LONGSHORE TRANSPORT AND *IN SITU* ABRASION USING RESIN TRACERS

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1 Summary

This report documents the production, testing and use of resin tracer pebbles to measure longshore transport rates on key beach sites along the Sussex coast. Three pilot investigations are detailed; in each case the resin pebbles are assessed in terms of their suitability and performance in the field with regard to recovery rates and their potential use to record abrasion in situ. Additionally, the resin pebbles are assessed against other tracer pebbles (painted pebbles and drilled limestone). The three investigations are presented in turn, providing an overview of the aims, methodologies, results and conclusions of the different trials.

2 Review

There remains a scarcity of longshore transport experiments for beaches that are composed of particle sizes larger than sand. Beaches that are steep, beaches with significant tidal range, and beaches experiencing higher wave heights (Schoones & Theron 1993) are also under researched, and in each case the necessary data required to allow a comparison with longshore transport (LST) formulae are seldom collected, or are overlooked.

Experiments designed to measure LST rates have employed traps, tracers and topographic surveys of sediment accumulation against retaining structures, such as groynes. Of these methods, traps have proven the most difficult to employ and the results are orders of magnitude smaller than those derived from the other two methods (e.g. Chadwick 1990).

Topographic surveys against structures can provide long-term net transport rates, but surveys may not be available at the desired temporal resolution or over long enough timescales. Also the amount of material available for transport can decrease with time so that potential transport and actual transport may diverge e.g. at Newhaven, East Sussex. In addition, beach configuration can change with time, altering transport rates by changing the incident wave angle.

The use of tracers to measure LST needs first to address the problem of accurate representation i.e. how representative is the movement data of tracers when compared to the movement of the beach as a whole. If LST experiments using tracers are to be useful, i.e. comparable to the transport rates derived from LST formulae, the following data need to be collected:

- Wave height (ideally breaking wave height which can be derived from off shore wave height, from observations during the experiment or in situ measurements).
- Wave direction (this should be observed during the experiment, or, alternatively, by calculating it from offshore wave data).
- Speed of transport (determination of the speed – ideally ms^{-1} – of the centroid of the transported tracers).
- Width of transport (width of beach that is moving as part of the determination of the active layer). Methods for measuring this include:
  - taking the length between high water mark and the beach toe and dividing by 2 (see Lee *et al.*, 2000, who give no rationale).
  - using the spread of the tracers, provided that the injection points are distributed over the beach profile.
- Depth of transport (depth of the active layer together with the width of transport allows for the volume of transport to be calculated). Methods for measuring depth include:
  - topographic surface surveys (although these are often shown to under-predict the depth of the active layer to some degree).
  - use of independent methods, e.g. depth of disturbance columns
  - use of tracer burial depths (different methods can be employed but 95% of the depth

of those that have moved has been suggested). This method relies on the assumption that the tracer can be detected at the maximum depths (using a metal detector), which is questionable once recovery reaches the maximum detector depth.

Issues that need to be taken into consideration relate to:

- Mixing of tracers with the beach sediment. The literature suggests that mixing has taken place after 2 tides, but also mentions that mixing is faster under higher waves (Wright 1982) or that it takes 2 to 7 days (Bray 1996). Mixing could be accelerated by distributing the tracers throughout the anticipated thickness of the mixing layer or 'to a depth that exceeds the sweep zone profile".
- Size and shape of the tracer: Tracer size and shape should be representative of the size and shape range found on the beach. (All experiments to date have used tracers that were larger than the D50 but mimicked the shape of the natural material, as smaller tracers are impractical, in fact a number of experiments, Wright, Nichols, Bray, use the same set of size and shape variations on different beaches). Differential transport due to shape and/or size does not seem to be significant on the rate of transport. However, different sizes have different maximum depths of detection and might therefore give differing results.
- Injection point. Differences in transport relating to different injection points across the beach have been reported though the differences seem to be relatively small.

Literature detailing past experiments provides scant information on search procedures, mentioning only full area searches (but not defining on what basis these are carried out) or strip searches (again with no mention on how these are delimited).

3 Research and development of synthetic tracer pebbles

3.1 Tracer pebble techniques

A considerable literature has grown up over the years relating to the detection of sediment transport using tracers (e.g. Russell, 1965; Caldwell, 1981; Madsen, 1989; Voulgaris *et al.* 1999). This technique has proved to be particularly useful for monitoring long-shore transport on mixed beaches (composite sand and gravel) and is used in favour of more traditional methods such as sediment traps which have been successfully employed on sand beaches. Generally tracer experiments can be divided into two main types:

1. Marking the indigenous beach material
2. Introducing some form of foreign or manufactured material e.g. Quartzite and limestone at Saltdean and Telscombe (Dornbusch *et al.* 2002), aluminium pebbles (Wright, 1978; Nicholls, 1985), radioactive and radio controlled (smart pebbles), (Bray *et al.* 1996; Lee *et al*. 2000).

Excluding aluminium, radioactive and radio controlled techniques, recovery of tracer pebbles in past investigations has been limited to the beach surface as detection is impossible once buried at depth by beach material. This severely reduces the potential for tracer recovery and can yield no information about tracer movement patterns and distribution with depth.

For the purposes of the BAR project a tracer needed to be developed that was easily identifiable at the beach surface, detectable and easily recovered at depth and yet behaved in a similar way as possible to the indigenous beach material. Previous discussions also highlighted the possibility of designing and producing a *unique tracer* for the BAR project. One that may be used to investigate not only sediment transport patterns and rate but also abrasion rates of pebbles over time.

This report documents the development and production of unique tracer pebbles produced for the BAR project. Past tracer experiments are outlined alongside present day technologies and an assessment of tracer requirements is made. This information is used to make recommendations for a suitable solution and the design and production methodology for the BAR tracer pebbles is presented.

3.2 Available tracer technologies

3.2.1 Painted pebbles

Painted pebbles, though cheap and easy to produce (on site) have the disadvantages of being visible only at the beach surface and that recognition decreases considerably over time due to the wear of the paint, giving the tracers a relatively short life span in terms of long shore transport investigations (Figure 1).

3.2.2 Fluorescent pebbles

Fluorescent pebbles were used fairly successfully in early trials during the 1960's and 1970's. Pebbles would be embedded with small fragments of fluorescent plastic e.g. Rhodazine and Ovitex, which showed up as red, green and blue under an ultraviolet lamp. Advantages were that the tracers could be picked out at night at low tide by means of a portable generator and ultraviolet lamp. (Russell, 1965). However, these experiments were designed on short temporal scales and were used to study the movement of material under conditions that lasted unchanged for only hours or days at a time. For the BAR project it was necessary to design tracers capable of lasting a year or more to enable measurements of the long-shore transport patterns occurring over months or even an entire year.

Figure 1: Spray painted flints after only 5 hours in the tumbler

3.2.3 Radioactive pebbles

Although relatively successful in early trials, radioactive tracers present a health risk and cannot be used on public beaches, this excludes their use for the BAR project investigations.

3.2.4 Radio controlled pebbles

Discussions with Mark Lee (formerly Southampton University) resulted in the decision to avoid using Smart-pebbles, as their performance to date has not been up to the standard expected. Detection proved problematic in saltwater environments yielding low recovery rates and after six years of research the pebbles are still only in their prototype stage.

3.2.5 Aluminium pebbles

Aluminium tracer pebble techniques yield considerable scope for recovering higher proportions of the injected tracers compared with previous techniques and are recommended in a number of transport studies. The use of aluminium or metal tracers allows for the recovery of pebbles that have become buried during the course of investigation. In previous experiments this has not been possible and a significant part of the tracer population has therefore been excluded from such studies. Recovering tracers at depth would also provide information on the vertical distribution and burial regime of the tracer, enabling the beach to be studied as a three dimensional feature. This offers a significant advantage compared to past investigations (Voulgaris et al. 1999). Aluminium tracer pebbles have proved to be successful in past experiments and present many advantages over other earlier forms of tracer pebble techniques.

3.2.6 Synthetic pebbles

The use of a synthetic tracer pebbles also demonstrates considerable scope for future tracer investigations and following research into synthetic materials, resin was thought to be the best material for tracer pebble production (T. Cane, *pers com*. 2003). In terms of surface transport such pebbles would have considerable advantages over painted or fluorescent pebbles. Bright colours can be moulded making them easily identifiable from the indigenous beach material and over time the resin pebble surface will "scuff up" making them less obtrusive but still identifiable after many months, allowing for longer-term tracer investigations to take place.

In addition there exists the possibility to manufacture synthetic pebbles capable of being detected at depth by means of metal or tagging mechanism embedded within the resin material. This represents the possibility of recovering tracers at considerable depths, possibly above 0.5m and has the same advantages as using aluminium tracers.

In trials measuring only long-shore transport synthetic pebbles have also proved to be highly durable, with field trials lasting over one year in duration. Although previously the majority of aluminium tracer investigations have taken place over small temporal scales it has been demonstrated that such experiments taking place over one year's duration are feasible (Wright, 1982).

Clearly both aluminium and synthetic pebbles show considerable advantages over other types of tracers used in past investigations. However synthetic tracers may provide further scope in that it is possible to use them in abrasion studies, whereas aluminium pebbles may not. For the purposes of this report it is necessary to assess the advantages and disadvantages of the two tracer techniques (Table 1).

3.2.7 Advantages and disadvantages of aluminium and synthetic tracer pebbles

Tracer Criteria	Tracer Type	
	Aluminium	**Synthetic**
Pebbles must be manufactured to reproduce the specific gravity, size and shape of the indigenous beach pebbles allowing them to behave in the same manner hydraulically.	Different pebble size, shape, density can be produced at manufacturers. (Caldwell, 1981; Wright, *et al*. 1978).	Pebbles of similar densities, size etc to flint can be moulded on site using latex moulds and resin materials.
Pebbles must be detectable at depth with detectors, greatly improving recovery rates.	Located with the use of a metal detector, early trials suggest depths up to 0.4m.	Pebbles can be embedded with metal or "tagged" and recovered using metal detectors or other device. Early trials suggest depths of 0.4m.
Abrasion studies can be carried out simultaneously with those of long shore transport.	Not possible, as aluminium wears in a different manner to flint. Metal will dent and absorb energy whereas rock undergoes fracture to produce "chatter" marks	May be possible as in theory synthetic resin should produce "chatter" marks which will wear in a similar way to flint. (Requires pilot tests).
Pebbles need to be individually identified and their movement monitored.	Pebbles can be number stamped during production.	Pebbles can be colour coded for reference and/or number stamped or etched during production.
Tracers can be produced in bulk relatively cheaply.	Bulk costs of around £4-£5 per pebble.	Cheap to produce, bulk costs estimated at £0.50 per pebble.
Pebbles must present no threat to public heath or marine environments.	No threat.	No threat.
Possible interference from "background noise".	Metal content of the beaches may pose problems if beaches are highly contaminated with metal objects.	Detection of security tags works in a different manner to metal detectors. If pebbles embedded with metal then metal contents of the beach may pose problems.

Table 1: Comparison of aluminium and resin pebbles.

3.3 Abrasion Studies

The possibility of combining both long-shore transport and abrasion studies using both aluminium and synthetic tracers was investigated. In the case of synthetic pebbles it was suggested by the manufacturers that the resin material used would wear in a similar manner to flint rock, both flint and resin fracture under impact to produce chatter marks therefore abrasion rates in theory, it was suggested, would be comparable. This assertion was tested using laboratory abrasion trials. Another suggestion was that indigenous flint pebbles be drilled and a metal core (copper, brass) be inserted for identification with a metal detector. In this way the pebbles would still be recoverable at depth and abrasion studies could be carried out on the natural flint surround. This technique was investigated and the results are outlined below.

3.3.1 Investigating drilled flints

Following investigation there are a number of issues associated with the use of drilled flint as a tracer pebble. The theory behind this technique is that the flint pebble will still respond to a metal detector and therefore be located at depth, while additionally abrasion studies may take place in conjunction upon the host flint pebble. The problem arises with trying to locate a flint pebble based upon a metal rod inserted within in it. For maximum cross-sectional interference at any orientation for a given volume, the metal inserted into the flint pebble would need to be large and if possible spherical. In this case drilling natural flints proved incredibly time consuming and allowed the insertion of only a small rod midway into the flint pebble. Not only does this present problems in so much that the characteristics of the flint may be changed but it is likely that the pebble will not be detectable at depth with certain orientations (Figure 2). In addition even if detected, a flint pebble with an aluminium rod or disk will look incredibly similar to all other flint pebbles on the beach and may not be easily identified and recovered.

Synthetic coloured pebbles overcome this problem. Firstly it is possible to embed a large metal core into the resin material during production and secondly synthetic pebbles will be coloured and will therefore look different to other pebbles on the beach making them easily identifiable once located with a detector.

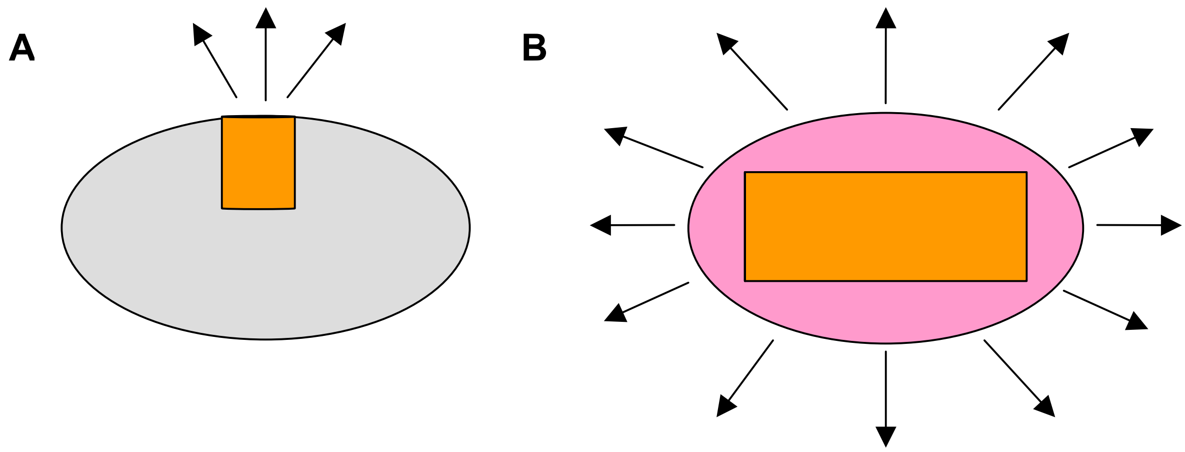


Figure 2: Drilled flint (A) allows for the insertion of only a small metal rod, manufacturing resin pebbles (B) allows a large metal core to be embedded maximising cross-sectional interference.

3.3.2 Investigating tagging systems

In terms of tagging the pebbles, in theory it is possible to insert or embed a metal core or more sophisticated tagging device during manufacture. However in practice attaching or embedding a tag within the flint pebbles was proved to be inappropriate. Not only was drilling time consuming but using a glue or other medium to secure the tag in place may change the properties of the flint and over time the glue may wear away and the tag be lost, or wearing away of the glue may alter abrasion readings. In terms of synthetic pebbles it would be possible to insert the tag or metal core during moulding which should not affect the property of the pebble and which would ensure the safety of the detectable device.

Research into alternative tagging technologies yielded various techniques available for use on a range of different scales, however prices for even the most basic electronic tags proved to be beyond costs considered reasonable for the BAR project. Mixed beach material contains a large range of grain sizes, ranging over three orders of magnitude from fine sand through gravels, right up to small boulders (Coates and Damgaard, 1999). Due to the large grain sizes involved, representative sample sizes must be correspondingly large, in this case requiring the production of thousands of tracer pebbles. For these reasons electronic tagging systems are considered too costly and the use of a large metal core for pebble detection was investigated and adopted.

3.3.3 Summary and recommendations

Having assessed the relative advantages and disadvantages of using metal inserts in indigenous pebbles and synthetic tracer pebbles for the study of long-shore transport, it was clear that the use of detectable synthetic tracers on mixed beaches yield more measurements per tracer, and significantly better information (including depth of mobility) over longer time scales than other techniques discussed. In addition previous studies advise the injection of coloured synthetic pebbles onto the beach alongside the metal tracer to allow for a rapid visual survey of the beach surface and monitor maximum distance travelled (Wright 1978). Investigations into tagging techniques and pebble manufacture resulted in the choice of resin embedded with a metal core. This type of tracer was used throughout early investigations and methodology of manufacture was developed, outlined below.

3.4 First generation resin tracer pebble manufacture

Investigations into tracer techniques resulted in the decision to use synthetic pebbles for the BAR project as these best fulfilled the necessary criteria. In terms of surface transport they have considerable advantages over painted or fluorescent pebbles, which abrade and lose their colour soon after injection. Bright colours can be moulded making them easily identifiable from the indigenous beach material. Over time the pebble surface will "scuff up" making them less obtrusive but still identifiable after many months, allowing longer-term tracer investigations to take place. In addition, it is possible to manufacture synthetic pebbles capable of being detected at depth by means of embedding a copper cylinder within the resin material. Field trials measuring long-shore transport with synthetic pebbles have proven them to be highly durable, with trials successfully lasting over one year in duration (Wright 1982).

3.4.1 Calculations for pebble manufacture

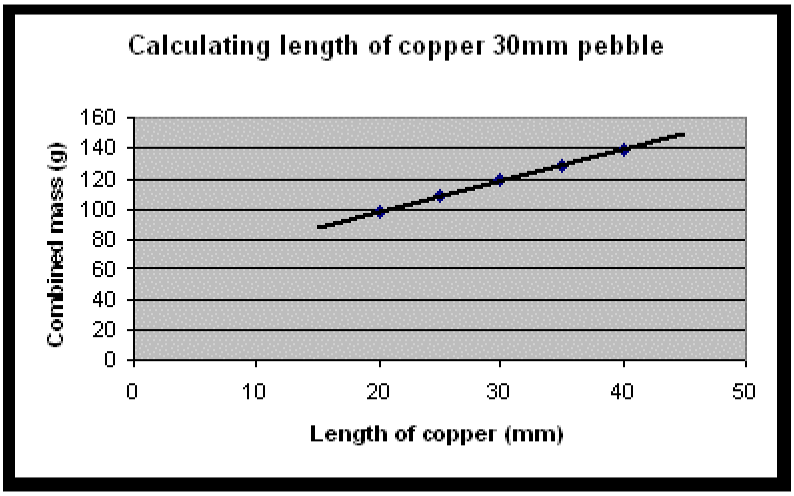
3.4.1.1 Calculating the density of pebbles

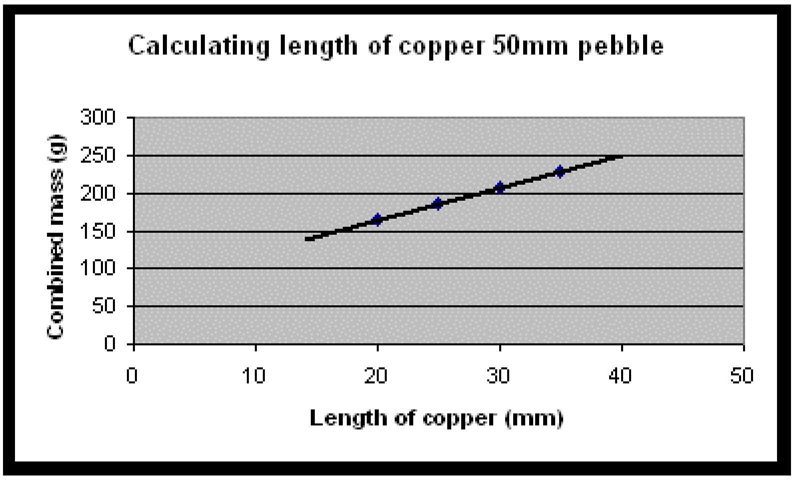
Length of copper (mm)	Volume of copper (cm^3)		Mass of copper (g)		Volume of resin (cm^3)		Mass of Resin (g)	
	30mm	50mm	30mm	50mm	30mm	50mm	30mm	50mm
20	5.32	10.66	47.35	94.8	47.68	74.34	50.54	70.1
25	6.65	13.32	59.19	118.5	46.35	71.68	49.13	67.62
30	7.98	15.99	71.02	142.31	45.02	69.01	47.72	65.1
35	9.31	18.65	82.86	165.98	43.69	66.35	46.31	62.59
40	10.64		94.7		42.36		44.9	

Length of copper (mm)	Combined mass (g)	
	30mm	50mm
20	97.89	164.9
25	108.32	186.12
30	118.93	207.41
35	129.17	228.5
40	139.6	

Density of resin = 1.06 gm/cm3
Density of flint = 2.68 gm/cm3
Mass of 30 mm pebble = 126.68 (g)
Volume of 30 mm pebble = 53 cm^3
Mass of 50 mm pebble = 216.0 (g)
Volume of 50 mm pebble = 85 cm^3

3.4.1.2 Calculating the required lengths of copper to achieve flint density





3.4.1.3 Results

3.3 mm copper length required for 30 mm pebbles

3.25 mm copper length required for 50 mm pebble

3.4.1.4 Cost of pebble manufacture

	Materials	Quantity (g)	Cost (£)	Quantity per pebble		Costs per pebble	
				30mm	50mm	30mm	50mm
	Resin	10000	38.56	50	70	0.192	0.270
	Catalyst	200	0	0	0	0	0.000
Pigment	White	500	3.44	1	1	0.014	0.007
	Coloured	500	5.28	1	1	0.021	0.011
Copper	15mm	100	10.3	3.3	0	0.339	0.340
	25mm	100	23.76	0	3.25	0	0.772

Total costs	0.566	1.39946

Pebble costs are £0.57 and £1.40 respectively; price of 50 mm pebbles is larger due to the required width of copper needed 25 mm as opposed to 15 mm.

3.4.2 Method of manufacture

The tracers developed for use in early trials were made from a casting resin with a copper core and modelled from a natural beach flint. Vinamould, a form of latex is used to make the pebble mould. It is heated until liquid then poured over a natural flint pebble, once cooled the pebble is removed and the mould can be used for pebble manufacture (Figure 3). Though all moulds were made from the one pebble, the moulds and therefore the tracers differ at the end where the resin is poured into the mould. Tracer pebbles were manufactured in a two-stage process by casting the bottom of the pebble first so that the copper can be placed in the centre of the tracer (Figure 4). After placement of the copper core the rest of the pebble is cast and according to the manufactures, bonds thoroughly to the pre-cast base. Depending on the amount of resin poured in at the second stage and the form of the mould, the top end of the pebble is either flat or forms a neck that is mechanically removed with a saw and/or file. Each tracer was then engraved with a unique identifier number 1-2mm deep. Tracers were than oven dried for 24 hours at 50°C and weighed on a balance with standard error of 0.002g. The average resin pebble produced in this process weighed 211g ranging between 195g and 228g, illustrating the variety resulting from different moulds and casting processes.

3.4.2.1 The mould

- Vinamould, a form of latex is used to make the mould.
- The Vinamould is cut into fine pieces roughly 2 cm^3 and melted in the microwave.
- Pebbles to be moulded are placed within a heatproof container, raised and secured in place using a plasticine disk (A).
- Melted Vinamould is poured over the pebble and left to cool for 2 hours (B).
- After 2 hours the Vinamould is cool enough to be removed and used (C).


(A)


(B)

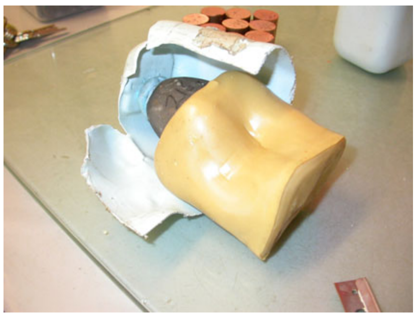

(C)

Figure 3: Manufacturing resin pebble moulds

3.4.2.2 The pebbles

- Mix up 10 cm^3 of the of resin (Regular Casting Resin), pigment (polyester colour paste) and catalyst (catalyst hardener for Casting resin), to begin with. Trails indicate 50 cm^3 resin for use with copper bar of 15mm diameter to obtain correct density of flint, 2.69 g/cm^3, add ½ spatula of pigment and 1 drop catalyst.
- Pour 10 cm^3 of resin mix into the mould and leave for 25 minutes to partially set (A).
- Place copper cylinder 25mm in diameter (maximum size for pebble offering maximum interference) within the centre of the mould.
- Mix up remaining 55cm^3 of resin with 1 spatula of pigment and 2 drops of catalyst pour this into the mould (B).
- Leave to set for 1 hour, when completely set remove pebble (C).

(A) (B) (C)

Figure 4: Manufacturing resin pebbles.

Initial trials using these resin pebbles took place during January and February of 2004 at Pevensey Bay each Sussex. These pebbles were also used during collaborative field work with French partners at the Cayeux spit later in the year. Their performance was assessed and necessary improvements made to the manufacturing process are described below.

3.4.3 Initial trials using resin tracer pebbles

Initial field trials using the pebble manufacture process described above gave some unfavourable results. The type of casting resin chosen for manufacture was too brittle and shattered even under relatively low wave conditions. The shattering that occurred was further investigated and was thought to be caused by air bubbles forming between the copper and the resin during the two-stage manufacturing process. In addition the manufacturing process was considered too slow with individual moulds required for each pebble. In order to successfully use these pebbles in field trials it was necessary to greatly speed up the process and produce a 'supply' of pebbles in reserve.

For these reasons it was necessary to improve both the design and manufacture process of the resin tracer pebbles. Improvements made are described below along with a detailed description of pebble manufacture for the second generation resin tracer pebbles.

3.5 Second generation resin tracer pebble manufacture

3.5.1 Creating the moulds

The construction of the ten pebble moulds is a lengthy procedure and has been simplified for the purposes of this report. No reference of the plug manufacturing process or tools used is made to due to the highly technical nature of the process.

- Twenty pseudo pebbles are hand formed using identical volumes of fibre reinforced modelling clay. These are gently dried at 36°C for 72 hours. The pebbles are then very lightly buffed to remove any anomalies and lacquered with a water based gloss varnish. The volume of the finished pseudo-pebble is checked as a small percentage of shrinkage occurs during drying. The ten most uniform pebbles are selected for the mould.
- A strip of MDF is cut 540 x 70 x 20 mm. The use of this piece of MDF in the moulding process produces a resin over spill trough in the final silicon mould.
- Ten 5mm holes are drilled and counter sunk in a line down the centre of the longest axis on the largest surface. Using each of these holes a 25 mm diameter smooth wooden rod approximately 20 mm high is screwed in place. These wooden rod pieces have been rifle barrel drilled with a 5mm internal diameter. A 75 mm long 5mm screw is threaded through the countersunk side of the MDF strip, through the rod, and then screwed into a 4mm diameter hole which has been drilled into the end of each pebble along it's long axis. The joint between the base of the pseudo pebble and the wooden rod is filled with plasticine type filler.
- Once this is completed ten pebbles perched upon pedestals are lined up along the MDF.

This strip of MDF is then centrally screw mounted on a larger piece of MDF approximately 700 x 200 mm to form the main 'tool'.

- A plug, boss and finally a GRP rubber injection casing is produced from this tool. (See above)
- With the injection casing bolted or clamped to the tool, vulcanising silicon rubber is injected in to the base of the mould at room temperature, using a pneumatic powered mastic gun. This is left to set for 24 hours.
- The external casing is removed and with the internal tool still in place a two-piece GRP support casing is laid up over the silicon mould. This casing is trimmed drilled for clamping bolts and placed in a framework of threaded rod and MDF (Figure 5).

The whole process for producing the pebble moulds takes about three weeks and material costs for the tools required are about £220 - £260. Thereafter material costs for each silicon mould are about £110 - 125 depending on the quantity produced. Once the moulds are completed the final epoxy resin pebble volumes are calculated and as the actual densities of flint are known, the required amounts of resin and lengths of copper core can be calculated to give a synthetic resin pebble comparable to the density of natural flint.

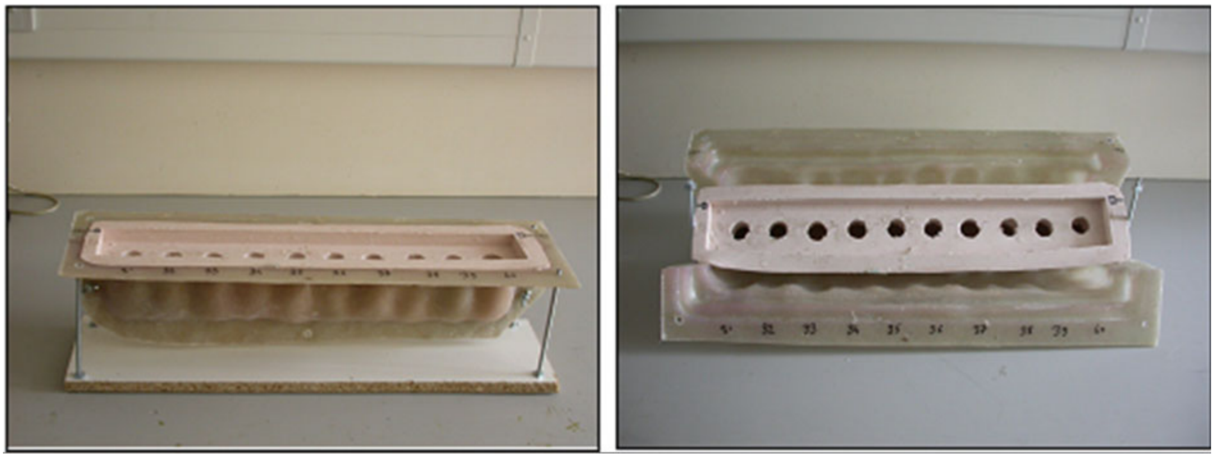


Figure 5. Manufacturing the moulds.

3.5.2 Creating the pebbles

3.5.2.1 <u>Materials</u>

- The second generation resin pebbles have been produced using Epoxy Resin, which is more malleable that the Casting Resin that was initially used.
- Resin and hardener: sold by ADL (Stevens) Resin & Glass. The price depends on the quantity of product ordered. For example, 25 kg of resin plus 12.5 kg of hardener costs £333.16. This quantity of Epoxy resin allows a production of 450 pebbles.
- Copper: The price depends again on the quantity ordered. However, the average price of one copper is around £1.63.
- Advanced mould release agents: a single spray can costs £10. One can is used for the production of 450 pebbles.

3.5.2.2 <u>The Epoxy Resin and hardener</u>

In addition to having a different resin, the second generation pebbles used different ratios of epoxy resin and hardener. When using epoxy resin, the hardener ratio should not be altered and the manufacturer advises to mix two parts resin to one part hardener by weight.

However, experience has shown that a better result is obtained by adding only 45% hardener. As soon as the mixture (resin and hardener) is fully mixed, the air bubbles are removed from the liquid using an air vacuum.

The resin pebbles are left to cool and are ready in 7 days at 25°C, or the process can be speeded up to 1 hour if 100°C heating is used.

3.5.2.3 The Copper

The principle aim was to be able to reproduce a perfect replica of a natural flint pebble with an equivalent B-axis. By a simple calculation based on the resin density (1.06 g/cm^3), the copper density (8.92 g/cm^3), the flint density (2.65 g/cm^3) and pebble volume (73 cm^3 on average) it has been determined that the copper length inside each pebble should be 3.3 cm.

3.5.3 Pebble production

- The first step in pebble production consists in pouring a small amount of resin into every mould. Once dried it can be used as a pedestal base for the copper core. In addition this base allows placement of copper into the middle of the mould resulting in the mass centre being close to the centre of gravity (Figure 6).
- the copper length is then introduced in the mould along with a small amount of fresh resin to avoid trapping any air.
- the entire mould is then filled with resin and after five to six hours of drying, the resin pebbles are extracted. At this stage they are soft enough to be smoothed with a cutter.
- After drying for a week at room temperature, the pebbles are ready to be deployed (Figure 7)

N/B Before or after every use, a mould release agent should be used to increase life expectancy of the moulds and to make pebbles extraction easier.

Figure 6: Pebble manufacture.

3.5.4 Conclusions

Figure 7: Final resin tracer pebble

On average, the cost of producing one pebble is £2.91 pounds (based on materials only and calculated for the production of 3000 pebbles). Compared to other tracer pebbles this method is still cheaper with the additional advantage of investigating abrasion in-situ. Large deployments of one thousand or more pebbles is possible at relatively small cost for efficient data collection.

4 Test 1: First generation resin tracer and painted pebble trial, January 13-14, 2004

4.1 Aim

The aim of this experiment was to assess the difference in longshore transport rates on 4 different beaches under the same environmental conditions.

Beaches were used as comparative pairs with Saltdean and Eastbourne (groyned beaches facing SSW and SSE respectively) being one and Seaford and Pevensey the other (open beaches facing SW and SE respectively). These trials deployed painted pebbles as tracers at each site. In addition resin pebbles were deployed at Pevensey Bay in order to assess their performance when compared to the more traditional painted pebble approach and to assess their suitability for combined field abrasion experiments.

4.2 Method

Each beach was seeded on 13-01-2004 with 100 pebbles, one third were put out at the beach toe, one-third half way up the beach and one-third near the last high water mark. The pebbles were spray painted and numbered with water resistant marker pen.

On 14-01-2004 all four beaches were searched for pebbles using the search procedure described below:

- Beaches are searched by walking along the contours starting at the beach toe up to the last high tide mark.
- Distance to be covered from the deployment points should be 200m for Seaford and Pevensey and for the one groyne compartment at Saltdean and the one + the downdrift compartment at Eastbourne. If at Seaford and Pevensey only a small number of tracers are found, the search should be extended to the next 'obstacle', e.g. a terminal groyne.
- Spacing of search paths should be 2m (if you drag your feet occasionally you can identify a path you have already walked).
- Recovered pebbles should be marked with a bamboo cane. If a pebble is found very early lying at the beach toe it should be moved up the beach by 10 paces and marked with **2** bamboo canes.

4.3 Environmental conditions

Storm conditions prevailed for the experiment (Figures 8 and 9) although the conditions were well below the 'one in one year' event

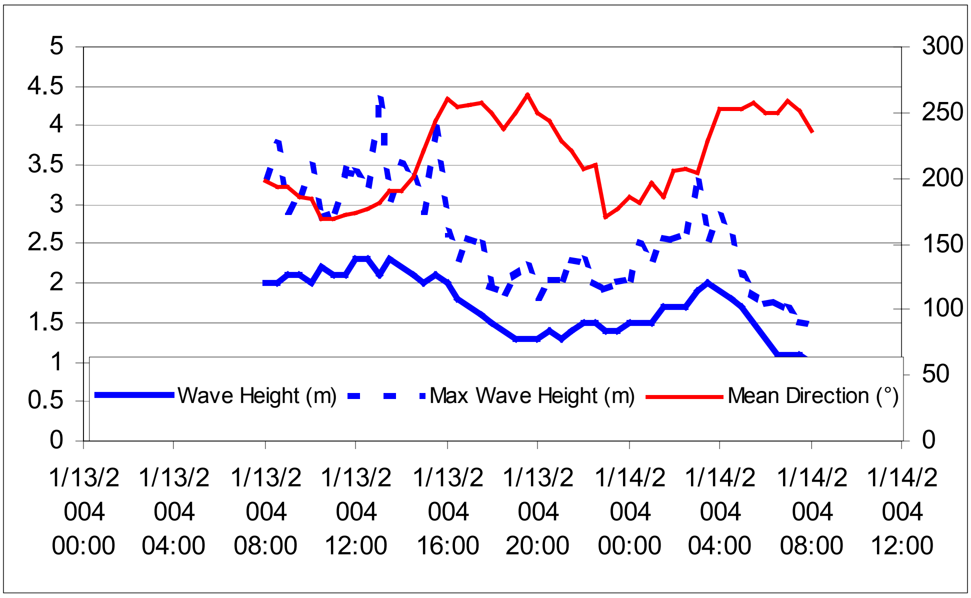


Figure 8: Wave conditions at the Rustington Buoy (water depth 9.9m OD, between Bognor and Worthing).

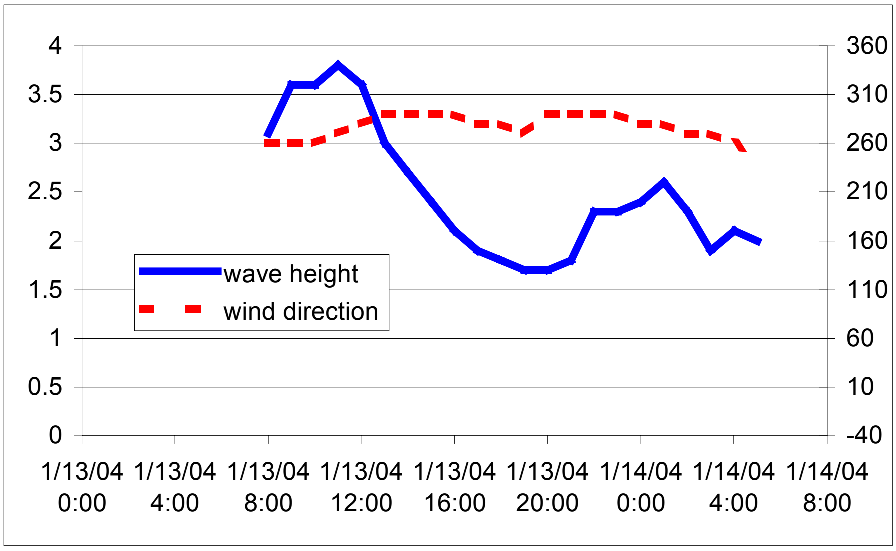


Figure 9: Wave and wind condition at the Greenwich light ship (~50km south of Newhaven).

Through observations on both days it was determined that waves at Saltdean were approaching the beach parallel and at Seaford at a small angle, that would result in an easterly energy component. At Eastbourne and Pevensey the waves broke onto the beach at a significant angle, which would result in a stronger longshore component of the wave energy than at Saltdean and Seaford.

4.4 Results

4.4.1 Saltdean

Figure 10 shows data from the two surveys. There are virtually no surface changes outside the error margin. All pebbles (5) found are from the deployment point highest up on the beach and the furthest distanced travelled is 5m. It is assumed that these pebbles have been pushed by a few waves during the high tide following deployment. No transport rate could be calculated other than stating that some of the pebbles placed highest up on the beach have been pushed up the beach in a slightly easterly direction by a few waves during one tide. The remaining pebbles must have found their way into the beach sediment. Despite the beach topography remaining unchanged it was noted that the surface composition had coarsened which should have favoured the appearance of the coarser painted pebbles on the surface.

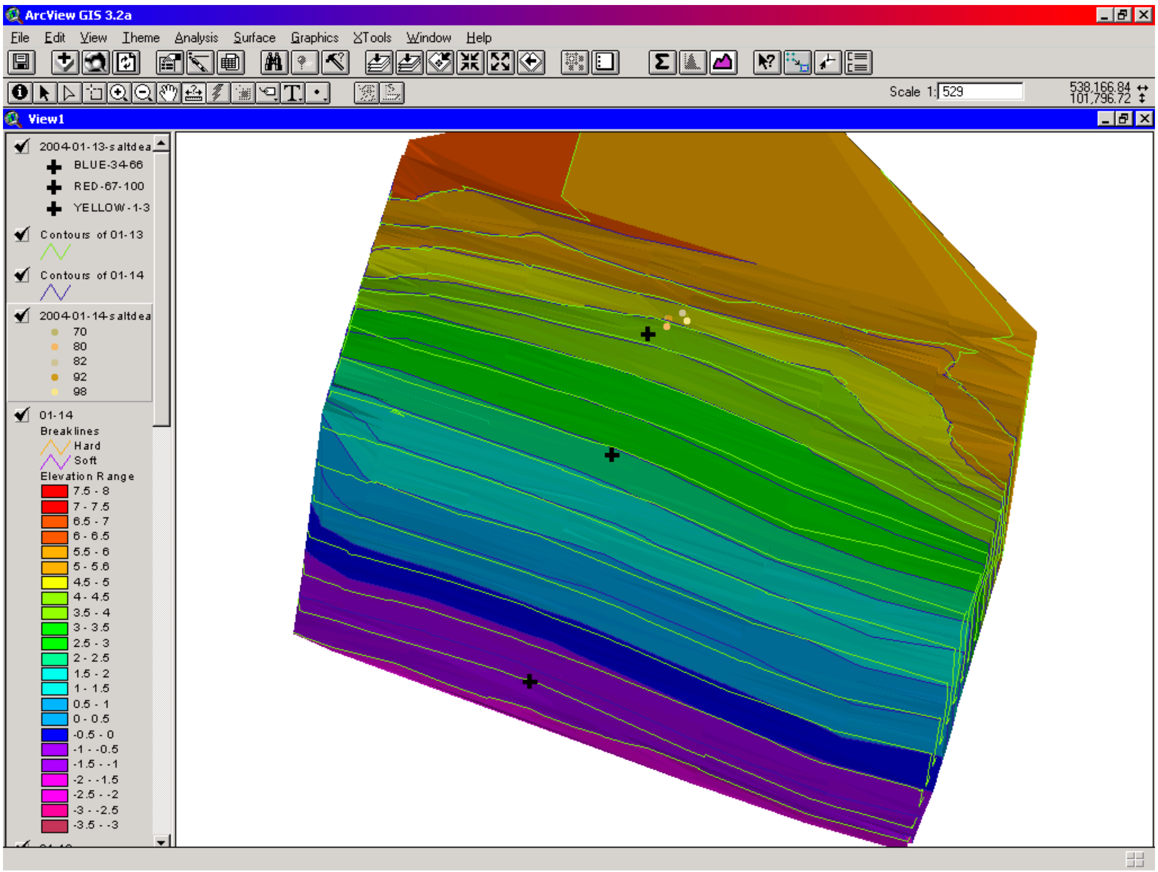


Figure 10: Black crosses show deployment points and light brown coloured dots the positions of relocated pebbles. Contour lines for both surveys are overlaid over the surface of the 14-01-2004.

4.4.2 Seaford

Figure 11 shows the results for Seaford beach. The elevation shows the difference between the two surveys for a stretch of beach 20m west and 300 east of the deployment line. Most of the beach face surveyed seems to have gained material, which would be in line with longshore transport observed at the beach, i.e. under the given wave conditions material is transported eastwards from the 'Buckle Inn'. Nevertheless, the pebbles deployed at the highest site were all found in situ the next day. Only one pebble from the mid beach deployment was found, which had moved 16.3m. Again, no longshore transport rate can be determined as it is likely that this one pebble was also pushed up by a few waves during the first high tide after deployment.

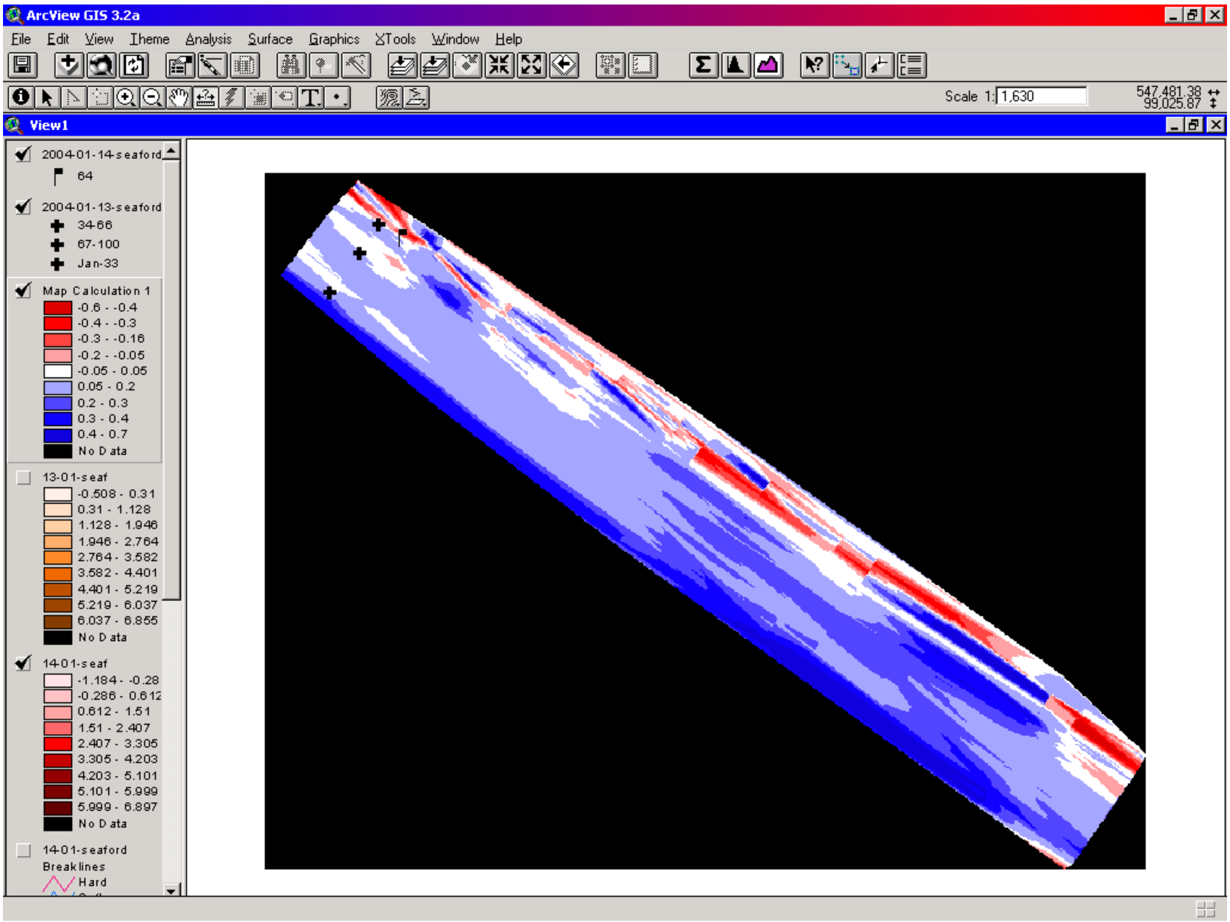


Figure 11: Comparison of surveys at Seaford. Black crosses show deployment points, black flag shows the position of the relocated pebble. Blue shows accretion, red erosion, though some of the erosion on the higher part of the beach is due to survey error.

4.4.3 Eastbourne

Comparison of the surveys at Eastbourne (Figure 12) demonstrates erosion of the whole groyne compartment, though the very high rates in the eastern part are exaggerated by the different position of the survey lines. Three painted pebbles from the middle deployment point were found in the downdrift groyne and have travelled between 34 and 36m.

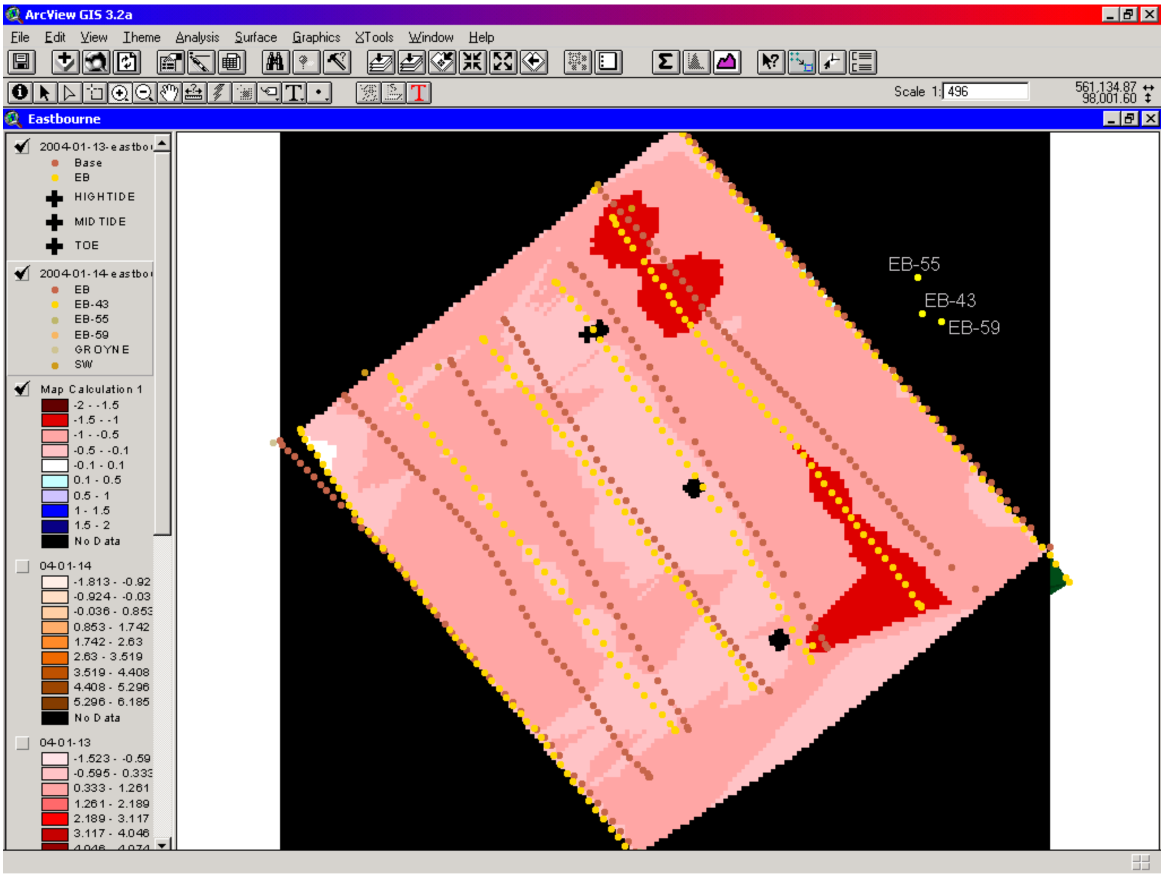


Figure 12: Comparison of the surveys at Eastbourne showing the difference in height between the two surveys. Black crosses show deployment points, yellow dots with label show location of found painted pebbles. Groyne compartment width is 59m.

4.4.4 Pevensey

Figure 13 shows the beach and the deployment points on 13-01-2003. Together with the 100 painted pebbles 75 resin pebbles were also deployed, numbered 1-25 at the beach toe, 51-75 at the top of the beach and 25-50 at the mid beach. Collection took place on January 14 and 15.

On January 14 one painted pebble was recovered 145m downdrift of the deployment site, (Number 38 shown in Figure 14). No painted pebbles were found on January 15. In comparison, 5 resin pebbles were found on January 14, but the top part of the beach could not be searched with the metal detector due to a malfunction. The search was continued and repeated on January 15 and another 5 pebbles were recovered. Pebbles 51-75 were found in situ under a thin blanket of shingle and must have suffered the same fate as the top pebbles at Seaford.

Though Figure 14 only shows the change between January 13 and 14 the change during the next 24 hours was similar in that the middle part of the beach was further eroded and material accumulated in the upper and lower parts of the beach. The accretion that took place against the terminal groyne was reversed between January 14 and 15. Average pebble movement was calculated to be 90m downdrift, ranging between 42 and 144m.

The dry weight of the resin pebbles was recorded before deployment and after recovery (24 hour drying period at 50°C). They looked physically worn and the reweighing confirmed that they had lost weight (Figure 15). One pebble had broken open along a weakness at the copper core. The rate of weight loss experienced is about 25 to 33% of that found during the first 2.5-hour interval in a tumbler (N = 3) and is within the order of the field abrasion rate for quartzite, thus providing a useful alternative to quartzite for field abrasion experiments. The small number of pebbles found did not allow statistical analysis, but a correlation between the distance a pebble had travelled with weight loss did indicate a positive trend (Figure 16).

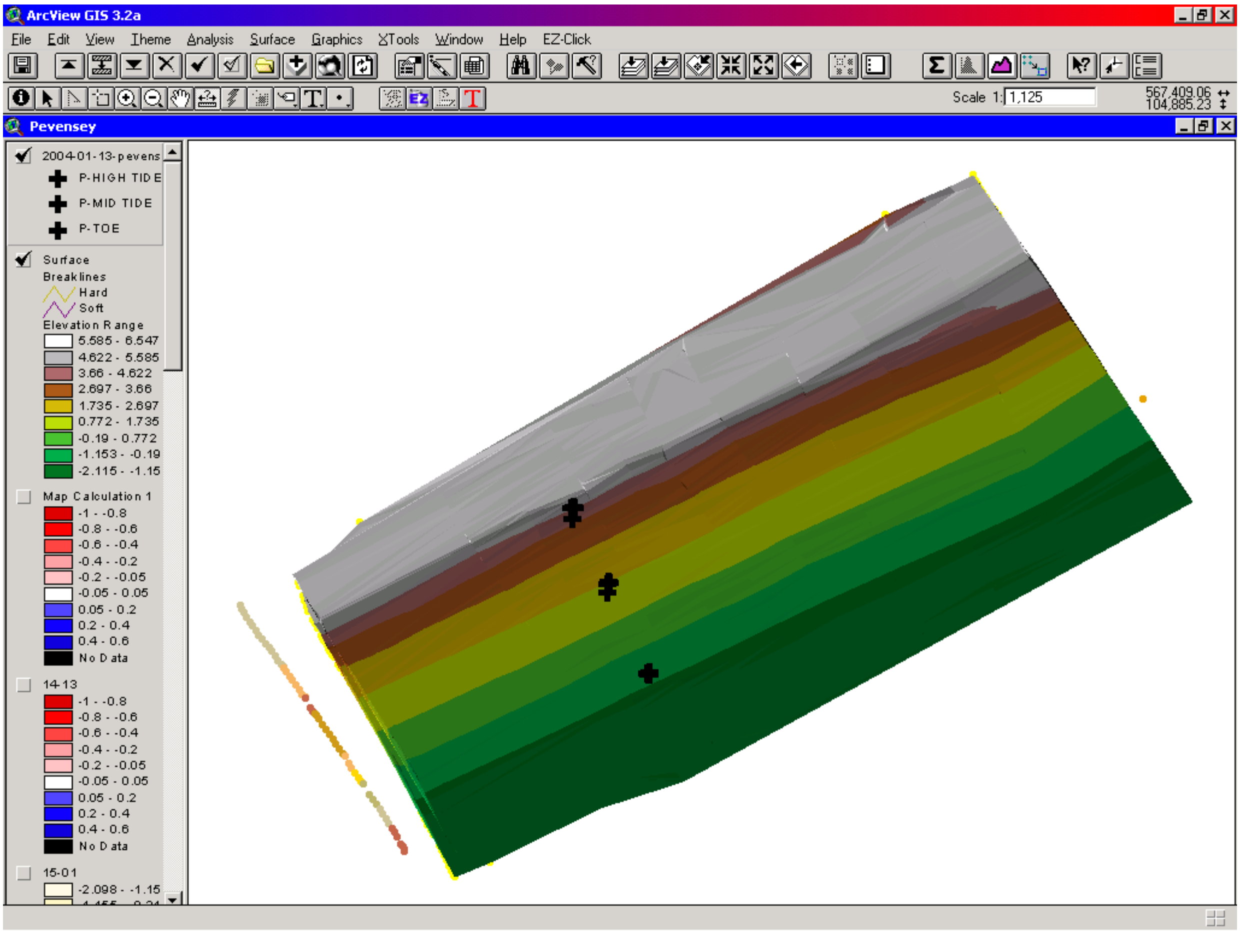


Figure 13: Beach at the eastern end of Beachlands, Pevensey Bay up to the terminal groyne. Black crosses indicated deployment points. Beach length 200m

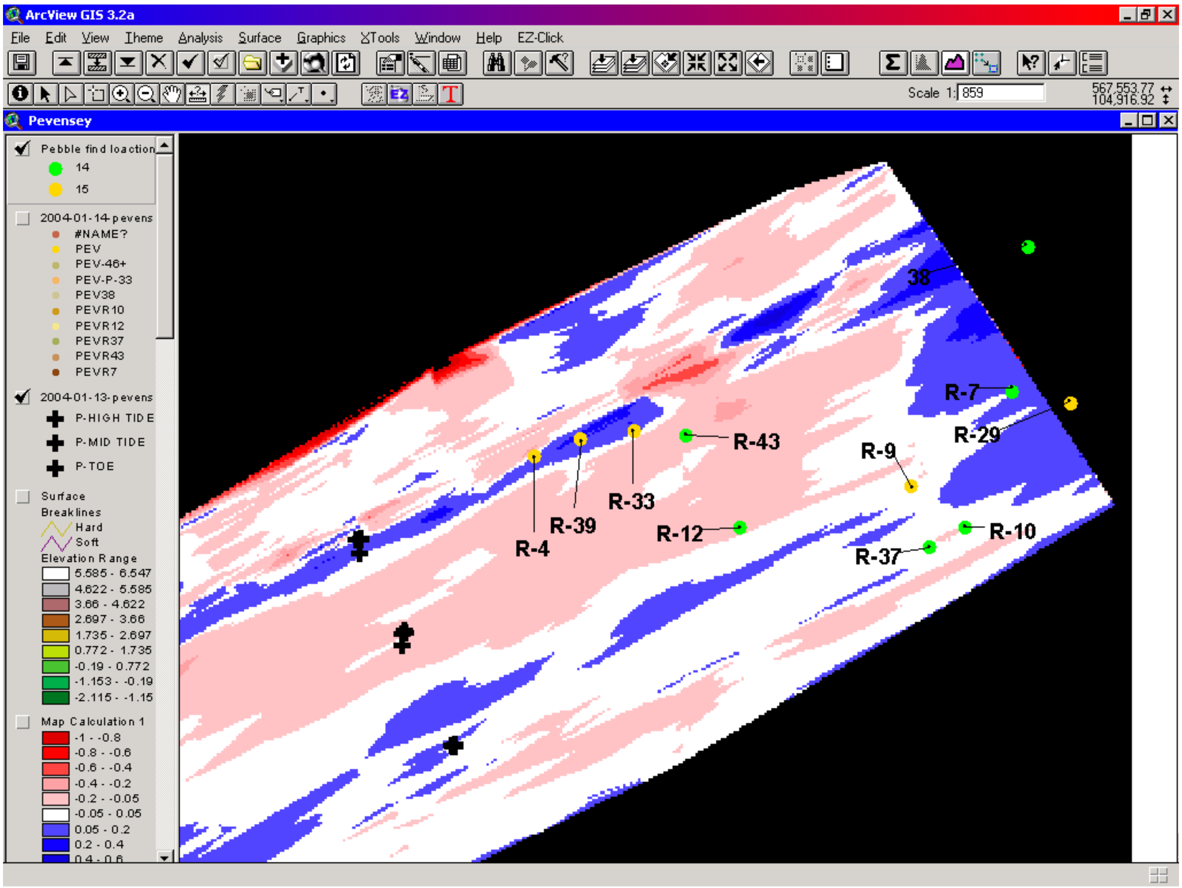


Figure 14: Difference in beach elevation between 13-01 and 14-01. Black crosses are deployment points. Green dots show locations of pebbles found on 14-01, yellow dots those found on 15-01; R denotes resin pebble.

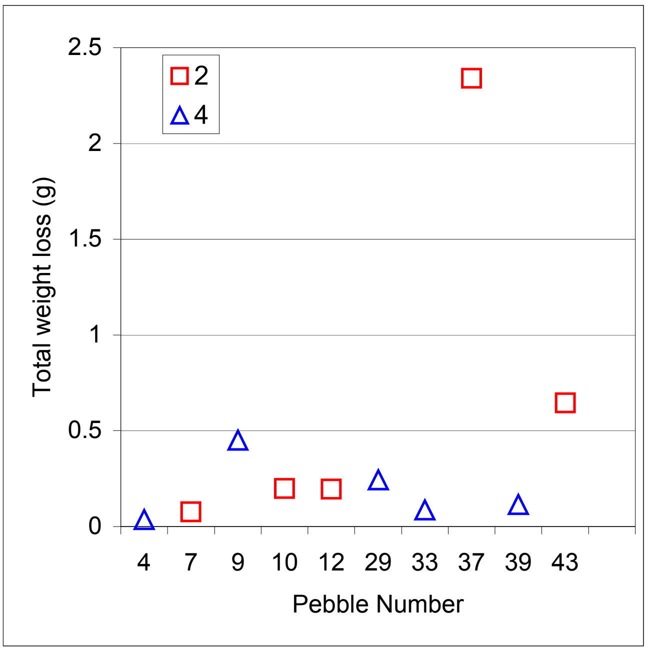


Figure 15: Total weight loss of the 10 resin pebbles from January 13 to 15, 2004. Red squares indicated recovery after 2 tides, blue triangles after 4 tides. Exceptional weight loss of 2.3g is due to breakage.

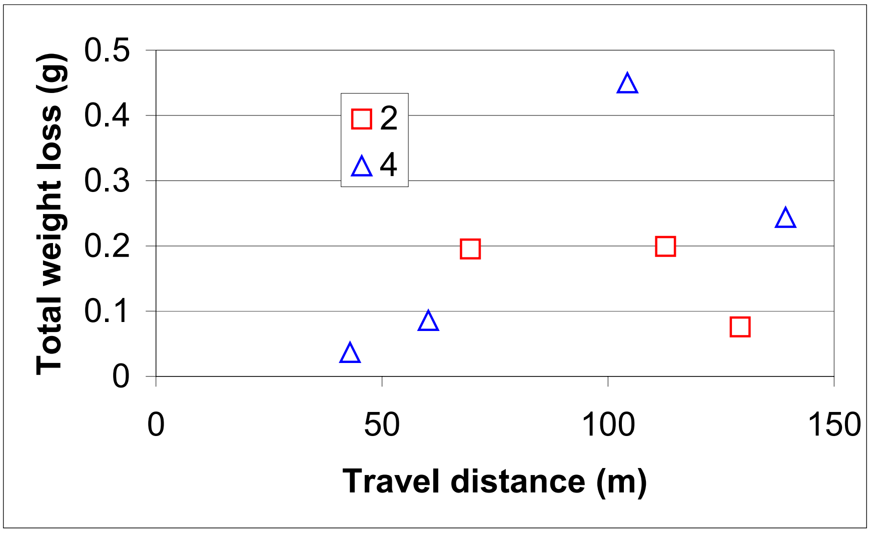


Figure 16: Scatter plot of weight loss compared with travel distance for the resin pebbles collected after 2 and 4 tides.

4.5 Discussion

The results of this trial demonstrated that painted pebbles are of limited value in measuring longshore transport under the particular environmental conditions that were experienced. The conditions over the test period were in no way exceptional (the one in one year event for the Rustington buoy is a wave height of 5.5m). Under gentler conditions it is possible that the recovery rate might be higher but it is unlikely that significant transport would occur under these conditions (i.e. no movement = 100% recovery). Recovery could only be increased by substantially increasing the number of pebbles deployed – however with no guarantee of a satisfactory result. The very few found pebbles seems to indicate that under normal wave approach (Saltdean, Seaford) longshore displacement seems to be smaller than under oblique waves (Eastbourne, Pevensey). The direct comparison between resin pebbles and painted pebbles at Pevensey showed that using resin pebbles the recovery rates were increased from 1% to 10% (data on January14) or even 20% (including pebbles found on January 15). Given the environmental conditions during the investigation, the recovery rate was quite high and encouraging for future work. Following this trial, it was decided that resin tracers provide a useful alternative to painted pebbles, and two further investigations were carried out using only resin pebbles, the results of which are detailed below:

5 Tests 2 & 3: Longshore transport and abrasion of first generation resin tracer pebbles

5.1 Aim

Two experiments for measuring longshore transport and weight loss of resin tracer pebbles were conducted between March 10 and April 7, 2004 at Pevensey Bay. The experiments differed only in the wave environment with the first occurring in part under high waves from a westerly direction and the second dominated by low waves from an easterly direction. As a result, different amounts and directions of pebble transport were recorded and different recovery rates were achieved. The aim was to investigate a distance weight loss relationship within the tracers and to further assess their general performance.

5.2 Method

Tracers were deployed during a spring tide in clusters of 33, near the beach toe, in a middle beach face position and below the last high tide mark, located between two groynes (Figure 17). A layer sufficiently thick to accommodate the pebbles was removed from the beach at the location and the pebbles were placed in the recess. The centre of the cluster was taken to be the deployment point and recorded with GPS. Pebbles were then searched for 2, 7 and 14 days after deployment by means of a metal detector. The area searched depended upon the prevailing wave direction, as searches must always take place downdrift of the deployment site. The search extended 500m to the west and 1km to the east searching every other groyne compartment. The position of the pebbles found was recorded with GPS; the pebbles were then removed to the laboratory, dried and weighed to measure the amount of weight loss. All metal detector searches were carried out by Uwe Dornbusch (eliminating any intra-operator errors) except for one compartment searched on 17-03. Searches were carried out with a Minelab Sovereign Elite detector fitted with a 37cm Coiltec all-terrain coil. Tests carried out previously had established an optimum discriminatory setting that filtered out most metals except copper and aluminium. Searches comprised swinging the detector head with a swath width of ~2m at a slow walking pace (one step = left to right swing, next step = right to left swing) resulting in a zig-zag pattern that is assumed to cover about 50% of the swath area. Using groynes as markers, the beach was searched by walking parallel to the contours following paths ~2m apart. 'Independent' observation confirmed that the paths were straight. In conjunction with deployment and beach searches, a GPS profile survey and beach surface sediment survey of the beach area was carried out, allowing for an assessment of the topographic changes of the beach that could be combined with tracer movement data.

Figure 17: Location of the test site showing some local features, the stretch of frontage that is no / low maintenance (white line) and the location of pebble deployment points.

6 Test 2: March 10 – March 24, 2004

Deployment took place on March 10 early in the morning, and searches were carried out on March 12 (morning and rising tide), March 17 (afternoon and falling tide) and March 24 (morning and rising tide).

6.1 Environmental conditions

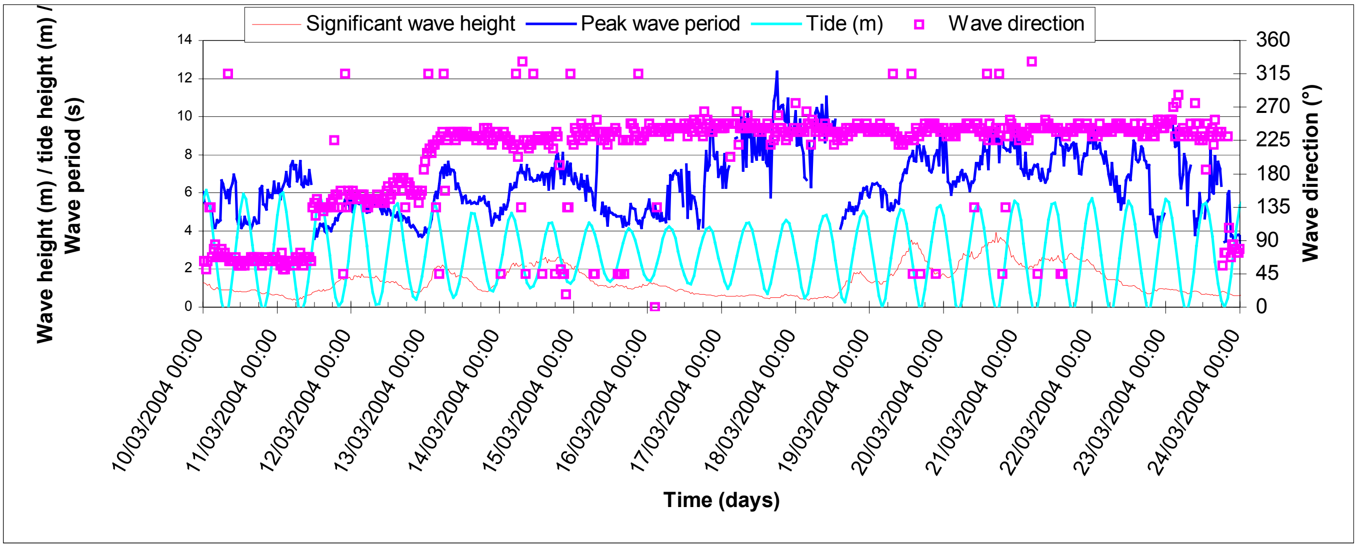


Figure 18: Wave conditions at the Hastings buoy and tidal predictions for Newhaven (heights only as a relative indicator of the state of the tide).

6.1.1 Deployment – 2 day search

During the first two tides of this time interval waves were less than 1 metre high resulting in little or no effect on longshore transport. However the high tide preceding the first search saw waves in excess of 1.5m coming from ~155°, i.e. at an oblique angle that would have resulted in eastward transport.

6.1.2 2-day search – 7 day search

High tide on the afternoon of March 14 coincided with waves in excess of 2.5m coming from ~230°. These, combined with conditions on March 13, are assumed to have resulted in significant eastward longshore transport. The remaining days before the search on March 17 were generally calm with wave height dropping below 1m.

6.1.3 7-day search to 14-day search

The period between March 19 and 22 saw a significant increase in wave heights, reaching >3.5m, which again coincided with wave directions from ~240°. This could have led to significant longshore transport.

7 Results

7.1 Pebble finds and transport

7.1.1 2-day search (EB, UD, TW)

A 290-metre length of beach was searched (Figure 19), covering the deployment groyne compartment and those to the east up to the 'terminal' groyne just east of the Sandcastle from the shingle beach toe to the high tide mark. Areas that were assumed to show erosional surfaces in the compartments in front of Sandcastle were not searched with the metal detector. The search lasted for 4 hours covering ~1800m².

7.1.1.1 Surface Change

The whole search area including the deployment sites are characterised by erosion not only on the upper beach but also the mid and lower shore face, indicating large scale longshore transport.

7.1.1.2 Pebble finds

Out of 100 resin pebbles deployed 19 were found. 3 of the 19 resin pebbles were found on the surface, the remaining 16 resin tracers were found with the metal detector at shallow depths of 5-10cm. The location of all 22 finds was determined with a handheld GPS. Qualitative observation indicates that most of these positions were recorded approximately (± 10m) in the correct location. The maximum, minimum and mean distance travelled by the resin pebbles was 170m, 33m and 104m. Looking at the transport trajectories, most of the pebbles found came from either the top or middle deployment point. Following transport they were deposited over the whole width of the beach face.

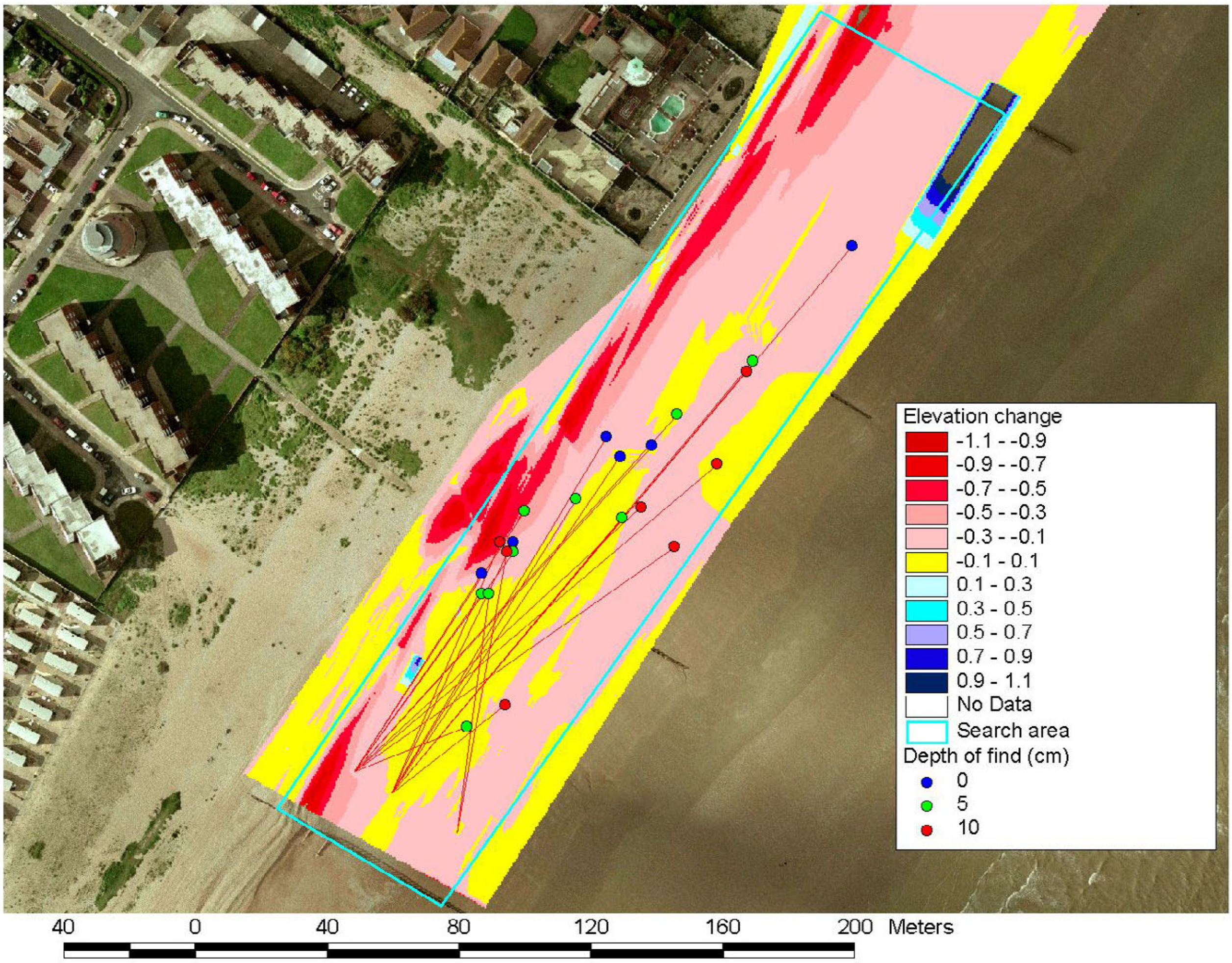


Figure 19: Recovery locations, transport paths, surface changes and search area for the search on March 12, 2004.

7.1.1.3 <u>Field abrasion</u>

Out of the 19 resin pebbles 3 were broken (Figure 20) and 13 were cracked leaving only 3 in their 'original' state. Figure 21 demonstrates weight loss over 4 tides against the distance the 16 unbroken tracers travelled. Apart from 3 tracers with weight loss in excess of 1g, the remaining 13 do seem to show a relationship between weight loss and distance traveled.

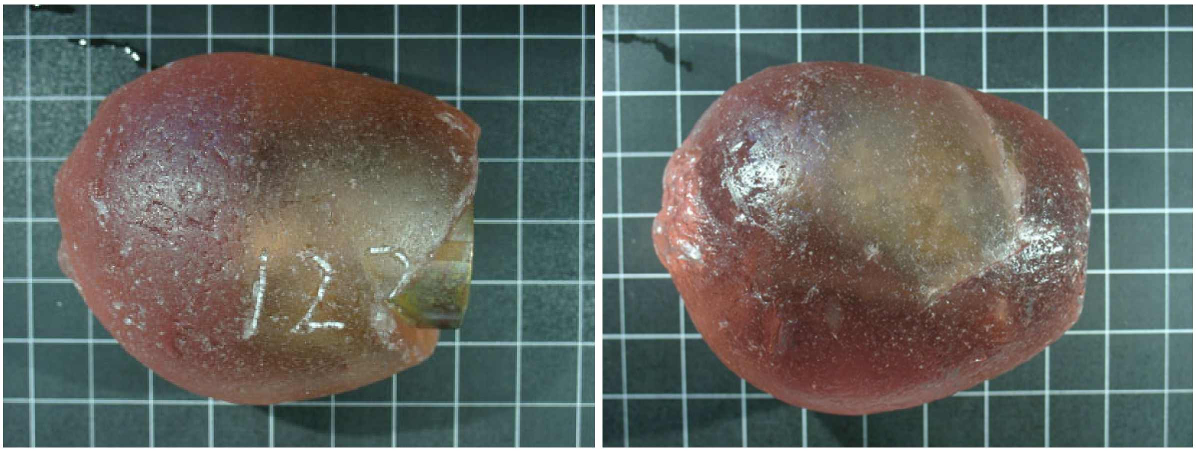


Figure 20: Examples of broken (left) and cracked (right) tracers found on 12-03-2004.

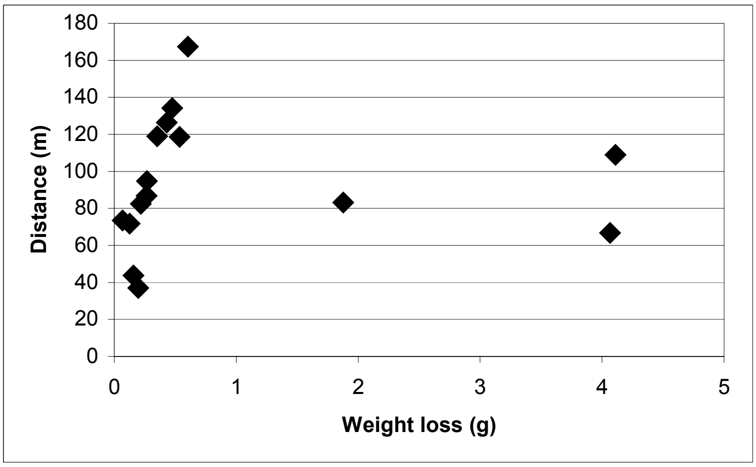


Figure 21: Scatter graph of distance the tracer has moved from its deployment point in relation to the absolute weight loss (Only cracked or intact tracers were considered).

The number of cracked and broken tracers was quite surprising given that cracking had not been observed at that scale either in the laboratory experiments (no cracking at all) or the previous longshore trial (breakage only were the copper core touched the outer skin of the tracer). It is possible that the amount of wave energy impacting on the beach leads to mechanical stress, but, as the subsequent experiments show, this is unlikely to be the cause of the breakage. Temperature variations in the field together with the different expansion coefficients of the copper and resin are again an unlikely candidate, as temperature variations experienced on drying in the lab are greater and have not, as yet, produced any cracking. Further testing of different resins is ongoing.

7.1.2 7-day search (EB, UD, TW)

Given the results of the 2-day search (area that could be covered and location of finds) and subsequent wave conditions, UD decided to move the search area further east. The area searched with the metal detector included (a) the easternmost groyne compartment in front of Sandcastle, (b) behind Sandcastle terminal groyne, and (c) two-groyne compartments further east (Figure 22). The total search area was ~1500m² in ~3 hours. In addition using the metal detector, the search area of March 12 was searched visually by UD.

Figure 22: Recovery locations, transport paths, surface changes and search area for the search on March 17, 2004.

7.1.2.1 Surface Change

Surface changes in the beach were less pronounced than for the previous search period, large areas appeared unchanged in surface elevation, especially west of the Sandcastle terminal groyne. East of that groyne larger parts of the beach face have been eroded with some accumulation-taking place on the upper part of the beach.

7.1.2.2 Pebble finds

Only 6 tracers were found, 3 on the surface and 3 at depths of 5-10cm. The distances travelled range from 40m to 530m. Given the wave conditions this spread is rather surprising as it illustrates that while some tracers seem to have been in transport throughout the majority of the trial, some have barely moved, although they originated from the same deployment location.

All pebble locations were recorded with the differential GPS and the handheld GPS and a few fixed points were also surveyed with both GPS systems. A key problem encountered with use of the handheld GPS is that, although it is capable of giving sufficiently accurate positions (accurate in comparison to the distance travelled), there is no way to verify the accuracy, which is likely to change over time, in proximity to obstructions and possibly in relation to the time the GPS was held in an optimum position for reception.

7.1.2.3 Field abrasion

Out of the 6 tracers found, only 5 were collected from the beach (the 6th, which had travelled the second longest distance, was 'lost' before it could be retrieved). Out of the five, two showed cracks and one was broken. Figure 23 shows the distance travelled and weight-loss of the 4 cracked and original-state tracers, indicating again that there seems to be a relationship between the two variables, as one would expect.

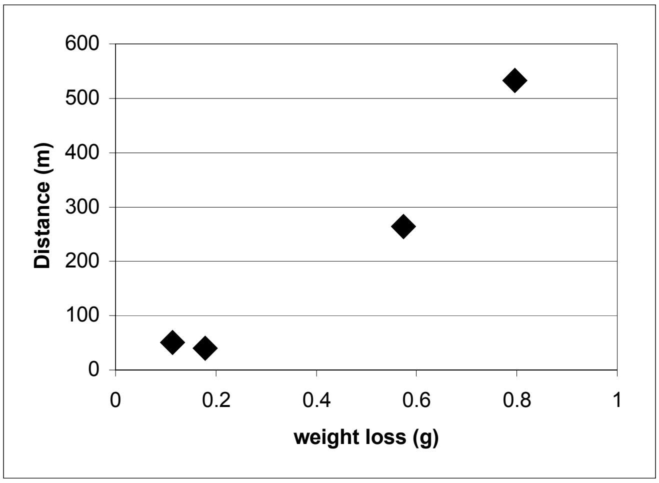


Figure 23: Scatter graph of distance the tracer moved from its deployment point in relation to the absolute weight loss.

7.1.3 14-day search (UD, TW)

Given the increased wave height over the preceding week, it was decided to concentrate the search on the area of the 2-day search (from the deployment groyne compartment to the Sandcastle terminal groyne) to try to determine whether some tracers still remained in this area. No attempt was made to try to find tracers that had moved even further.

7.1.3.1 Surface Change

In line with the wave and tide environment, the surface changed as a result of erosion of the upper beach (storm response during advancing spring tide) followed by accumulation of a spring tide bar under quieter condition below the erosion zone.

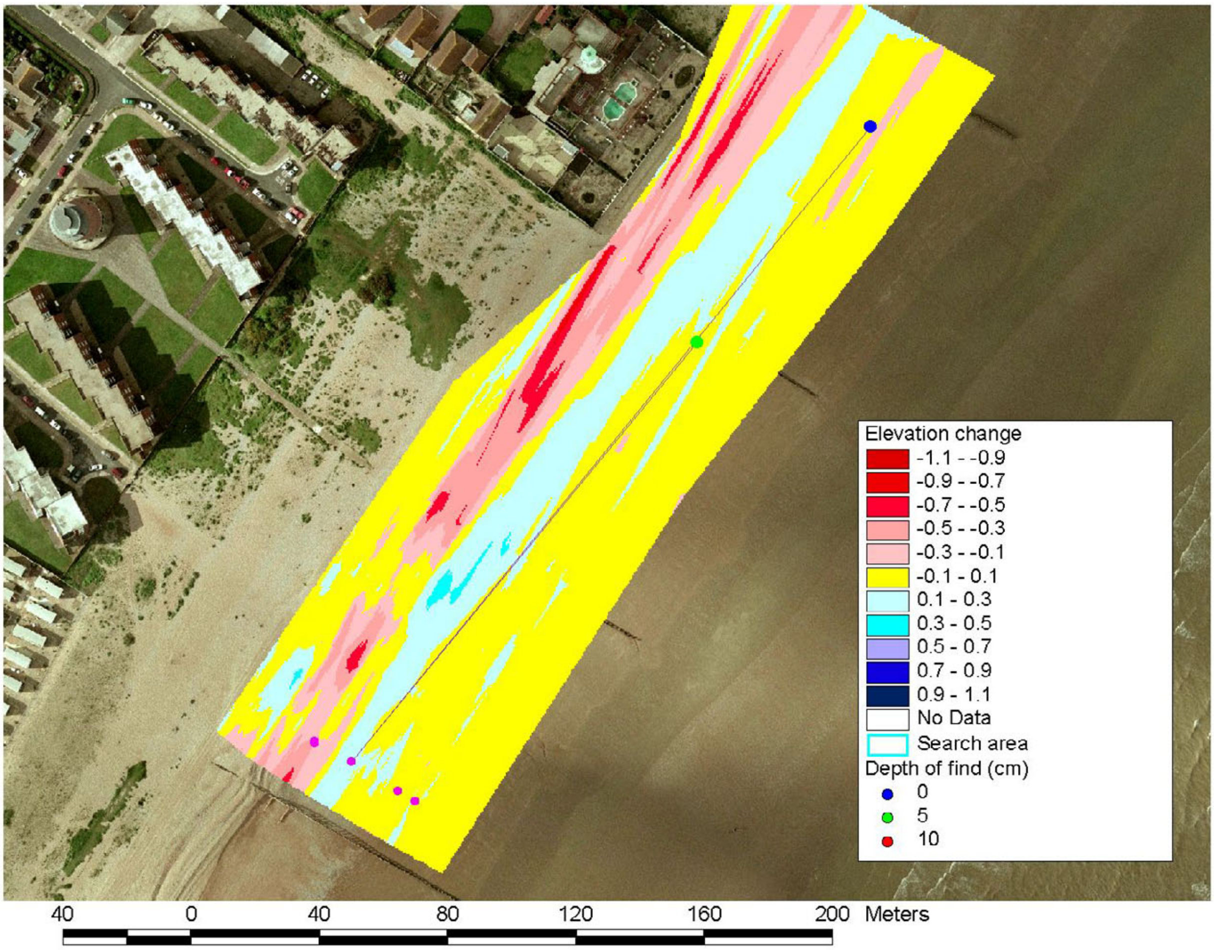


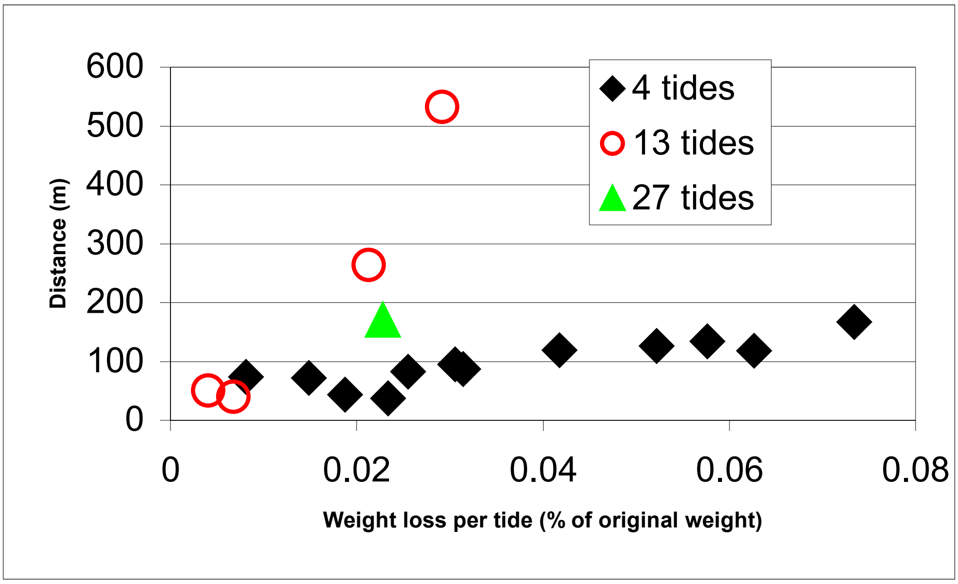
Figure 24: Find locations, transport paths and beach surface changes for the search on March 24, 2004.

7.1.3.2 Pebble finds

One resin tracer (green marker in Figure 24) was found at a distance of 170m from the deployment point at a depth of 5cm.

7.1.3.3 Field abrasion

The abrasion results of the previous finds are combined in Figure 25 and the weight loss reduced to the percentage weight loss per tide (Figure 25a). Only tracers where the weight loss seemed to be due to abrasion rather than breakage were considered. Those pebbles that travelled furthest did not show the highest weight loss per tide, suggesting that they may not have moved during the whole period. The scatter plot shown in Figure 25b, in which the total weight loss in percent is plotted against the distance travelled, supports this suggestion. Here those that have travelled furthest and/or have been on beach longer show a higher weight loss. However, one should be cautious with the interpretation given that the pebble number is small and uncertainties arise in the case of the weight loss of pebbles showing cracks.



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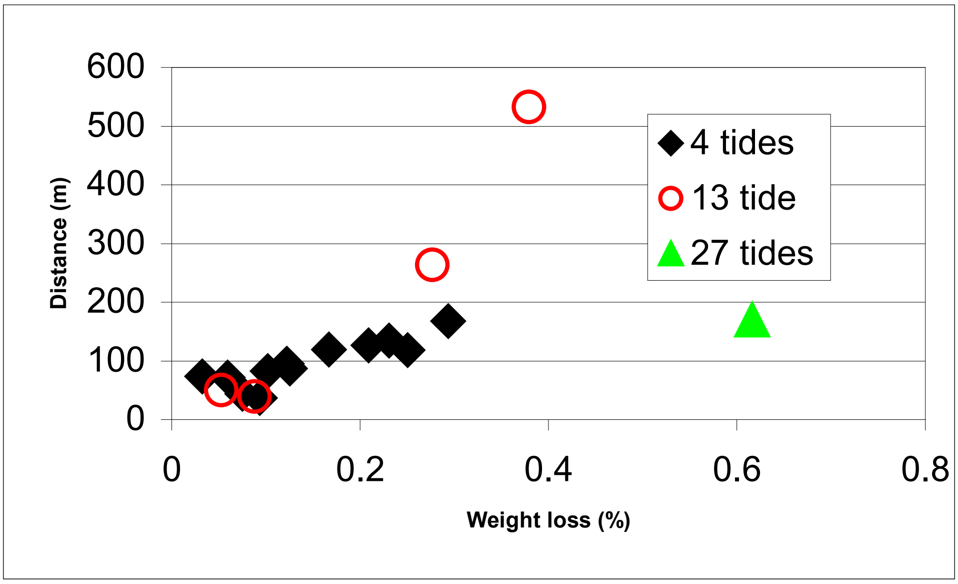

B

Figure 25: A) Weight loss per tide compared to distance travelled and time spent on the beach. B) Total weight loss compared to distance travelled and time spent on the beach.

7.1.3.4 Comments

Metal detecting and digging:

The metal detector worked well and with some experience and the proper settings it is possible to recognise the signal emitted by the tracer pebbles. However, the ratio of tracer finds to 'false alarms' (this is a qualitative assessment only) is in the range of ~1:4. With all pebbles found at depths <15cm it was in most cases possible for the detecting person to uncover the pebbles by pushing the loose pebble cover out of the way with a foot, making a separate 'digger-person' unnecessary.

Search area and GPS recording:

Contrary to earlier, optimistic estimates, it was found that only a comparatively small area of beach (~15,000 to 20,000m²) could be searched with the metal detector between tides. The original idea of searching 'every other' groyne compartment was found to be impractical during searches carried out at a rising tide as the beach in this condition needs to be searched in paths along the whole of the search area to keep up with the tide. Walking an extra distance to hop compartments would add considerably to the overall distance to be walked and would effectively reduce the net search area. However, during a falling tide it is possible to search one groyne compartment after the other making compartment hopping much less of a problem. Although the search paths were closely spaced and the detecting person walked sufficiently slowly, it is likely that the 50% coverage mentioned in the "General experiment set-up" is too optimistic. Swinging the metal detector for 4 consecutive hours and at intervals of 2, 4 and 7 days puts considerable strain on the muscles / tendons of wrist and upper body of the operator that could lead to RSI-syndrome. The present timing seems to be the maximum possible for one person. The experience gained in comparison of the differential and handheld GPS mean that it is much more desirable to use the differential GPS especially under conditions where the travel distance may be < 50m (positional uncertainty >10%).

8 Tetst 3: March 24 to April 7, 2004

Deployment took place on March 24, 2004 early in the morning, and searches were carried out March 26 (morning and rising tide), March 31 (afternoon and falling tide) and April 7 (morning and rising tide). The beach toe deployment position was changed in relation to Experiment 2 because the beach toe had moved landward by ~5m and had become sandy foreshore. The two other deployment points remained the same. Throughout most of this experiment wave conditions were much gentler (Figure 26) than those during Experiment 2, allowing an evaluation of the method under different conditions.

8.1 Environmental conditions

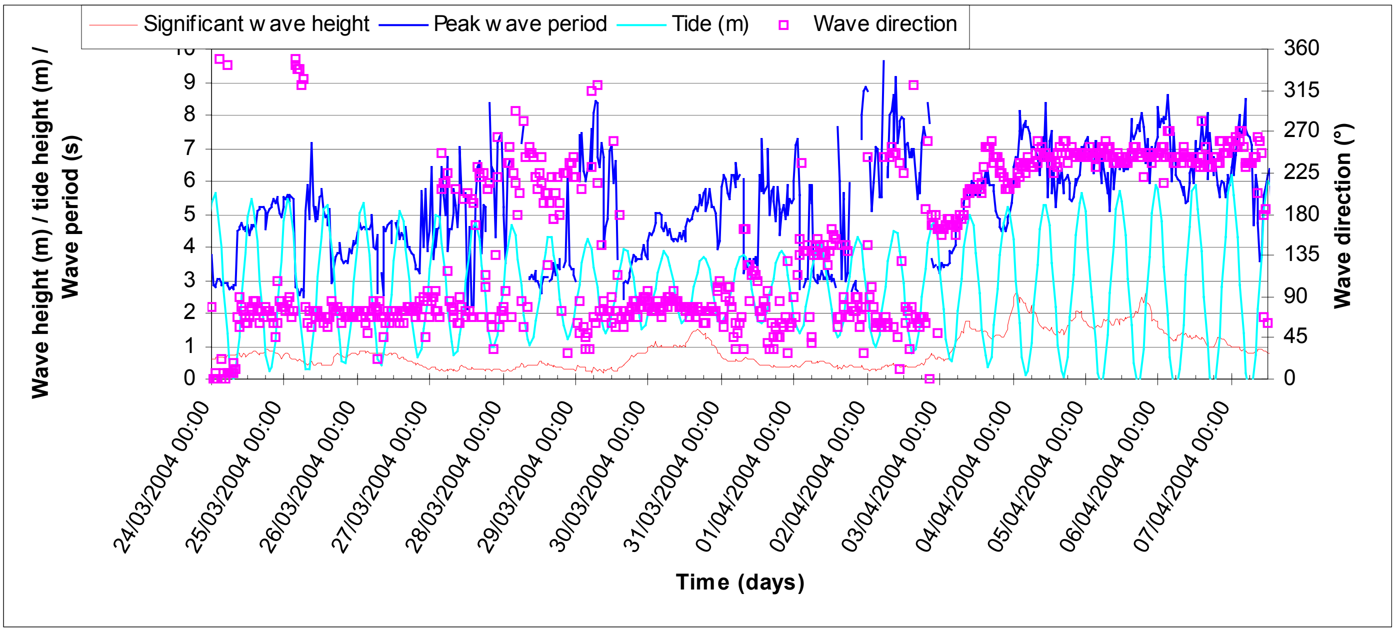

Figure 26: Wave conditions at the Hastings buoy and tidal predictions for Newhaven (heights only as a relative indicator of the state of the tide).

8.1.1 Deployment – 2 day search

Small waves <1m from the east-southeast (ESE) occurred over this period, producing almost negligible wave incidence at the beach. The expectation was that only a small amount of westward movement of pebbles would be observed.

8.1.2 2 day search – 7 day search

During the first part of this time period, weak waves of <0.5m with varying wave directions offshore were encountered, indicating poorly developed wind-waves. However, immediately prior to the 7 day search, on March 31 wave heights picked up, to exceed 1m. Wave direction was still from the ESE, resulting in an expected westward transport.

8.1.3 7 day search to 14 day search

During this time period, increases in wave height >2m occurred and there was a significant shift in wave direction from ESE to WSW, coinciding with a change towards the equinoctial spring tide. Times of wave height peaks do not seem to have coincided with high tide events. Given WSW-waves, the wave height on the beach was likely to have been smaller than at the Hastings buoy because of the sheltering effect of Beachy Head.

8.2 Pebble finds and transport

8.2.1 2-day search (EB, UD)

The search began in the deployment compartment, and because of the number of finds this yielded and the wave conditions preceding the search, only the neighbouring compartments were searched (Figure 27). The whole search area was ~600m².

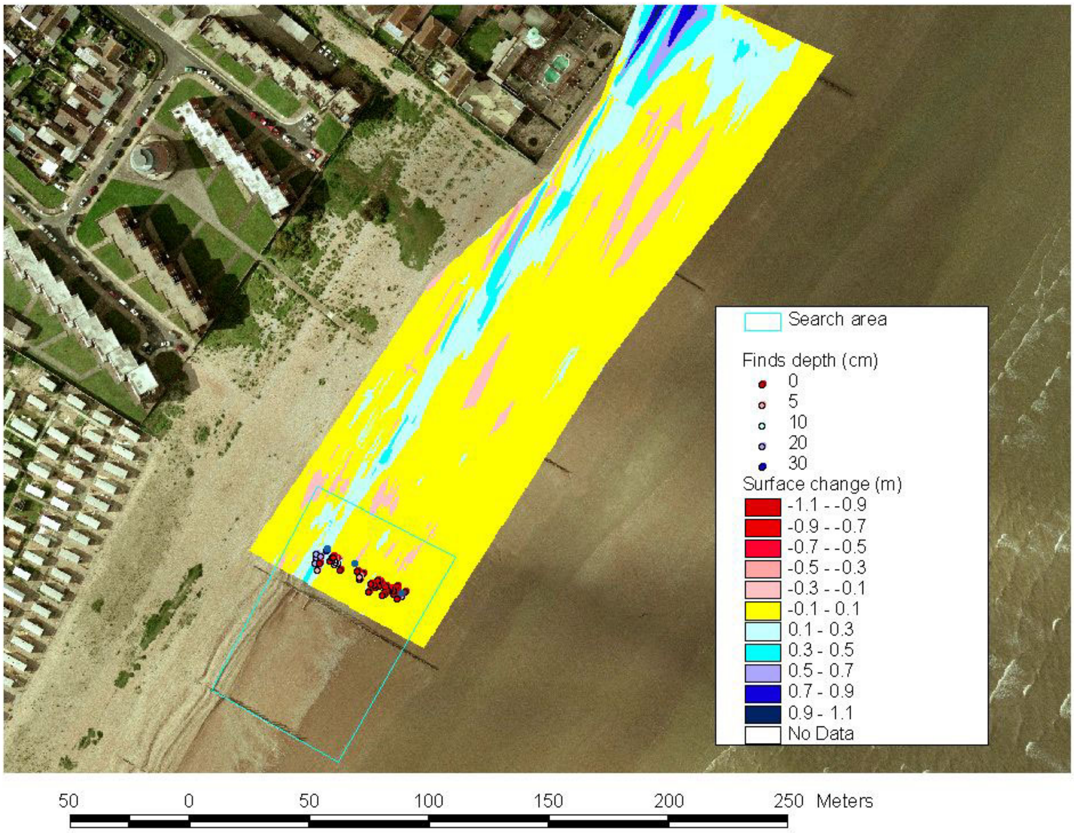

Figure 27: Recovery locations, search area and surface changes for the search on March 26, 2004

8.2.1.1 Surface Change

The survey on March 24 did not include the groynes west of the deployment compartment and therefore only changes in that compartment and compartments to the east are shown. The most noticeable feature is the development of a high tide berm (up to 0.5m accumulation) as a recovery feature from the previous storm. In more detail, Figure 28 shows that material accumulated over the top deployment point but that both the middle and bottom points experienced surface erosion mobilising all the pebbles deployed there.

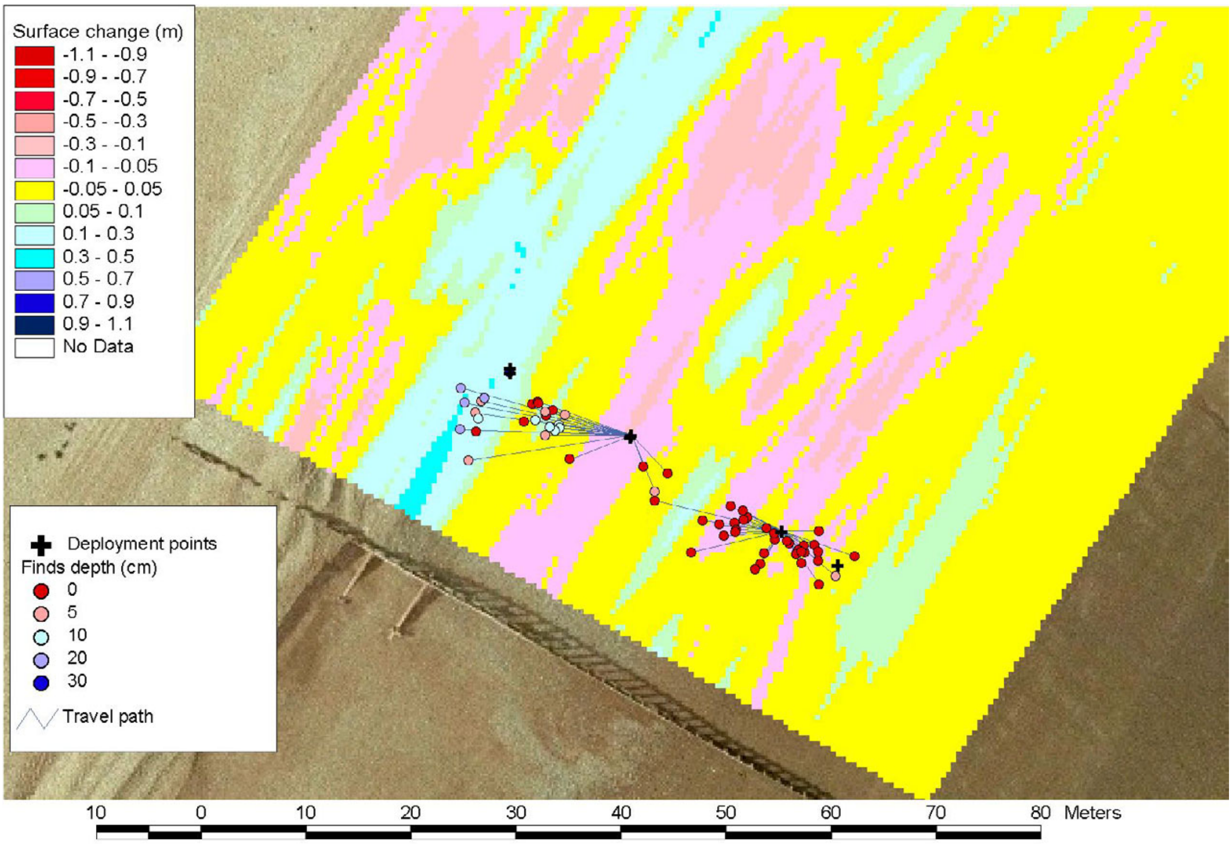

Figure 28: Detailed diagram of recovery locations and surface change on 26-03-2004.

8.2.1.2 Pebble finds

Out of 100 resin pebbles 85 were located. Of those 85, 25 were found at the top deployment point at a depth of 30cm. This indicates that 8 pebbles from the top deployment point are likely to have moved, but none of these were found. Out of the 66 deployed at the middle and bottom deployment points, 60 were actually found giving a recovery rate of 91%. The number of finds at the surface was 42, at 5cm depth 8 were found, at 10cm another 6, and between 20 and 30 cm depth 4 more were recovered.

With one exception, all the tracers were found west of the deployment point, illustrating that even small wave incidence will lead to directional transport. The tracers at the bottom deployment point moved equally up (14) and down (15) the beach (4 just moved laterally). By contrast, those from the middle deployment point showed a transport asymmetry with 24 moving up the beach compared to 3 moving down. It can be assumed that the remaining 6 tracers have been buried in the berm.

The maximum distance travelled is 16.8m and the minimum 0.8m. The distances travelled and spatial distribution could only have been recorded with a differential GPS, supporting the argument against the use of handheld GPS mentioned earlier.

8.2.1.3 Field abrasion

Because of the environmental conditions and the fact that two more searches were scheduled, only 37 of the 60 pebbles that had moved were collected and brought back to the laboratory. Of these 7 showed cracks and two were actually broken. Given the wave conditions, the reason for these failures was not thought to be the mechanical stresses experienced. Pebble 248 (Figure 29) seemed to point towards a different source of weakness. The pebble shows two cracks forming a T with a cavity where they met at the base of the pebble where the copper was actually quite close to the pebble surface. The cavity does not seem to be the result of a breakage but does show a smooth surface that could have been the result of an air bubble trapped in the resin under the copper when it was placed on top of the pre-cast base. The pebbles with cracks were found at OD heights of between –1.3 and +0.9m with the water level at high tide reaching up to ~2.9m. This would mean that a water column of between 3.2m and 2m was covering the pebbles for part of the time, which could lead to considerable pressure from air pockets trapped in the resin. Further testing of different resins and mixes are ongoing.

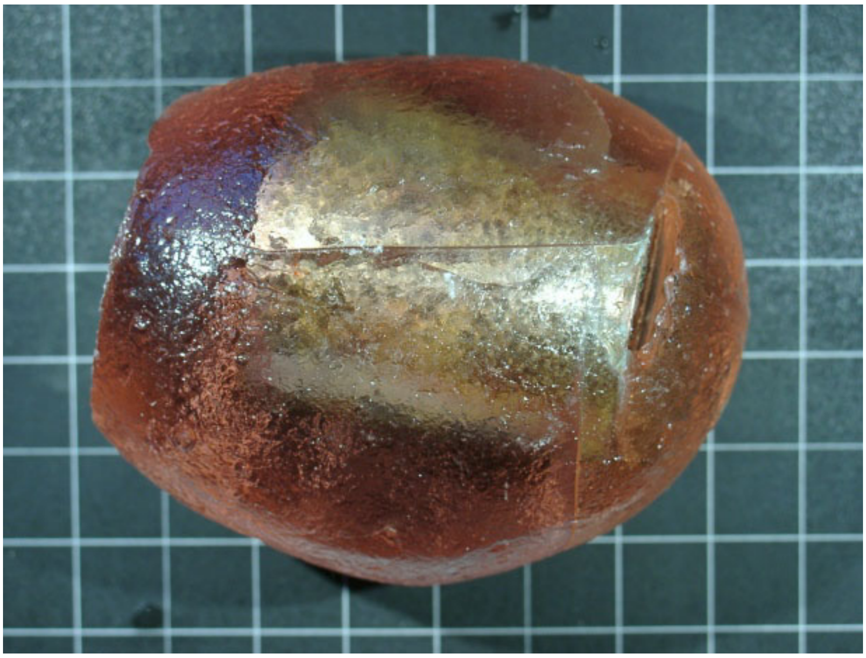

Figure 29: Crack and cavity of pebble 248

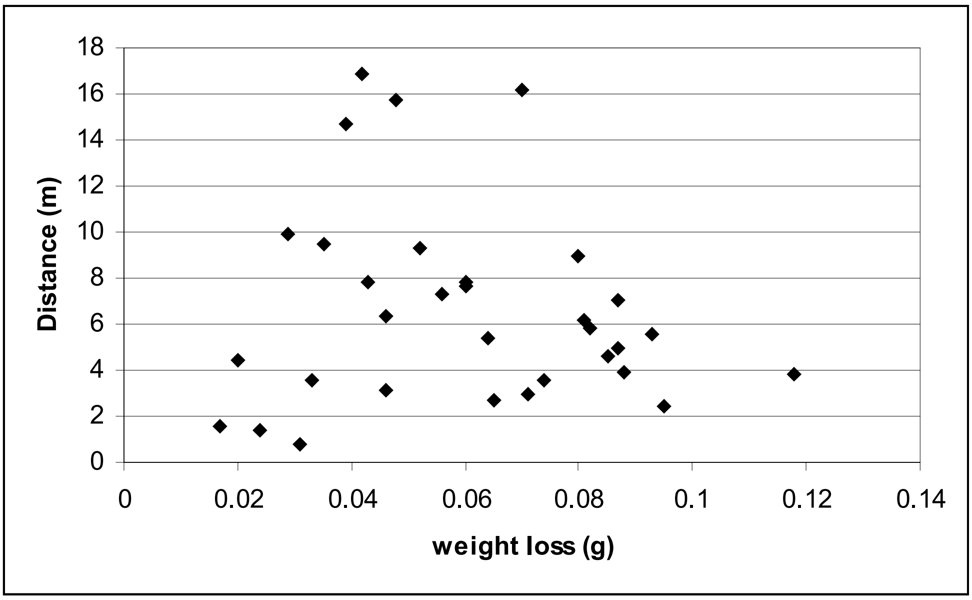

Figure 30: Scatter graph of distance the tracer moved from its deployment point in relation to the absolute weight loss.

8.2.2 7-day search (UD, TW)

Following the results of the 2 day search in relation to the wave conditions, the search area was slightly extended westward as further westward travel was expected to have occurred.

After the searching the area shown in Figure 31, areas in which pebbles were found were searched again in paths across the beach and at a slower pace, resulting in 4 more finds, 2 of which were at depths of 30cm.

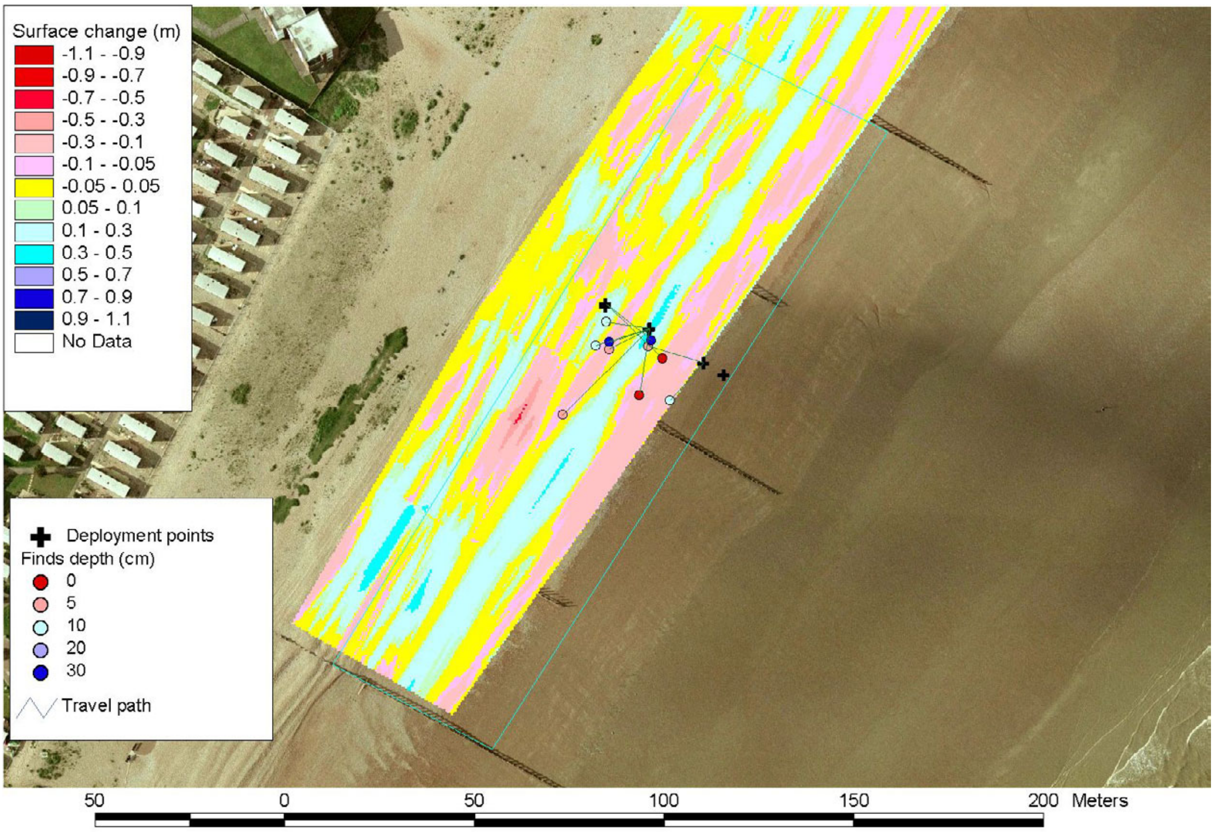

Figure 31: Recovery locations, transport paths, surface changes and search area for the search on March 17, 2004.

8.2.2.1 Surface Change

Surface changes reflect the recovery of the beach during the change towards a neap tide from a storm at spring tide by the development of a number of stacked berms, the lowest and largest of which is found at the level of the mid-deployment point.

8.2.2.2 Pebble finds

Of the 10 pebbles found 1 was found at the surface and the others at depths up to 30cm. The westward travel was increased, with the largest distance being 32m through a largely dysfunctional groyne.

Surprisingly, 2 pebbles from Experiment 1 were found, indicating that they had not moved eastwards during the conditions of the first experiment.

8.2.2.3 Field abrasion

Figure 32 demonstrates that the additional time the tracers have spent on the beach is not reflected in increased weight loss. The two tracers with weight loss >0.4g are from Experiment 1 and their higher weight loss could indicate that they were abraded but did not move during Experiment 1.

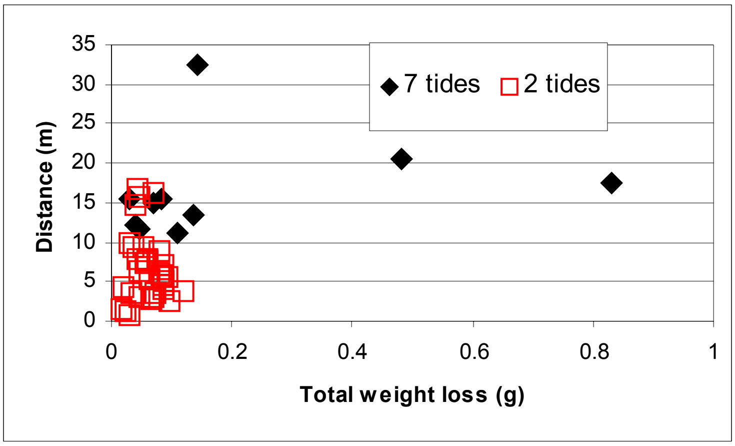

Figure 32: Scatter graph of the distances moved by tracers from their deployment point and their absolute weight loss (2 day and 7 day collections).

8.2.3 14-day search (UD)

Because of the change in wave conditions and the circumstance that only one person was available to carry out the work, the topographic survey was limited to the deployment groyne compartment and the two compartments immediately east and west (Figure 33). During the survey a number of pebbles were spotted on the surface, and, based on these finds and taking the wave approach into consideration, the search was concentrated on the deployment compartment and the two compartments to the east.

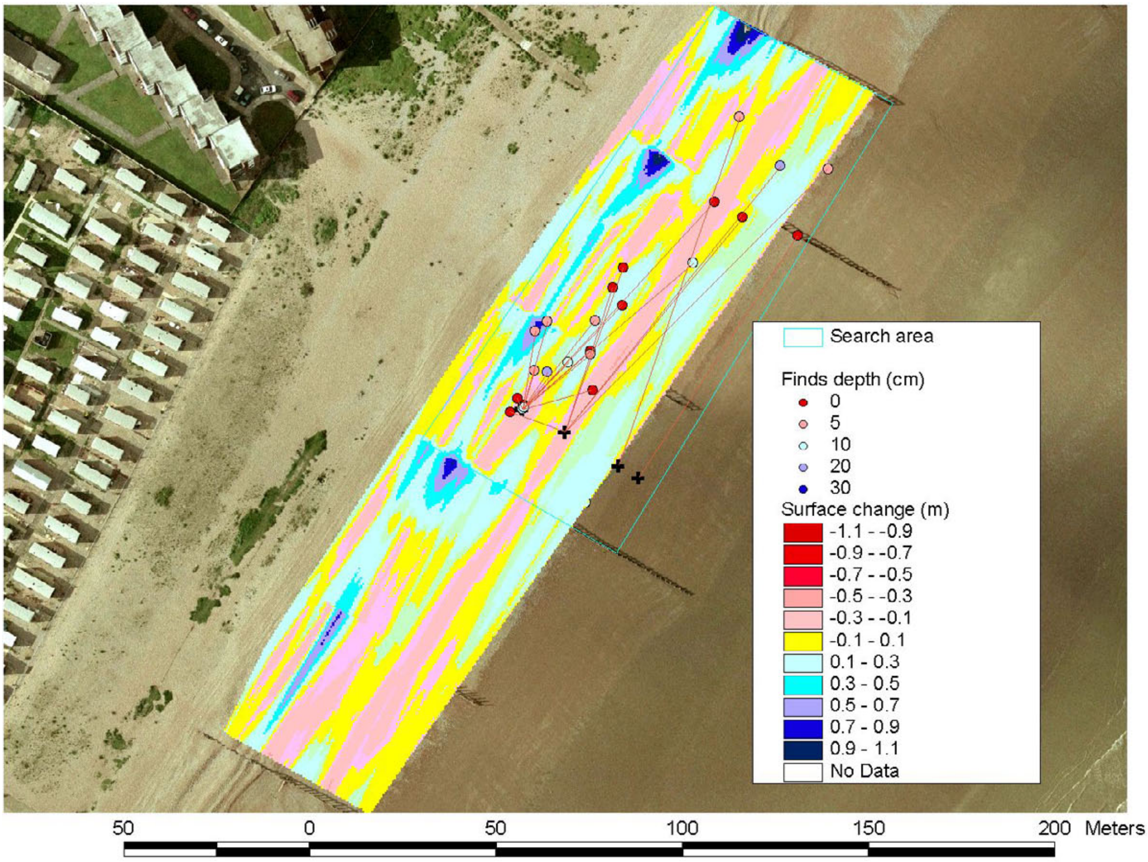

Figure 33: Recovery locations, transport paths, surface changes and search area for the search on April 7, 2004.

8.2.3.1 Surface Change

In agreement with the change in wave height and direction, erosion of part of the middle and lower beach took place and this material moved either to the beach toe or to the high tide berm. Significant transport in the eastern direction can be inferred from the build up of material against the west facing upper parts of the groynes (the upper parts are in a somewhat better state than those lower down the beach and thus better at accumulating material). Of interest is the change at the top deployment point. Deployment took place at a height of 2.38m OD, and, during the previous searches, this point was characterised by accumulation, resulting in most of the tracer remaining in place. The comparison with the previous survey shows a surface lowering of 20cm but the final surface height is still 2.5m, 12cm higher than at the time of deployment. If no 'active' layer had existed, the tracers could be expected to be still in place.

8.2.3.2 Pebble finds

32 pebbles were found, 11 on the surface and 21 at depths of 5 to 20cm. Only 9 out of the original 33 tracers from the top deployment point were still in place ~10cm below the surface. Of those that were mobilised, 14 were found during the search. As with the previous search, one tracer from Experiment 1 was also found. The maximum distance travelled was 99m and the mean 38m. Three of those found were previously recorded during the search on March 26. They had undergone first westward movement, then possible burial as they were not spotted during the 7-day search, followed by eastward movement.

8.2.3.3 Field abrasion

Figure 34 shows the weight loss-distance relationship for the tracers of Experiment 2. Those collected on day 14 that had travelled further than those collected at the 2 and 7-day search also show higher weight loss. The one that travelled 100m and lost 0.8g was broken. Given that most of those found at the 14-day search came from the top deployment point and had been buried for a considerable part of the 14 days their weight loss reflects travel distance rather than time spent on the beach.

Surprisingly, of those 9 pebbles that were still found in the original position only 2 showed a weight gain (0.02g) but 7 showed a weight loss that for many is one order of magnitude higher than the balance error (min 0.001, average ~0.02, maximum 0.096g). Either these pebbles did experience abrasion without moving (e.g. became lodged in the sediment while material moved over them) or a weighing error occurred. The latter seems less likely because this error should have affected all pebbles. Error presumably occurred in the case of the two that showed a gain.

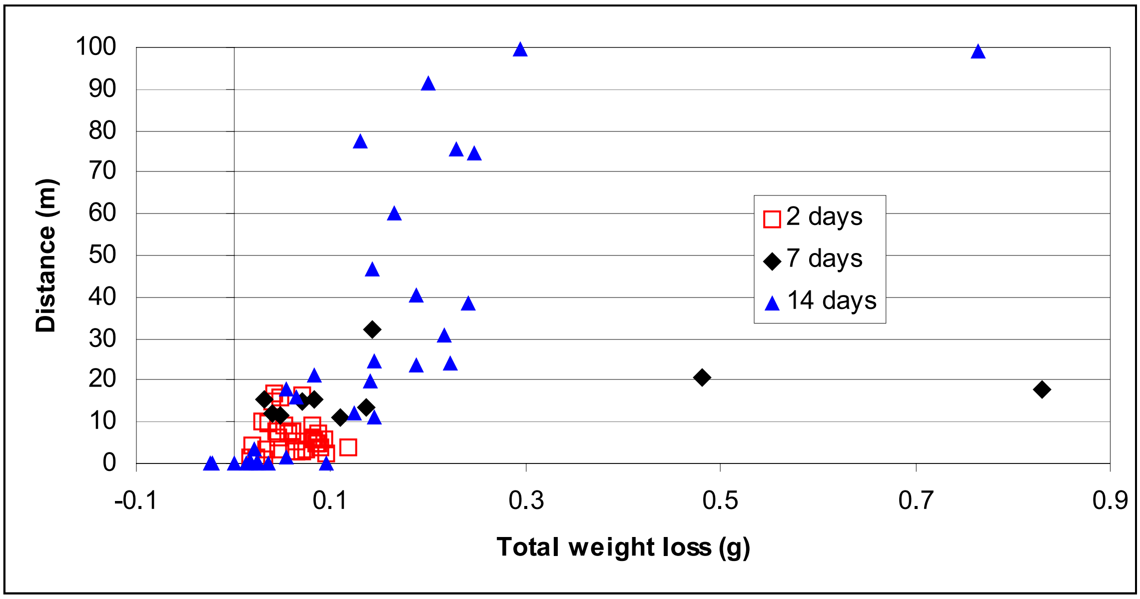

Figure 34: Scatter graph of distance the tracers moved from their deployment point in relation to the absolute weight loss for the 2 days, 7 days and 14 days collection.

9 Discussion

9.1 Detection at depth versus at the surface

The detectability at depth of the resin tracers has resulted in significantly increased recovery rates compared with finds only at the surface using painted pebbles. The relative benefit appears to change with the conditions found on the beach. Under very gentle conditions and over short time periods the amount of finds at the surface can be much higher than at depth (thus the 2 day search during Experiment 2 yielded 42 pebbles at the surface, and 18 at depth). Nevertheless, those found at depth increase the overall number of finds and give an indication of the surface change or active layer thickness. Increasing either the time the tracers have spent on the beach (7 day search, Experiment 2) or the wave heights (2 day search, Experiment 1) decreases substantially the proportion of tracers found on the surface, probably as a result of the larger degree of sediment mixing. The settings of the metal detector allow for a good discrimination between the signal from the tracers and other objects on the beach resulting in relatively few 'false' signals.

However, while tracers buried at quite shallow depths (< 15) are likely to be picked up even if the detector head is to one side of them, deeper buried tracers seem to be detected only when the head is directly above them. In other words, the detection rate in a given area decreases with depth (e.g. as a hypothetical example: 100% of those on the surface are found, ~40% of those at 0-15cm depth, 10% of those at 15-30cm and 0% at >30cm). This has important implications in terms of representation, for example, tracers found in relation to those not found. Thus, if 1% of tracers are found at 30cm does it mean that 10% of all tracers are at that depth? Another implication is that the relationship will vary with the intensity of the search. For example, if the search is more intense will the proportion of finds at 30cm increase by the same amount as that of those found at 10cm? However, the number found at the surface is unlikely to change, as it cannot increase beyond 100%.

Looking at the objects that have produced the 'false' signals, it is apparent that even relatively small copper objects produce a similar signal to the copper core in the tracers. To assess the signal that comes from a cheaper tracer, 3 tracers with 22mm copper pipe were produced and when these were placed on the beach they did actually produce very much the same signal as the larger copper core. However, these 'small core' tracers are much lighter and so the missing copper weight has to be made up by some cheaper metal (e.g. lead). For future experiments, further thought needs to be given to whether the tracer composition needs to be changed, how much material costs could be saved, and how much more work would be involved in producing these composite tracers.

9.2 Search strategy

The main problem encountered relates to space-time, as the total area that can be searched is limited by a) tidal conditions and b) human resources. Given these conditions, the area that can be searched will depend on the intensity (speed and path spacing) of the search. From the experiments conducted, it was found that covering the same area twice actually results in additional finds (7-day search Experiment 2). Under the spacing employed in the two experiments a maximum of ~16,000 to 18,000m² can be searched, which raises the second problem as to where to search. As discussed earlier, the idea of 'groyne hopping' can be realised only on a falling tide and is therefore not practical as a general strategy. If therefore the search area is a continuous stretch of beach the length of beach that can be searched is ~300m. This distance has almost been achieved after 2 days in Experiment 1 and is likely to be exceeded by tracers under more severe conditions.
The system of searching at 2, 7 and 14 days after deployment worked for Experiment 2 but was inadequate for Experiment 1. Given that abrasion and transport is less vigorous under gentle wave conditions (i.e. the shorter the time spent on the beach the smaller the amount of weight loss, probably approximating to the error margin) it likely that the search timing for future experiments should be variable depending on the wave conditions, e.g. similar to the one used for gentle conditions but at much shorter intervals under more severe conditions, possibly up to one day or even one tide after deployment. Because every search involves removing the pebbles found, the number to search for decreases over time. It is likely that a 'top-up' of tracers needs to occur at every search.

The last search of Experiment 2 demonstrated that surveying, searching and recording location of the pebbles could be carried out to a limited extent by one person (The GPS antenna needs to go into the backpack so that positional accuracy is ~±20cm). On a rising tide it proved difficult to tie the searches in with Tamsin Watt's regular surveys as find locations at the bottom of the beach might be reached by the sea prior to her return. On the other hand, having a person on site exclusively for the topographic surveys and find locations is not a good use of time, especially if the finds are relatively sparse.

The optimum search procedure would involve a team of 2 people with 2 metal detectors where the second person joins the first after finishing the topographic surveys (~30min). As they will both search 'next to each other' one person can then record the finds of both searchers. Fortunately, the metal detector used so far has two main frequency settings that specifically allow for a second detector to work in close proximity without interference.

9.3 Field abrasion

Abrasion has successfully been measured using the resin tracers. However, two issues have arisen with the first generation resin pebbles that need to be discussed prior to more substantial future experiments:

- The amount of breakages is unacceptably high and makes the weight loss measurements somewhat unreliable. Given that the breakage occurred both under high and low wave energy seems to indicate that pressure changes in relation to air trapped in the pebble might be the reason. It is suggested that a number of 'new' pebbles are subjected to either (or both) a treatment in the vacuum apparatus or water pressure testing by fixing them in a cage to the rock platform /lowering them from a pier to assess whether this is the likely cause.

- Given the manufacturing process, most tracers have sharp corners at the top if sawn /filed off or even slightly raised rims. These corners and rims are prone to be abraded first, possibly by breaking, so that the initial weight loss is likely to be larger than during subsequent exposures. The scale of this effect should be assessed in a laboratory experiment where tumbling intervals could be as short as 5min, 10min, 15min, 30min etc. Alternatively, attempts could be make to reduce the size of the opening in the moulds so that the top becomes more like the original natural pebble.

These observations were used to improve the resin tracer pebbles design and led to the development of the second generation resin tracer pebbles (Section 3.5).

9.4 Longshore transport rate and surface sediment change

This report has not attempted to calculate a rate of longshore transport, either from the tracer movement or from the topographic changes. At this point in timefurther discussion is required in order to select the best methodology to employ.

Similarly this report does not document the relationship between find locations and surface sediment cover as the method for mapping surface sediment cover has only just been agreed.

Uwe Dornbusch & Tamsin Watt November 2004

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2004-01-08-Protocol_Longshore transport experiments.doc

2004-01-15-Report_Longshore transport experiment 02-painted pebbles.doc

2004-02-02-Protocol_Casting of resin tracers 01.doc

2004-03-26-Report_Resin pebble abrasion resistance.doc

2004-07-15-Report_Short note on testing new resin tracers.doc

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