Note

HASKONINGDHV UK LIMITED
RIVERS, DELTAS & COASTS

To	:	Stephanie Hampshire, Mott MacDonald
From	:	Mike Walkden / Alice Johnson
Date	:	13th August 2013
Copy	:	
Our reference	:	9W6431/N2/303282/Exet
Subject	**:**	**SCAPE Modelling of Shore Evolution: Cromer to Cart Gap: Addendum 1 Management Scenarios 3 and 4.**

Introduction

Royal HaskoningDHV was commissioned by Mott MacDonald to run a Soft Cliff And Platform Erosion (SCAPE) numerical geomorphological model of the shore of North Norfolk (UK) between Cromer and Cart Gap. This work was an element of the Cromer to Winterton Ness Coastal Study, which Mott MacDonald has undertaken for North Norfolk District Council. During the initial commission, the model was used to explore geomorphic response to two alternative scenarios of coastal management: Scenario 1 - 'Do Nothing' and Scenario 2 - 'SMP Policy 6' over the period 2013 to 2120. Each scenario was represented in a probabilistic manner, involving 250 simulations, each with stochastic elements, and so most of the results were probabilistic. The model outputs that were passed to Mott MacDonald comprised upper and lower limits of cliff top recession (in metres) at the 5th and 95th percentiles, by section and year, and sediment transport rates (in cubic metres per year) at Cart Gap (model section 29), by time and quantile. These results were then used by Mott MacDonald to assess the relative merits of the management policies. This work, the SCAPE numerical model, and the scenarios are described in Royal HaskoningDHV (2013).

Two further simulations were commissioned during a later stage of the project, which were:

Scenario 3	Modified SMP2 Policy 6; identical to Scenario 2, except with 'Hold the Line' policies at Overstrand, Mundsley, Bacton, Walcott and Ostend for the long term; and
Scenario 4	SMP2 Policy 6 with additional sediment nourishment from Trimingham to Overstrand otherwise identical to Scenario 2.

This note describes the results of these two additional scenarios, and is an addendum to Royal HaskoningDHV (2013).

Scenario 3

Management scenario 3 (MS3) was defined as being identical to management scenario 2 (see Royal HaskoningDHV (2013) except at the following settlements, where structures were held in place throughout the simulation:

- Overstrand (model sections 61-66, 30 to 32.5 m from Winterton Ness)
- Mundesley (model sections 47-51, 23 to 25 m from Winterton Ness)
- Bacton (model sections 38-41, 18.5 to 20 m from Winterton Ness)
- Walcot/ Ostend (model sections 35-38, 17 to 18.5 m from Winterton Ness)

The locations of the SCAPE model sections are illustrated in Figure 1.
Scenario 3 therefore represents a state in which significantly more coast protection is implemented than under scenario 2.

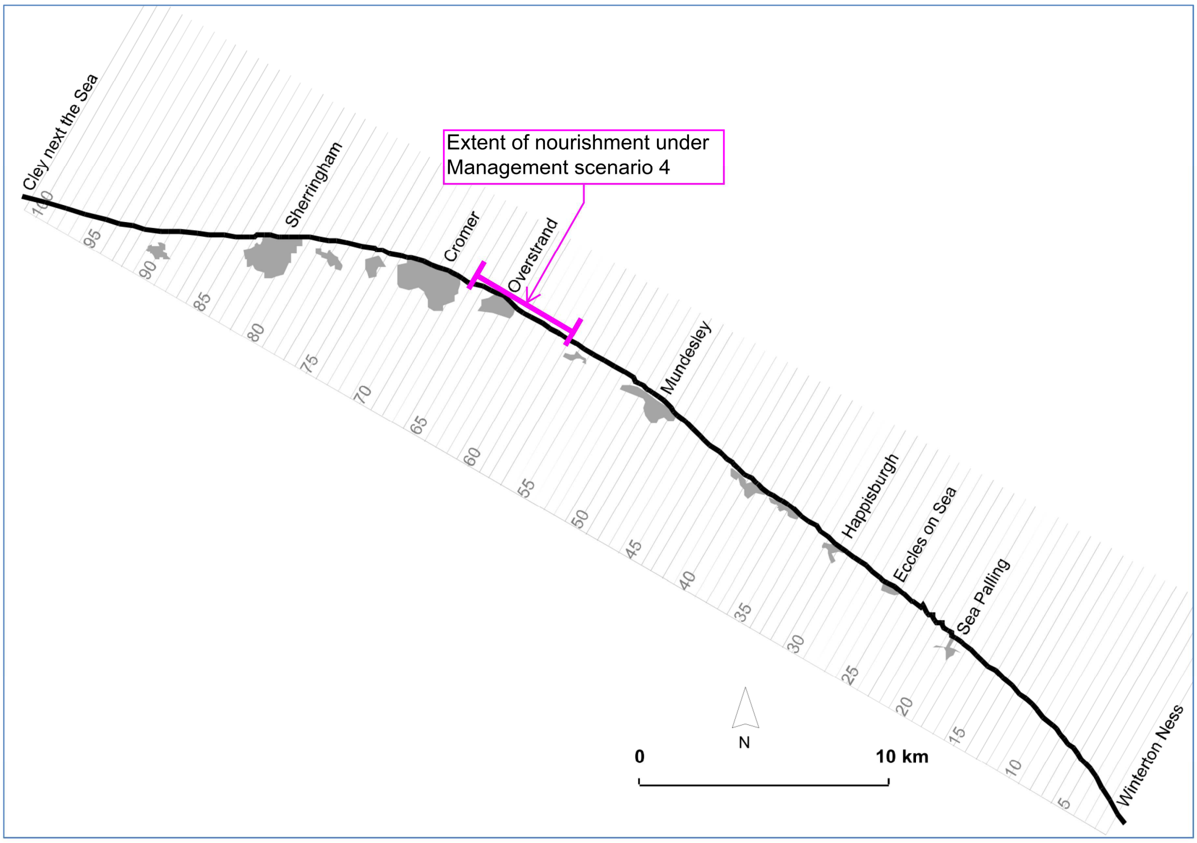

Figure 1. Location of 101 model sections, spaced at 500 metre intervals, showing the location of nourishment simulated under Scenario 4.

One probabilistic set of (250) SCAPE simulations were run under this scenario, each with stochastic representation of:

- Cliff failure
- Structure failure
- Wave sequencing
- Rotation of the wave climate (driven by climate change)

Further descriptions of these stochastic elements can be found in Royal HaskoningDHV (2013). The resulting projections of cliff top recession were then aggregated into a histogram and the 5th and 95th percentiles were extracted, shown below.

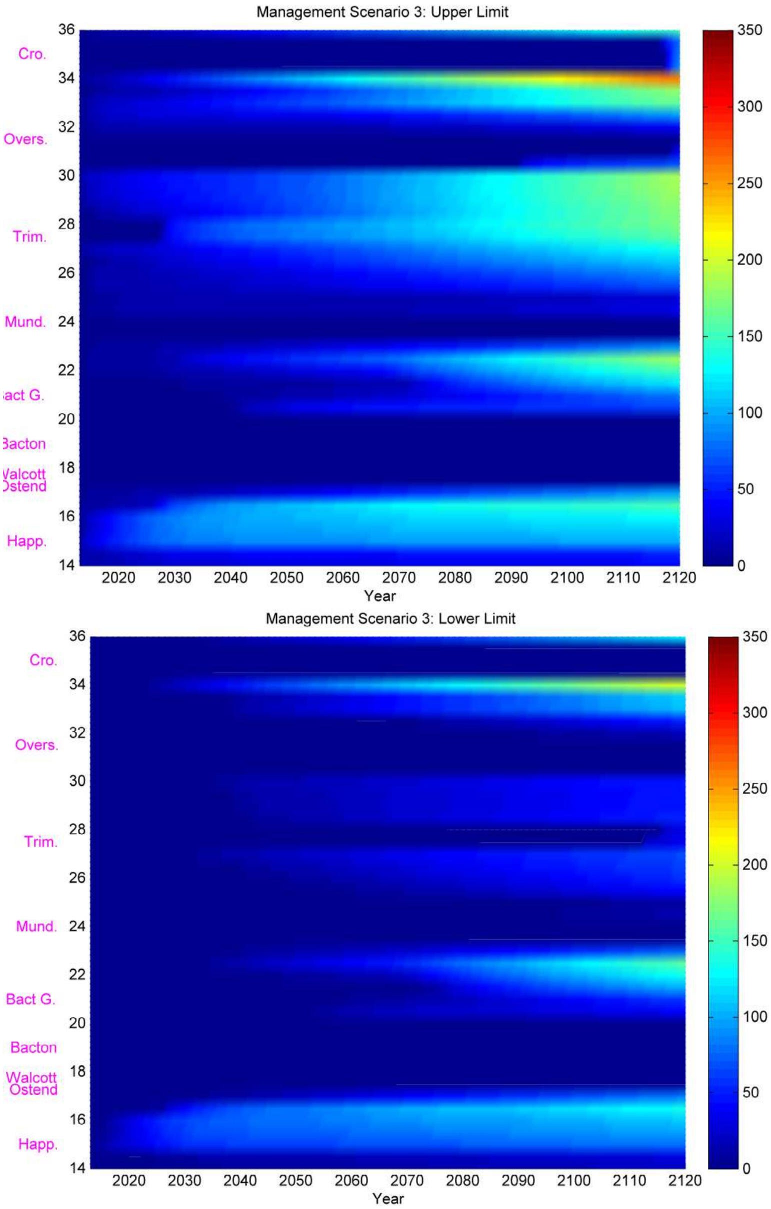

Figure 2. 5th (lower panel) and 95th (upper panel) percentiles of cliff top recession projected under MS3; colour represents recession distance in metres, the vertical axis represents distance (in km) from Winterton Ness.

In Figure 3. , the upper limits of cliff top recession distance under scenarios 2 and 3 are compared. It can be seen that, as would be expected, recession is prevented under scenario 3 where the additional 'Hold the Line' policy is implemented at Overstrand, Mundesley, Bacton and Walcott/ Ostend.

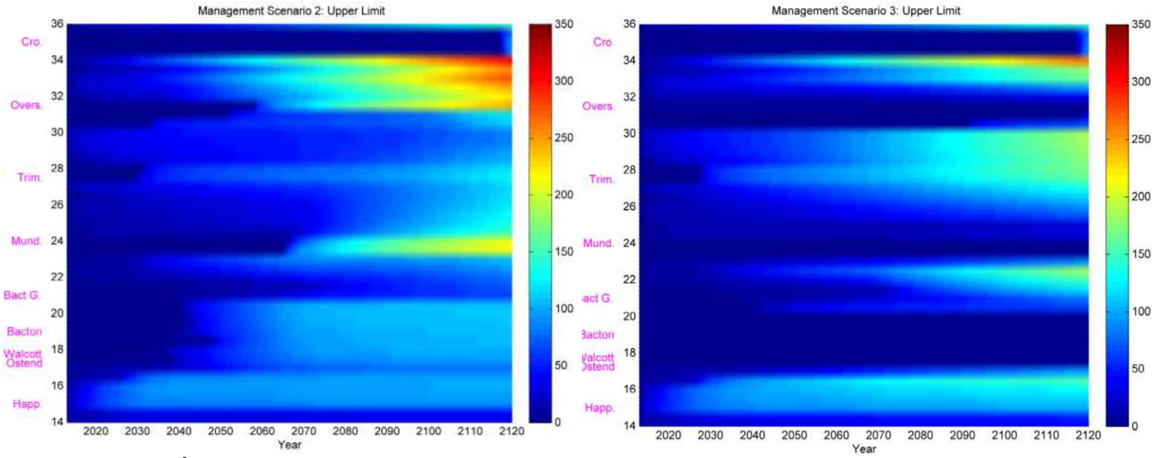

Figure 3. 95th Percentiles of cliff top recession under scenarios 2 (left panel) and 3 (right panel); colour represents recession distance (m), the vertical axis represents distance (km) from Winterton Ness.

These two simulations are also compared in Figure 4 to Figure 6, which illustrate the range in cliff top recession (5th to 95th percentiles), in different years.

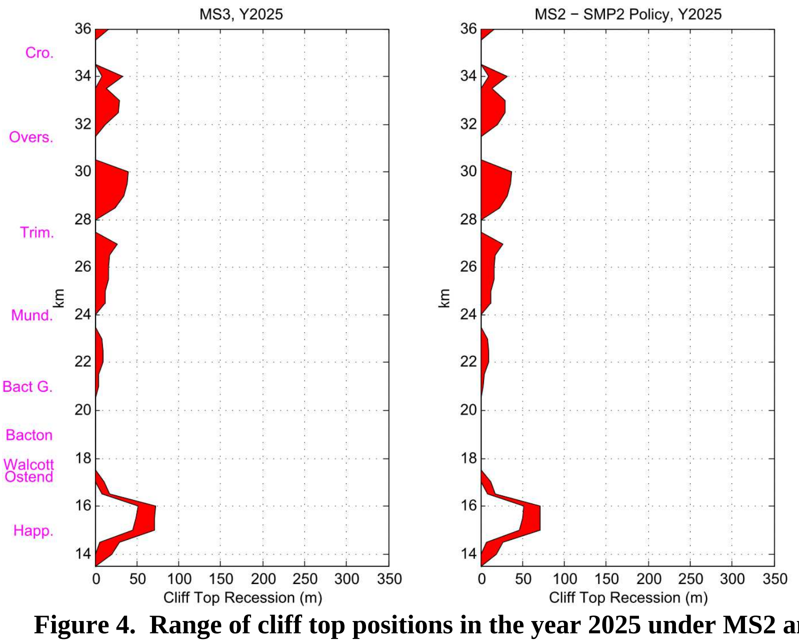

Figure 4. Range of cliff top positions in the year 2025 under MS2 and MS3

The results for 2025 are very similar, because in many locations (under scenario 2) existing structures have yet to reach the end of their residual life.

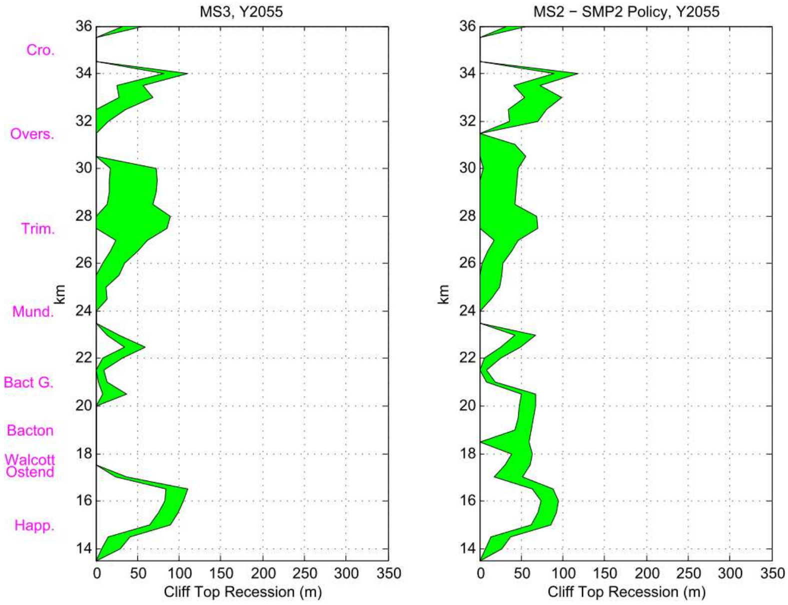

Figure 5. Range of cliff top positions in the year 2055 under MS2 and MS3

Differences are quite noticeable by 2055 (Figure 5), scenario 2 shows significant recession at Ostend, Walcott, Bacton and Overstrand, whereas under scenario 3 each of these places is protected.

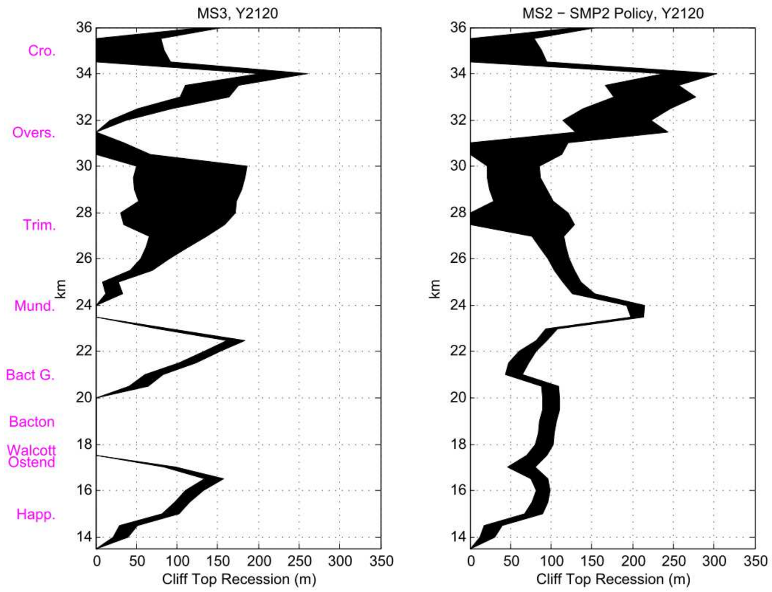

Figure 6. Range of cliff top positions in the year 2120 under MS2 and MS3

By 2120 (Figure 6) the differences are more marked. Recession is seen throughout the model south of Trimingham under scenario 2. It may be noted that although recession is prevented in at those locations defended under scenario 3, non-defended areas show significantly greater recession (relative to scenario 2). For example between Happisburgh and Ostend recession reaches around 140 m under scenario 3, but only around 100 m under scenario 2. Similarly in the Trimingham area recession reaches over 180 m under scenario 3, and only around 130 m under scenario 3. These differences may be attributed to the fact that the scenario 3 coast protection is preventing the release of sediment to the shore, which would otherwise provide benefit in reducing the recession of 'undefended' areas.

These differences in sediment release can also be seen in the sediment transport rates at Cart Gap (see Figure 7).

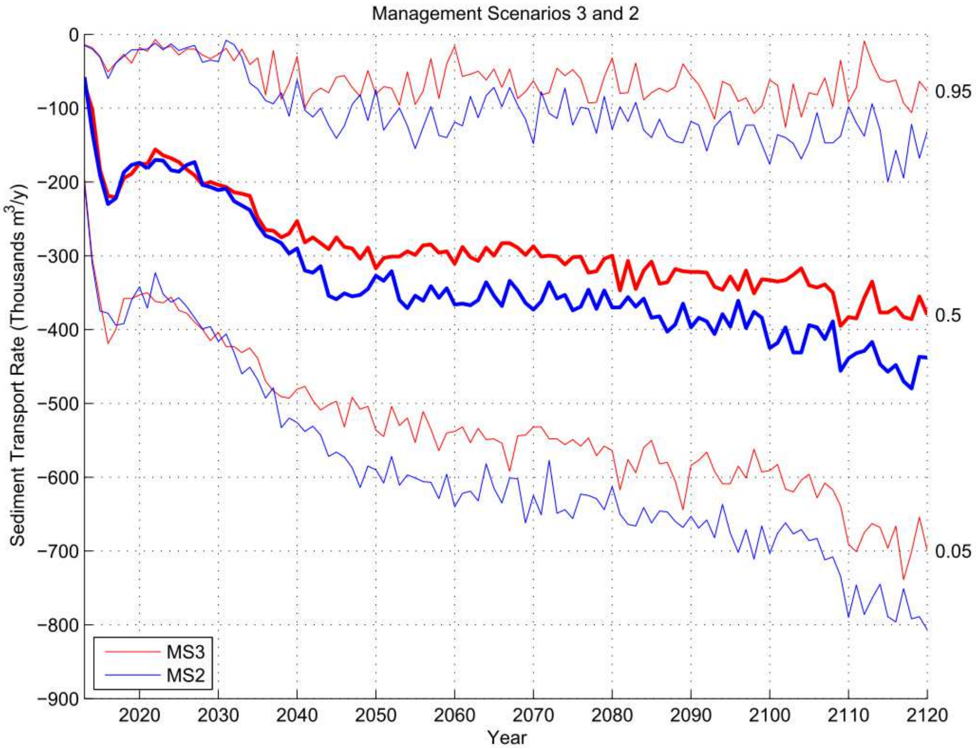

Figure 7. Sediment transport rates at Cart Gap under MS3 and MS2 at the 5th, 50th and 95th percentiles; negative values indicate transport south.

The sediment transport rates under management scenario 3 are also summarised in Table 1, and the change in transport rates, relative to scenario 2, are shown in Table 2.

Year	Percentile				
	2.5%	25%	50%	75%	97.5%
2010s	-375	-237	-168	-104	-16
2020s	-398	-260	-179	-100	1
2030s	-485	-322	-238	-157	-5
2040s	-532	-375	-283	-192	-29
2050s	-566	-398	-298	-200	-36
2060s	-577	-406	-295	-195	-17
2070s	-597	-408	-305	-206	-10
2080s	-628	-435	-324	-218	-8
2090s	-641	-443	-333	-227	-16
2100s	-647	-453	-341	-231	-6
2110s	-738	-508	-372	-241	0

Table 1. Average annual sediment transport rates at Cart Gap under Management Scenario 3 for a range of non-exceedance percentiles; thousands of cubic metres per year; negative values indicate transport south.

Year	Percentile				
	2.5%	25%	50%	75%	97.5%
2010s	3	1	3	1	-1
2020s	-2	1	4	3	5
2030s	13	21	12	10	10
2040s	75	55	53	49	29
2050s	71	56	49	49	20
2060s	86	66	61	52	20
2070s	85	66	54	53	52
2080s	71	56	51	57	58
2090s	81	64	54	52	38
2100s	100	81	74	70	88
2110s	100	82	73	85	70

Table 2. *Differences* in average annual sediment transport rates at Cart Gap between two management scenarios (MS3 minus MS2) for a range of non-exceedance percentiles; thousands of cubic metres per year.

In summary, the increased length of ‘Hold the Line’ policy under scenario 3 result in reduced cliff recession at the defended areas, increase cliff recession in some other areas, and reduced southerly sediment flux at Cart Gap.

Scenario 4
As noted above, management scenario 4 (MS4) was commissioned to explore the effects of periodic additional beach nourishment from Overstrand to Trimingham. The nourishment was

specified as comprising 100 m^3/m of beach material, at and between model sections 58-67, every 4 years, starting in 2013. This results in a volume of 0.5 million cubic metres being artificially introduced every four years. All coastal structures (seawalls, groynes and revetments and low beach level response) were represented as defined for Scenario 2 (see Royal HaskoningDHV, 2013). The location of the model sections are illustrated in Figure 1, which also shows the extent of the simulated nourishment.

To support comparison between scenarios 2 and 4, the same stochastic modelling inputs were adopted for both. These include: rotation of wave climate, wave sequence, and residual lives of the various structures. Given that scenario 4 involves additional nourishment, it was generally expected that (relative to the results of the scenario 2 simulations):

- Coastal recession rates might be reduced between Overstrand and Trimingham;
- This coast protection would extend both north and south over time; and
- Southerly sediment transport might increase at Cart Gap (implying benefit to the flood vulnerable coast south of this point).

The results presented below explore whether the model reveals such behaviour. Figure 8 illustrate the results passed (digitally) to Mott MacDonald for the assessment of the relative merits of management scenario 4.

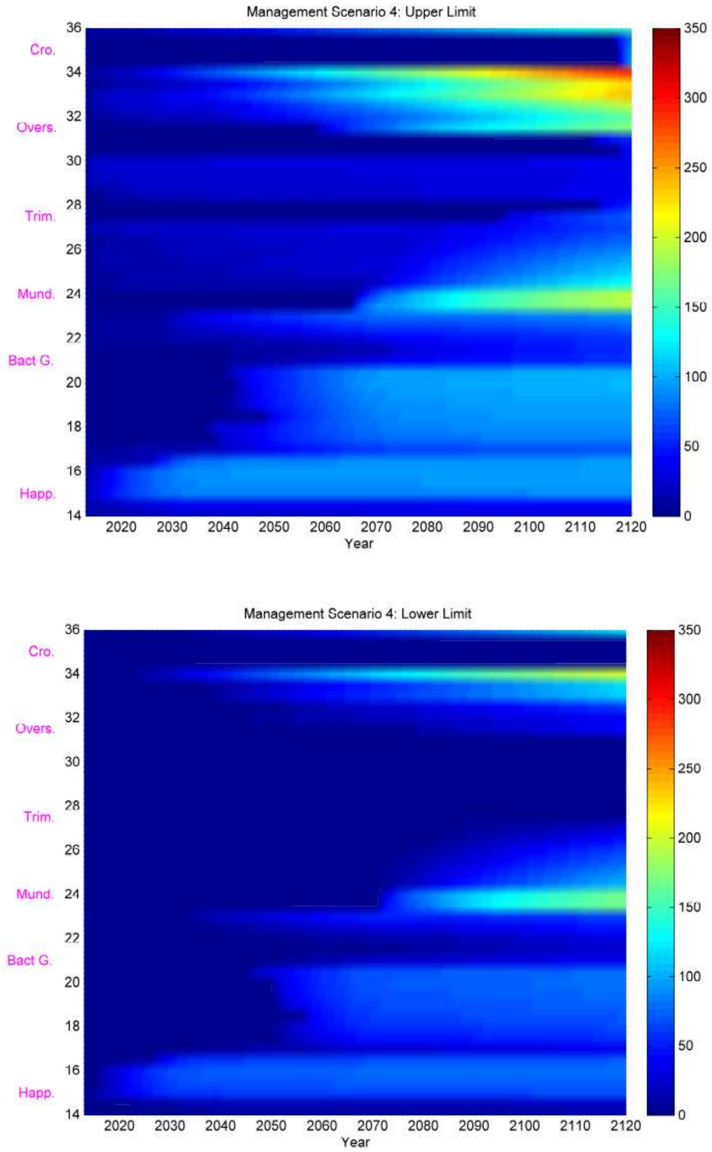

Figure 8. Cliff top recession under management scenario 4, at the 5th (lower panel) and 95th (upper panel) percentiles.

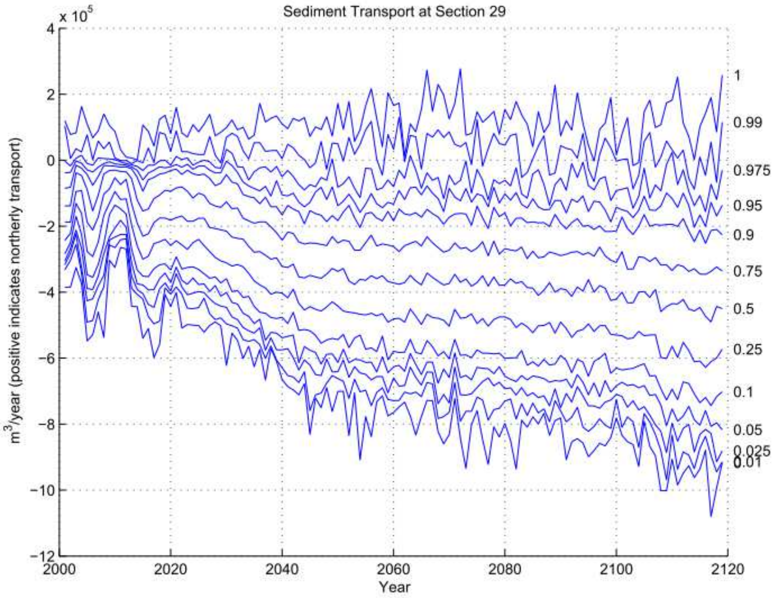

Figure 9: Sediment transport rates at Cart Gap (negative values indicate southerly transport).

A subset of these sediment transport rates are summarised (per decade) in Table 3, and the change in transport rates (relative to scenario 20, are shown in Table 4.

Year	Percentile				
	2.5%	25%	50%	75%	97.5%
2010s	-378	-238	-171	-105	-15
2020s	-396	-259	-183	-104	-4
2030s	-502	-346	-254	-169	-19
2040s	-609	-430	-338	-242	-58
2050s	-644	-459	-352	-251	-62
2060s	-672	-479	-364	-256	-48
2070s	-691	-482	-367	-266	-67
2080s	-706	-496	-381	-280	-73
2090s	-726	-511	-391	-282	-56
2100s	-753	-538	-418	-306	-95
2110s	-846	-593	-450	-331	-74

Table 3. Average annual sediment transport rates at Cart Gap under Management Scenario 4 for a range of non-exceedance percentiles; thousands of cubic metres per year; negative values indicate transport south.

Year	Percentile				
	2.5%	25%	50%	75%	97.5%
2010s	0	0	0	0	0
2020s	0	1	0	-1	0
2030s	-4	-3	-4	-2	-4
2040s	-2	-1	-2	-1	0
2050s	-7	-5	-5	-3	-6
2060s	-9	-7	-8	-9	-11
2070s	-9	-8	-8	-7	-5
2080s	-8	-5	-6	-5	-7
2090s	-5	-4	-4	-3	-2
2100s	-6	-4	-3	-5	-2
2110s	-8	-3	-5	-5	-4

Table 4. *Differences* in average annual sediment transport rates at Cart Gap between two management scenarios (MS4 minus MS2) for a range of non-exceedance percentiles; thousands of cubic metres per year.

The upper panel of Figure 8 is reproduced below, next to the equivalent figure derived from management scenario 2. Comparison between the two reveals the effect of the nourishment on (the upper limit of) cliff top recession distances.

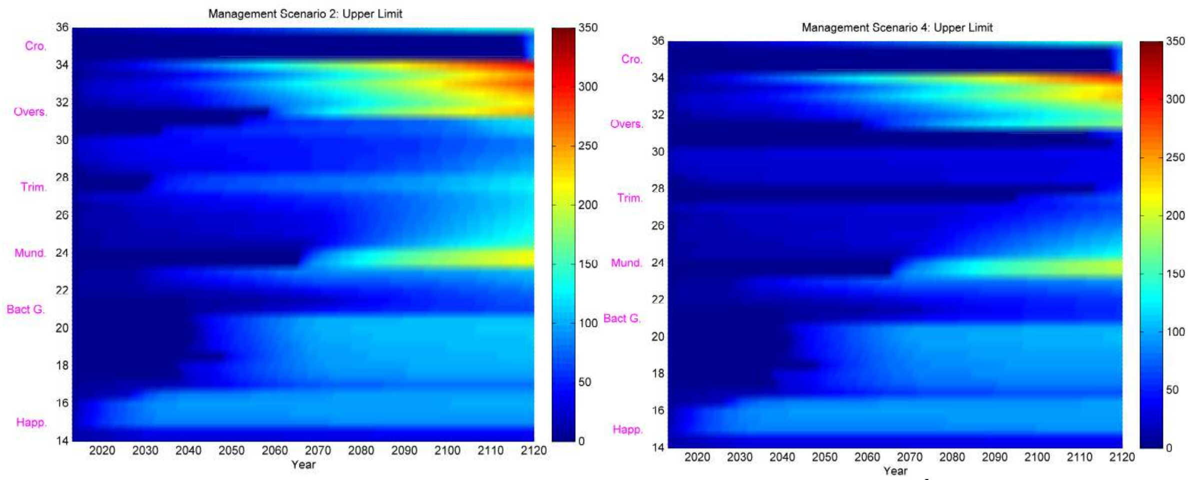

Figure 10. Comparison between the upper estimates of recession (at the 95th percentile) under MS2 and MS4; note that the locations of settlements are indicated in the left hand margin of each panel.

It can be seen that (as expected) scenario 4 exhibits lower recession in the nourishment area (Overstrand to Trimingham), relative to scenario 2. However, the additional nourishment does not appear to have a strong effect beyond this area. This impression is supported by great similarity (in Figure 11 and Table 4) between the sediment transport rates projected under scenarios 2 and 4 at Cart Gap.

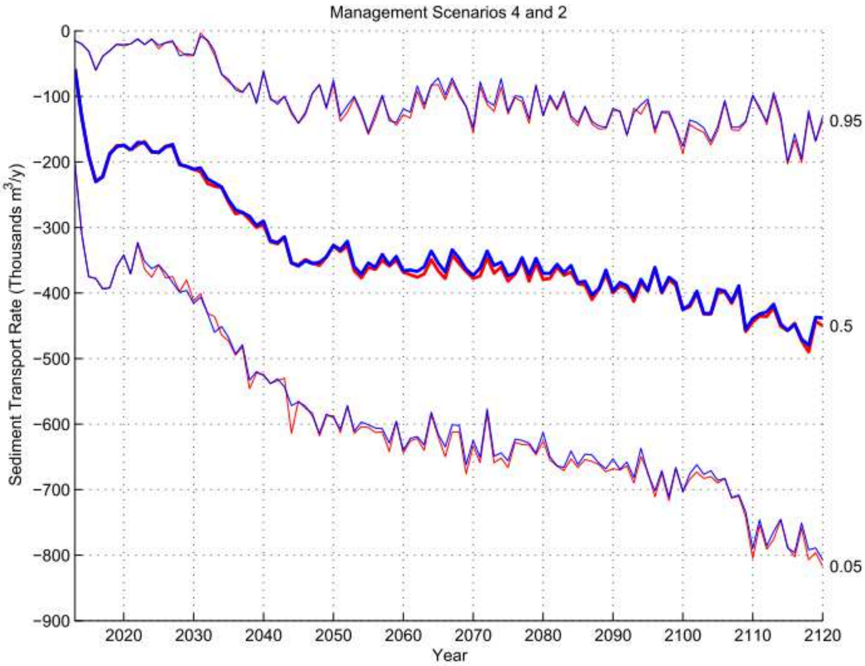

Figure 11. Sediment transport rates at Cart Gap under MS4 and MS2 at the 5th, 50th and 95th percentiles; negative values indicate transport south.

It can be seen that the sediment transport rates are very similar at section 29 for both management scenarios, throughout the simulation period, and this implies that the additional nourishment would bring little material (within a 100 year timeframe) to the beaches south of Cart Gap when compared to management scenario 2 (MS2).

To understand the response of the coast to the nourishment it is necessary to look in greater detail. Figure 12 shows the upper and lower limits of cliff top recession in 2120.

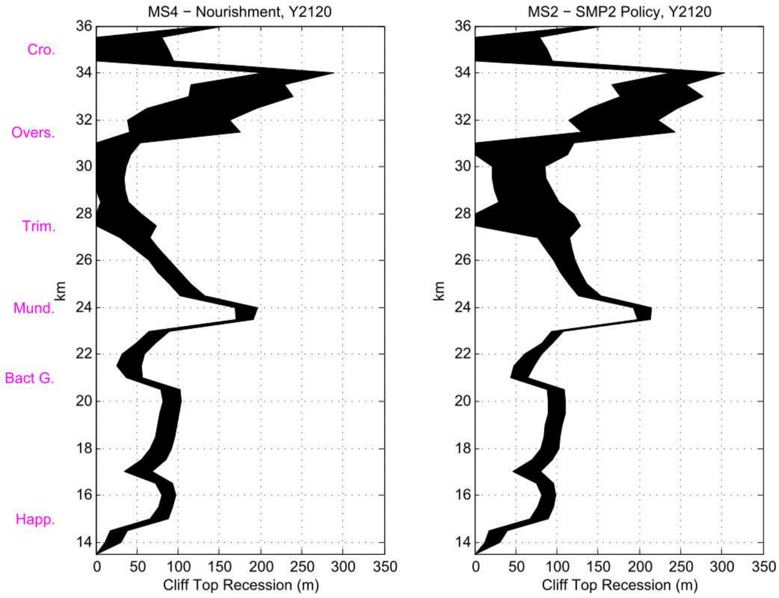

Figure 12. Range of cliff toe recession (5th to 95th percentiles) under management scenarios 2 and 4; the vertical axis represents distance from Winterton Ness.

The nourishment region (model sections 58 and 67) is located between 28 and 32 km in the graphs above. These graphs show that there is little difference in cliff toe recession at the very northern end of the model. Differences between MS4 and MS2 start to grow between around 34 km and 32 km, and are strongly expressed over the whole nourishment area. A difference in recession is evident until about 19 km; south of this point both management scenarios provide similar results.
Further detail can be revealed by examining the difference in recession shown by individual simulations that are identical except for the introduction of nourishment.

Figure 13 to Figure 15 show the difference in cliff toe recession between two such simulations, and how this develops through time. As would be expected, there is no difference between the results of the two management scenarios before the nourishment begins in year 2013. Differences then appear and increase through time. This more detailed examination reveals that differences do, in fact, occur away from the area directly nourished. By the year 2060 some coast protection benefit is observed throughout the frontage (except where structures force zero recession). In areas however, this only amounts to a few metres. By the end of the simulation period (2120) an (approximately) triangular distribution of recession difference is seen, ranging from almost 90 metres at Overstrand to around zero at Cart Gap.

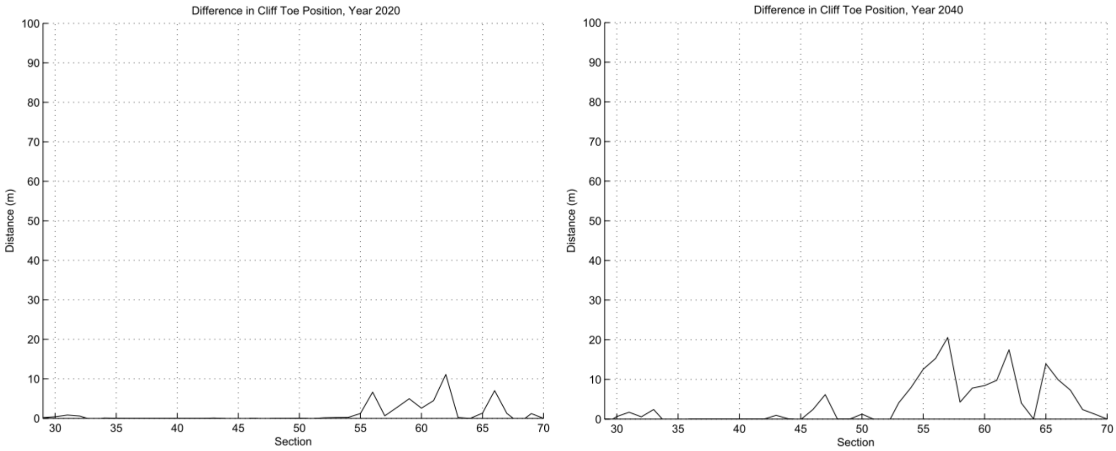

Figure 13. Difference in cliff toe position in management scenarios 2 and 4 in years 2020 and 2040.

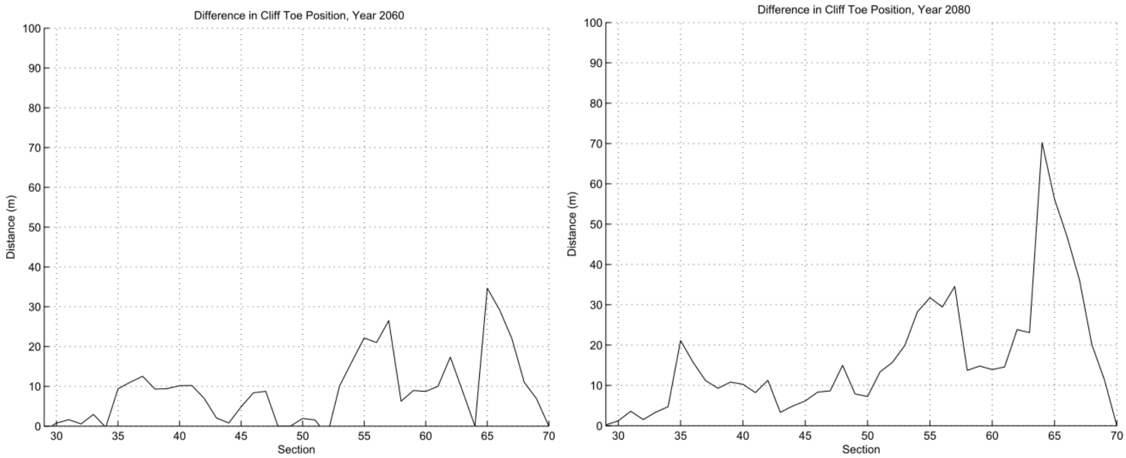

Figure 14. Difference in Cliff toe position under management scenarios 2 and 4 in years 2060 and 2080

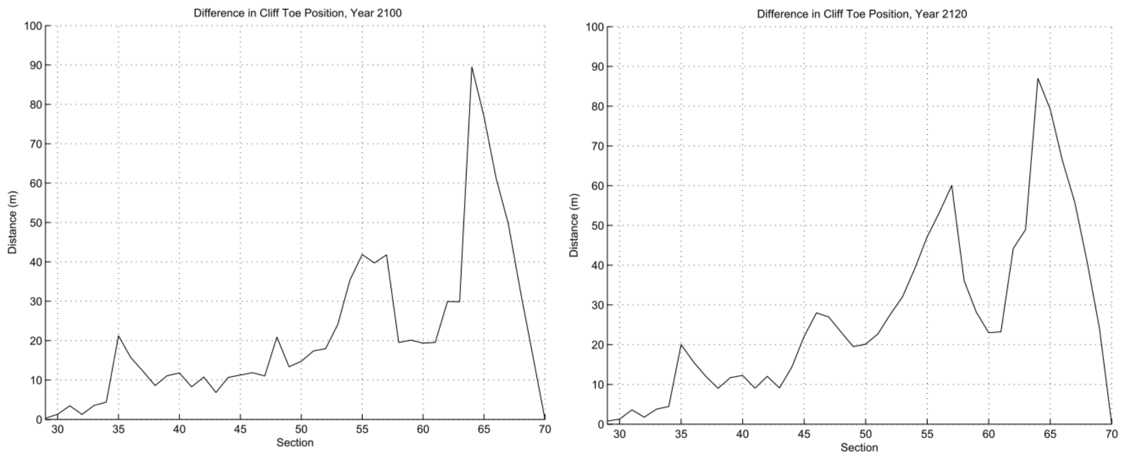

Figure 15. Difference in cliff toe position under management scenarios 2 and 4 in years 2100 and 2120.

Although the nourishment material does have an effect away from area nourished, the reduction in cliff recession rates is much less in these areas. To understand why, it is necessary to examine the beach volume, which plays an important role in linking the nourishment to cliff recession rates. An example taken from the centre of the nourishment area (model section 63) is shown in Figure 16.

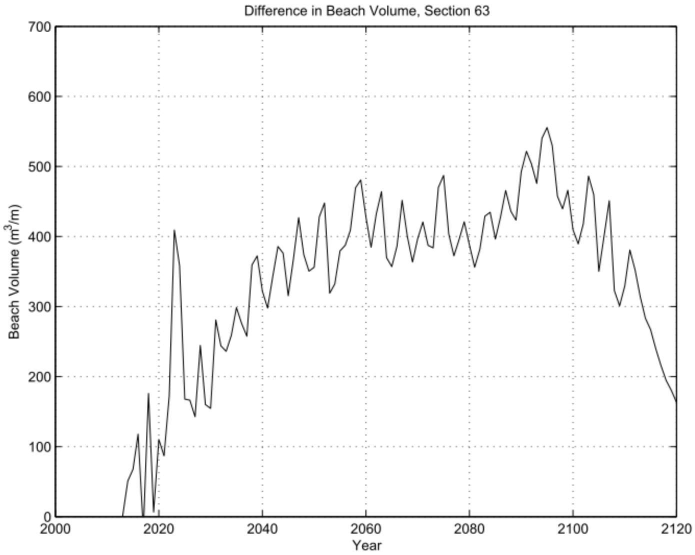

Figure 16. Difference in beach volume between scenarios 2 and 4 at model section 63 (in cubic metres per metre of coast); note that positive values indicate greater volumes under MS4.

At the start of the simulation, before nourishment occurs, there is no difference in beach volume at model section 63 between scenario 2 and scenario 4. The first nourishment event occurs in 2013, and this is revealed as a spike in volume difference at this time. A series of subsequent spikes are then driven by the later nourishment events, every four years. Overall the beach volume is, of course, greater under scenario 4 than under scenario 2.

It may be noted that although each nourishment event involves the addition of 100 m^3/m of shore (in the nourishment area) over a period of one year, the increase in beach volume at Section 63 under scenario 4 (relative to scenario 2) by the end of year 2013 amounts to less than 51 m^3/m.

This difference in quantity of sediment on the beach and quantity introduced from the cliffs does not appear to be due to diffusion of sediment along the coast (which seems to occur at a low rate, as indicated above). Instead it appears to result from the reduced cliff recession caused by the nourishment. In effect a significant proportion of the nourished volume is negated by the coast protection benefit it provides.

Some difference in beach volume is found south of the nourishment area. For example at model section 45 (a position south of Mundesley) the difference in beach volume eventually grows to around 90 m^3/m, but even this modest increase is quite variable until around 2080 (as can be seen in Figure 17).

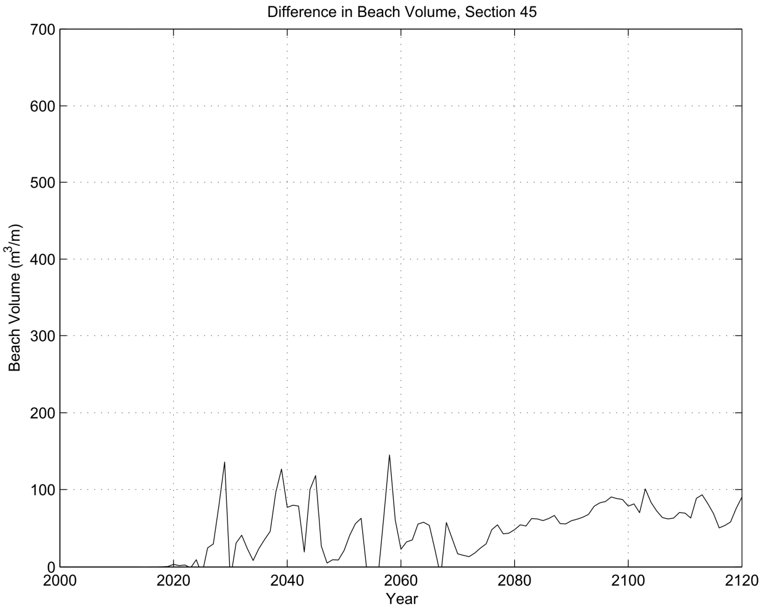

Figure 17. Difference in beach volume at section 45 (south of Mundesley).

North of the nourishment area the difference in beach volume is even smaller. Figure 18 shows the difference in beach volume caused by the nourishment at Cromer (Section 70). Very little change can be seen.

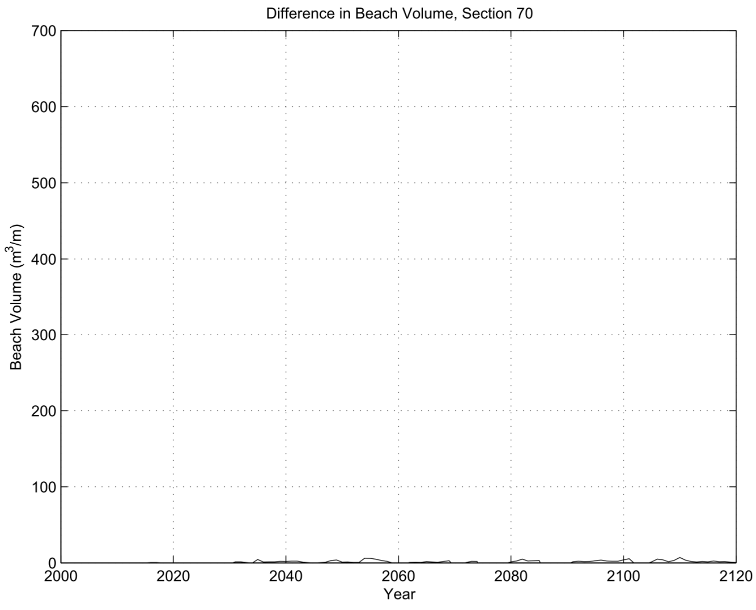

Figure 18. Difference in beach volume at Section 70 (Cromer).

The overall difference in beach volume between the two scenarios (for the single simulation examined) can be seen in Figure 19.

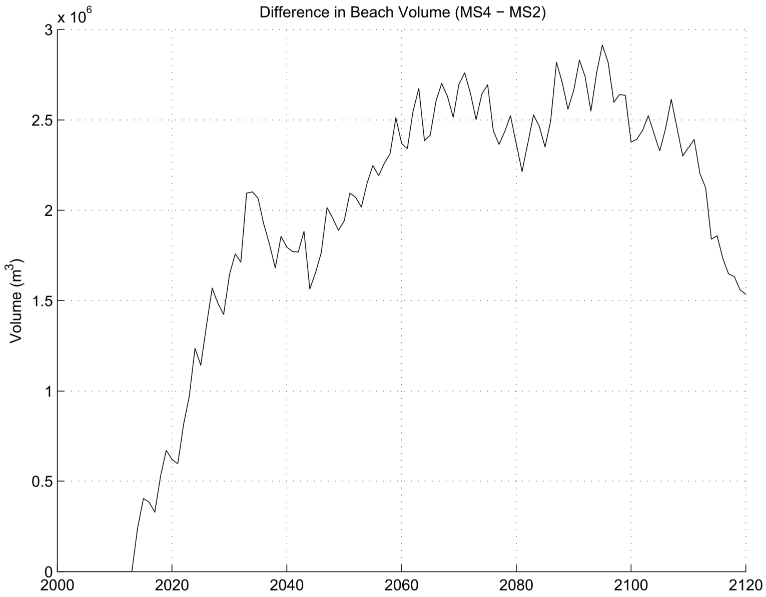

Figure 19. Difference in total beach volume throughout the model caused by the nourishment.

By 2100 a total of 25 nourishment events have occurred, providing a total of 12.5 million cubic metres of sediment. Very little of this increase has been lost alongshore, and yet there is only an increase of around 2.5 million cubic metres in the overall volume of the modelled beach. In other words, only around one fifth of the nourishment volume is expressed as in increase in beach volume.

Summary and Discussion

Under management scenario 4 a total of 12.5 million cubic metres of beach material is introduced to the coast over one century in comparison to scenario 2. This boosts beach volumes along the study area by around one fifth of this volume, protecting the cliff in nourished areas; the remaining quantity appears to be negated by reductions in cliff and shore platform recession rate in nourished areas.

These reductions in recession rate appear to spread through the model quite slowly, and are most strongly expressed in the area where the nourishment is introduced. In addition, the differences in (generally southerly) sediment transport at Cart Gap are very small. These observations suggest that rates of diffusion of the nourishment material are low, and so the nourishment to the north may not reduce the need to nourish in the Sea Palling area over the coming century compared to scenario 2.

Such low diffusion rates may be surprising, given, for example, the speed (around 0.8 km/ year) with which large scale sand waves have been observed to propagate south along the coast from the Mundesley area (which the SCAPE model is known to capture quite well). The speed of these sand waves seems to imply that once nourishment material reaches the area south of Mundesley it would only take a further (circa) ten years to reach Cart Gap, and move south to the coastal flood vulnerable frontage.

To understand such diffusion, it is necessary to consider the processes that drive it. In the broadest terms, alongshore sediment transport is driven by the difference between the shoreline angle, and the angle of wave attack. Changes that increase this angle (within limits) tend to increase sediment transport rate. Therefore to increase transport of sediment it is necessary to (1) ensure that sufficient sediment is available and (2) change the shoreline angle (assuming an unchanging wave climate). Management scenario 4 appears to achieve (1) but not (2).

Within the 5 km of coast along which the beach was nourished, the rates of nourishment were uniform, implying little or no change in beach shoreline angle. The added material would influence shoreline angle at the ends of the area of nourishment, but the scale of change would seem to be small. The nourishment rates amounted to 100 m^3/m over a one year period, and that this seems to be reduced by at least one half by falls in the supply of beach material from the cliff. This leaves (at most) around 50 m^3/m of additional material across the beach face. If the beach width is assumed to be of the order of 200 metres, then a change in beach level of only 0.25 metres is implied. This suggests relatively small changes in the alongshore transport rate and in this context, low rates of diffusion of the nourished material are not surprising.

It may be noted that this argument presupposes that the system is not starved of sediment under the ‘baseline’ condition (in this case represented by management scenario 2). This is indeed the case because management scenario 2 involves the progressive failure of significant lengths of coast protection structures (and therefore the release of large volumes of sediment currently sealed within the cliff). Greater diffusion of nourished material might occur if the ‘baseline’ management tended to ‘starve’ the system of sediment, through the maintenance of more extensive coast protection structures. However, under such a condition, there may be greater tendency for beach sediment to be held within the artificial headlands created by such management, and this may act against diffusion of the nourished material.

Reference

Royal HaskoningDHV (2013) Appendix C: SCAPE Modelling of Shore Evolution: Cromer to Cart Gap.