



LONGSHORE DRIFT ON THE SUSSEX, KENT & PICARDIE COASTS:
PRELIMINARY NOTES ON THE BAR NATURAL AND RESIN TRACER
EXPERIMENTS

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1 The Sussex and Kent experiments

1.1 Summary

New experiments were started in October 2004 to determine rates of longshore transport of shingle along the Sussex and Kent coasts using white limestone cobbles as natural tracers. The cobbles closely match the natural flint pebbles in density and size (B-axes ranging from 60 to 100 mm). The experiments compliment the ongoing BAR work with resin tracer pebbles and provide an opportunity to investigate longer-term transport rates.

Three keys sites have been selected where longshore drift is unrestricted by groynes. Birling Gap in East Sussex is a very exposed location, whereas St Margaret's Bay and Deal in Kent are relatively sheltered. At each site 300 cobbles have been deployed in a linear transect across the beach starting near the high water mark.

The direction and amounts of cobble movement at the three sites are clearly dependent on wave conditions. Even though the cobbles can be detected only when they happen to be on the surface of the beach, they provide a useful guide to rates of longshore transport.

The experiment demonstrates the need to make long term measurements in order to estimate the net annual movement of beach material. Whilst short term experiments, such as this, can accurately link pebble movement with wave parameters, they are liable to miss important counter-movements of beach material or may in fact, only measure the counter movement.

1.2 Introduction

Longshore drift along the Sussex and Kent coast is usually from west to east because most of the coast is exposed to storm winds and waves advancing up the Channel from the west or south-west. As a result of this longshore drift, shingle tends to accumulate on the west side of groynes and harbour arms. However, reverse drift movements ("counter drift") are observed when winds blow from the east or south-east. In addition, sections of coast that are sheltered from the prevailing westerly or south-westerly winds experience southward drift, for example the east side of Dungeness and Thanet.

For coastal management purposes, rates of longshore drift are usually estimated using the CERC formula or a substitute (Morfett *et al.*, 1996; VanWellen *et al.*, 2000). Few attempts have been made to check the accuracy of these estimates because the actual measurement of longshore drift is beset with practical difficulties. In fact only two large-scale studies have been made with tracer pebbles on the Sussex and Kent coast:

1.3 Previous experiments at Elmer and Shoreham, West Sussex

Bray *et al.* (1996) conducted trials of aluminium pebbles (32-46 mm 'b' axis) on Shoreham beach in June and September to October 1995. The beach provides a good study site as it is free of groynes for a distance of 1.5 km. It was found that the pebbles could be re-located at depths of up to 0.3 m below the surface using a metal detector. Additional trials were conducted using much smaller aluminium pebbles (7-30 mm), natural flint pebbles coated in fluorescent paint and 'smart' pebbles fitted with an electronic transmitter system. Transport rates of around 10m³/tide were recorded with low energy waves, increasing to 150m³/tide with medium energy waves, and 300m³/tide in the case of the sole observed high-energy event. In order to arrive at these estimates, assumptions had to be made about the depth of shingle that had moved.

Additional measurements of longshore drift and on/offshore movement were made at Elmer in October/November 1995 (Cooper *et al.*, 1996; Cooper, 1997). Rapid coastal erosion at this site had necessitated major protection works. The beach had been artificially recharged with flint shingle dredged from the floor of the Channel and protected by the construction of a series of offshore rock islands, which greatly reduced wave energy. Both coarse and fine aluminium pebbles were deployed together with fluorescent-coated natural flint pebbles. Drift rates of just under 60m³/tide were observed during medium energy wave conditions (SW F4/5/6). It was concluded that the rates were less than half of those occurring on the open beach at Shoreham (King *et al.*, 1996).

Recovery rates for aluminium pebbles were much higher than for the fluorescent pebbles, but the distances travelled were similar. Coarse pebbles moved further than fine tracers during high-energy wave events, but not during medium-energy wave events.

1.4 Previous experiments at Rye Harbour, Dungeness and Deal

In 1959-60 very labour-intensive experiments were conducted on the beach near Rye Harbour using pieces of crushed concrete containing fluorescent minerals. These pieces were similar in size to natural flint pebbles, but were presumably more angular in shape. The beaches were re-seeded at regular intervals, and the depth of transport ("active layer") was estimated from laboratory experiments. The volume of longshore drift eastwards over a 22 week study period was determined to be about 880 tons per week and over a 52 week period about 590 tons per week, i.e. about 31,000 tons a year. This represents about 60% of the rate obtained by direct measurement of the rate of beach accretion (Russell, 1960). At Dungeness the rate over a 33-week study period was about 1770 tons per week eastwards, while at Deal over a period of 22 days the rate was relatively low, around 31 tons per day northwards (Russell, 1960; Anon, 1962).¹ In 22 weeks the majority of the pieces at Rye Harbour moved between 0 and 300 m, but the furthest travelled 900 m or more along the beach.

1.5 The BAR experiments

Following Executive Committee discussions, it was agreed to gather data to determine:

- A. The effects of different wave heights and wave directions on longshore pebble movement.
- B. Actual long-term rates of drift at selected sites.

Objective A was achieved by seeding beaches with artificial pebbles made of resin with copper cores, which can be re-located using a metal detector (Dornbusch, April 2004). The tracers needed to be re-located at frequent (daily or weekly) intervals. If the time intervals were too long, the pebbles became increasingly spread out and thus more and more difficult to find because of the limited range of the metal detector. Also the wave environments are liable to change greatly, making it impossible to correlate transport rates with specific energy conditions.

Objective B is best achieved by deploying natural tracer pebbles. Painted pebbles suffer the disadvantage that the paint wears off, while resin pebbles with copper cores are difficult and expensive to manufacture in sufficient numbers.

Separate reports document preliminary experiments using resin pebbles at Pevensy Bay and further experiments with resin pebbles undertaken at Pevensy and in France. The

¹ According to Dornbusch (June 2004), Joliffe (1961) reported the annual drift rates as 37,460 m³ at Rye Harbour, 88,000 to 125,000 m³ at Dungeness and ~10,000 m³ at Deal.

present report is concerned solely to describe progress with the realisation of Objective B.

1.6 Choice of tracer

It was decided to use natural cobbles composed of hard, crystalline limestone with diameter ranges from 60 to 100 mm. They have been chosen in preference to other commercially available cobbles because:

- They closely match the natural flint pebbles in density and size.
- They are a uniform white colour, which contrasts well with the darker flint pebbles making them relatively easy to find on the beach surface (Figure 1).
- They are more varied in size than the resin tracers (B axis = 50 to 60 mm) and may therefore yield more realistic rates of longshore drift for the coarser flint cobbles.



Figure 1: Pictures of both tracers used to investigate the longshore transport. A-Picture of a new natural tracer. B-Picture of the resin cobbles.

1.7 Choice of sites

It was planned to seed beaches without groynes (i.e. with unrestricted longshore drift) in exposed and sheltered locations in both Sussex and Kent:

	SUSSEX	KENT
Exposed to SW winds	e.g. Birling Gap or Seaford	e.g. White Cliffs of Dover
Sheltered from SW winds	e.g. Holywell or E. Pevensey/Cooden	e.g. Deal or St Margaret's Bay

Table 1: List of the different sites matching queries necessary to investigate longshore transport on a long term basis. For locations see Figure 2.

Beach seeding took place in October. Seaford beach had to be excluded from the study as the annual beach recycling was said to be imminent. Because the beach beneath the White Cliffs of Dover proved difficult to access, it too was also excluded. Due to time constraints only 3 beaches have been seeded to date:

1.7.1 Birling Gap

The cliffs and shore platform at Birling Gap are cut into Seaford Chalk. It is a natural beach of shingle, oriented WNW-ESE (110 degrees), with basal sand extending from the base of the cliffs over the upper part of the platform. The beach has been known to disappear during storms, but is quickly observed to reappear or 'recover'. Old picture postcards (Figure 4 and Figure 5) suggest that the volume of beach material has remained quasi-constant for more than a century, except when it is temporarily removed during storms. On October 7, 2004, 300 cobbles were laid out under Went Hill (about 320 m west of the steps) in a narrow strip from the head of the beach (~HWM) to the toe; cobble location was recorded using a GPS (Figure 3, Figure 7).



Figure 2: Map of the different sites location (Reproduced from Ordnance Survey of Northern Ireland mapping with the permission of the Director and Chief Executive, © Crown Copyright).

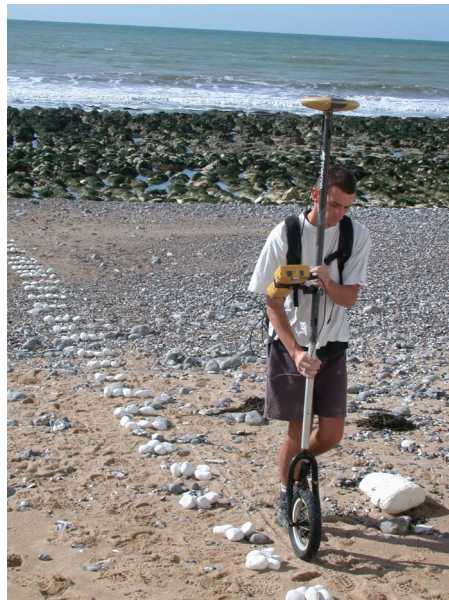


Figure 3: Tracer deployment and location recording.



A



B

Figure 4: Judge's postcard views of Birling Gap, first published in 1910-1912.



Figure 5: Judge's postcard view of Birling Gap, ca. 1960.

1.7.2 St Margaret's Bay

The coast is oriented NE-SW (40 degrees). Most of the beach at St Margaret's Bay has been recharged following continued beach erosion. However, at the north-eastern end, beyond the large terminal groyne, a natural beach of grey flint cobbles rests on a wide chalk shore platform, backed by high cliffs. On October 12, 2004, this site was chosen to deploy 300 tracer cobbles, these were laid out in a strip from HWM (just below the head of the beach) to the toe, in a position about 130 m beyond the terminal groyne (Figure 9).

1.7.3 Sandown Castle, Deal

The beach to the north of the Castle, where the experiments are being carried out, is oriented NNW-SSE (160 degrees) and is backed by low dunes and former marshland. Extensively recharged since the drift experiments of Russell (1960) and Anon (1962), it consists of small brown flint pebbles, resting on chalk that is believed to outcrop on the seabed just offshore. Old photographs suggest that the pebbles of the original beach were about the same size as the recharge pebbles. South of the Castle, an extensive groyne field has been built to protect the Deal frontage. A strip of 300 cobbles was deployed by three iron posts about 350 m north of the Castle (Figure 11). The strip extended from HWM to beyond the second post, i.e. it ended some distance above LWM. No shore platform has been seen, but the beach has yet to be inspected at low water spring tide.



Figure 6: Sandown Castle, ca. 1908 photographed by Levy et Cie., Paris.

1.8 Pebble identification

Initially, when pebbles were re-located, it was not thought necessary to mark them. However, following further discussion, they are now being marked with an identifying pattern of small holes so that the subsequent movement of individual pebbles can be monitored.

1.9 Preliminary results

1.10 Birling Gap



Figure 7: Map location of each tracer recovered along the time.







		Centroid distance east (+) or west (-) of the Injection point	Number of cobbles recovered
	06-12-2004	+12.7 m	15
	30-11-2004	-51 m	17
	22-11-2004	-81 m	5
	20-10-2004	-40 m	18
	16-10-2004	-71 m	7
	07-10-2004	0 m (Deployment)	300 (Deployment)

Table 2: Variation of the centroid position and the number of cobbles recovered along the time.

Given the site's mean south-westerly wind direction, net movement was expected to be to the east. The first results (October 2004, Figure 7), however, recorded a westward drift reaching up to 190 m from the injection point. Further surveys conducted on November and December 2004 showed, on average, an eastward drift with the greatest distance travelled, recorded at 75 m east of the injection point.

The recovery rate at this site was around 7 % for each survey and this was considered sufficient to produce an interpretation. This must however take into account that detection is only made on the beach surface.

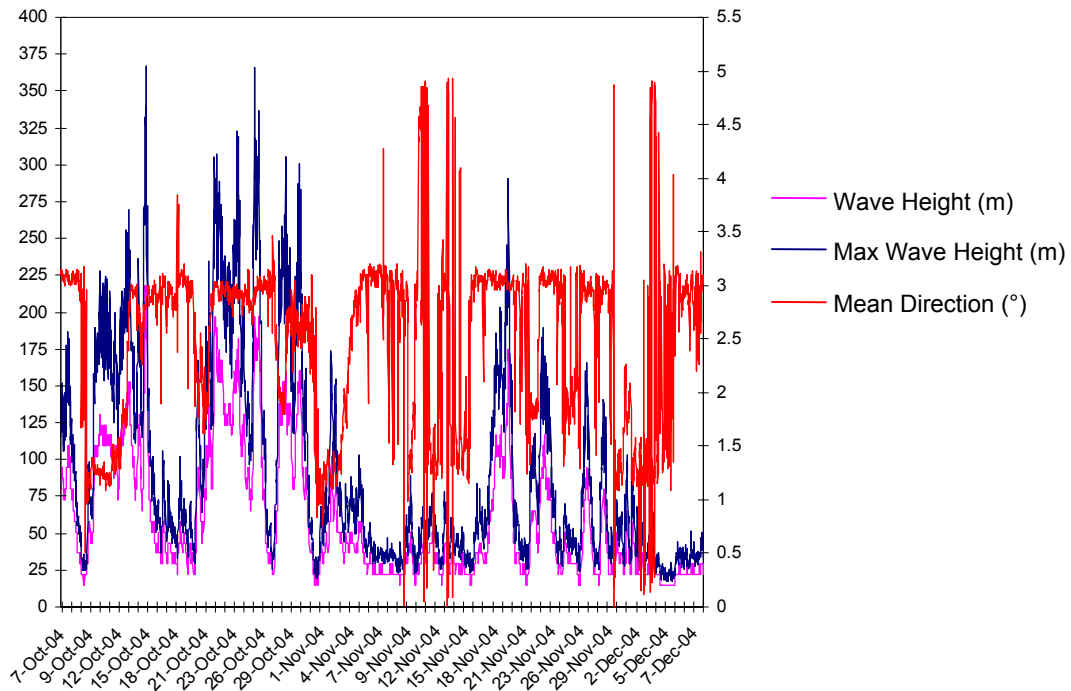


Figure 8: Wave conditions data from The Channel Coastal Observatory's buoy in Pevensey Bay.

These movements can be directly linked to the wave conditions (Figure 8). Westward drift corresponds with wave directions close to 90 degrees, whereas Eastward drift corresponds to the usual wave approach of about 220 degrees. The drift distance appears to be linked to the wave height, with greater movement occurring during rough swells.

When the recovery rate is sufficient (i.e. more than 10 pebbles are recovered) the centroid variation of locations demonstrates that tendency of migration toward the West or the East is a function of the different condition waves.

Although the number of marked pebbles recovered was low, the observations of pebble movement demonstrate that the tracers followed the same trajectories along and across the beach.

1.11 St Margaret's Bay

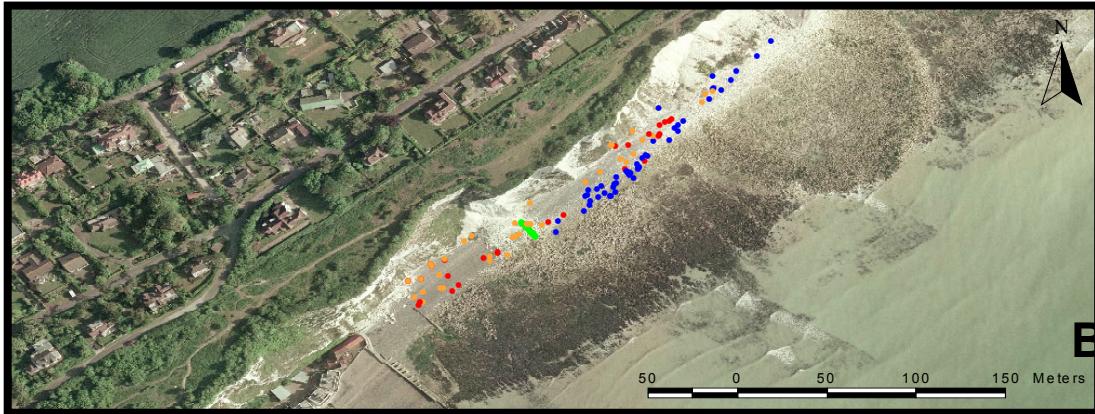


Figure 9: Map location of each tracer recovered along the time.





		Centroid distance east (+) or west (-) of the Injection	Number of cobbles recovered
	07-12-2004	+10.40 m	38
	19-11-2004	+14,20 m	26
	27-10-2004	+83 m	50
	12-10-2004	0 m (Deployment)	300 (Deployment)

Table 3: Variation of the centroid position and the number of cobbles recovered against time.

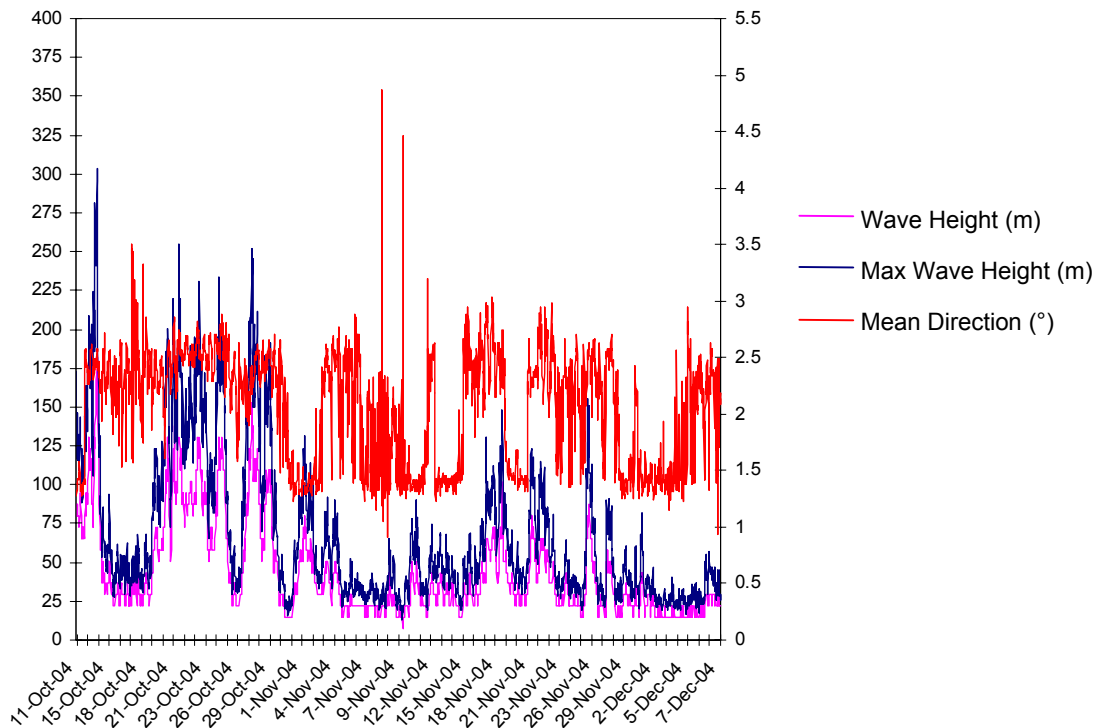


Figure 10: Wave conditions data from The Channel Coastal Observatory's buoy in Folkestone.

The first survey (October 2004, Figure 4) showed a significant north-easterly drift of up to 200 m, corresponding with wave directions close to 175 degrees (Figure 10). The following surveys (November and December 2004, Figure 4) revealed that the tracers had returned to their point of injection and continued in a south-easterly direction for up to 80 m. Waves during this period wave close to 100 degrees.

Variation of the centroid location (Table 3) further demonstrates these observations by remarkable movements northward (83 m) during the first survey followed by a net return toward the injection point during the following surveys.

The recovered rate at this site is relatively significant, close to 17 % in October 2004, when compared to the other sites investigated and to other previous experiments based on surface recovery of tracer pebbles.

Movement observations based on a pebble per pebble basis is more complicated. Some pebbles behave in the same way, with the same amplitude of movement while other pebbles behave completely differently in movement, direction and amplitude. It is hoped that future surveys will better explain these preliminary results.

1.12 Sandown castle, North of Deal

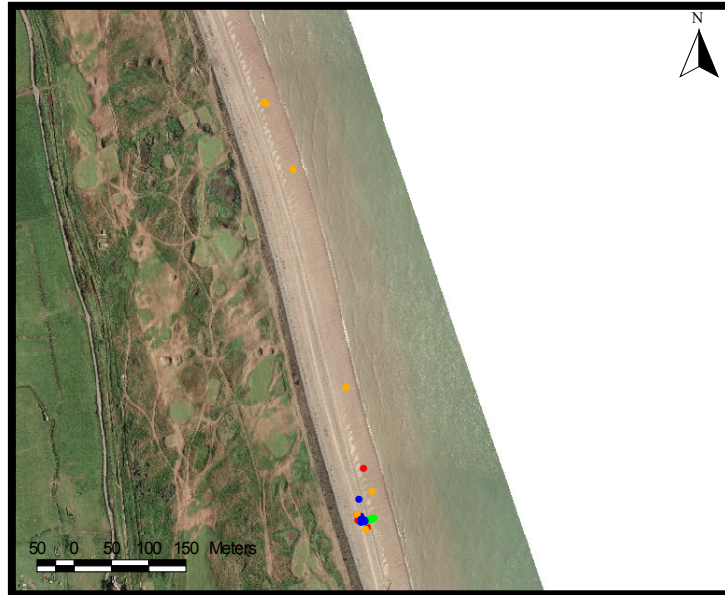


Figure 11: Map location of each tracer recovered along the time.





		Centroid distance east (+) or west (-) of the Injection point	Number of cobbles recovered
	07-12-2004	+245 m	7
	19-11-2004	+17.60 m	4
	27-10-2004	+1.70 m	45
	12-10-2004	0 m (Deployment)	300 (Deployment)

Table 4: Variation of the centroid position and the number of cobbles recovered along the time.

Cobble recovery rates have been lower than at the other two sites for reasons that are presently being investigated. The period October to December 2004 showed very variable amounts of northerly transport with some pebbles moving only very short distances and others moving more than 500 m. Recovery rates at Sandown Castle were very low and this may be due to most of the tracer cobbles becoming buried under a new storm berm. These tracers are considerably larger than the D50 of the artificial recharge material, therefore thought needs to be given to the use of smaller tracers. A second reason could be linked to a large longshore transport rate, which at the moment is responsible for the development of a shingle spit in Sandwich Bay treating the Sand dunes sources at this location.

1.13 Conclusions

The direction and amount of cobble movement at the three sites are clearly dependent on wave conditions. Even though the cobbles can be detected only when they happen to be on the surface of the beach, they provide a useful guide to rates of longshore transport. These observations allow validation of this method (use of limestone tracers and detection only on surface) to investigate rates of longshore transport.

These experiments demonstrate the need to make long-term measurements in order to estimate the net annual movement of beach material. Whilst short-term experiments can accurately link pebble movement with wave parameters, they are liable to miss important counter-movements of beach material or in fact may only measure counter movement. Survey procedure such as these allow for better predictions of longshore transport rates and can therefore improve existing numerical models or even aid the creation of one more accurate with regards to future management of shingle coasts.

The experiments will be continued for at least a year in order to estimate the annual rates of movement and further site visits and measurements will be made. It is intended to seed the beaches at Samphire Hoe and either Holywell or Pevensy Bay early in 2005.

Detailed studies will also be made of the depth of the active (moving) layer of the beaches. These measurements are necessary to provide estimates of the sediment volumes involved in longshore transport.

Thus, comparison will be made between the rates of movement obtained via the natural tracers and the resin pebbles on a short term scale. This comparison will also include the employment of fluorescent tracer pebbles so that both sand and pebble components can be incorporated in the measurements of beach response to wave attack.

Finally, there is one further question with Birling Gap in mind. The Cliff retreat rates west are around 60-75 cm/year and therefore the supply of fresh flints to the beach must be quite substantial. The fact that the volume of the beach today is about the same as it was 100 years ago is puzzling. Is abrasion very rapid? Or are substantial amounts of longshore drift occurring? So far, the field measurements have revealed only minor amounts of drift. This question will also be one of the priorities for future research.

2 Joint field experiment: Cayeux, 12 – 17 December 2004

Between 12th to 17th December 2004 resin tracer pebbles were deployed south of Cayeux to measure longshore transport. Over the same period beach topography was surveyed and equipment for measuring wave height and direction deployed. Over the first 4 days the shore parallel weak swell waves were efficient in mixing the tracers with the beach material to depths of ~20cm but did not produce any significant transport. Storm waves arriving between the 16th and 17th lead to significant tracer movement and changes in the beach topography with significant erosion of the recharge material at the top of the beach. The average weight loss of the tracers recovered on the 17th (N=22) was 0.5g or 0.2%.

2.1 Aims

- Calculate rates of longshore transport over a period of 5 days using artificial tracers and beach topography surveys.
- Compare measured rates of transport with those calculated from longshore transport formulae based on wave height and direction measured close to the transport site.

2.2 Introduction

The shingle spit between Ault and Le Hourdel faces significant erosion at its proximal end, as a consequence of which groynes have been installed as far as to the south of Cayeux. This has shifted erosion northwards so that the beach immediately north of the groyne field is now the focus of erosion (Figure 12) and accumulation occurs to the north. To balance the erosion, material from the accumulation zone is collected and returned overland to the south of Cayeux where it is put back onto the beach. This results in a high (11m French datum) accumulation of uncompacted beach material in this area (Figure 13).

Rates of longshore transport are difficult to measure so that these rates are often calculated using longshore transport formulae (LSTF) based on wave conditions. However, these formulae are poorly calibrated against field data. In this experiment, the expertise of the Université du Littoral in measuring wave height and direction in the nearshore zone is combined with the expertise of the University of Sussex in measuring longshore transport movements. The intention was to work towards comparison and calibration of LSTF.

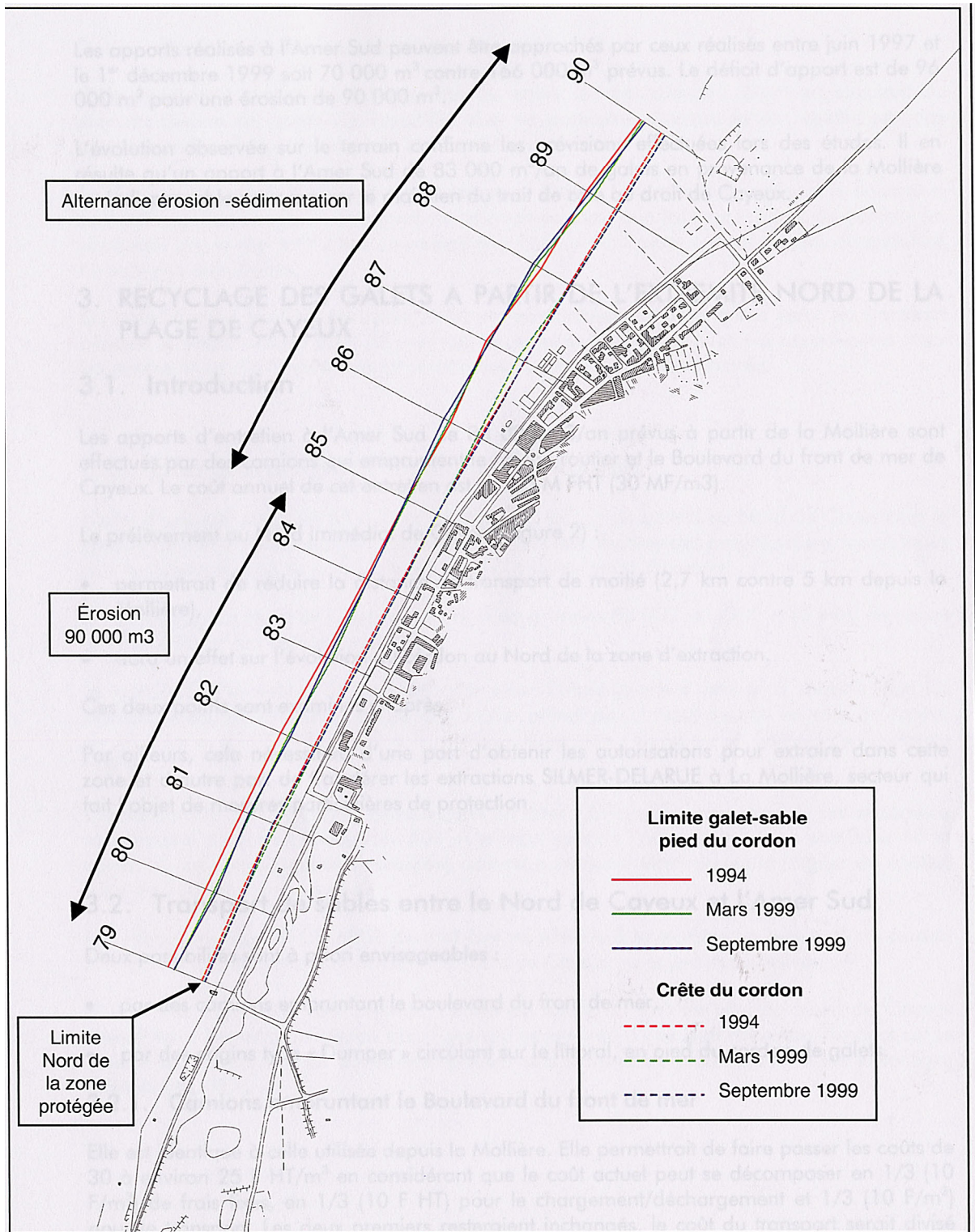


Figure 12: Overview over recent erosion and accumulation patterns north of the groyne field. The 'Limite Nord de la zone protégée' is formed by a terminal groyne that is also a slipway shown in Figure 8A. The northern end of Figure 14 is halfway between line 81 and 82. In the present state, the groynes allow beach material to by-pass them, particularly around the beach toe and at the storm berm.



A)

B)

Figure 13: Photos of the field site taken on 13th December

A) View south with terminal groyne in the background. The active beach (dark colour) gradually merges into the recharge material with only the wet shingle indicating the limit of the active beach. The flatter foreshore is partly covered with pebbles. (Amer Sud monument is in the background).

B) View north showing a sandier foreshore and a berm separating the active beach from the recharge material. Lighter coloured patch on the beach (red circle) shows tracer deployment location.

2.3 Method

Beach surveys: Topographic beach surveys were carried out using a differential GPS with a wheel attached, following cross shore profile paths of variable spacing with data capture every 0.3m along the profiles. During the first three dates low tides were in the morning and afternoon allowing two surveys per day. However, profile lengths and density had to be adjusted to account for the changing tide levels and the need to record the locations of tracer pebbles. Topographic surveys used a bench mark at the Amer Sud (monument shown in Figure 8A) using the following coordinates ($x = 539117.45\text{m}$, $y=275125.06\text{m}$, $z=9.49\text{m}$, projection=French Lambert Zone I).

Tracer pebbles: 170 resin tracer pebbles with a copper core (b-axis = 53mm, density comparable to flint) were deployed on the beach surface in the afternoon of the 12th December in a mid-beach position (Figure 13b). Metal detector searches were carried out in the morning and afternoon of the 13th and 14th and during the morning only of the 15th, 16th and 17th. The position of each re-located tracer pebble was recorded with the GPS together with the depth at which the pebble was found. All recovered pebbles were then repositioned at the original deployment point.

Disturbance columns: Columns of numbered pebbles were buried in the beach in three locations near the tracer deployment point (one at the deployment point, one higher up the beach and one lower down) and the depth of the top of each pebble was recorded.

Wave data: Wave data was recorded with an S4 by the Université du Littoral (Figure 20). Processing of the raw data has so far only included the provision of mean values. At the time of writing the calculation of a directional spectrum is still in the process of being carried out.

2.4 Results

The first survey 12 December (Figure 14) included the northernmost groynes, indicating the general northward transport pattern. To the south of the pebble deployment point the active beach merged into the recharge material (see Figure 13A), north of it a berm had built up in front of the recharge material slope (widening of the area between 4 and 7m, Figure 14).

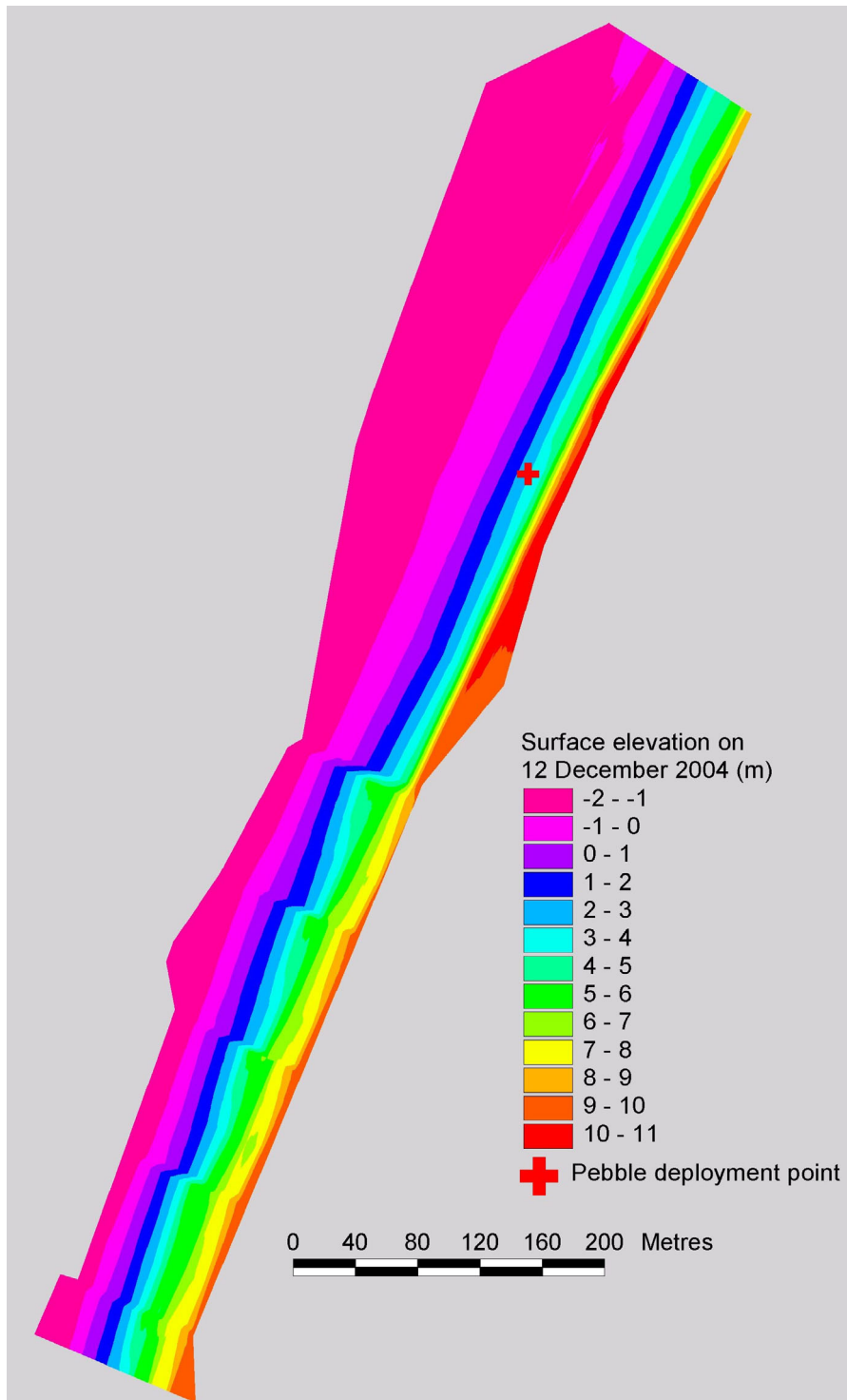


Figure 14: Topography of the northern end of the groyne zone and the field site to the north. Deployment point for tracer studies is shown and located 210m north of the terminal groyne to avoid lee effects. Northern limit of survey is between lines 81 and 82 in Figure 12. Beach geometry in the groyne bays indicates northward transport.

2.5 Surface change and longshore transport rates

Surface elevation changes between the 12th and 16th were small (Figure 16). Although Figure 11 shows changes in excess of $\pm 20\text{cm}$ for most of the survey comparisons, in almost all cases these result from the surface interpolation process. The unusually wide profile spacing of $>50\text{m}$ employed to accomplish some of the survey, necessitated by the changing tide levels, together with surface undulations caused by gentle cusping (Figure 15) appears to have resulted in surface change maps that show excess surface variations paralleling the profile lines. This interpretation is supported by, for example, the fact that the erosional change shown in the southern part of the beach between 12th and 13tham in Figure 16 is equalled by an accumulation of a similar magnitude in the afternoon survey of the 13th. Nevertheless, subtle changes can be observed such as the topographic change at the deployment point from a cusp embayment on 13th December to a cusp horn on the morning of the 14th (Figure 15).

From the 16th to the 17th wind speeds picked up from the northwest and consequently off-shore wave heights reached more than 1.5m. Due to differing survey extents associated with the inclusion of the recharge material, the surface change shown between the 12th and 17th is clearer than between 16th and 17th. Severe erosion of recharge material south of the deployment point occurred with a recession of the recharge slope by 4 to 6m (Figure 16). North of the deployment point erosion involved mainly the berm feature shown in Figure 13B. Whilst some of the eroded material was deposited on the lower beach and upper foreshore, the net change is dominated by erosion (Figure 17). The net gains are small (less than 200m^3) resulting in a relatively uniform rate of longshore transport in the order of 1500 to 2000m^3 over two high tides. The rate of transport is about 2% of the annual erosion suggested in Figure 12.



Figure 15: Tracer search on the morning of the 14th December on a rising tide. Enthusiastic assistance was provided by students from Université du Littoral. Swell waves are approaching from a slight northerly angle. Pebble finds are located on a beach cusp horn. Deployment location shown near group of people.

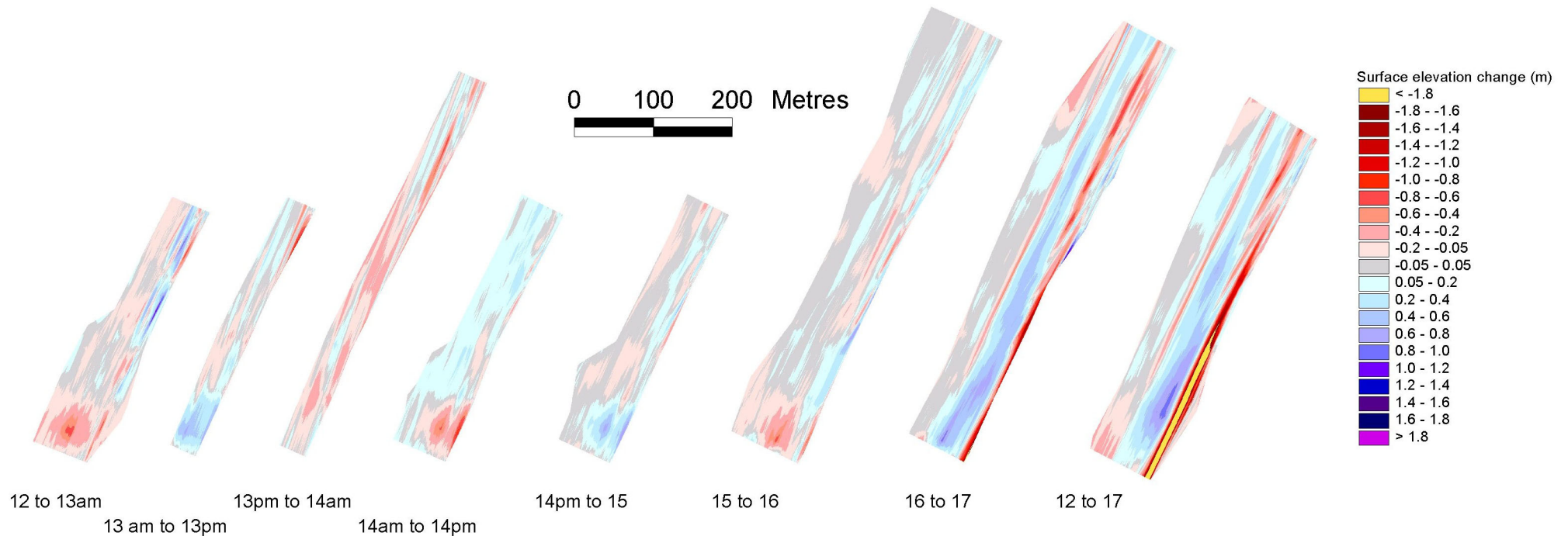


Figure 16: Maps showing surface changes between each survey. Numbers refer to the date in December 2004 with am and pm indicating morning and afternoon surveys. Surveys included the slope of the recharge material only on 12, 13am, 16 and 17 December. Due to tide levels, the foreshore survey was very limited on 13am, 13pm and 14am. Excessive, oscillating changes shown in the southern part of the beach are due to variations in profile spacing that did not take into account adequately the beach topography. Differences in profile spacing are also responsible for the alternating pattern of different levels of accretion and erosion on the upper beach between 12 and 13am, though another likely factor is differential tilting of the rover on profiles surveyed up and down the beach. The reason for the widespread erosion and accretion from 13pm to 14am is not clear. A fault in the rover antenna height was not found so it might be possible that the height of the base station was entered in error. The increased magnitude of change towards the upper part of the beach during most surveys from 12 to 16 is likely to be a result of tilting of the rover antenna. However, the magnitude of changes from 16 to 17 exceeds the survey errors so that the pattern of erosion and accretion is thought to be representative of the true changes.

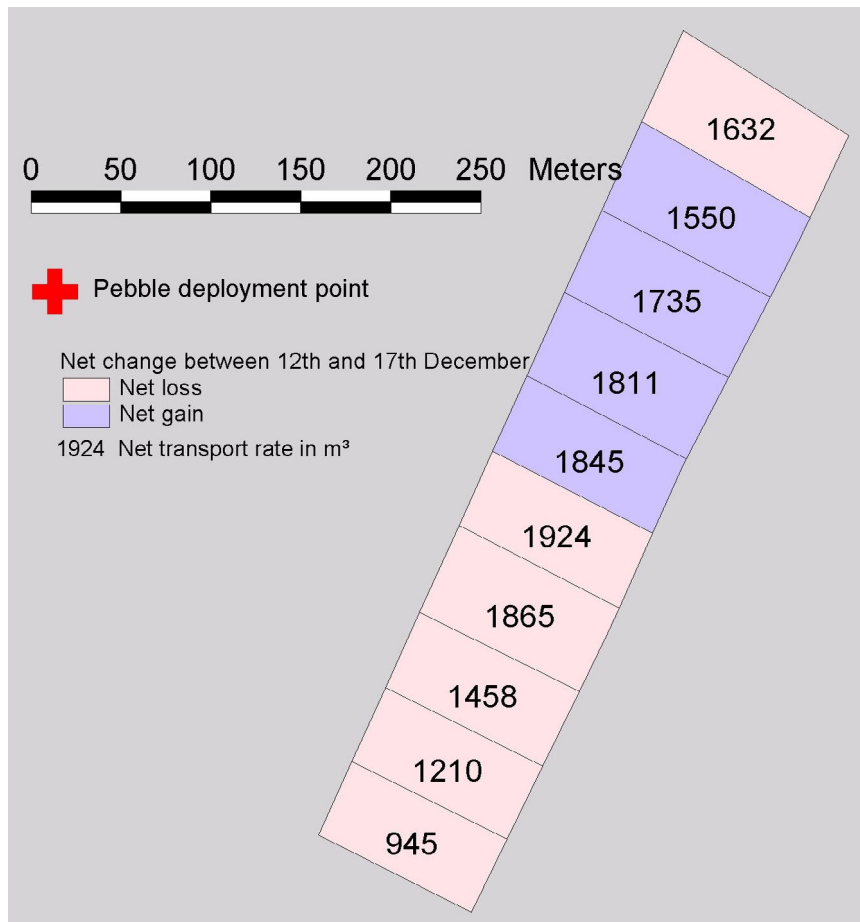


Figure 17: Net change for ~50m segments of the beach between the surveys on 12th and 17th shown in colour with the calculated amount of material transported through each cell shown as a value in m³.

2.6 Tracer movement

After deployment of tracers in the late afternoon of 12th December, a first site visit occurred on the morning of the 13th (Figure 18). Due to time restraints no metal detector search was conducted but the general position of visible tracers together with the location of some farther travelled pebbles was recorded. Almost all pebbles are visible in Figure 18. Average movement over this period was ~1m up the beach (Figure 19). Subsequent collections found the tracers still in close proximity to the deployment point with the mean distance travelled up to the 15th being less than 5m (Figure 19). Mean displacement over this period was down beach as a consequence of those that moved down beach travelling further than those that moved up the beach. In addition, tracers spread laterally by a few metres. While the majority of tracers were found at the surface, significant numbers (in some searches more than 50%) were found below the surface to depths of 30cm. Recovery rates were quite high. On 16th and 17th significant transport occurred in a northerly direction with a maximum distance travelled on the 16th of 75m, but a high recovery rate of 68% was maintained. On the last search, on the 17th, significant northward transport occurred to a maximum distance of 165m. The recovery rate dropped dramatically and the comparatively large number of tracers found at >20cm indicates that mixing and burial was much greater than during previous days (Table 5).



Figure 18: Deployment location on the morning of 13th December. Almost all deployed pebbles can be seen in the photo. Note also how well the tracer pebbles fit into the host population.

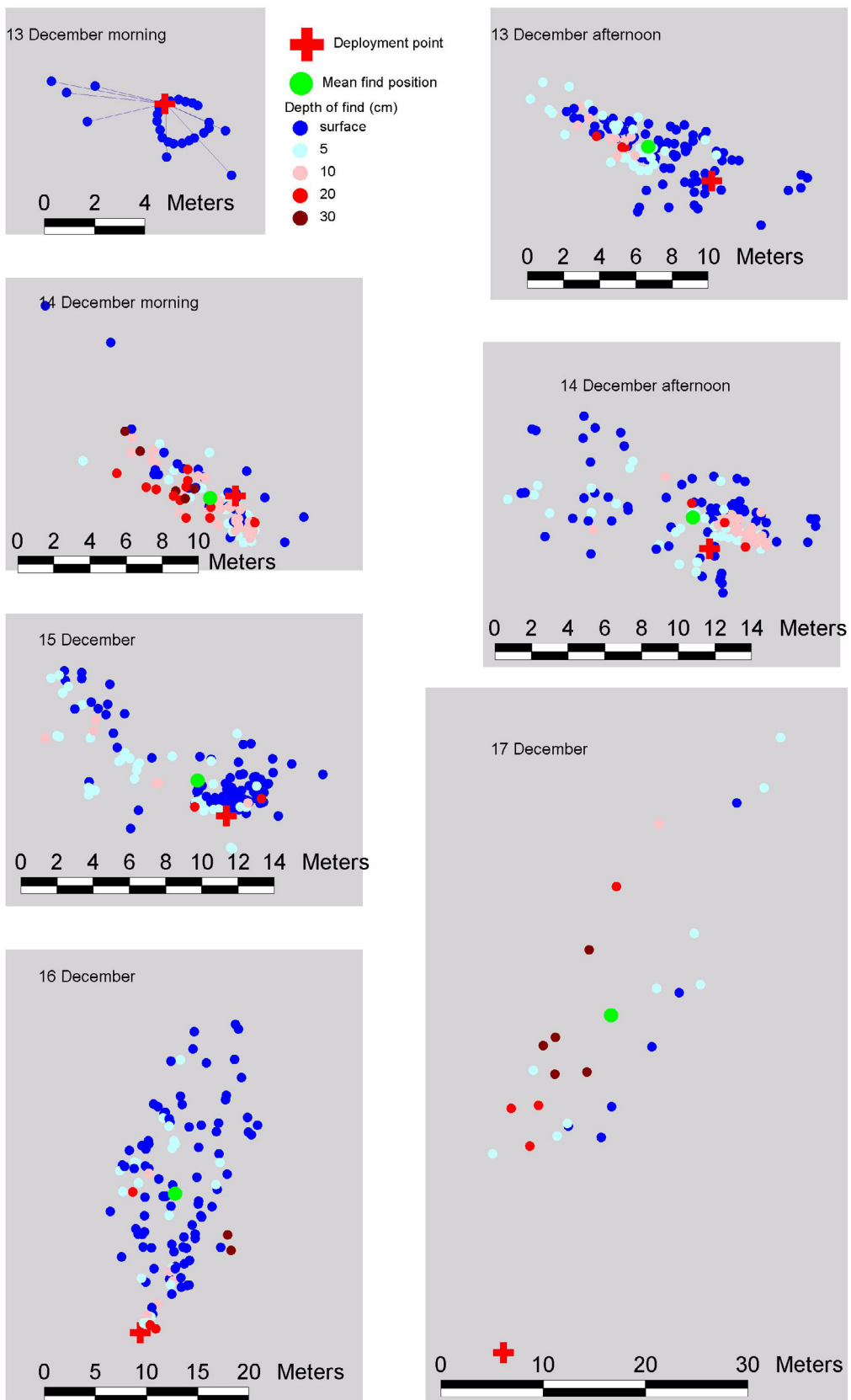


Figure 19: Location and depth of tracers found during searches

	13 th afternoon	14 th morning	14 th afternoon	15 th	16 th	17 th
Surface	91	32	67	110	84	6
5cm	35	29	37	42	20	9
10cm	9	29	22	6	6	1
20cm	3	13	3	2	3	4
25cm	1					
30cm		5			2	5
Recovery (%)	82	63	76	94	68	15
Mean distance	4.8m	2m	3m	5m	33m	87m

Table 5: Summary table of the number of tracers found showing depth below the surface, the recovery rate and the mean distance all tracers have travelled (compare with Figure 19)

2.7 Active layer thickness

The columns of buried pebbles recorded erosion and deposition in the same order of magnitude as indicated by the surface tracers. However, the depth at which tracers are found produces more meaningful results with regard to the thickness of the active layer not least because the number of columns has to be small compared to the number of tracer pebbles. The main disadvantage of the pebble columns is that once they are buried under >0.3m of new material, they are increasingly difficult to relocate due to the amount of digging involved.

2.8 Longshore transport from tracer movement

Taking the mean travel distances for the 16th and 17th, assuming a beach width of 36m and a mixing depth of 20 cm for the 16th and 30 cm for the 17th the transport rate for each day is 490m³ and 940m³ respectively. This gives a total transport of 1430m³, which is close to the lower range calculated from the topographic changes.

2.9 Wave conditions

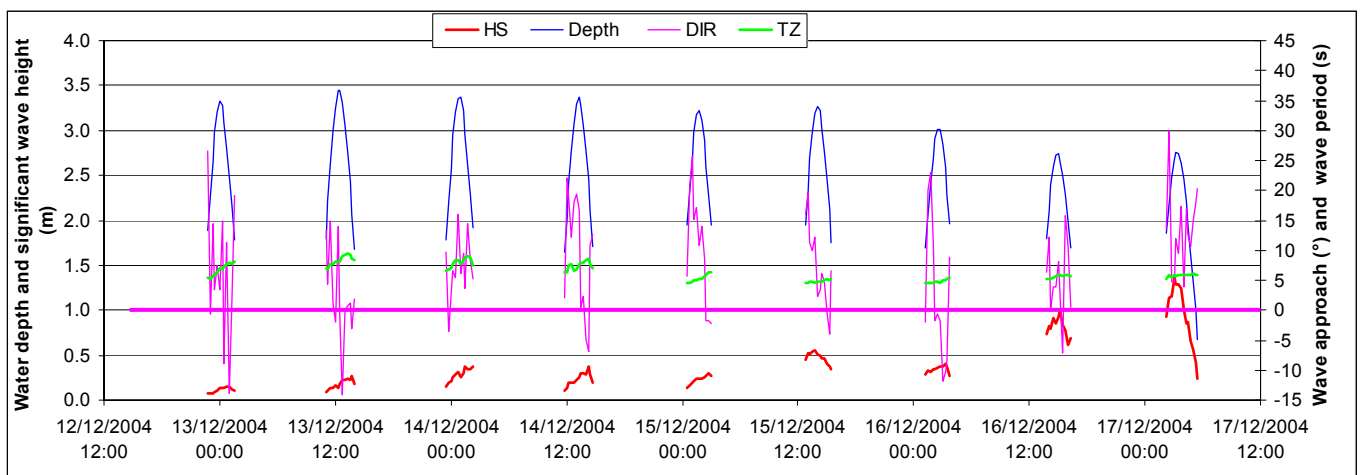


Figure 20: Wave conditions measured with an S4 on the foreshore off the terminal groyne at Cayeux. Data shown for the time when S4 was covered by >1.5m, corresponding to the height of the beach toe. Positive values for the wave approach would indicate waves from northerly directions, negative values from southerly directions with the orthogonal shown as a bold line.

An S4 was located at X=538815,219 Y=274775,00 Z= -1,578m that is ~600m south of the deployment point. Wave and current data were measured using an S4 sampling every 15 minutes (Figure 20). Wave height was less than 0.5m except for the last two tides when significant wave heights of up to 1.3m were measured. Wave direction. was oscillating around the orthogonal during the first 2 tides which would explain the lack of longshore movement. However, for the following period including the last two tides when northward transport was measured, the wave direction would not support this. Further investigations into the accuracy of the wave direction data seems to be needed.

2.10 Longshore transport rate calculation based on wave data

Preliminary investigations into the calculations of the rate of longshore transport based on wave parameters have been carried out but appear to still need further investigation.

Most formulae calculated longshore transport rate in kg s^{-1} so that the volumes mentioned previously have to be converted. Based on the figures of 1500 to 2000 m^3 over two tides and based on the water level and wave information in Figure 15, the shingle beach toe was covered for ~3.5 hours during each tide, i.e. 7 hours between the surveys on the 16th and 17th. Assuming the material density of 2650 kg m^{-3} and sediment density of 0.67 the transport rate would have been between 108 and 143 kg s^{-1} .

2.10.1 Chadwick – Van Wellen formula (Van Wellen et al 2000, eq 46)

The Chadwick – Van Wellen formula was developed and calibrated based on data from Shoreham, West Sussex. It takes the form of

$$Q_{ls} = 1.34 \frac{(1+e)}{(p_s - p)} H_{sb}^{2.49} T_z^{1.29} \tan \alpha^{0.88} D_{50}^{-0.62} \sin 2\theta_b^{1.81} \quad (1)$$

which was taken as

$$Q_{ls} = 1.34 \frac{(1+e)}{(p_s - p)} H_{sb}^{2.49} T_z^{1.29} \tan(\alpha^{0.88}) D_{50}^{-0.62} \sin((2\theta_b)^{1.81}) \quad (1a)$$

where Q_{ls} is the transport rate in $\text{m}^3 \text{s}^{-1}$, e is the void ratio (0.68), p_s is the sediment density (2650 kg m^{-3}), p is the fluid density (1030 kg m^{-3}) H_{sb} is the significant wave height at breaking (1.3m), T_z is the zero crossing period (6s), α is the beach slope in radians (0.104rad, ie 6°), D_{50} is the mean grains size in metres (0.02m) and θ_b is the angle between the breaking wave crest and the beach contours in degrees (5°). Using these values the resulting transport rate is 6.3 kg s^{-1} or 62 m^3 for the 7 hours of wave action. While wave height and period seem realistic, it might be that the approach angle is taken too low. Using an angle of 25° would result in a transport of 750 m^3 , almost half of what was actually measured.

2.10.2 CERC formula (Van Wellen et al 1999, eq 2)

This is the CERC formula with the K -coefficient calibrated for shingle beaches as 0.0527. It takes the form of

$$Q_{ls} = K \left(\frac{(1+e)}{(p_s - p)} \right) \left(\frac{1}{16} pg H_{sb}^2 C_{nb} \sin 2\theta_b \right) \quad (2)$$

where all factors and values are the same as in (1), g is the acceleration of gravity 9.81 ms^{-2} and C_{nb} is the wave group velocity at breaking (10 ms^{-1}). Using these values, the resulting transport rate is 246 kg s^{-1} or 2400 m^3 for the 7 hours of wave action.

2.10.3 Kamhuis 1991 (Kamhuis 1991, eq 12)

The formula takes the form of

$$Q = 2.27 H_{sb}^2 T_p^{1.5} \tan \alpha^{0.75} D_{50}^{-0.25} \sin^{0.6} 2\theta_b \quad (3)$$

where Q is the transport rate in m³-s, T_p is the peak period and all others as in (1). Based on the given values, the transport rate is 14kg^{-s} or 133m³ over 7 hours.

2.10.4 Discussion

It appears to be rather difficult to link the measured rate of transport to the wave parameters using the three formulae above. Formula (1) seems to depend to a large extent on the accurate determination of the incident wave angle and it would appear as if the data from the experiment is not sufficiently reliable to be entered into the calculation. Entering different values from a direction spectrum still to be calculated will probably alleviate this problem. However, even assuming rather large angles the total amount of movement is barely half the measured rate. Formula (2) relies heavily on the K-factor. Although the value of 0.05 was calculated for the shingle beach at Shoreham, it seems to overpredict the amount of movement. However, if a K-value of 0.035 is used the transport volume amounts to 1700m³. A K-value of 0.035 would be suggested from the work of Bray et al (1996) also based on experiments at Shoreham. Though equation (3) was developed for sandy beaches it was thought to overpredict transport on gravel beaches by the factor 2-5 (Reeve et al 2004:175) but would appear to under predict the transport in this experiment by the factor 10.

2.11 Tracer abrasion

Of the 25 pebbles recovered on the 17th, four were composed of the old resin and 21 of the new resin. Two of the old resin pebbles showed cracks which resulted in significantly higher weight loss compared to those pebbles unbroken (Figure 21). Otherwise, a difference in weight loss between the old and new resin tracers does not seem to be detectable. Because all pebbles had been on the beach during the previous days the relationship between transport distance and rate of weight loss cannot be expected to be as close as when the pebbles had only been on the beach for the transport they experienced on the 17th. Alternatively, the difference in travel distance may be insufficient to produce significantly different amounts of wear. Nevertheless, the weight loss shows that pebbles undergo abrasion even whilst transported over relatively short distances of less than 160m.

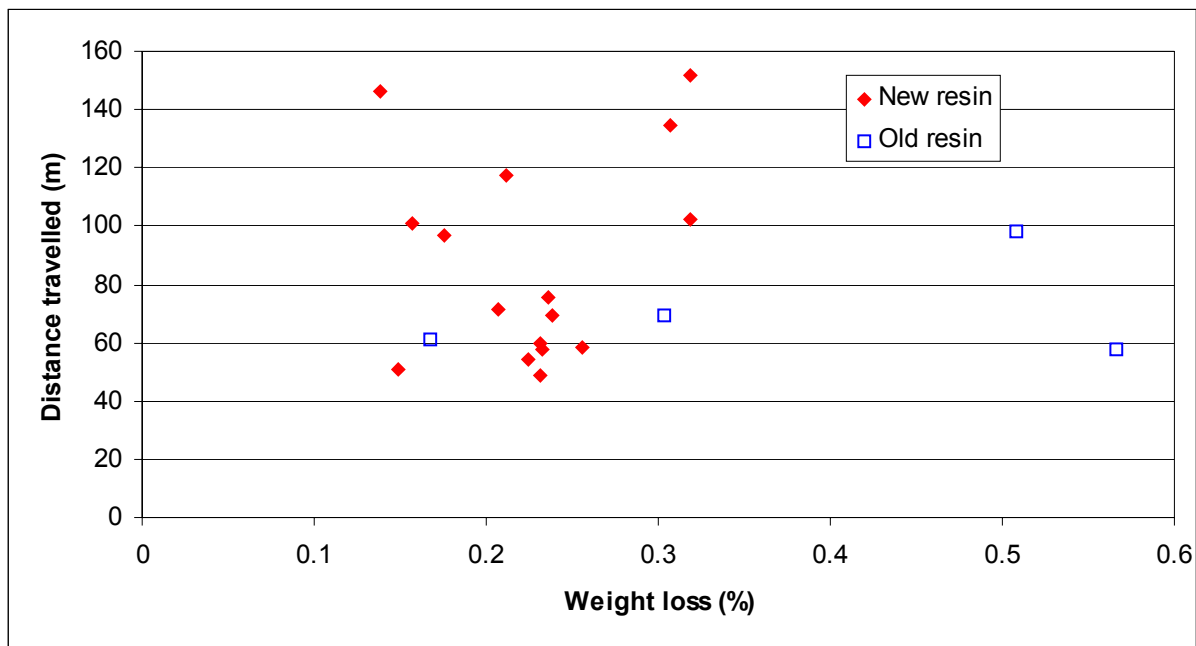


Figure 21: Scatter graph showing the percentage of weight loss of the tracer pebbles compared to the transport distance on the 17th. The old resin tracers with weight loss >0.4% have been broken.

2.12 Discussion

Despite no longshore movement occurring during the first days of the experiment, the results for these days are valuable in that they demonstrate, through the distribution of depths at which tracers were found, that even under gentle wave conditions, mixing of shingle occurs to a depth of more than 10cm and the tracers mix readily into the matrix supported subsurface layer.

Previous work has shown that longshore transport calculations based on topographic surveys work well on beaches that are closed or semi closed - i.e. where either the output (e.g. against harbour arms) or the input (e.g. as in this experiment in the lee of a terminal groyne) are restricted. In this experiment, calculations based on tracer movements come up with a similar rate of transport to that calculated from the topographic surveys. However, the relatively small number of tracers recovered on the 17th put the validity of the mean travel distance into question because, given the spread of the tracers, the addition or removal of just a few tracers could significantly change the mean distance, and consequently the transport rate. While the width of beach undergoing transport is relatively easy to determine to an accuracy of a few metres, the depth of the active layer remains rather more problematical and it might be just coincidence that the transport rate calculated from the tracer movements is similar to that calculated from the topographic surveys.

2.13 Outlook for Phase 2 of BAR

The joint experiment has allowed the collection of data that could not have been collected by individual teams. From the comparison of the field data with that based on longshore transport formulae it is recommended that future joint experiments should pay more attention to data collection e.g. wave direction should also be recorded by field observations, as this is a crucial factor for some of the longshore transport formulae.

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