implementing the UK Biodiversity Action Plan. In the recent set of EA's Functional Action Plans a series of actions have been set out with regard to biodiversity which, include the implementation of projects to deliver biodiversity targets, such as the creation of saltmarsh habitat. Clearly in areas where habitats are being lost, whether designated of international conservation importance or not, there is scope through the UK BAP for the EA to make positive contributions to habitat creation targets. For the Suffolk estuaries any potential (or need) for habitat creation would also be part of the overall strategic flood defence policy and therefore contribute both towards more effective flood defences and also to environmental well being.

# LIST OF ABBREVIATIONS

| | |
|---|---|
| AGHV | Area of Great Historic Value |
| AGLV | Area of Great Landscape Value |
| AONB | Area of Outstanding Natural Beauty |
| BAP | Biodiversity Action Plan |
| BGS | British Geological Society |
| CCA | Coastal Conservation Areas |
| CEWP | Classification of Estuaries Working Party |
| CMP | Catchment Management Plan |
| CPA | Coastal Protection Area |
| CWS | County Wildlife Site |
| cSAC | Candidate Special Area of Conservation |
| DDN | Delay Do Nothing |
| DN | Do Nothing |
| EA | Environment Agency |
| EC | European Community |
| EMP | Estuary Management Plan |
| EN | English Nature |
| ESA | Environmentally Sensitive Area |
| EU | European Union |
| FC | FC |
| FCDD | Flood and Coastal Defence Division of MAFF |
| FEPA | Food and Environment Protection Act (1985) |
| GCR | Geological Conservation Review |
| GDO | General Development Order |
| HMIP | Her Majesty's Inspectorate of Pollution |
| HR | HR (Hydraulics Research) Wallingford |
| HTL | Hold The Line |
| IPCC | Intergovernmental Panel on Climate Change |
| LEAP | Local Environment Agency Plan |
| LNR | Local Nature Reserve |
| MAFF | Ministry of Agriculture, Fisheries and Food |
| MNR | Marine Nature Reserve |
| NCC | Nature Conservancy Council |
| NCZ | Nature Conservation Zone |
| NPV | Net Present Value |
| NNR | National Nature Reserve |
| NT | National Trust |
| NRA | National Rivers Authority |
| OD | Ordnance Datum |
| PAGN | Project Appraisal Guidance Notes |
| POL | Proudman Oceanographic Laboratory |
| PPG | Planning Policy Guidance |
| pSAC | Possible Special Area of Conservation |
| RNLI | Royal National Lifeboat Institution |
| RSPB | Royal Society for the Protection of Birds |
| RIGS | Regionally Important Geological/Geomorphological Site |
| pSSSI | Proposed Site of Special Scientific Interest |
| SAC | Special Area of Conservation |
| SAM | Scheduled Ancient Monument |
| SMA | Sensitive Marine Area |
| SMP | Shoreline Management Plan |
| SMR | Sites and Monuments Register |
| SNCI | Site of Nature Conservation Importance |
| SPA | Special Protection Area |
| SSSI | Site of Special Scientific Interest |
| VMCA | Voluntary Marine Conservation Area |
| WRA | Water Research Council |