Overstrand to Walcott Strategy Study

"Do Nothing" – Erosion probability and erosion losses

Part II: Technical Support Information

Report EX 4692
October 2004

Overstrand to Walcott Strategy Study

"Do Nothing" – Erosion probability and erosion losses

Part II: Technical Support Information

Report EX 4692
October 2004

HR Wallingford

Address and Registered Office: HR Wallingford Ltd. **Howbery Park, Wallingford, OXON OX10 8BA**
Tel: +44 (0) 1491 835381 Fax: +44 (0) 1491 832233

Contract - Consultancy

This report describes work commissioned by North Norfolk District Council whose representative was Mr Peter Frew. The HR Wallingford job numbers were CDR3212 and CDR3214. The work was carried out by Douglas Benwell of the Engineering Systems and Management Group and George Motyka of the Coastal and Seabed Processes Group at HR Wallingford. The HR Wallingford project manager was Mr Paul Sayers.

Prepared by ....

(name)

....

(Title)

Approved by ....

(name)

....

(Title)

Authorised by ....

(name)

....

(Title)

Date ....

Summary

Overstrand to Walcott Strategy Study

“Do Nothing” – Erosion probability and erosion losses

Part II: Technical Support Information

Report EX 4692
October 2004

This report addresses the prediction of changes in the coastline between Cromer and Ostend, near Walcott, under various assumptions about the future abandonment, maintenance or renewal of coastal defences, including the so called “Do Nothing” option. This is the first policy option to be considered in the strategic assessment of other coastal defence policies for this frontage, and provides a “baseline” against which the benefits of maintaining or installing defences can be properly assessed. By predicting the future changes in the beaches and cliffs as the existing defences are assumed to deteriorate and fail, without intervention, the losses of land, properties and infrastructure are also evaluated. With this knowledge of the extent and timing of such losses, the economic consequences of the “Do Nothing” option can then be evaluated (see separate report entitled “Economic Evaluation”).

The prediction of coastline evolution under the “Do Nothing” option also provides an indication of the location and timing of the greatest potential economic losses and thereby indicates the areas where, and when, coastal defences will most be needed. This prediction exercise therefore informs the choice of more realistic coastal defence policy options, for example maintaining or improving defences in those areas where the risks arising from cliff top recession are greatest.

Predictions of beach and cliff top changes have been made for various times into the future, up to 100 years hence, in order to complete the economic evaluation procedures as specified in guidelines provided by Defra. Estimates of the residual service life of the existing defences have obtained from the detailed inspection carried out in this project, see earlier report on “Defence Condition Survey”. Forecasts of the changes in beaches and cliffs have been based on a numerical model, cliffSCAPE, developed and specifically calibrated for the Norfolk coastline from Sheringham to Happisburgh. This model uses information on the geology of the cliffs, and on the waves, tides and sediment transport along the beaches.

Contents

Contents continued

Figures

Appendix

1. INTRODUCTION

1.1 Purpose of report

This report describes the prediction of future changes in the coastline between Cromer and Walcott under the so-called “Do Nothing” option. This is the first policy option to be considered in the strategic assessment of other coastal defence options for this frontage, and provides a “baseline” against which the benefits of maintaining or installing defences can be properly assessed. By predicting the future changes in the beaches and cliffs, as the existing defences are allowed to deteriorate and fail without intervention, the losses of land, properties and infrastructure are evaluated. With this knowledge of the extent and timing of such losses, the economic consequences of the “Do Nothing” option can then be evaluated (see also separate report entitled “Economic Evaluation”).

Predictions of beach and cliff top changes have been made for various times into the future, up to 100 years hence, in order to complete the economic evaluation procedures as specified in guidelines provided by Defra. Estimates of the residual service life of the existing defences have obtained from the detailed inspection carried out in this project, see earlier report entitled “Defence Condition Survey”. Forecasts of the changes in beaches and cliffs have been based on a numerical model, cliffSCAPE, developed and specifically calibrated for the Norfolk coastline from Sheringham to Happisburgh.

1.2 Background to prediction methods

The coastline between Overstrand and Walcott is characterised by weak and unstable cliffs that are susceptible to erosion. Prior to the construction of coastal defences the cliff recession in this area averaged at between 0.65m to 0.75m per year (Cambers, 1976). Changes in the rate of cliff erosion occur in response to changes in the weather conditions, variations in cliff lithology, as well as changes in the strength and frequency of wave action at the cliff toe. In general, the cliff recession is virtually zero along defended stretches of coast and most rapid in between them, as shown in Figure 1.1, taken from the “Cliff Processes” section of report EX4692.

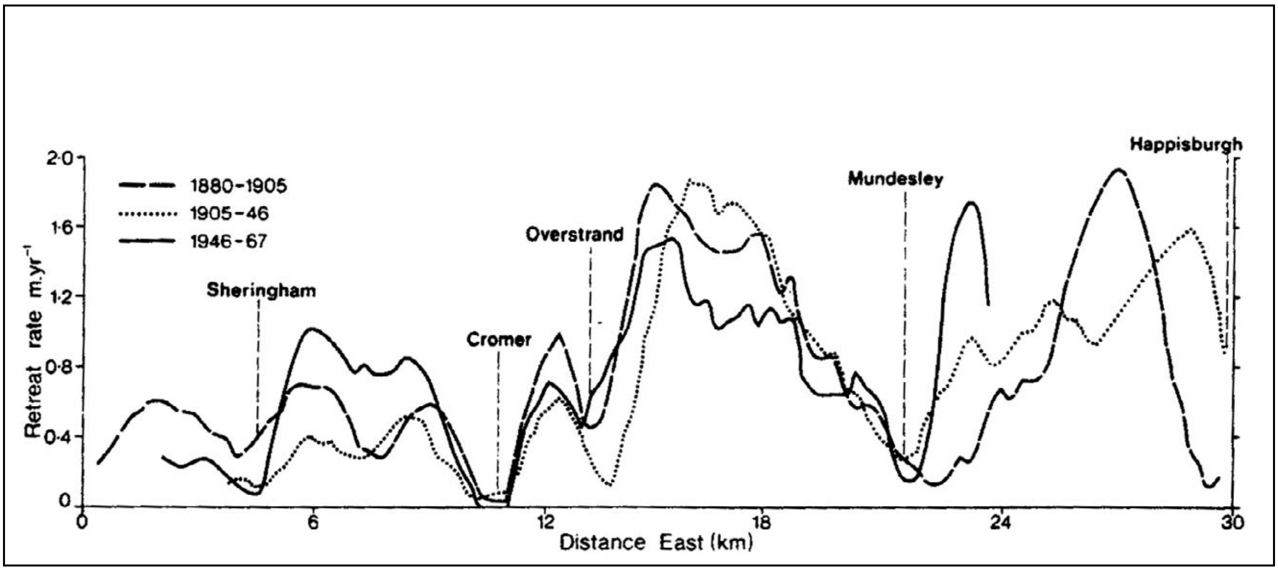


Figure 1.1 Variation in cliff recession rates along the North Norfolk coast (Cambers 1976)

Within the area covered by this study, the coastal defences are concentrated on the centres of population, i.e. at Overstrand, Trimingham, Mundesley, Bacton and Walcott, and typically comprise concrete seawalls and groynes. Outlying frontages are protected by less robust defences, consisting typically of groynes with sloping timber revetments. Where the latter have failed, there are now gaps in the defences, so the standard of protection varies. Because of the nature of the cliffs, and the lack of defences in some areas, there is considerable variation in the rate of cliff retreat.

There is considerable interaction between adjacent defended and undefended frontages, because of the alongshore movement of beach material, as well as the continuity of cliffs from one defence length to the next. For this reason, the coastline has been examined on a “regional” basis, covering the entire frontage from west of Sheringham, as far eastward as Happisburgh, over the frontage shown in Figure 1.2, taken from the “Littoral Sediment Processes” section of Report EX 4692.

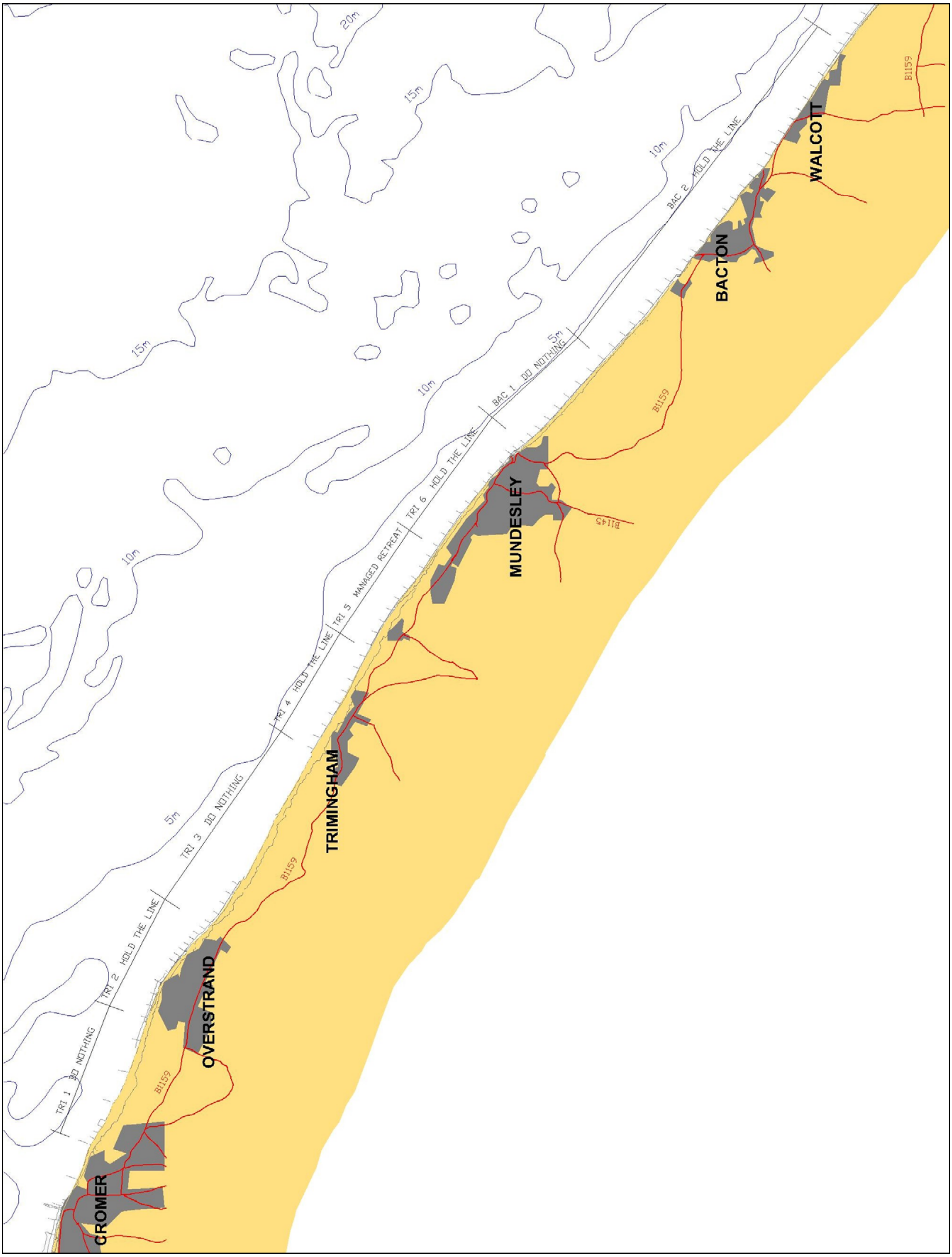


Figure 1.2 SMP policy options for the study area

Before considering the impacts of the "Do Nothing" option, or any other assumed policy option, it is first worthwhile recalling the policy options recommended by the Shoreline Management Plan for this area (Halcrow, 1996). This is important as the "performance" of these options will need to be compared against the "Do Nothing" scenario. In this Shoreline Management Plan, the coastline between Cromer and Walcott was sub-divided into eight "Management Units", with the recommendation being to adopt the same coastal defence policy for the whole length of each these Units.

The Management Units and the recommended policy options for the area are also shown in Figure 1.2. Briefly they are as follows:

Management Unit TRI1	(Cromer to Ovestrand)	Do Nothing
Management Unit TRI2	(Overstrand)	Hold the Line
Management Unit TRI3	(Overstrand to Trimingham)	Do Nothing
Management Unit TRI4	(Trimingham)	Hold the Line
Management Unit TRI5	(Trimingham to Mundesley)	Do Nothing
Management Unit TRI6	(Mundesley)	Hold the Line
Management Unit BAC1	(Mundesley to Bacton)	Do Nothing
Management Unit BAC2	(Bacton and Walcott)	Hold the Line

In this present Strategy Study the impact of a potential change in the overall policy is assessed. The first option against which others are compared is the "Do Nothing" option. The second option is one which sustains the defence policy recommended by the 1996 Shoreline Management Plan, as described for each Management Unit, in the table above. This option is referred to as "Management Scenario 3 - SMP policy options". This study also considers a possible amendment to this policy, which is referred to as "Management Scenario 4 - Revised policy options". This option is the same as Scenario 3, except that a Do Nothing policy would be adopted for Management Unit TR14 (Trimingham), instead of the Hold the Line policy recommended for this Unit in the 1996 SMP.

The situation that develops following the adoption of any of these three coastal defence "policy options" is referred to in the remainder of this report as a "scenario". The modelling of the coastline and cliff top changes for each scenario produces information for the economic evaluation of the "costs" resulting from the adoption of a policy, but this evaluation is considered in a separate report, called Economic Evaluation.

1.3 Modelling approach

When evaluating alternative coastal defence policies, it is necessary to carry out predictive modelling of the evolution of the shoreline, in order to examine the impacts of those policies. Such modelling indicates how the beaches will respond to changes in the coastal defences, littoral drift changes, sea level rise etc. and hence how coastal defences elsewhere will be affected by the changes in the beaches. The situation becomes more complicated when the coastline includes a "backshore", e.g. dunes or soft cliffs, that itself responds to the beach changes. In past studies, the future rates of dune of cliff recession were simply extrapolated using information on past rates of retreat, but this does not allow for any changes in the coastal defences, as anticipated in some of the scenarios now being considered.

In this study, therefore, a more sophisticated approach is adopted. Cliff recession rates have been predicted using a hybrid beach and cliff model called cliffSCAPE. This model examines the beach and cliff response to changes in the patterns of wave attack (it does not represent the processes of the weathering or other such "sub-aerial" erosion mechanisms, which will also add, in some measure to the long-term recession of the soft cliffs along this coastline).

When coastal cliffs retreat, it is not just the cliff top and face that is eroded, but also the shore platform in front of it, so that both the beach and cliff profiles interact and change with time. It is therefore important to use a model that can represent the evolution of both the beaches and the "backshore".

During the present study, the cliffScape-RS version of the model was used. This reproduces cross-sectional changes in beach and cliff profile with time, and is made quasi 3-dimensional, by allowing interactions between adjacent sections of the model. Essentially this model operates in the following manner:

- Using the breaking wave conditions, the bulk longshore transport rate of the beach sediment is calculated;

- This transport is then distributed across the foreshore, depending upon how long different parts of the intertidal zone are submerged during a typical tidal cycle, i.e. producing a “cross-shore sediment transport distribution”. The changes in the transport rate with distance alongshore are then used to quantify the beach accretion and erosion patterns in individual sections of the model (using the principle of mass continuity for the beach sediments);

- At each model “section” along the coastline, the erosion of the shore platform is then calculated from the incident wave conditions, depending also on the thickness of the sand cover over the shore platform. The cliff is then predicted to respond to the change in foreshore level by the removal of a slice of the cliff face, whose horizontal width is proportional to the vertical change in foreshore level. The sediment removed from the cliff forms a “talus” on the foreshore. The coarse fraction of this talus is then added to the volume of beach in that model section, while the fine-grained sediments from the talus are assumed to be dispersed offshore. The extra beach sediment produced by the cliff recession becomes available to transported alongshore, to supply adjacent sections of the coast;

- As the shoreline platform lowers, and the cliff face erodes, the cliff top then retreats. Because of the complicated and spatially varying land-sliding processes involved, there is no simple relationship between the rates and timings of cliff toe retreat and cliff top recession. To reflect this a separate stochastic model has been used, based on the geological assessment of the cliffs along different sections of the coastline, to provide a statistical prediction of the cliff top recession. This provides a range of possible future cliff top positions at any time into the future, with a probability ascribed to each;

- The changing position of the cliff top is subsequently used to predict of the loss of assets, e.g. residential properties and infrastructure. The timing and extent of these losses are later converted into financial losses, thus determining the economic “costs” of cliff erosion and the “benefits” achieved through preventing it. Note that since the cliff top position is predicted using a stochastic model, so too are the economic “costs” associated with the recession of the cliffs.

The heart of the prediction process in this study, is the cliffSCAPE model. This and any similar model is to some degree dependent on the accuracy of its calibration, in this case from the historic analysis of cliff top retreat rates. Before using cliffSCAPE, therefore, it was first necessary to calibrate it against historic cliff recession rates, taking into account differential rates of recession in protected and unprotected stretches of coastline. This calibration is described in Part 2: Technical Support Information report (EX 4692).

Once the model had been calibrated, the various coastal defence structures were introduced into it, as follows:

- Seawalls: These form a hard defence, behind which the cliffs are not allowed to retreat until the defences fail, at the mean estimate of their residual life;

- Groynes: These help to maintain beach levels and slow down cliff erosion. These are assumed to have 50% efficiency on longshore sediment transport up to their point of failure and 0% efficiency afterwards; and

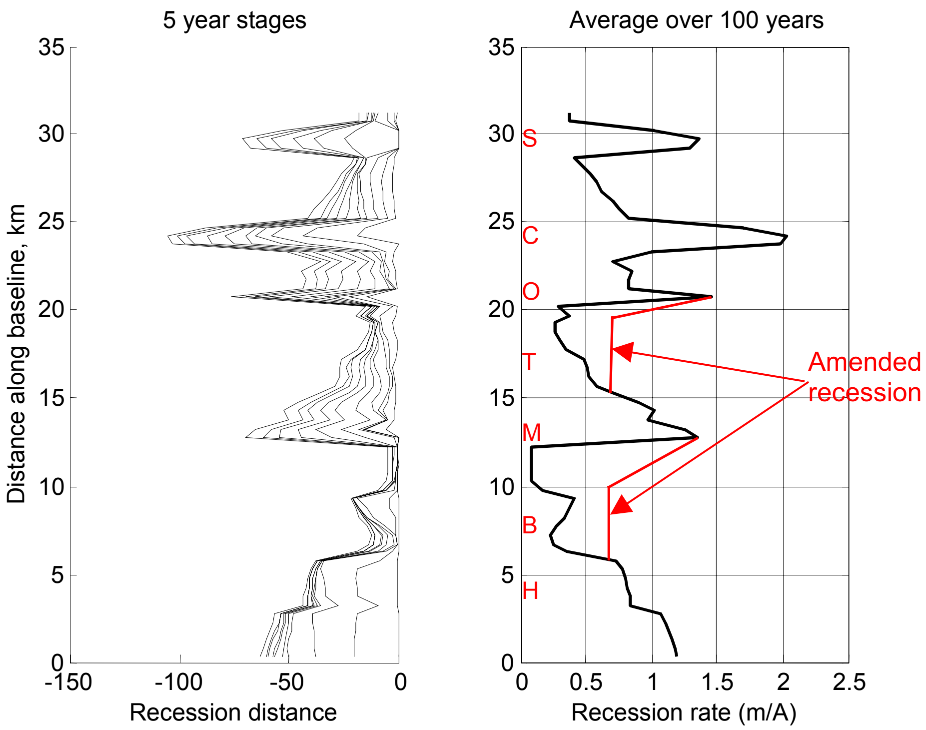
- Revetments: These structures slow down but do not entirely halt cliff erosion. These are assumed to produce a 75% reduction in wave energy up to the point of failure, and then have 0% efficiency afterwards.

The cliffSCAPE model was next validated, by reproducing the evolution of the beach/cliff profile at a number of selected cross-sections along the coast and by the evolution of the plan-shape of the shoreline (see EX 4692). Having obtained a match between measured and modelled changes, the numerical model was then used to examine various management options, including the "Do Nothing" scenario that is the subject of the present report.

1.4 Brief description of the "Do Nothing" scenario

In this scenario, it is assumed that all the coastal defences along this frontage are allowed to deteriorate, without any maintenance work being carried out, and ultimately fail at the mean estimated value of their residual life. Again, once a failure of the defences has occurred, no remedial action is taken, and future shoreline changes are allowed to progress naturally. This is generally an unrealistic and impractical scenario, and some remedial measures would have been taken to protect against damage to property and persons. However, this hypothetical scenario provides a standardised mechanism for assessing the value of defending a frontage, and is used as a "baseline" for the national prioritisation of coastal defence works.

Before describing the impacts of the Do Nothing scenario within each defence length (see next sections of report), it is necessary to discuss its impact from a regional perspective. Figure 1.3, taken from the Cliffscape results and with some minor amendments, shows the results for the Do Nothing scenario, in terms of the position of the cliff line at 5 year intervals. This figure also shows the cliff recession rate averaged over 100 years. As mentioned earlier, in this scenario the coastal defences are assumed to fail at the mean estimate of their residual life and then removed entirely.



No.	Management scenario	Notes
2	Do Nothing	Structures removed at the mean estimate of residual life

Figure 1.3 Recession rates for the Do Nothing scenario

It can be seen from these model results that the rate of cliff toe recession reaches a maximum at positions on the coastline that are presently protected by coastal defence works. This is an expected response to the cliff suddenly being exposed to wave action, as the shore platform in front of this cliff would have been eroding for some years at each of these points. (Aerial survey photographs clearly show the promontories that have developed at each of these hard points by differential erosion).

Another interesting feature of the modelling results is that, once the defences are removed, a significant reduction of the erosion rate is predicted to the east of each of these defended frontages. This predicted reduction in erosion rates extends several kilometres "down-drift", i.e. to the east and south, and in the direction of movement of the beach sediment transport. The reason for this is that a large proportion of the sediments eroded from the cliffs where they are presently defended feeds into the littoral zone, helping to maintain the beaches along the down-drift stretches of coast, east of each former hard point. The cliffs at Mundesley, for example, are estimated to contain nearly 70% sand (Cliff Processes section of EX4692). Thus a large proportion of the material released by cliff erosion nourishes the down-drift beaches, rather than being lost offshore. In down-drift areas the beaches subsequently accumulate sediment, and cliff erosion is reduced.

For the purpose of assessing the worst case scenario, however, the results of the modelling have been modified to allow for some long-term cliff retreat, even in areas where the beaches are stable, and where the cliffSCAPE modelling would therefore predict no cliff recession. Under these circumstances, it is assumed that the "baseline cliff recession" is equal to the minimum value of the measured long-term rate of cliff top recession, that is, about 0.65 metres per year, as mentioned earlier. Where the cliffSCAPE model prediction is lower than this rate, the cliff recession rate is set to this value, as can be seen in Figure 1.3. This procedure applies principally to the Do Nothing scenario, where all the defences are ultimately allowed to fail and hence so that cliff recession can be expected along the whole coastline. However, similar modifications are also made to the results of modelling the other policy option scenarios, as described in other sections of the study report.

1.5 Use of the cliff top recession rates for benefit-cost analysis

Having obtained the cliff top positions, it is now necessary to apply the results in a manner which allows the cliff top properties that are likely to be lost by cliff recession to be analysed. As mentioned above, the Cliffscape modelling only allows the cliff top to recede at times where the base of the cliffs is being actively eroded. At times when the beach is stable or accreting the base of the cliff is assumed to be stable also, and the cliff top is therefore not allowed to retreat during such periods.

From the evidence of the historic rates of retreat in this area, and from general observations and engineering, a "best estimate" was carried out of the likely enhancement of the cliff retreat, to reflect the ongoing recession of an unprotected cliff, even when the beach conditions are preventing toe erosion. This enhancement is shown in the amendments to the modelled cliff recession rate, given in Figure 1.3, and referred to in section 1.4. These amendments now have to be translated into a (modified) position of the cliff line. In this case the "best estimate" is based on a value that falls between the modelling results (a low bound value) and the values extrapolated using engineering judgement (an upper bound value).

The positions of the cliff line and of the assets at risk of erosion, based on these predicted rates of cliff retreat, are shown in Figures 2.1 to 2.10, for the various management units. In each figure the positions of the cliff top, at the 50% exceedance level, are plotted at time intervals, from year zero to 100 years after the Do Nothing scenario is put into operation. To derive this line an average was taken between:

- The cliff line at the 10% probability of exceedance level, as derived by the CliffSCAPE model
- The cliff line at the 90% probability of exceedance level, as derived by extrapolation from the model, i.e. based on the amended rates of cliff recession shown in Figure 1.3.

In the following section of the report the various assets that are likely to be lost through cliff retreat are described, while the economic statistics pertaining to these recession rates are found tabulated in Appendix 1.

2. DESCRIPTION OF COASTAL CHANGES BY MANAGEMENT UNITS

The modelling of the coastline, and its future changes, covered the long stretch of coastline from Sheringham to Happisburgh, and incorporated the effects of longshore drift and hence of changes in coastal defences, over that whole frontage. It is, however, much easier to assess the consequences of the alternative defence policy options by presenting the results of that modelling for each of the eight Management Units between Cromer and Walcott in turn. This presentation method is also consistent with the overall approach of defining coastal defence management policies for each such Unit.

The eight Management Units are described in sections 2.1 to 2.8, starting with a description of the present state of the coastline. Each section describes the coastal processes and present defences, and the environmental (natural and human) assets of that stretch of coastline. The final part of each of these sections explains the consequences of adopting the "Do Nothing" policy option for the whole of the Cromer to Walcott frontage.

2.1 Management Unit TRI 1: Cromer to Overstrand

2.1.1 Coastal Processes

The cliffs between Cromer and Overstrand are fronted by beaches, which consist of a mixture of sand and shingle, underlain in places by a chalk platform. Despite the beach and platform the cliffs are liable to erode and are classified as "actively unstable" (see Cliff Processes section of report EX 4692). They exhibit on-going slope instability and there is a resulting loss of cliff top land. Aerial photographs show that there is a shingle "storm" beach along the foot of the cliffs that helps to protect them from wave attack. However, numerous large slips have taken place along this frontage, the one in 1973 taking out a 7m wide and 100m long slice from the golf course, near the Cromer/Overstrand boundary (see Cliff Processes section of report EX 4692).

The alignment of the toe of the cliffs indicates that a very shallow embayment is developing between the hard points at Cromer and Overstrand. The long-term rate of cliff recession will therefore be highest in the centre of this frontage.

The net littoral drift is from west to east. The permeable timber groynes along this frontage have helped to maintain a mobile cover of beach sediment over the underlying shore platform, but without maintaining a strong difference in level across them. They are also sufficiently low for shingle travel across them, thus helping to maintain the continuity of the upper beach. The shingle is presently trapped at the first groyne on the Overstrand frontage (the western end of Management Unit TRI 2).

2.1.2 Coastal defences

The first recorded coastal defences along this frontage, i.e. closely spaced timber groynes, date back to the late 19th century. By 1930, however, many of the original groynes had disappeared and the form and layout of the present groyne system had begun to appear. In addition to the permeable timber groynes that extend over the whole frontage, there is also a 350m long timber breastwork at the western end of the frontage. This revetment is essentially an eastward (down-drift) extension of the Cromer defences.

The linear defences (i.e. those running parallel to, and behind or at the beach crest) from west to east have been classified, in the Defence Condition Survey Report, as follows:

Defence length TRI 1.01. (Start 622762E 341972N. Finish 623097E 341800N).

- Timber breastwork (built in 1976) in poor condition. Likely failure damage is by deterioration of the timber structure.

Defence length TRI 1.02. (Start 623097E 341800N. Finish 624320E 341257N).

- Cliff toe unprotected.

2.1.3 Human and built environment

The cliff top land along this frontage is almost entirely given over to recreational use, mainly by the Royal Cromer Golf Club. In addition, the cliff edge is also used as a walking path, linking Cromer with Overstrand.

Environmental designations

The whole of the cliffed frontage lies within a Special Site of Scientific Interest (SSSI) and Special Area of Conservation (SAC). The cliffs are composed of Pleistocene sands and clays, with freshwater seepage in places, and are subject to frequent cliff falls and landslips. They are one of the best examples of unprotected vegetated soft cliffs on the North Sea coast. Their nature conservation value is very high. This area is also an Area of Outstanding Natural Beauty.

Heritage features

The heritage features within the study area are listed in Table 2.6 of the Economic Valuations Interim Report, dated 1/12/03, and are as follows:

- Overstrand Hall (Grade 2 Listed Building). NGR 620333E 341512N

2.1.4 Consequences of the Do Nothing Option

Interaction of defence failure and cliff top retreat rates

Cliff recession within this frontage could lead to outflanking of the "hard" defences within the adjacent management unit to the west (i.e. the Cromer frontage, within Management Unit RUN3). The Cromer defences will therefore require some form of transitional protection, which will intrude into the western end of Management Unit TRI 1.

To the east, the Overstrand frontage forms a hard point against which the sediment builds up. Even with the Overstrand frontage eroding rapidly under the Do Nothing scenario (see next management unit) it will remain a promontory for many years hence, and will continue to act as a groyne, containing beach material within Management Unit TRI 1. This will thus continue to modify the cliff erosion in this Management Unit.

Description of erosion and assets lost

The cliff lines predicted by the cliffSCAPE-RS model are shown in Figure 2.1.

At the western end of the frontage there is a timber revetment that is in poor condition. Under the Do Nothing scenario, this revetment will fail after about 15 years, and after 50 years some 99m of cliff top recession will have taken place (50% probability level). This will increase to about 148m after 100 years. Cliff top recession will cause loss of undeveloped land, footpaths etc.

Over much of the frontage the cliffs do not have linear defences protecting their toe. Under the Do Nothing scenario, cliff recession here will continue, and after 50 years some 128m of cliff top recession will have taken place, (50% probability level). This will increase to about 155m after 100 years. Cliff top recession will cause loss of golf course land and the present cliff top footpath, which will have to be located inland if still required. The land lost within the golf course has been assigned a nominal value of tree times the equivalent area of agricultural land.

In summary, the cliff frontage in management unit TRI 1 does not contain any housing that would be lost by cliff top erosion. The land lost is therefore agricultural and amenity land. The predicted cumulative Do-Nothing losses, from year zero through to year 100, have a net present value of £329,000. These are shown sequentially in Tables 1 to 6 for years 0 to 10, 10 to 20 etc. and are then summarised as cumulative totals in Table 7 of Appendix 1. A summary of main impacts is presented in the table below.

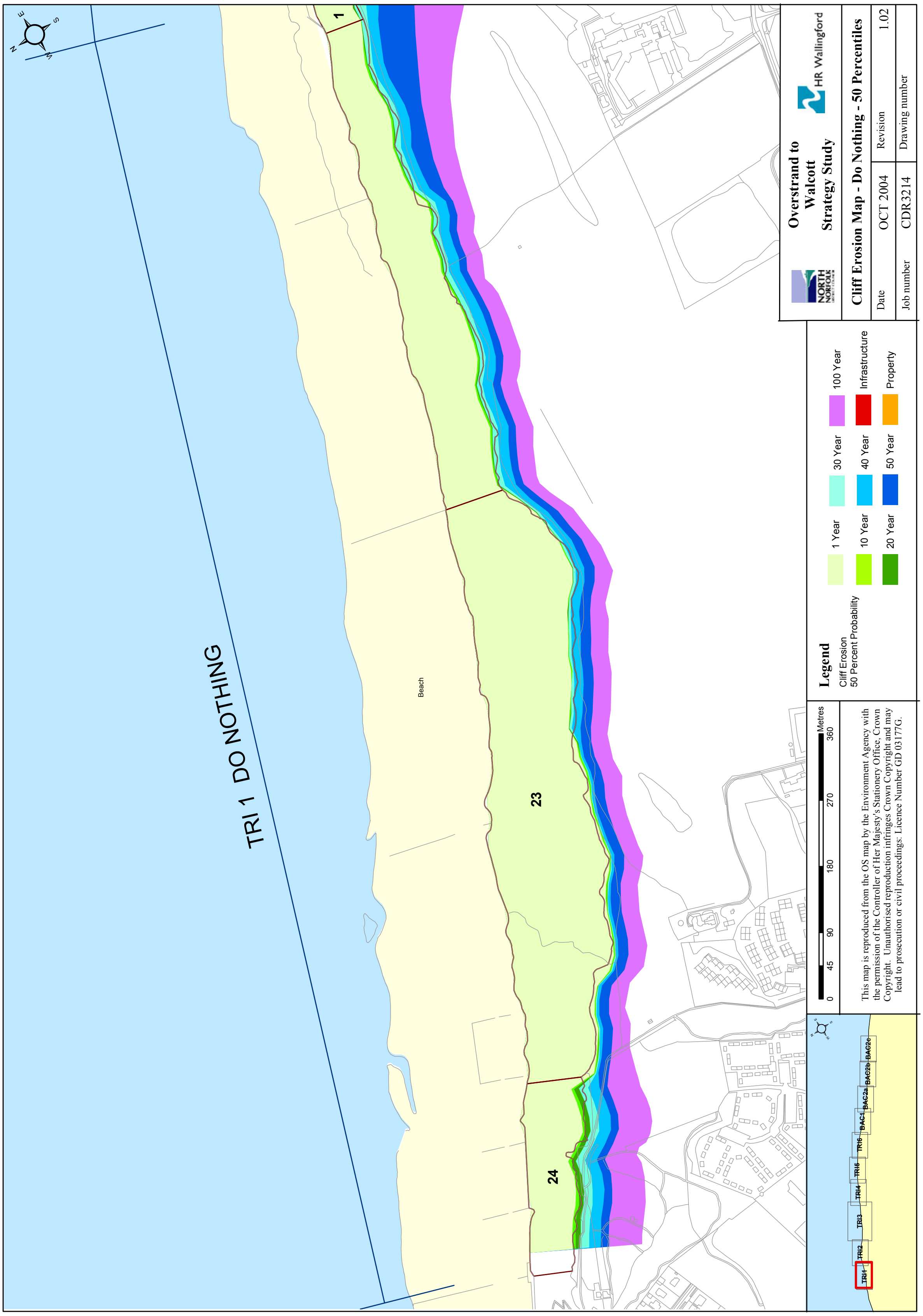


Figure 2.1 Predicted cliff recession to 100 years. Do Nothing scenario TRI1

2.1.5 Summary of main impacts – Management Unit TRI 1

Do Nothing option	**Impact on environmental Designations**	**Impact on tourism and leisure**	**Impact on archaeology and cultural heritage**	**Impact on built environment**
Failure of defences will lead to accelerated cliff retreat and increase in sediment budget/beach levels. Note that a transition from soft to hard defences at the western end of Management Unit TRI 1 will continue to be necessary.	Continued erosion enhances environmental interests. Too rapid an erosion rate would affect the state of the vegetated cliff slopes however.	Loss of land affects recreational usage (walking) of cliff top. It will also reduce the area of the golf course.	Heritage sites unaffected, as these are well inland.	No loss of properties and little impact on infrastructure, but coastal paths and amenity land (area of golf course) will be lost through cliff retreat.

2.2 Management Unit TRI 2: Overstrand

2.3 Coastal Processes

Overstrand was founded as a fishing village but is now essentially a rural and predominantly residential settlement. In the summer months it becomes a quiet holiday resort.

The cliffs at Overstrand are fronted by beaches, which consist of a mixture of sand and shingle, underlain by a chalk platform. These cliffs are well vegetated and are classified as marginally stable, but having some localised small-scale instability on the cliff face. There are also stretches where the cliffs are actively unstable, where on-going slope instability and loss of cliff top land is taking place. One such area is the eastern end of Overstrand, where catastrophic failures have occurred in the recent past (see "Coastal Defences", below).

The beach appears to provide little protection to the cliff toe, with the coastal defences being either regularly overtopped (the timber revetments north and south of the central area of Ovestrand) or having scour in front of them (the concrete wall in the central area). As a result the defences are in danger of being undermined.

The net littoral drift is from north-west to south-east. Aerial photographs show that this frontage has a narrow upper beach and a sandy lower one that is intersected by tidal gullies. They also show that little shingle reaches this frontage, and that it is held up at the westernmost groyne. A great deal of erosion would be required before the promontory effect on sediment transport was significantly reduced.

2.3.1 Coastal defences

The first seawalls and groynes at Overstrand were built in the late 19th century, principally to protect private and commercial property. In the 1920's a seawall was constructed that linked the originally privately funded walls. These defences were badly damaged in the 1940's and then virtually destroyed during the 1953 surge.

The walls that were reconstructed after 1953 remain the town's principal defences, although there has been a catalogue of repair and extension as late as 2000. The 1953 surge also prompted the construction of timber revetments along the coastline on either flank of the town.

The defences have had little effect on cliff stability and the combined action of the sea and cliff failure continues to be a problem along this frontage. A feature of the defences is that there are drains on the back of the seawall that collect water from field drains on the cliff itself (the cliffs are weak and are prone to mud slides). In the 1960s there was a large cliff failure at a point of beach access to the west of the central frontage, which necessitated in the construction of a gabion retaining wall above the concrete seawall. Catastrophic failures occurred to the east of the town in May 1990, followed by further failures in November 1992 and January 1994. Some 90m of cliff top were lost, threatening a large number of houses. Subsequently a major cliff stabilisation scheme and coastal defence scheme have been implemented, with the base of the cliff now being protected by a large mass of granite. In 2000 the western end of the walls failed, so that the original 19th century wall (rehabilitated in the 1980's) had to be reconstructed.

The stability of the concrete walls at Overstrand is strongly dependent on the stability of the aprons and piles fronting them. Over the central and western parts of the frontage (over 50% of the total frontage) the steel piles are at the end of their useful life, having become badly corroded. These are likely to buckle, if the beach falls by 1m below the pile tops, so that the walls are at risk of failure by overturning. Also, few of the weep holes in the walls are functioning, which may lead to excessive pore water pressures developing in the lower part of the cliff.

The frontage has a series of timber permeable groynes, which are in good condition and are functional. However, the beach levels within them are low and there is little shingle present on the upper beach, so the feed to the down-drift beaches to the east is considered to be limited.

The linear defences from west to east are classified as follows:

Defence length TRI 2.01. (Start 624320E 341257N. Finish 624734E 341106N).

- Timber breastwork (built in 1967) in poor condition. Likely failure damage by cliff falls or by failure of toe due to low beach levels.

Defence length TRI 2.02 (Start 624734E 341106N. Finish 624763E 341098N).

- Concrete block revetment (built in 1949) in poor condition. Likely failure mechanism are damage by cliff falls, failure of toe due to low beach levels, or deterioration of timber/steel framework encapsulating the concrete blocks.

Defence length TRI 2.03.1 (Start 622846E 342356N. Finish 622897E 342349N).

- Vertical concrete seawall/promenade (built in 1890 and refurbished in 1998) in very good condition. Likely failure mechanism is slip circle failure of the cliff.

Defence length TRI 2.03.2 (Start 622897E 342349N. Finish 622961E 342349N).

- Vertical concrete seawall/promenade (built in 1953) in steel piles in very poor condition. Likely failure mechanism is (imminent) steel pile toe and apron failure, quickly followed by seawall failure.

Defence length TRI 2.03.3 (Start 622961E 34239N. Finish 623237E 342306N).

- Vertical concrete seawall/promenade (built in 1920 and refurbished in 1955) in steel piles in very poor condition with a residual life of 0 to 3 years. Likely failure mechanism is steel pile failure. Also, failure of gabion baskets to cliff face could lead to cliff instability.

Defence length TRI 2.03.4 (Start 623237E 342306N. Finish 623301E 342297N).
- Vertical concrete seawall/promenade (built in 1920 and refurbished in 1955) in good condition with a residual life of 10 to 20 years. Likely failure mechanism is wall instability precipitated by deep-seated cliff failures.

Defence length TRI 2.03.5 (Start 623301E 342297N. Finish 623338E 342289N).
- Vertical concrete seawall/promenade (built in 1920 and refurbished in 1955) in concrete apron damaged by abrasion and in poor condition. Likely failure mechanism is wall instability precipitated by deep-seated cliff failures and failure as a retaining wall.

Defence length TRI 2.03.6 (Start 623338E 342289N. Finish 623370E 342279N).
- Vertical concrete seawall/promenade (built in 1955) in fair condition. Likely failure mechanism is wall instability precipitated by deep-seated cliff failures and failure as a retaining wall.

Defence length TRI 2.03.7 (Start 623370E 342279N. Finish 623436E 3422251N).
- Vertical concrete seawall/promenade (built in 1890 and refurbished in 1978) in in good condition with a residual life in excess of 20 years. Likely failure mechanism is wall instability precipitated by deep-seated cliff failures and failure as a retaining wall.

Defence length TRI 2.03.7 (Start 623370E 342279N. Finish 623436E 342251N).
- Vertical concrete seawall/promenade (built in 1890 and refurbished in 1978) in good condition, with a residual life in excess of 20 years. Likely failure mechanism is wall instability precipitated by deep-seated cliff failures and failure as a retaining wall.

Defence length TRI 2.04 (Start 623436E 342251N. Finish 625432E 340612N).
- Sloping timber revetment and rock armour (built in 1989 and refurbished by addition of large rock in 1996) in rock armour in very good condition, but revetment in poor condition. Likely failure mechanism is deterioration of the timber revetment (the rock armour is extremely stable. Likely to cause outflanking of seawall in TRI 2.3.7. Likely to cause damage to residential property.

Defence length TRI 2.05 (Start 625432E 340612N. Finish 625555E 340483N).
- Sloping timber revetment (built in 1975) in poor condition. Likely failure mechanism is deterioration of the timber components through cliff failure or loosening of the joints. Increased cliff erosion likely to lead to loss of small number of properties.

2.3.2 Human and built environment

The cliff top land is used for tourism-related activities at the western end of Overstrand, predominantly residential or open space in the central area, with mixed residential and agricultural land at the eastern end of the frontage. The town also has a few shops, two hotels, a pub, a café and a caravan site.

The town's sewerage system connects up to a cliff top storage tank and a pumping station further inland. These rely on cliff stability being maintained and both are at risk from cliff retreat. Given that the existing sewerage network flows towards the current point of discharge, relocating the sewerage facilities further inland would not be feasible. Major reconstruction would be needed, taking the effluent further inland rather than towards the sea (see Economic Valuations Interim Report, dated 1/12/03).

There is access to the beach from the cliff top. Part time fishermen operate from Overstrand, although the extent of fishing activity is thought unlikely to be economically significant in terms of justifying coastal defences (see Economic Valuations Interim Report, dated 1/12/03).

Environmental designations

The western outskirts of Overstrand lie within a Special Site of Scientific Interest (SSSI) and Special Area of Conservation (SAC). The Overstrand cliffs are composed of Pleistocene sands and clays, with freshwater seepage in places. They are subject to fairly frequent cliff falls and landslips. They are one of the best examples of unprotected vegetated soft cliffs on the North Sea coast. Their nature conservation value is very high. This area is also an Area of Outstanding Natural Beauty.

The central frontage of Overstrand is a County Wildlife Site. This comprises the maritime cliffs and foreshore, much of which is influenced by coastal defence works. The eastern outskirts of Overstrand lie within an SSSI (see Management Unit TRI 3).

Heritage features

The heritage features within this Management Unit are listed in Table 2.6 of the Economic Valuations Interim Report, dated 1/12/03, and are as follows:

- Pleasuance-gazebo (Grade 2 Listed Building). NGR 624655E 340987N.
- Pleasuance-rose garden (Grade 2 Listed Building). NGR 624693E 340987N.
- Pleasuance-covered wal (Grade 2 Listed Building). NGR 624713E 340901N.
- The Pleasuance (Grade 2 Listed Building). NGR 624752E 340906N.
- Pleasuance-clock tower (Grade 2 Listed Building). NGR 624791E 340912N.
- Methodist Chapel (Grade 2 Listed Building). NGR 624818E 340782N.
- Sea Marge-hotel (Grade 2 Listed Building). NGR 624966E 340770N.

2.3.3 Consequences of the Do Nothing Option

Interaction of defence failure and cliff top retreat rates

By their geological nature the cliffs are unstable and cliff slips have occurred in a number of places. The protection of the cliff toe appears to have been only partially effective in stabilising these cliffs.

At present the promontory formed by holding the defences at Overstrand tends to reduce littoral transport. Under the Do Nothing scenario, the loss of the defences will allow littoral drift to be re-established, at least in part. However, the main increase in the sediment budget that will benefit the down-drift beaches to the east will be from the local cliff erosion. (The cliffs at Overstrand contain about 50% sand). The net result is that the beaches to the east of the eroded area (those within Management Unit TRI 3) will benefit significantly from the increased sand supply and will erode more slowly than those in Management Unit TRI 2.

Description of erosion and assets lost

The cliff lines predicted by the cliffSCAPE-RS model are shown in Figure 2.2.

The cliffs at the western end of the frontage are protected by a timber revetment, which is in poor condition. Under the Do Nothing scenario the revetment will fail after about 3-5 years, and after 50 years some 130m of cliff top recession will have taken place, at the 50% probability level. This will involve significant loss of residential and commercial land. In addition, the sewerage storage tank will have been lost. The recession will have increased to about 202m after 100 years, resulting in the loss of more residential properties and the loss of the pumping station, requiring major reconstruction of the sewerage system (see Economic Valuations Interim Report, dated 1/12/03). An electricity sub-station will also then be at imminent risk.

The main frontage of the village is protected by a concrete blockwork/seawall, whose condition varies from very good to very poor, depending on location. The deterioration of any section of these defences would quickly spread laterally, causing adjacent sections to collapse. Under the Do Nothing scenario there will be imminent failure of the wall and by year 50, some 142m of cliff top recession will have taken place, at the 50% probability level. This will have caused the loss of large number of residential properties and several commercial ones. By year 100 some 215m of cliff top recession will have taken place, with a further proportional loss of properties and commercial premises.

The eastern part of Overstrand is protected by a timber revetment that is in poor condition, but which has been bolstered with rock armour, thus extending its life. This armour is essentially a seaward extension of rock armouring to the toe of a large landslip (See "Coastal Defences" section). Under the Do Nothing scenario the deterioration of the timber revetment will lead to cliff recession, and after 50 years some 102m of cliff top recession will have taken place, at the 50% probability level. This will result in the loss of several properties and the imminent failure of others. After 100 years some 162m recession will have taken place.

In summary, the cliff frontage in management unit TRI 2 is intensely developed and by year 100 it is predicted that 164 commercial and residential properties will have been lost through cliff recession. These include 3 listed buildings. Services, involving the loss of a pumping station and a sewerage sump, and toilets, will also have been lost. The predicted cumulative Do-Nothing losses, from year zero through to year 100, have a PV of £8,396,000. These are shown sequentially in Tables 1 to 6 for years 0 to 10, 10 to 20 etc. and are then summarised as cumulative totals in Table 7 of Appendix 1. A summary of main impacts is presented in the table below.

2.3.4 Summary of main impacts – Management Unit TRI 2

Do nothing option	**Impact on environmental Designations**	**Impact on tourism and leisure**	**Impact on archaeology and cultural heritage**	**Impact on built environment**
Seawall failure will enhance cliff retreat. Change from protected to unprotected cliffs will significantly increase the sediment budget and improve beach levels down drift (to east of Ovestrand).	Loss of defences may be only marginally beneficial to the County Wildlife Site as the cliff is already disturbed by development and toe protection works that will not disappear when the defences fail.	Loss of land will impact adversely on tourism and beach usage.	3 listed buildings will have been lost through cliff erosion by year 100, as the historic centre is close to the sea.	164 properties (residential/commercial), plus infrastructure (pumping station, sewerage sump and a public toilet) will have been lost by year 100 through cliff retreat.

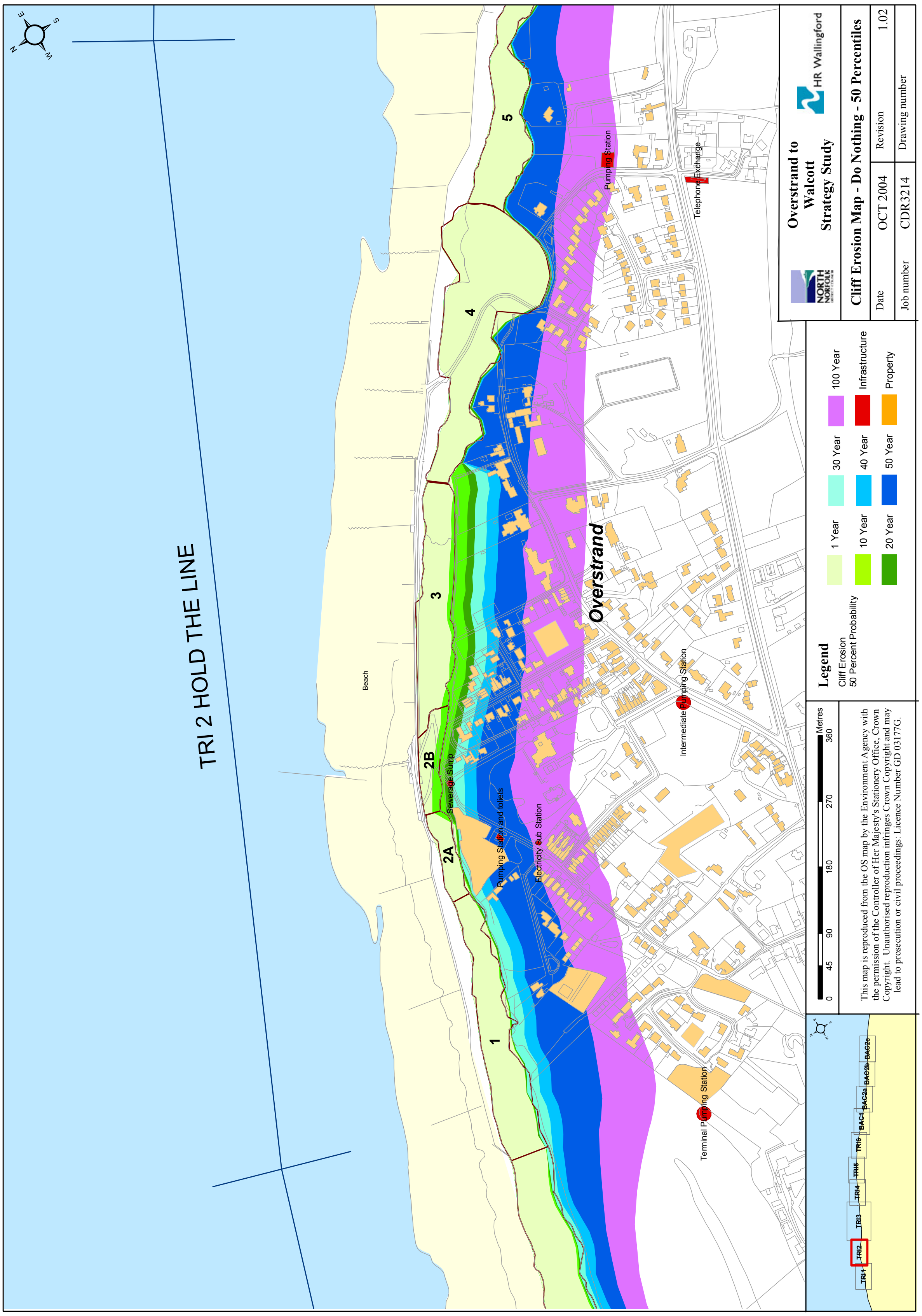


Figure 2.2 Predicted cliff recession to 100 years. Do Nothing scenario TRI2

2.4 Management Unit TRI 3: Overstrand to Trimingham

2.4.1 Coastal Processes

The frontage between Overstrand and Trimingham is the most natural Management Unit in the area, with protection (a sloping timber revetment and permeable timber groynes) being restricted to the western end of the frontage.

The unstable and actively retreating cliffs are fronted by a shore platform, consisting largely of a sand beach that is littered with pebbles. The beach provides little protection to the cliff toe and the cliffs are under regular wave attack at high tide. The cliffs, which are up to 64m in height, are prone to massive failures. This gives the cliff toe an irregular outline in plan shape, with several old slips still extending the toe across the beach. This frontage gives some idea of how the whole coastline from Cromer to Walcott would eventually look under the "Do Nothing" scenario. From the aerial surveys it is clear that natural beach build up will not be sufficient to allow the coast to develop an equilibrium form, and cliff retreat will continue into the foreseeable future, with sediments travelling freely down-drift, i.e. in and easterly direction.

The net littoral drift is from north-west to south-east, causing shingle to be transported eastwards to the outskirts of Trimingham, where a massive shingle ridge has developed westward of the westernmost groyne. Thus, with the protection offered by the present defences, the cliff recession is most rapid to the western end of the frontage (down-drift of the Overstrand defences) and least at the eastern end (up-drift of the Trimingham defences).

2.4.2 Coastal defences

This frontage is almost unique within the study area, in that it does not have a history of extensive defence works. The western part of the management unit is protected by a sloping timber revetment, built by NNDC in 1987, as an extension to, and contiguous with, the timber revetment at the eastern end of Overstrand. The revetment is well forward of the line of the cliffs and is regularly overtopped. It is also very permeable, built with the aim of slowing down the rate of cliff retreat, but not halting it. The beach therefore continues "through" the revetment and appears to be little affected by it. There are also a number of timber groynes along this frontage.

At the other end of the frontage there were two groynes built by 1892, the date of the first Ordnance Survey, and which had disappeared by 1908, the next Ordnance Survey date.

Groynes are restricted to the western end of the frontage. The linear defences, from west to east, are classified as follows:

- Sloping timber revetment (built in 1975) in poor condition. Likely failure mechanism is deterioration of the timber components through physical damage, or loosening of the joints. Consequences of failure are increased cliff erosion and loss of agricultural land and playing fields and ultimately the loss of a number of residential properties.

Defence length TRI 3.02 (Start 626152E 340043N. Finish 627781E 339129N).

- Unprotected sandy beach, which is not heavily used, by virtue of extremely difficult access. Lack of protection means a continuation of cliff erosion processes and loss of agricultural land (there are no properties at threat).

2.4.3 Human and built environment

The cliff top land is predominantly agricultural land and playing fields, with a small number of residential properties also at risk at the western boundary close to the outskirts of Overstrand (TRI 2). Elsewhere within this management unit there is solely agricultural land at the cliff top. The beach itself though relatively unspoilt is not heavily used, due to poor access from the cliff top.

Environmental designations

The Management Unit is within an SSSI and an Area of Outstanding Natural Beauty. The cliffs at Sidestrand expose one of the best pre-glacial stratigraphic sequences in England and their nature conservation value is very high.

Heritage features

The heritage features within the study area are listed in Table 2.6 of the Economic Valuations Interim Report, dated 1/12/03, and are as follows:

- Sidestrand-church of St Michael (Grade 2 Listed Building). NGR 624959E 340715N.
- Sidestrand-Garden Close, Main Road (Grade 2 Listed Building). NGR 62580E 339718N.
- Sidestrand-18 to 20 Ivy Cottages (Grade 2 Listed Building). NGR 626557E 339212N.

2.4.4 Consequences of the Do Nothing Option

Interaction of defence failure and cliff top retreat rates

Under the Do Nothing scenario, the sand released by cliff erosion at Overstrand (from within Management Unit TRI 2) will tend to accrete within the Overstrand to Trimingham frontage (Management Unit TRI 3), thereby reducing cliff recession here.

Description of erosion and assets lost

The cliff lines predicted by the cliffSCAPE-RS model are shown in Figure 2.3.

At the western end of the frontage, there is some cliff toe protection, but the timber revetment there is in poor condition. Under the Do Nothing scenario the revetment will fail after about 3-5 years, and after 50 years 65m of cliff top recession will have taken place, at the 50% probability level. This will cause the loss of open space/agricultural land. After 100 years about 130m of cliff top recession will have taken place, resulting in the loss of several properties and the imminent failure of several others at Sidestrand.

Over much of the frontage the cliffs are unprotected and the immediate backshore not built upon. After 50 years some 115m of cliff recession is anticipated, with about 160m of recession after 100 years (at the 50% probability level). This will result in the loss of agricultural land, but with no properties or infrastructure being lost.

In summary, the cliff frontage in management unit TRI 3 is largely unprotected and only lightly developed, the only cliff top housing being concentrated at the western end of the frontage on the outskirts of Overstrand. By year 100 it is predicted that only 5 properties will have been lost through cliff recession, though several others will then be at close proximity to the cliff edge. The predicted cumulative Do-Nothing losses, from year zero through to year 100, have a net present value of £173,000. These are shown sequentially in Tables 1 to 6 for years 0 to 10, 10 to 20 etc and are then summarised as cumulative totals in Table 7 of Appendix 1. A summary of main impacts is presented in the table below.

2.4.5 Summary of main impacts – Management Unit TRI 3

Do nothing option	**Impact on environmental Designations**	**Impact on tourism and leisure**	**Impact on archaeology and cultural heritage**	**Impact on built environment**
Cliff erosion will continue, but will be modified by the influx of sediment from the rapid erosion of the cliffs at Overstrand.	Erosion will be sufficiently rapid to maintain fresh exposures on cliff face and hence maintain environmental interests.	Loss of land through cliff top retreat will affect agricultural land. There is no access to the beaches, hence the impact of cliff erosion on tourism will be low.	No losses as listed buildings are well inland.	5 properties (residential) at the western end of the frontage will have been lost by year 100 through cliff retreat. Elsewhere, there will be loss of agricultural/amenit y land.

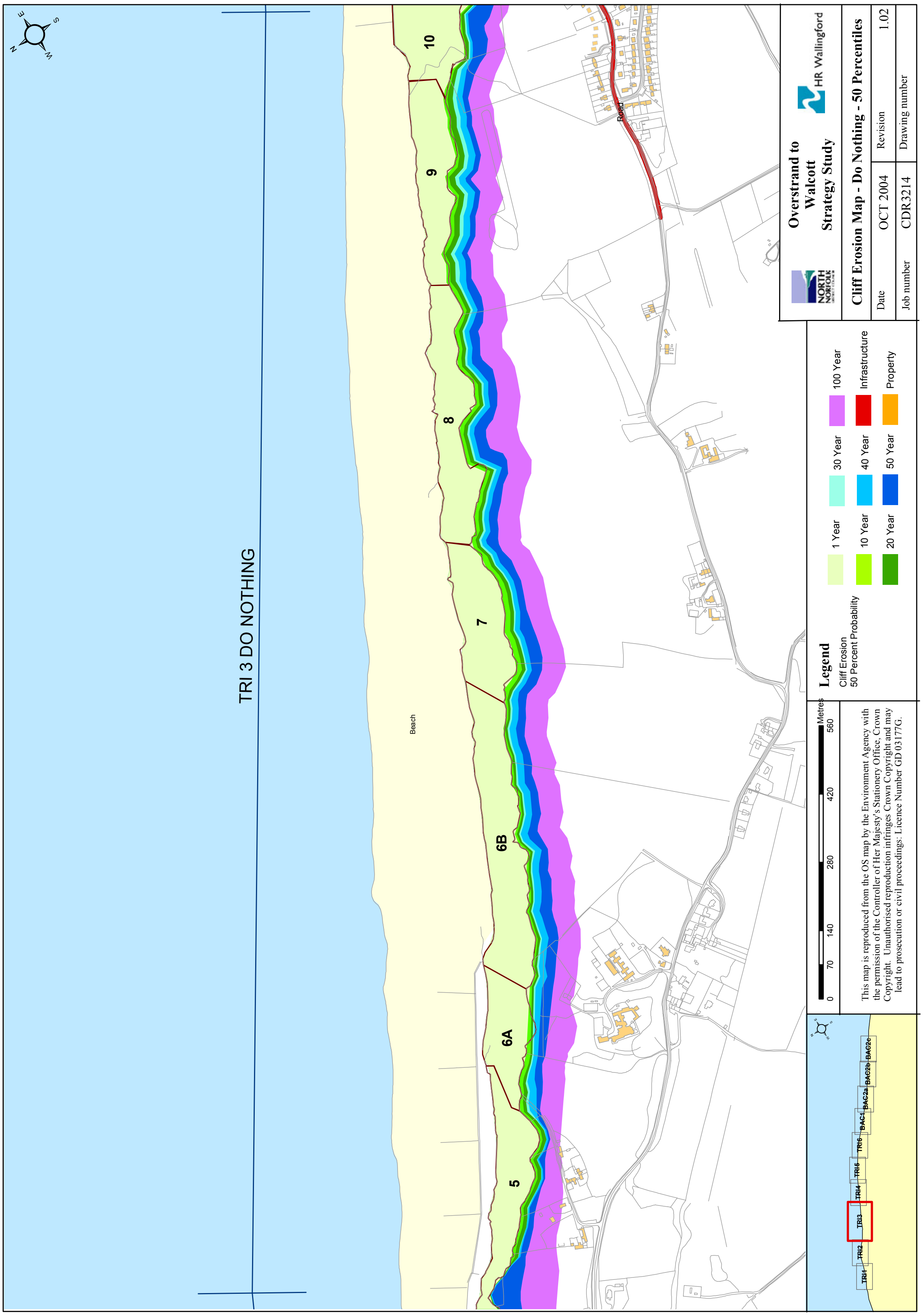


Figure 2.3 Predicted cliff recession to 100 years. Do Nothing scenario TRI3

2.5 Management Unit TRI 4: Trimingham

2.5.1 Coastal Processes

The cliffs fronting the village of Trimingham are classified as actively unstable (see Cliff Processes section of report EX 4692). The cliffs are subject to failure, while the linear defences are poor and only partially successful in reducing cliff retreat. Aerial photographs show that the cliffs are partly vegetated, but the large areas of non-vegetated cliff face point to areas of instability, especially the lower parts of the cliffs.

The beach is predominantly sand and the foreshore is at a flat gradient, extending at this same gradient to the landward side of the defences. This indicates that the defences do not dissipate much of the wave energy. Where these longitudinal defences are derelict, the beach itself provides little protection to the foot of the cliffs. (The groynes along this frontage also do not retain a sufficiently high beach to protect the cliff toe effectively).

The littoral drift is from north-west to south-east. Aerial photographs show that beach sand tends not to collect in the western part, but is transported to the eastern part of the frontage, to accrete on the boundary between management Units TRI 4 and 5. This is because the plan shape of the coastline between Overstrand and Mundesley is relatively straight and the littoral drift is relatively constant.

2.5.2 Coastal defences

The coastal defences at Trimingham date back to 1844, when a groyne was first constructed, and was subsequently destroyed by heavy seas. A series of such groynes were built in the 19th century, but had all been destroyed by1900. In the 1970’s timber revetments and groynes were constructed, but the works were fraught with difficulty as cliff failures severely damaged the revetments. Since completion, the revetment has been persistently damaged by cliff failures. In places, significant quantities of talus bear upon the rear face of the revetment, severely damaging the steel pile toe.

The defences have had little effect on cliff stability and the combined action of the sea and cliff failure continues to be a problem along this frontage. The permeable timber groynes are designed to trap only a proportion of the littoral drift, thus allowing some sand supply to the down-drift beaches. But, with little material trapped, the cliffs continue to erode.

The defences from west to east are classified as follows:

Defence length TRI 4.01. (Start 627781E 339129N. Finish 628660E 338641N).

- Sloping timber revetment, with concrete wall and steel pile toe as its foundation (built in 1975) in very poor condition. Likely failure mechanism is damage by cliff failure, with slumped material pushing through revetment (toe unlikely to fail first). Consequence of failure is increased wave attack leading to an acceleration of the slip/erosion failure cycle.

Defence length TRI 4.02 (Start 628660E 338641N. Finish 629138E 338391N).

- Sloping timber revetment, with steel pile toe (built in 1975) in very poor condition. Likely failure mechanism is low beach destabilising the revetment toe, with cliff failures also damaging the toe through mass movement. Consequences of failure are as for TRI 4.01.

2.5.3 Human and built environment

The erosion of cliff top threatens the village of Trimingham, with its associated commercial and residential properties and its infrastructure. Two large cliff top caravan parks are interspersed by residential properties. Access to the beach is via Vale Road, which is the only access point for about 6km of coastline.

East of the centre of Trimingham there is a threat of loss of smallholdings, a limited number of residential properties, the coast road and the radar station of RAF Neatishead, with its associated permanent dwellings, office buildings and land.

In this defence length the coastal road, the B1159, is relatively close to the cliff top. It is assumed that when coastal recession cut off this road, a permanent diversion consisting of a 7.3m wide all purpose rural road would need to be constructed as a replacement (see Economic Valuations Interim Report, dated 1/12/03).

There is access to the beach from the cliff top. Part time fishermen also operate from Trimingham, although the extent of fishing activity is thought not to be economically significant (see Economic Valuations Interim Report, dated 1/12/03).

Environmental designations

The area lies within a Special Site of Scientific Interest (SSSI) and in an Area of Outstanding Natural Beauty.

Heritage features

The heritage features within the study area are listed in Table 2.6 of the Economic Valuations Interim Report, dated 1/12/03, and are as follows:

- Hall Farmhouse (Grade 2 Listed Building). NGR 627720E 338723N.
- St John the Babtist church (Grade 2 Listed Building). NGR 627938E 338755N.

2.5.4 Consequences of the Do Nothing Option

Interaction of defence failure and cliff top retreat rates

Under the Do Nothing scenario, the Trimingham frontage will erode and some sand will be transported to the downdrift frontage (Management Unit TRI 5). However, the proportion of sand in the Trimingham cliffs is relatively low (averaging at about 40%), so the cliffs within Management Unit TRI 5 will nevertheless continue to erode rapidly. The modelling correctly predicts a gradual increase in erosion rates in an easterly direction.

Description of erosion and assets lost

The cliff lines predicted by the cliffSCAPE-RS model are shown in Figure 2.4.

Along the central frontage of Trimingham the cliff toe is protected by a timber revetment that is in very poor condition. Under the Do Nothing scenario, this revetment will fail after about 0-3 years, and after 50 years some 180m of cliff top recession will have taken place, at the 50% probability level. This will result in the loss of several properties and the imminent failure of several others. This recession will increase to about 210m after 100 years, with a further loss of properties. The coast road, the B1159, by then will have been undermined.

The cliffs in the eastern outskirts of Trimingham are similarly protected by a timber revetment that is in very poor condition. Under the Do Nothing scenario, this revetment will also fail after about 0-5 years, and after 50 years some 126m of cliff top recession will have taken place, at the 50% probability level. This will increase to about 165m after 100 years. By then several properties will have been lost through cliff retreat.
In summary, the cliffs at Trimingham are protected by a revetment that is in poor condition and by year 100 it is predicted that 42 residential properties and 1 commercial property will have been lost through cliff recession, in addition to the cutting off of the coast road that runs through the village. This road will then have to be relocated. The predicted cumulative Do-Nothing losses, from year zero through to year 100, have a net present value of £2,820,000. These are shown sequentially in Tables 1 to 6 for years 0 to 10, 10

to 20 etc. and are then summarised as cumulative totals in Table 7 of Appendix 1. A summary of main impacts is presented in the table below.

2.5.5 Summary of main impacts – Management Unit TRI 4

Do nothing option	**Impact on environmental Designations**	**Impact on tourism and leisure**	**Impact on archaeology and cultural heritage**	**Impact on built environment**
Cliff erosion, though moderate, will improve sediment budget, building up beach levels downdrift (to east) of TRI 4.	The erosion will maintain fresh exposures and enhance environmental interests.	Loss of land through cliff top retreat will have an effect on tourist facilities, including the loss of beach access.	No listed buildings at risk.	It is predicted that by year 100 some 42 residential properties and 1 commercial property will have been lost through cliff retreat. The coast road will also have been cut off and will need to be relocated.

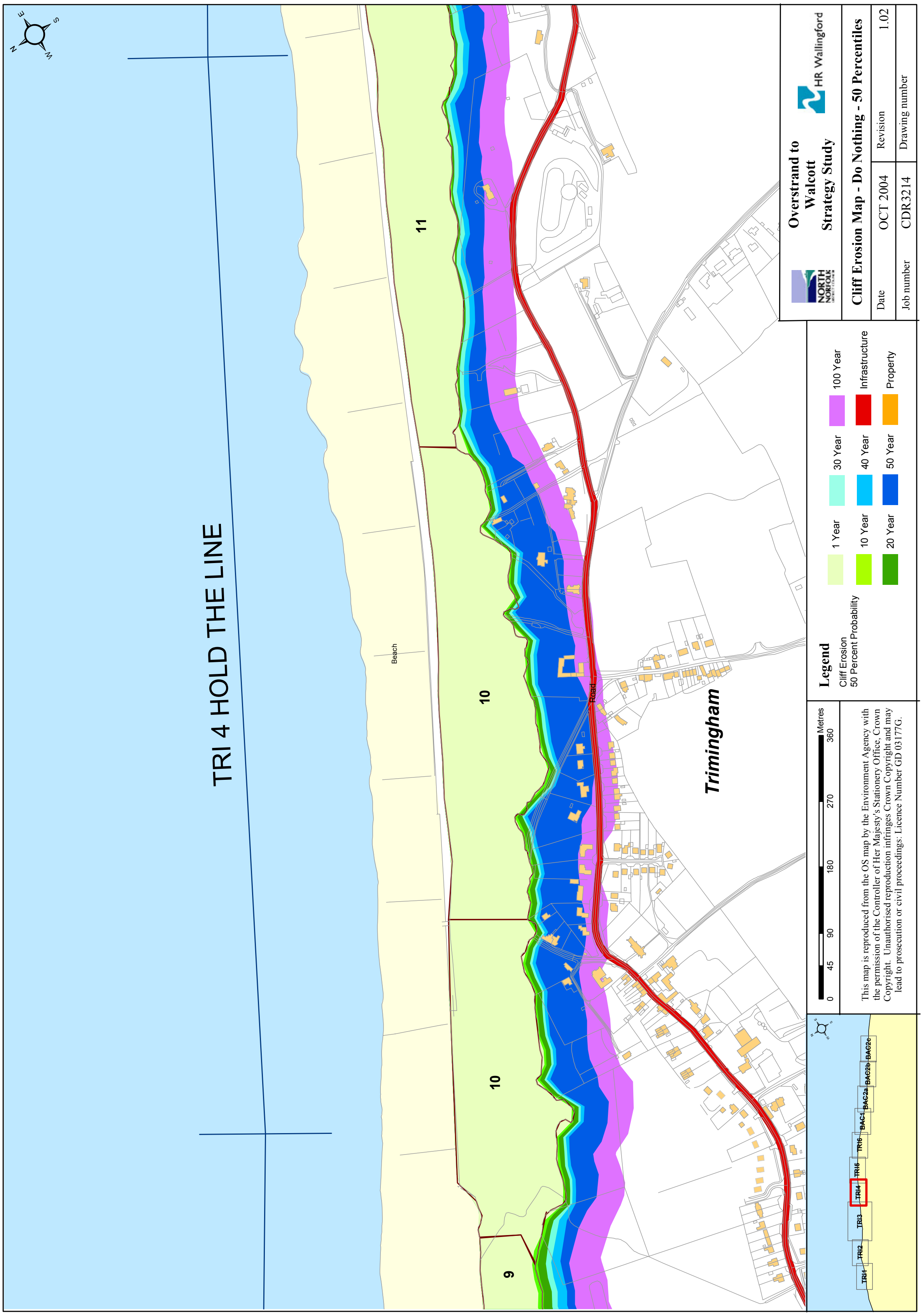


Figure 2.4 Predicted cliff recession to 100 years. Do Nothing scenario TRI4

2.6 Management Unit TRI 5: Trimingham to Mundesley

2.6.1 Coastal Processes

The partly vegetated, sloping sandy cliffs along the Trimingham to Mundesley frontage are classified as marginally stable (see Cliff Processes section of report EX 4692). Localised small-scale instability is largely confined to the cliff face, although some minor cliff top land loss can occur. The cliffs have a wide sand beach that has scattered pebbles on its surface. The beach in front of the timber revetment is relatively high and provides considerable protection to the cliff toe. This contrasts strongly with the lower beach in management unit TRI 4. The "hard point" at Mundesley (TRI 6) acts as a large groyne allowing the beach to accrete in TRI 5, but its influence clearly does not extend westwards (updrift) as far as TRI 4. As well as the timber revetment that continues uninterruptedly over the whole of this Management Unit, there is also a field of permeable timber groynes over the whole frontage.

The net littoral drift is from north-west to south-east. Sand is transported over the foreshore and overwhelms some of the groynes. The cliffs within this stretch of coastline have eroded more slowly than elsewhere and a natural promontory has thus developed at the western end of this frontage (visible as the convex plan shape in this part of TRI 5 (see figure 2.5). Aerial photographs show that beach material also tends to accrete in this area, which further aids cliff toe stability. Along this frontage many of the groynes have their landward ends buried in sand accumulation.

2.6.2 Coastal defences

There were no coastal defences within this management unit until 1967, at which time the timber revetment and groynes were extended westwards from Mundesley to cover this frontage. The fact that protection was not provided till such a late date, by comparison with the frontage to the south/west, indicates that this frontage has historically been more stable than adjoining ones.

The revetment is forward of the line of the cliffs but is largely intact, with only short stretches showing any damage by cliff falls. The permeable timber groynes that extend over this frontage are also generally in good condition.

The linear defences from west to east are classified as follows:

Defence length TRI 5.01 (Start 629318E 338391N. Finish 629988E 337829N).

- Sloping timber revetment (built in 1972) in fair condition. Likely failure mechanism is low beach causing instability of the steel pile toe. Deterioration of the timber and steel components through physical damage caused by cliff failure.

Defence length TRI 5.02 (Start 629988E 337829N. Finish 630474E 337499N).

- Sloping timber revetment (built in 1967) in good condition. Likely failure mechanisms are the same as for TRI 5.01.

2.6.3 Human and built environment

This frontage includes two large caravan parks, residential property, smallholdings, as well as an important beach access off Vale Road. This was formerly an important launching point for boats, though it is apparently not used for this purpose currently. The erosion of cliff top land would cause a severe loss of tourism amenities, because of the extensive areas put down to caravan hard standings.

Environmental designations

The western part of the area is within an SSSI and an Area of Outstanding Natural Beauty. The cliffs west of Mundesley are a nationally important site for their extensive Plestocene sequence and their nature conservation value is very high.

Heritage features

There are no Listed Buildings along this frontage.

2.6.4 Consequences of the Do Nothing Option

Interaction of defence failure and cliff top retreat rates

The cliffs between Trimingham and Mundesley are retreating relatively slowly. This is partly due to the accretion of beach material on the updrift side of the promontory formed by holding the line of the defences at Mundesley (Management Unit TRI 6). However, the frontage itself forms a promontory.

Under the Do Nothing scenario, the cliff recession will increase as the promontory that has formed by differential rates of retreat begins to be straightened out. Accelerated cliff erosion will provide large volumes of sand to be transported alongshore (south-eastwards). Defence length TRI 7, and possibly areas further eastward, will therefore benefit from this increase in erosion in TRI 6.

Description of erosion and assets lost

The cliff lines predicted by the cliffSCAPE-RS model are shown in Figure 2.5.

At the western part of this frontage there is a timber revetment that is in fair condition. Under the Do Nothing scenario the revetment will fail after about 3-5 years, and after 50 years up to 115m of cliff top recession will have taken place, at the 50% probability level. This will result in the loss of land used as hard standing for caravans. The recession will increase to about 162m after 100 years, with a loss of several permanent buildings within the western caravan site. The important beach access point will also have been lost.

Within the eastern part of the frontage there is, again, a timber revetment that is in good condition. Under the Do Nothing scenario the revetment will fail after about 5-10 years, and after 50 years up to 90m of cliff top recession will have taken place, at the 50% probability level. This will result in the loss of one or two properties and several permanent buildings within the eastern caravan site that is effectively on the outskirts of Mundesley. The recession will increase to about 138m after about 100 years.

In summary, the cliffs along the partly developed frontage between Trimingham and Mundesley are presently relatively stable. However, under a Do-Nothing scenario they will begin to retreat, as the defences fail and the sand is transported to Mundesley and beyond, leaving the cliffs vulnerable to erosion. It is predicted that by the year 100 some 20 properties will have been lost through cliff retreat. The predicted cumulative Do-Nothing losses, from year zero through to year 100, have a net present value of £507,000. These are shown sequentially in Tables 1 to 6 for years 0 to 10, 10 to 20 etc. and are then summarised as cumulative totals in Table 7 of Appendix 1. A summary of main impacts is presented in the table below.

2.6.5 Summary of main impacts – Management Unit TRI 5

Do nothing option	**Impact on environmental Designations**	**Impact on tourism and leisure**	**Impact on archaeology and cultural heritage**	**Impact on built environment**
The cliffs will come under wave attack on the promontory in TRI 5 once the defences fail. Cliff erosion and the pronounced easterly littoral drift will then move sand past Mundesley frontage (TRI 6) to benefit the beaches within BAC 1 and 2.	The erosion will maintain fresh exposures and enhance environmental interests.	Loss of land through cliff top retreat will have a significant impact on tourism as two large caravan sites will suffer significant land loss.	No listed buildings at risk.	It is predicted that by year 100 some 20 residential properties, and an access point to the beach, will have been lost through cliff retreat.

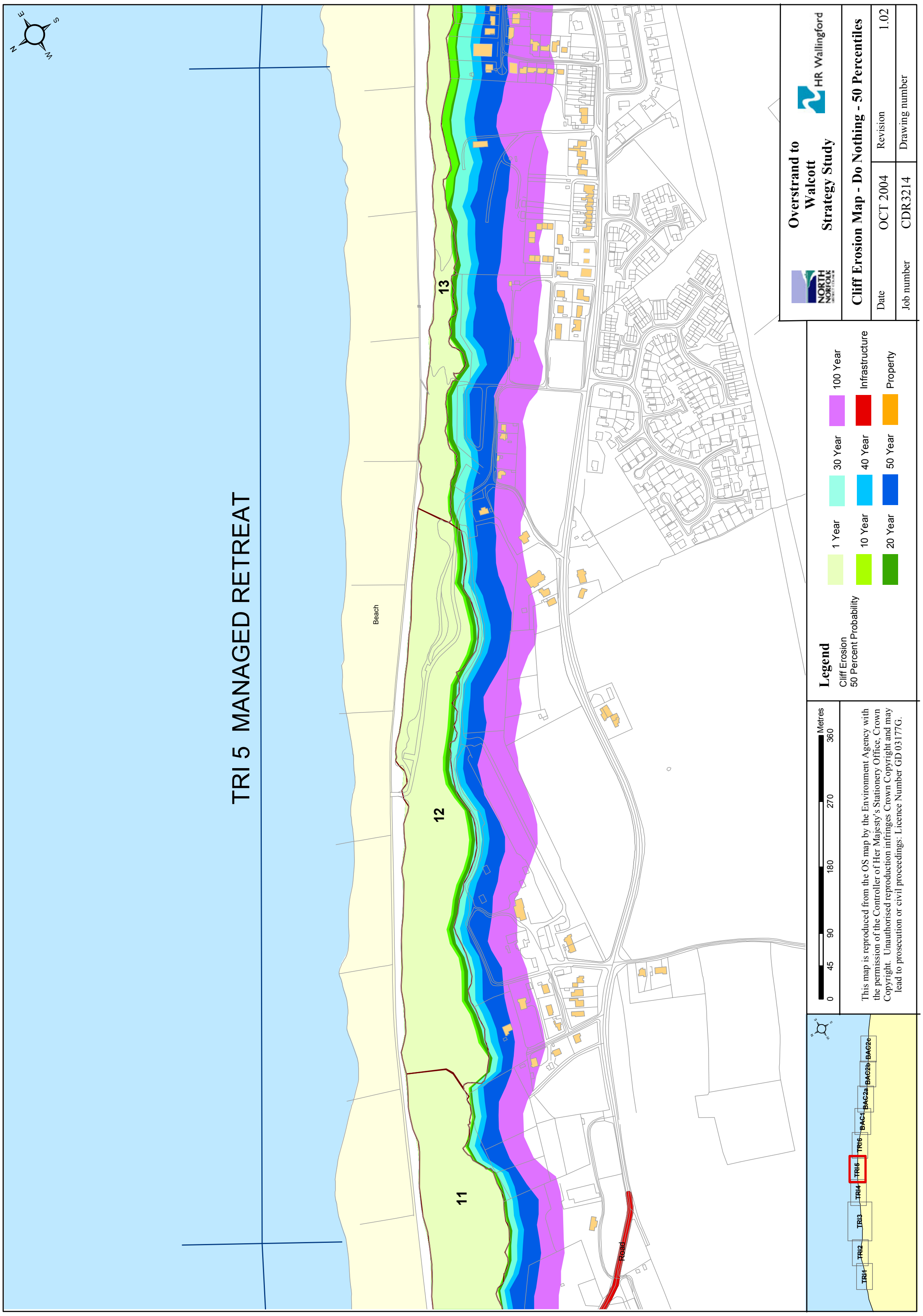


Figure 2.5 Predicted cliff recession to 100 years. Do Nothing scenario TRI5

2.7 Management Unit TRI 6: Mundesley

2.7.1 Coastal Processes

Mundesley is a small settlement, which is significantly increased in population during the summer months. It is situated at a major change in the alignment of the coast, brought about by holding the line of the defences at the town centre (the cliffs on either side had been able to erode until defences were built there). The high, steep and partly vegetated cliffs at Mundesley are protected by substantial defences. They are classified as marginally stable in the west, becoming relatively stable at the town centre itself (Cliff Processes section of report EX 4692).

The beaches, of sand with a scattering of pebbles, provide some protection to the linear defences at the cliff toe. They have moderate amenity value.

The net littoral drift is from north-west to south-east. The sand accretion is very evident at the large groynes at the town centre. Without the groynes in place the sand would be rapidly transported eastwards to increase the already large sand accumulation within defence length BAC 1.01 and beyond.

2.7.2 Coastal defences

The coastal defences at Mundesley date back to the latter part of the 19th century, when much work was carried out by private landowners. By 1905 (the date of the second Ordnance Survey) a publicly funded seawall had been built to protect the town centre. The defences were subsequently extended eastwards and westwards at various dates (by then the line of the cliffs had retreated, leaving the central defences jutting out further seawards). For example, after the 1953 surge, sloping timber breastworks extended the defences westwards towards Trimingham and eastwards towards Bacton.

The permeable timber groynes are in good condition and are functional, trapping large volumes of sand on their westward sides, particularly at the pumping station, where the groynes are longer than elsewhere.

The linear defences from west to east are classified as follows:

Defence length TRI 6.01. (Start 630474E 337499N. Finish 630973E 337130).

- Sloping timber breastwork (built in 1967) in fair condition. Likely failure mechanism is low beach causing instability of steel toe. Cliff failures damaging both the timber and steel components of the revetment. Failure would lead to loss of residential property.

Defence length TRI 6.02 (Start 630973E 337130N. Finish 631320E 336850N).

- Concrete block revetment encapsulated in steel-rail crib (built in 1955) in fair condition. Likely failure mechanism is corrosion of steelwork, or displacement of structure through cliff failure. Failure would lead to loss of residential property.

Defence length TRI 6.03.1 (Start 631115E 336782N. Finish 631183E 336775N).

- Vertical mass concrete seawall (built in 1950) in poor condition. Cliffs behind are steep, vegetated and relatively stable. Likely failure mechanism is sliding, due to slim design of wall. Failure would lead to loss of substantial commercial property and residential property.

Defence length TRI 6.03.2 (Start 631183E 336775N. Finish 631220E 336768N).

- Vertical concrete seawall/promenade (built in 1910) in very good condition. Likely failure mechanism is sliding, if there was excess hydrostatic pressure developed behind the wall. Cliffs behind are steep, vegetated and relatively stable. Failure would lead to loss of property.

Defence length TRI 6.03.3 (Start 631220E 336768N. Finish 631384E 336740N).

- Vertical concrete seawall/promenade (built in 1910) in very good condition. Cliff type and likely failure mechanism is as for TRI 6.03.2. Failure would lead to loss of public open space and commercial property. Road also at risk in medium term.

Defence length TRI 6.03.4 (Start 631384E 336740N. Finish 631433E 336738N).

- Vertical concrete seawall/promenade/retaining wall (built in 1880) in poor condition, but backed by a high beach. Likely failure mechanism is structural failure of the seawall acting as a retaining wall, although currently beach levels are high. Failure would lead to limited property damage.

Defence length TRI 6.03.5 (Start 631433E 336738N. Finish 631490E 336725N).

- Vertical concrete seawall/promenade/retaining wall (built in 1880) in fair condition. Likely failure mechanism is structural failure of the seawall acting as a retaining wall, although currently beach levels are high. Failure would lead to limited property damage.

Defence length TRI 6.03.6 (Start 631490E 336725N. Finish 631497E 336728N).

- Vertical concrete seawall/promenade/retaining wall (built in 1880) in poor condition. Likely failure mechanism is structural failure of the seawall acting as a retaining wall, although currently beach levels are high. Failure would lead to property damage in oldest part of Mundesley.

Defence length TRI 6.03.7 (Start 631497E 336728N. Finish 631518E 336728N).

- Vertical concrete seawall/promenade/retaining wall (built in 1880) in good condition. Likely failure mechanism is structural failure of the seawall acting as a retaining wall, although currently beach levels are high. Failure would lead to property damage in oldest part of Mundesley.

Defence length TRI 6.03.8 (Start 631527E 336727N. Finish 631543E 336727N).

- Vertical concrete seawall/promenade wall that once protected sewer outfall storage tanks (built in 1880) in good condition. Likely failure mechanism is structural failure of the seawall acting as a retaining wall, although currently beach levels are high. Failure would lead to property damage in oldest part of Mundesley and potential loss of sewage infrastructure.

Defence length TRI 6.03.9 (Start 631543E 336727N. Finish 631632E 336701N).

- Vertical concrete seawall/promenade wall that ends at a ramp that forms beach access (built in 1880 and refurbished in 1970) in very good condition. Likely failure mechanism is structural failure of the seawall acting as a retaining wall, following excessive surcharge and/or cliff failure (although currently beach levels are high). Failure would lead to property damage in oldest part of Mundesley, loss of the sewage outfall head-works and pumping station, and loss of long sea-treated effluent outfall. This location is dictated by the layout of the existing sewerage network. It could not be simply inland, but would require major reconstruction and taking effluent inland rather than towards the sea (see Economic Valuations Interim Report, dated 1/12/03).

Defence length TRI 6.04 (Start 631711E 336486N. Finish 631814E 336358N).

- Sloping timber revetment (built in 1958 and 1964) in fair condition. Likely failure mechanism is low beach causing instability of structure (although currently beach levels are high and there are low dunes in front of the cliffs). Consequences of failure would be accelerated cliff erosion, leading to loss of residential property and damage/disruption to access road serving the pumping station and RLNLI facilities located in TRI 6.03. Beach has high amenity value due to closeness to town centre.

2.7.3 Human and built environment

The cliff top is intensively developed and there is considerable residential and commercial property at risk (Mundesley has quite a number of shops, tea-rooms, restaurants, public houses, car parking areas), as well as several important beach access points.

There is also an important coastal road, the existing B1159, which runs relatively close to the cliff edge in the town centre. It is assumed that when coastal recession cuts off this road, a permanent diversion consisting of a 7.3m wide all purpose rural road would be constructed as a replacement. Many services are also at risk, including a sewerage pumping station, a long sea sewage outfall, an intermediate pumping stations and an electricity sub-station (see Economic Valuations Interim Report, dated 1/12/03).

There is access to the beach from the cliff top. Part time fishermen also operate from Mundesley, although the extent of fishing activity is thought unlikely to be economically significant in terms of coastal defence expenditure (see Economic Valuations Interim Report, dated 1/12/03).

Environmental designations

The cliffs on the western outskirts of Mundesley lie within a County Wildlife Site, part of which runs adjacent to the Mundesley Cliffs SSSI (in defence length TRI 4).

Heritage features

The heritage features within the study area are listed in Table 2.6 of the Economic Valuations Interim Report, dated 1/12/03, and are as follows:

- Brick Kiln, Kiln Cliffs (Grade 2 Listed Building). NGR 630310E 337452N.
- WW2 Underground HQ (Historic site). NGR 630950E 337100N.
- Church of All Saints (Grade 2 Listed Building). NGR 631062E 336946N.
- No 14, The Dell (Grade 2 Listed Building). NGR 631545E 336545N.

2.7.4 Consequences of the Do Nothing Option

Interaction of defence failure and cliff top retreat rates

The cliffs at Mundesley are steep and there are properties close to the cliff edge, so that any erosion would have a significant impact if the defences were allowed to fall into disrepair. Under the Do Nothing scenario, the failure of the defences would result in rapid cliff retreat, because of the very pronounced promontory at the town centre, which would focus wave energy there. Cliff top properties would very quickly become at risk. Cliff erosion would release large volumes of sand, which would then be transported rapidly eastwards towards Bacton (the sand content of the cliffs in Mundesley is nearly 70%). This increase in the budget of sandy sediments will reduce the tendency for beach erosion, and associated cliff retreat, within Management Unit BAC 1 and further eastward.

Description of erosion and assets lost

The cliff lines predicted by the cliffSCAPE-RS model are shown in Figure 2.6.

The cliffs on the western outskirts of Mundesley are protected by a timber revetment. This is in fair condition. Under the Do Nothing scenario, the revetment will fail after about 5-10 years, and after 50 years up to 105m of cliff top recession will have taken place, at the 50% probability level. This will result in the loss of a large number of residential properties. Cliff top recession will increase to about 162m after 100 years, with a proportional increase in the number of properties lost.

The western to central parts of Mundesley are protected by a concrete block revetment. Under the Do Nothing scenario these will fail after about 3-5 years, and after 50 years up to 114m of cliff top recession will have taken place, at the 50% probability level. This will result in the loss of a large number of residential properties, together with the undermining of part of the B1159 coast road and the loss of the WW2 headquarters. Cliff top recession will increase to about 173m after 100 years, with a proportional increase in the number of properties lost.

The central part of Mundesley is protected by a seawall in condition varying from very good to poor condition. Under the Do Nothing scenario, this wall will fail after 10-20 years, and after 50 years up to

100m of cliff top recession will have taken place, at the 50% probability level. This will result in the loss of a large number of residential and commercial properties and the loss of more of the B1159 coast road coast road. In addition an electricity sub station, a sewerage pumping station and associated sewerage network, as well as a long-sea sewerage outfall, will have been lost. Cliff top recession will increase up to 159m after 100 years, with many more properties being lost. In addition, the RNLI facilities will also be lost.

The eastern part of Mundesley is protected by a timber breastwork that is in fair condition. Under the Do Nothing scenario the revetment will fail after 10-20 years, and after 50 years some 82m of cliff top recession will have taken place, at the 50% probability level. This will result in the loss of a number of residential properties. Cliff top recession will increase to 146m after 100 years, with more properties being lost.

In summary, the exposed cliffs along the densely developed frontage of Mundesley will erode rapidly once the defences fail. It is predicted that by year 100 some 254 residential properties and 7 commercial properties will have been lost through cliff retreat. There will also be a loss of many essential services and it is estimated that an electricity sub-station, a sewerage pumping station, a long sea outfall and RNLI facilities will all have been lost by year 100. Much of the old part of the town will also have disappeared. The predicted cumulative Do-Nothing losses, from year zero through to year 100, have a net present value of £13,230,000. These are shown sequentially in Tables 1 to 6 for years 0 to 10, 10 to 20 etc and are then summarised as cumulative totals in Table 7 of Appendix 1. A summary of main impacts is presented in the table below.

2.7.5 Summary of main impacts – Management Unit TRI 6

Do nothing option	**Impact on environmental Designations**	**Impact on tourism and leisure**	**Impact on archaeology and cultural heritage**	**Impact on built environment**
Mundesley is situated on a major promontory that presently control littoral drift on the frontages to the west. Failure of coastal defences at Mundesley will lead to cliff erosion and transport of sand in large quantities to the Bacton area (BAC 1 and beyond).	Cliffs are disturbed through cliff developments, while the defences are so substantial that they would remain on the foreshore after failure. Cliff erosion may therefore not significantly enhance environmental interests in the town centre.	Cliff erosion will severely impact on residential land and tourist infrastructure, through loss of amenity land.	By year 100 three heritage sites in the town centre will be lost through cliff erosion (including Pleasuance clock tower and rose garden and one listed hotel). An important WW2 bunker on the western outskirts would also have been lost.	By year 100 some 261 residential/commercial properties and essential services (sewage, electricity, roads) will have been lost through cliff erosion.

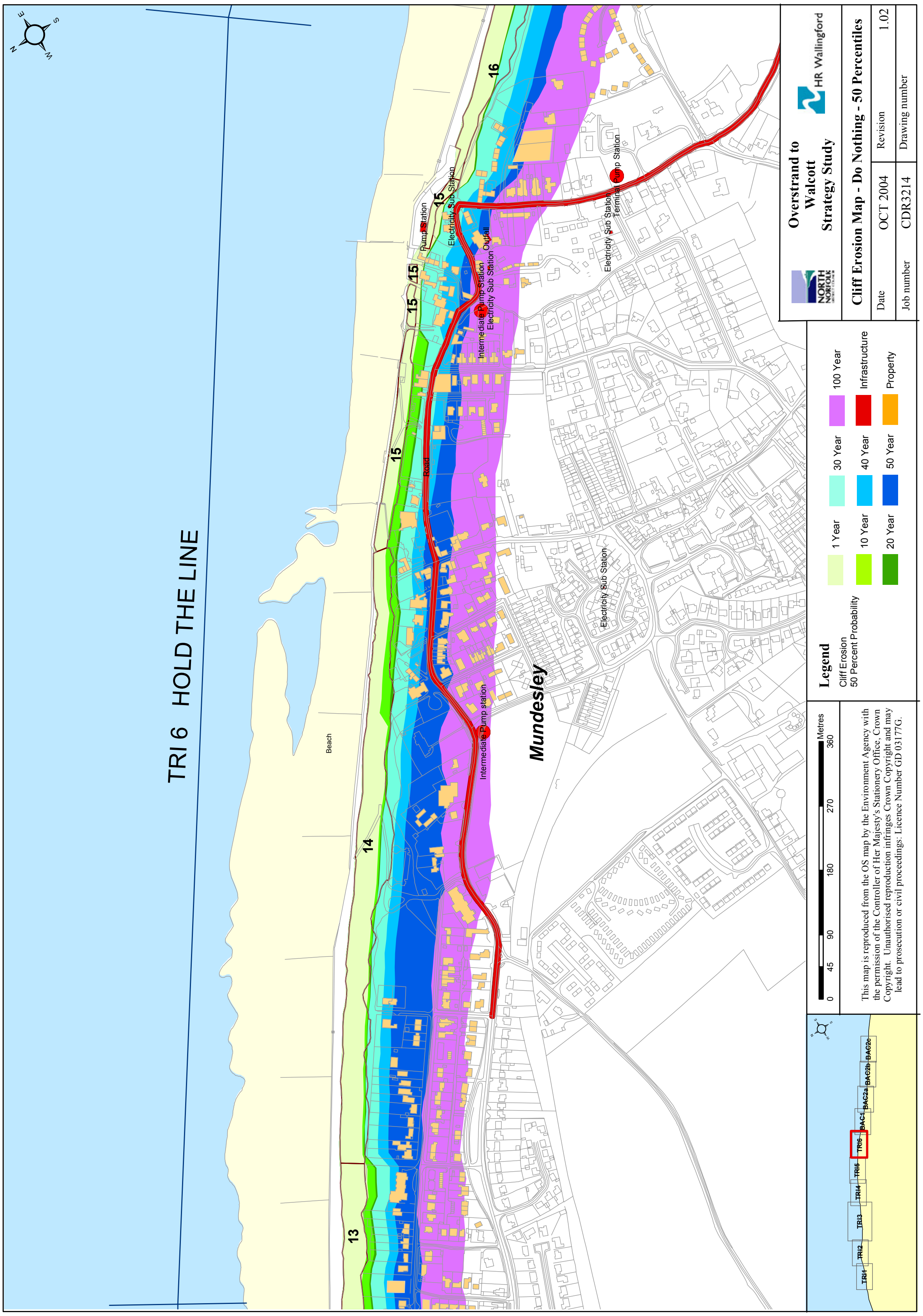


Figure 2.6 Predicted cliff recession to 100 years. Do Nothing scenario TRI6

EX 4692 "Do Nothing" Part II 28/10/04
34
HR Wallingford

2.8 Management Unit BAC 1: Mundesley to Bacton

2.8.1 Coastal Processes

The partly vegetated, sloping sandy cliffs along the Mundesley to Bacton frontage are relatively stable. The cliffs have a wide sand beach that has scattered pebbles on its surface. The beach in front of the timber revetment is relatively high and provides significant protection to the cliff toe, aided by the build up of sand dunes.

This frontage is relatively undeveloped, so that few cliff top assets at risk. As well as the timber revetment that continues uninterruptedly over the whole of this frontage there is a field of timber groynes that significantly slow down the west to east littoral drift.

The net littoral drift is from north-west to south-east. The groynes show a pronounced accretion on their western sides, indicating significant transport volumes.

2.8.2 Coastal defences

There were no coastal defences within this management unit until 1964/6, at which time a timber revetment was constructed to join up with the defences at Mundesley to the west and Bacton to the east. This revetment is well forward of the line of the cliffs, but is generally in good condition because of the wide beach. The timber groynes are also generally in good condition, except that their seaward ends require some maintenance.

The linear defences from west to east are classified as follows:

Defence length BAC 1.01 (Start 631814E 336358N. Finish 632869E 335376N).

- Sloping timber revetment (built in 1964/6) in fair condition. Likely failure mechanism is low beach causing instability of the structure, damage due to cliff failure. However, currently there is a stable beach, with dune building at the rear of the revetment (revetment is inundated with sand). Consequences of failure will be increased erosion of the cliff.

2.8.3 Human and built environment

This frontage consists primarily of agricultural land, but there is also a moderate sized holiday facility at the western end, on the outskirts of Mundesley.

Environmental designations

The western half of the area lies within an SSSI and an Area of Outstanding Natural Beauty.

Heritage features

The heritage features within the study area are listed in Table 2.6 of the Economic Valuations Interim Report, dated 1/12/03, and are as follows:

Great Barn, Paston Hall (Ancient Monument, Grade 2 Listed Building). NGR 632191E 334540N.
Church of St Margaret (Grade 1 Listed Building). NGR 632283E 334434N.
No 14, The Dell (Grade 2 Listed Building). NGR 631545E 336545N.

None of these assets, however, lie within the 50-year projections of cliff top retreat.

2.8.4 Consequences of the Do Nothing Option

Interaction of defence failure and cliff top retreat rates

Under the Do Nothing scenario the cliff recession in this area will be modest, due to the input of sediments from the west by littoral drift, from the rapid erosion of the sandy cliffs at Mundesley (Management Unit TRI 6).

Description of erosion and assets lost

The cliff lines predicted by the cliffSCAPE-RS model are shown in Figure 2.7.

This frontage has a timber revetment, which is in fair condition. The foreshore between the revetment and the cliff toe is also wide and covered by dunes, indicating that the onset of erosion would not have an immediate impact on the cliff stability. Under the Do Nothing scenario, the revetment will fail after 10 – 20 years, and after 50 years some 78m of cliff top recession will have taken place, at the 50% probability level. This will result in the loss of undeveloped land/footpaths, but also with the loss of several permanent buildings at the holiday facility on the eastern outskirts of Mundesley. After 100 years about 128m of cliff recession will have taken place, with further losses of buildings at the holiday facility.

In summary, the relatively stable cliffs along the lightly developed frontage between Mundesley and Bacton will only begin to erode rapidly once the beach has eroded and the defences have failed. It is predicted that by year 100 some 29 residential/holiday properties of relatively low value will have been lost through cliff retreat. Some of the losses would be at a holiday facility that could be relocated. The predicted cumulative Do-Nothing losses, from year zero through to year 100, have a net present value of £393,000. These are shown sequentially in Tables 1 to 6 for years 0 to 10, 10 to 20 etc and are then summarised as cumulative totals in Table 7 of Appendix 1. A summary of main impacts is presented in the table below.

2.8.5 Summary of main impacts – Management Unit BAC 1

Do nothing option	Impact on environmental Designations	Impact on tourism and leisure	Impact on archaeology and cultural heritage	Impact on built environment
The sloping, partly vegetated cliffs will erode relatively slowly, the beaches being fed by erosion at Mundesley (TRI 6).	Cliff erosion is likely to be sufficient to maintain fresh exposures and keep up environmental interests.	Holiday camp on the eastern outskirts of Mundesley will be affected by cliff erosion, requiring relocation in the long term. Agricultural land will also be lost.	No listed buildings at risk.	After 100 years some 29 residential/holiday properties of relatively low value will have been lost through cliff retreat. No infrastructure at risk.

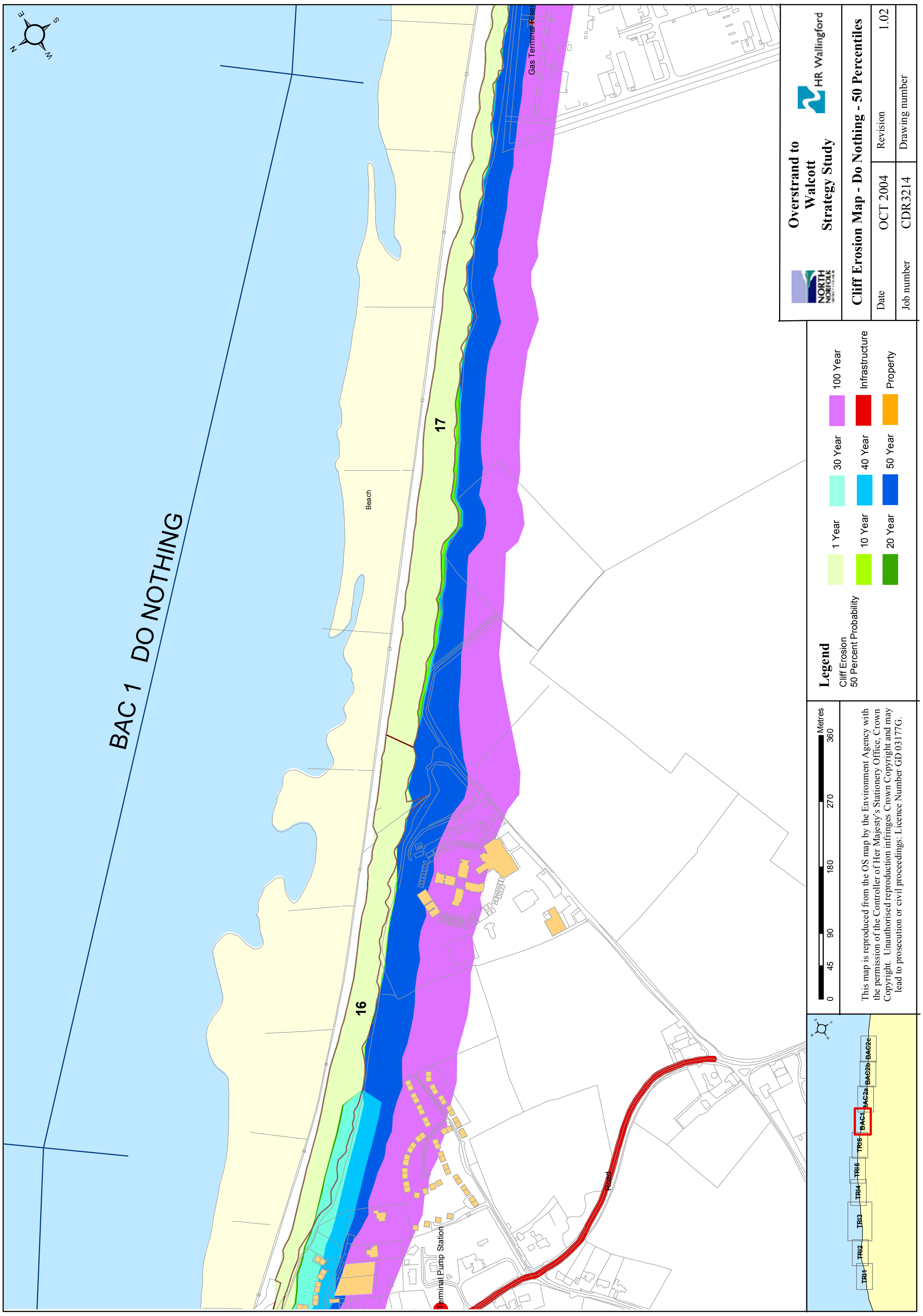


Figure 2.7 Predicted cliff recession to 100 years. Do Nothing scenario BAC1

2.9 Management Unit BAC 2: Bacton, Walcott and Ostend

2.9.1 Coastal Processes

The low cliffs are actively unstable at the western end of the Bacton Gas Terminal frontage, relatively stable at the central part and marginally stable at the eastern end of the frontage (Cliff Processes section of EX 4692). The sand beaches are very healthy, with the groynes being almost submerged by accretion, except at the western end where the groynes are shorter.

Further eastwards, the cliffs on the Bacton to Walcott frontage have been almost completely stabilised by a sloping seawall that extends their full height. Here there are two slight embayments, within which sand has accumulated, again burying the groynes at their landward ends. Aerial photographs indicated very large quantities of sand in suspension immediately offshore.

The beaches, which are of sand with a scattering of pebbles provide some protection to the linear defences at the cliff toe, further aiding stability.

The net littoral drift is from north-west to south-east, and the timber (impermeable) groynes capture considerable quantities of sand.

2.9.2 Coastal defences

There is a long history of erosion in this area, with references to the loss of the medieval church in Keswick in 1382 and "great encroachments" in 1836 and 1845. However, defences were not built until 1954 (after the 1953 surge) when the seawall from Bacton to Keswick was constructed. Subsequently a timber revetment was built west of Bacton. The western end of the frontage is dominated by the Bacton Gas Site, which is of major economic importance to the nation. Further east the communities are predominantly residential, with a strong usage for tourism.

The timber groynes generally date back to the 1970's and 1980's, but are in good condition, because of the high beach levels.

The linear defences from west to east are classified as follows:

Defence length BAC 2.01. (Start 632869E 335376N. Finish 633776E 334585N).

- Sloping timber breastwork (built in 1966) in fair condition. The revetment is presently almost buried by sand accretion and there is some marginal dune growth between the revetment and the cliff toe. Likely failure mechanism is low beach causing instability of the structure. Damage due to cliff failure reduces in likelihood from west to east as the cliff reduces in height. Consequences of failure are increasing erosion of the cliff and damage to gas industry facilities at the Bacton Gas Site. In the Do Nothing option the cliff top components under threat would be relocated rather than the whole plant reconstructed. There is also a buffer zone, which delimits the cliff top and determines when economic losses begin to be incurred through cliff top recession. Beach erosion would also affect the gas pipelines laid shallowly through the intertidal zone (see the Economic Valuations Interim Report, dated 1/12/03, for further details).

Defence length BAC 2.02 (Start 633776E 334585N. Finish 633963E 334445N).

- Sloping timber revetment (built in 1955) in good condition, steel and concrete breastwork in very good condition, timber breastwork in poor condition. Likely failure mechanism is low beach causing instability of the structure. Failure would result in a risk to caravan site and to residential property. Beach itself is volatile but has high amenity value. At present, the sand accumulation found in defence length BAC 2.01 does not stretch this far eastwards, leaving the beaches in front of the caravan site quite low. The aerial photographs show massive quantities of sand in suspension, although it cannot be determined whether sand is being removed from the beaches or being added to them.

Defence length BAC 2.03 (Start 633963E 334445N. Finish 635348E 333322N).

- Sloping concrete seawall with concrete apron and steel sheet pile toe, with a small return wall to rear (built in 1978) in apron in fair condition, piles in good condition. The adequate state of the defences is linked to the healthy state of the beaches (in this area the groynes are almost buried in sand accretion). The low cliff along this frontage is entirely protected by the seawall, which extends to its full height. Likely failure mechanism is steel pile failure due to low beach levels, with apron failure due to undermining. This results in a risk of property damage.

Defence length BAC 2.04 (Start 635348E 333322N. Finish 636003E 332894N).

- Sloping concrete seawall with concrete apron and steel sheet pile toe, with a small return wall to rear (built in 1954); revetment is in fair condition, the apron in fair condition and the piles in good condition. This frontage has low beach levels, because the necessity to protect the coast road has pushed the seawall seawards of the natural line of the coast. The land behind the wall is low and there is a flood risk if the defences failed. Likely failure mechanism is steel pile failure due to low beach levels, with apron failure due to undermining. This results in a risk to residential and tourism facilities and severe communication problems, if the existing coast road, the B1159, was damaged. It is assumed that when coastal recession cut off this road, a permanent diversion consisting of a 7.3m wide all purpose rural road would be constructed as a replacement (see Economic Valuations Interim Report, dated 1/12/03).

Defence length BAC 2.05 (Start 636003E 332894N. Finish 636476E 332584N).

- Sloping concrete seawall with concrete apron and steel sheet pile toe, with a small return wall to rear (built in 1954); revetment is in fair to poor condition, apron is in fair condition and the piles in good condition. Low cliff protected by wall that extends upwards to its full height. The beach levels are volatile and the frontage does not receive the sand in large quantities, because of the accretion of sand within defence length BAC 2.03, which does not feed through very well to the down-drift beaches. Likely failure mechanism is steel pile failure due to low beach levels, with apron failure due to undermining. This results in a risk to residential properties.

Defence length BAC 2.06 (Start 636476E 332584N. Finish 636918E 332294N).

- Sloping timber revetment (built in 1961, refurbished in 1994) in good condition. The beach levels within this frontage are high and the landward ends of the groynes are often buried in sand. Aerial photographs show very large quantities of sand in suspension, which may feed the beaches. The groynes also have a strong differential levels that indicate strong easterly transport. The low-lying hinterland contains holiday accommodation, residential properties and agricultural land. Likely failure mechanism is storm damage to timber structure. This results in a risk to residential and holiday properties.

2.9.3 Human and built environment

The threat to the human and built environment is described under each defence length, above.

Environmental designations

No known designations.

Heritage features

The heritage features within the study area are listed in Table 2.6 of the Economic Valuations Interim Report, dated 1/12/03, and are as follows:

- Manor Farm Barn, Bacton (Grade 2 Listed Building). NGR 634167E 333660N.
- Manor House, Bacton (Grade 2 Listed Building). NGR 634192E 333637N.
- Manor House, Bacton (Grade 2 Listed Building). NGR 634178E 333637N.
- Bromholme (house) (Grade 2 Listed Building). NGR 634629E 333516N.
- The Pilgrim House, Bacton (Grade 2 Listed Building). NGR 634732E 333471N.

- Barn at Pilgrim House (Grade 2 Listed Building). NGR 634751E 333493N.
- 1-4 Keswick Cottages, Bacton (Grade 2 Listed Building). NGR 635075E 333389N.
- Malthouse Farmhouse, Walcott (Grade 2 Listed Building). NGR 636011E 332366N.

2.9.4 Consequences of the Do Nothing Option

Interaction of defence failure and cliff top retreat rates

The cliffs become lower from west to east. If the defences fell into disrepair the cliff recession would increase slightly and the commercial facilities, properties and tourist facilities would be quickly threatened because of their closeness to the shoreline and the "lack of volume" within the cliffs to withstand erosion.

Under the Do Nothing scenario the supply of material by littoral drift, from the rapid erosion at Mundesley (Management Unit TRI 6) will provide an important input to the beaches in this area (BAC 2).

Description of erosion and assets lost

The cliff lines predicted by the cliffSCAPE-RS model are shown in Figures 2.8 to 2.10.

The western part of this frontage, within the Bacton Gas Site, is protected by a timber breastwork, which is in good condition. The revetment is almost buried in sand and there are dunes between it and the cliff toe. Under the Do Nothing scenario, this revetment will fail after 10 – 20 years, and after 50 years some 42m of cliff top recession will have taken place, at the 50% probability level. This will result in the loss of the buffer zone at the Gas Site. Cliff recession will increase to about 88m after 100 years, resulting in the loss of some of the buildings at the Gas Site.

East of the Bacton Gas Site the frontage is protected by a sloping timber revetment whose toe is in poor condition. Under the Do Nothing scenario, the revetment will fail after 5-10 years, and after 50 years some 38m of cliff recession will have taken place, at the 50% probability level. This will result in the loss of several permanent buildings at the caravan site. Cliff recession will increase to 72m after 100 years, resulting in the loss of further permanent buildings at the caravan site.

At Bacton itself (Figure 2.9) the housing is situated very close to the rear of the seawall. Under the Do Nothing scenario the wall will fail after 5-10 years, and after 50 years some 33m of cliff recession will have taken place, at the 50% probability level. This will result in the loss of large numbers of residential and holiday properties. Cliff recession will increase to 68m after 100 years, resulting in the loss of many more properties.

Between Bacton and Walcott (right hand edge of Figure 2.9 and left hand side of Figure 2.10) the B1159 coast road runs immediately behind the seawall and there are also several residential properties that are close to the shoreline. Under the Do Nothing scenario, the seawall will fail after 5-10 years and the land behind it will be flooded. After 50 years the coastline will have receded 28m or more (interpolating from the cliff positions to east and west). This will result in the loss of the B1159 coast road and several properties. After 100 years the coastline will have receded about 62m, with many more properties being affected.

At Walcott, (Figure 2.10) the residential properties are again close to the rear of the defences. Under the Do Nothing scenario the seawall and timber revetment will fail after 5-10 years, and after 50 years the coastal edge will have retreated by about 34m. This will result in the loss of many residential and holiday properties. After 100 years the recession will have increased to about 69m, with continued losses of properties. The erosion will feed the beaches to the east, between Walcott and the western end of Happisburgh.

In summary, the narrow line of cliffs between Bacton and Walcott will provide only a narrow buffer zone against cliff retreat and the properties on the immediate backshore will begin to be affected soon after the defences are abandoned. It is predicted that by year 100 some 263 residential/holiday properties and 3 commercial properties will have been lost through cliff retreat. The predicted cumulative Do-Nothing losses, from year zero through to year 100, have a net present value of £72,250,000. These are shown sequentially in Tables 1 to 6 for years 0 to 10, 10 to 20 etc and are then summarised as cumulative totals in Table 7 of Appendix 1. A summary of main impacts is presented in the table below.

2.9.5 Summary of main impacts – Management Unit BAC2

Do nothing option	**Impact on environmental Designations**	**Impact on tourism and leisure**	**Impact on archaeology and cultural heritage**	**Impact on built environment**
Coastal retreat will provide only a small volume of material to the sediment budget. The erosion between Bacton and Walcott will affect low-lying land that will get flooded.	No impact.	Even the modest rate of cliff retreat predicted will significantly on residential and tourist developments, which are sited close to the shoreline.	Heritage sites are well inland and not at risk.	By year 100 some 263 residential/tourist properties will be lost, and the coast road will have been cut off.

2.10 Overview of the losses under the Do-Nothing scenario

The cliffed frontage within the study area has undergone piecemeal development over the years, making the population density variable, depending on location. Historic development is centred on the towns of Mundesley and Overstrand, where defences have been in place since Victorian times. These two towns have a high concentration of housing and services, and are where highest losses through cliff erosion are anticipated under the Do-Nothing scenario. More recent development in the area, at Trimingham for example, contain a high proportion of (low-density) holiday housing, where resulting losses through cliff retreat are relatively low by comparison. An “anomaly” is the eastern end of the study area, between Bacton and Walcot, which was relatively undeveloped until the last half century. This area now contains high-density shore front housing, which is at immediate risk because the line of the cliffs is very narrow. This area also contains high value cliff top commercial developments at the Bacton gas terminal.

Cumulative losses through cliff retreat, arranged by defence code are presented in Table 7. Here it can be seen that the greatest losses are concentrated around the centres of population at Trimingham (TRI 2), Mundesley (TRI 6) and Bacton to Walcot (BAC 2). By comparison the losses at Trimingham (TRI 4) can be considered to be relatively low. This is because of the low-density development at Trimingham and the lack of major services (electricity sub-stations, sewerage pumping stations and outfalls).

In summary the costs of implementing the Do-Nothing scenario would have very high social impacts at Mundesley and Overstrand, and between Bacton and Walcot. Elsewhere, the social impacts are relatively low.

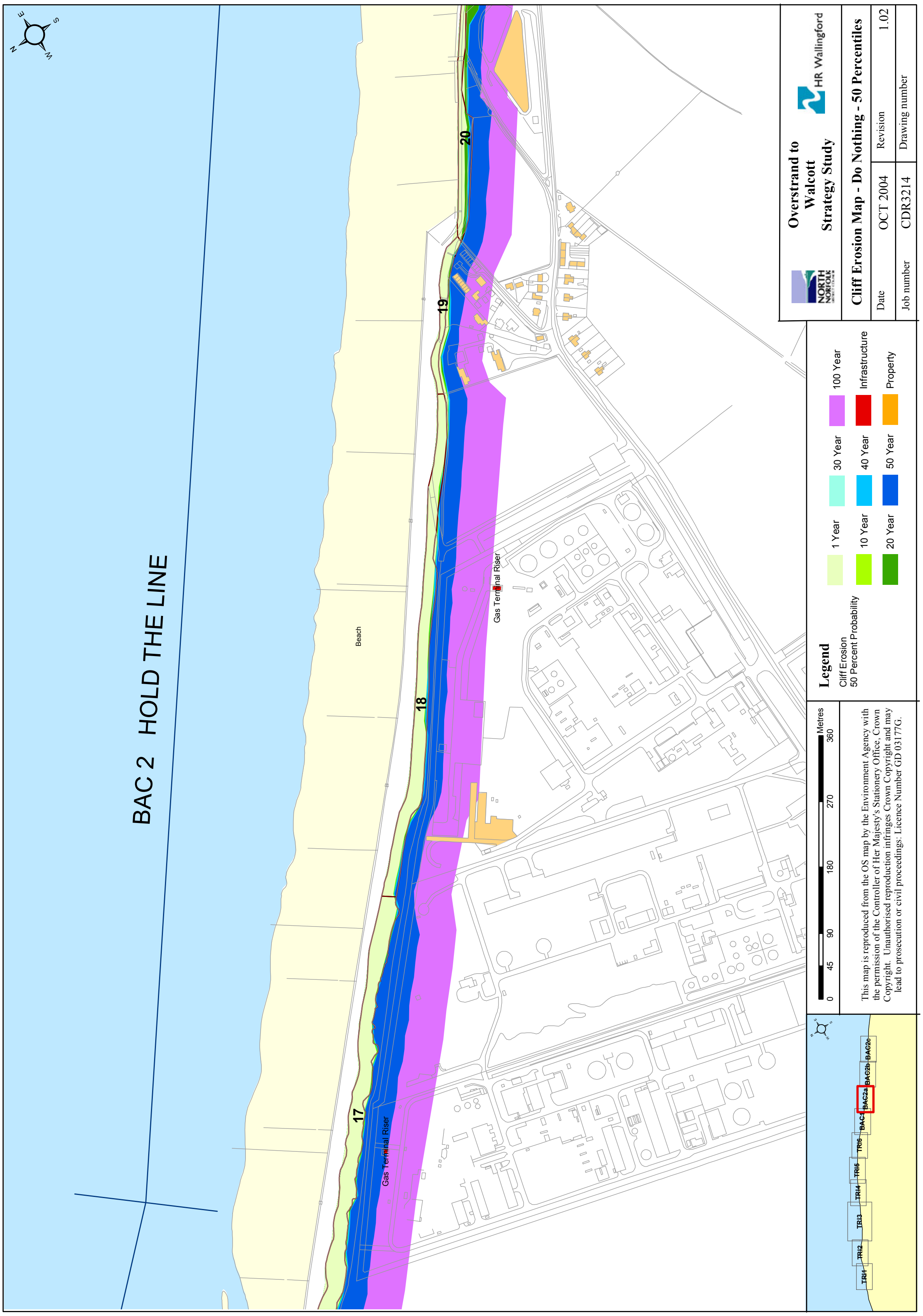


Figure 2.8 Predicted cliff recession to 100 years. Do Nothing scenario BAC2

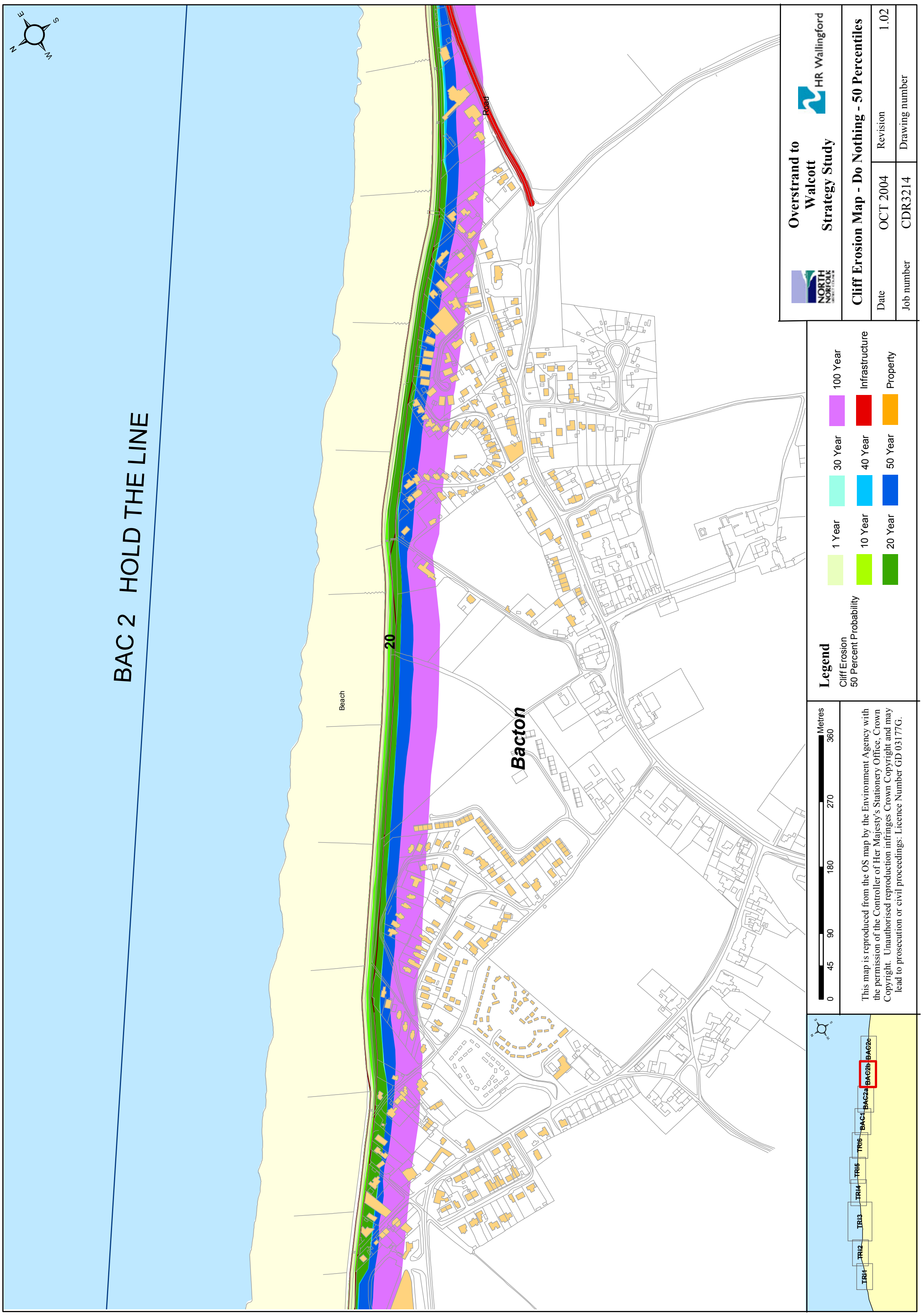


Figure 2.9 Predicted cliff recession to 100 years. Do Nothing scenario BAC2 (cont.)

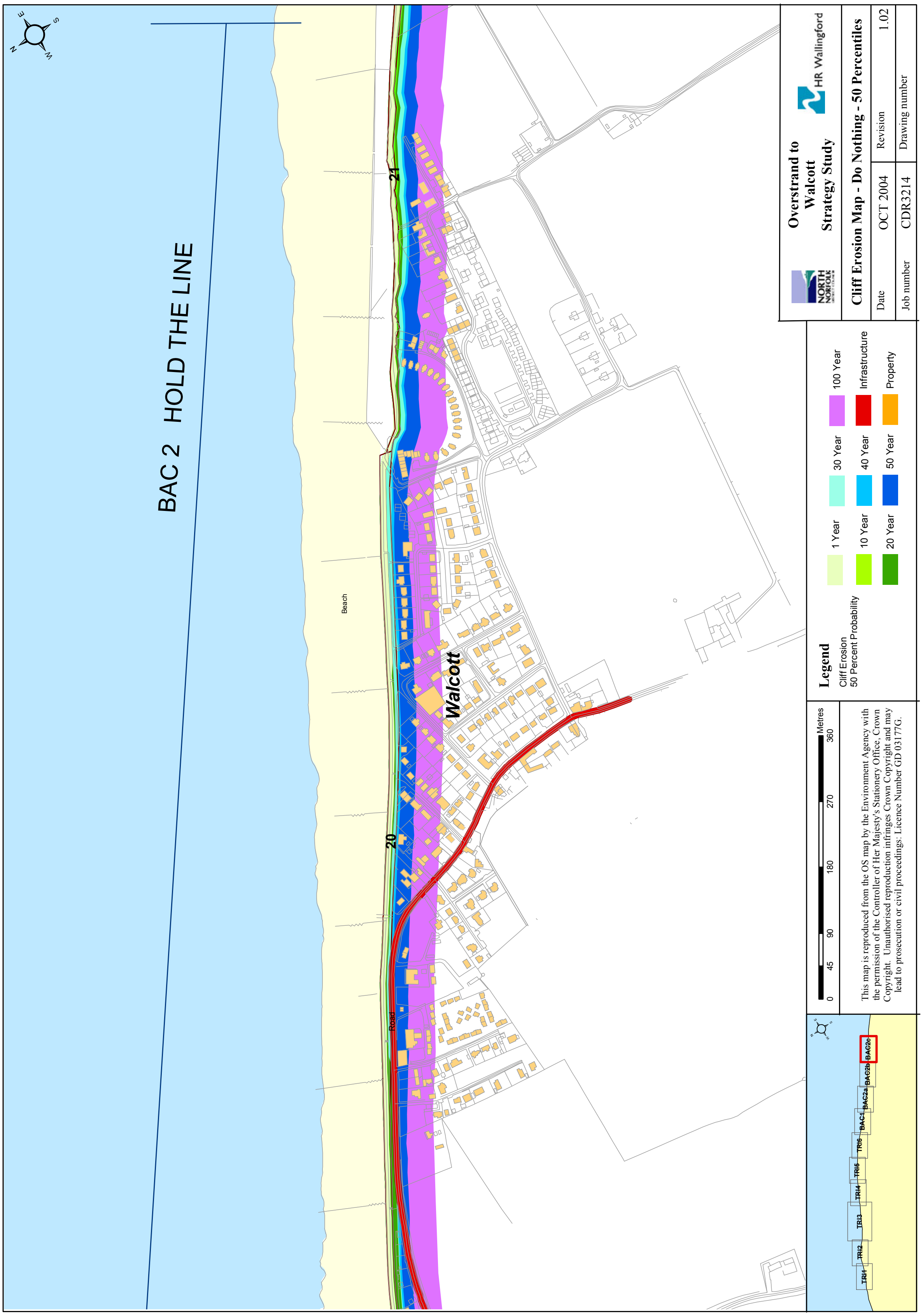


Figure 2.10 Predicted cliff recession to 100 years. Do Nothing scenario BAC2 (contd)

Appendix

Appendix 1

Do Nothing costs

Appendix 1 Do Nothing costs

KEY

Asset Breakdown

Properties	Residential properties
	Amenities
	Caravans
	Chalets
Transportation	Roads
Commercial	Telephone exchanges
	Water provision and wastewater
	Electrical substations
	Car parks
	M o D
	BN Gas Terminal
Agricultural Land	£6,798 per hectare
Heritage Sites	Pleasuance Gazebo
	Pleasuance, Rose Garden
	Pleasuance, Covered Walk
	The Pleasuance
	Pleasuance, Clock Tower
	Methodist Chapel
	Sea Marge (hotel)
	Church of St. Michael
	Garden Close, Main Road
	18-20 Ivy Cottages
	18-20 Ivy Cottages
	Hall Farmhouse
	St John the Baptist Church
	Brick Kiln, Kiln Cliffs
	Church of All Saints
	14 The Dell
	WW2 BUNKER
	Manor Farm Barn
	Manor House
	Manor House
	Bromholme (house)
	The Pilgrim House
	Barn at Pilgrim House
	1-4 Keswick Cottages
	1-4 Keswick Cottages
	1-4 Keswick Cottages
	1-4 Keswick Cottages
	Malthouse Farmhouse
	Overstrand Hall
	Great Barn
	Church of St. Margaret

Table 1 Losses between Year 0 and Year 10

Year 0 to 10	Management Units								
Number of assets affected	TRI1	TRI2	TRI3	TRI4	TRI5	TRI6	BAC1	BAC2	Total
Properties (No.)	0	3	0	0	0	15	0	8	26
Transportation (No.)	0	0	0	0	0	0	0	1	1
Commercial (No.)	0	2	0	0	0	1	0	0	3
Recreation and Tourism (No.)	15	0	0	0	0	0	0	0	15
Heritage Sites (No.)	0	0	0	0	0	0	0	0	0
MOD (No.)	0	0	0	0	0	0	0	0	0
Agricultural (Ha)	0	0	13	0	0	0	4	0	17
Value of assets lost (£k)	TRI1	TRI2	TRI3	TRI4	TRI5	TRI6	BAC1	BAC2	
Properties	0	94	0	0	0	1,965	0	978	3,036
Transportation	0	0	0	0	0	0	0	1,283	1,283
Commercial	0	1,699	0	0	0	1,483	0	0	3,182
Recreation and Tourism	306	0	0	0	0	0	0	0	306
Heritage Sites	0	0	0	0	0	0	0	0	0
MOD	0	0	0	0	0	0	0	0	0
Agricultural	0	0	91	0	0	0	24	0	115
Total loss (£k)	306	1,793	91	0	0	3,448	24	2,261	7,921

Table 2 Losses between Year 10 and Year 20

Year 10 to 20	Management Units								
Number of assets affected	TRI1	TRI2	TRI3	TRI4	TRI5	TRI6	BAC1	BAC2	Total
Properties (No.)	0	4	0	2	0	0	0	20	26
Transportation (No.)	0	0	0	0	0	0	0	0	0
Commercial (No.)	0	0	0	0	0	1	0	0	1
Recreation and Tourism (No.)	0	0	0	0	0	0	0	0	0
Heritage Sites (No.)	0	0	0	0	0	0	0	0	0
MOD (No.)	0	0	0	0	0	0	0	0	0
Agricultural (Ha)	0	0	1	0	0	0	0	0	1
Value of assets lost (£k)	TRI1	TRI2	TRI3	TRI4	TRI5	TRI6	BAC1	BAC2	
Properties	0	878	0	363	0	371	0	1,438	3,050
Transportation	0	0	0	0	0	0	0	0	0
Commercial	0	0	0	0	0	17	0	0	17
Recreation and Tourism	3	0	0	0	0	0	0	0	3
Heritage Sites	0	0	0	0	0	0	0	0	0
MOD	0	0	0	0	0	0	0	0	0
Agricultural	0	0	9	0	0	0	0	0	9
Total loss (£k)	3	878	9	363	0	388	0	1,438	3,078

Table 3 Losses between Year 20 and Year 30

Year 20 to 30	Management Units								
Number of assets affected	TRI1	TRI2	TRI3	TRI4	TRI5	TRI6	BAC1	BAC2	Total
Properties (No.)	0	11	0	0	0	29	0	9	49
Transportation (No.)	0	0	0	0	0	1	0	0	1
Commercial (No.)	0	0	0	0	0	0	0	0	0
Recreation and Tourism (No.)	1	0	0	0	0	0	0	0	1
Heritage Sites (No.)	0	0	0	0	0	1	0	0	1
MOD (No.)	0	0	0	0	0	0	0	0	0
Agricultural (Ha)	0	0	1	0	0	0	0	0	1
Value of assets lost (£k)	TRI1	TRI2	TRI3	TRI4	TRI5	TRI6	BAC1	BAC2	
Properties	0	1,172	0	150	0	4,721	0	346	6,389
Transportation	0	0	0	0	0	1,269	0	0	1,269
Commercial	0	0	0	0	0	0	0	0	0
Recreation and Tourism	12	0	0	0	0	0	0	0	12
Heritage Sites	0	0	0	0	0	0	0	0	0
MOD	0	0	0	0	0	0	0	0	0
Agricultural	0	0	6	0	0	0	0	0	6
Total loss (£k)	12	1,172	6	150	0	5,990	0	346	7,676

Table 4 Losses between Year 30 and Year 40

Year 30 to 40	Management Units								
Number of assets affected	TRI1	TRI2	TRI3	TRI4	TRI5	TRI6	BAC1	BAC2	Total
Properties (No.)	0	13	0	2	1	21	0	9	46
Transportation (No.)	0	0	0	0	0	0	0	0	0
Commercial (No.)	0	0	0	0	0	0	0	0	0
Recreation and Tourism (No.)	1	0	0	0	0	0	0	0	1
Heritage Sites (No.)	0	0	0	0	0	0	0	0	0
MOD (No.)	0	0	0	0	0	0	0	0	0
Agricultural (Ha)	0	0	2	0	0	0	0	0	2
Value of assets lost (£k)	TRI1	TRI2	TRI3	TRI4	TRI5	TRI6	BAC1	BAC2	
Properties	0	1,552	0	176	119	3,224	0	684	5,755
Transportation	0	0	0	0	0	0	0	0	0
Commercial	0	0	0	0	0	0	0	0	0
Recreation and Tourism	27	0	0	0	0	0	0	0	27
Heritage Sites	0	0	0	0	0	0	0	0	0
MOD	0	0	0	0	0	0	0	0	0
Agricultural	0	0	13	0	0	0	1	0	14
Total loss (£k)	27	1,552	13	176	119	3,224	1	684	5,796

Table 5 Losses between Year 40 and Year 50

Year 40 to 50	Management Units								
Number of assets affected	TRI1	TRI2	TRI3	TRI4	TRI5	TRI6	BAC1	BAC2	Total
Properties (No.)	0	40	0	20	6	58	4	69	197
Transportation (No.)	0	0	0	1	0	0	0	0	1
Commercial (No.)	0	1	0	0	0	2	0	1	4
Recreation and Tourism (No.)	2	0	0	0	0	0	0	0	2
Heritage Sites (No.)	0	0	0	0	0	2	0	0	2
MOD (No.)	0	0	0	0	0	0	0	0	0
Agricultural (Ha)	0	0	3	0	0	0	3	0	6
Value of assets lost (£k)	TRI1	TRI2	TRI3	TRI4	TRI5	TRI6	BAC1	BAC2	
Properties	0	11,545	0	4,138	830	8,608	335	231,389	256,845
Transportation	0	0	0	2,403	0	0	0	0	2,403
Commercial	0	60	0	0	0	2,966	0	7,000	10,026
Recreation and Tourism	34	0	0	0	0	0	0	0	34
Heritage Sites	0	0	0	0	0	0	0	0	0
MOD	0	0	0	0	0	0	0	0	0
Agricultural	0	0	20	0	0	0	21	0	41
Total loss (£k)	34	11,605	20	6,541	830	11,574	356	238,389	269,349

Table 6 Losses between Year 50 and Year 100

Year 50 to 100	Management Units								
Number of assets affected	TRI1	TRI2	TRI3	TRI4	TRI5	TRI6	BAC1	BAC2	Total
Properties (No.)	0	89	5	18	13	131	25	148	429
Transportation (No.)	0	0	0	0	0	0	0	0	0
Commercial (No.)	0	1	0	1	0	3	0	2	7
Recreation and Tourism (No.)	3	0	0	0	0	0	0	0	3
Heritage Sites (No.)	0	3	0	0	0	0	0	0	3
MOD (No.)	0	0	0	0	0	0	0	0	0
Agricultural (Ha)	0	0	8	0	0	0	5	0	13
Value of assets lost (£k)	TRI1	TRI2	TRI3	TRI4	TRI5	TRI6	BAC1	BAC2	
Properties	0	17,024	450	3,214	1,807	19,447	1,986	39,494	83,423
Transportation	0	0	0	0	0	0	0	0	0
Commercial	0	8	0	2,403	0	2,769	0	8,283	13,463
Recreation and Tourism	64	0	0	0	0	0	0	0	64
Heritage Sites	0	0	0	0	0	0	0	0	0
MOD	0	0	0	0	0	0	0	0	0
Agricultural	0	0	54	0	0	0	32	0	86
Total loss (£k)	64	17,032	504	5,617	1,807	22,216	2,018	47,777	97,036

Table 7 Cumulative PV costs for the Do Nothing scenario

Losses by defence code (£k)		Losses (non-discounted)					
	Total PV (£k)	**10**	**20**	**30**	**40**	**50**	**100**
TRI1	329	306	309	321	348	382	446
TRI2	8396	1793	2671	3843	5395	17000	34032
TRI3	173	91	100	105	119	138	642
TRI4	2820	0	363	513	689	7231	12848
TRI5	507	0	0	0	119	949	2756
TRI6	13230	3448	3836	9826	13051	24625	46841
BAC1	393	24	24	24	25	381	2399
BAC2	72250	2261	3698	4044	4727	243116	290893
Total Loss (£k)	98098	7921	11000	18676	24472	293821	390857

Losses by asset type (£k)		Losses (non-discounted)					
	Total PV (£k)	**10**	**20**	**30**	**40**	**50**	**100**
Properties	87920	3036	6086	12475	18230	275075	358497
Transportation	2398	1283	1283	2552	2552	4955	4955
Commercial	7307	3182	3199	3199	3199	13225	26688
Recreation and Tourism	329	306	309	321	348	382	446
Heritage Sites	0	0	0	0	0	0	0
MOD	0	0	0	0	0	0	0
Agricultural	144	115	124	129	144	184	270
Total Loss (£k)	98098	7921	11000	18676	24472	293821	390857