A SURVEY OF BEACH POLLUTION AT A SEASIDE RESORT

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(With 3 Figures in the Text)

A series of infections with *Salmonella paratyphi B* which occurred at a seaside resort in North Devon every summer between 1943 and 1946 concentrated local attention on a very unsatisfactory sewage outfall, which discharged into the sea at all stages of the tide and frequently caused fouling of the adjacent beach. The local authority, concerned at the possible association between beach pollution and the enteric infections and also by the prospect of serious economic loss in an area dependent on the summer tourist traffic, planned a new sewage disposal scheme based on the controlled discharge of sewage into the sea from a point which had been shown by float tests to be more suitable than the old outfall site.

After discussion with the local sanitary authority and the consulting engineers who drew up the plans for the new scheme, it was agreed that bacteriological surveys of the outfall area should be made both before and after the installation of the new scheme. The main purpose of this paper is to give the results of these surveys, the first of which was carried out in the summer of 1948 and the second in the summer of 1950, 3 months after the new scheme had come into operation.

ENGINEERING AND EPIDEMIOLOGICAL ASPECTS OF BEACH POLLUTION

The problem of sewage pollution of bathing beaches is a complex one. The discharge of sewage into the sea from coastal towns is determined partly by financial considerations and partly by the lack of suitable space for sewage works in most seaside resorts. If the sewage outfall can be pushed far enough out to sea and the sewage liberated at a reasonable depth below the surface, pollution of beaches will not occur, and this method has been successfully used at several seaside towns in this country, e.g. Bournemouth and Brighton. The prolongation of outfalls for long distances under the sea is, however, both difficult and expensive, and in many coastal areas sewer outfalls discharge sewage just below or even above low-water mark. Where this occurs on a beach used for bathing, two quite distinct problems arise. One is the health hazard occasioned by the deliberate discharge of potentially pathogenic material; the other is an aesthetic problem when the amenities of the area are affected by deposition of excreta on the sands, discoloration of the sea water by 'sleek' fields and the formation of slimy deposits on the beach round the outfall. The disfiguration of a popular beach by sewage may discourage summer visitors, and active local authorities are justified even on economic grounds in planning sewage disposal schemes which minimize the pollution of their beaches.

If this problem is approached on frankly aesthetic grounds, it should be possible to set a maximum permitted level of sea water contamination on a bathing beach below which a sewage nuisance is very unlikely, and plans for an adequate sewage

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disposal scheme would then aim at so using suitably placed outfalls and local tidal currents that, so far as possible, pollution of a greater degree than the accepted figure did not occur along the stretch of beach concerned. Two such maximal pollution limits mentioned in the American literature on the discharge of sewage into coastal waters are 1000 or 3000 coliform organisms per 100 ml. of sea water.

There is, however, a tendency to seek bacteriological standards for bathing beaches in terms of risks to health rather than the preservation of local amenities. This approach raises many difficult questions, including of course the important one of whether there is any evidence that sewage-contaminated beaches have in the past been responsible for human infection.

The relationship between beach pollution and disease has been discussed more often in American and German literature than in the literature of this country. Winslow & Moxon (1928) were concerned with this problem in relation to bathing in polluted waters at New Haven, Connecticut, where untreated sewage was discharged into a harbour, the shores of which were used for bathing; these authors stated that most of sixty-one typhoid cases which occurred in the area in 1921–2 were attributed to bathing in this polluted harbour. In Schleswig-Holstein, however, Steiniger (1951) reported that no paratyphoid infections had been traced to bathing in the harbour at Husum, although *S. paratyphi B* could be isolated regularly in large numbers from the water and the silt of the harbour in which vast numbers of people bathed every summer.

Much useful work on this subject has been done by the Joint Committee on Bathing Places of the American Public Health Association and the Conference of State Sanitary Engineers. In one of its reports (Report, 1940) this Committee expressed the view that there was surprisingly little evidence in support of infection through bathing. In a progress report of the same committee (Report, 1952) an account is given of various studies on the subject. In a Chicago investigation, for instance, no noticeable correlation was found between the coliform counts of bathing waters from two beaches and illness among bathers. In another study in Kentucky, epidemiological data were obtained on persons swimming in the Ohio river and on another group using a large outdoor pool equipped with a filtered and chlorinated re-circulating water supply. Samples of water for bacteriological examination were collected daily from the river and the pool during this survey, and showed median counts of 2300 coliform organisms per 100 ml. and less than 3 per 100 ml. respectively. Nevertheless, the reported incidence of illness during the survey was appreciably greater in swimmers using the pool, the main complaints being infections of the eye, ears, nasal sinuses and throat, which were attributed to diving, chemical irritation or direct contact with other bathers rather than to bacterial pollution of the bathing water.

An ultimate answer to the question whether sewage pollution of beaches is a serious hazard to health must rest on numerous careful surveys of beach contamination in relation to local epidemiology. The purpose of the present work was to obtain information which might be relevant to both aspects of beach pollution, i.e. to relate the hoped-for improvement in beach conditions after the installation of the new scheme to bacteriological findings, and also to obtain survey information on

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an area of beach where contamination of the sea water with *S. paratyphi B* was known to be occurring.

THE NEW SCHEME FOR SEWAGE DISPOSAL

The resort where the work described here was done has an excellent beach which runs approximately north and south. Under the old conditions the sewage from the town, which has a summer population of 3000–5000, was discharged through an outfall extending only to the low-water mark along the rocks at the northern end of the sands. Before discharge the sewage was passed through a small underground tank on the cliffs above the beach, but the capacity of this tank was small and it served no useful purpose. The sewage only flowed straight through this tank and then down the outfall so that it was discharged at all stages of the tide. Moreover, the sewer was broken and sewage leaked from it on to the sands. Because of this unsatisfactory state of affairs, deposits of solid excreta were often to be found on the beach and adjoining rocks, and sewage was also continually being washed back into stagnant pools among the rocks. Many complaints were received from residents and visitors, and the local authority placed warning notices on the beach to discourage bathing in the neighbourhood of the sewer.

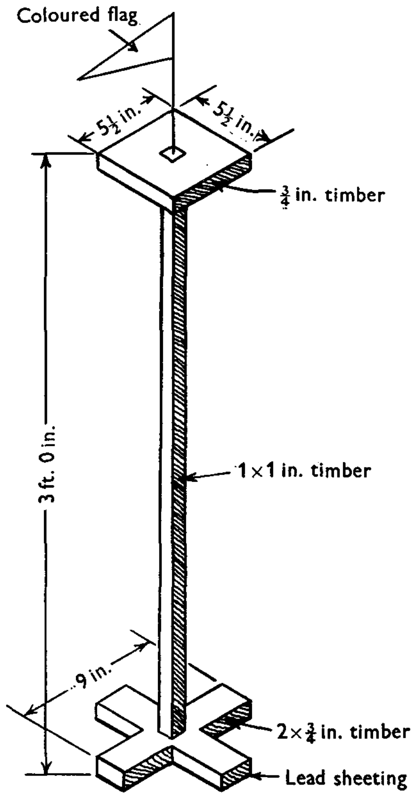

Fig. 1. Diagram of the wooden float used for float tests.

The location of the new point of outfall was governed primarily by the need to discharge the sewage at a point below low-water mark from which tidal currents could be expected to carry it away from the beaches. For satisfactory discharge it was also essential to find the time in each tidal cycle relative to high water when the tidal currents were in the right seaward direction and of the required strength. The choice of position for the outfall site was limited by the fact that all the drainage from the area gravitated to that part of the sea front which was around the old outfall, so that the new outfall must start from some adjacent point where the sewage could be collected for discharge.

The final choice of a new outfall site was determined by a series of float tests. These were carried out with wooden floats 3 ft. long, so designed and weighted as to float with the top just level with the surface of the sea, leaving a small flag above by which the float was kept in view. The float used, which was intended to give a true indication of the path of currents in the sea up to 3 ft. below the surface is illustrated in Fig. 1. These floats were placed in the sea from a boat at regular

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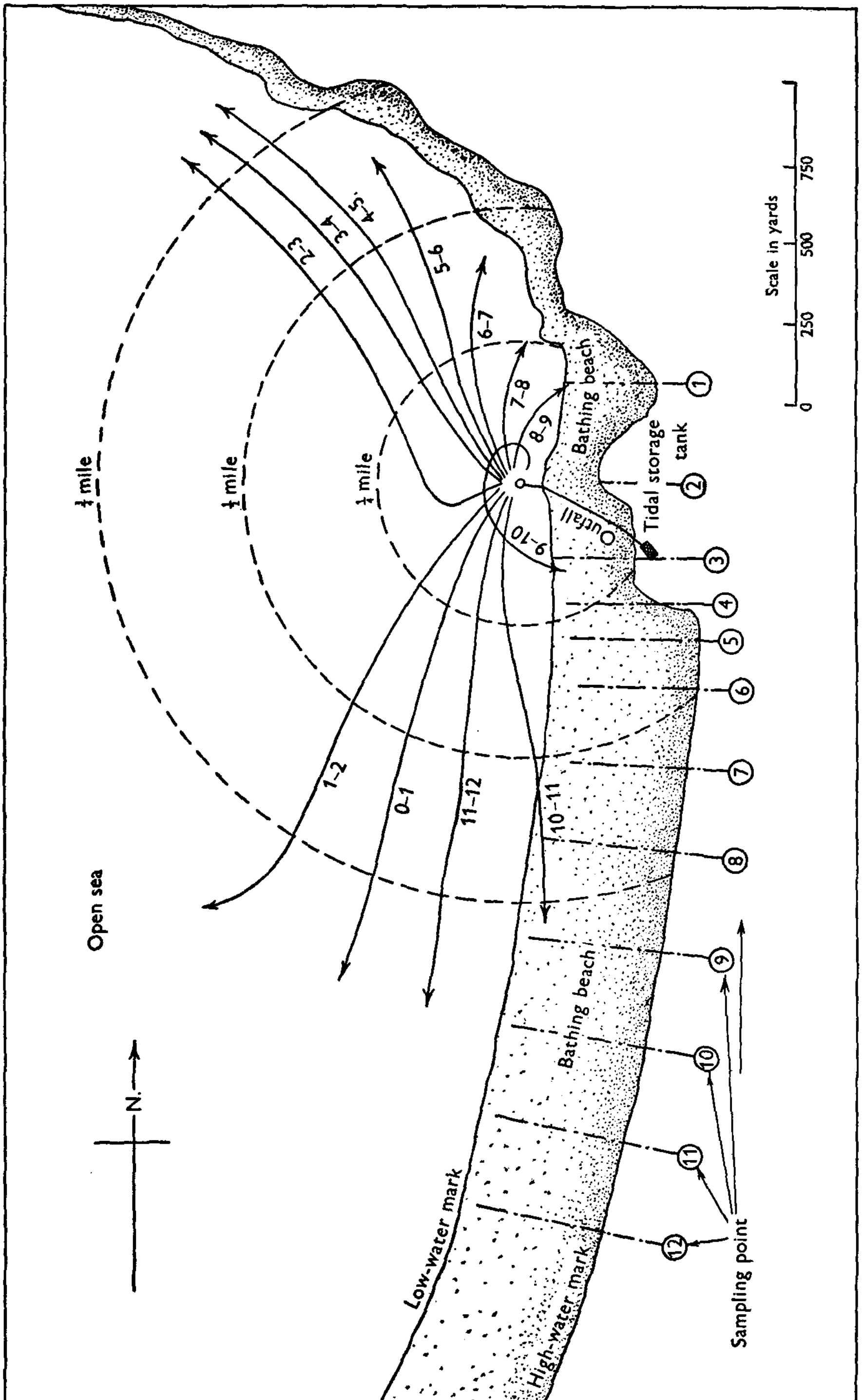

Fig. 2. Diagram of the beach investigated, showing the lines along which samples were taken at points 1–12 and also typical courses taken by floats placed in the sea at the new outfall site at hourly intervals after high water. The new outfall is shown between points 2 and 3; the old outfall followed the line drawn from point 3.

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intervals of time at possible outfall sites, and their course followed in the boat and plotted by sextant observations. The general results of the float tests are summarized in Fig. 2, which shows the typical courses taken by floats placed in the sea at the point of discharge of the new outfall. At high tide, a float placed in the sea at the outfall point was carried southward parallel to the beach and then out to sea on a strong south-westerly current. It was proposed that under the new scheme sewage should be discharged during the short period at or immediately after high tide, and float tests suggested that both at spring and at neap tide sewage would thus be carried away from the beaches on this south-westerly current. From 2 to 5 hr. after high tide, float tests showed there was a northerly current from the outfall. From 7 to 10 hr. after high water, the currents ran towards the beach north or south of the outfall. These tidal currents were well known to local fishermen.

The new scheme, which was ready for operation in the spring of 1950, differed from the old in three important respects. First, the point of discharge was further out to sea and below low-water mark, at a point some distance north of the old outfall. Secondly, the sewage was now held up in an underground tidal storage tank on the cliffs so that it could all be discharged within half an hour at a chosen time. Thirdly, Dortmund settling tanks were provided through which the whole flow passed before entering the tidal tank. Solids settled in these tanks, leaving the clarified effluent to pass over in to the tidal storage tank. The sludge which accumulated in the settling tanks was to be discharged out to sea when conditions of tide, wind and weather were particularly favourable.

Planning of the bacteriological surveys

Both surveys were carried out at the height of the holiday season, when the local population was at its maximum and beach pollution therefore most marked. Through the co-operation of one of the local hotels a small temporary laboratory was set up in a garden shed for each survey period.

Sampling points

Most samples were taken from twelve sampling points along the shore covering a stretch of about 8000 ft., the average distance between adjacent sampling points being about 900 ft. The positions chosen, which are shown in Fig. 2, were governed to some extent by the availability of natural reference marks which could be observed from the sea. The range of observations was not extended farther north than sampling point no. 1, about 1600 ft. north of the old outfall, as the coast was rocky beyond this point and not suitable for bathing, but the southward range was extended to about 6400 ft. from the outfall so as to include the sands which form the main bathing beach. Complaints of sewage pollution of the beach under the old conditions referred mainly to the stretch of beach between points 1 and 6.

The sampling points were determined by choosing two fixed objects, well above high-water level and suitable for observation, which were already marked on the 1 in 2500 Ordnance Map or were fixed by chain survey or theodolite so that they could be readily located again for future surveys. Where no suitable objects were available, cairns of stones were set up and their positions fixed by survey. Samples were taken along lines which were fixed at right angles to the shore by two markers at each sampling point. Each marker consisted of a 6 ft. ranging rod placed well inshore and a wooden stake which was painted red and fixed above high water where practicable or as near as possible to high-water mark. The markers were placed in position by lining them up with the fixed objects referred to above, and checked by chainage. They were allowed to stay in position until the first survey was completed and were set up again in the same positions for the 1950 survey.

Material examined

Preliminary observations on another beach suggested that the samples taken for bacteriological investigation should include both sea water and sand. The examination of sand was considered desirable, not only to assess the risks of direct contamination to people on the beach, but because it seemed possible that by acting as a filter for polluted sea water the sand might be a better index of the average degree of pollution on a particular stretch of beach.

In 1948 some of the sea-water samples were taken from a motor-boat at points checked by sextant observations, with the object of demonstrating bacterial pollution of the channels along which floats travelled from the outfall. This method was abandoned after the boat had been swept ashore in a brisk westerly wind and, apart from these samples collected in the early part of the 1948 survey, all other samples of sea water in both surveys were collected by wading into the sea from the beach and filling a wide-mouthed 6 oz. bottle from below the surface of the water.

The method of collecting sand samples will be described later.

Bacteriological tests

Pilot tests, before the main surveys, showed that sea-water samples taken in the neighbourhood of the sewer contained coliform bacilli of the faecal, aerogenes and intermediate types. As the vast majority of the coliform organisms reaching the sea off the beach investigated came from the sewer, it was decided that the presumptive coliform test, as used in water examination, should form the main basis of the surveys. All samples giving a positive result in the presumptive test were submitted to a 44° C. test for faecal coli, but owing to limited space and lack of adequate staff in the temporary laboratory, most of the 44° C. tests had to be done at Exeter, where batches of positive tubes from the presumptive test were transported two or three times a week. The effect of this delay on the validity of the results of the faecal coli tests is discussed later.

Tests for faecal streptococci were done by the method of Hajna & Perry (1943). The method of Mackenzie, Taylor & Gilbert (1948) was used to detect possible false positives in the presumptive coliform test due to *Clostridium welchii*.

RESULTS OF THE BACTERIOLOGICAL TESTS

The main findings of the two surveys are set out in the following sections, which describe in turn: (i) the results of the presumptive coliform tests in the 1948 survey; (ii) the corresponding results for the 1950 survey; (iii) the results of the faecal coli tests; (iv) the results of tests for faecal streptococci and of the indirect test for *Cl. welchii*; (v) the results of sand examination; and (vi) the effect of meteorological and tidal factors on the extent of pollution.

(1) *Results of the presumptive coliform tests on sea water in the* 1948 *survey*

Apart from various special series of tests, which will be described in later sections, 201 samples of sea water were collected during the 1948 survey from the twelve sampling points, at different stages of the tide and under various meteorological conditions. The results of the presumptive coliform tests on these samples, grouped somewhat arbitrarily according to the frequency with which results fell within certain ranges, are summarized in Table 1, which for convenience also gives the corresponding results for the 1950 survey.

Table 1. *Comparative results of* 1948 *and* 1950 *surveys. Frequency distribution of presumptive coliform counts*

Year	Total no. of samples	Presumptive coliform count per 100 ml. 0	1–25	30–100	100–250	300–1000	>1000
1948	201	3	24	10	33	61	70
1950	370	50	177	34	36	39	34

Table 2. 1948 *survey frequency distribution of presumptive coliform counts*

Sampling point	Presumptive coliform count per 100 ml. 0	1–25	30–100	100–250	300–1000	>1000	Total no. of samples
1	—	—	3	1	6	6	16
2	—	—	—	2	3	11	16
3	—	—	—	—	2	14	16
4	—	—	—	—	6	10	16
5	—	1	2	—	6	7	16
6	—	1	—	1	8	6	16
7	—	2	2	9	4	5	22
8	—	7	1	6	7	1	22
9	1	6	2	8	7	1	25
10	1	2	—	3	5	1	12
11	—	4	—	1	4	3	12
12	1	1	—	2	3	5	12
Total	3	24	10	33	61	70	201

The distribution of results in terms of sampling points is shown in Table 2. The proportion of samples which gave presumptive coliform counts of more than 1000 per 100 ml. was about the same from points 1 to 6, corresponding to that part of the beach which was subject to serious fouling with sewage. With increasing distance from the outfall counts were smaller, but at point 12 a high proportion of samples yielding more than 1000 coliforms per 100 ml. was again found. The explanation of this pollution at point 12 can be seen in Fig. 2 to be due to the direction of tidal currents just before high tide. During the 1950 survey, when the track followed by sewage from the outfall could be observed on calm days owing to the large volume discharged at any one time, this contamination of the beach by sewage at point 12 was occasionally observed.

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(2) *Results of the presumptive coliform tests on sea water in the* 1950 *survey*

The total number of sea-water samples examined in the 1950 survey was 370; the results of the presumptive coliform tests on these samples are set out in Table 1. The significant fall in the proportion of samples yielding more than 1000 coliform organisms per 100 ml. is evident, viz. 9·2 % as against 35 % in the first survey. Table 3, in which the 1950 results for the different sampling points are recorded,

Table 3. 1950 *survey frequency distribution of presumptive coliform counts*

Sampling point	Presumptive coliform count per 100 ml. 0	1–25	30–100	100–250	300–1000	>1000	Total no. of samples
1	—	3	3	7	5	12	30
New sewer	—	5	2	1	4	2	14
2	—	9	4	5	7	3	28
3	—	8	4	5	6	7	30
4	1	11	1	9	5	2	29
5	3	11	7	2	4	3	30
6	3	15	4	3	3	2	30
7	6	15	3	1	2	2	29
8	5	19	2	1	2	—	29
9	8	19	1	1	—	1	30
10	11	16	0	—	1	—	28
11	7	24	1	1	—	—	33
12	6	22	2	—	—	—	30
Total	50	177	34	36	39	34	370

shows that only point 1 failed to yield better results under the new conditions. It is interesting that the only complaints about the beach made by visitors and residents during the summer of 1950 were in respect of the area around this sampling point. All the other points showed considerable improvement, particularly points 9 to 12.

The pollution at sampling points north of the outfall which still persisted at the time of the 1950 survey has since then been diminished by a slight modification of the times of discharge and a less frequent emptying of the sludge in the settling tanks, so that no complaints about the beach have been made during the past few seasons.

(3) *Results of the faecal coli tests*

In the area investigated, the vast majority of the coliform organisms found in the sea water were almost certainly derived from the sewer. A small stream runs on to the beach at point 6, but this causes contamination of the sea only at very high tides. Hence the presumptive coliform counts were probably a satisfactory index of sewage contamination. As already mentioned, the majority of the 44° C. tests were done at Exeter some days after completion of the presumptive test, so that the results obtained may slightly underestimate the true faecal coli counts. In both surveys, however, a certain number of 44° C. tests were done on the spot and these gave results similar to those done after transport to the main laboratory, when the faecal coli counts for most specimens were either equal to, or at most showed a 2-tube difference from the presumptive counts. Thus, in the 1950 survey, of 320 samples of sea water giving positive results in the presumptive test, 159 gave

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faecal coli counts equal to the original presumptive counts, eighty-nine showed a 1-tube and forty-five a 2-tube difference. A rough indication that the proportion of faecal to total coliform counts was approximately the same in both surveys is given by Table 4, which shows the proportion of samples falling into various ranges of presumptive count in which the faecal coli tests gave results within the same or in lower ranges.

Table 4. *Comparison between the results of the presumptive coliform test and the faecal coli test in* 1948 *and* 1950

(Frequency distribution of results of faecal coli test on samples falling within certain ranges in the presumptive coliform test.)

Result of presumptive coliform test	Percentage of samples giving faecal coli counts in the ranges: 0–100		100–1000		>1000	
	1948	1950	1948	1950	1948	1950
0–100	100	100	—	—	—	—
100–1000	32	33	68	67	—	—
>1000	—	2	29·3	36·2	70·7	61·8

One possibly important exception to the parallelism between the presumptive and the faecal coli counts was that in the neighbourhood of the sewer outfall, some samples, particularly of sand, showed very high presumptive counts with very low faecal coli counts. The impression was formed that in sewage silted on to the sea-bed around the outfall the non-faecal coliform organisms persisted longer than *Bact. coli* of faecal type or else underwent multiplication. The relative survival of different coliform organisms in sea water has not been investigated in the present work.

(4) *Other bacteriological tests*

Two routine tests, other than the presumptive coliform test and the 44° C. tests, were used during the 1950 survey. First, the specific fluid medium for faecal streptococci described by Hajna & Perry (1943) was used in parallel with the presumptive coliform test throughout the greater part of the survey, but it yielded only eight positives, all but one of which were from waters containing more than 600 coliform organisms per 100 ml. Secondly, the possibility of false positive results in the 44° C. test due to *Cl. welchii* was investigated by subculturing all positive tubes from 166 presumptive tests in duplicate into MacConkey medium and into brilliant green bile broth (Mackenzie, *et al.* 1948) for incubation at 44° C. Both tests gave identical results with 156 samples. With ten samples, fewer positive tubes were recorded in the brilliant green bile broth medium, but all the corresponding MacConkey-positive tubes yielded *Bact. coli* type I strains, which grew readily on further subculture into the brilliant green medium. These results showed, therefore, that in the present survey *Cl. welchii* did not interfere with the validity of the 44° C. test for faecal coli. No attempt was made to demonstrate *Cl. welchii* by plating on to the appropriate Wilson-Blair medium.

(5) Bacteriological examination of sand

The possibility of assessing beach pollution by bacteriological examination of sand was investigated in both surveys. Sand might well act as a filter to polluted sea water and thus give a better general indication of the average state of pollution of a given beach than sea-water samples from the same area. Preliminary experiments on a beach in South Devon, where the water was consistently free of coliform organisms, showed that *Bact. coli* from broth cultures poured on to a marked spot on the sands could be recovered 4 in. below the surface some 2 or 3 days later, although the area had been regularly covered by the tide. Multiple specimens of sand taken from points up to 5 yards apart on a given beach were also found to give coliform counts falling within a reasonably narrow range.

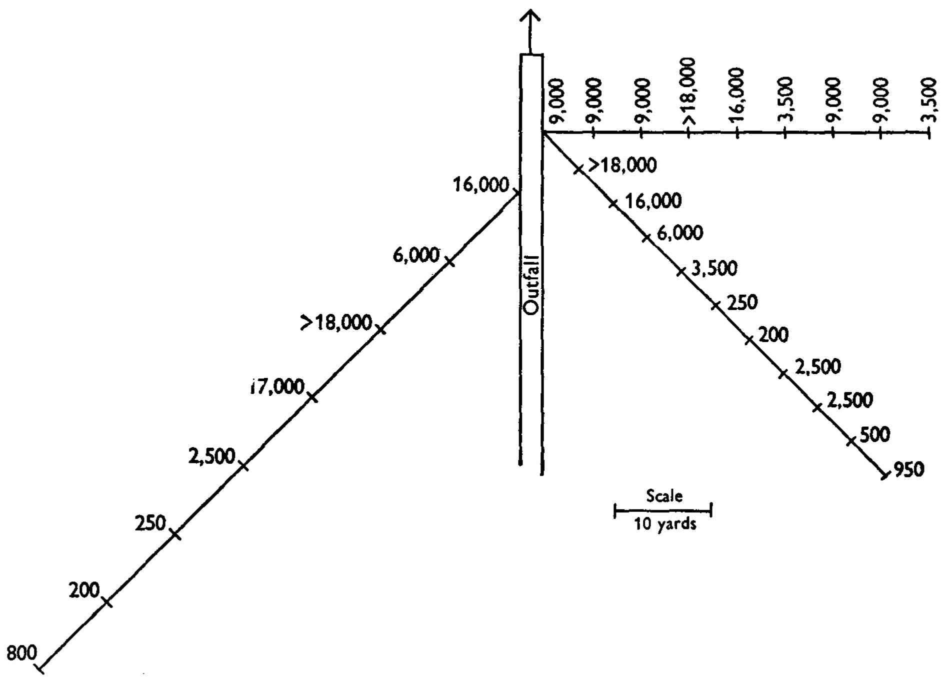

Fig. 3. Presumptive coliform counts on sand samples collected from the vicinity of the old outfall. Samples were collected at intervals along three straight lines diverging from the seaward end of the outfall. The figures shown represent the presumptive coliform counts of the supernatants of 1 in 3, v/v, suspensions in $\frac{1}{4}$-strength Ringer solution of sand samples collected at the points indicated.

During both surveys, therefore, numerous samples of sand were examined in addition to sea water. The method used was to collect composite samples of sand from surface level to a depth of about 4 in. with a sterile wooden spatula. A 50 c.c. volume of the sample was placed in a $9 \times 1\frac{1}{2}$ in. boiling tube and shaken thoroughly with 100 ml. of sterile $\frac{1}{4}$-strength Ringer's solution. The sand particles were allowed to settle and coliform counts were made on the supernatant fluid.

In the 1948 survey a number of sand samples were taken around the mouth of the sewer outfall at low tide. The presumptive coliform counts of these samples per 100 ml. of supernatant washings are shown in Fig. 3. A notable finding with these samples was the low proportion of faecal coli, particularly in the higher presumptive coliform counts, e.g. seven samples giving presumptive coliform counts of 16,000 or more per 100 ml. of washings gave faecal coli counts of 2500, 1300, 350, 130, 130, 40 and 40 per 100 ml. respectively, on the results of 44° C. tests done on the spot and not at Exeter. Only four of the 571 sea-water samples examined during both surveys showed a discrepancy of this degree between the results of the presumptive and faecal coli tests. These results suggested that the coliform population of the sea-bed about the sewer outfall was different from that of the sea water, and that, in particular, coliform organisms of the intermediate-aerogenes-cloacae (I.A.C.) group were either more resistant to sea water than *Bact. coli* of faecal type or else were multiplying in the sand around the outfall, where organic matter capable of supporting their growth was undoubtedly present. Weston & Edwards (1939), in their report on an extensive survey of sewage pollution in Boston Harbour, noted that the silt at the bottom of the harbour had a far higher coliform content than the surface water. A careful investigation of the silt from the sea bottom about the points of discharge of sewer outfalls might give useful information on the relative survival of different types of coliform organism and possibly of other Enterobacteriaceae in sea water.

Table 5. *Results of examination of sand samples*—1948 *and* 1950

Sampling point	No. of samples with presumptive coliform counts (per 100 ml.) 1948			1950		
	0–100	100–1000	>1000	0–100	100–1000	>1000
1	—	—	—	4	3	—
2	—	—	—	1	—	—
3	2	18	21	1	—	—
4	—	3	2	4	3	—
5	2	3		6	2	—
6	2	3	—	3	4	—
7	3	4	—	8	1	—
8	5	2	—	8	1	—
9	6	4	—	9	—	—
10	6	1	—	8	1	—
11	3	3	—	8	1	—
12	5	2	—	9	—	—
Total	34	43	23	69	16	—

Apart from the sand examinations described, samples of sand were taken in 1948 and 1950 from the various sampling points along the beach. The results of presumptive coliform counts done on these samples are summarized in Table 5 and show a general agreement between the bacteriological findings on sand samples and on sea-water samples from the corresponding areas.

(6) *Effect of weather and tides on beach pollution*

In both surveys the results of the presumptive coliform tests showed that the degree of pollution at a particular sampling point varied not only with its distance from the sewer outfall, but also with the wind and the state of the tide at the time of sampling. The distribution of coliform counts on samples collected in sunny weather was not significantly different from that of samples obtained in cloudy weather.

A brief account of the effect of various meteorological and tidal factors on sea-water pollution at different sampling points follows.

(a) *Variation in pollution with tidal state*

Given the complex tidal currents shown by the float test results in Fig. 2, it is not surprising that the degree of pollution at the various sampling points was found to vary with the time of sampling in relation to high water. Thus, in 1948, sea-water contamination was least at points 5 to 8 during the 4 hr. after high tide, while the greatest pollution was found in the incoming tide. The opposite was true of points 9 to 12, i.e. the worst contamination occurred within the first few hours after high water, both in 1948 and in 1950.

North of the outfall the relationship between tidal state and pollution was apparently altered by the new arrangements. In 1948, a special series of 15 min. samples collected during the greater part of a tidal cycle from a beach north of the outfall showed maximal contamination between high-water time and 4 hr. later, while in 1950 greater pollution occurred at low tide.

(b) *The effect of spring tides on pollution*

Local observation suggested that sewage discharged at high-water time was more likely to contaminate the beaches during spring tides than during neap tides. The data of the 1950 survey were analysed for evidence of this effect. The presumptive coliform counts obtained at different groups of sampling points were classified in fourfold tables according as (i) the counts obtained were above or below the median count for the group of points concerned, and (ii) the tide on the day of sampling was higher or lower than an arbitrarily chosen high tidal level at the nearest point for which tidal data were available. Table 6 shows the results of

Table 6. 1950 *survey. Effect of spring tides on pollution at points* 1, 2 *and the new sewer*

(*Median group*: 170–250 coliform organisms per 100 ml.)

Presumptive count	Total no. of samples	Height of tide >26 ft.	Height of tide <26 ft.
>250	33	18	15
<170	34	5	29

$\chi^2 = 11{\cdot}7$. $P < 0{\cdot}001$.

such a classification for points 1, 2 and the line of the new sewer; it indicates a highly significant increase in pollution when a spring tide occurred. There was also a significant increase in pollution at spring tides at points 9–12 ($\chi^2 = 27{\cdot}84$; P, 0·001), a less marked increase at points 7 and 8 ($\chi^2 = 6{\cdot}171$; P, 0·02), but no increase in pollution at points 3–6.

(*c*) *The effect of wind direction and strength on pollution*

A similar analysis of the 1950 results according to wind direction at the time of sampling showed a significant increase in sea-water contamination along the beach on days when the wind was from the north. This effect of northerly winds was particularly evident at points 9–12.

The effect of wind strength on pollution of the beach was not very marked during the summer months when the two surveys were made, although it was well known that in the storms of winter sewage was blown ashore at this resort. In 1950, however, a higher proportion of more heavily contaminated sea-water samples was obtained in the second week of the survey than in the first or third weeks, and this seemed to be associated with a greater average wind force during this time.

Epidemiological aspects of beach pollution in the area investigated

Beach pollution was blamed locally in the summer of 1946 for a serious outbreak of enteric fever due to *S. paratyphi B* involving at least twenty-one patients, who had probably been infected on 1 of 2 days in mid-June. Inquiry showed, however, that only about half of the patients had bathed or paddled, while twenty had eaten ice-cream from a particular source. The known handlers of the suspected ice-cream gave no evidence of recent infection or of a paratyphoid carrier state. Eighteen months later the ease with which *S. paratyphi B* could be isolated from the old sewage tank on the sea front prompted an attempt to trace the organism back to its point of entry into the sewerage system, and this eventually led to the discovery that the wife of the ice-cream vendor of 1946 was a paratyphoid carrier (Moore, 1948). A study of the older paratyphoid case histories then suggested that the same carrier might have infected some of them, and it is interesting to note that a sporadic case of paratyphoid fever in the same area in 1952 occurred in a child who lived some distance away but frequently had her tea after school at the same carrier's house.

In discussing the 1946 outbreak, the Report of the Chief Medical Officer of the Ministry of Health for 1948 (Report, 1950) made the comment that all coastal sea water contains sewage in greater or lesser dilution, and that bathing in it was therefore always attended by some risk from swallowing water. In the experience of the Ministry's medical officers, this risk was negligible, and it followed that, wherever multiple cases of enteric fever occurred in a seaside resort, the source and vehicle were most likely to be found ashore. While this was undoubtedly true of the outbreak described, at least two or three of the sporadic cases of paratyphoid B fever which have occurred in this town or in visitors to the town were, in the writer's opinion, almost certainly beach infections. One such case occurred in a small boy while the 1950 survey was actually in progress. He had played on the beach north of the outfall, and his father had complained to the local authority of some sewage pollution of this beach. Both parents were so cautious about their child's diet that possible foodborne infection could be excluded with greater confidence than usual. No other paratyphoid excreter was found in the household, and there was no history of contact with the known local carrier. In addition, it was known that *S. paratyphi B* was present in the sewer outfall at the time.

One can never prove conclusively that a sporadic case of paratyphoid B fever has not had some contact with infected food or a carrier, and to this extent beach infection can probably never be proved beyond a doubt. But an interesting fact which has been mentioned elsewhere (Moore, Perry & Chard, 1952) is that in the three districts served by the Exeter laboratory where sporadic cases of paratyphoid and typhoid fever have occurred regularly during the past ten years there is a common epidemiological factor in the lack of an adequate barrier against contact between the local population and sewage from the area. In two of the areas concerned there has been an unsatisfactory sewage outfall, in the third a polluted river from which water has been drawn for watering allotments. One would like to suggest that in an endemic enteric district where the local population is not completely protected from contact with sewage it is safer to assume that this contact is playing a direct or indirect part in maintaining the endemic infection in the area and to take steps to lessen the chances of this exposure to potential infection.

DISCUSSION

One of the questions to which an answer was sought in the investigation described in this paper was whether or not the many factors involved in the dissemination of sewage from sea outfalls might make it impossible to obtain in a limited period a coherent picture of the degree of contamination to which a given beach was subject. The results of these two surveys suggest that, given a sufficiently large series of examinations, the presumptive coliform test gives an excellent indication of the pattern of beach contamination in a given area, and shows up the variations in the degree of pollution due to meteorological and tidal factors.

In the area where the present survey was done the presumptive coliform test not only gave a consistent picture of beach contamination, which showed broad agreement with the results of local observation and float-test findings, but also permitted detailed analysis for the effect of winds and tides and gave a quantitative estimate of the fall in contamination with increasing distance from the outfall. The area investigated was of course topographically a simple one; the presumptive coliform test might give more complex results in, say, a survey of a beach at the mouth of a large river. Possibly on such a beach the faecal coli test would be more useful.

The validity and interpretation of any coliform test on sea water depend to a considerable extent on the survival in this medium of organisms of the coli group. A limited experience has confirmed the work of other observers that coliform organisms die out fairly rapidly in sea water. This increases the value of presumptive or faecal coli tests inasmuch as any demonstrated contamination of sea water with coliform organisms is likely to be of recent origin. It is also generally assumed that sea water has a rapidly lethal effect on enteric organisms. This has not been seriously investigated in the present study, but in a laboratory experiment in which sea water from the area under discussion was artificially infected with *S. paratyphi B* in an inoculum of about 10,000 organisms per ml. the organism was recovered by enrichment for up to 2 months later.

The main drawback to the laboratory techniques used in the work reported here was that the tests were too cumbersome except for special investigations. If bacteriological survey is to be applied to the problem of beach contamination, and if it is accepted that for the results to be of value, a large number of samples should be examined, a simple test for coliform organisms would be invaluable. The technique suggested by Clegg & Sherwood (1947) for shellfish examination or the membrane filter method (Goetz & Tsuneishi, 1951) are examples of techniques which might prove suitable for this purpose. Whether a simplification of bacteriological technique was practicable would depend to some extent on what degree of contamination it was desired to demonstrate. The results of the present survey have shown that for the area investigated the parts of the beach which were the object of complaint before and after the installation of the new sewerage scheme showed a high proportion of sea-water samples with more than 1000 coliform organisms per 100 ml. If a standard of this order were accepted as one above which sea-water counts on a bathing beach should not go, a simple MacConkey plate or roll-tube inoculated with 1–2 ml. of water might well be adequate in the examination of a given specimen.

SUMMARY

Bacteriological surveys of beach pollution were made at a seaside resort before and after the installation of a new sewer outfall.

The presumptive coliform count on samples of sea water was found to be a satisfactory index of contamination, and showed good agreement with sanitary survey and with the results of float-test observations. The faecal coli count was in general constantly related to the results of the presumptive test, but there was some indication that coliform bacilli of the I.A.C. groups persisted or multiplied in the sand around the outfall.

The degree of contamination of the sea water at a given sampling point was shown to depend not only on its distance from the outfall but on various meteorological and tidal factors.

For bacteriological surveys of beach pollution, it is suggested that a large series of tests by a relatively simple technique is preferable to a more limited investigation by more complex methods.

The possibility of laying down bacteriological standards for bathing beaches is discussed. An upper permitted limit of the order of 1000 coliform organisms per 100 ml. would discriminate between areas on the beach investigated which were unsatisfactory by sanitary survey before and after the installation of the new sewerage scheme, and those parts of the beach which were apparently not subject to serious pollution with sewage.

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REFERENCES

Clegg, L. F. L. & Sherwood, H. P. (1947). The bacteriological examination of molluscan shellfish. *J. Hyg., Camb.*, **45**, 504–21.

Goetz, A. & Tsuneishi, N. (1951). Application of molecular filter membranes to the bacteriological analysis of water. *J. Amer. Wat. Wks Ass.* **43**, 943–69.

Hajna, A. A. & Perry, C. A. (1943). Comparative study of presumptive and confirmative media for bacteria of the coliform group and for faecal streptococci. *Amer. J. publ. Hlth*, **33**, 550–6.

Mackenzie, E. F. W., Taylor, E. W. & Gilbert, W. E. (1948). Recent experiences in the rapid identification of *Bacterium coli*, Type I. *J. gen. Microbiol.* **2**, 197–204.

Moore, B. (1948). The detection of paratyphoid carriers in towns by means of sewage examination. *Mon. Bull. Minist. Hlth Lab. Serv.* **7**, 241–8.

Moore, B., Perry, E. L. & Chard, S. T. (1952). A survey by the sewage swab method of latent enteric infection in an urban area. *J. Hyg., Camb.*, **50**, 137–56.

Report (1940). Report of the Committee on Bathing Places. *Amer. J. publ. Hlth*, **30**, no. 2, pt. II, 50–1.

Report (1950). *Report of the Ministry of Health for the year ended* 31*st March* 1949. London: H.M. Stationery Office.

Report (1952). Report of the Committee on Bathing Places. *Amer. J. publ. Hlth*, **42**, no. 5, pt. II, 99–105.

Steiniger, F. (1951). Paratyphus-B-Bakterien im Nordseewasser. *Zbl. Bakt.* (1 Abt. Orig.), **157**, 52–6.

Weston, A. D. & Edwards, G. P. (1939). Pollution of Boston Harbor. *Proc. Amer. Soc. civ. Engrs*, **65**, 383–418.

Winslow, C. E. A. & Moxon, D. (1928). Bacterial pollution of bathing beach waters in New Haven Harbor. *Amer. J. Hyg.* **8**, 299–310.

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