Joint Defra / Environment Agency Flood and Coastal Erosion Risk Management R&D Programme

Practical aspects of executing renourishment schemes on mixed beaches

Science Report - SC030010

Product Code: SCHO0608BOFD-E-P

Environment Agency

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Department for Environment
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Executive summary

Mixed sand and shingle beaches are a common component of coastal defences in the UK, comprising over one-third of all beaches in England and Wales and almost all the beaches on the south coast of England. The majority of these beaches demonstrate erosive tendencies, consequently replenishment and recycling schemes have become commonplace in order to maintain an adequate level of defence. Practical beach experiments were conducted at two recently replenished sites in the southeast of England – Hythe to Folkestone and Tankerton – to monitor beach evolution and the suitability of future recycling operations.

In 2004, the final phase of a beach replenishment at Tankerton was completed, by Canterbury City Council (CCC), adjacent to the previous phases completed in 1999. The main aim of the experiment was to monitor intensively the different beach types and to determine relative changes with time. This was not done in isolation but in conjunction with monitoring the adjacent more mature beach. To this end, five groyne bays were filled with significantly different material: locally recycled, very fine, very coarse, an experimental cap and a standard replenishment mix. For each of the five groyne bays, the experiment involved comparing beach profile/plan response, beach sediment changes, and changes to the position and response of the water table within the beach itself.

Experimental bays at Tankerton highlighted the difference in beach performance that can result from a range of replenishment materials subjected to the same physical processes (tides, waves, structure arrangement and coastal orientation). In practical terms, the difference in performance between the fine and coarse sediments is more significant than originally thought, not only with regards to the initial losses over the first three years, but also in terms of the presence of undesirable effects such as cliffing, reduction in stable beach gradient, berm erosion and seaward migration of the beach toe. It is concluded that the extra expense of sourcing coarser material is often justified by the improved performance, reduced erosion rates and longer scheme life.

Since the completion of the first Hythe Coast Protection Scheme in 1996, Shepway District Council (SDC) has been managing an annual beach recycling operation to maintain design beach profiles along a 9km frontage. The relatively uniform alignment and bathymetry of the Hythe to Folkestone frontage suits a managed open beach arrangement and this has proved successful in providing a ‘soft’ defence in front of the old seawall. Following the completion of the 2004 Hythe to Folkestone Harbour Coast Protection Scheme, a Department for Environment, Food and Rural Affairs/Environment Agency research and development programme was established to identify methods for optimising beach recycling operations through managed improvements to beach recycling practises. This has provided information on how to create long-term cost savings and how to improve the design of the beaches, thereby allowing them to respond more effectively to storm events.

Results from the Hythe coast protection scheme recycling experiments demonstrated that an optimal recycling frequency of twice a year provided the most suitable balance between cost and beach defence standard. More significantly, it concluded that key savings could be made by altering the method of placement. By placing the replenishment material to a design height only and allowing the beach to sort naturally, foregoing the labour-intensive re-profiling and supervision, the duration and cost of recycling operations could be significantly reduced. It was concluded that, given the speed at which the beach evolved, this was not to the detriment of the aesthetic or amenity qualities of the beach and now forms an established methodology for recycling at this site.

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Shepway District Council

Contents

Figures

Tables

Abbreviations

CSA	Cross-sectional area
Defra	Department for Environment, Food and Rural Affairs
DTM	Digital Terrain Model
GPS	Global Positioning System
Hs	Significant wave height
HAT	Highest Astronomical Tide
RTK	Real Time Kinematic
MLWN	Mean Low Water Neap
SANDS	Shoreline and Nearshore Data System
SDC	Shepway District Council
SRCMP	Strategic Regional Coastal Monitoring Programme

1 Introduction

1.1 Background

Mixed sand and shingle beaches are a common component of coastal defences in the UK, comprising over one-third of all beaches in England and Wales and almost all the beaches on the south coast of England. The majority of these beaches demonstrate erosive tendencies; as a consequence, replenishment and recycling schemes have become commonplace in order to maintain an adequate level of sea defence.

Over the period 1995–2005, the average amount of sand and shingle dredged each year for beach recharge was almost 2.5 million tonnes, of which about 70 per cent was sand and about 30 per cent shingle (Brampton *et al*. 2007). This equates to 7.5 million tonnes of shingle over this 10-year period alone. Given sea level rises and a predicted increase in the frequency and intensity of storms, this amount will increase if current beach management practices are maintained.

Shingle is readily available from a number of areas: typically offshore dredge sites but also potentially locally-sourced and recycled material. This material can vary markedly in terms of its composition, cost and subsequent beach performance. Historically, coastal managers have, where possible, made an effort to acquire material with a similar composition to the native beach. Due to cost and availability constraints, this is often not feasible, typically resulting in material with a finer grading envelope.

Finer material can cause a number of problems. These include, but are not limited to:

higher initial loss rates;

increased longshore transport;

shallower stable beach gradient;

cliffing of the beach face (McFarland *et al.* 1994);

and uncertainty regarding the long-term lifespan of the scheme.

Overfill ratios have been available for years (SPM 1984), allowing engineers to calculate the extra volume of finer material required to produce a performance that is equivalent to the desired recharge grading curve. These ratios were developed for sandy beaches and their application to mixed shingle beaches in the UK has not been adequately validated.

At present, an appraisal of the performance of different sediment grading statistics is hard to obtain for recent replenishment schemes. This is due to the plethora of other contributing factors, such as different hydrodynamic climates, coastal orientation, beach shape, controlling structures, sediment supply and others. The problem is further compounded by limited data availability on replenishment composition, especially the evolution of the 'new' beach.

1.2 Project aims and objectives

At many locations around the coastline of England and Wales, a shingle beach forms an important first line of defence as the front component of the flood or coastal defence system – dissipating energy and also providing some element of amenity. At some locations, the beach may be a natural feature. At many other locations, a new beach may be created, or the existing beach nourished, by importing shingle from other sources, principally from offshore sites.

To optimise the benefits of this investment, the nourished beach has to be carefully designed and effectively managed over the long term. Design parameters that need to be assessed include the size grading of the imported shingle, the volume required and the profile of the resulting beach. Management options may include: re-profiling after winter storms; re-cycling of beach materials in the longshore direction; or periodic re-nourishment. Some guidance on these aspects is contained in CIRIA's Beach management manual, but there are no definitive rules. For some schemes, it may not even be possible, for economical or practical reasons, to follow the general guidelines. Consequently, many beach nourishment schemes are designed and managed by a process of experimentation, based on local conditions.

In the summer of 2004, two significant beach nourishment schemes were scheduled for the coastline of Kent – one at Tankerton in north Kent (managed by Canterbury City Council) and the other at Hythe in south Kent (managed by Shepway District Council). At both sites, some novel aspects of beach design and beach management were tested, with a view to reducing both the capital and maintenance costs of beach nourishment schemes. Both schemes were funded through the normal procedures for flood and coastal defence works, and were carefully monitored to check that they fulfil local requirements.

This research project utilised these two ongoing beach nourishment schemes to carry out more detailed measurements and monitoring at both sites. This made it possible to derive results that are generally applicable to all beach nourishment operations.

The **overall objective** of this research project was to investigate various methods for improving the cost-effectiveness of beach nourishment and beach management schemes, based on a detailed analysis of two ongoing beach nourishment schemes in Kent. The specific objectives are detailed below.

Specific objectives

To investigate the long-term performance of nourished beaches in cases where the imported shingle contains a higher proportion of fines than is naturally stable for the beach. This aspect was studied at the Tankerton site and two different methods for placing the imported shingle were tested.

To examine a number of different elements in the beach recycling process, including alternative placing of beach materials at the deposition area. These aspects were studied at the Hythe site.

To compare the performance of existing and newly-renourished beaches. This aspect was studied at both sites.

To analyse and present the results in a manner that allows them to be used generally for the design and maintenance of cost-effective beach nourishment schemes.

It is anticipated that the suggestions for improved beach nourishment practices developed during this project will lead to a wider knowledge of the benefits of adopting particular methodologies when carrying out beach recycling. This knowledge can be utilised by coastal managers and designers nationwide.

The ultimate aim of this project is, through improved beach nourishment, to enhance the performance of beaches, assist in prolonging their serviceable life and reduce the costs of nourishment where possible.

To increase dissemination, the outputs from this project will feed into the ongoing revision of CIRIA's *Beach Management Manual*.

2 Study sites

2.1 Tankerton

Tankerton in north Kent (Figure 1) is a typical erosive mixed shingle and sand beach, stretching from Whitstable harbour to the mouth of the Swalecliffe Brook. Two-thirds of the length of this beach was renourished in 1998–99 (Phase I & II), with the remaining length of beach receiving renourishment in spring/summer 2004 (Phase III).

Figure 1 Aerial view of Tankerton coastline, north Kent

The coast is subjected to a tidal range of 4m and has an established storm threshold of 1.6m Hs (significant wave height) for waves measured 1km offshore. In an average year, this will be exceeded a few times during the most severe storms.

For economic and availability reasons, the Phase I renourishment material provided to Tankerton contained a higher proportion of fines than is naturally stable on the beach. This meant that there was a high degree of uncertainty about both the anticipated losses of sediment and beach performance. Traditional methods for calculating overfill ratios were employed, but recognition was given to the fact that these ratios were originally derived for sand beaches.

A broad array of monitoring methods were utilised to monitor the evolution of the new beach. These included regular topographic surveys and sediment sampling at different depth intervals throughout the beach. Significantly, the results demonstrated that the beach composition evolved over the first year of monitoring towards the initial native characteristics (see Table 1). This was coupled with higher than anticipated initial loss rates, mainly comprising finer material, and problems with beach performance.

Table 1 Sediment statistical summary for Phases I & II

Sediment sample	Percentage composition (%)		
	<5mm	**5–10mm**	**>10mm**
Borrow material	**39**	**18**	**43**
Sep 1999	**30**	**22**	**48**
Oct 1999	**31**	**22**	**47**
Jul 2000	**25**	**20**	**55**
Pre-nourishment	**20**	**18**	**62**

2.2 Hythe

The Hythe to Folkestone frontage is located on the south Kent coast and has been defended since the middle of the 19th century. The net littoral drift of shingle is eastwards, but the natural supply from the west has recently been declining. The continued loss in beach volume has caused beach levels in front of the seawalls to drop. As a result of this ‘coastal squeeze’, the 7km of seawalls that protect close to 3,000 residential properties have been subjected to considerable wave attack. The frontage has frequently suffered localised flooding and the seawalls, which are in a poor state of repair, have failed on numerous occasions.

2.2.1 The Hythe Coast Protection Scheme (1996)

On 30 July 1993, Shepway District Council (SDC) formally launched the Hythe Coast Protection Scheme. This addressed the need to improve coastal defences along the 5km stretch of coastline between the Hythe Ministry of Defence firing ranges and the village of Sandgate. At this time, the only protection provided to the seawall was from a relatively low and unstable beach held by a series of timber groynes (long coastal defence structures that run perpendicular to the shoreline), which were in a poor state of repair. The condition of the coastal defences was such that within the following five years frequent breaches were likely, potentially resulting in extensive inland flooding and erosion of the coastline (see Figure 2).

Figure 2 Photograph showing extensive coastal flooding at Sandgate – pre-coast protection scheme

2.2.2 Options considered

SDC commissioned a detailed study of the geomorphology and processes acting along the coastline. Engineers examined various strategies through the use of user-groups, taking into consideration the associated technical, economic and environmental concerns. It was concluded that the optimum defence option would be a large scale beach re-nourishment, coupled with the installation of rock structures perpendicular to the shore.

The preferred option – beach recharge and rock structures

The preferred option involved the construction of two rock groynes and the recharge of the protective shingle beaches. Due to the predominant south westerly winds, the net littoral drift of beach material is west to east. The rock groynes perform the dual function of restricting the movement of the mobile beach material, as well as acting as a collection point for the redistribution of the shingle.

Construction Works

Due to the specialised nature of the required construction works, and to make administration easier, the project construction was carried out in two phases under separate contracts.

Phase 1

The first phase of the works was carried out by Costain Civil Engineering Limited. Work commenced on site in August 1994 and consisted of the construction of two rock groynes at Twiss Road and Battery Point. These structures, orientated at right angles to the sea wall, each comprised a 6000m^3 core of filter rock, with the individual rocks ranging from 60kg to 1 tonne in weight. This was overlaid by two layers of armour rock totalling 10,000m^3 and weighing 3–9 tonnes per piece. The groynes are 135m long and tapered both horizontally and vertically (see Figure 3).

Figure 3 Photograph of a typical rock groyne along the Folkestone to Hythe frontage

Phase 2

For the second phase of the works, Ham Dredging Ltd was appointed to carry out the beach replenishment. This contract required placing 1.25 million m^3 of shingle delivered by the sea. These works were completed by the end of September 1996 (see Figure 4).

Figure 4 Photograph of a typical rock groyne along the Folkestone to Hythe frontage

Ongoing beach management programme & beach monitoring

Following the successful completion of the Hythe Coast Protection Scheme in 1996, SDC established a beach profile database. This database was populated by data produced by regular beach monitoring surveys carried out using Real Time Kinematic Global Positioning System (RTK GPS) surveying equipment.

From the results of the beach surveys, it was confirmed that a programme of annual beach recycling was required. This was carried out between the two new rock structures in order to counteract the littoral processes that transport beach material from the west of the frontage to the east. This ongoing beach management was an integral part of the scheme and essential in maintaining a 1-in-200-year standard of protection.

The Hythe to Folkestone Harbour Coast Protection Scheme (2004)

Following the success of the 1996 Hythe Coast Protection Scheme, the open managed beach philosophy was recommended in the 2001 Folkestone to Rye Coastal Defence Strategy study. This was the preferred option for raising the standard of protection along the entire 7.5km length of Management Unit 20 (Hythe to Folkestone). In March 2004, work commenced on the Hythe to Folkestone Harbour Coast Protection Scheme, funded by the Department for Environment Food and Rural Affairs (Defra).

Construction detail

A highly successful partnering contract between SDC and a specialist marine contractor, Van Oord, was undertaken to improve the deteriorating sea defences along the frontage. The project included the construction of five new rock groynes, utilising 210,000 tonnes of rock armour imported from Norway. Additionally, 380,000m^3 of shingle was pumped ashore in order to replenish the diminishing beaches.

At Folkestone, it was decided to construct two static equilibrium bays, formed by a large rock headland structure and two smaller rock structures (see Figure 5), which were in-filled with beach material. Work on the scheme was completed in September 2004.

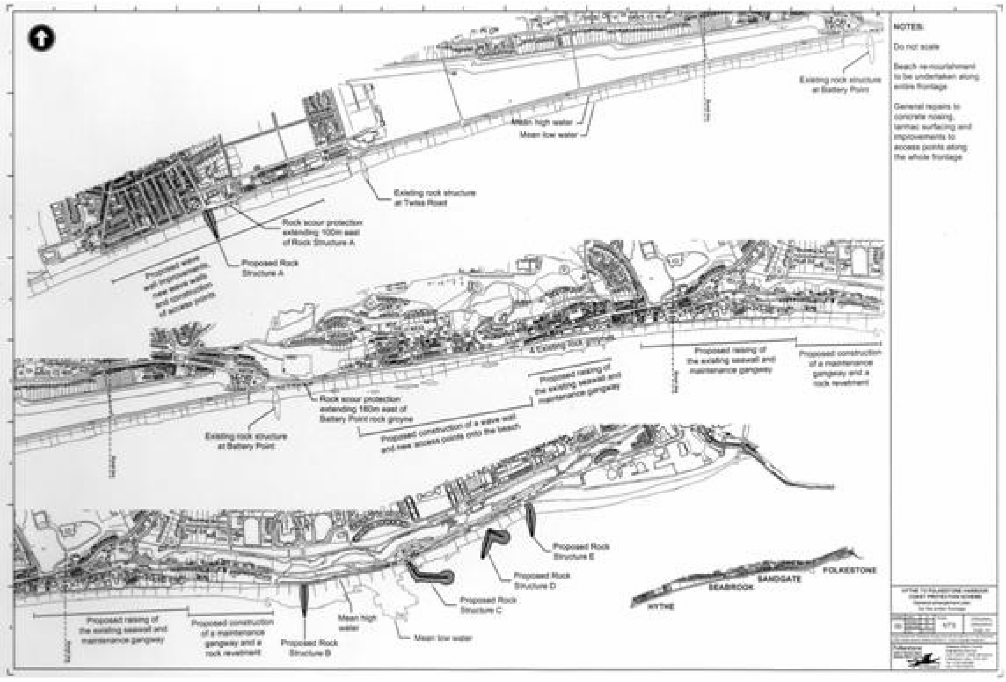


Figure 5 Location drawing highlighting the new rock structures in the 2004 Hythe to Folkestone Harbour Coast Protection Scheme

The results of the project have been outstanding. The finished scheme, as shown in Figure 6, won several engineering awards and SDC received the Society of Procurement Officers Award for Outstanding Achievement in Local Government Procurement for 2004. What was once an area under-utilised by the public has now been transformed into an area frequented by visitors and local residents alike.

Figure 6 Photograph of the finished scheme at Folkestone

Ongoing monitoring

The RTK GPS techniques used to monitor the beaches following the 1996 Hythe Coast Protection Scheme have continued to evolve and improve. In 2003, the Defra-funded Strategic Regional Coastal Monitoring Programme (SRCMP) was launched. In addition, SDC, along with New Forrest District Council, Canterbury City Council and the

Environment Agency, have helped to develop the use of GPS surveying techniques, allowing cost-effective monitoring of beaches in the southeast of England.

As well as providing data on beach profiles, both volumetric changes and bathymetric survey data have also been collected as part of the SRCMP – all of which have been utilised during the research project. In addition, a Datawell directional wave rider Mk III buoy was deployed in July 2003 (located just over 1km offshore on the 12mCD contour), providing real time wave data streamed over the internet.

3 Tankerton renourishment scheme

3.1 Methodology

3.1.1 Experimental bays

In order to build on the results of the Phase I monitoring, a section of the coastline was designated as a field test site. This comprised six 40m-wide groyne bays, each of which was filled with a different renourishment material (see Figure 8). The proposed material is detailed in Table 2.

Table 2 Sediment composition of experimental groyne bays

Groyne bay	D_{50}	Description
Control	**12–14mm**	Established test bay from previous replenishment (Phase I)
Bay 1	**12–14mm**	Recycled material from adjacent coastline
Bay 2	**18–20mm**	‘Coarse’ replenishment from Owers Bank
Bay 3	**6–8mm**	‘Fine’ replenishment from Hastings Bank
Bay 4	**Mixed**	Standard replenishment capped with coarse native material
Bay 5	**14–16mm**	Standard replenishment

Note: The term D_{50} represents the average particle size.

With the exception of the control bay on the mature beach, all bays were replenished within a week of each other as part of the Canterbury City Council Tankerton sea defence scheme. As the composition of dredged shingle can vary dramatically depending on the dredging location, a grading envelope was included in the contract specification to define the limits of acceptable material.

Figure 7 Dredged shingle delivered by barge

In order to verify that the shingle complied with the grading envelope, each barge load was sampled a minimum of three times at different locations. These samples provided an indication of the sediment statistics for each groyne bay, which would form the basis of all future analysis. The test bays were replenished and re-profiled to the design beach gradient in the last week of May 2004, with the scheme being completed and officially opened in September 2004.

Figure 8 Location of experimental groyne bays

Recycled material (Bay 1)

Historically, shingle has been recycled from the spit at Long Rock and used to replenish erosive parts of the coast to the immediate east and west. This material was used to fill bay 1; samples of the material indicated that it had a D_{50} of 14mm with a reasonably low fine content.

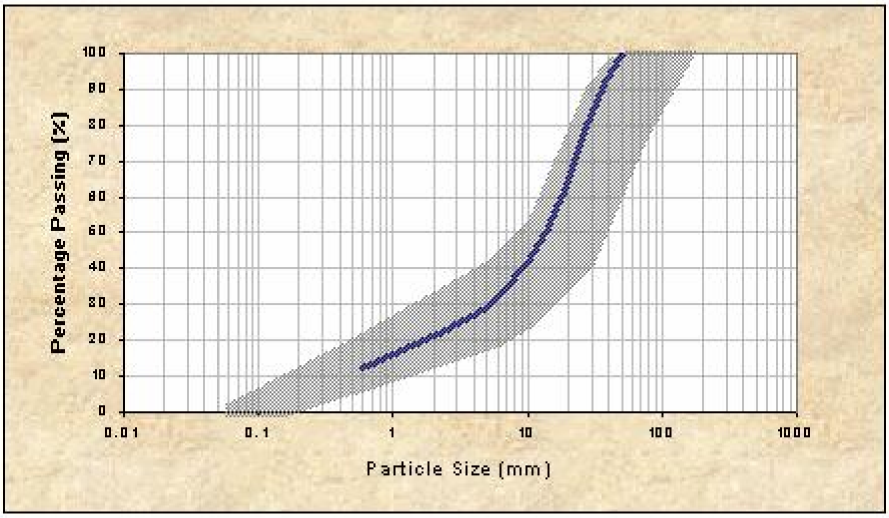


Figure 9 Grading envelope – recycled material (grey polygon = contract grading envelope; blue line = shingle sample).

Fine material (Bay 2)

For the purposes of the experiment, bay two was filled with fine material that did not conform to the contract grading envelope. It was sourced from Hastings Bank, with more than 40% composed of material with a diameter less than 1mm. This material had a D_{50} of 6mm.

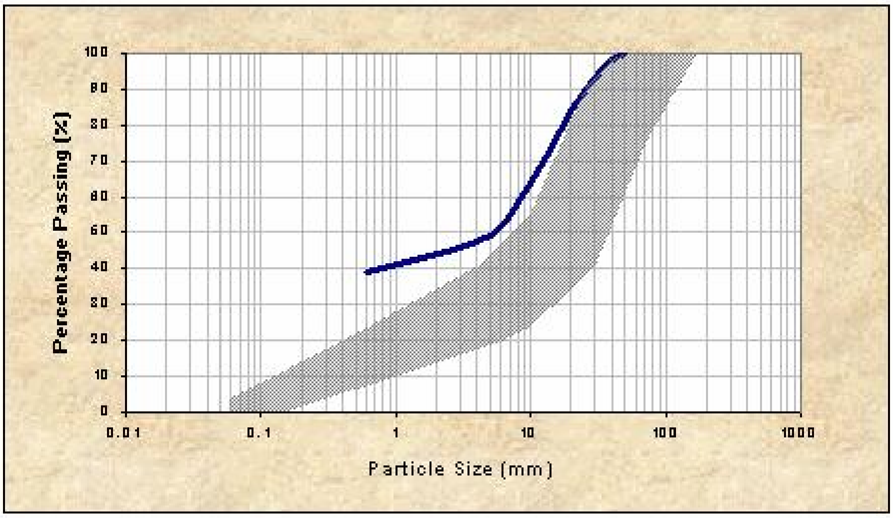


Figure 10 Grading envelope – 'fine' material (grey polygon = contract grading envelope; blue line = shingle sample)

Coarse material (Bay 3)

Sourced from Owers Bank, a coarse vein of material was utilised with a low fine content and a D_{50} of 18mm. Although such material is more desirable for beach replenishment, it is typically far more expensive.

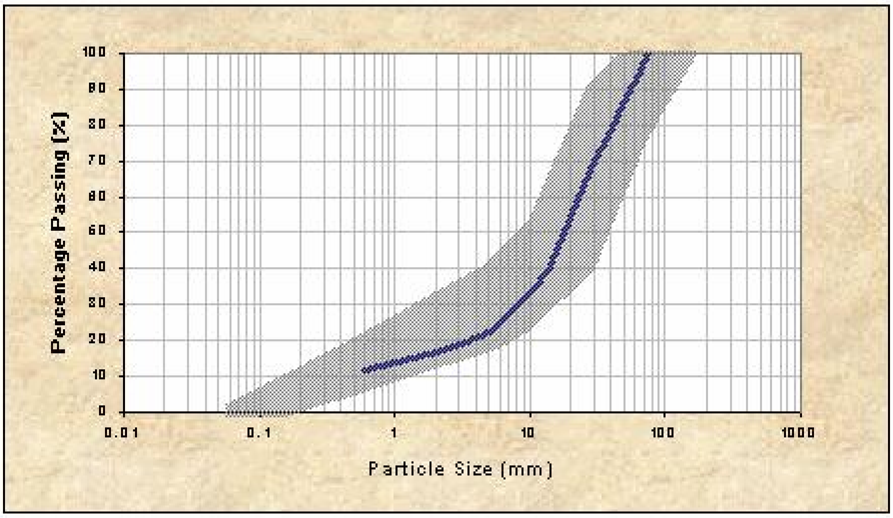


Figure 11 Grading envelope – 'coarse' material (grey polygon = contract grading envelope; blue line = shingle sample)

'Capped' replenishment (Bay 4)

Coarse, well-sorted material was scraped off the top of the native beach and stockpiled. The bay was then part-filled with the standard replenishment material (see section 2.1.5) and capped with the native material. It was hoped that this layer of naturally-sorted material would prevent some of the problems traditionally encountered as beaches evolve.

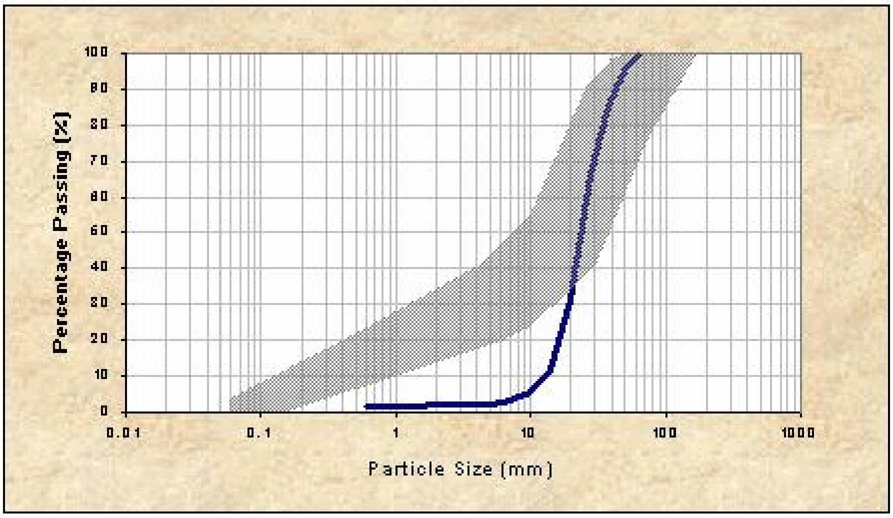


Figure 12 Grading envelope – 'capped' material (grey polygon = contract grading envelope; blue line = shingle sample)

'Standard' replenishment (Bay 5)

The remainder of the Tankerton Phase III scheme was replenished in line with the contract specification. Discounting the test bays, samples taken from the delivered material indicated that it was coarser than anticipated, with a D_{50} of 16mm. In order to compare the evolution of the test bays with the normal replenishment, bay 5 was subjected to the same monitoring techniques.

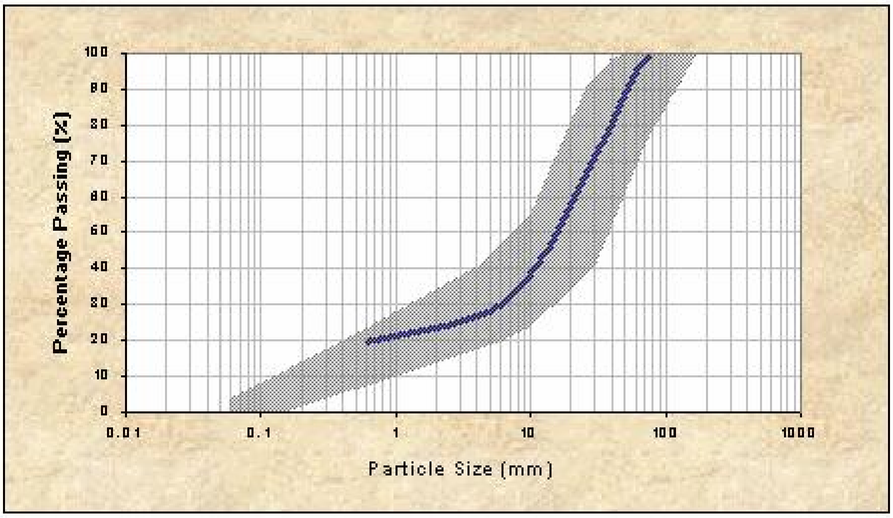


Figure 13 Grading envelope – 'standard' material (grey polygon = contract grading envelope; blue line = shingle sample)

Control bay

In addition to comparisons made between the five test bays on the new beach, a control bay on the mature beach was also monitored. This bay had taken part in the research conducted during the first two phases of the replenishment, which meant that sampling data and sediment statistics were readily available.

3.1.2 Surveying

Surveys were conducted using GPS technology to accurately monitor spot heights along the beach. Two methods were employed: a simple survey constituting a profile line down the centre of each groyne bay; and a more complex beach plan survey that covers every crest, trough, structure and change in beach gradient at a maximum point spacing of 5m. The more detailed surveys can be used to produce accurate models of the groyne bays and to calculate changes in beach volume.

As part of the sea defence works, comprehensive beach plan surveys were conducted prior to the replenishment and immediately after each bay was filled. These surveys were used to calculate the quantity of delivered material and to provide the baseline for any volume changes during the course of the experiment.

Two profile surveys – spring and autumn – and a summer beach plan survey are conducted annually by the SRCMP. These were supplemented by additional surveys where it was deemed appropriate, especially during the early stages of evolution (year 1).

3.1.3 Sediment sampling

Dredged material was sampled at a minimum of three locations within each barge delivery. These samples were analysed in line with BSI sampling regulations with regards to methodology, sample size and sieve diameters (Table 3). While staff were still required on site, processing was conducted at the site compound. After this time, however, samples were taken to Canterbury City Council's sediment laboratory for analysis.

Table 3 Sieve size and limits of scheme grading envelope

Sieve size (mm)	Specified % passing (grading envelope)	
	Minimum	Maximum
<0.6	6	22
0.6	7	24
1.18	11	30
2.36	14	36
3.35	16	39
5	17	43
6.3	20	47
10	24	55
14	29	67
20	34	80
28	39	92
37.5	48	98
50	60	100
63	69	100
75	77	100

Sediment with a diameter of less than 0.6mm was not sent for further analysis. Previous work carried out as part of the Coastlink Project (Posford 2001) did involve sending some finer samples away for analysis. In this case, however, cost considerations made this infeasible given the research project budget and the hundreds of samples that would need to be analysed over the course of the project.

Accurate sampling of a mature or replenished beach is a more complicated process. The composition of the beach varies not only as you move seawards down the beach, but also (more critically) within the beach itself. As a consequence, meaningful sediment sampling has to be conducted using boreholes extending from the beach surface right down to the underlying clay, at several locations along the beach.

Figure 14 Borehole rig on newly-replenished beach

Boreholes were taken along the centre line of the groyne bay at distances of 15m, 20m and 25m from the seawall (see Figure 14). This involved extracting a core of material that extended from the beach surface to the point where solid clay is reached. Samples are typically taken every 0.5m. Each sample was removed, sealed in a bag and taken to a sediment lab, where it was subjected to a sieve analysis to determine its composition and grading.

Setting up and positioning the rig necessitated disturbing the beach. A surface sample was taken at each location prior to moving plant machinery on to the beach to create a level platform and to position the rig. Following sampling, the beach face was re-profiled to match the gradient of the undisturbed beach over the rest of the groyne bay. Although this resulted in some mechanical sorting of the beach face, it was deemed less invasive than digging huge holes in the beach and back filling them on completion of sampling.

3.1.4 Permeability/water levels

Changes in water levels within the beach directly reflect the permeability of the beach substrate. This permeability, in turn, is governed by the sediment grading composition and, most notably, by the quantity of fine material in the beach.

Groundwater levels within the beach were monitored using boreholes at intervals along the centre line of the groyne bay (Figure 15). Budget restrictions limited the number of boreholes that could be placed and maintained in each groyne bay. It was also agreed that no boreholes would be placed in the first three bays due to the proximity of the sailing club.

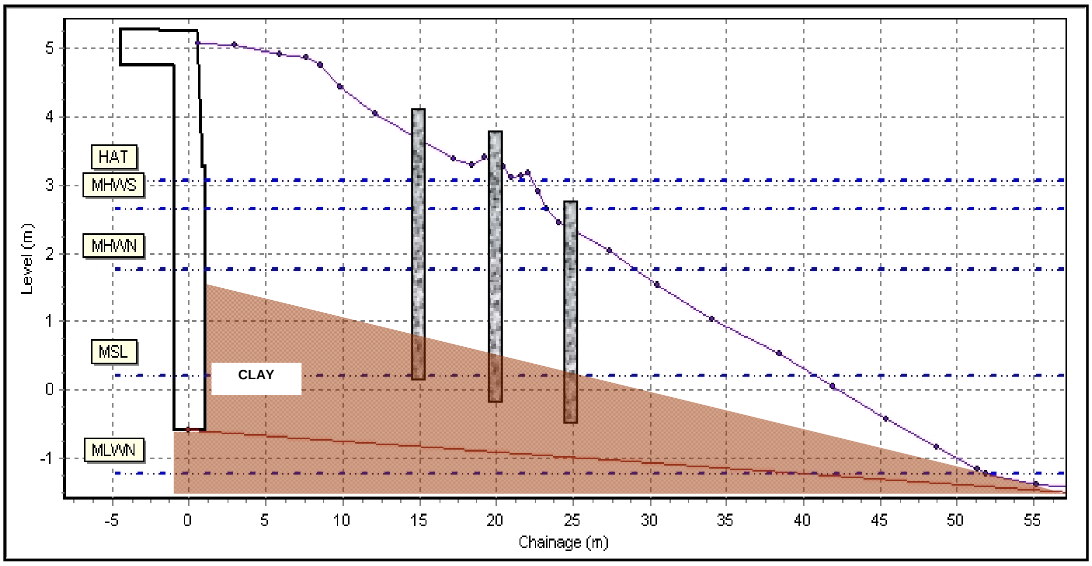


Figure 15 Location of boreholes for groundwater monitoring

Three bays had boreholes installed for the duration of the project: these were the control bay, the ‘capped’ bay (bay 4) and the standard replenishment (bay 5). A view was taken that as the lower beach only contained a relatively small depth of shingle and was fully submerged for large periods of time, no instruments would be installed there. In contrast, the back of the beach would experience comparatively little of the hydrodynamic action and may not show any significant changes over the course of the research. Consequently, each bay had three boreholes at distances of 15m, 20m, and 25m from the seawall. These locations represent the most active beach sections covering the mobile high water crest up to 0.5m above the highest astronomical tide.

Boreholes were driven 0.5m into the clay and 50mm-diameter perforated tubing covered in a geotextile (Figure 16a) inserted into them, prior to removing the borehole casing and letting the beach collapse in on itself. It was hoped that the geotextile would help prevent the tubes silting up with fine sediment. Because the public had access to the beach, it was necessary to install caps (Figure 16b) to prevent the instruments being tampered with or removed. These consisted of a perforated steel tube, a lockable cap and a base plate to prevent the unit being dragged out of the beach. These caps were placed over the tubing and the beach was then backfilled to the level of the cap (Figure 16c).

The MiniTROLL® is an advanced data logging probe (Figure 16d), being completely self-contained and featuring an internal data logger with a pressure/level sensor. It is used to collect information for the analysis of both short- and long-term water level trends. The depths of the boreholes were measured and chains were then cut to a length that would suspend the instruments 0.5m above the bottom of the tubes. Cap levels were surveyed with GPS to provide an accurate level for each instrument.

Figure 16 **Components of beach water level monitoring system**

Due to the potential for the miniTROLLs to degrade in seawater, they were originally only deployed for short periods of time, covering a couple of tidal cycles. After the first few months, the length of deployment was increased to several weeks at a time. Sampling frequency depended on the length of each session and ranged from five seconds to five minutes.

In addition to the miniTROLLS, a barometer was kept on site to record fluctuations in atmospheric pressure. When the instruments were recovered, all the data was downloaded into Win-Situ® software and true water depths were calculated after adjusting for atmospheric pressure.

3.2 Results and discussion

3.2.1 Visual observations

Material placement

Shingle was brought in on a barge and deposited as close as possible to the toe of the beach, where it was pushed into each bay and profiled to the design beach gradient using a variety of plant machinery. This labour intensive method may have resulted in some degree of beach compaction and has been proposed as a contributing factor to beach face cliffing.

After placement, the newly-replenished bays all looked similar, with the exception of the bay containing recycled material, which had a different colour to the dredged sediment. Immediately after placement, a slick of fine material could be seen leaching from the beach (see Figure 17). This was a consistent feature for the first week following the replenishment.

Figure 17 Fine material leaching from the beach after replenishment

First month

After the new beach had been worked by tidal and wave action, changes in the beach appearance became apparent. The upper beach face appeared coarser due to the loss of fine material, with differences between the coarse and fine bays now apparent to the naked eye. The berms of all the bays (the part that stays mostly above water) had re-orientated to face the dominant wave climate and the bottoms of most bays were covered in fine sand. After each high tide, water would flow out of the beach, carrying the finer material past the toe of the beach (see Figure 18). This continued until the rising tide reached the toe of the beach, suggesting that the beach never fully drained.

Figure 18 Exfiltrating water following high tide

Long term

After the first few months, the fine material at the base of the beach disappeared and was replaced by some coarser angular material (see Figure 19). It is not known why this fine material was expelled from the beach, but it had completely disappeared by the start of the 2004 winter season.

Figure 19 Angular 'grit-like' sediment deposited along the beach toe

Cliffing of the beach face occurred in some bays and was particularly evident in the fine bay (see Figure 20). These cliff-like scarps initially formed as the beach was worked over by spring tides and, in later months, as the beach was subjected to storm events that affected the unsorted sections of the rear beach. No such structures formed in the capped bay and the effects were minimal in the other bays.

Figure 20 Cliffing in the 'fine' bay a few months after placement

As the beach evolved, a high water crest developed and the berm re-orientated in line with the predominant wave direction at a quicker rate. Coupled with slight erosion, this caused problems with the locations of the borehole caps. Exposure of the boreholes varied greatly over time as the beach moved; some had to be lowered after the first year because they protruded above the beach by up to 0.5m. In contrast, some boreholes became covered and had to be located using a metal detector and dug out with a shovel to retrieve the instrumentation.

Another effect of a more mobile beach was that it resulted in the cross-contamination of the bays, caused by shingle overtopping when the coast was subjected to an aggressive wave climate. As a consequence, different bays were no longer distinguishable by sight and at first glance the coarse and fine bays seemed to have a comparable surface layer. This cross-contamination has an effect on volume calculations and erosion rates, as the bays are no longer acting as isolated cells.

At the end of the first summer, the recycled bay had become highly vegetated. This was a result of the material source coming from a highly vegetated area and effectively seeding the beach. This vegetation spread to neighbouring bays over the course of the experiment, but any effects on improving the consolidation of the beach were deemed minimal.

3.2.2 Beach profile/plan response

Profiles

Profile surveys have the benefit of being quick and relatively inexpensive to carry out but still provide a reasonable indication of changes in beach volume, berm width and gradient. They also provide information on seasonal variation and post-storm impacts that are not picked up by the less frequent beach plan surveys. It should be noted that profile surveys may not fully account for reorientation within the groyne bay or for those occasions when material is not distributed uniformly.

A summary of the changes in cross-sectional area (CSA) at key dates is presented in Table 4. The complete data set is not included, but notable changes in beach shape are presented for each individual bay on the following pages.

Table 4 Total change in profile CSA (m^2) over time

Date*	Bay 1 – recycled material*	Bay 2 – 'fine' material	Bay 3 – 'coarse' material	Bay 4 – 'capped' material	Bay 5 – 'standard' recharge
June 2004		0	0	0	0
July 2004	0	-5.5	+0.2	-3.5	-1.1
November 2004	-0.9	-8.3	-3.0	-3.7	-3.4
February 2005	-9.5	-9.1	-6.9	-9.5	-5.4
July 2005	-8.8	-11.9	-6.2	-8.8	-6.7
November 2005	-9.6	-12.7	-6.2	-9.2	-8.0
June 2006	-9.7	-12.4	-6.2	-8.6	-8.1
December 2006	-11.6	-13.3	-6.5	-11.5	-9.8
March 2007	-11.4	-10.0	-4.3	-12.4	-9.2
June 2007	-11.4	-13.1	-8.3	-14.2	-9.3
October 2007	-11.4	-11.9	-6.1	-13.2	-8.1

Notes: Not all surveys included; only a representative sample.*The recycled bay was topped up and re-profiled in July 2004; as a consequence, calculations are made from this later date.

As expected, the highest initial loss rates were experienced with the finer (Bay 2) material over the first month. The only other bay to exhibit a notable loss was the experimental capped bay. Five months after the replenishment, the coarse material, capped material and standard replenishment bays were performing consistently in terms of loss rates. In contrast, the finer material bay was losing almost twice as much, while the recycled bay displayed little significant change.

Over the 2004–05 winter period, the beach was subjected to its first significant storms and all bays experienced a further reduction in CSA. It also became apparent that the increased wave climate resulted in shingle overtopping the groynes. It is unclear to what extent this may affect future results, but subsequent surveys will no longer represent discrete units. Despite this, the majority of each bay is still composed of the original replenishment types and groyne overtopping will become less significant as levels drop.

The last survey was conducted in October 2007, three years after the replenishment, and indicated that the coarse bay lost the least material. Erosion was far more evident in the fine and recycled bays and worst still in the capped bay. In terms of loss rates, the standard replenishment was better than most, but slightly worse than the coarse bay. To put these CSA losses into context, over the same three-year period the coarse material bay lost 6.1m^2 and for the capped bay lost 13.2m^2, while the mature control bay lost only 2.2m^2.

Recycled material (Bay 1)

From the profile surveys, it would appear that the majority of the erosion occurred over the 2004–05 winter period (Figure 21). This resulted in a reduction in berm width, losses along the upper beach and a shallower beach face gradient.

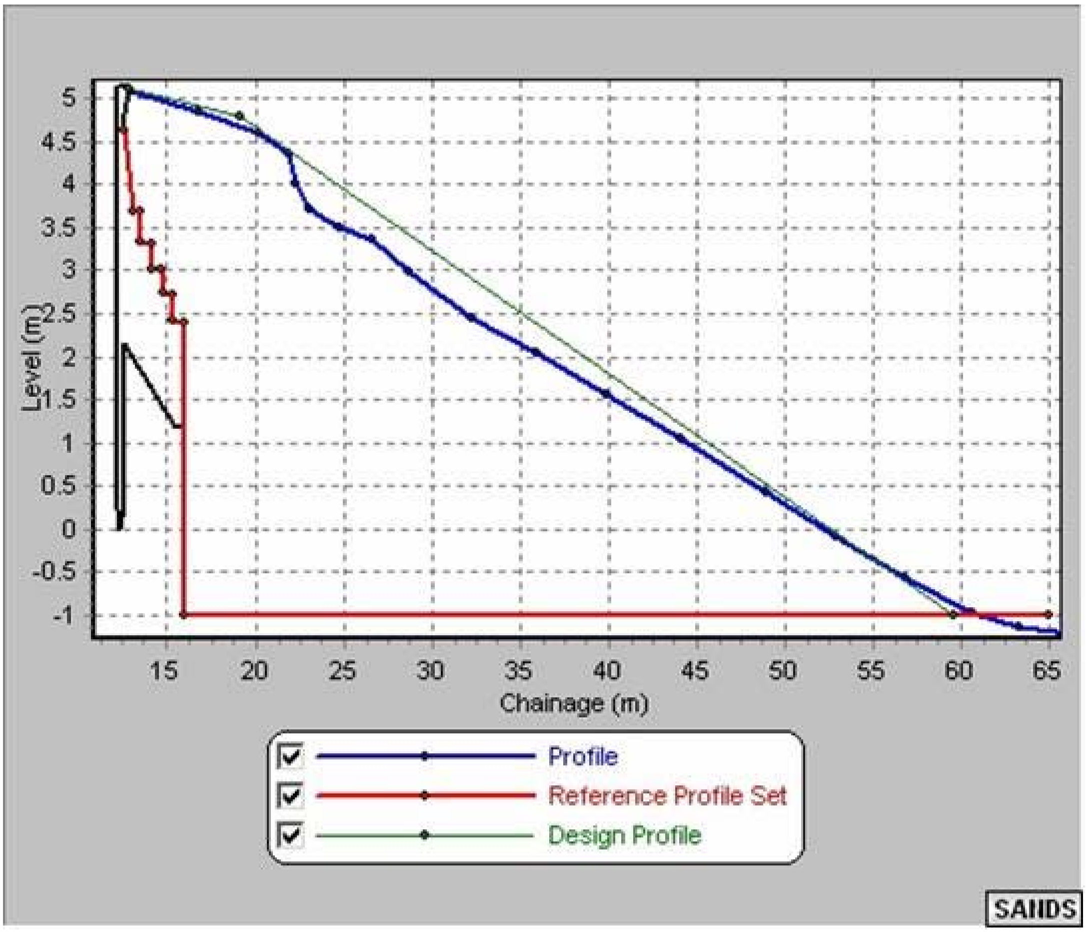


Figure 21 Recycled bay profile survey, February 2005

Following the initial losses over the first winter, the bay has remained fairly stable with just a minor reduction in berm width.

Fine material (Bay 2)

Large losses were experienced in the fine bay from the moment the scheme was finished. By the start of July 2004, only a month after replenishment, the active beach face had flattened to a 1:9 gradient, erosion was evident on the upper beach and the position of the beach toe had migrated seaward (Figure 22).

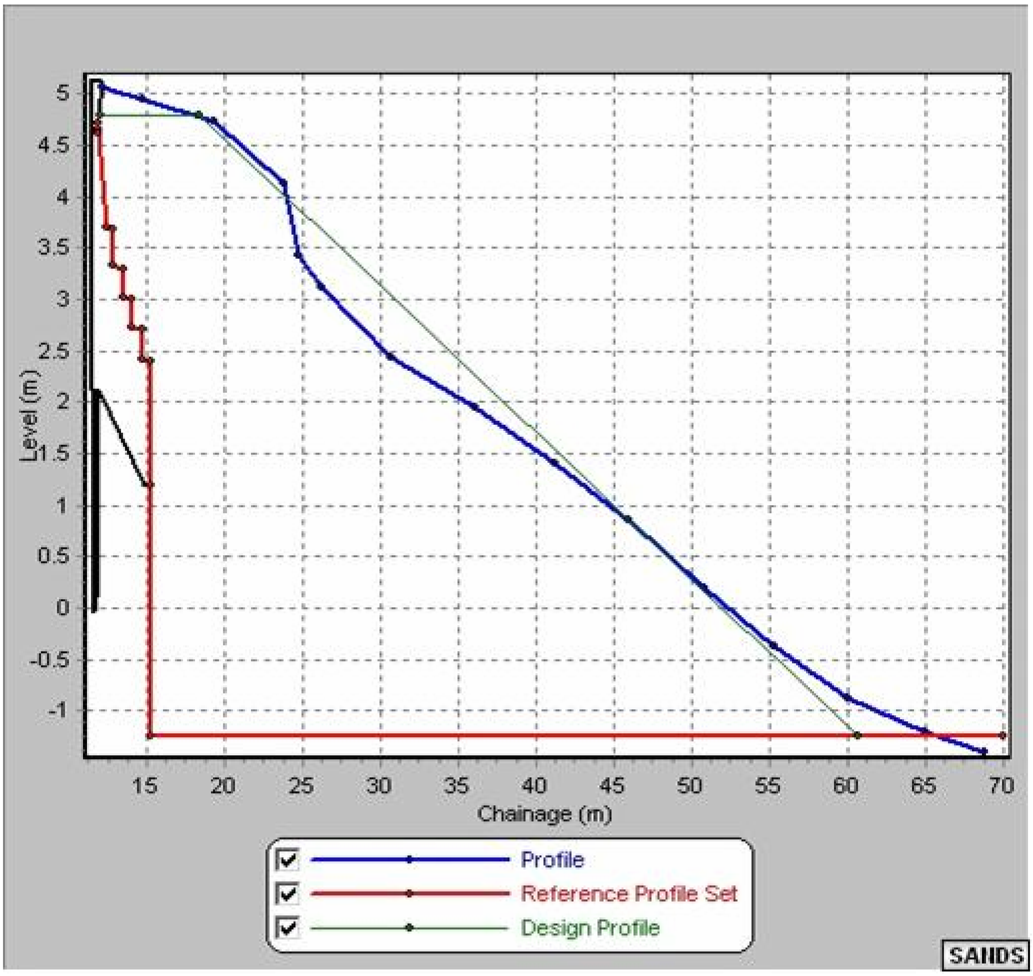


Figure 22 Change in fine bay profile over the first month

Over the first year, the beach appeared to lose a high proportion of the fines and to work itself into a stable beach slope with a 1:8 gradient. The erosion rate of the groyne bay was also markedly reduced following the first winter.

Coarse material (Bay 3)

Apart from the initial loss over the first winter period, the coarse bay witnessed no significant erosion for the rest of the experiment. Significantly, a profile gradient of 1:7, consistent with the design profile, was maintained throughout.

'Capped' replenishment (Bay 4)

Large losses were experienced in this bay, both over the first year and later in the experiment. It is possible that these losses were not just caused by erosion, but also by settlement. The coarse cap contained barely any fine material and, as such, contained a large proportion of voids between the sediment. As the beach was worked by the hydrodynamic climate, the finer replenishment material may have migrated into these voids and contributed to the apparent drop in volume (Figure 23).

Initially, cliffing did not occur in this bay, undoubtedly due to the coarse cap, which also prevented the underlying replenishment material from being sorted. When this coarse cap was finally swept aside during a storm, it resulted in the expulsion of fines from the unsorted delivered material and a drop in beach volume later in the experiment.

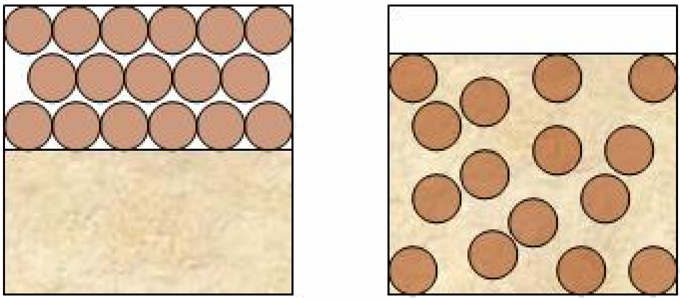


Figure 23 Potential drop in beach volume without loss of sediment

<u>'Standard' replenishment (Bay 5)</u>

The standard replenishment performed well, maintaining the defined beach slope gradient of 1:7 and eroding less than all the bays apart from the coarse material bay, which eroded by 25% less than the standard replenishment over the course of the experiment. To put this into context, the fine bay eroded twice as much as the coarse bay over the same period, but all bays eroded by three to six times more than the mature control bay.

Beach Plan

In order to validate the profile results, periodic beach plan surveys were performed to provide more accurate data on volumetric changes and to map the entire groyne bay. Figure 24 shows the difference between the scheme out survey in 2004 and the 2007 beach plan survey. Erosion is evident along each berm, although it is less pronounced in the coarse bay. It is also less pronounced on the west side of each bay, as a result of beach reorientation.

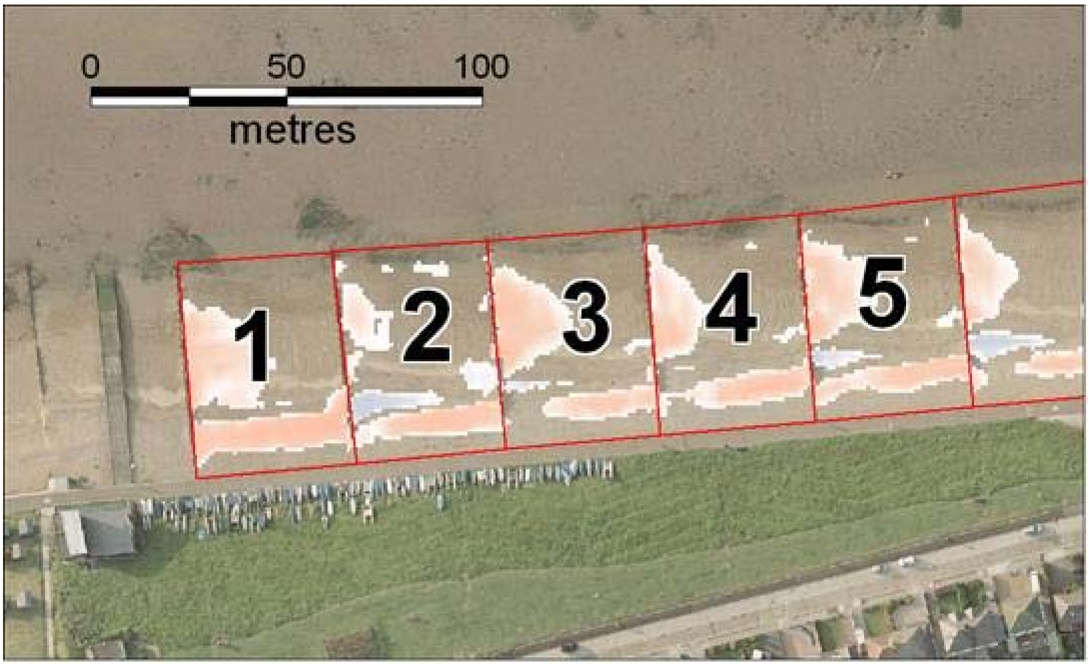


Figure 24 Map of erosion (pink-red) and accretion (pale blue-dark blue) between July 2004 and June 2007

From these difference grids, it is possible to calculate the volumetric change over time. These results are presented in Table 5. It should be taken into consideration, however, that these results only represent a snapshot in time and as such do not reflect the results of the profile surveys that were conducted up to the autumn of 2007.

Table 5 Volume calculations of erosion rates between July 2004 and June 2006

Bay number	Replenishment type	Replenishment volume (m^3)	Volume change (m^3) (2004–07)	Loss as percentage of recharge
1	Recycled material	2,249	-513	**22.8%**
2	Fine material	2,149	-358	**16.7%**
3	Coarse material	1,973	-274	**13.8%**
4	‘Capped’ bay	2,522	-361	**14.3%**
5	Standard recharge	2,154	-177	**8.2%**

As with the profile surveys, the worst performing bays were the recycled, fine material and experimental cap. The standard replenishment and the coarse bay outperformed the others but not by the margins highlighted by the profile surveys. Consideration should be given to the effect of sediment movement between bays. Although it is impossible to quantify this effect, it could have had a substantial impact on the figures over the past two years.

Of particular note is the huge loss highlighted in the recycled bay, equating to nearly a quarter of the replenished material. Although the sediment grading curves would suggest that this material was reasonable, it may be that shingle that accretes on Long Rock is more predisposed to sediment transport. This could be a function of its shape, density or other geological property.

3.2.3 Sediment sampling

The principal objective of this exercise was to monitor the expected changes in the particle size distribution of the beach sediments in the replenished beaches and to compare them with the samples collected as ‘control’ from the adjacent mature beach. The resulting dataset is large and it is far from easy to present the particle size distributions in a simple manner. Consequently, the results are presented in line with the results of the previous research conducted on the first two stages of replenishment. This should be sufficient to test the original theory that replenished beaches evolve a sediment profile that is similar to the native beach, especially with regards to the amount of finer material.

Tables 6–9 show the results of the sediment sampling split into the three bands depicted in the original research theory. In contrast to this theory and the previous research, the percentage composition of material with a D_{50} of less than 5mm fluctuated over the course of the experiment. Also in contrast to the original research, the quantity appeared to reduce, tending towards the natural sample as the experiment progressed.

Consideration was given to this being due to the accuracy of the sampling technique. However, the increases and decreases of fine content were mirrored in both of the two bays on the new beach. This would suggest that it represents an actual change and that the quantity of fines in the beach fluctuates over time, both up and down.

There is plenty of fine-grained sediment offshore from this beach. Some of this will be washed into the permeable beach sediments during the rising tide and some will be washed out again during the falling tide. The net balance of these amounts will vary depending on the tide and wave conditions, as well as on the available sediment.

Table 6 Sediment sampling results from the pre-nourishment beach

Native beach		TOP (15m)	MID (20m)	BOT (25m)	Average
Mar 2004	<5mm	19.5%	20.0%	26.9%	22.1%
	5–10mm	10.9%	11.3%	11.0%	11.1%
	>10mm	69.6%	68.7%	62.2%	66.8%
Apr 2005	<5mm	-	-	-	N/A
	5–10mm	-	-	-	N/A
	>10mm	-	-	-	N/A
Jun 2006	<5mm	-	-	-	N/A
	5–10mm	-	-	-	N/A
	>10mm	-	-	-	N/A
Average		N/A	N/A	N/A	**22.1%**
		N/A	N/A	N/A	**11.1%**
		N/A	N/A	N/A	**66.8%**

Table 7 Sediment sampling conducted on the 'mature' beach

Control bay		TOP (15m)	MID (20m)	BOT (25m)	Average
Mar 2004	<5mm	31.0%	26.6%	24.0%	27.2%
	5–10mm	21.7%	16.0%	22.9%	20.2%
	>10mm	47.3%	57.4%	53.1%	52.6%
Apr 2005	<5mm	42.2%	43.9%	34.4%	40.2%
	5–10mm	14.5%	19.0%	17.1%	16.9%
	>10mm	43.3%	37.1%	48.5%	43.0%
Jun 2006	<5mm	46.7%	32.6%	38.1%	39.1%
	5–10mm	20.9%	20.0%	22.7%	21.2%
	>10mm	32.3%	47.3%	39.2%	39.6%
Average		40.0%	34.4%	32.2%	**35.5%**
		19.0%	18.3%	20.9%	**19.4%**
		41.0%	47.3%	46.9%	**45.1%**

Table 8 Sediment sampling at the 'capped' bay

Bay 4		TOP (15m)	MID (20m)	BOT (25m)	Average
Jun 2004	**<5mm**	27.4%	39.9%	35.6%	34.3%
	5–10mm	12.2%	14.0%	13.4%	13.2%
	>10mm	60.3%	46.1%	51.0%	52.5%
Aug 2004	**<5mm**	32.4%	42.3%	37.6%	37.4%
	5–10mm	15.1%	16.2%	18.5%	16.6%
	>10mm	52.6%	41.5%	43.9%	46.0%
Apr 2005	**<5mm**	27.7%	19.4%	25.7%	24.3%
	5–10mm	13.5%	20.4%	17.4%	17.1%
	>10mm	58.8%	60.2%	56.9%	58.6%
Jun 2006	**<5mm**	26.7%	36.3%	35.2%	32.7%
	5–10mm	15.5%	13.0%	15.6%	14.7%
	>10mm	57.8%	50.7%	49.2%	52.6%
Average		28.6%	34.5%	33.5%	**32.2%**
		14.1%	15.9%	16.2%	**15.4%**
		57.4%	49.6%	50.3%	**52.4%**

Table 9 Sediment sampling conducted on the standard replenishment

Bay 5		TOP (15m)	MID (20m)	BOT (25m)	Average
Jun 2004	**<5mm**	30.4%	36.0%	19.4%	28.6%
	5–10mm	16.7%	14.8%	13.6%	15.0%
	>10mm	52.9%	49.2%	67.0%	56.4%
Aug 2004	**<5mm**	40.4%	35.9%	36.5%	37.6%
	5–10mm	12.9%	18.4%	17.8%	16.4%
	>10mm	46.8%	45.7%	45.7%	46.1%
Apr 2005	**<5mm**	23.2%	32.5%	30.2%	28.6%
	5–10mm	13.0%	18.3%	12.0%	14.4%
	>10mm	63.8%	49.2%	57.7%	56.9%
Jun 2006	**<5mm**	33.4%	33.1%	29.3%	31.9%
	5–10mm	17.6%	16.9%	17.8%	17.4%
	>10mm	49.0%	50.0%	52.9%	50.6%
Average		31.9%	34.4%	28.9%	**31.7%**
		15.1%	17.1%	15.3%	**15.8%**
		53.1%	48.5%	55.8%	**52.5%**

3.2.4 Permeability/water table

Control bay

Variation in the beach water table was initially monitored in the control bay. This produced a series of results that was repeated on numerous occasions and was defined as the standard reaction of a ‘mature’ beach to wave and tidal action (see Figure 25).

As the tide rises up the beach, there is a time lag as water starts to infiltrate the beach. At this point, the beach ground water level is higher in the boreholes towards the back of the beach. The closer to the seawall, the longer the lag, with the first borehole not reacting to the rising tide until two hours after the sea level has reached the water height in the borehole.

Increases in water table height are most pronounced in the lower beach, where water heights fluctuate by around 1.5m during a tidal cycle. In contrast, the central borehole has an amplitude in the region of 0.5m and the first borehole rarely alters by more than 200mm.

Peak levels in each borehole are not reached at high tide, as might be expected. This is consequence of the time lag, with peak levels being reached at the point where the falling tide is approximately equal to the rising levels in the boreholes. After the falling tide has moved past the toe of the beach, water levels drop until the arrival of the next rising tide. Boreholes never empty completely and there is always a standing volume of water in the beach. These typical observations are superimposed onto a beach profile in Figure 26, Figure 27 and Figure 28.

It should be noted that there is an increase in the magnitude of water table fluctuations and the amount of standing water left in the beach as the tidal range increases towards spring tides and a reduction in both as the tidal range decreases towards neaps.

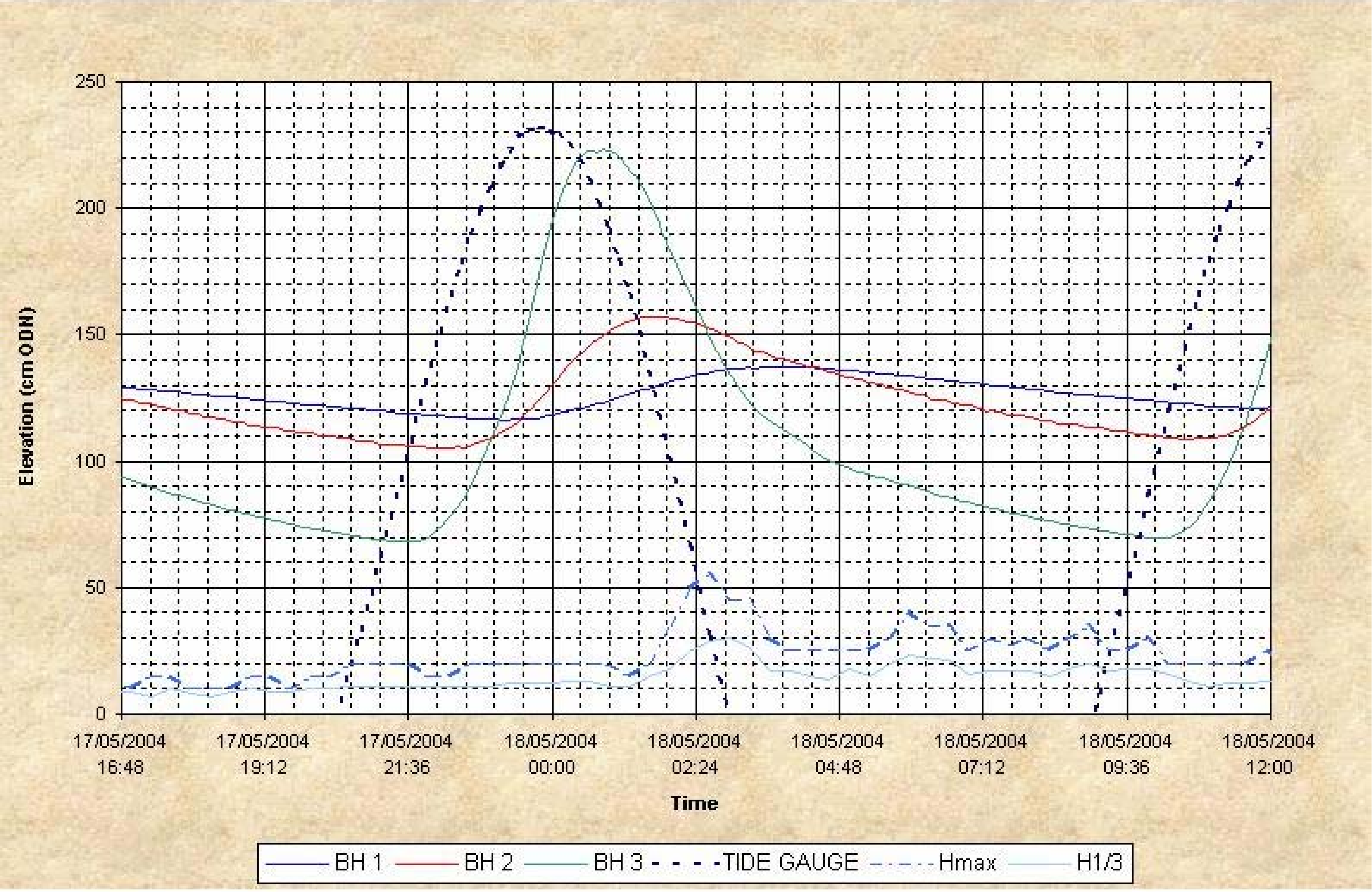


Figure 25 Variation in beach water table during a tidal cycle on a mature beach

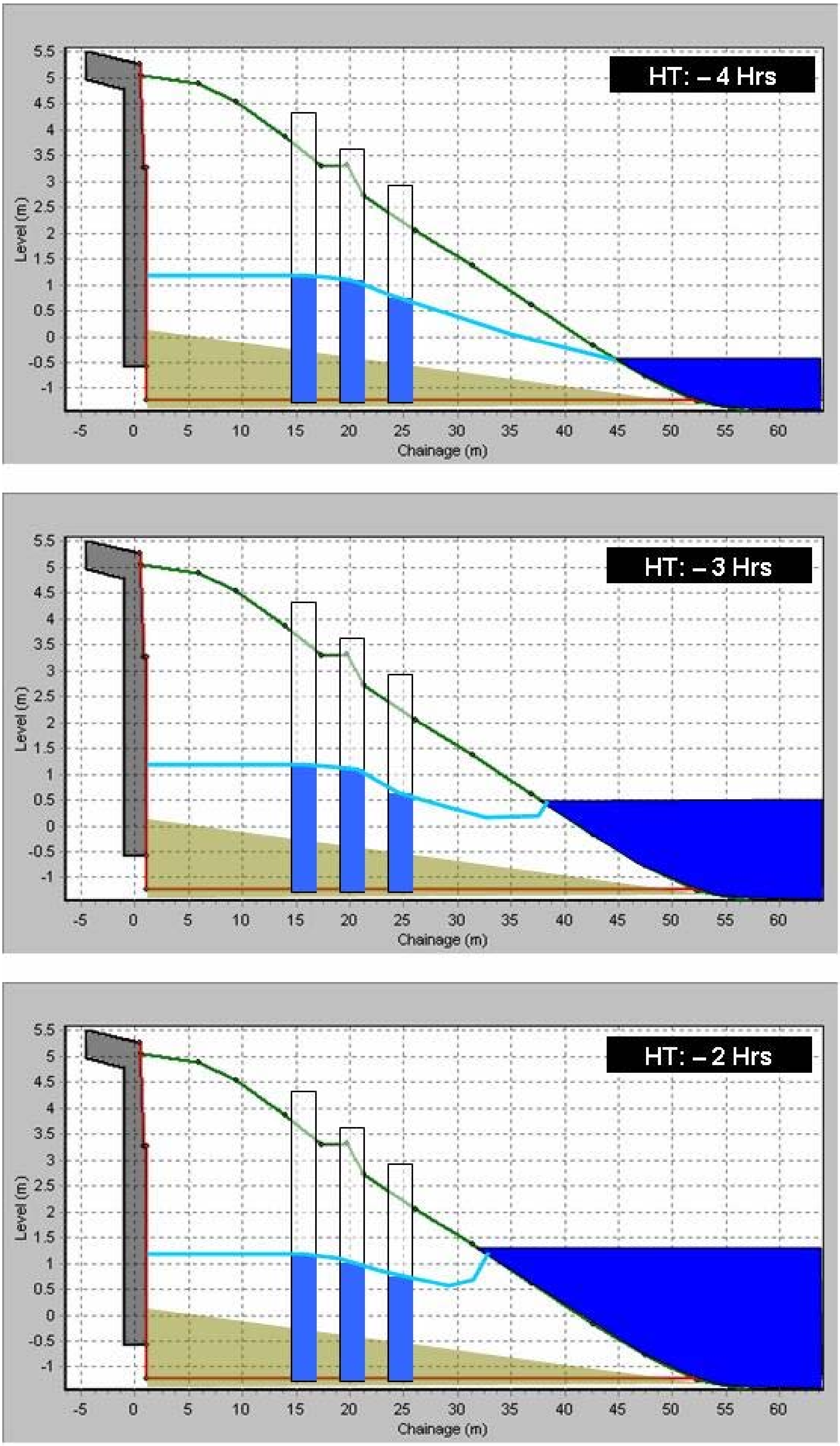


Figure 26 Beach water table fluctuations (part I)

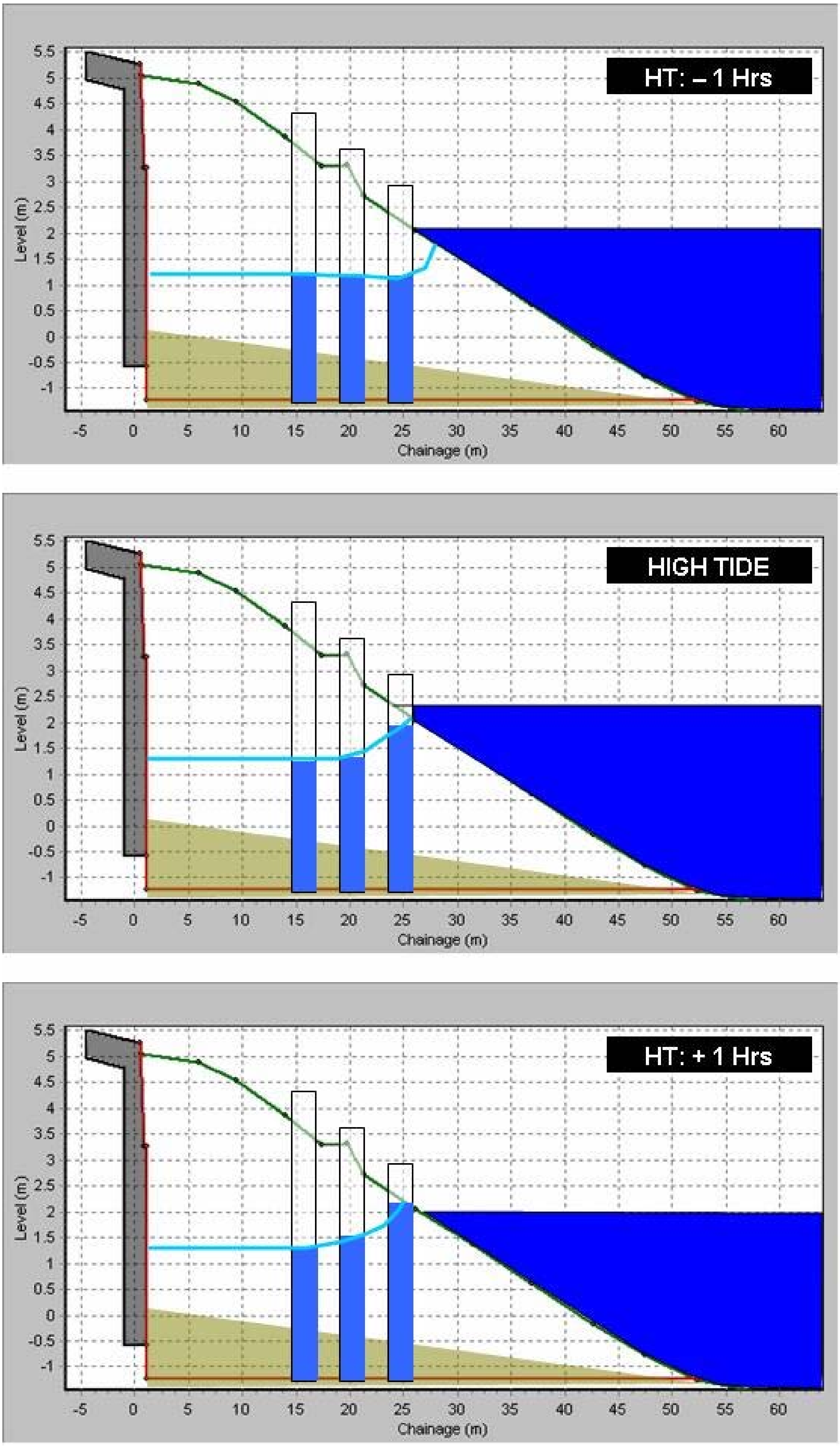


Figure 27 Beach water table fluctuations (part II)

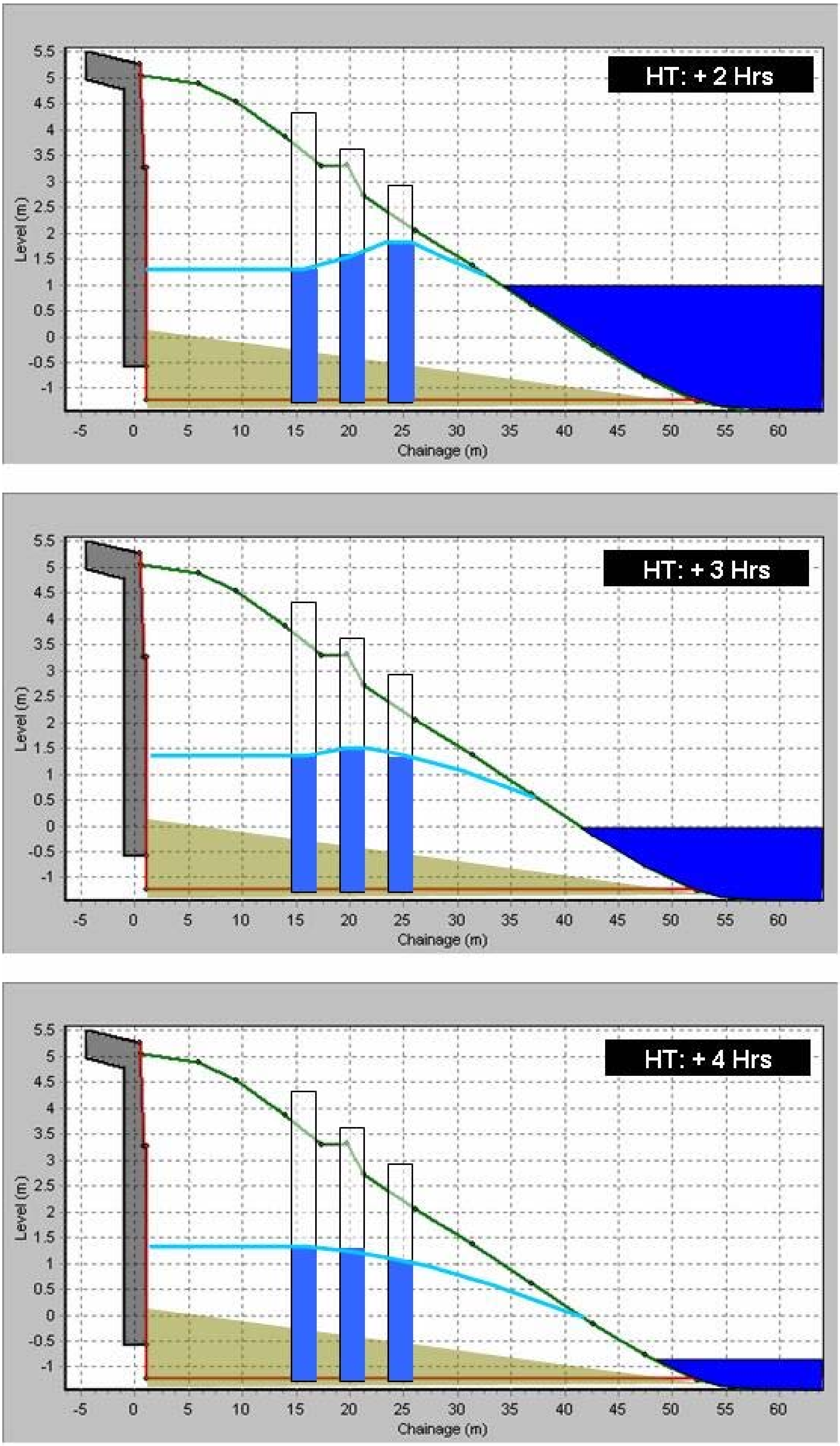


Figure 28 Beach water table fluctuations (part III)

Initial response

Monitoring the new beach immediately after replenishment produced completely different results. A time lag was still present, with peak borehole water levels occurring around three hours after the high tide. In the standard replenishment bay, all three boreholes would rise and fall in unison with an amplitude of under 0.5m, reflecting the reduced permeability of a newly-replenished beach. Readings were taken in tandem at the control bay; the results were consistent with previous readings and those expected for a mature beach.

Initial readings at the capped bay produced different results (Figure 23). While the two boreholes at the back of the beach behaved in a similar manner to the standard replenishment, water levels in the third borehole fluctuated by a greater margin. This supports the suggestion that the method of ‘capping’ improves the permeability of the beach face.

Evolution

As the months progressed, the magnitude of the fluctuations in the lower borehole gradually increased, as the beach was worked by wave and tidal action. This represents an increase in permeability and is almost certainly due to the decrease in fine content. After the winter storms, the middle tubes began to experience an increase in water level movement. By the summer of 2005, results from the new beach were comparable to those taken in the control bay.

A number of problems were encountered after 2005 with the instrument setup. Several of the caps had to be lowered to compensate for drops in beach level. Silting up of the boreholes also became an issue, especially with the lower boreholes, to the point where two had to be reinstalled during subsequent sediment sampling. The silt was mostly composed of fine sand.

Some miniTROLLS® also succumbed to the effects of saltwater, which destroyed most electronic components, including the batteries, when the rubber seals failed. This reduced the number of boreholes that could be monitored in each tidal cycle.

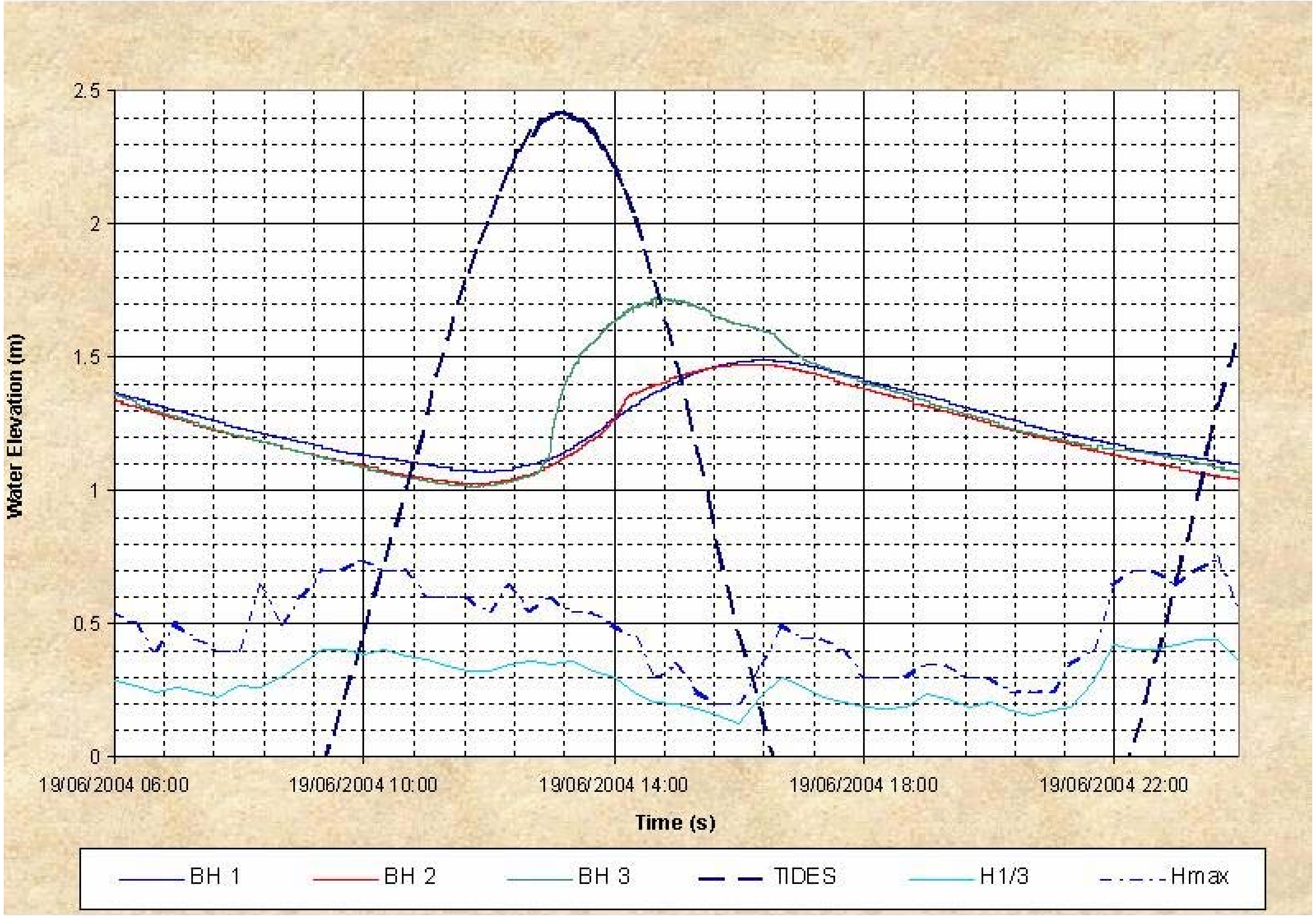


Figure 29 **Fluctuations in water level in the capped bay (June 2004)**

4 Hythe Beach Nourishment Scheme

4.1 Methodology

4.1.1 Alternative methods of material placement at the deposition sites

The Beach Management Plan, prepared as part of the 1996 Hythe Coast Protection Scheme, laid down some relatively strict guidelines for placing recycled material. These guidelines have incurred some high supervision costs; in particular, the requirement to place beach material to a set profile (1:8 gradient) has been difficult to achieve during particular tide and weather conditions.

Over the 12 yeas that SDC has been carrying out the recycling works, less emphasis has been put on these guidelines. The main focus has been on ensuring that an adequate volume of beach has been moved from the down-drift to the up-drift end of the beach.

The approach taken at the start of this study was to look at two separate factors of the recycling: the gradient of the beach; and the method of placement at the deposition site. To aid the reporting element of the project, this section has been further subdivided into two sections:

profile of the beach – cross shore/profile response;

method of placement at the deposition site.

H4 Profile of the beach – cross shore/profile response

Since 1996, the preferred option for managing the SDC frontage was to profile the beach to a 1:8 gradient using a bulldozer. The exact profile was determined by using RTK GPS equipment to give the engineer an exact measurement of the gradient. Marked wooden stakes were driven into the shingle to give the bulldozer driver an exact reference point for grading the material. The rationale behind this method was that the recycled beach material should be spread evenly along the active face of the beach. If the beach material is placed at too steep a gradient, the newly-placed material in the upper part of the profile is drawn down towards the toe of the beach. As a result, the crest width is reduced and the standard of the defence is arguably compromised.

However, observations over time indicated that regardless of how much the gradient of the beach was artificially manipulated, the beach would be naturally re-graded by the sea. It would eventually find a natural angle of repose – a gradient between 1:7 and 1:9. As it was undoubtedly expensive to carry out detailed mechanical reshaping of the beach gradient (due mainly to high supervision costs), it was debatable whether this re-grading exercise was required in the first place. Or indeed whether the cost of over-placement could compensate for the beach material that is drawn down into the toe.

To investigate this process, a programmed number of GPS surveys were undertaken along predetermined locations, in order to provide an accurate record of the beach profiles. In conjunction with the data collected as part of the SRCMP, this allowed the compilation of an extensive dataset.

To establish a baseline, a pre-recycling survey (or in-survey) was conducted. This gave an indication of the current gradient of the beach and allowed all subsequent placed material to be referenced to it. The conventional stakeout method was used to inform the driver of where to move the material in order to produce the desired crest height (see Figure 30).

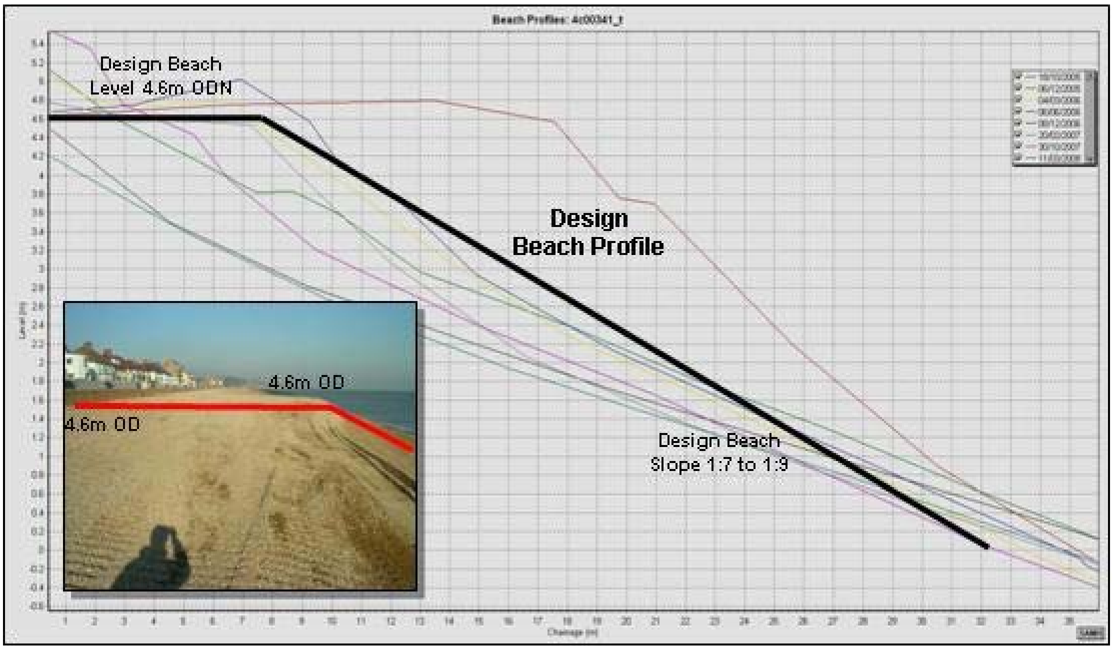


Figure 30 SANDS plot identifying the design beach profile, ideal crest width and gradient

Following each recycling operation, the beach was resurveyed (termed an out-survey). The results of these surveys were subsequently entered into the Shoreline and Nearshore Data System (SANDS) database. This database allows all collected information to be readily compared and helps to identify any changes to the beach profile.

H4 Alternative method of placement at the deposition site

In addition to the research on the gradient of the beach, attention was also paid to the method of beach placement. In the past, the beach has been built out seawards (longitudinally) over a large area, allowing an appropriate design crest width to be achieved. The deposited material was subsequently graded to the desired slope using the technique described above.

Due to the high supervision costs associated with this method, it was suggested that a more informal method of placement could be adopted. This would involve simply tipping material in a concentrated location, allowing the dump trucks to utilise a turning circle and hence have a quicker turnaround from the extraction site to the deposition site.

The drivers of the dump trucks were instructed to tip the beach load in one pile moving seawards. A bulldozer would follow behind and level the pile to a design height only, indicated by painted marks on the seawall. The bulldozers were instructed not to unnecessarily move beach material (to mechanically profile the beach), but rather simply to push the material level, allowing it to fall down the beach slope to a natural gradient.

Stage 1

This study was extended to incorporate the potential effects of varying the location of the deposited material. During the first phase of the study (2004–05) material was deposited at the western end of sub-cell 1 (see Figure 31). As there are no rock control structures situated in this location, the frontage is exposed to waves approaching from all directions, ranging between 110° and 250°. This scenario was devised to investigate whether material could be deposited in an exposed location with minimal grading. An example of a site that may require this approach would be one where access to the site is limited (for example, where the coast is surrounded by a site of special scientific interest), meaning that end tipping, with limited profiling, is the only method available for depositing material.

Figure 31 A series of photographs showing the placement of recycled beach material in cell 1 (no rock structure present)

A control beach was established in order to ascertain whether changes made to the placement method and deposition location had any significant effects on the sediment transport rate. The neighbouring beach to the east of the test bay provided an ideal control bay. The length of the frontages are approximately equal (500m in length – see Figure 5). Both also have the same alignment and contain similar types and sizes of sediment. Furthermore, each bay has a rock groyne on the eastern end, which collects sediment drifting from west to east. The main difference between them is that the control bay is bound by a rock groyne on the western extent.

Stage 2

During the second phase of the project (2005–06), the experiment was reversed. Sub-cell 1 was used as the control bay, as it had re-orientated to its original position, which meant that the historic recycling methodology could be applied. In sub-cell 2, the new methodology was adopted – with deposited material tipped and levelled only. This time, however, the material was deposited on the sheltered eastern side of the groyne. Pre- and post-recycling surveys were conducted for all scenarios and data collected as part of the SRCMP were also utilised.

4.1.2 Comparison of performance between existing and newly renourished beaches

Initial loss of fines over the project duration

Before a successful beach recharge scheme can be implemented and beach recharge volumes calculated, careful consideration needs to be paid to a number of important factors. These include: a through understanding of the area in question; the general coastal geomorphology; the local hydrodynamic conditions; sediment transport mechanisms; and the form and composition of the nearshore regime (Bird 1996).

Offshore beach recharge typically contains a large proportion of fine material and as such it can be classed as a composite structure. Due to this finer material washing out of the beach structure, replenished beaches typically lose a large volume of material within the first six months (Houghton *et al.* 1999).

This fine material can have a detrimental effect on the beach as it can block interstitial voids, causing compaction. It can also reduce the permeability of the beach, allowing cliffing to occur. However, with constant wave action, this finer material is removed and the replenished beach material evolves into a mature beach with a well-sorted structure. Mature shingle beaches, as a result, are a very effective and practical method of coast protection. They react well to variable wave conditions and are capable of dissipating over 90% of the incident wave energy (Powell 1990).

With the native beaches being in place for over eight years (at the start of the investigation), a large amount of sorting has taken place. These beaches have lost their initial fines and have developed into a mature beach with a distinctive structure – larger material in the upper layers, reducing in size further down into the beach core. This good degree of sorting allows wave energy to be dissipated more readily and has therefore reduced the risk of overtopping.

The study area contains a combination of both mature beaches and newly-renourished beaches, allowing the following two topics to be investigated.

How quickly is fine material lost from the newly-renourished beaches (placed as part of the 2004 scheme)?

What volume of beach material is made up of this fine material? This has been facilitated through a volumetric analysis of the beaches using data from the numerous surveys carried out during the study period.

Modification of shingle grading on the active veneer of the beach

In the 12 year period that SDC has been carrying out beach recycling, a natural degree of sorting of the shingle size has taken place along the frontage. This is particularly notable at the down-drift collection points.

As a result, it was proposed that, through careful selection of material at the extraction site, it may be possible to encourage further this natural sorting of material on the newly-renourished beaches.

Under the current recycling regime, material is excavated from a borrow area approximately 5m landward of the active face of the beach. This practice re-introduces finer material that has migrated from the beach back into the system. It is proposed that the material extracted from the borrow area of the experimental beach be restricted to the active face. This will help encourage the larger material to stay in circulation along the whole beach frontage, rather than remaining dormant up against the terminal groyne.

It was believed that if the existing beach material could be actively sorted through modified recycling procedures, in such a way as to increase the average D_{50} size along the frontage, there would be two tangible benefits.

First, it was suggested that an increase in the D_{50} size of material in the active veneer of the beach would result in a measurable improvement in the cross-shore response of the beach to storm events.

Second, it was suggested that the other main benefit would be a reduction in the net sediment transport rate, with a consequent measurable reduction in the volume of beach material required to be recycled each year. This hypothesis was tested by comparing the control beach and the experimental beach volumes, utilising the pre- and post-recycling topographic surveys. These detailed surveys of the beach surface are used to create three-dimensional computer generated models known as digital terrain models (DTMs). By subtracting one survey from another, accurate difference models can be established. Volumes of beach material can subsequently be derived from this model and areas of erosion or accretion can be identified. This information can then be used to inform the recycling process. Additionally, comparisons of beach movement within each sediment cell can be analysed in detail.

The experiment was carried out using two beach sections: one as a control, where standard recycling procedures were carried out as before; and another beach section to be recycled in a different manner.

In addition, sediment samples were taken at fixed locations along the beach, in both the study bay and the control bay, in order to understand the composition of the beach.

Trial pits were dug using an excavator at fixed intervals along designated beach profiles. In conjunction with the surface samples taken at each location, samples were also taken at depths of 1m and 2m below the surface of the beach.

The method employed to carry out the sampling involved using an excavator with an attached ditching bucket. The bucket was used to scrape layers of shingle away, exposing the material below. Creating large $3m^2$ trial pits prevented the sides of the trench from becoming too steep and collapsing. If beach material was allowed to fall into the trench, it would have contaminated the sediment sample on the bottom layer. By employing the aforementioned method, this error factor was avoided.

A shovel was subsequently used to fill sample bags (10–20kg) from the different sediment layers. These bays were then labelled and removed from site for sorting and analysis.

Once collected, the samples were oven dried and sieved to a set methodology conforming to British Standards.

4.2 Results and discussion

4.2.1 Alternative methods of material placement at the deposition sites

The profile of the beach – cross shore/profile response

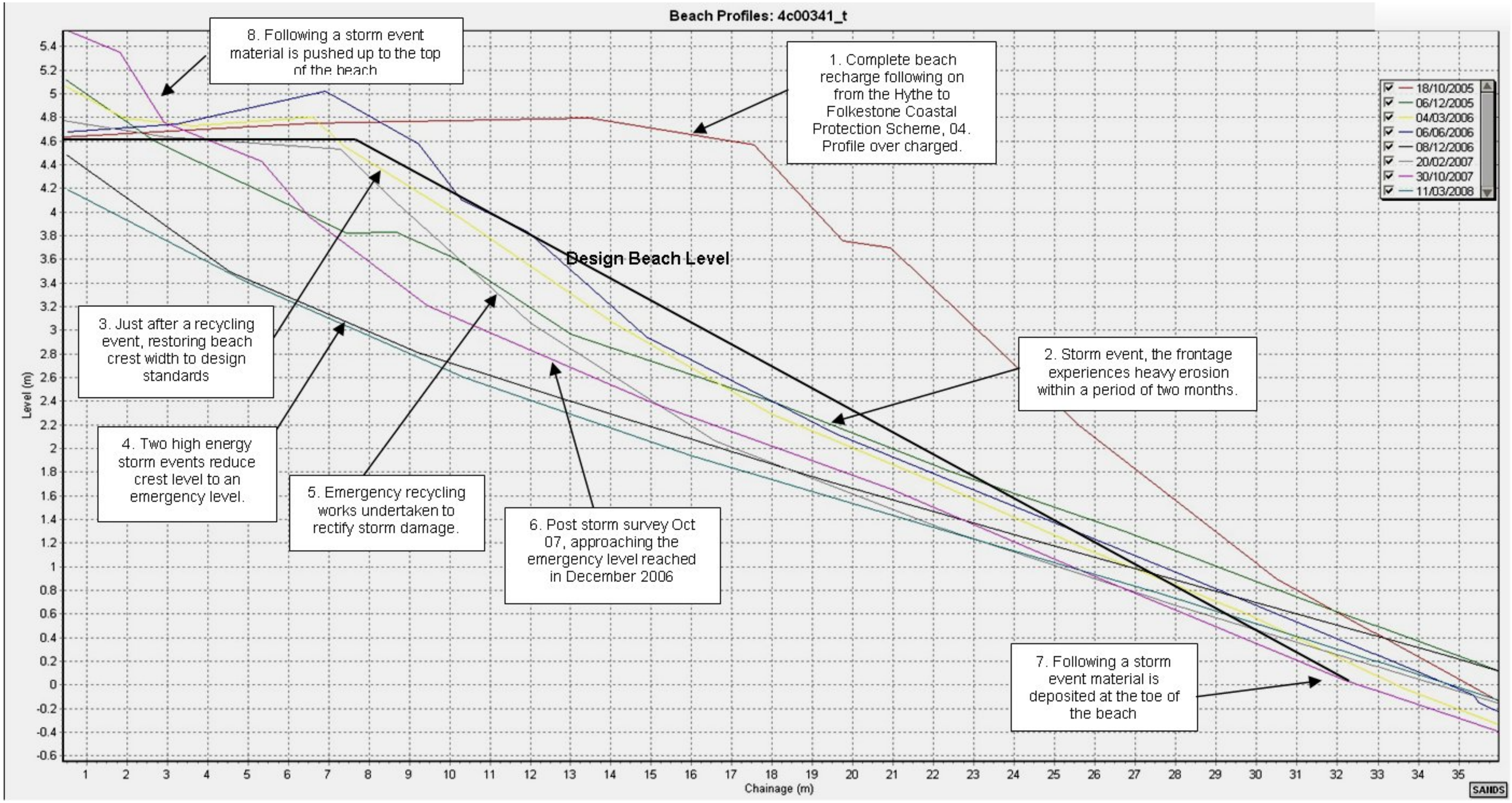
Analysis of the GPS profile surveys clearly identifies a steepened profile associated with the recycling events. The over-placing of deposited recycled material at the top of the beach, in conjunction with levelling the crest to a specified height, has resulted in a significant increase in the crest width.

As the material is pushed off the top of the crest by the bulldozer, this coarse material finds its own natural gradient in the top section of the profile. However, the base of the profile remains unchanged and there is a clear distinction between the artificially-placed material and the natural beach profile. This is illustrated in Figure 32.

Although consideration was paid to achieving an artificial profile down to the beach toe, it was decided that this was an unrealistic proposal. This is because beach recycling does not – and cannot – always coincide with a mean low water spring tide. As such, it was unrealistic to expect material to be deposited to the very toe of the beach. Additionally, it was observed that the finer material in the beach naturally migrates to the lower section of the beach profile – as was also the case with the native control beach. In consequence, the resultant gradient in the lower section of the beach profile will always differ from the gradient in the upper section, where the coarser recycled beach material can hold a much steeper gradient. As a result of these findings, we will focus our discussion of the recycled beach material around the upper (artificially-managed) section of the beach profile.

In addition, it is evident from each successive post-recycling survey that the upper section of the beach profile maintains this steepened gradient, unless it is subjected to a significant storm event.

Figure 32 shows the beach profile at one location (the deposition site – cell 1) after a number of different storm events. The post-storm profiles clearly show that during a storm the beach profile is significantly altered, becoming flatter in appearance. Material in the crest is drawn down the beach face to be deposited at the toe of the beach. It is subsequently redistributed along the frontage, eventually being deposited at the collection point on the western side of each rock structure. In addition, coarse beach material is also displaced from the upper section of the profile and is pushed up to – and in some cases over – the primary defence and onto the maintenance gangway behind. In these cases a ramping effect is displayed, allowing subsequent waves to run up the beach, over the primary defence, reaching the secondary sea defence behind.



8. Following a storm event material is pushed up to the top of the beach

1. Complete beach recharge following on from the Hythe to Folkestone Coastal Protection Scheme, 04. Profile over charged.

3. Just after a recycling event, restoring beach crest width to design standards

2. Storm event, the frontage experiences heavy erosion within a period of two months.

4. Two high energy storm events reduce crest level to an emergency level.

5. Emergency recycling works undertaken to rectify storm damage.

6. Post storm survey Oct 07, approaching the emergency level reached in December 2006

7. Following a storm event material is deposited at the toe of the beach

Figure 32 SANDS plot at St Leonards Road (west cell 1), showing recycling events (pre & post) and post-storm surveys

Following a storm event, the more frequent low energy waves transport material deposited at the beach toe further up the profile, thus eventually forming a berm. If this profile is not artificially managed, the excess shingle in the upper section of the profile is not drawn back down the profile and instead remains up against the primary defence. In turn, the beach crest width is reduced and the standard of protection is lowered. See Figure 33 below.

a: Crest Width after recycling approx. 20m crest width, Beach Level 4.6m OD

b: Crest Width after storm event (2007) approx. 0m, shingle pushed against the seawall and beach level significantly lowered.

c: Current Crest Width after storm event approx. 0m, shingle depleted from base of seawall exposing foundations to wave action.

Figure 33 Showing the profile after (a) recycling and (b & c) after two consecutive storm events

Collating this information has led to the conclusion that re-profiling the beach to a specified gradient is both expensive and unnecessary. Instead, by allowing end-tipped material to form its own gradient and by adjusting the deposited material mechanically to a design height only, a natural gradient is eventually established whilst maintaining the desired 1-in-200-year standard of protection.

4.2.2 Alternative method of placement at the deposition site

In addition to the conclusions drawn from the beach profile data above, this section will use volumetric analysis to consider the effects of end tipping material (using a less formal method of placement). This method of analysis allows the practitioner to observe more comprehensibly how and where the newly-deposited material is naturally redistributed over time.

Stage 1

In the first stage of the research period, material from cell 1 was deposited in one concentrated location in the form of a large stockpile, as seen in Figure 34. This material was levelled by a bulldozer and allowed to find a natural gradient, as described above.

The stockpile was made up of approximately 1000m^3 of coarse beach material, recycled from an extraction site 500m to the east (west of rock structure A). The stockpile protruded seawards of the natural crest line and was not sheltered by any man-made structure.

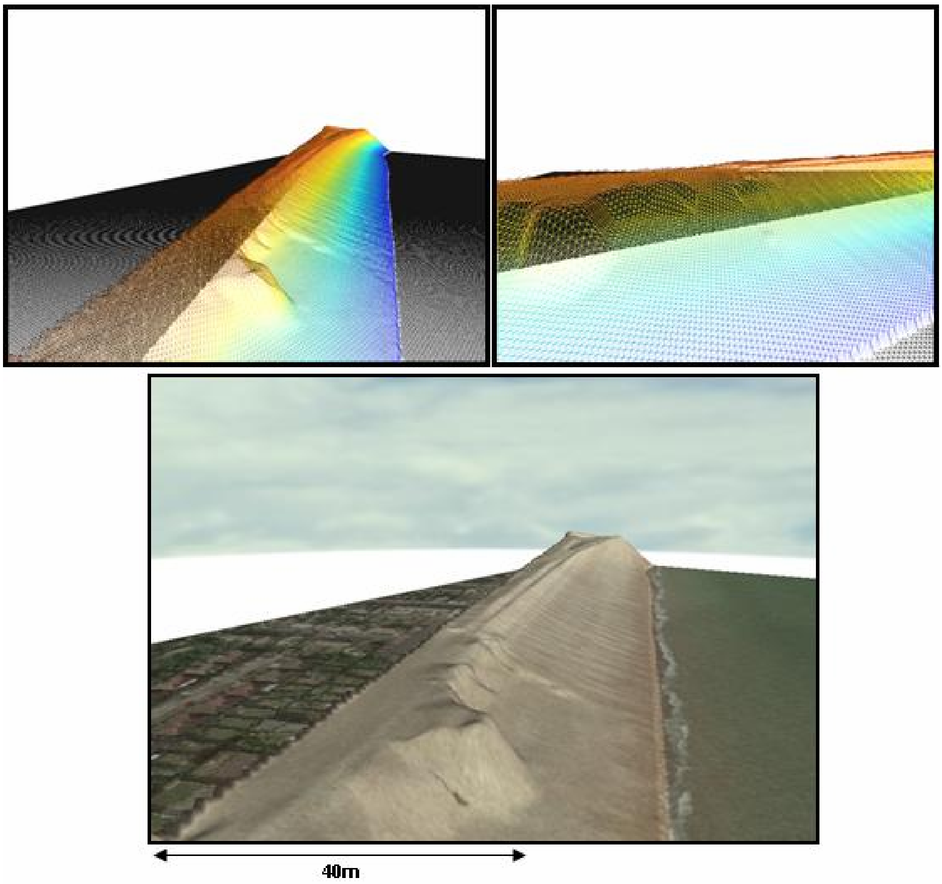


Figure 34 DTM of site showing stockpile in cell 1

It was initially envisaged that the stockpile would remain in place for several weeks, slowly being eroded and redistributed along the frontage. However, following the initial placement, the whole frontage was subject to a relatively small storm event, with waves approaching from a south-south west direction. The storm lasted for approximately two and a half days, with waves reaching 1.66m Hs (wave max = 2.72m).

After the first day of the storm, almost all evidence that the stockpile had existed had been washed away. This initial impression was confirmed three days later, when a post-storm survey was conducted. This survey found that there was no remaining evidence that the stockpile had ever been created.

As can be seen from the volumetric analysis (Figure 35), the material had been redistributed along the frontage, finally being trapped on the western side of the rock groyne – 500m east of the original deposition site.

Figure 35 Volumetric analysis – a cut/fill model showing stockpile redistributed along the frontage

When compared to the erosion on the neighbouring control beach (recycled using the former method of depositing the beach material along a large 150m line), it was clear that the stockpile had in fact increased the erosion rate by providing a readily-available source of material for transport.

The experiment was repeated over the next two phases of the research project: each time, the stockpile was eroded at a more accelerated rate than had previously been experienced at the site when using traditional recycling methods.

Although the stockpile always lasted longer than the first storm event example, it was found that as the wave energy increased, the rate of stockpile erosion also increased. From these findings, it became possible to draw two main conclusions.

It was clear from the survey results and subsequent volumetric analysis that any material deposited in a concentrated area (protruding seaward of the natural crest line) would quickly, within 2–3 tidal cycles, be eroded to a more natural plan shape.

Despite the stockpile being initially eroded, once the material was distributed along the frontage it would remain there until subject to a storm of a significant magnitude (Force 6 and above).

Stage 2

During the second phase of the research project, this experiment was reversed. Once cell 1 (variable) and cell 2 (control) had re-established their original orientation, the experiment was reversed to see what difference, if any, placing a stockpile of material in the shelter of a rock groyne would make. This meant that cell 1 was now being used as the control bay (to be recycled using the traditional method), whilst cell 2 became the variable beach.

As in phase 1, the recycled material was stockpiled in a concentrated location, but this time in the shelter of rock groyne A (see Figure 36). In contrast to the results observed in phase 1, the stockpile did manage to remain in place for a longer period of time when deposited in the shelter of the rock groyne.

Figure 36 Stockpile being placed at Stade Street, in the shelter of groyne A

During the beginning of phase 2 of the research project, no storms of a significant magnitude were experienced. However, it was observed that despite a small amount of initially-deposited material being redistributed along the frontage, the stockpile was not reduced at the same rate as had occurred at the open beach location. In fact, when a storm of significant magnitude did occur, there was less evidence of erosion at the study beach than at the control beach. Therefore, though the majority of the study beach stockpile was redistributed along the frontage, there was significantly less erosion at the eastern end of the study beach in comparison to the control beach. The conclusion drawn from these findings was that the stockpile provided a greater amount of protection than would have been afforded by the traditional method of recycling.

As a result of the findings of this trial, the same method of material placement was adopted further along the frontage in cell 5. The main difference at this location was the orientation of the frontage – which changes from an alignment of 170° on the western side of the groyne to an alignment of 150° on the eastern side of the groyne. See Figure 5.

Due to this change in alignment, it was found that regardless of the method of placement and the size of the material being placed, the rate of erosion could not be influenced – only changing according to the magnitude of the wave energy.

So, in summary, it can be inferred from the above results that on an open beach the most successful method of placement is to deposit material along a large section of the beach (longitudinally). The material can still be end tipped, unprofiled and levelled to a crest height only, but it needs to be deposited in a number of locations, not in one concentrated area.

Conversely, when a control structure is present and the material is deposited in the shelter of that control structure – in a concentrated location – it appears to remain there for a longer period of time. This is possibly due to the sheltering effects of the control structure. However, during very rough weather the material is still eroded, albeit at a reduced rate.

However, it must be noted that when the alignment of the frontage changes, none of these factors –the size of the deposited material, the type of placement, whether or not it is placed in the shelter of a control structure – appears to have a significant effect on reducing the sediment transport rate. In this case, the rate of erosion of the deposited material is mainly dependant on the magnitude of the approaching wave energy.

4.2.3 Comparison of performance between existing and newly renourished beaches

Initial loss of fines over the project duration

In order to ascertain the percentage loss of fines over the project duration, two methods were employed. First, sediment samples were extracted from the beach at fixed locations over the study period and were subsequently analysed, producing grading curves for each specific location. Second, volumetric calculations were carried out using the results of regular topographic surveys of the beaches. This was done in order to draw comparisons between the volumes of beach material in each study cell. By comparing the results from the newly-renourished beaches with those from the existing native beaches, it was possible to infer whether the loss of beach material was due to fine material being washed out of the beach or simply a result of material being redistributed between study cells.

Initially, due to a period of calm weather, the migration of fine material out of the newly-renourished beaches was slow. Neither the control (native) beaches nor the study (newly-renourished) beaches experienced any significant sediment loss and beach volumes remained healthy.

Sediment samples analysed at the selected locations identified a mixed distribution of fine material in the newly-renourished beaches. At the same time, the samples extracted from the native beaches showed a more uniform sediment distribution – with larger material in the upper sections of the beach becoming progressively finer moving through the beach structure. This provided evidence of a greater degree of natural sorting in the native beaches.

However, as the frontage experienced more severe weather conditions and higher incident wave energy, the newly-renourished beaches began to display a greater degree of sorting – in line with the native beaches. The beach volumes in the newly-renourished beaches began to decrease, while remaining constant in the native beaches, as fine material began to migrate out of the beach and move offshore. Beach samples taken from the renourished beaches in the later stages of the study began to show a large percentage of fine material in the lower profile of the beach, with the beach profile displaying a shallower gradient.

Sediment sampling analysis continued to show a high percentage of fines trapped in the upper section of the newly-renourished beach profile, untouched by frequent wave action. However, as storms of greater magnitudes reached the frontage towards the end of the study period, the larger waves began to wash through the upper sections of the beach, releasing the finer material. During these larger storm events, the beaches were eroded to such a degree that the fine sediment trapped in the upper beach was released into the system. Once again, beach volumes in the newly renourished beaches began to fall more than those in the control beach.

The upper beach did experience slight cliffing (3–4cm in height) but this was not deemed significant, and the subsequent high tides covered the cliffing with a layer of coarser material.

The initial loss of fines was anticipated and compensated for by over-placing the renourished beach material. As a result, although there was a decrease in the volume of beach material in the newly-renourished beaches, beach levels remained healthy and well above minimally-acceptable volumes. As a result of the dynamic nature of the frontage and the high wave energy experienced, the newly renourished beaches have been naturally sorted at an unexpectedly accelerated rate, bringing them in line with the more mature native beaches. This means that the standard of defence offered by the newly-renourished beaches is comparable with that offered by the native beaches.

As expected, in areas where the wave energy is at its highest, the greatest degree of sorting and the highest loss of fines were observed (see Figure 37).

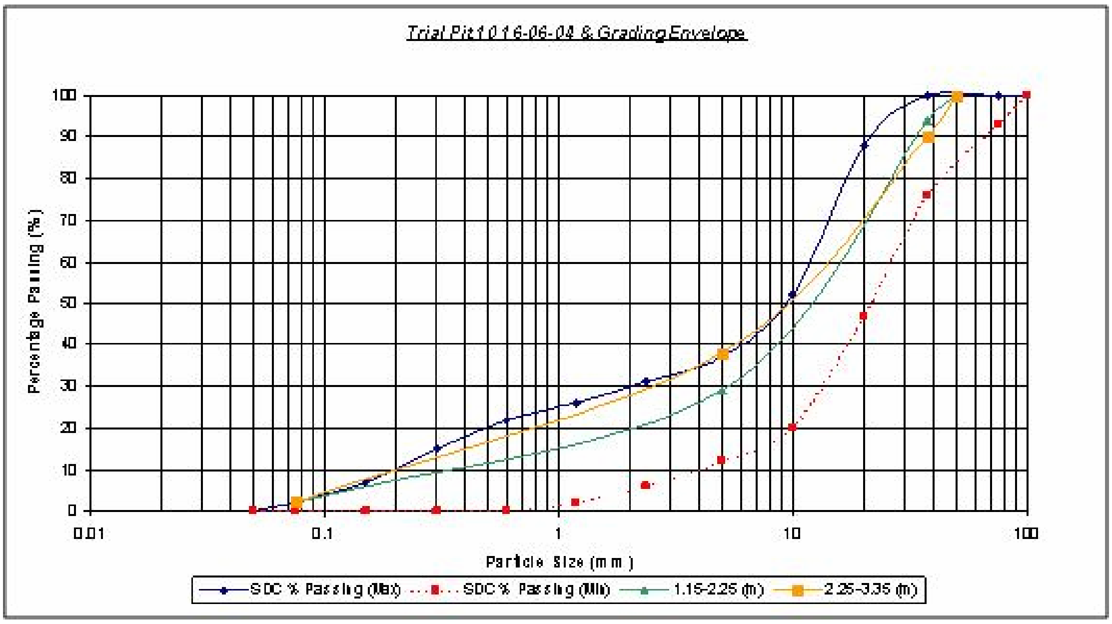


Figure 37 A typical example of the grading curve produced following sediment sampling (the red and blue lines indicate the grading envelope)

Modification of shingle grading on the active veneer of the beach

One of the initial aims of the research project was to investigate whether coarser sediment could be encouraged to stay in active circulation, thereby reducing drift rates along the frontage. Former observations allowed SDC to identify that the larger sediment appeared to remain at the back of the beach, lying dormant against the rock groynes at the down drift collection points. Therefore, it was suggested that by varying the method of recycling – and the location of the extraction site – coarser beach material could be collected and redistributed, leaving the finer material behind.

In order to develop this theory, beach samples were taken at selective locations throughout the project duration (as described in the previous section).

Carrying out this initial sediment sampling at both the variable (newly-renourished) beach and the control (native) beach produced a clear picture of the beach structure.

During the 2004 coast protection scheme, marine contractors (Van Oord) were required to supply grading curves based on regular sediment samples taken from the marine-dredged material being pumped ashore. It was decided that due to the vast quantities of data supplied by the contractor, a good starting point would be to cross-check these results independently in order to obtain some knowledge of the composition of the beach at the placement stage. This also allowed the contractor's findings to be verified.

All of SDC's sediment samples were taken at the same locations as the contractor's sampling sites (see Figure 38), allowing for a direct comparison of results. This comparison revealed a good match between the current findings and the contractor's findings. Comparing the initial samples highlighted that the contractor's grading curves were accurate and could therefore be used as a baseline. It also gave a good indication of the composition of the sediment pumped ashore (average D_{50}) and what percentage of fines were present in the beach structure.

As subsequent grading curves were produced from the regular samples, this reinforced the findings suggested in the previous section. The results indicated that the fine beach material is quickly sorted, and is either removed from the system (if too fine) or redistributed and deposited at the toe of the beach.

Furthermore, visual observations taken from inside the trial pits, together with an analysis of the associated samples taken at these fixed locations (along the beach profile), produced some interesting results.

Based on previous visual observations of the native beach, the coarser beach material appeared to be distributed over the whole beach as a veneer, mainly concentrated on the active face of the beach. However, the depth to which this veneer extended was unknown and further investigation was required. After analysing the results taken from the control beach, it became evident that the veneer was much thinner than initially suspected, with a coarse layer of shingle only 1–2m deep. Moreover, analysis revealed that the samples taken at the trial pits on the surface and at 1m and 2m below the surface showed similar characteristics – regardless of the location along the control beach. Larger sediment could be found at the top of the beach, becoming progressively finer moving down through the beach structure. Adjacent samples taken near the toe of the beach coincided with the findings taken from the 2m+ trial pits, indicating that the beach is layered in structure.

Figure 38 Photographs showing trial pits and sediment samples being taken

In contrast, there was no evidence that the newly-renourished beach was structured in such a way. In fact, despite a relatively fine layer of coarser material (approximately 0.5m thick) deposited on the surface on the beach, the findings showed that the samples taken from the newly-renourished beaches were mixed – the fine sediment mixed in with larger sized material.

However, as the research progressed, it became evident that constant wave action and over-washing was beginning to sort the beach. The very fine material found in original samples was no longer present, with both the surface samples and the samples taken at 1m depth containing less fine material. Conversely, the samples taken on the lower beach contained more fine material, as did the deep 2m samples.

Furthermore, it was also found that more fines were released into the system following a storm event. This also occurred after any beach management works that disturbed the structure of the beach.

Sediment samples and subsequent analysis of the results provided some sound information on the structure of both the control beach and the newly-renourished study beach. Sampling also highlighted that there is only a very thin veneer of large material (approximately 1m in thickness) at the extraction site.

The practicalities of recycling beaches using heavy plant machinery make it uneconomical to spend vast amounts of time digging for larger material; it also makes the logistics of loading the dump trucks extremely difficult. As a result, the idea of altering the extraction location was dismissed.

In essence, searching for coarser material slows down the process of beach recycling. Because of the large quantities of material required, it is simply not economically viable to recycle the beach in such a way.

Furthermore, there was an opportunity to test the theory that beach material with a large D_{50} is transported at a slower rate by wave action than sediment with a small D_{50}. During the research project, cell 5 experienced a significant amount of erosion, so much so that it prevented the heavy plant machinery from accessing the cell due to the large drop in beach levels next to the newly constructed rock groyne (see Figure 39). Cell 5 was renourished with beach material containing a high percentage of fines. Due to the change in the alignment of the beach at this location, the drift rates were significantly increased. As a result, the beach was regularly washed at most states of the tide. This not only led to the beach eroding dramatically at the western end of the cell, but meant that relatively little fine material remained in the beach.

Figure 39 Photographs showing the dramatic storms and subsequent erosion east of groyne B (cell 5).

To allow the beach to be reinstated and to permit heavy plant machinery to access cell 5, large material from the neighbouring native beach (cell 4) was tipped over the groyne. This material had a very large D_{50}, in excess of 20mm, and over 1000m^3 was deposited into cell 5. In addition, the now washed and beached material (which had become trapped by the large rock headland to the east of the cell) only consisted of large sediment, with no fine material present. As such, this material was recycled back to the western section of the cell, forming a large stockpile next to the groyne (following the success of the previous experiments).

The belief was that this large stockpile, consisting of beach material with a very large D_{50}, would remain in the shelter of the groyne for several months. However, despite a relatively stable period during which the tides re-graded the face of the stockpile, a storm event occurred the following week and removed all of the newly-deposited material. Over 10,000m^3 of beach material was removed within a 24-hour period within the cell. Due to the large size of the sediment, it proved difficult for the following low energy easterly waves to push the sediment back up the beach.

The experiment was repeated on two more occasions over the study period: both times, the same results were found following relatively mild storm conditions. Therefore, it can be confidently concluded that under stormy conditions shingle size does not appear to make a significant difference to the sediment transport rate. This is because all of the material, regardless of size, was redistributed. However, it is questionable whether further consideration should be paid to the placement of finer material. This is because it may be more beneficial to place finer material anywhere, since it may move more freely back and forth along the frontage under more moderate wave conditions (easterly wave conditions, against the net drift direction).

Potential for Cost Savings

In order to ascertain whether any cost savings can be made, it is first important to understand what costs are associated with the current beach management contract. Some of the most significant costs of the contract include the mobilisation of heavy plant to and from site, the associated health and safety that is required and the client supervision costs.

One of the main questions that was raised at the beginning of this research project was whether the frequency that the recycling operation was carried out was suitable, or whether any savings could be made be varying the number of times recycling is carried out per year.

It can be argued, for example, that recycling several times a year, for a shorter period of time during each operation, is more cost effective than one large recycling operation lasting for several weeks (carried out on an annual basis). As the machines are required to be on the beach for less time during these shorter beach works, the plant hire costs are reduced. Likewise, re-profiling the beach more regularly during these works would enable material that has accumulated against the front of the seawall to be redistributed more readily. This would form a wider beach crest that would remain throughout the year. As such, the beach crest would be less likely to erode back to the seawall, as is the case when the traditional bi-annual recycling method is undertaken. However, the associated cost of remobilising the plant for each operation, in addition to the increase in supervision and health and safety costs, it far out ways any cost savings that can be made by recycling larger quantities of beach material on a less frequent basis.

Therefore, it can be concluded that it is not cost effective to recycle the beach more frequently than twice a year. However, the question that needs to be raised is, what if the beach recycling is carried out on a less frequent basis, say once every 2 years, are there any savings to be made?

Despite the obvious fact that the cost of the mobilisation will be lower, the implications for recycling less frequently need to be investigated. In order to maintain a high standard of protection along the frontage a larger quantity of material will be required to be moved, to compensate for the large movement of sediment over the two-year period that the beach has remained unmanaged. This will inevitably drive the cost up. The results have shown from this research project, that despite recycling a large quantity of beach material, the rate of sediment transport is very dependant on weather conditions and the associated wave climate. If the rate of sediment transport is very high in any one year, a large amount of material will erode at the western extent of each bay. As such, the standard of protection at that location will fall and this potentially leaves the beach vulnerable to wave attack until the next recycling operation. By recycling less than twice a year it potentially provides savings, but increases the potential risk of reducing the standard of the beach.

So if the cost of recycling more than twice per year is too high, and recycling less frequently than twice a year potentially compromises the standard of protection across the frontage, it can be concluded that bi-annual recycling is the most suitable method for this frontage. By recycling the beach twice a year, once in September, (before the winter storms) and again in March, the beach is reinstated following the winter storms and a high standard of protection is maintained year round.

Therefore, if the frequency of the recycling operation remains constant, it is necessary for different methods of recycling to be explored to ascertain whether cost savings can be made. One answer would be to recycle using a less formal method of placement. This would enable supervision costs to be reduced and more beach material to be placed, as the turn around time is reduced.

5 Conclusion

5.1 Tankerton Beach renourishment

An anticipated loss of finer material in the early stages of beach development was supported by a number of visual observations at Tankerton. A slick of fine material was clearly visible leaching from the beach during the high tide cycles following replenishment. During the first month, there were also deposits of fine sand at the foot of the beach. These were observed being washed offshore by water draining out of the beach as the high tide receded. After the first month, the beach face appeared visibly coarser and over time the sandy deposits at the foot of the beach disappeared. These were temporarily replaced by a coarser, grit-like angular material that was expelled from the beach. As the groyne bays were subjected to the driving forces of wave and tidal action, the beach berms re-orientated in line with the dominant wave direction. Cliffing was observed as a major problem in the fine bay, but was less apparent in the other bays and almost non-existent in the coarse and capped bays.

Sediment sampling supported the observations and showed a marked reduction in fines within the surface layer of the active beach face. This trait was consistent with all future observations. Previous research on the evolution of the first two phases of the experiment theorised that replenished beaches evolve a similar sediment profile to the native beach, in terms of the amount of finer material present. It was suggested that this could be a function of the hydraulic climate. Although sampling in this experiment demonstrated an initial reduction in material with a $D_{50} < 5$mm, especially in the upper beach, results over the course of the experiment were highly variable. It is not thought this can be attributed to the accuracy of the sampling methodology because the results are consistent for each location, with increases and decreases in fine content mirrored in each of the sample bays over time.

There is plenty of fine-grained sediment offshore from this beach: some of this will be washed into the permeable beach sediments during the rising tide and some will be washed out again during the falling tide. The net balance of these amounts will vary depending on the wave and tide conditions, as well as on the available sediment. It has been theorised that larger waves and storm events result in a net loss of finer material, typically over the winter period, whereas the more sedate summer climate results in an increase in the beach fine content. Whilst results from this research support this theory, they are too sporadic to prove it categorically.

One of the key controlling factors of beach permeability is the fine content of the beach. Results show that a mature beach (replenished over five years ago) has a consistent reaction to the effects of a rising tide. The beach ground water level increases rapidly at the front of the beach, with rises of a lower magnitude moving back through the beach. This reflects a fairly permeable front or active part of the beach face, with decreasing permeability at the back and lower beach. However, even in a mature beach, the ground water level never drains completely before the return of the rising tide.

Readings from the newly-replenished beach demonstrated completely different characteristics. Variations in ground water levels were minimal, with a magnitude of less than 500mm; all boreholes rose and fell by the same amount and at the same time. This highlights the huge reduction in permeability of dredged sediments when compared to an adjacent mature beach. As a consequence, when it is first placed, the replenished beach is less effective at dissipating wave energy, produces a reduced dynamic response to hydraulic conditions and is vulnerable to undesirable effects such as cliffing.

In contrast to water level readings in the standard bay, the ‘capped’ bay produced greater fluctuations in the lower beach, although not as great as the mature beach. This increase in the permeability of the beach face is thought to be the reason that no cliffing was observed in this bay. Over time, the amplitude of water level fluctuations increased, undoubtedly in response to the loss of finer material as the beach evolved. It is believed that the most significant changes occurred over the first winter and were largely as a consequence of increased wave action and storm events. By the time the beach was a year old, water level fluctuations were comparable to those on the mature beach.

Volume losses were significantly different for each type of material. Initially, the largest losses occurred in the fine bay. There was also a significant loss in the capped bay, but this was largely attributed to the settlement of the coarse cap, with fine sediment filling the large proportion of voids between the coarse, highly-sorted shingle. The most significant losses occurred over the first winter in all of the bays, which was undoubtedly a response to the increased wave climate and storm events. It’s likely that these losses mainly involved fines, as supported by the increase in permeability shown by the water level monitoring.

Despite the beach overtopping groynes in places and the bays not acting as discrete units after the first winter, total losses in profile cross-sectional area after three years of the experiment were 6–13m^2. The coarse material performed the best, with the fine material losing double the amount. It is theorised that larger than expected losses in the recycled bay were due to the material having a greater propensity for sediment transport, due to a combination of its shape, geological characteristics and size. Further sampling and analysis would need to be conducted to verify this. It is also proposed that volumetric losses at the capped bay may not have been entirely due to erosion, but were also partially the result of settlement.

To put these results into context, losses witnessed on the mature beach were only 2m^2 over the same period. In monetary terms, the difference in the quantity of extra shingle lost at the fine bay, compared to the coarse bay, equates to approximately £5,000 (2004 as placed rate). In addition to the increase in the erosion rate, the finer material was also subject to cliffing, a larger reduction in berm width, seaward migration of the beach toe and the development of a shallower beach face gradient. All of these characteristics are undesirable and also affect the performance of the beach as a sea defence. It is also believed that, in future, the fine bay may be subject to higher losses when storms move the beach and are able to sort the relatively unaffected sections at the back of the beach.

5.2 Hythe Beach renourishment

This research project has produced some interesting findings with regards to the amount and type of material that needs to be moved in order to retain the necessary standard of protection.

This research project has shown that it is both expensive and unnecessary to re-profile the beach to an exact gradient. Instead, it is far more cost effective to level the beach to a design height only and allow the subsequent tides to reshape the beach profile naturally. Similarly, it has been found that by informally end tipping material in a stockpile at specific locations, the speed of the recycling process can be increased. This allows a greater quantity of material to be recycled and permits a large source of material to be eroded over a longer period of time, thus maintaining the standard of protection.

The beach management contract is based on day rates, rather than on the quantity of material moved. Therefore, by increasing the volume of material moved each day, no direct cost savings are made. However, the overall length of time that the plant machinery is required to be on-site may be reduced, as a sufficient amount of material is recycled over a shorter period of time. This time saving, coupled with the reduced supervision time, should be reflected in cost savings.

This research project has identified that not only is it more time consuming to try to recycle large beach material selectively, but that it has little effect on reducing the sediment transport rate along the frontage. Therefore, it can be concluded that it is more cost effective to extract material using traditional methods of recycling, but to deposit this material using the new methods identified in the project.

6 Practical Guidance

6.1 Replenishment

Sediment composition of offshore dredged material has a significant effect on the performance of newly replenished beaches and the expected scheme lifespan.

In practical terms scheme design should take into consideration the following;

Removing a coarse layer of native beach material and using it as a ‘cap’ for the replenished material does improve the initial beach performance, however these benefits are relatively short lived and in no way compensate for the additional costs of the labour intensive beach placement.

Sediment sampling results from Tankerton and Folkestone demonstrated that ‘mature’ (over five years old) mixed sand and shingle beaches were highly sorted. These comprised coarse surface layers with very little fines around the upper beach and an increasing fine content as you moved down to the core of the beach and out to the beach toe.

Dredged material typically has a significantly higher proportion of fine material that results in a reduction in permeability, enhanced erosion rates, reduction in the maximum stable beach gradient and cliffing of the beach face. Results from the Tankerton experiments demonstrated that these negative effects increased the finer the recharge material.

It has been common practice to use overfill ratios (SPM, 1984) to compensate for finer material by simply replenishing more. Results from this research would suggest that, for mixed shingle beaches, these underestimate the extra volume of material that is required to produce a scheme performance consistent with the more desirable coarse material.

Beaches at both sites mainly evolved over the first winter period, resulting in a loss of fines with a corresponding increase in permeability and a more dynamic beach response to wave action. Despite this the relatively undisturbed parts at the back of the beach remain unsorted, thus future losses are inevitable when these areas are finally uncovered by storm events.

It is therefore critical that a suitable grading envelope is specified for beach replenishment schemes in order to maintain the design beach and for the scheme to fulfil its predicted lifespan. Delivered sediment should also be sampled on delivery to ensure compliance. Although the cost of recharge material is largely dependant on the relative location of the dredging grounds to the beach the extra cost of using a more suitable site, or screening material, should be considered. The benefits of reduced erosion rates and superior beach performance should more than justify the increased expense.

6.2 Recycling

Where recycling is possible it reflects a much more viable option of increasing the defence standard, typically around a tenth of the cost of replenishing the beach with an equivalent quantity of dredged material. Whilst a replenishment scheme is a one off event, introducing a specified quantity of sediment, recycling operations form part of an on-going beach management process. The optimal frequency and duration of which are largely dictated by the prevalent weather conditions and hydrodynamic climate.

The conclusions of this project support the following practical guidance;

Attempting to locate and only recycle coarser material is viewed as impractical and uneconomical.

Placement of recycled material as a single stockpile, as opposed to spreading the material along the frontage, and allowing natural processes to redistribute the shingle along the coastline actually increased the erosion rate by providing a source of material that was readily available to be transported. It was concluded this technique, on an open beach, was less beneficial than the standard recycling methodology.

Beach recycling does not – and cannot – always coincide with a mean low water spring tide. As a result at sites like Folkestone, where the beach toe is located below MLWN, it is impractical to create an artificial profile down to the beach toe.

Recycling material and manipulating it to conform to a design beach with a pre-determined gradient is a labour intensive process. Research has shown that end tipping material to a design crest level and allowing the beach to naturally evolve a stable gradient was much more cost effective. This can either reduce the overall cost of recycling operations, or alternatively allow for a much greater volume of shingle to be recycled using the same budget.

Optimal recycling frequency along the Hythe to Folkestone frontage was found to be twice a year. Recycling at a higher frequency was deemed prohibitively expensive due to the high mobilisation costs associated with each event. Conversely recycling less than twice a year would result in an unacceptable reduction in the defence standard.

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