

CHAPTER 24
THE USE OF FLUORESCENT TRACERS FOR
THE MEASUREMENT OF LITTORAL DRIFT

by

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ABSTRACT

The paper is concerned with experiments, carried out by the Hydraulics Research Station, in an attempt to measure littoral drift along natural beaches. A preliminary laboratory experiment is described in which the dilution method was used to measure uni-directional drift along a model shingle beach, and in which the measurement was found to be reasonably accurate. A modified dilution method is described for use on beaches where the direction of the drift reverses from time to time; and there is then a description of how this method was used to measure the littoral drift along three shingle beaches on the coast of England. In one case it was possible to measure the drift by alternative means and so obtain a check on the accuracy of the method. An Appendix describes how some of the tracer materials were made.

INTRODUCTION.

A considerable literature has grown up over the last 5 years relating to the detection of the movement of sediments by tracers. Many of the experiments, which have been carried out in a great variety of countries, have been purely of a tentative nature intended merely to study the feasibility of using a new technique. Although all the experiments have shown that the technique is indeed feasible, and have been successful in that they have shown the general direction in which material was moving, it has always been found difficult to interpret the result in quantitative terms. The second generation of experiments, which one might expect to be concerned with quantitative measurements of sediment discharge, have not yet begun to appear in print.

Tracers have already shown themselves to be most useful in those situations where there is the greatest uncertainty about the movement

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of sediments; where experiments have been justified if they merely revealed a trend in a particular direction. There are beaches for example along which there is doubt concerning the direction of the predominant drift and where a tracer experiment which revealed the direction of movement might be justified. On many beaches, however, the direction of the predominant drift is already known and a tracer experiment would be pointless unless it revealed the actual quantity of material in movement. It is to the solution of this problem, of how to measure rates of littoral drift along beaches, that this paper makes a contribution.

The tracers used for the work have been fluorescent ones. They have been developed during the past year or so from ideas and techniques described by Zenkovitch (1) and his colleagues (2) at the Institutes of Oceanology and Organic Chemistry of the U.S.S.R. Academy of Sciences. There are, however, differences between the work described in the Russian literature and the lines along which the work at the Hydraulics Research Station is developing.

Whereas the tracers described so far have been designed to have a short life, and have been used to study the movement of material under conditions which last unchanged for only hours or days, the tracers developed at the Hydraulics Research Station are designed to last for a year or more and so enable measurements to be made of the littoral drift occurring over a whole year. Another difference is that whereas the Russian experiments have been concerned with sand, those at the Hydraulics Research Station have been mainly with shingle beaches.

THE DILUTION METHOD IN UNIDIRECTIONAL FLOW.

The simplest possible quantitative measurement that could be made, using a tracer, would be the measurement of the sediment transported along a channel by steady unidirectional flow, in the case where the sediment was all of one size. The easiest method to employ - the so-called dilution method - involves the injection of tracer into the channel at a known steady rate for a long time, followed by sampling of the channel bed downstream of the injection point. Downstream of the injection point the material on the bed will contain tracer material mixed up with ordinary bed material in the ratio q/Q ; where q is the rate (mass per time) at which tracer is injected, and Q is the rate (mass per time) at which sediment is transported past the injection point. Accordingly, the sediment transport rate can be calculated if the injection rate q and the concentration C of tracer in the sediment are known. Q is simply q/C .

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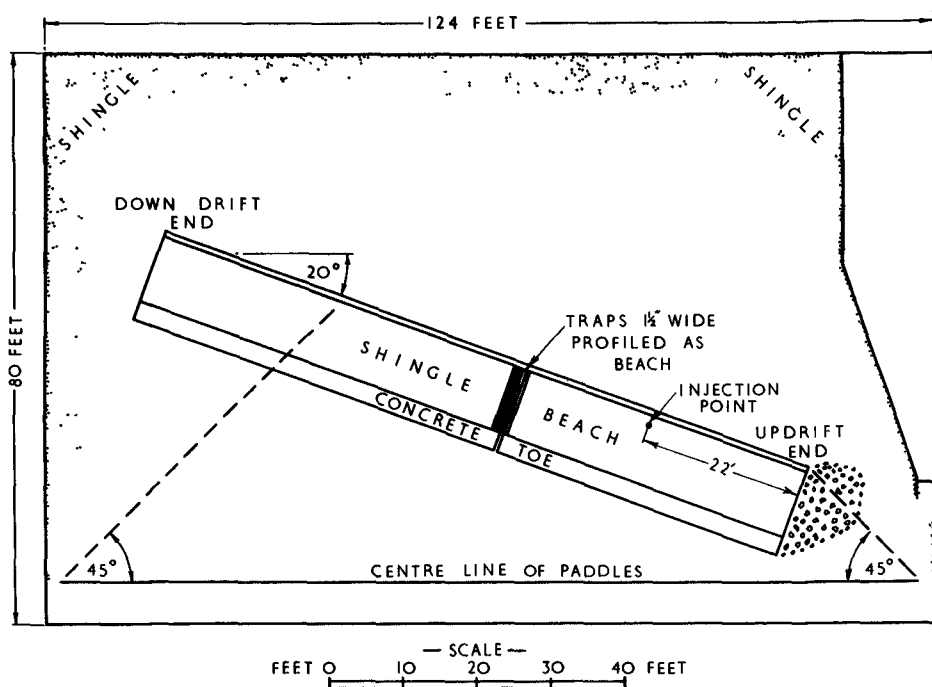


Fig. 1. Plan of the Model Shingle Beach.

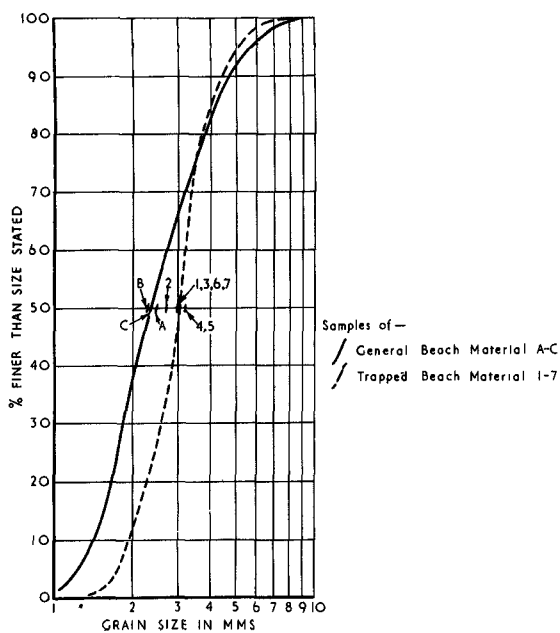


Fig. 2. Grading curves and values of d_{50} for shingle on the model beach, and for shingle caught in the traps of the model beach.

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It is worth noting that the speed at which sediment travels does not enter into the calculation, nor does the width of the stream, nor the thickness of the sediment layer that is in motion.

A complexity would immediately be introduced into this imaginary experiment if the sediment were no longer all of one size. The complexity arises because the tracer material has to be typical of the material in transit i.e. it must have a particle size distribution typical of the material in transit; and the material in transit is likely to be different from the material lying on the bed. In this case it becomes necessary to trap and examine material in transit and to use the trapped material as a model for designing the correct tracer.

THE DILUTION METHOD APPLIED TO MEASUREMENT OF LITTORAL DRIFT ALONG A MODEL SHINGLE BEACH.

In order to find how accurate the method could be in favourable conditions, a model experiment was conducted, in which the littoral drift along a rather simplified shingle beach was measured by the dilution method and the result compared with the drift measured directly by catching it in traps. The beach was long and straight (as in Fig. 1) and consisted of fine stones described by the distribution curve shown in Fig. 2.

There are several differences between the conditions to which the model beach and a real beach would be subjected, many of them associated with the need to produce in the model a steady littoral drift. In this category was the omission of any tides or reversing tidal currents from the model. The waves, furthermore, had an almost constant waveheight. There was indeed a small variation in waveheight of about 10% on either side of 2 inches, and a similar variation in the period, the cycle of which repeated every 4.7 minutes. The direction from which the waves came was held constant at 70° from the beach alignment.

The object of varying cyclically the characteristics of the waves was to cause periodic erosion and accretion of the beach and so to cause the surface shingle to mix with that in the lower layers. Had the beach been absolutely stable, the layer of shingle that was mixed with tracers might have been too thin, - only one stone thick for example - and then the method of measuring concentration, which involves counting visible tracer particles in situ, would have given false readings. All the simplifying conditions were designed to bring the processes of measuring the littoral drift by the dilution method almost to the simplicity found in the steady unidirectional case described above, but there is a major difference between the

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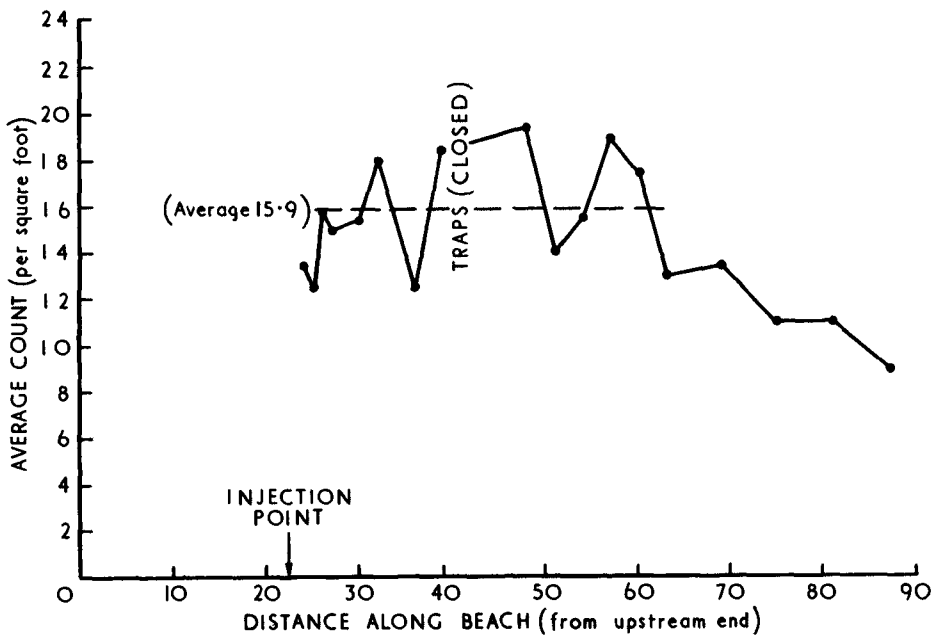


Fig. 3. Distribution of tracers, visible on the surface of the model beach.

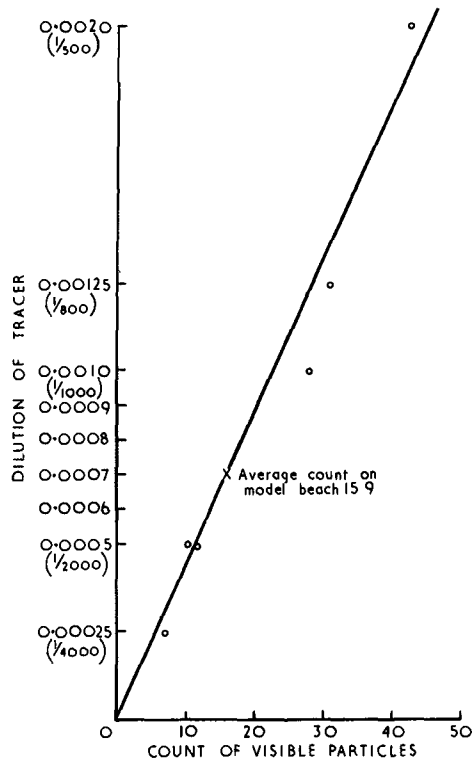


Fig. 4. Calibration test relating tracer particles visible per square foot to the proportion by weight of tracer in the in-situ beach material.

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simplified shingle beach and unidirectional flow in a channel, to be found in the much greater sorting that takes place on a beach. On a beach the different grades of material are found on different contours, are subjected to different hydraulic forces, and are moved along at different speeds. In the model in question, for example, the finest material was found at the crest of the beach, while the coarsest particles stayed on the plunge-line.

The movement of different size fractions at different speeds along different contours should present no obstacle to the satisfactory working of the dilution technique provided:-

- (i) The tracer material is typical of the material in transit.
- (ii) That the tracer particles find their way to the contours that are appropriate to their size.

The first condition was satisfied in the simplified shingle beach experiment, by using as a tracer some material taken from traps in the beach and coating it by the process described in the Appendix.

It is inevitable, however, that if tracer is injected just casually on to the beach (as in this experiment it was), rather than placing the appropriate size fractions on appropriate contours that, for some distance along the beach, tracer particles will find themselves among particles of the wrong size and that their speed of travel will be different from that of beach particles of their size. Further along the beach the tracer can be expected to become properly sorted. Evidence that suggests this behaviour can be found in the results of the experiment.

Tracer was injected almost continuously at a point shown on Fig. 1 at a rate of 1/400 of a litre every three minutes. In the first experiment the tracer was injected for one hour, but a study of the beach revealed that the duration of the injection had not been long enough, in that there was not a sufficiently long length of beach along which the concentration of tracer was uniform. The figure required was the uniform concentration that would have been reached all along the beach, had the injection continued indefinitely; and this figure, in view of the scattered result was difficult to pick out.

Accordingly the experiment was repeated, this time with the injection continuing for two hours. The tracer was changed so as to avoid confusion between the two experiments, from Primuline which fluoresces blue to Eosine which fluoresces orange. The concentration of tracer at points along the beach is shown in Fig. 3, where the number of fluorescent particles visible per sq. ft of surface is plotted as a function of distance from the injection point. It can be seen that the concentration, expressed as counts per sq. ft., had not

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reached its steady value at the down-drift end of the beach, but that it was roughly constant within 40ft of the injection point. It was assumed that the average count in this area - 15.9 per sq. ft - was the figure that would have been reached everywhere had the injection continued for a very long time.

Through the scatter of points on Fig. 4 one can possibly discern a lower figure for the counts close to the injection point than 20ft further from it. A likely explanation is that the tracers in this area had not yet been sorted and were not moving at a speed and along contours appropriate to their size.

In order to convert figures expressed as numbers of particles visible per sq. ft., into a concentration, one has the choice either of estimating the number of ordinary stones visible in a square foot from consideration of the particle size, or of carrying out calibration experiments. The latter course was in fact followed and the results are shown in Fig. 4. For making this experiment, tracers and stones were first mixed up in certain known concentrations, spread out in a layer at least 2" thick and examined for the number of visible tracer particles. Each mixing and counting was carried out three times, and the counts averaged. The best straight line through the averaged points has been drawn on Fig. 4. The steady concentration reached in the beach experiments can be found by referring to that corresponding in Fig. 4 to 15.9 counts per sq. ft. It is found to be .0007.

Therefore, the littoral drift can be calculated as

$$\frac{1}{.0007} \times \frac{1}{400} \times \frac{60}{3} \text{ litres per hour}$$

or 71.5 litres per hour.

The littoral drift was also obtained mechanically by trapping material, as it drifted along the beach, in two $1\frac{1}{2}$ inch wide slots, disposed as shown on Fig. 1. The measurement by traps and the measurement by tracer were carried out in different experiments but under conditions that were thought to be identical.

In three runs, which were each of 14.1 minutes duration; i.e. they each lasted for three whole wave period cycles, the trapped material amounted to 13.55, 13.13 and 13.99 litres, averaging at 13.56 litres. Accordingly the drift was

$$13.56 \times \frac{60}{14.1}$$

or 57.5 litres per hour.

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The degree of agreement is encouraging. The lack of agreement, such as it is, is probably compounded of two main errors.

In the first place an error must be expected when using any method that involves the counting of randomly distributed particles. This error is shown in the Appendix to exceed 7% only once in every 10 similar experiments; and since the error in the result is about 20% there is likely to be another source of error.

The major error is probably due to the moving layer of shingle and tracer being undesirably thin. In the calibration test, by which the counts per square foot were related to concentration, some of the tracer particles that were visible were not on the surface but up to a particle diameter or so below the surface. One would, therefore, get the correct assessment of concentration on the beach only if the tracers were mixed down to a depth of one or two particle diameters. If only the surface layer was mixed one would underestimate the concentration by say 10% or 20%. Observations of the beach, when it was in movement, indicated that quite good mixing in depth was taking place on the upper beach but that on the lower beach where the waves broke, and to seaward, there was very little mixing in depth. Accordingly, there would have been an underestimate of the concentration and a corresponding overestimate of the calculated littoral drift. This is consistent with the results of the experiment.

A surprising feature of the results of the experiment was that the size of the material in transit was found, by analysis of the trapped material, to be coarser than the material of which the beach was composed. Typical size-distribution curves for the two materials are shown in Fig. 2 together with the values of d_{50} for a number of similar samples. This is in direct contrast to the behaviour of sediments in uni-directional flow. The explanation is that sorting moved the finest particles to the crest of the beach, where they were moved only by small hydraulic forces, and then only intermittently; while the larger particles stayed at the plunge-line and were subjected to the biggest hydraulic forces.

THE DILUTION METHOD. MOVEMENT OF MATERIAL IN TWO OPPOSITE DIRECTIONS.

In cases where the drift reverses from time to time owing to waves coming from different directions, tracer that is injected on a beach spreads out on both sides of the injection point, the greater part of it moving in the down-drift direction from the point of view of the bigger or more persistent waves. Under these more complicated conditions it has been found possible to obtain the littoral drift from the distribution of tracers, only when the drift is assumed to be much more consistent than it really is in nature. The most serious assumption that has to be made is that in each period between injections - in practice it is frequently one week - the littoral

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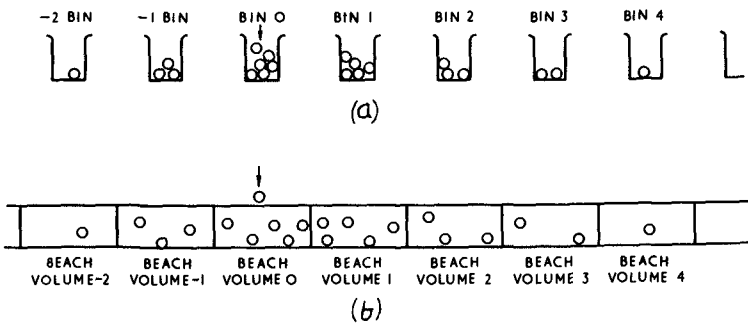


Fig. 5(a). An analogy to the spread of tracers through a beach: the spread of particles among bins. In each time interval the contents of each bin are completely shared with the bins on either side, and another quantity is injected into bin No. 0. (b) The bins are replaced by equal volumes of beach. The spread of tracer proceeds as in (a).

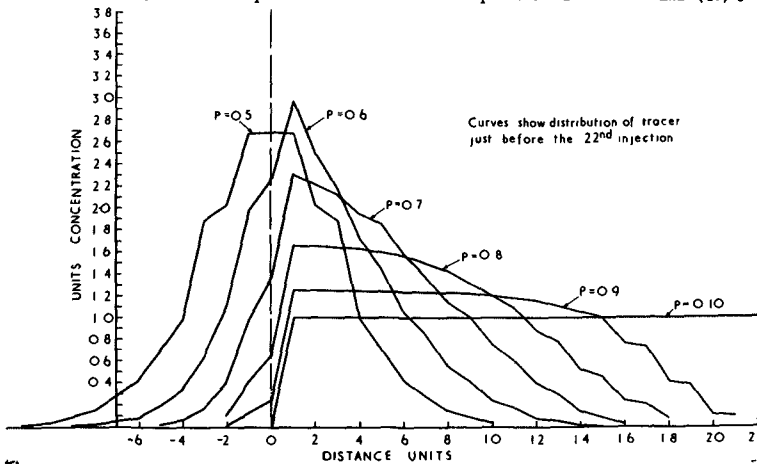


Fig. 6. The evaluation of the quantities given in Table II for various values of p and q .

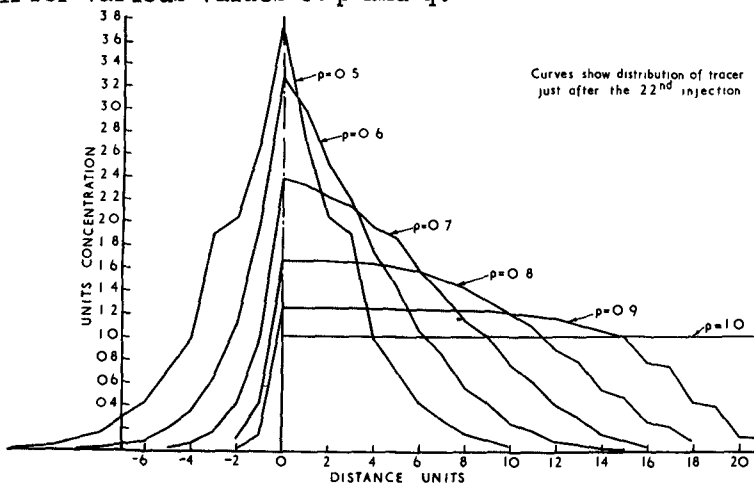


Fig. 7. The distribution of tracers just after the 22nd injection.

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drift repeats itself precisely.

The mathematics that has been used to relate the movement of tracer to the littoral drift is exact when used to predict movement of quite different kinds and, for clarity, one of these other kinds of movement will be dealt with first.

An Analogy.

Suppose that there are a number of bins in a row (as shown in Fig. 5a) the contents of which were continually being emptied into the bins on either side of them, while into the central bin Number '0' material is injected. In time the injected material would spread to all the other bins.

Let us assume that unit quantity of material is added to bin '0' in each interval of time.

In each interval of time let a proportion p of the contents of each bin be tipped to the right, and the remaining proportion q tipped to the left. $p + q = 1$.

The material then begins to spread through the bins, as shown in the following table. Each horizontal line shows the material contained in each bin after specified numbers of injections.

TABLE I

-2	-1	Bin '0'	Bin 1	Bin 2	Bin 3	Time
		1				After 1st Inject
	q	0	p			1st Exchange
	q	1	p			2nd Inject.
q^2	q	$2pq$	p	p^2		2nd Exchange
q^2	q	$1+2pq$	p	p^2		3rd Inject.
q^3 q^2	$q+3pq^2$	$2pq$	$p+3p^2q$	p^2	p^3	3rd Exchange
q^3 q^2	$q+3pq^2$	$1+2pq$	$p+3p^2q$	p^2	p^3	4th Inject.
q^3 q^2+4pq^3	$q+3pq^2$	$2pq+6p^2q^2$ etc.	$p+3p^2q$	p^2+4p^3q etc.	p^3 p^4	4th Exchange

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After 21 time intervals, that is to say just before the 22nd injection, it can be shown that distribution of material in the different bins is that shown in Table II. In Fig. 6 is shown plotted the distribution curves for various values of p and q , namely:

($p = 1, q = 0$), ($p = .9, q = .1$), ($p = .8, q = .2$), ($p = .7, q = .3$).
 ($p = .6, q = .4$) and the symmetrical case where $p = q = .5$

It will be seen that the maxima occur at the bin next to the injectic point. If the distribution of material is examined directly after an injection but before the material has been exchanged, it will be found that the distribution is a maximum at the point of injection. For example, the distribution after the 22nd injection is that already given with one unit added to the quantity at the injection point. These distributions are shown in Fig. 7.

The problem of material distributing itself among the bins begins to show some similarity to the problem of tracers distributing themselves along a beach, if the injected material is looked upon as a tracer, and the bins are assumed already to contain equal volumes of beach material. The beach material moves from bin to bin without affecting the total volume of material in the bins. The addition of beach material to the bins does not affect the manner in which tracer spreads from bin to bin, and this remains predictable by the same mathematics.

In Fig. 5b the tins have been replaced by adjacent compartments of a beach. The size of the compartments is chosen so that the mass of material in each, M , is such that in one time-interval the drift to the right is pM and the drift to the left is qM , where $p + q = 1$. In each time-interval the whole contents of each compartment are completely re-distributed, partly to the right and partly to the left, as in the case of the bins. Then after 21 intervals of time, in which the moving mass M and the proportions p and q remained the same, tracer regularly injected into the central compartment would distribute itself, as in Table II.

If the standard time-interval were t weeks,
 The Littoral drift is at the rate $(p - q)\frac{M}{t}$

If the tracer is added to the beach at a rate $\frac{m}{t}$

After 21 t weeks the distribution of tracer along the beach is that shown in the table multiplied by m .

i.e. If the concentration in the table at a point x is N_x ,
 the mass of tracer in compartment x is $m.N_x$

As the mass of ordinary beach material in the compartment is M
 the concentration of tracer is $\frac{m N_x}{M}$

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TABLE 2

x	Final Concentration after 21 Injections
21	p^{21}
20	p^{20}
19	$p^{19}(1+21a)$
18	$p^{18}(1+20a)$
17	$p^{17}(1+19a+210a^2)$
16	$p^{16}(1+18a+190a^2)$
15	$p^{15}(1+17a+171a^2+1330a^3)$
14	$p^{14}(1+16a+153a^2+1140a^3)$
13	$p^{13}(1+15a+136a^2+969a^3+5985a^4)$
12	$p^{12}(1+14a+120a^2+816a^3+4845a^4)$
11	$p^{11}(1+13a+105a^2+680a^3+3876a^4+20349a^5)$
10	$p^{10}(1+12a+91a^2+560a^3+3060a^4+15504a^5)$
9	$p^9(1+11a+78a^2+455a^3+2380a^4+11628a^5+54264a^6)$
8	$p^8(1+10a+66a^2+364a^3+1820a^4+8568a^5+38760a^6)$
7	$p^7(1+9a+55a^2+286a^3+1365a^4+6188a^5+27132a^6+116280a^7)$
6	$p^6(1+8a+45a^2+220a^3+1001a^4+4368a^5+18564a^6+77520a^7)$
5	$p^5(1+7a+36a^2+165a^3+715a^4+3003a^5+12376a^6+59388a^7+203490a^8)$
4	$p^4(1+6a+28a^2+120a^3+495a^4+2002a^5+8008a^6+31824a^7+125970a^8)$
3	$p^3(1+5a+21a^2+84a^3+330a^4+1287a^5+5005a^6+19448a^7+75582a^8+293930a^9)$
2	$p^2(1+4a+15a^2+56a^3+210a^4+792a^5+3003a^6+11440a^7+43758a^8+167960a^9)$
1	$p(1+3a+10a^2+35a^3+126a^4+462a^5+1716a^6+6435a^7+24310a^8+92378a^9+352716a^{10})$
0	$0+2a+6a^2+20a^3+70a^4+252a^5+924a^6+3432a^7+12870a^8+48620a^9+184756a^{10}$
-1	q (same factor as for +1)
-2	q (" " " " ")
-3	q (" " " " ")
.	.
.	.
.	.
-19	$q^{19}(1+21a)$
-20	q^{20}
-21	q^{21}

NB $a = pq$

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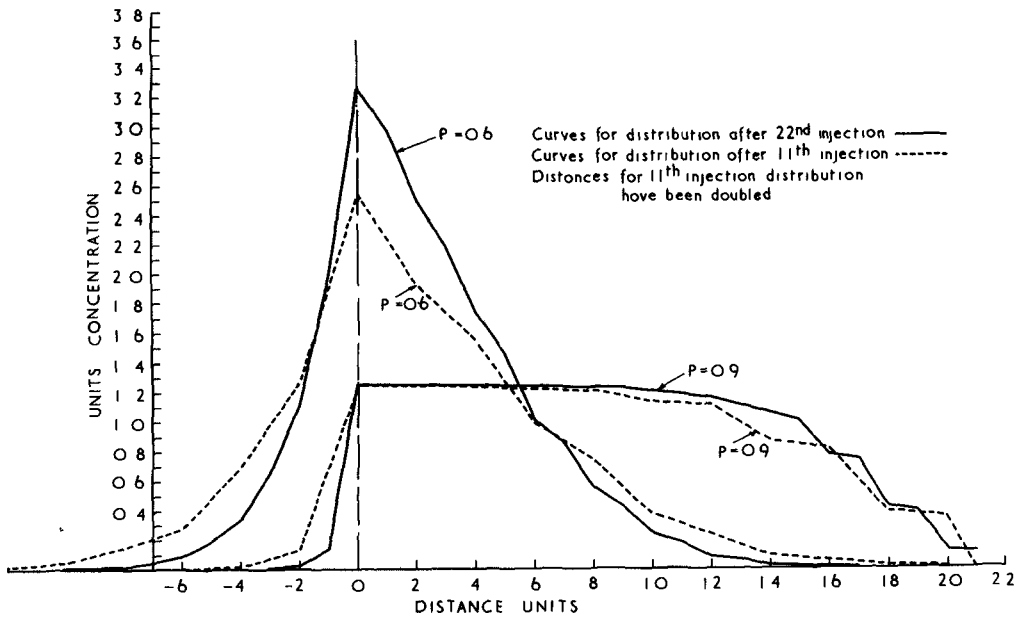


Fig. 8. A comparison between the distribution of tracer after 22 injections and that after 11 injections at the same mean rate.

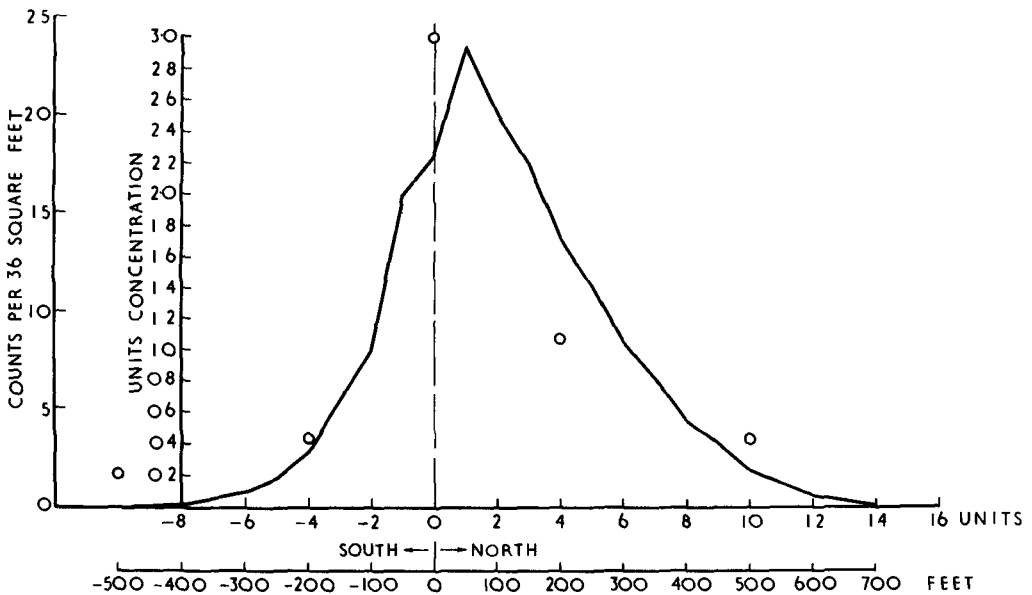


Fig. 9. The distribution of tracer at Deal after 22 days of injection at the rate of 1 cwt per day.

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If the measured concentration at point x is C_x

The net rate of transport Q which is $(p - q)\frac{M}{t}$

Can be written $Q = \frac{(p - q)}{t} \times \frac{m N_x}{C_x} \dots\dots\dots(1)$

When the value of Q is required, the concentration C_x of tracer along the beach is measured and plotted as a function of distance along the beach. The curve so obtained is studied for its similarity to the various curves of Fig. 6 and the values of p and q that give the most similar theoretical curve are chosen.

If the experimentally found curve of C_x is precisely similar to one of the curves in Fig. 6 then N_x/C_x has the same value at all distances from the injection point; and there is no doubt about the value of N_x/C_x to insert in equation (1). If on the other hand, the two curves are not precisely similar, judgement has to be used in order to select the most significant value of N_x/C_x . One could for example, use the maximum value of N/C that is found immediately down-drift of the injection point.

With p , q , N_x and C_x found and with m and t known from the rates of injection, the expression $\frac{p - q}{t} m \frac{N_x}{C_x}$ can be evaluated.

The computation of all the theoretical N_x curves for large numbers of injections is a very lengthy process. Fortunately there is an indication that the number of injections is only of secondary importance in determining the N_x curve and that the mean rate of injection is the important parameter. Curves of N_x for a smaller number of injections, namely 11, are shown in Fig. 8 and compared with corresponding curves for 21 injections carried out at the same mean rate. The difference is seen to be small. The error introduced by assuming the tracer to be injected in 21 equal fractions when, in fact, a smaller amount was injected at shorter intervals but at the same mean rate, is probably small compared with the inevitable errors introduced by assuming that identical drift took place in each of the equal intervals of time.

Only at the origin has it been found possible to calculate the concentrations reached after injection has been continuing for an infinitely long time. The concentration N_0 immediately after an injection can be shown to be $1/(p - q)$; while immediately before the next injection it is $1/(p - q) - 1$.

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MEASUREMENT OF LITTORAL DRIFT ALONG NATURAL SHINGLE BEACHES.

Measurements of littoral drift have been in progress since April 1959, when tracers were first dumped on the shingle beach at Deal on the coast of Kent. Measurements have since been made at Rye and Dungeness where the beaches are also shingle.

Shingle beaches were chosen for the experiments in order to avoid an added complication which is present when attempting to measure littoral drift along sandy beaches. The added complication is the unknown rate of loss of tracer from the beach. Continuous interchange of material between the beach and the sea-bed offshore, which persists without necessarily involving any changes in the beach profile, is responsible for the dispersion of the tracer offshore, and constitutes a serious difficulty. In order to use the modified dilution method, one either needs to know that there is no loss of tracer offshore or has to be able to measure the loss, and there is no obvious or easy way in which this measurement can be made.

In fact a preliminary experiment was carried out on the sandy beach at Dawlish in 1959, but it has not so far been followed up. 30 lb of fluorescent tracer sand was injected every day for 21 days, following which the beach was surveyed. The data obtained could be interpreted to reveal a figure for the littoral drift, using the modified dilution method, but we had no idea of how much tracer had been lost offshore nor of the exaggeration of the apparent littoral drift which this loss caused.

On the majority of shingle beaches, on the other hand, there is a sharp dividing line between shingle on the upper beach and the sand lower down, that is uncovered around the time of Low Water; and it is reasonable to assume that shingle-tracers, behaving like shingle itself, would be confined to the beach. In the experiments at Deal, Dungeness and Rye the general procedure was the same but with certain differences in detail.

The tracer that was initially dumped on the beach at Deal consisted of broken dense concrete, incorporating the fluorescent substance anthracene. After four months the tracer was changed to a concrete incorporating Rhodamine, manufactured as described in the Appendix. Later on the fluorescent substance was changed to a plastic manufactured by Messrs. Levy-West, and later still to a plastic incorporating Uvitex. These substances, in ultra-violet light, fluoresced green, red, yellow, and blue respectively and were easily distinguishable from one another. Similar changes were made in the tracers used at Rye.

The size of the particles of crushed concrete was matched as well as was possible to the stones lying on the beach but the size would have been matched to the material in transit, had the nature of this material been known. Even in the matching of the tracer to the material in situ, there was need to use subjective judgement; because the material in situ varied so much from place to place that

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a sample of almost any size could be obtained by taking it from a selected contour.

Initially the tracer was dumped at the rate of 1 cwt. per day for 21 days; when a survey of the distribution of the tracer was carried out, and the rate of drift over the 21 days calculated. The tracer was then dumped at the same mean rate, but at 7 cwt. each week, and the distribution of tracer surveyed at various intervals. The distribution was always surveyed after 22 weeks and 52 weeks so that the drift during those periods could be calculated, but there were surveys at other periods as well.

The surveys were carried out at night using a portable ultra-violet lamp and generator. Posts were driven into the top of the beach-ridge at the injection point and at distances of 200 ft, 500 ft, 1000 ft, 2000 ft, and 3000 ft on either side of it. When a survey was carried out, the equipment was carried to each post in turn and the number of fluorescent pebbles visible in a given area at high-water, half-tide, and low-water was counted. The area in which pebbles were counted was initially 36 sq. ft, defined by a square Dexion frame, and later 100 square feet, defined by a lighter rod-and-string framework. It was found that a survey of one beach could be carried out by two people in two nights, though ideally three people were required to help carry the equipment.

The results of some of the experiments are presented below. There is the data for Deal after 21 daily injections - i.e. after 22 days - for Rye after 22 weeks, for Dungeness after 33 weeks, and for Rye again after 52 weeks.

The most interesting of the three sites from the experimental point of view is Rye, because there it has been found possible to measure the rate of drift of shingle by other means and compare the two figures. At Rye there is a dominant easterly drift and the shingle on the west beach is trapped by the Western Breakwater of the River Rother. For many years shingle has been removed; at one time for use as ballast, but more recently for beach nourishment elsewhere. The toe of the shingle beach is now well inshore of the seaward limit of the breakwater. Accordingly the drift past any point on the west beach can be equated to the amount of shingle, carried away by human agency, plus the accretion of beach between the point in question and the breakwater.

From a comparison between a survey carried out in June 1959 and another in June 1960 it was found that the beach had accreted by a total volume of 17,400 cubic yards. The Kent River Board inform us that the quantity of shingle removed from the beach during the same period was 32,000 cubic yards. Accordingly the drift past the injection point should have been

$$32,000 + 17,400 = 49,400 \text{ cubic yards.}$$
$$\text{or } 53,000 \text{ tons.}$$

which can be compared with a figure found below.

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Deal after 22 days.

Data:-	Position ft	Counts per 36 sq ft
	1000 south	0
	500 south	1.8
	200 south	3.5
	0	24
	200 north	8.6
	500 north	3.5
	1000 north	0

Calibration Test:-

$$\frac{\text{Concentration by weight}}{\text{Count per 36 sq ft}} = .00004$$

Best fit (p,q) curve is $p = .6$, $q = .4$ see Figure 9

Best length scale is 1 unit = 50 ft

Best concentration scale is 1 unit = 8 counts per 36 sq ft

$$\text{Drift} = (p - q) \cdot \frac{m}{t} \cdot \frac{N_n}{C_n}$$

$$m/t = 1 \text{ cwt per day}$$

$$= \frac{1}{8 \times .00004}$$

$$\therefore \text{Drift} = \frac{(.6 - .4) 1}{8 \times .00004} \text{ cwt per day northwards}$$

$$= \frac{.2}{20 \times 8 \times .00004} \text{ tons per day northwards}$$

$$= 31 \text{ tons per day}$$

Rye after 22 weeks.

Data:-	Position ft	Counts per 100 sq ft
	500 west	0
	200 west	.6
	0	4.5
	200 east	25.6
	500 east	16.1
	1000 east	24.0
	2000 east	10.0
	3000 east	1.7

Calibration Test:-

$$\frac{\text{Concentration by weight}}{\text{Count per 100 sq ft}} = .000019$$

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Best fit (p.q) curve is p = .9, q = .1 see Figure 10

Best length scale is 1 unit = 143 ft

Best concentration scale is 1 unit = 16.8 counts per 100 sq ft

$$\text{Drift} = (p - q) \cdot \frac{m}{t} \cdot \frac{N_x}{C_x}$$

$$\begin{aligned} m/t &= 7 \text{ cwt per week} \\ &= \frac{1}{16.8 \times .000019} \end{aligned}$$

$$\therefore \text{Drift} = \frac{(.9 - .1) 7}{16.8 \times .000019} \text{ cwt per week eastwards}$$

$$= \frac{.8 \times 7}{20 \times 16.8 \times .000019}$$

$$= 880 \text{ tons per week eastwards}$$

Dungeness after 33 weeks.

Data:-	Position ft	Counts per 100 sq ft
	1000 west	0
	500 west	5
	200 west	4
	0	5
	200 east	3
	500 east	20
	1000 east	12
	2000 east	5
	3000 east	2

Calibration Test:-

$$\frac{\text{Concentration by weight}}{\text{Count per 100 sq ft}} = .000013$$

Best fit (p.q) curve is p = .8, q = .2 see Figure 11

Best length scale is 1 unit = 166 ft

Best concentration scale is 1 unit = 9.1 counts per 100 sq ft

$$\text{Drift} = (p - q) \cdot \frac{m}{t} \cdot \frac{N_x}{C_x}$$

$$\begin{aligned} m/t &= 7 \text{ cwt per week} \\ &= \frac{1}{9.1 \times .000013} \end{aligned}$$

$$\therefore \text{Drift} = \frac{(.8 - .2) 7}{9.1 \times .000013} \text{ cwt per week eastwards}$$

$$= 1,770 \text{ tons per week eastwards}$$

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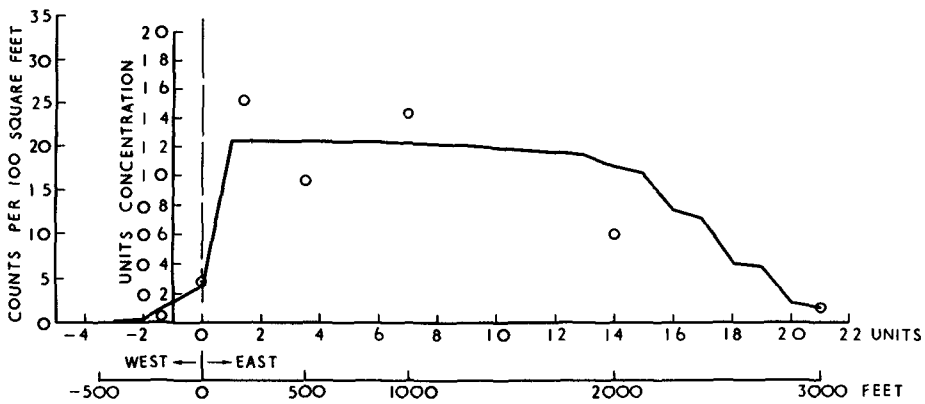


Fig. 10. The distribution of tracer at Rye after 22 weeks of injection at the rate of 7 cwt per week.

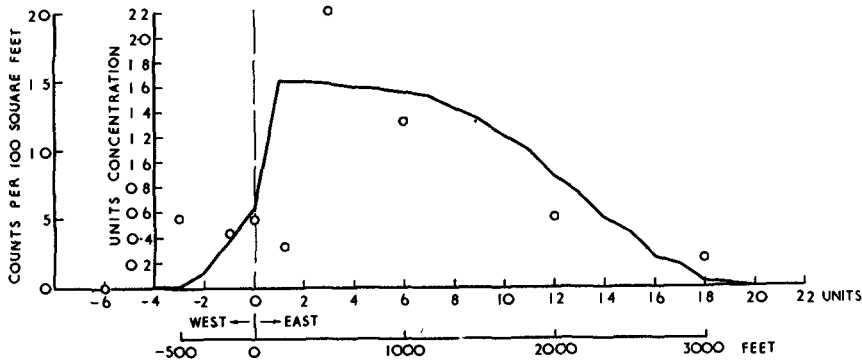


Fig. 11. The distribution of tracer at Dungeness after 33 weeks of injection at the rate of 7 cwt per week.

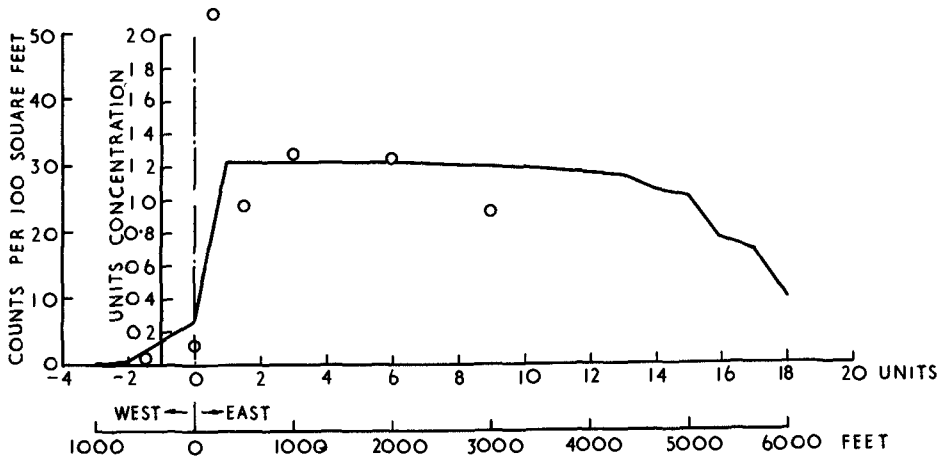


Fig. 12. The distribution of tracer at Rye after 52 weeks of injection at the rate of 7 cwt per week.

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Rye after 52 weeks.

Data:-	Position ft	Counts per 100 sq ft
	500 west	0
	200 west	1
	0	3
	200 east	53
	500 east	24
	1000 east	32
	2000 east	31
	3000 east	23

Calibration Test:-

$$\frac{\text{Concentration by weight}}{\text{Count per 100 sq ft}} = .000019$$

Best fit (p,q) curve is p = .9, q = .1 see Figure 12

Best length scale is 1 unit = 333 ft

Best concentration scale is 1 unit = 24.8 counts per 100 sq ft

$$\text{Drift} = (p - q) \cdot \frac{m}{t} \cdot \frac{N}{C_p}$$

$$\begin{aligned} m/t &= 7 \text{ cwt per week} \\ &= \frac{1}{24.8 \times .000019} \end{aligned}$$

$$\therefore \text{Drift} = \frac{(.9 - .1) 7}{24.8 \times .000019} \text{ cwt per week eastwards}$$

$$\begin{aligned} &= 590 \text{ tons per week eastwards} \\ &\text{or } 31,000 \text{ tons per year} \end{aligned}$$

Discussion

Although there is a check on the above results only in the case of 52 weeks' littoral drift at Rye, the other results are at least consistent. The smallest drift was found to be at Deal which is least exposed to big waves; and the biggest was at Dungeness which is most exposed and has the deepest water close inshore. The measure of agreement between drift at Rye calculated by cubature and that calculated from the distribution of tracers, 53,000 tons per year and 31,000 tons per year respectively, is fairly encouraging, considering the difficulties involved.

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In view of the not very precise measurements of littoral drift that would be adequate for the design of sea-defences, the method can be said to be useful.

ACKNOWLEDGEMENTS

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Appendix I

SAMPLING.

Initially the numbers of tracer pebbles visible in a 36 sq ft area were counted near the top of the beach, in the middle of the beach and at the lower limit of the shingle. Latterly the standard area was increased to 100 sq ft. The advantage of examining a larger area is that by counting larger numbers, when these numbers are subjected to random variations, one gets a proportionately more accurate result.

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If n is the size of a sample i.e. the total number of stones visible in a given area.

And if P' is the probability that any pebble is a tracer,

$P'n$ is the number of stones visible.

If P is the probability in the whole population of a pebble being a tracer,

Pn is the average number of visible tracers that would be determined by frequently repeated sampling.

If δ is the permitted error expressed as a fraction of P , i.e. δ is equal to $\frac{P - P'}{P}$ then it is known that, if the confidence level

is to be .90, then

$$n \gg \frac{2.8}{P \cdot \delta^2}$$

$$\delta \gg \sqrt{\frac{2.8}{n \cdot P}}$$

This indicates that the proportional errors that are likely to occur are inversely proportional to the square root of the numbers counted. It shows, for example, that if the average number of particles counted was 8, one in every ten counts would differ from the true mean by more $\frac{2.8}{8} \times 8$ or 4.7.

We can make use of this information to determine the likely errors introduced into the results of the model beach experiment by the counting of randomly distributed tracers.

The count of 15.9 particles per square foot was obtained by averaging the counts obtained in 3 square feet at 14 different sections along the beach.

∴ The total number of particles counted was $15.9 \times 14 \times 3$ or 665

∴ At a confidence level of .9 $\sqrt{\frac{2.8}{665}}$

Interpreted, this means that if the experiments were repeated many times, one result in every ten would be in error by more than $\sqrt{\frac{2.8}{665}} \times 15.9$ or 1.04. This is about 7%.

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Appendix II

PRODUCTION OF TRACERS

Concrete Tracer Pebbles.

The ideal tracer has not only to be fluorescent, it has also to be of the correct size, shape and density. It has to resist abrasion or, should there be some abrasion, it should nevertheless retain its fluorescent properties. The tracer pebbles used by H.R.S. have consisted mostly of a dense concrete, containing particles of fluorescent plastic in them. Size has been controlled by sieving, density and abrasive resistance by control of the cement-stone mix, but little attention has been paid to the shape. The pebbles produced by crushing and sieving appeared to be neither sharper, flatter or rounder than normal beach pebbles, and they were not further treated to alter their shape.

Most of the tracer pebbles used have incorporated the organic dye Rhodamine, but other dyes and phosphors have also been used and many others that have not been used have been tested and shown to be suitable. Suitable proportions of dye, plastic and concrete are given below, but other proportions can work equally well. The proportion of dye in the plastic can, in some cases, be varied through extraordinarily wide limits, as for example between .1% and .001% without appreciably effecting on the one hand the price and on the other hand the effectiveness of the tracer.

The plastic that is used is a proprietary brand of liquid urea resin known as Aerolite Resin C.B.U. combined with the hardening agent Acid Hardener G.B.Q, manufactured by C.I.B.A. (ARL) Ltd. of Duxford, Cambridgeshire.

The pebbles were prepared in the following way:-

- (i) 37.5lbs Resin C.B.U. were poured into a concrete mixer.
- (ii) .80lbs of Rhodamine B were dissolved in 3.75lbs of Acid Hardener G.B.Q. and added to the resin in the rotating mixer.
- (iii) when mixed, the liquid was poured on to waxed sheets and allowed to set. It would set in slabs about $\frac{1}{4}$ " - $\frac{3}{8}$ " thick.
- (iv) the plastic set in 2 or 3 days, depending on the ambient temperature and was then crushed and granulated. The biggest particles in the granulated material were approximately 3mm in diameter.
- (v) concrete was made according to the following mix:-

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13 parts cement.
26 parts quartz dolorite.
1 part granulated dyed plastic.

The wet concrete was spread out to set in slabs 3" thick.

- (vi) the slabs were broken up in a jaw crusher and the required size fraction separated out by rotating screens attached to the crusher. The rejected fraction - some 50% of the whole - was entirely fines. It was incorporated in subsequent batches of concrete as a filler.

Preparation of fine Fluorescent Shingle for the Beach Model.

The tracer material was made in four different colours, the dyes used were:-

Red - Rhodamine 'B'
Blue - Primuline.
Orange - Eosine.
Yellow - Auramine.

One lb. of tracer of each colour was made. A solution of surface-coating Araldite 985-E was made up and separated into four beakers, each containing about $\frac{1}{2}$ litre. Dye at 1% of the weight of the resin was added to each solution and well stirred. The stones were put in a dry beaker, and sufficient resin and solvent was poured over it to cover the surface. The resin was immediately decanted and the stones spread on thick wire gauze and allowed to stand for $\frac{1}{2}$ hr. to permit of evaporation of excess solvent. The material was then stoved at 160°C for about 1 $\frac{1}{2}$ hours and allowed to cool. Particles which had stuck together were separated by tumbling them in a cloth bag.

Surface coating Araldite 985-E is said to be 8/10ths as hard as glass as measured in Sward units and there was certainly no evidence in the beach model that any of the coating had been worn off the stones.

Sand Tracers.

Sand tracers have been produced by taking sand from the beach that has to be studied and coating each grain with a thin layer of fluorescent plastic. The process involves mixing sand up with a liquid fluorescent resin, allowing it to set into a cake, disintegrating the cake so that the individual particles are again separated, and then sieving to exclude particles of the wrong size.

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The ingredients needed are:-

- (i) Aerolite Resin C.B.U.
- (ii) Acid Hardener G.B.Q.
- (iii) Rhodamine or other suitable dye that will fluoresce in aqueous solutions.
- (iv) Dry beach sand.

Preparation.

(The quantities given below are suitable for mixing in a concrete mixer of 5/3 cubic foot capacity).

- (i) 37.5 lbs of resin CBU are poured into a concrete mixer.
- (ii) 0.80 lbs of Rhodamine 'B' is dissolved in 3.75 lbs Acid Hardener GBQ, and added to the mixer while it is in motion.
- (iii) 200 lbs of dry sand is added over a period of 3 or 4 minutes. When the coating appears to be complete, the machine is switched off and the mixture poured on to sheets of waxed + board. The mixture sets very rapidly in a warm atmosphere. It is important to spread the material quickly over the sheets with a trowel, so that it may be broken up conveniently when set. About $\frac{1}{2}$ " is a suitable thickness for the layers. Breakage is facilitated by cutting lines with a trowel across the layers before they set.

Hardboard covered with Silicone Wax is very suitable. P.V.C. sheet + is also satisfactory.

It will be found that the surface of the drying mix will harden first. Setting is accelerated by turning the pieces over with a trowel and exposing the underside. At 80°F, complete hardening takes 2 - 3 days. The fumes given off after mixing are very strong and unpleasant, but we have been assured by the manufacturers of the resin, that they are in no way dangerous.

When the pieces of glued sand have set, they are broken up into pieces not bigger than $\frac{1}{2}$ " x $1\frac{1}{2}$ " x $1\frac{1}{2}$ " in a jaw crusher, before granulating them to produce a material of the same particle size as the original sand. The fragments are granulated in a fixed-beater-cross machine, known by the trade name of Spruemaster, (supplied by Messrs. Christy and Norris Ltd., of Chelmsford, Essex) - in which the impact between the jaws shatters the lumps, and produces a finished product of the correct size. The machine has a screen in it with conical holes, which retain the large particles until they are reduced to the right size.

The material is sieved.

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If only a few grammes of the sand are required, the above quantities can be reduced proportionately and the mixing can be carried out in a beaker. Crushing down the product can be done with a hammer on a steel sheet. Most of the early samples were made by this method.

Other dyes can be substituted for Rhodamine 'B' if other colours are desired.

Dye	Colour	% of dye in resin	Supplied by
Titan Yellow	Pale blue	2%	The General Chemical & Pharmaceutical Co Sudbury.
Primuline	Blue	2%	
Auramine	Yellow	2%	
Rhodamine 'B' Extra 525%	Red)	Not exceeding 1%	C. I. B. A. Clayt Bush House London W.2.
Rhodamine 6 A Extra	Red)		
Kiton Rhodamine 3 R 250%	Red)	1%	
Kiton Rhodamine B 440%	Red)		
Eosine YS 140%	Orange	1%	
Erythrosine BSB Special	Orange		
Kiton Yellow EFF	Yellow-Green	1 - 2%	
Uvitex SWN Conc.	Bright-blue		
Kiton Yellow EFF)	Green	1 - 2%	
Kiton Blue A 190%)			
Victoria Blue 150%)	Green	1 - 2%	
Auramine O 166%)			

Most of the substances in the Table fluoresce only in solution. The exceptions are Uvitex and Kiton Yellow which are naturally fluorescent.

Nearly all the fluorescent pigments and hydro-carbons are subject to photolysis, i.e. their brilliance decays under the action of ultra-violet light. The substances mentioned above have been subjected to "weathering tests" and have been found the most satisfactory of all those that were tested. Fluorescein tends to decay in a few days, but might be useful for tests where the durability is not important, or

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where a short life is an advantage.

Kiton Yellow, Rhodamine 'B' extra 525%, Uvitex SWN were all found to retain maximum brilliance when exposed to unfiltered UV tests equivalent to one year's natural weathering.

The above substances fluoresce strongly under U.V. emission in the region of 3660 A.U.

Choice of a colour.

It has been found that some beaches contain substances that have a natural fluorescence, and it is, therefore, advisable first to examine a beach at night using ultra-violet light. In one instance it was found that parts of a certain shell had a fluorescence similar to that of Rhodamine B", but usually the numbers present are very small indeed. The use of a U.V. Lamp emitting shorter wavelengths (2537 AU) is necessary if the fluorescence of most natural impurities in the samples is required to be omitted. The "Hanovia" Chromatolite lamp is particularly suitable for this purpose. If care is taken to ensure that the dye fluoresces with a different colour from that of any of the naturally occurring substances, detection of 1 fluorescent particles in 1×10^6 is a simple matter.