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An appraisal of sewage pollution along a section of the Natal coast

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INTRODUCTION

Rapid industrial and municipal expansion taking place on the Natal Coast has focused attention on the ever-increasing quantities of waste ejected into the sea, and on the effects of this practice upon recreational waters adjoining the beaches. For Natal, though swiftly assuming the stature of an industrial giant, continues in its rôle of prime holiday resort and playground for Southern Africa.

At a local level, a determined attack on sewage- and waterborne-waste disposal problems has been initiated by certain Natal municipalities and industries. This has involved waste-water reclamation projects, increased industrial re-use of water, larger and more efficient treatment plants to keep pace with expansion, and, for the immediate future, three submarine pipelines to carry presently irretrievable water in the form of waste, far out to and under the sea thereby utilizing the ocean for effective dilution and dispersal of pollution.

The South African Council for Scientific and Industrial Research has been vitally concerned with many facets of these submarine pipelines, and problems ranging from outfall design to the collection of physico-oceanographic data are being investigated off this section of the coast.

In particular, the National Institute for Water Research of the South African Council for Scientific and Industrial Research has, for a number of years, been measuring environmental phenomena (on a selective basis) in this region in order to determine the degree of pollution, to pinpoint the sources and to establish standards for subsequent monitoring of the fully operational outfalls. The broad aspects of this have already been dealt with (Stander, Oliff & Livingstone, 1967), and the detailed chemical and faunal picture has been fully documented (Oliff *et al.* 1967*a*, *b*).

The present text is a digest, offering the salient features of detailed bacteriological work on the region.

Various factors in pollution of the sea were studied from a number of sources, ranging from 'clean' beaches, through various levels of contamination, to grossly polluted areas. From the distribution and occurrence of micro-organisms, and other data, a bacteriological standard for classifying these and similar waters was formulated. Such a method of appraisal should be of value in monitoring changes in the future.

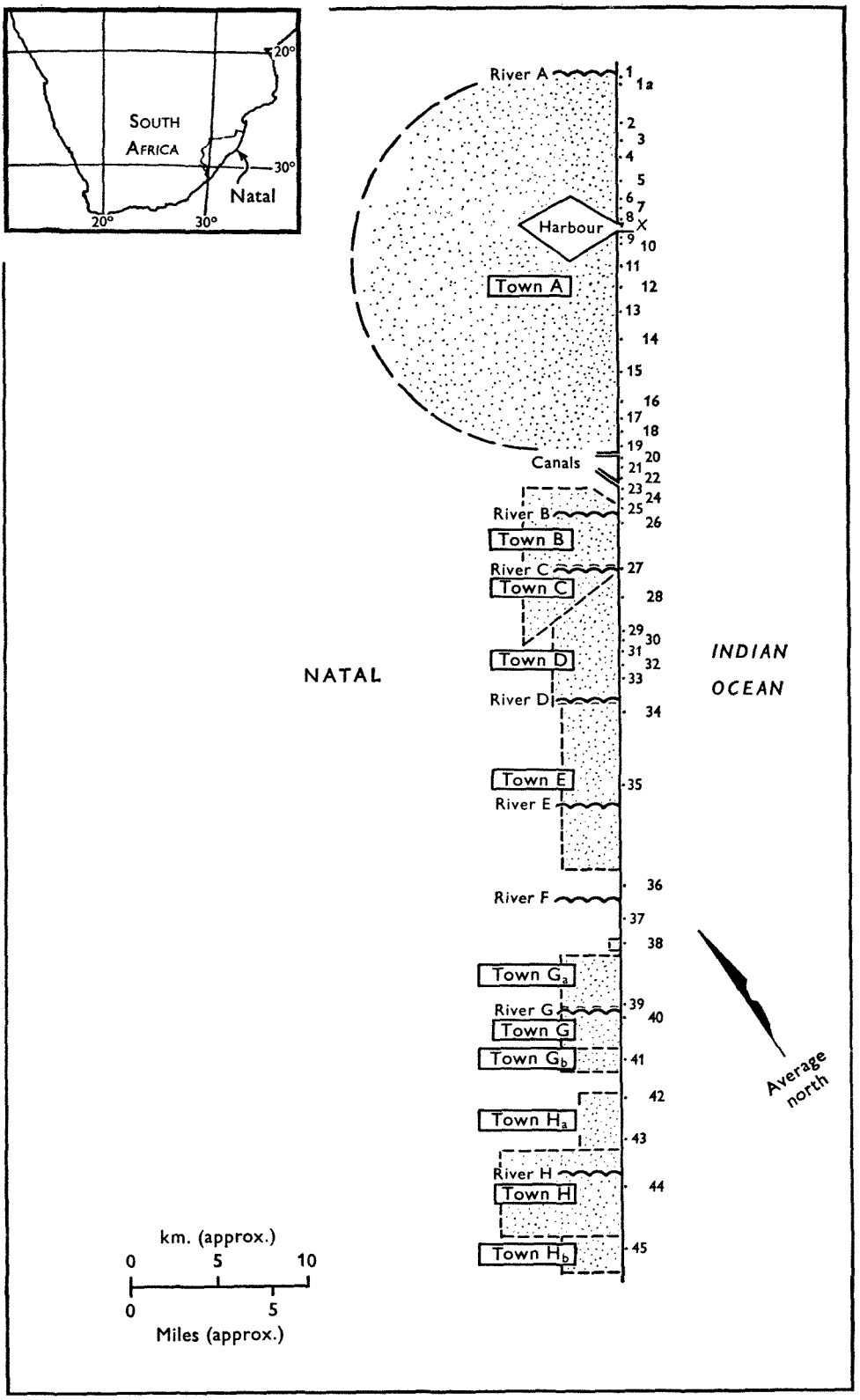

Fig. 1. Section of Natal coastline (schematic) showing sampling stations and main towns and rivers.

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DESCRIPTION OF THE SURVEY AREA

Natal is 36,000 square miles in extent, and constitutes about 7½ % of the total area of the Republic of South Africa. The province supports a population of 3,000,000. Climate ranges from the tropical to the subtropical in the east, with temperate mountain ranges in the west. For the particular coastal region under survey, shown in Fig. 1, the following annual averages apply:

Rainfall	874·4 mm.	Humidity	76 %
Temperature	19·9° C.	Evaporation	67·9 in.

Prevailing winds blow roughly parallel to the coast, alternately from the north-east and south-west, with almost equal frequency. In the sea, nearshore currents flow parallel to the coast and reverse direction every 1–2·5 days; their average velocity is between 0·1 and 0·6 ft./sec. Onshore currents occur 10–33 % of the time. Wave height is normally 3–6 ft., and wave approach is somewhat oblique about 50 % of the time. Rip currents occur on about 40 % of occasions; longshore currents flow about 10 % of the time, their usual coefficient of diffusion being of the order of 60 sq. ft./min. (Stander *et al.* 1967).

On the section of coastline examined, certain relevant background data were assembled. These primarily referred to the years 1965 and 1966, and included population, area, and important disposal, sanitary or polluting features of the various towns. Broadly speaking, these aspects, and coastal topographical features, dictated the siting of sampling stations.

By extrapolation, it is reasonable to suggest that, given parallel conditions of climate and similar features for some other region, equivalent bacteriological indices would probably occur in its neighbouring sea. Conversely, given a clear bacteriological picture of the sea-water of a region, a fair estimate of the factors contributing to its pollution potential can be made.

Extension of the area-typing was borne out by a short survey on a sector of the Cape coastline. Annual climatic averages for this temperate Cape sector are as follows:

Rainfall	486·3 mm.	Humidity	72 %
Temperature	17·3° C.	Evaporation	69·2 in.

SELECTION OF INDICATORS

Bacteriological assessment of these waters required a fairly broad approach. Certain indicators were considered and rejected as being of little if any practical value in the work. (Their use in some other context is often of undoubted importance.) These included *Streptococcus faecalis*, *Clostridium perfringens*, the bacteriophage of *Salmonella typhi*, and *Mycobacterium tuberculosis*, among others. The following indicators were finally selected.

Total coliforms

This count provides a fair non-specific indication of terrigenous pollution generally. Obviously, it is not specific enough when faecal pollution is under consideration.

Presumptive Escherichia coli

This group provides a more accurate picture of faecal pollution and is in common use throughout most parts of the world. However, the numbers include, indiscriminately, *E. coli* I which is of faecal origin, Irregular II, of doubtful habitat, and Irregular VI, usually of non-faecal origin and capable of proliferation in jute, rags, hemp, etc. (Wilson & Miles, 1964) and, at least in Natal, in the marginal vegetation of rivers. As an example of the differentiation applied to the present survey, a paper mill on River A, producing paper from rags imported from Japan and ejecting waste into the river, showed the following typical analysis on one of its felt-base effluents:

Total presumptive *E. coli*	233,450,000 per 100 ml.
E. coli I	Nil per 100 ml.
Irregular II	150,070,000 per 100 ml.
Irregular VI	83,380,000 per 100 ml.

Escherichia coli *I*

This organism is an indicator of definite and recent faecal pollution.

Parasite units

These were measured as numbers of ova of *Taenia* species and *Ascaris* species, and proved valuable in the work of plume tracking; their importance as a quantitative measure of the grosser degrees of sewage pollution ensured their inclusion in this particular survey. They can remain in sea-water for several hours before becoming unrecognizable.

Coagulase positive, mannitol positive staphylococci

This organism was recorded on a presence- or absence-in-the-sample basis. However, its presence in local sea-water, despite its predilection for NaCl, was rare in comparison to its occurrence in local inland waters, and it would appear to indicate very recent specific pollution possibly of a non-faecal nature. Though common in the respiratory tract of man, it is also to be found in the faeces of about 25 % of normal individuals. Some significance may or may not be attached to its recovery near to relatively stagnant or stored sea-water, i.e. a harbour mouth, a canal mouth experiencing tidal damming effects, river mouths, unchlorinated tidal swimming pools, etc. These staphylococci are present, however, in appreciable numbers in polluted rivers examined by ourselves and others (Brand, Kemp, Pretorius & Schoonbee, 1967). The organism has been reported as succumbing fairly rapidly in polluted sea-water. (Anon., 1956.) For these reasons its recovery was regarded as having some local significance.

Salmonella typhi, *salmonellas and shigellas*

Isolation of salmonellas from polluted waters proved a relatively straightforward and speedy process, and was therefore extensively used in this survey. The organisms probably do not live for more than a few days at most in sea-water,

and many of the claims to the contrary may be due to the use of old laboratory cultures rather than freshly isolated strains. Coetzee & Fourie (1965), using naturally occurring typhoid bacilli in the form of faeces from a typhoid carrier, found a T-90 (the time taken for a 90 % reduction in the viable count) in the region of 4 hr. in sea-water. Shigellas, which are known to be less hardy than salmonellas, probably survive for even shorter periods, and consequently shigella isolations from sea-water, uncommon though they are, can be regarded as of great importance in evaluating degrees of pollution.

Salinity

This single measure of a physical nature was included in order to indicate the degree of dilution of the saline medium by fresh water.

MATERIALS AND METHODS

Sampling

Water samples were collected in sterile containers 6 ft. from banks of rivers and canals, the side of a boat or, in the surf zone, 6 ft. from the shoremost lip of a just broken wave. An ordinary sample-stick with bottle-holding attachment was used. Pipe and drain effluents were sampled direct.

For all surface investigations, the water layer between the surface and 6 in. deep was sampled. In depth work and sediments various patent sampling bottles and dredges were used.

Total coliforms

Two 100 ml. samples of water, or of appropriate dilutions in sterile distilled water, were membrane-filtered. The membranes were resuscitated for 1 hr. at 37° C. on pads impregnated with resuscitation broth (Oxoid), then transferred to pads impregnated with MacConkey membrane broth (Oxoid) for a further 17 hr. (total incubation, 18 hr.). A selection of yellow colonies were Gram-stained for microscopy.

All yellow colonies were recorded, after adjustment for dilution, as total coliforms, average per 100 ml.

Total presumptive Escherichia coli

Two 100 ml. samples of water, or of appropriate dilutions in sterile distilled water, were membrane-filtered. The membranes were resuscitated for 2 hr. at 37° C. on pads impregnated with resuscitation broth (Oxoid), then for a further 16 hr. at 44·5° C. in a water bath (total incubation, 18 hr.) on pads impregnated with MacConkey membrane broth (Oxoid).

A selection of yellow colonies were Gram-stained for microscopy. All yellow colonies were recorded, after adjustment for dilution, as total presumptive *E. coli*, average per 100 ml.

Escherichia coli *I, Irregular II and Irregular VI*

A representative number of yellow colonies from the membranes from the *presumptive E. coli test (see above)* were subcultured into tryptone broth (Difco) and incubated at 44·5° C. for 24 hr. From these tubes, subcultures were made in Koser's citrate medium (Difco) with 0·5 % of brom thymol blue indicator solution,* and incubated at 44·5° C. for 96 hr. The tryptone broth cultures were tested for indole production with Kovacs's reagent. From these results a differential *E. coli* I, Irregular II and Irregular VI count per 100 ml. was calculated. (References to the above methods: Difco Laboratories, 1953, 1962; Ministry of Health, 1956; Taylor, 1958; American Public Health Association, 1960; Oxoid Division, 1961; Wilson & Miles, 1964.)

Parasite units

Originally 1 l. of sea-water, and, later in the survey, 250 ml., was used. Increased clarity of the microscopic films with the smaller sample afforded less chance of ova present escaping notice; this appeared to compensate for the difference in the total volume examined. The sample was allowed to stand for 30 min. and the supernatant, except the last $\frac{1}{2}$–1 in., was carefully drawn off with a small water-vacuum pump and discarded. The retained portion was shaken well, and centrifuged in 50 ml. tubes at 3000 rev./min. for 3 min. All *Ascaris* and *Taenia* ova in the whole deposit were counted under the microscope, and the numbers recorded.

Coagulase positive, mannitol positive staphylococci

Two 25 ml. samples were membrane-filtered. Membranes were cultured on *Staphylococcus* medium no. 110 (Difco) at 37° C. for 43 hr. A selection of the yellow and orange colonies were Gram-stained for microscopic checking. A further selection were subcultured on plates of the same medium, and growth was tested for coagulase production, using diagnostic plasma (dehydrated) (Warner-Chilcott). On the area of medium from which growth was removed, a few drops of brom-cresol purple indicator were placed to detect mannitol fermentation (Difco Laboratories, 1953). Results were recorded as presence or absence per 50 ml.

Salmonella typhi, *and* Salmonella, Shigella, Proteus *and* Pseudomonas *groups*

The method used was developed from that of Livingstone (1965). Originally, 2 l. of sea-water was filtered through a sterile cotton wool plug and the plug placed in 250 ml. of freshly prepared selenite brilliant green broth (Difco) (SBG). Later, 250 ml. of the actual sample was added to 6 g. of SBG powder; the broth so formed was split into two 125 ml. subsamples and to one of these about 0·6 g. (i.e. about 0·5 %) dulcitol was added. Increased sensitivity obtained in some cases from the dulcitol-containing portion, and possibly a lessening of the effects of logarithmic growth of unwanted organisms crowding out any salmonellas present

* Brom thymol blue, 1·6 g., N-NaOH, 1·3 ml., absolute alcohol, 20 ml., distilled water to make 50 ml.

in the smaller samples, appeared to compensate for the difference in total volume of the sample examined.

For further testing, a modified SS (Difco) agar was used, in which the lactose was increased to 1·5 %, and 1·5 % of saccharose, not normally present, was added. Both halves of the sample were incubated at 37° C. for 20 hr., and each was then subcultured on two plates of the modified SS agar. One of each pair was incubated at 37° C. and the other at 40° C. for 20 hr. A selection from the clear colonies on these plates were then inoculated on triple-sugar-iron (BBL) agar slopes and in urea broth (Oxoid). Growth not showing the characteristics of *Proteus* or *Pseudomonas* was 'purified' on modified SS agar and tested against appropriate polyvalent antisera (Burroughs-Wellcome). All salmonellas and shigellas were submitted elsewhere (Dr H. W. Botes, Onderstepoort Veterinary Research Laboratories, Transvaal; and Dr J. H. McCoy, Public Health Laboratory, Hull Royal Infirmary, Yorkshire, England) for independent confirmation and serotyping. (*S. typhi* isolated were sent for phage-typing to Dr C. G. Crocker, Institute for Pathology, Pretoria).

Results were recorded as presence or absence of the various organisms per 250 ml.

Salinity

Salinity readings were made (courtesy local National Physical Research Laboratory) on an electrical conductivity salinometer.

RESULTS AND DISCUSSION

Judging from the plethora of bacterial candidates offered in the literature, there would appear to be no perfect indicator of sewage pollution. Criteria for 'safe' or 'ideal' recreational waters at the seaside range from the absence of 'a sewage nuisance' on frankly aesthetic grounds (Moore, 1954*a*, *b*) to the absence of *E. coli* (Yotakis, 1959); the most popular criterion apparently being the 1000 coliforms per 100 ml. standard (McKee & Wolf, 1963). However, the main concern here was the need to measure local water quality effectively in order to assess future changes in that quality.

In Natal, a feature of the coastline is the large number of rivers threading their way to the sea. The mouths of about a quarter of these are closed by a sandbar for 40–50 weeks in the year. Others perennially flow into the sea, and at times considerable flooding occurs when all river mouths burst wide, and the sea is discoloured for miles. Here, coliforms or presumptive *E. coli* are comparatively valueless, and if one's standard is based on *E. coli* I, care must be exercised to ensure that it is indeed this particular organism of faecal pollution that is being evaluated and not Irregular VI, the 44·5° C. positive coliform, which is not necessarily of faecal origin (Wilson & Miles, 1964), and which is capable of proliferation around marginal vegetation, at least in Natal rivers.

As *E. coli* I is able to survive more than 24 hr. in local sea-water and as some offshore currents can attain speeds of up to 16–24 miles/24 hr. (F. P. Anderson, personal communication) the finding of this indicator off the 'clean' beaches is not surprising.

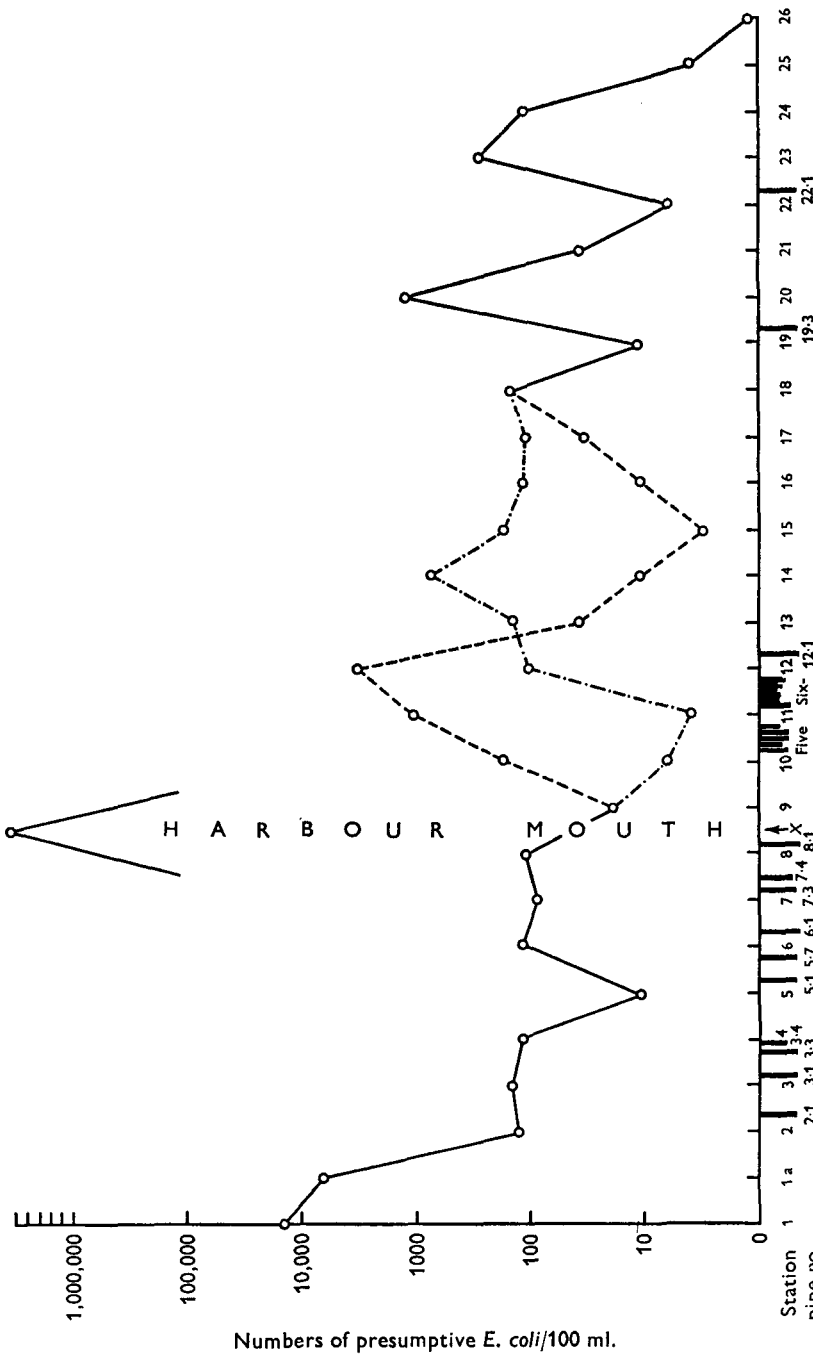

Fig. 2. Numbers of presumptive *E. coli* recovered from the surf sampling stations, showing the positions of pipes, drains and canals discharging sewage. Between stations 9 and 18: ←– – – north-going current; –·– → south-going current.

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In fact, the complete and consistent absence of *E. coli* I from any particular beach in this area is a near impossibility. Figure 2 shows graphically the numbers of presumptive *E. coli* and the position of various pipes, drains and canals between Stations 1 and 26 ejecting sewage, and provides some indication of the influence of currents.

It is apparent that the use of *E. coli* I alone as an indicator would be of no value to those concerned in monitoring the effects of the diversion of sewage through the new submarine outfalls.

A means of measuring local water quality was therefore evolved employing a graded process whereby any improvement or worsening of the nearshore sea-water as regards sewage pollution could be assessed.

Water quality gradation

In order to cover every possible local contingency of sewage affecting neighbouring bathing beaches the present work was necessarily diversified in approach; and a planned system of adverse scoring was adopted. Each indicator was selected

Table 1. *Evaluation of indicators*

Indicator	Degree	Value
E. coli I per 100 ml.	0–10	1
	11–100	2
	101–1000	4
	>1000	8
Parasite units per 250 ml.	1–7	4
	>7	8
Coagulase and mannitol positive *staphylococci* per 50 ml.	Present (+)	4
Salmonellas per 250 ml.	Present (+)	4
Salmonella typhi per 250 ml.*	Present (+)	4
Shigellas per 250 ml.	Present (+)	4
Salinity, in ‰	<34‰	4

* *S. typhi* if present would therefore contribute a total value of 8, scoring 4 under salmonellas and 4 under *S. typhi*.

Table 2. *A system of classifying sea-waters by indicator values*

Indicator values	Class
1–4	I
5–8	II
9–16	III
>16	IV

and scored basically on a value of 4 (the figure for 101–1000 *E. coli* I per 100 ml.). Certain indicators regarded as of special pollution significance were given greater weight by being accorded high values; the design of the system ensured higher scoring for these, if their numbers or infrequency of occurrence were thought to warrant this. This system of scoring is shown in Table 1. Table 2 shows how the

total indicator scores from Table 1 were used to divide the waters into four classes I to IV.

Such a system ensured that the quantity of sewage effluents discharged, often extremely variable in the case of pipes, drains and canals, made little impact on the overall system and could be dispensed with in the data processing. Only direct measurements on the quality of the medium were involved. These measurements were based broadly enough to ensure that no random momentary upsurge or lessening of any single factor was possible whereby gradation was altered to the extent of calling for major reclassification of the sea-water. Any important change would involve most of the factors.

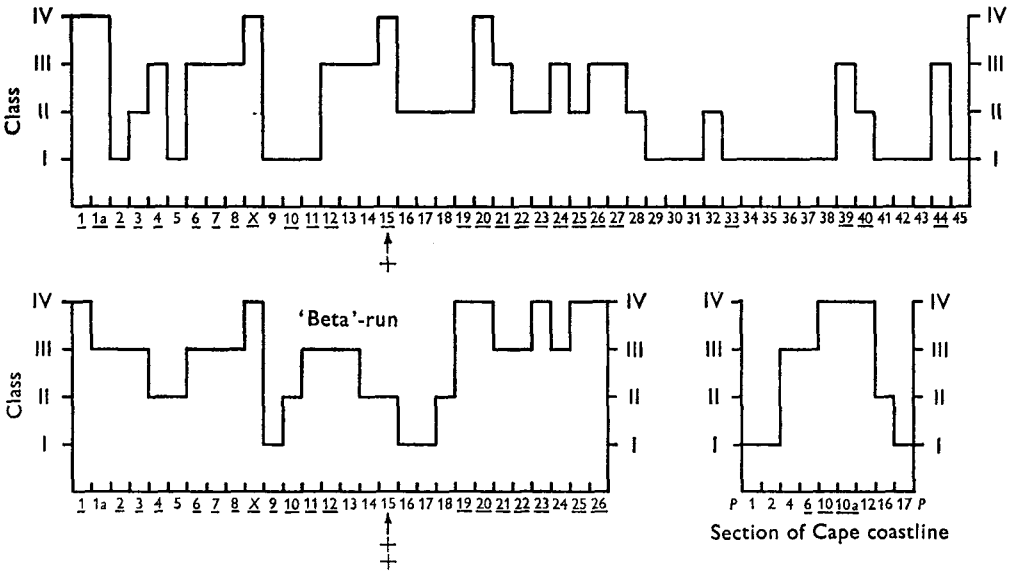

Fig. 3. Gradation of surf-waters by indicator values. Station numbers underlined indicate proximity to known sources of pollution. +, Tidal bath before chlorination; ‡ tidal bath later, chlorinated.

Moreover, as can be seen from the 'Beta' run classification in Fig. 3, a single series of samples down the coast afforded a very close approximation of conditions obtaining in the region, provided sanitary conditions upon the neighbouring land remained unchanged. This occurred despite the great restlessness and turbulence of wave, wind and current in the region.

The evolution and application of indicator values to a system of water gradation could involve nearly insuperable problems regarding objectivity. However, in the present survey, such a potential weakness was, it is thought, fairly obviated by firmly relating the classification of the sampling stations, arrived at from bacteriological findings, with their onshore sanitary features and conditions. Some indication of the more significant stations is shown in Table 3 and Fig. 3.

Classification of every sampling station examined in the light of this system appears in Table 3. The classification is again presented in Fig. 3 in schematic form.

Table 3. *Gradation of surf-waters by indication values*

Average of 3 runs										Beta run									
Station no.	*E. coli* I	Parasite index	C+M+staph.	*S. typhi*	Salmonellae/ Shigellae	Salinity	Total	Class	Actual or potential polluting features in the vicinity	Station no.	*E. coli* I	Parasite index	C+M+staph.	*S. typhi*	Salmonellae/ Shigellae	Salinity	Total	Class
									River A mouth: domestic and industrial discharges									
1	8	4	.	4	4	4	24	IV	.	1	8	4	4	.	4	4	24	IV
1*a*	8	4	.	.	4	4	20	IV	.	1*a*	8	.	.	.	4	.	12	III
2	2	.	.	.	.	.	2	I	Pipe 2.1: sewage	2	8	.	.	.	4	.	12	III
3	4	.	.	.	4	.	8	II	Pipes 3.1, 3.3, 3.4: sewage	3	8	.	.	.	4	.	12	III
4	4	4	.	4	4	.	16	III	.	4	8	.	.	.	.	.	8	II
5	1	.	.	.	.	.	1	I	Pipes 5.1, 5.7: sewage	5	8	.	.	.	.	.	8	II
6	4	4	.	.	4	.	12	III	Pipe 6.1: sewage	6	8	4	.	.	.	.	12	III
7	2	4	.	.	4	.	10	III	Pipes 7.3, 7.4: sewage	7	8	4	.	.	.	.	12	III
8	4	4	.	.	4	.	12	III	Pipe 8.1: sewage	8	8	.	.	.	4	.	12	III
X	8	8	4	4	8	4	36	IV	Main harbour discharge at *X*: approx. 20 m.g.d. sewage and industrial effluent	*X*	8	8	4	.	4	4	28	IV
9	2	.	.	.	.	.	2	I		9	1	.	.	.	.	.	1	I
10	4	.	.	.	.	.	4	I	Pipes 10.5, 10.6, 10.7, 10.9, 10.10: sewage	10	4	4	.	.	.	.	8	II
11	4	.	.	.	.	.	4	I	Pipes 11.2, 11.3, 11.5–11.7, 11.9–11.15, 11.17, 11.20, 11.21, 11.23: sewage and whaling effluents	11	8	4	.	.	4	.	16	III
12	8	4	.	.	.	.	12	III	Pipe 12.1: sewage	12	8	4	.	.	4	.	16	III
13	2	4	.	.	4	.	10	III	.	13	8	4	.	.	.	.	12	III
14	4	4	.	.	4	.	12	III	.	14	4	4	.	.	.	.	8	II
15	4	4	4	4	4	.	20	IV	Unchlorinated tidal swimming bath; chlorinated later	15	4	.	.	.	4	.	8	II
16	2	.	.	.	4	.	6	II	.	16	2	.	.	.	.	.	2	I
17	2	.	.	.	4	.	6	II	.	17	1	.	.	.	.	.	1	I
18	4	.	.	.	4	.	8	II	.	18	1	.	4	.	.	.	5	II
19	1	.	.	.	4	.	5	II	Canal 19.3: domestic and industrial discharges	19	8	4	4	.	4	4	24	IV
20	8	4	4	4	4	4	28	IV	.	20	8	4	.	.	4	4	20	IV
21	2	4	.	.	4	.	10	III	.	21	8	4	.	.	4	.	16	III
22	1	.	.	.	4	.	5	II	Canal 22.1: domestic and (largely petroleum) industrial discharges	22	8	.	4	.	.	4	16	III
23	2	.	.	.	4	.	6	II	.	23	8	4	4	.	4	4	24	IV
24	2	4	.	.	4	.	10	III	.	24	8	.	.	.	.	4	12	III
25	1	.	.	.	4	.	5	II	.	25	8	4	4	.	4	4	24	IV

Table 3 (*cont.*)

Station no.	Average of 3 runs: *E. coli* I	Parasite index	C+M+staph.	*S. typhi*	Salmonellae/Shigellae	Salinity	Total	Class	Actual or potential polluting features in the vicinity
									River B mouth. Unchlorinated tidal swimming bath
26	1	.	.	.	8	.	9	III	.
27	2	.	4	.	4	4	14	III	.
									River C mouth
28	2	.	4	.	.	.	6	II	.
29	1	.	.	.	.	.	1	I	.
30	2	.	.	.	.	.	2	I	.
31	1	.	.	.	.	.	1	I	.
32	1	.	.	.	4	.	5	II	.
33	1	.	.	.	.	.	1	I	Chlorinated tidal swimming bath
									River D mouth (usually closed)
34	1	.	.	.	.	.	1	I	.
35	2	.	.	.	.	.	2	I	2 unchlorinated tidal swimming baths
									River E mouth
36	2	.	.	.	.	.	2	I	.
									River F mouth (limited flow)
37	2	.	.	.	.	.	2	I	.
38	2	.	.	.	.	.	2	I	.
39	4	.	4	.	.	4	12	III	.
									River G mouth: domestic and industrial discharges
40	4	.	4	.	.	.	8	II	Unchlorinated tidal swimming bath
41	2	.	.	.	.	.	2	I	.
42	2	.	.	.	.	.	2	I	.
43	2	.	.	.	.	.	2	I	
									River H mouth: domestic and industrial discharges
44	8	.	.	.	.	4	12	III	Tidal swimming bath: chlorinated
45	4	.	.	.	.	.	4	I	Tidal swimming bath: 'usually chlorinated'

Station co.	'Beta' run: *E. coli* I	Parasite index	C+M+staph.	*S. typhi*	Salmonellae/Shigellae	Salinity	Total	Class
26	8	4	4	.	4	4	24	IV
					Cape section			
P1	1	.	.	.	.	.	1	I
P2	1	.	.	.	.	.	1	I
P4	8	.	.	.	4	.	12	III
P6	8	.	4	.	4	.	16	III
P10	8	4	4	.	4	.	20	IV
P10*a*	8	8	4	.	.	.	20	IV
P12	8	8	4	.	.	.	20	IV
P16	2	.	.	.	4	.	6	II
P17	1	.	.	.	.	.	1	I

(P6, near a wool washery discharge; P10 and 10*a*, main sewage outfall; P12, two waste pipes, from a cannery and a tannery.)

Future water quality

A submarine outfall, carrying sulphite waste from a cellulose processing plant has been established recently between Stations 39 and 40, subsequent to the present work. This effluent, formerly discharged at River G (see Fig. 1), was found to be toxic to coliforms. Consequently, in this case, some deterioration of water quality, measured on bacteriological grounds alone is expected in the sea-water in the vicinity of River G when this outfall is fully operational.

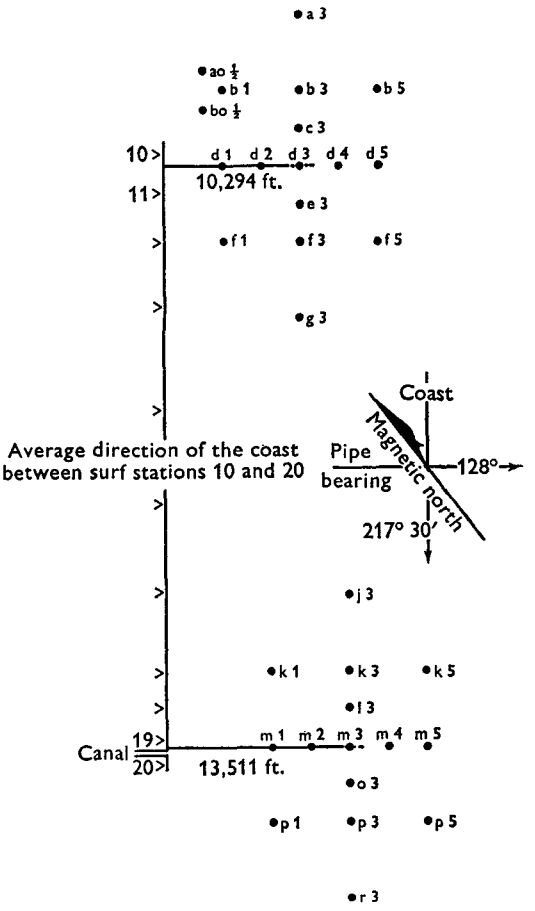

Fig. 4. Section of coast showing forthcoming submarine outfall lines with sea monitoring stations (arbitrary grid system: ½-mile units). Scale, 1:80,000.

Most of the sewage entering the sea between Stations 1 and 26 was untreated during this survey, apart from coarse meshing and primary settling in tanks near Station X while awaiting discharge with the outgoing tide. Two major submarine outfalls are planned for the region, near Stations 10 and 19. Occultation, that is, removal of the organisms surveyed here to and below the lowest levels of present-day detection and enumeration methods through dilution, dispersal, sedimentation and loss of viability, will obviously produce a steady and measurable bacterial

improvement of the water quality, as all the major and most of the minor discharges are collected and diverted to central treatment plants for pumping and dispersal under the sea. Sea-sampling stations were established in the pipeline area (Fig. 4) and the nature of their backgrounds established in preparation for the forthcoming monitoring programme. It is expected that many of the present Class IV and III surf-sampling stations will be promoted to the altogether more desirable grades of Class II and even Class I, when these pipelines are fully operational.

SUMMARY

A bacteriological survey was made on the distribution and occurrence of coliforms and pathogenic indicators of pollution within the surf-zone and near-shore waters along a section of the Natal Coast, prior to the use of submarine outfalls. The distance covered measured approximately 47 miles. The waters sampled and assessed ranged from 'clean' beaches to heavily polluted areas; a single short run off an Eastern Cape coastal region was included for comparative purposes. In all cases, the bacteriological picture was related to sanitary features on the shore. The method is based on *Escherichia coli* I counts, parasite units, staphylococci, salmonellas and salinity, and provides an objective approach to the assessment of any future changes in water quality consequent on development.

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REFERENCES

AMERICAN PUBLIC HEALTH ASSOCIATION, AMERICAN WATER WORKS ASSOCIATION AND WATER POLLUTION CONTROL FEDERATION (1960). *Standard Methods for the Examination of Water and Waste Water*, 11th edn. New York: American Public Health Association, Inc.

ANON (1956). *An Investigation of the Efficacy of Submarine Outfall Disposal of Sewage and Sludge*, Publication no. 14. California: State Water Pollution Control Board.

BRAND, P. A. J., KEMP, P. H., PRETORIUS, S. J. & SCHOONBEE, H. J. (1967). Water quality and abatement of pollution in Natal rivers. *Natal Town and Regional Planning Report*, Vol XIII, pt. 1 *et seq.*

COETZEE, O. J. & FOURIE, N. A. (1965). The efficiency of conventional sewage purification works, stabilization ponds and maturation ponds with respect to the survival of pathogenic bacteria and indicator organisms. *J. Proc. Inst. Sew. Purif.* pt 3.

DIFCO LABORATORIES (1953). *Difco Manual of Dehydrated Culture Media and Reagents for Microbiological and Clinical Laboratory Products*, 9th ed. (reprinted 1963). Detroit: Difco Laboratories.

DIFCO LABORATORIES (1962). *Difco Supplementary Literature*. Detroit: Difco Laboratories.

LIVINGSTONE, D. J. (1965). An improved method for isolating salmonellae from polluted waters. *Publ. Hlth, Johannesburg* **65**, 87.

MCKEE, S. E. & WOLF, H. W. (1963). *Water Quality Criteria*. Publication 3–A. California: State Water Quality Control Board.

MINISTRY OF HEALTH (1956). The bacteriological examination of water supplies. *Rep. publ. Hlth med. Subj., Lond.* no. 71.

MOORE, B. (1954*a*). A survey of beach pollution at a seaside resort. *J. Hyg., Camb.* **52**, 71.

MOORE, B. (1954*b*). Sewage contamination of coastal bathing waters. *Bull. Hyg., Lond.* **29**, 689.

OLIFF, W. D., BERRISFORD, C. D., TURNER, W. D., BALLARD, J. A. & MCWILLIAM, D. C. (1967*a*). The ecology and chemistry of sandy beaches and nearshore submarine sediments of Natal. I. Pollution criteria for sandy beaches in Natal. *Water Res.* **1**, 115.

OLIFF, W. D., BERRISFORD, C. D., TURNER, W. D., BALLARD, J. A. & MCWILLIAM, D. C. (1967*b*). The ecology and chemistry of sandy beaches and nearshore submarine sediments of Natal. II. Pollution criteria for nearshore sediments of the Natal coast. *Water Res.* **1**, 131.

STANDER, G. J., OLIFF, W. D. & LIVINGSTONE, D. J. (1967). Problems in using the sea as part of a waste disposal system. Conference Paper no. 3. The Institute of Water Pollution Control: Annual Conference, June, 1967.

TAYLOR, E. W. (1958). *The Examination of Waters and Water Supplies* (Thresh, Beale and Suckling), 7th ed. London: J. A. Churchill Ltd.

THE OXOID DIVISION (1961). *The Oxoid Manual of Culture Media, including Ingredients and and other Laboratory Services*. 2nd ed. London: The Oxoid Division of Oxo Ltd.

WILSON, G. S. & MILES, A. A. (1964). *Topley and Wilson's Principles of Bacteriology and Immunity*, 5th ed. London: Edward Arnold Ltd.

YOTAKIS, L. (1959). The bacteriology of bathing beaches and the counting of *Esch. coli* and *Strep. faecalis* in sea-water (Trans.). *Int. J. prophyl. Med. Soc. Hyg., Wien* **3**, 159.