A MICROBIAL STUDY OF WATER QUALITY IN THE MARINE ENVIRONMENT OFF DURBAN:

1964 - 1988

by

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Frontispiece DURBAN, 1988 *Photo: Gonsul Pillay*

PREFACE

The experimental work in this thesis was carried out in the Natal Branch (formerly Regional) Laboratory of the CSIR, Durban, from March 1964 to August 1988, under the supervision of Mr C G Contrafatto and Dr M H Schleyer.

These studies represent original work by the author and have not been submitted in any form to another University. Where use was made of the work of others it has been duly acknowledged in the text.

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ABSTRACT

In 1964, the city of Durban was discharging 90 x 10^3 m^3/day wastewater from the harbour mouth with the outgoing tides, while the discharge from a sewer on the Bluff into the surf-zone amounted to 20 x 10^3 m^3/day. In addition, there existed more than 90 beach pipes and stormwater drains (not all of them legal), about one third of which carried contaminative material on to the beaches and into the surf.

Twenty-eight sampling stations were established between the Mgeni River and Isipingo and subjected to detailed bacteriological surveillance, prior to the construction of a pair of submarine outfalls to serve the region's disposal requirements.

A microbial system of evaluating seawater quality was developed using *Escherichia coli* I, parasite ova, staphylococci, salmonellae (including *Salmonella typhi*) and the salinity as indicators . A comprehensive "before" picture was therefore created against which to measure future changes in the sea off Durban.

In 1968/69 the pair of submarine pipelines was commissioned with their attendant treatment plants. The harbour effluent was diverted to the new complex, and pollution from the minor outfalls was progressively halted with their wastes similarly joined to the new works. The system of water quality gradation was applied to the surf-zone and out to sea to measure the efficacy of the new pipelines, providing an "after" picture. Throughout the subsequent engineering innovation of sludge disposal via the outfalls (which proved successful), and during climatic extremes involving a severe drought (with stringent water consumption restrictions), cyclones and catastrophic floods, the classification system continued to function satisfactorily, covering 25 years in all: alterations in the water quality were shown to be invariably a consequence of changes effected upon the shore or meteorological events. The system has also proved useful in identifying and measuring the impact of contaminative foci in Cape waters and at Richards Bay.

The relevant oceanography and current dynamics, the rationale for the selection of the indicators used and the methodology, along with more general aspects of marine pollution and associated risks are discussed.

Finally, the feasibility is examined of curtailing the numbers of parameters measured and simplifying the classification system while retaining its usefulness and serviceability as an instrument for assessing the impact of domestic effluent on the marine environment off Durban.

CONTENTS

CHAPTER 1 : INTRODUCTION

1.1 POLLUTION : A GENERAL PERSPECTIVE

In an ideal world where perfect paradigms prevailed there would be no waste, and therefore no pollution. In the absence of such a paradise, on a planet whose main pollutant is, arguably, humanity itself, it is surely the responsibility of every civilized society to confront the problems inherent in the disposal of the waste it generates with all the affordable care, practical concern and available skills it can muster to preserve its environment, not only for its own well-being and survival, but for those of future generations.

One fact is paramount: this is a provenly tough and resilient planet, the only one in the known universe upon which diverse and abundant life exists. The earth's environmental circumstances have changed in the past due to sketchily perceived events probably involving climate, vulcanism, polar shifts, cosmological catastrophes, etc, to the detriment of its then prevailing life-forms. Today, the planet's presently dominant life-form is in the strange position of possibly effecting unwanted changes in the biosphere from its own waste-products - fouling its own nest, as it were - to its own injury. Fearful of propagating its own destruction, an awareness - occasionally compounded by ignorance and hysteria fed by, at times, an alarmist media - has surfaced in humanity's consciousness of the price invariably attached to modern comforts, the enjoyment of technological facilities and uncontrolled population growth. This comparatively recent disseminative perception of responsibility towards matters ecological and environmental can only be welcomed. Yet a perspective has to be maintained: something practical has to be done about the waste.

1.2 CHARACTERIZING MARINE POLLUTION

Sea pollution, in the widest sense of involving any impurity, comprises the addition of anything at all that impinges upon the marine environment. Such addenda range naturally from rainwater (affecting merely the salinity) to drowned animals, soil (which may include naturally-occurring toxic metals) and whole tree-trunks discharged into the sea by rivers in flood;

and the sea has coped with this load for many millions of years. Garber (1986) has commented on the abundance of naturally-occurring heavy metals in the sea in the vicinity of volcanic activity (eg: in the waters around Hawaii), and she quotes from W H Harvey's *The Seaside Book* (1849: out of print) in which the Dublin botanist observed that sulphur compounds in the sea off the West coast of tropical Africa corroded the copper bottoms of ships, ie: before our present era of widespread industrial and technological development.

In its strictest sense, and with particular relevance to coastal-zone management, the term pollution is associated with the more sinister concept of unnatural defilement or contamination; and here, humanity is invariably the perpetrator.

The sea presents as a convenient matrix into which humanity's domestic and industrial waste can be discharged. And the principle is basically logical: the separation, diversion and disposal of unpleasant or potentially harmful waste-products away from the land upon which people live to the sea which is only intermittently visited by humans is a relatively cost-effective solution, certainly a tempting option in coastal-zone waste management provided the disposal designs and engineering constructs are exceptional. Ideally, the receiving sea dilutes and disperses jettisoned waste rapidly and effectively, neutralizing any harmful elements, while retaining its own pristine, essentially oceanic characteristics intact. A clear blue (or green) sea with translucent waves forming to break on unsullied beaches is a universal and important part of the human aesthetic. It is regarded as every individual's birthright. And it is a vision which coastal management bodies discount or ignore to their peril.

Inefficient marine disposal of effluent can adversely affect the sea in a discharge area. The recipient sea may become discoloured; slicks, unacceptable foaming, solids and odours can appear making people in the vicinity angry and dissatisfied. Disgruntled holiday-makers may resolve never to return; resort owners and commercial interests contemplate selling up and moving; conference centres and socio-cultural organizations decay, while anglers, bathers and boatmen give up in disgust.

1.2.1 Aesthetics

Aesthetics, which include the careful siting of marine disposal outfalls, are of prime importance to enlightened management of coastal resorts and resources. Questions that have to be squarely confronted prior to outfall construction are:

1. Will the outfall be sited remote from recreational/residential/ sea-food industry areas? (Has the local medical officer of health been consulted?)

2. Will the outfall be in or near a bay where the incoming tide can back up the effluent or delay its dispersal in the open sea?

3. Have the prevailing wind-, coastal current- and wave-directions (which are seldom 90° to the shore) at the discharge site been considered and related to the movement of a potential plume?

4. Is there a river-mouth or other water-way near-by? (Discolouration or turbidity generated by natural terrigenous waters will not serve to mask a faulty discharge; indeed, human nature ensures that any opacity in the vicinity will be attributed to the proximate outfall. Similarly, an efficient works and outfall can be unfairly compromised by an adjacent polluted waterway.)

5. Will the proposed outfall downgrade existing amenities? (Eg: is there a frequented promontory or tidal pool in the vicinity against which, or in which waste material will tend to accumulate driven by the prevailing wind, current or wave action? Will the discharge exacerbate shoreline erosion?)

Visual/olfactory impacts cannot be too strongly emphasized: if the public can actually see or smell pollution, worse is invariably inferred regarding the risk to human health.

Meticulous siting of a marine pipeline as a permanent sanitary feature on the coast, along with expert design criteria, can preclude costly procedures in the future such as the reconstruction or extension of an initially badly planned outfall. Intelligent demarcation of recreational areas in relation to all established coastal features is obviously of equal importance.

1.2.2 Investigatory protocols

It is only after the macroscopic factors, when the prefigured aesthetics are acceptable, that investigations essentially involving the microscopic should follow to establish the character of an effluent, an assessment made of its properties and its potential for harming the recipient milieu.

Initially, as wide a spectrum of tests as possible should be performed on the effluent at the treatment works to establish its composition, and on the anticipated discharge-affected area prior to construction or functioning of the outfall. Findings on the works effluent can provide data to assist in calculating and predicting dilutions, while the environmental surveys will provide the background against which changes consequent upon development can be measured.

In the marine environment, measurements should be made along the shore, on the existing biota, over the projected diffuser site and its surrounds: on the surface, the sea sediments and on the waters in between. The spectrum of surveillance should include:

1. Physical oceanography and modelling of the target area which will be affected by the discharge.

2. Microbiology on effluents which include sewage: indicator organisms; other bacteria; parasite ova; viruses and coliphages under certain circumstances; meiofauna and benthic macrofauna.

3. Chemistry: salinity; settleable solids; dissolved solids; Kjeldahl nitrogen; chemical oxygen demand (COD); oxygen absorbed (OA); pH; temperature; particle size; carbohydrates and other nutrients; petrochemicals; radiochemicals; toxic metals; chlorinated hydrocarbons and polychlorinated biphenyls (PCBs); any other deleterious substances.

4. Testing of the effluent's toxicity to sensitive marine organisms if possible.

(The investigations underlined above represent the minimum of tests which can later comprise the routine protocol for regular monitoring; however, the full spectrum of investigatory procedures can be considered in the light of affordability. Obviously, if an effluent includes the discharge from eg: a nuclear power station, tests for radiochemicals and water temperatures would constitute essential components in the subsequent routine surveillance.)

1.3 WASTE DISPOSAL AT DURBAN

In 1964, Durban did not have a wastewater works to treat domestic and trade effluents produced within the borough. A large portion of the city was without waterborne sewerage, and fairly extensive residential areas had evolved using septic tanks and soakpits (Macleod, 1972).

Untreated wastewater from the central area (approximately 90 x 10^3 m^3/day) drained towards the vicinity of the harbour mouth where it was accumulated and temporarily stored after coarse screening, then discharged with the outgoing tide at Station X (Fig. 1); the process started in July 1896 (Connell, 1988). In the south, the sewered area drained to a pumping station, and this waste (some 20 x 10^3 m^3/day) was ejected into the surf-zone from the Finnemore Place sewer between Stations 12 and 13. In addition, there existed about one hundred stormwater drains and minor waste-pipes between the Mgeni River and Isipingo, not all of them legally sanctioned. About a third of these demonstrated microbial evidence of faecal pollution, along with the canalized Mlaas River and Reunion Canal (Livingstone and de Goede, 1965). The former canal proved to be faecally contaminated (and still is) when measured bacteriologically, much of the pollution stemming from upstream of Durban (Livingstone and Calder, 1988). At the Reunion mouth, a mixture of domestic and petrochemical waste continues to be demonstrable from the petroleum refinery campus in the vicinity.

North of the Mgeni is the kwaMashu Works built in 1958, reconstructed and extended in 1975; and the Northern Works completed in 1969. These are conventional works discharging treated final effluents to the Mgeni River, and are therefore outside the scope of this monograph which is primarily concerned with the microbial water quality of the marine environment off Durban. However, the Mgeni itself bears fluctuating pollution loadings which originate for the most part upstream of Durban, and which affect the surf-zone near its mouth (Station 1) depending on the state of the tide and longshore currents.

1.3.1 The submarine outfalls

Rapid industrial and municipal expansion was envisaged by the Durban City Council in 1964, and a programme was initiated to reticulate the whole of the city, to develop and upgrade the trunk sewer system to cope with expected future loadings, and to study the feasibility of constructing stable submarine outfalls for the efficient and safe discharge of domestic and industrial wastewater to sea (Macleod, 1972). With much of the central catchment area already sewered and draining to the Point, the city secured the old whaling station site on which to build the Central Works, to eventually treat 135 x 10^3 m^3/day of waste water. The works for the southern catchment area was constructed on the north bank of the Mlaas Canal to provide treatment for the effluent which, it was estimated, would reach 230 x 10^3 m^3/day - this plant was designated the Southern Works (Macleod, 1981).

It was believed a pair of meticulously researched, responsibly managed and rigorously monitored submarine outfalls serving these works would provide an efficient ocean disposal system for their respective effluents. The base of the Central Works Outfall (CWO) was to be situated near Station 10

(Fig. 1), and that of the Southern Works Outfall (SWO) close to Station 19 near the mouth of the Mlaas Canal, both pipelines to be constructed approximately at right angles to the coast (Macleod, 1981).

Design calculations based on detailed oceanographic data indicated that a pipeline 4 km in length at a site near Station 19, with a diffuser section measuring 420 m, would provide a minimum dilution of 1 000 at Station 15, allowing for an onshore current frequency of 5% in the vicinity (Anderson, 1967). With increased discharge as the outfalls attained their designed capacities, increased diffuser port velocities and, consequently, increased dispersion could be expected (Macleod, 1981).

The two submarine outfalls were assembled on the shore in sections, pulled out to sea and firmly anchored on the seabed - a signal engineering feat for a notoriously turbulent and dynamic coast with its high-energy oceanic characteristics.

The SWO started to discharge on 22 November 1968; and the CWO a year later on 24 November 1969. By March 1980 both outfalls had attained approximately 50% of their designed capacities (Livingstone, 1982). Depending on vagaries of the weather (bearing directly on stormwater flows) and private sector efforts to economize on water consumption, this percentage has hovered between 40% and 50% to date.

1.3.2 Orientation and direction of the microbial study

By 1964, oceanographic investigations in the area were well under way, and chemical and faunal studies had recently commenced along the coast between the Mgeni and Sipingo Rivers. In that year, exploratory bacteriological testing of the beaches, beach and surf-zone pipes, and of the various city-generated effluents started. A fairly extensive array of bacterial species were investigated and, eventually, a system of classifying the water quality was evolved from a selection of these.

Twenty-eight sampling stations were sited along the coastline and the water quality of the surf at each station measured and classified. A grid of sea-sampling stations was also charted proximate to the end of each planned outfall where the seawater and sediments were assessed to establish baseline criteria prior to the commissioning of the pipes. A stage had been set which presented a unique opportunity for comparing before and after water quality conditions as a major industrial city, harbour and resort changed over to the new ocean disposal system.

Since no precedents existed, the bacteriological findings were to be regularly submitted to a Steering Committee consisting of the Medical Officer of Health, the Regional Director of State Health, private pathologists (including the Director of the Institute of Parasitology), the City Engineer, representatives of the Department of Water Affairs, agents and delegates of various interested bodies in Natal and the Cape (including a local anti-pollution body), and CSIR Directors and colleagues. Despite inevitable personnel changes due to deaths, retirements and modified designations (particularly of government departments), this Committee exists to the present day and exercises a participatory role in the continued scrutiny of the surf off Durban.

At the time, as occurs now, the prevailing indicator employed for assessing sea pollution was the "faecal" or thermotolerant coliform (presumptive *Escherichia coli*) (McKee and Wolf 1963; Lusher, 1984). The Steering Committee, in 1964, expressed reservations regarding this solitary indicator organism or group of organisms providing the sole criterion for the detection and assessment of degrees of pollution in the marine environment at Durban. An offer was therefore made to extract from the presumptive figures the actual *Escherichia coli* I index; to examine a range of possible corroborative indicators; and to include the salinity as a physical measurement providing an evaluation of dilution of the sea by terrigenous water. To this the Committee agreed; and, eventually, a selection of microbial indicators and the salinity were yoked together into a system of seawater classification depending on the values accorded them. The system comprises adverse scoring for the *E. coli* I numbers, and the presence of staphylococci, salmonellae, shigellae, parasite ova, and the salinity if it is depressed.

It could be argued that the extended microbial spectrum of the envisaged investigations contravened William of Ockham's hallowed scientific precept or "razor" from the 14th Century: *non sunt multiplacanda entia praeter necessitatem* ("entities are not to be multiplied beyond necessity") (Anon, 1986). However, at the time, it was not known which entity or combination of entities (ie: indicators) best served the intended purpose: to detect sources of pollution and to ascertain if possible the degree of their impingement on the marine environment, thus qualifying as necessities. This composite testing was essentially of an exploratory nature before its evolution - after selection - into an authentic measuring tool. Having arrived at the present system that provenly works, or at least provides useful gradations of seawater diluted by domestic effluent, the question arises: can this measuring tool be simplified, is it possible to reduce the number of entities while retaining the system's proven efficiency? A solution is outlined in Chapter 6: CONCLUSIONS AND EXTRAPOLATIONS.

After the original publication of the system of classification employed at Durban (Livingstone, 1969), several authorities worldwide initiated their own multiple indicator systems culminating in the European Economic Community's directive (Commission of the European Communities, 1976) which included faecal streptococci - an indicator examined and discarded in the Durban work (see Chapter 3: INDICATORS AND METHODOLOGY). The EEC directive is influenced by dubious notions of "health hazards", which is not the case at Durban (Mackenzie and Livingstone, 1983).

The overall objective of the local investigation was to establish the prevailing microbial flora in the surf-zone against which changes wrought by the forthcoming submarine outfalls method of waste disposal could be assessed. The system of measuring and classifying seawater is still in use as it has proved most serviceable in evaluating changing circumstances on the shore and alterations in the nature of the underwater discharges. Some amplification of the principles underlying this overall objective follow:

1. The Durban work is designed to trace sources of pollution and to measure degrees of pollution in the marine environment; no claims are made for real or potential "health hazards" - the assessment of such being regarded as the prerogative of the City Medical

Officer of Health when informed of the microbial facts and in the light of parochial epidemiological trends. (The question of "health hazards" is examined in Chapter 5: MARINE POLLUTION AND ASSOCIATED RISKS.)

2. The Durban work is designed for local conditions: specifically, between the Mgeni River and Isipingo; it is not advocated as being universally applicable. For example: parasite ova in the northern hemisphere may have limited value as indicators when compared with the southern; although, with the present flood of immigration from the south to Europe, the indicative role of parasite eggs in the sea may well have to be reassessed in northern coastal waters fairly soon.

3. The inclusion of salinity, as in the Durban work, has not yet become part of the modalities tested elsewhere in the world, presumably because not even the most committed has characterized a reduced salinity as a "health hazard"; yet a markedly reduced salinity is possibly a better indication of potentially hazardous marine waters than the most exhaustive catalogue of pathogens.

It can be added, this system of water classification has been applied successfully to the surf at Port Elizabeth (Livingstone, 1969); it is proving useful in environmental impact surveys at Richards Bay (Livingstone and Calder, 1985, 1989), and has been adapted and applied for use in monitoring the coast in the vicinity of Cape Town (Tredoux and Engelbrecht, 1989).

To conclude this section, the environmentally oriented measurements involving microorganisms that do not occur naturally in the sea have been, wherever feasible in this work, related to the physical reality of shore-based sanitary features and/or meteorological events. There cannot be a sudden bloom of escherichiae, for example, in an aquatic coastal area in the absence of a pipe, a waterway or other polluting source, or a rainstorm washing terrigenous detritus into the proximate marine environs. For this reason, the effort has been made throughout this monograph to provide reasonable linkage between any downgrading of the water classifications and shore-based features or weather events. As it is, this quarter-century of microbial surveys fortuitously encompassed climatic extremes of drought, cyclones and Natal's catastrophic flooding in 1987, and consequently provides a singular historical record of sea conditions - particularly the related microbiological conditions - at the Durban coast between 1964 and 1988. A chronology of events that have influenced the water quality of the sea off Durban during the period under review is presented in Table 1.

TABLE 1

Chronology of developmental and meteorological events

1962	Start of sea-current studies
1964	Start of microbial studies
1968	3 March: 106,1 mm rain
	22 November: Southern Works Outfall (SWO) starts to discharge
1969	May: floods; 170,5 mm (monthly mean: 55,9 mm)
	24 November: Central Works Outfall (CWO) starts to discharge; sewer at harbour mouth (Station X) stopped
1970	May: mechanical failure at Central Works (CW); untreated effluent from CWO; minor sewers between Stations I and X stopped
	July: shore-based sewer breaks in the vicinity of the Mlaas Canal
1971	May: floods; 227,1 mm (monthly mean: 55,9 mm); CW repaired
	July: heavy rainfall; 117,3 mm (monthly mean: 38,1 mm)
	October: shore-based sewer breaks repaired; sugarcane by-products and other factory effluents diverted into SWO
1974	4 February: 100,1 mm rain
	11 March: 94,0 mm rain
1975	11-13 February: 140,1 mm rain
	October: whaling factory at Station 12 closed; minor sewers in the vicinity stopped
1976	March: floods; 396,7 mm (monthly mean: 122,4)
	2-3 October: 86,2 mm rain
1977	6 February: 143,5 mm rain
	4 March: 157,9 mm rain
1978	14 March: 147,8 mm rain

Table 1 continues

Table 1 continued

1979	February: Finnemore Place sewer (between Stations 12 and 13) stopped
	December: drought starts; water restrictions commence
1980	7-8 September: 88,7 mm rain
	14 October: modified effluent (sludge reintroduced to settled sewage) starts from CWO
1981	2 February: modified effluent stops from CWO
	10 June: modified effluent starts from CWO
	August: floods; 252,2 mm (monthly mean: 63,7 mm)
1982	February: drought severity intensifies; more stringent water restrictions implemented
	14 June: modified effluent starts from SWO
	25 June: modified effluent stops from CWO
1983	31 May: modified effluent discharge as an experiment ends
	July rainfall: 131,2 mm (monthly mean: 38,1)
1984	January and February: cyclones Domoina and Imboa impact on Natal; drought ends; water restrictions lifted
	July rainfall: 133,1 mm (monthly mean: 38,1)
1985	February: floods; 360,8 mm (monthly mean: 112,5 mm)
	30 October: 105,0 mm rain
1986	18 January: 110,0 mm rain
	28-29 August: 104,6 mm rain
1987	September: Natal Floods; Mlaas Canal mouth breaks and changes position 250 m northwards; Southern Works (SW) landline breaks
	November: SW landline repaired
1988	8-9 March: 197,2 mm rain

1.4 THE APPENDIX

Data that may be useful for comprehending the assemblage of results but which may impair the momentum of this monograph have been transferred to the Appendix.

1.5 PHILOLOGICAL NOTE

Before considering the physical aspects of the region studied, and in order to avoid possible ambiguities in interpretation, the meanings of the following words used in this text are here defined and standardized:

Inshore:	0 to 1,0 km seaward from the shore
Offshore:	>1,0 km seaward from the shore
Longshore:	along the shore
Onshore:	towards the shore

(The nebulous terms "near-shore" and "foreshore" have been eschewed for clarity.)

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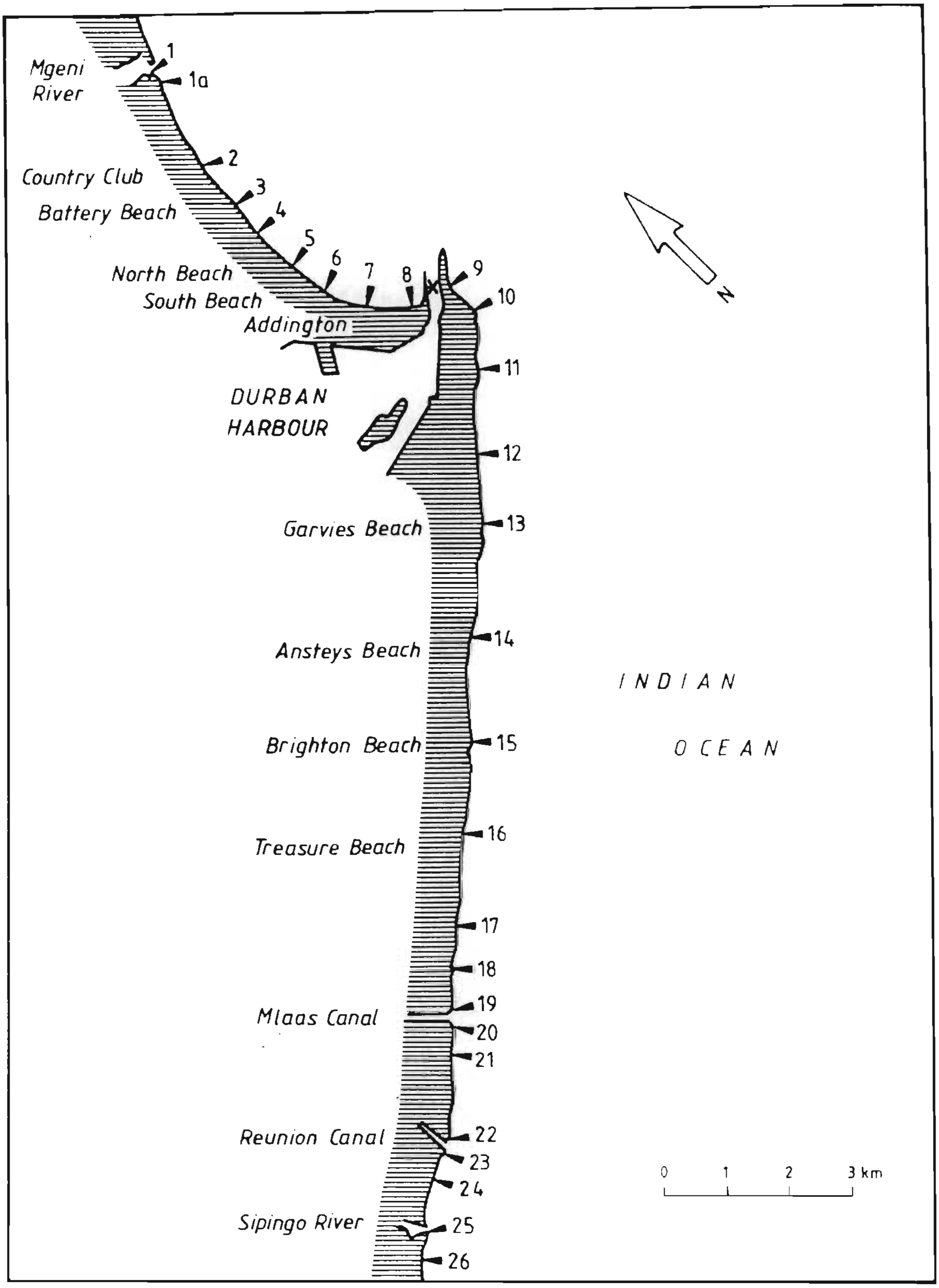

Fig. 1. Durban beaches and the locality of the surf sampling stations. (Station X, between Stations 8 and 9, is the site of the harbour-mouth discharge which stopped in November 1969.)

CHAPTER 2 : PHYSICAL CONSIDERATIONS

2.1 CLIMATE

The Natal coastal belt which lies approximately northeast/southwest has a humid subtropical climate with a warm summer. (The latitude meridian 30°S and that of 30°E longitude intersect in southern Natal.)

2.1.1 Sunlight, temperature, wind and pressure

Sunlight has a lethal effect on bacteria suspended in shallow layers of clear seawater - the closer the sun approaches the vertical, the deeper its rays penetrate (ZoBell, 1946). This property does not extend to depths exceeding 200 mm, the penetration decreasing with wave-length: ultraviolet radiation is less penetrative than the visible spectrum as a whole (ZoBell, 1946). The hours of sunlight recorded over a period of ten years ranged from 7,4/day in May to 5,2/day in October (Hunter, 1988).

Maximum and minimum temperature means range from 28°C to 11°C, with recorded extremes of 42°C and 2,8°C; temperatures above 30°C occur less than 30 days per annum (Hunter, 1988).

South of Durban, southwesterly and northeasterly winds are roughly balanced in frequency; to the north, northwesterly winds predominate. Anderson (1967) in his resume of the early work in the region noted that analyses of surface currents in terms of the geostrophic winds showed a good correlation between north-going currents and north-going winds, but no correlation between south-going winds and current direction. No satisfactory correlation between onshore currents and wind could be determined.

The average atmospheric pressure at sea level is 992 mb with a maximum of about 1 040 mb (Hunter, 1988).

2.1.2 Precipitation

The mean annual precipitation from 1964 to 1988 measured at Durban by the

Louis Botha Meteorological Office was 1 000,72 mm. In winter, monthly precipitation figures are typically 30% less than the summer rains which fall mainly between November and March.

When the Agulhas Current with its attendant banner of cumulus cloud veers into closer proximity to the coast, increased rainfall is not uncommon, the winds bearing rain being usually southwesterly, that is, against the Current. Clearly, the Agulhas Current is a major instrument in the natural orchestration of Natal's coastal climate.

2.1.2.1 Floods

Although tropical cyclones are rare, two such cyclones - Domoina and Imboa - impacted on the Natal coast in January/February 1984 within a fortnight of each other causing major flooding and wave damage.

Towards the end of September 1987, a cold front (low pressure) followed by an extremely high pressure system influxing moist air reached Natal where it lingered for four days. This resulted in catastrophic floods - hereinafter designated the Natal Floods - which inundated much of the coastal region, damaging the infrastructure of bridges, roads and railways. The beaches became untenable: carcasses, tree trunks and riverine vegetation swept down the massively swollen rivers into the surf-zone. Much of this debris was washed ashore by wind, wave and tide to rot in alternating humid episodes of sunshine and more rain. The brown sea bore testimony to the probable fate of Natal's topsoil if the vulnerable terrain on the banks of water-courses continues to be exploited agriculturally, along with the drainage of swamps (Perry, 1989). Herculean efforts on the part of local authorities eventually cleared the beaches of detritus, but it required many weeks at Durban and several months elsewhere.

Annual rainfall for the 25 years under review is presented in Fig 2.1. It should be noted the picture is not straightforward: above average rainfall can be distributed over several weeks or months and this "spread" will not cause abnormal floods. For example: rainfall in

March 1976 measured 396,7 mm (average: 122,4 mm); an excess of 20 mm occurred on only five days, and these were spread from the 4th to the 27th March. Conversely, heavy precipitation concentrated in a few consecutive days will impact with marked effect on the region. The Natal Floods were caused by just such a phenomenon: between 26 and 29 September 1987, 303,9 mm rain were recorded (the September average is 71,0 mm) by the Louis Botha Meteorological Office, a comparatively sheltered weather station; 30 weather stations throughout Natal recorded precipitation in excess of 900 mm during the same period (Anon, 1989). Moreover, a year of so-called "normal" flood can be superimposed on a drought cycle, as in 1981 when the May rainfall was 136,9 mm (average: 55,9 mm) and in August was 252,2 mm (average: 63,7 mm).

The intensity of floods is reported in cumecs by engineers and hydrologists; for example, Hulley and Beaumont (1989) examining the flows of the Mgeni during peak levels during the Natal Floods, estimated the flow at 5 000 to 5 500 cumecs. Tracing historical records, they list two previous floods of similar magnitude: 1917, discharge estimated as 5 700 cumecs; and 1856, discharge estimated at between 6 000 and 14 000 cumecs. However, the 1987 flow was attenuated by the Albert Falls, Midmar and partially completed Inanda Dams; using reverse routing techniques, the corrected figure for 1987 (to compare with 1917 and 1856) is between 6 350 and 6 850 cumecs. The return period of such a flood is estimated at between 70 and 130 years, but if global warming proceeds apace, similar synoptic events may be expected more frequently. Floods causing damage occur naturally about once every two years in South Africa (Smith *et al.*, 1981), and, in the absence of hydrological expertise, it is here tentatively noted for the Durban region, after scrutiny of the Louis Botha Met. Office data, that flood years generally appear to result when annual rainfall is in excess of 1 100 mm (average is about 1 000 mm), and floods *per se* during months when precipitation is three times the monthly average or more.

Flood episodes can reduce the salinity inshore affecting the water quality of the marine environment temporarily, or - in the case of the Natal Floods - for weeks (see Chapter 4 : RESULTS AND DISCUSSION).

In any event, the silt-laden appearance of the brown-stained surf aesthetically discourages sea bathing.

2.2 OCEANOGRAPHY

2.2.1 Temperature, salinity and specific gravity (SG) of seawater

The temperature of the sea surface offshore from Durban varies between 26°C in summer and 21°C in winter (Carter, 1977). In the surf-zone, observations by the author among others have revealed temperatures of 17°C and even less, probably caused by the upwelling of colder shelf layers driven ashore after surfacing, under the influence of prolonged northeasterly winds (Connell, A D, pers. comm.*).

Measurements since 1964 have shown that the salinity (measured as conductivity) of undiluted seawater along the Natal coast is invariably in excess of $35^{\circ}/_{\circ\circ}$.

The SG (in g/cm^3 at 20°C) of undiluted seawater off the coast is 1,0252 (Russell *et al.*, 1983a).

2.2.2 The Agulhas Current

The flow of the sea off Durban is dominated by the south-going Agulhas Current which has as its sources water from the Mozambique Channel and from the Indian Ocean east of Madagascar. The Agulhas Current is a western boundary current recognized as one of the world's major ocean currents with its core about 20 km to 60 km offshore, and with a mean width that can attain 100 km at times. The core of the current meanders about 15 km to either side on average, and these fluctuations can reach 30 km and more from day to day. Using satellite tracked buoys, Grundlingh (1977 and 1979) showed the marked variation in the Current's meanders. These perturbations are probably due to a combination of seabed topography primarily, and atmospheric forcing (Schumann, 1988).

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The different topography to the south and the subsequent movement of the Agulhas Current towards the coast results in the existence of a semi-permanent cyclonic gyre off Durban, and the flow on the shelf is generally northwards (Schumann, E H, pers. comm.*). During its journey to the Cape the Current spins off gyres which measure 10 km to 20 km across, although they can attain a diameter of 100 km. These pulsed gyres initiate the mainly north-going longshore currents, while the gyres themselves are gyrating south at 21 cm/sec (Lutjeharms and Roberts, 1988). In addition (see Fig 2.2), vortex shedding occurs in the Natal Bight in the vicinity of the Tugela River mouth, the so-called Natal Pulse which moves south down the coast at about 20 km/day, growing in diameter, enclosing cyclonic cold-core eddies (Lutjeharms and Roberts, 1988; Lutjeharms and Connell, 1989). It has been postulated that these "pulses" probably originate from friction between the Agulhas Current and its proximity to the coast, starting as lee eddies trapped between the shore and the Current, their rotation vigorously impelled by the latter, causing cyclonic vortices west of the main flow. It is feasible that the rapidly widening available space in the vicinity of the Tugela mouth affords relatively negative lateral pressure, a relaxation of the enforced channelling north of the Natal Bight, allowing the initiation of the precursor eddies. It is not impossible that the Natal Pulse is a detached gyre, a more self-contained product of the whole Agulhas system off Natal. ("Natal Pulse" appears to be an inappropriate label: perhaps "Natal Vortex" more accurately describes the helical appearance of the kinetic structure involved).

2.2.3 Ocean currents in the vicinity of the outfalls

(This section adapted from Russell *et al.*, 1983a)

Detailed current measurements were made to monitor the ocean's movements in the vicinities of the Central and Southern Works Outfalls. The calibrations were used to correlate past and present environmental surveys with actual current occurrences, to determine the predominant directions near the seabed, and to confirm the ocean current data originally used in the design of the pipelines.

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The deep currents 5 m above the sea-floor were measured at the CWO in about 65 m depth of water from July 1981 to July 1982, and at the SWO about 50 m deep from July 1982 to May 1983. Surface currents were measured by visual observations and photographs using a graduated telescopic camera focused on surface current buoys moored in water 35 m deep, distanced between the outfalls.

Analyses of the current records confirmed that the ocean currents in this area were predominantly north-going, parallel to the shore (see Table 2.1). Near the CWO, approximately 12% of the recordings showed onshore directions (WNW, NW and NNW), but only 1,2% exceeded 0,2 m/s. Near the SWO, approximately 6% showed onshore movement, only 0,2% exceeding 0,2 m/s. A schematic diagram of current direction and frequencies is presented in Fig 2.3 (more detailed depictions appear in the Appendix: Figs A2.1 and A2.2).

TABLE 2.1

Characteristics of the ocean currents in the vicinities of the outfalls: directions, frequencies and velocities; 3 km offshore and 5 m above the seabed

	CWO	SWO
North-going (NNE, NE, ENE)	42%	43%
Offshore (ESE, SE, SSE)	11%	19%
South-going (SSW, SW, WSW)	16%	16%
Onshore (WNW, NW, NNW)	12%	6%
Maximum velocity	0,9 m/s	0,9 m/s
Average velocity	0,2 m/s	0,2 m/s
Velocities >0,1 m/s	78%	76%
Onshore velocity >0,2 m/s	1,2%	0,2%

All velocities >0,5 m/s were north-going

These calculations compared favourably with Anderson's (1967) compilation which reported: 5% onshore frequency would occur at Station 15 (Brighton Beach) with a 4 km pipeline at Station 19 (near the mouth of the Mlaas); and that at all other areas the frequency would be less (see Fig 2.4).

2.2.4 The longshore currents

Measurements over a number of years have confirmed the general (65% of the time) northwards flow of the longshore currents along this section of the coast. Periodic fluctuations are superimposed on the system: changes in current direction occur with weak onshore/offshore components during the transitions, the periods varying from two to ten days (Schumann, E H, pers. comm.*). These changes in longshore current direction can obviously influence the transport of indicator organisms along the beaches (see Fig 2.5 adapted from Livingstone, 1969).

Current velocities near the seabed off Durban are lower than at the surface by a factor of 0,3 to 0,4; but these remain dynamic enough: sediment movement resulting in undermining of the submarine outfalls has had to be countered by draping mesh over the pipes to trap the itinerant sand (Connell, 1988).

In the Durban Bight itself (see Fig 2.2), a counter-current in its turn can form, possibly from the break in the coastline north of the Bluff allowing further eddy shedding, causing the flow along the main bathing beaches to move occasionally southwards (Schumann, 1988).

2.2.5 The surf-zone

Surf-zone systems tend to be "closed eco-systems", and although substantial mixing occurs within these, exchanges of new seawater from beyond the breaker-zone takes place relatively slowly (Lord *et al.*, 1989). For this

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reason, the discharge of effluent into the surf-zone, or into rivers and estuaries that flow into the surf-zone, is worthy only of unreserved condemnation. And it is for this reason that the City of Durban sealed off all its surf-zone discharges after constructing the pair of deep-sea outfalls to carry its wastewaters efficiently out to sea with minimum impact on the marine environment and on the beaches in the region.

The surf-zone itself is dominated by wave action: wave height is normally one to two metres, and wave approach is somewhat oblique 50% of the time. Rip-currents occur about 40% of the time, but these rarely exceed 100 m in length seaward of the surfzone (Stander *et al.*, 1967; Oliff *et al.*, 1969; Oliff and Addison, 1970).

2.2.5.1 Tides

Means of the tidal ranges at Durban are

high-water springs:	1,96 m
low-water springs:	0,24 m
high-water neaps:	1,35 m
low-water neaps:	0,85 m;

with high-water springs maxima of 2,30 m occurring on occasion. (Heights are metres above Chart Datum, the datum of soundings of the largest scale navigational chart pertaining to the area.) Abnormal meteorological and celestial conditions can affect these levels (The Hydrographer, 1988).

2.2.5.2 Chlorination

In considering surf-zone discharges, the "chlorine option" warrants some discussion. Chlorination kills the majority of infective micro-organisms: the practice is universally applied to make domestic water supplies safe. However, in the case of effluents, chlorination can produce lifeless environs in the area of discharge, adversely affecting the ecology in the neighbourhood (Capuzzo *et al.*, 1976; Capuzzo *et al.*, 1977; Goldman and Davidson, 1977); and, in the case of estuarine or river discharge, killing or damaging the adjacent zones of riverine flora with attendant vulnerabilities to the integrity of banks and soil in the event of flooding.

An efficient disposal system should render chlorination redundant and unnecessary in the interests of environmental protection.

2.3 THE SUBMARINE OUTFALLS

Ocean outfalls are used for waste disposal mainly because of the very large dilutions which can be achieved in the sea. The initial dilution is dependent on the water depth and the design of the diffuser section. Further dilution occurs during transport of the waste by currents; and further dispersion is effected by the turbulent action of wind and oceanic waves on any surfaced material.

As referred to in Chapter 1 : INTRODUCTION, the pair of submarine outfalls constructed at Durban commenced with the discharge of screened and settled sewage: the Southern Works Outfall (SWO) draining the southern catchment from November 1968, and the Central Works Outfall (CWO) serving the central catchment area from November 1969. The bases of the pipelines are at Stations 19 and 10 respectively (see Fig 2.4).

2.3.1 Hydrographic data on the outfalls

These appear in Table 2.2 (adapted from Livingstone, 1983).

TABLE 2.2

Hydrographic data on the Durban submarine outfalls

	CWO	SWO
Length (km)	3,201	4,198
Main diameter (m)	1,23	1,37
Number of diffusers	18	34
Length of diffuser section (m)	421,8	421,8
Diameter of diffuser section (m)	0,76	0,92
Depth of diffuser section (m)	48 - 53	54 - 64

2.3.2 Discharge flow-rates

Officially, the designed capacities of the Central and Southern Works and their adjacent outfalls in $m^3 \times 10^3$/day are 135 and 230 respectively, and these are the limits presently permitted by the Department of Water Affairs. (All figures quoted in this section: Richardson, G W, pers. comm.*) However, subsequent hydraulic calculations have shown that maxima of 205 and 345 respectively are theoretically attainable. The average daily rate of discharge from the outfalls is presented in Table 2.3 (flows from 1969/70 to 1978/79 are estimated).

Clearly, the outfalls are operating presently at about half of their designed capabilities; and with no measurable harmful effects on their marine surrounds (McGlashan and Macleod, 1986). In fact, video taping at depth along the lengths of each submarine pipeline visually reveals the richness and abundance of marine fauna in their vicinities, and of marine flora growing on both structures, even upon the diffusers.

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TABLE 2.3

Annual (1 July to 30 June) average daily effluent discharge from the Durban submarine outfalls, and as percentages of their respective design capacities (d.c.)

Year	CWO		SWO	
	$m^3 \times 10^3$/day	% of d.c.	$m^3 \times 10^3$/day	% of d.c.
1969/70	107	79	58	25
1970/71	115	85	79	34
1971/72	106	79	104	45
1972/73	100	74	105	46
1973/74	84	62	106	46
1974/75	85	63	105	46
1975/76	82	61	86	37
1976/77	79	59	99	43
1977/78	78	58	109	47
1978/79	76	56	115	50
1979/80	71	53	114	50
1980/81	66	49	131	57
1981/82	70	52	136	59
1982/83	62	46	113	49
1983/84	49	36	92	40
1984/85	53	39	103	45
1985/86	56	41	107	46
1986/87	55	41	112	49
1987/88	62	46	119	52
1988.07.01 to 1988.12.01	60	44	118	51

2.3.3 The experimental discharge of settleable material

Prior to October 1980, only effluents after primary treatment were discharged through the outfalls. (Primary treatment consists of the removal of screenings and grit along with floatable and settleable material - the last commonly referred to as "sludge" - for separate disposal.) Owing to rising costs of land disposal and the diesel fuel required for incinerating sludge the effluents were partially reconstituted by the re-addition of the settleable fraction. These experimentally modified discharges were intensively monitored for two years with particularly successful results. In each pipeline, the average sludge solids concentration of the modified effluent constituted 0,64% of the total flow (National Institute for Water Research and National Research Institute for Oceanology, 1984). (Fig A2.3 in the Appendix shows in diagrammatic form the modifications made to the Works.)

2.4 DILUTIONS

2.4.1 Physical dilutions and computer modelling

(Data in this section were summarized from Russell *et al.*, 1983b)

Dispersion of an effluent is dependant on the physical parameters involved: the density difference between the receiving water and the waste, depth of the outfall, diffuser design and discharge rate, and the speed and direction of the currents.

The construction of Durban's pair of submarine outfalls was based on dilution calculations by Brooks (1959). For the sludge disposal experiment, the dilutions were recalculated using a series of mathematical models developed by Roberts (1977) during his investigations into the behaviour of a buoyant effluent discharged from a diffuser into a current. Dilutions were initially calculated on the basis of a buoyant jet discharging into stagnant receiving water. Calculations were also made of the effluent with and without the addition of sludge. Further studies were made to ensure there would be no separation of the sludge from the buoyant effluent which could influence the validity of the computations. The most relevant results are abstracted in Tables 2.4 to 2.7.

TABLE 2.4

Densities of seawater and of the discharges (g/cc) from the submarine outfalls

Seawater	1,0252
CWO: settled sewage (no sludge)	0,9991
mixed effluent	0,9992
SWO: mixed effluent	0,9989

TABLE 2.5

Dilutions obtained when a buoyant jet is discharged into stagnant receiving water

	CWO	SWO
Initial average dilution	294	341
Dilutions after hydraulic modelling:		
highest average dilution	372	450
lowest average dilution	235	249

TABLE 2.6

Dilutions relative to velocities of currents and their angles of intersection with the ocean outfalls

	CWO	SWO
Diffuser port flow (m^3/s)	0,032 to 0,063	0,03 to 0,074
Current velocities (cm/s)		
with no effect on dilution	<3,7	<4,6
increasing dilution 100%		
at 90°	7,4	9,1
at 45°	11,1	13,6
at 0°	22,1	27,3
increasing dilution 500%		
at 90°	18,4	22,7
at 45°	27,7	34,1
at 0°	55,3	68,2

TABLE 2.7

Buoyancy of sludge particles, their size and distribution

Diffuser port discharge velocity	0,9 m/s
Sludge particle rise velocity	<5 mm/s
Sludge particle size (um)	% distribution
<1 to 10	67
11 to 20	21
21 to 40	8
41 to 140	4

To summarize: a direct onshore current of 0,25 m/s at the SWO (see Figs 2.3 and 2.4) results in a minimum dilution of 2 000 in the surf at Station 19; and from the CWO a minimum dilution of 3 000 at Station 10. At all other stations the dilution would be greater. For current speeds >0,25 m/s the dilutions would increase due to increased vertical mixing through the water columns in the recipient waters. Dilutions actually achieved were far more favourable than the dilutions originally calculated for in the design of the outfalls. Moreover, when the design capacities of the pipelines are attained, dilutions should improve even further with the increased diffuser-port velocities (National Institute for Water Research and National Research Institute for Oceanology, 1984).

2.4.2 Dilutions calculated bacteriologically

Major causes of the decrease in terrigenous and sewage microbial populations in the sea are largely due to dilution, dispersal and sedimentation (Livingstone, 1978). Other factors probably play a part, eg: osmotic shock, UVL near the surface, predation and competition from indigenous microscopic marine biota, and possible antibiotic, bacteriostatic and bactericidal components occurring naturally in seawater. Chemicals and detergents included in an effluent prior to discharge could also kill or impair a proportion of the organisms, depending on contact times.

Nevertheless, using the calculation of the smallest *E.coli* I index (see Chapter 3: INDICATORS AND METHODOLOGY) in the sewage tested divided by the largest index measured as close as possible to the outfall diffuser section, some indication of the dilutions obtaining near the diffusers becomes feasible, and the following results were obtained by Livingstone and Calder (1983).

> From the Central Works: 6,88 x 10^6; and from d3 (see Fig 2.4) 12 480, or 13 800 at c3 (both at 48 m depth), a dilution of about 500 was apparent close to the diffusers.
>
> From the Southern Works final mix: 2,1 x 10^7; and from m3 (50 m deep): 10 400, a dilution of about 2 000 became evident near the diffusers.

In the light of the ocean dynamics of the region, and the dilution of the effluents that occurs near the diffusers, the possibility of contaminative bacteria reaching the shore across the intervening body of water from the outfalls in significantly measurable (or infective) doses after such dilutions, must be regarded as remote. The two submarine outfalls in the sea off Durban adequately fulfilled their engineering design during the controlled admixture of sludge to their respective discharges.

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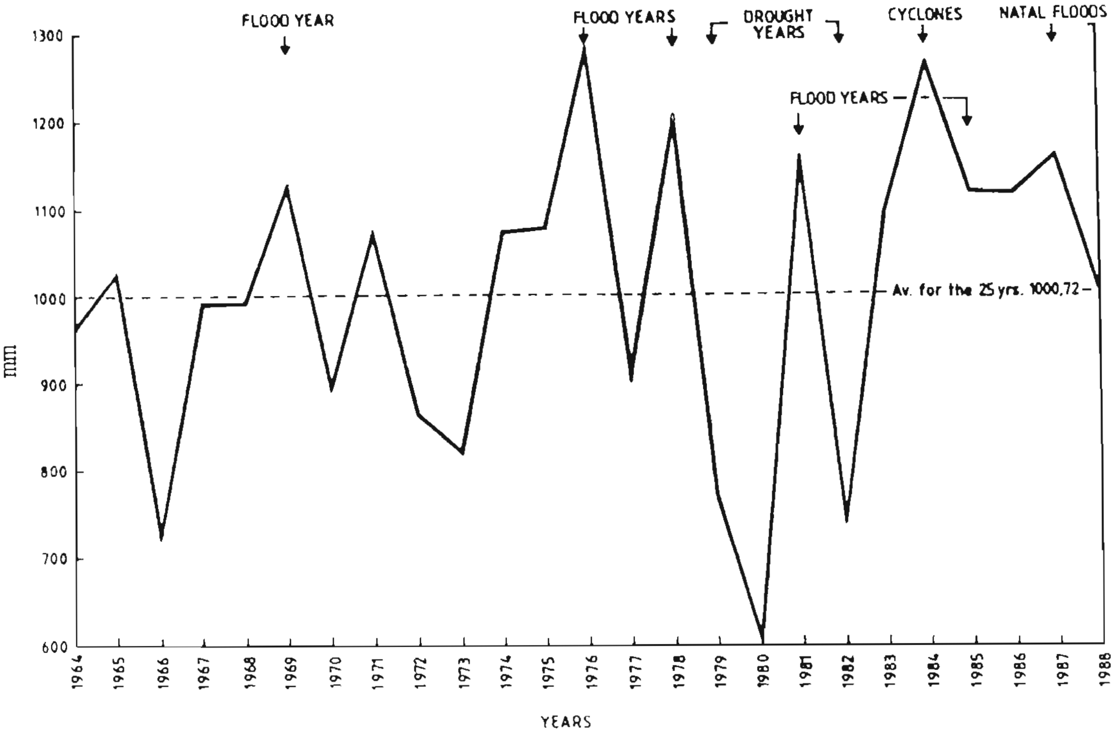

Fig 2.1 Annual rainfall (in mm) : 1964 to 1988, showing flood and drought years

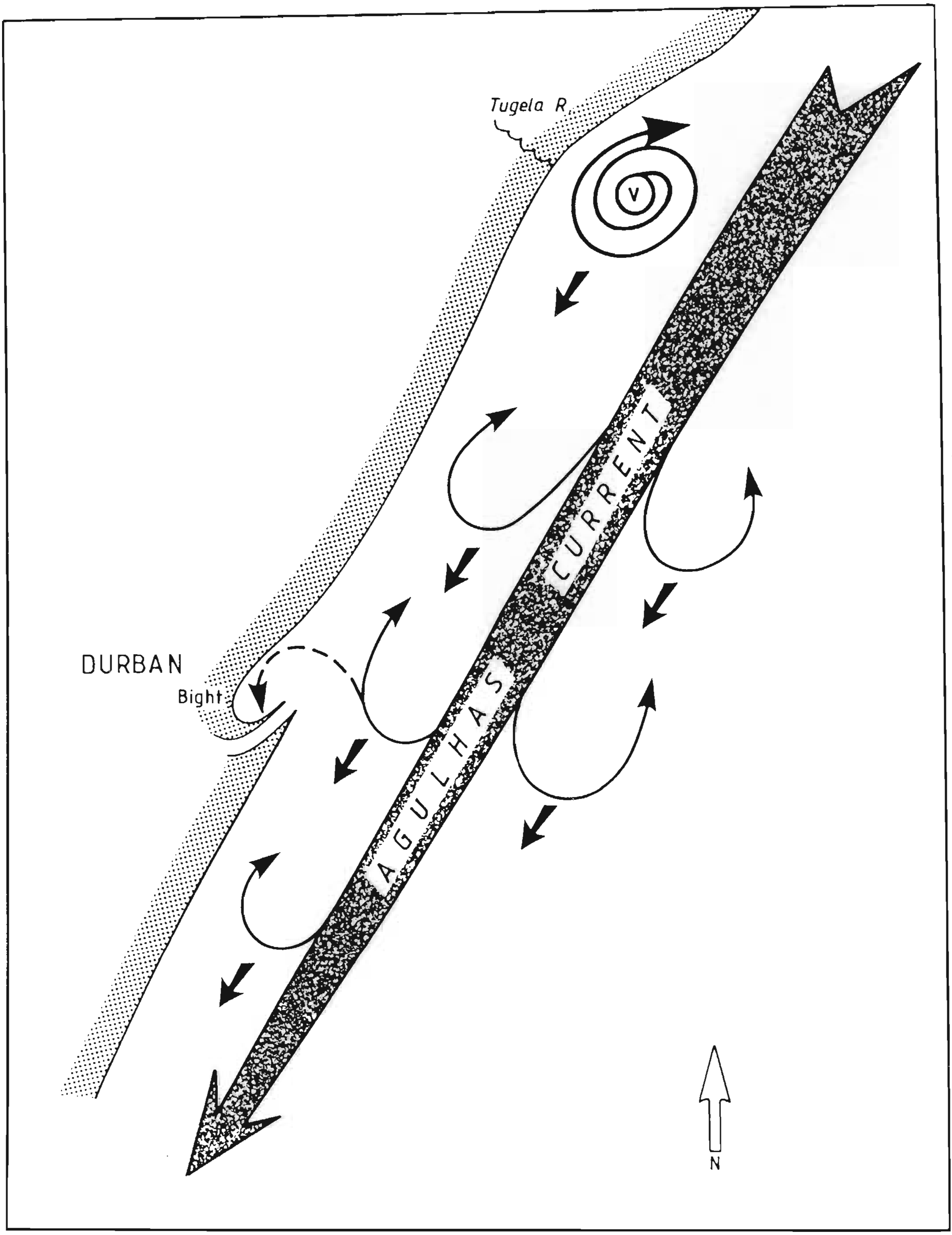

Fig 2.2 Schematic depiction of the Agulhas Current showing gyre shedding and a "sub-gyre" producing a counter-current in the Durban Bight; also, off the Tugela mouth, a Natal "Pulse" or "Vortex" (V).

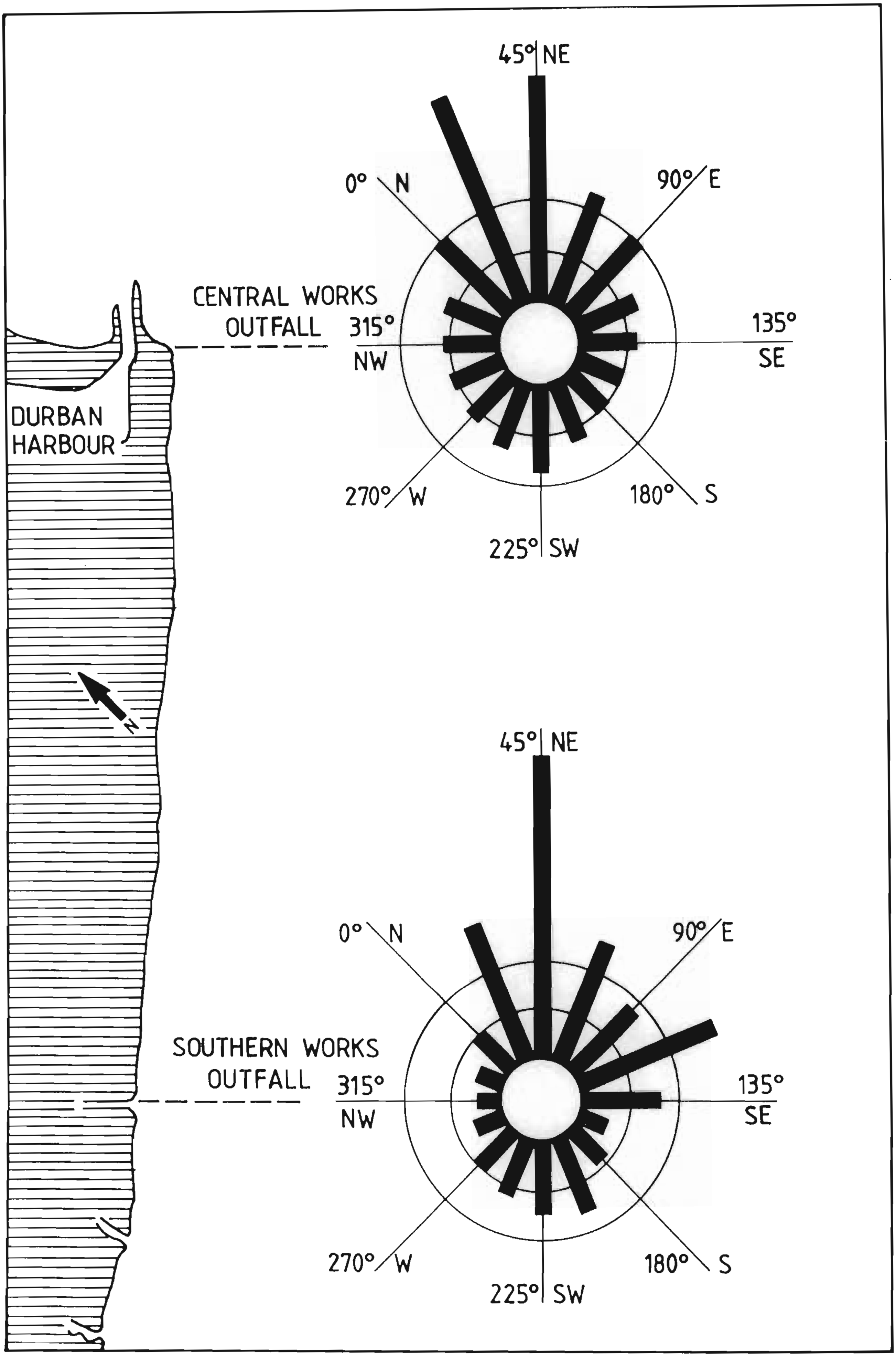

Fig 2.3 Schematic depiction of current directions and frequencies in the vicinities of the two outfalls

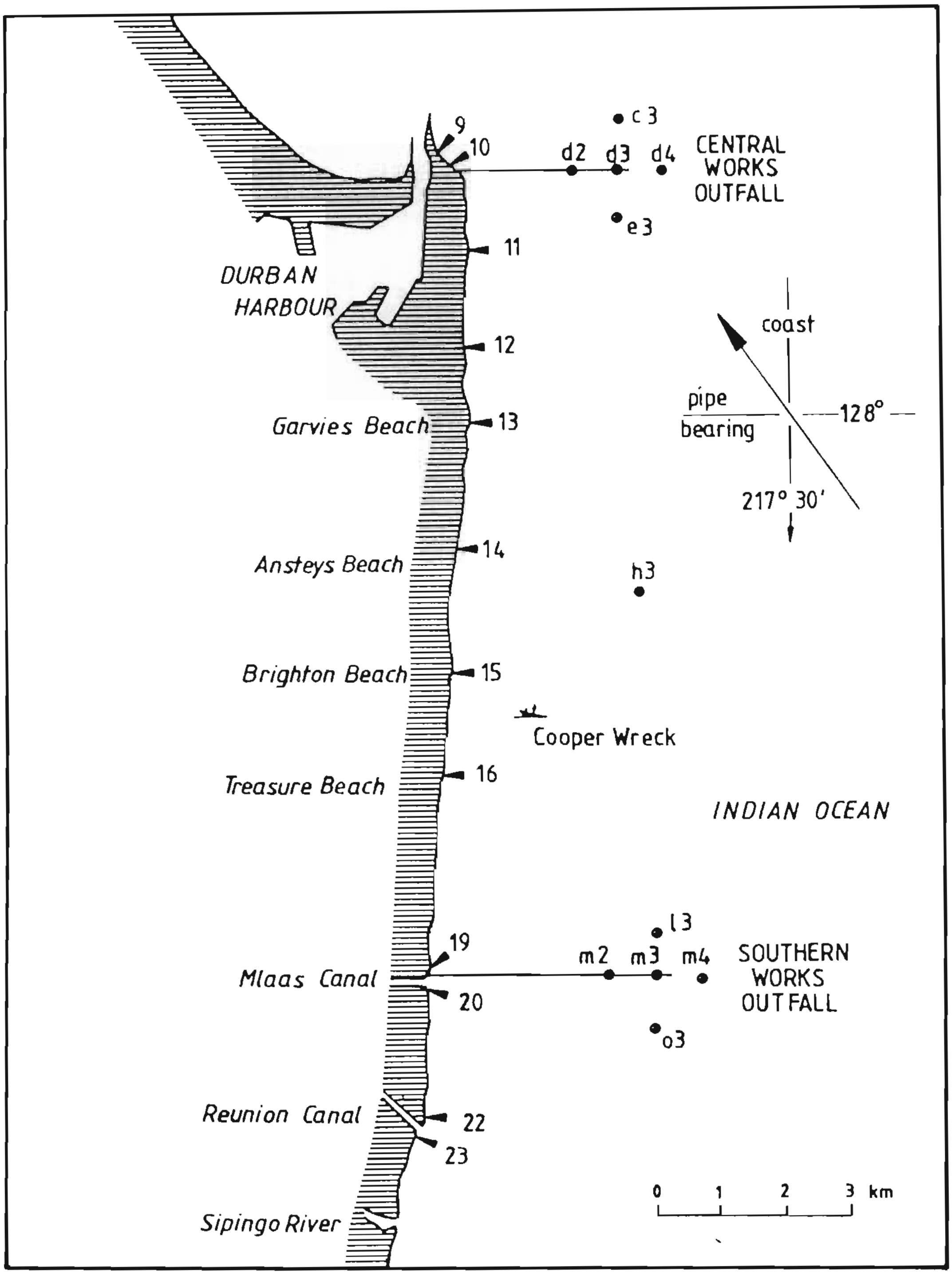

Fig 2.4 Map showing the location of the two submarine outfalls, and the offshore and beach sampling stations for the modified effluent discharge

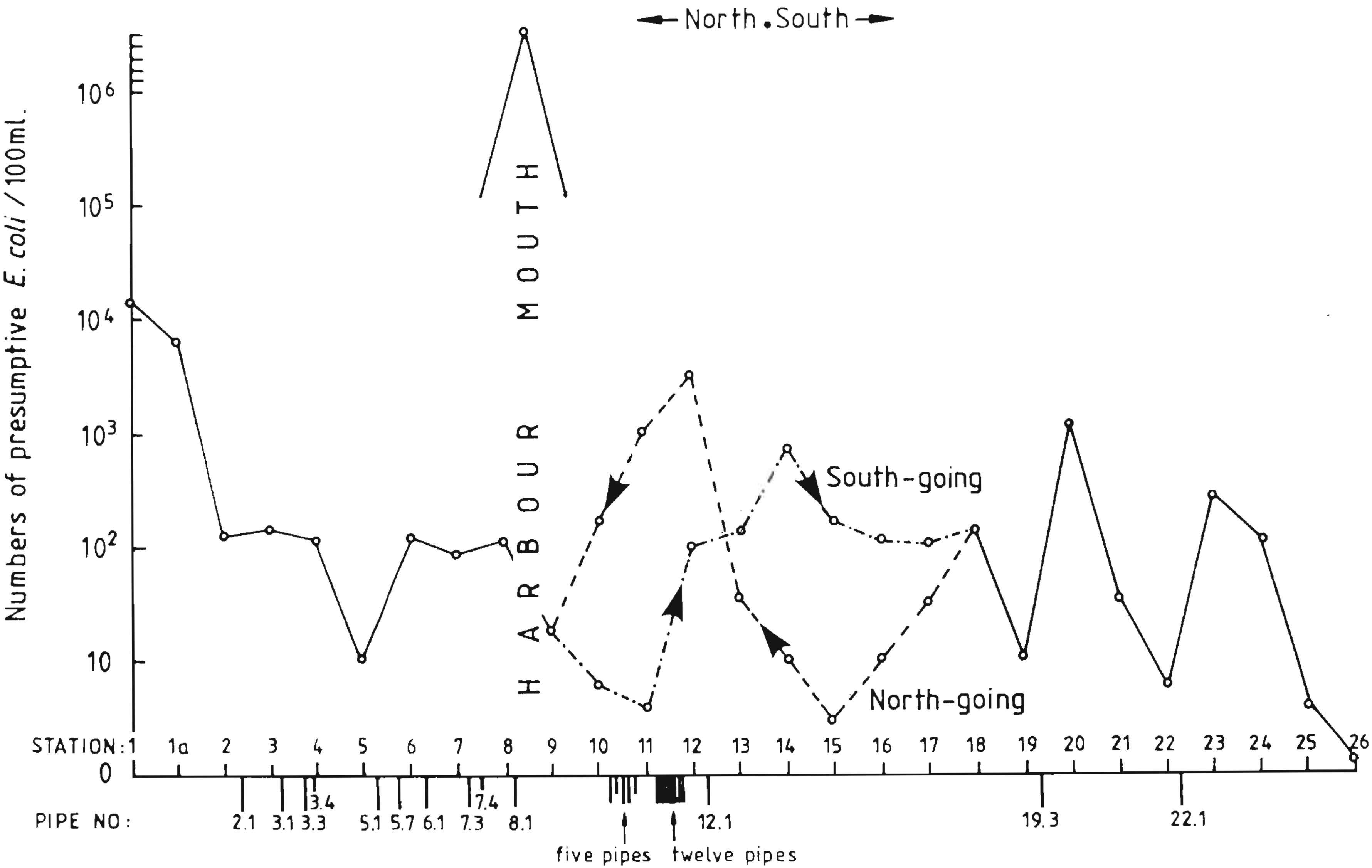

Fig 2.5 Presumptive *E. coli* (or thermotolerant coliforms) during an observable current reversal between Stations 9 and 18: <— — — north-going current; —·—·—> south-going current. (The approximate location of contaminated pipes, stormwater and other drains, and canals is included; Pipe No. 12.1 was a suburban sewer discharging into the surf-zone.)

CHAPTER 3 : INDICATORS AND METHODOLOGY

3.1 DOMESTIC EFFLUENT INDICATORS: AN OVERVIEW

The selection of microbial indicators to measure seawater quality, particularly the impact of domestic wastewater discharges, is based on the principle of determining the incidence of allochthonous bacteria (transient organisms which are temporary sojourners in an ecosystem) in the sea.

The human gut is host to between 400 and 500 species of bacteria (Pownall, 1986), and it is generally recognised that there is no ideal indicator organism (Report, 1976; Geldreich, 1977; Waite, 1985). Coliforms are not confined to colons; indeed, Waite (1985) questions the whole concept and validity of total coliform numbers. However, as these organisms do not occur naturally in seawater, it could be argued that they provide an approximate indication of the invasion of the saline medium by terrigenous or fresh- (not necessarily sewer-) water.

Summarizing the findings of several workers, Prescott *et al.* (1946) concluded that 95% of coliforms in faeces are *Escherichia coli* I. Gastro-intestinal microbes thrive in the dark at a constant temperature of 37 °C, in a highly nutritious matrix. The average weight of moist faeces excreted daily by the average individual is 100-150 g, some 20-30% of which is composed of undigested food residues, the remainder of water and bacteria (McCoy, 1971). *E. coli* I is regarded as the most characteristic of the normal inhabitants of the healthy individual - their numbers approach 10^9/g of faeces. In fresh water, the time of survival of these organisms may be measured in weeks (Carrington, 1980); in seawater, the period has been measured in hours (McCoy, 1971) or longer, depending on circumstances. In general, 50-60% of the daily faecal load is present in the crude sewage between 06:00 in the morning and midday.

The ideal indicator-bacterium should occur in sufficient numbers and be relatively easy to detect and enumerate. It should not occur naturally in the milieu being tested (- *E. coli* I is excreted by most vertebrates including marine mammals and sea birds). It, or sufficient numbers of it should not be killed or rendered non-culturable too quickly in seawater. It should not be capable of proliferating or surviving too long in salt water (as is the case with *Vibrio cholerae* according to Lee *et al.*, 1982, and the clostridial spores). The bacteriological results should be fairly rapidly forthcoming (- viruses can take many weeks to culture and identify). The indicator-bacterium should preferably present no or little danger to laboratory staff involved in working with it. Although several other microbial candidates are put forward from time to time by their various advocates, and the list is growing, *E. coli* I most closely fulfills these criteria. The organism remains historically proven as the indicator of choice. Recognised as not without flaws, *E. coli* I is nevertheless universally accepted as a reasonably reliable index of sewage pollution in the marine environment, more so than any other microbial entity.

Because indicators are usually present in far greater numbers than the more dramatic pathogens, and because the demonstration of opportunistic pathogens often requires sophisticated techniques and manipulations, the presence of the indicators is frequently taken to infer the presence of the pathogens (ie: the attendant "health-hazard"). It is not always recognised that *E. coli* I - normally a commensal in the mammalian and avian bowel - is also a pathogen, being a common cause of urinary tract infections and a secondary invader of skin and tissue lesions, while some serotypes cause epidemic infantile enteritis among other pathogenies. (No difference has been determined between the incidence of these conditions at the seaside and inland.)

3.1.1 Objectives of indicator systems

In selecting a microbial measuring system for use in the sea, the aim should preferably be clearly defined:

1. If the detection of general increments of terrigenous water is required, the presumptive coliforms and the salinity should be monitored (- many of the coliforms occur in soil and natural freshwater, but not in undiluted seawater (Wilson and Miles, 1964)).

2. If the objective is to detect sewage pollution with some degree of its intensity, the *E. coli* I index scaled in orders of magnitude (ie: up to 10, 11-100, 101-1 000, >1 000 organisms per 100 ml) plus the salinity should be perfectly adequate. (The *E. coli* I count on most raw sewages ranges between 10^6 and 10^8; the salinity of undiluted seawater off the Natal coast is >35 $^o/_{oo}$.)

3. If the aim is water quality gradation or to establish a comprehensive background in a target area or to measure the more detailed aspects of coastal developmental impact and changes, the addition of other indicators can be considered, eg: including parasite ova, salmonellae, *Staphylococcus aureus*, etc with the *E. coli* I index and salinity may prove useful. (*S. aureus* occurs as a naso-pharyngal commensal in about half the healthy population according to Moore, 1971, is excreted by 25% of normal individuals - McCoy, J H, pers. comm.*), and is an organism commonly found in sewage (Wilson *et al.*, 1984)). This overall aim has been the objective of the present study.

4. In special cases such as epidemiological surveys, and if the considerable expense involved is regarded as warranted, viruses, mycobacteria, protozoan cysts, *Candida* yeasts, etc can be pursued by sophisticated staff in appropriately equipped laboratories (- it should be noted more than 30 species of yeasts are common in aquatic environments (McKee and Wolf, 1963)).

Work on the chemistry and fauna of the marine environment at Durban commenced prior to 1964 (Oliff *et al.*, 1967a, 1967b); however, no independent bacteriological base-line had been established against which to measure future changes consequent upon development. Effluent entering the sea at Station X was untreated apart from coarse meshing and primary settling in tanks while awaiting discharge with the ebb tides, and the waste from a number of pipes, stormwater drains and canals contributed to the seriously contaminated picture. At the time, as obtains today, *E. coli* I appeared to be the faecal pollution indicator of choice. At the

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time, as happens now, a number of claims for rival contenders for the role of prime indicator were - and are - put forward by various proponents and a selection of these are reviewed by Waite (1985). A fairly wide spectrum of supplementary indicators was therefore investigated in order to ascertain whether the *E. coli* I index could usefully be reinforced.

It may be of importance to note here that many, if not all, microbial indicators of pollution have "health hazard" connotations: most of these organisms if ingested or inoculated in sufficient numbers may cause disease providing certain conditions are fulfilled. This is unfortunate: the objective measurement of pollution, or of the efficacy of waste disposal systems is an independent discipline; excursions into the realms of "health hazards" with all the attendant complexities of epidemiology, minimum infective dosages, public health and specific pathognomies remain the prerogative of the medical profession, and could be regarded as strictly beyond the scope of the microbiology of effluents. While certain pathogenic characteristics of the various indicators examined here cannot be altogether ignored, no greater claim is made for these microbes than: if they are present in the sea, they are present in the adjacent human population; infectivity cannot be automatically claimed for such micro-organisms. (A detailed discussion on sea pollution and an evaluation of the risks appears in Chapter 5: MARINE POLLUTION AND ASSOCIATED RISKS.)

3.1.2 Investigation of indicators for this survey

As already mentioned, the most useful indicators should be not uncommon, and fairly rapidly identifiable by routine techniques. Also, the bacteria should not survive in seawater for an inordinate time or else their recovery from a site remote in space or time from their point of entry into the marine environment renders their role in pollution source detection valueless. For a list of indicators considered and discarded, with reasons for their rejection, see Table 3.1.

TABLE 3.1

Indicators tested and rejected in this survey

Rejected indicator	Comment
Bacteriophage of *S. typhi*	Several isolations made, but very rare.
Candida albicans	Yeast. Occurs in significant numbers only close to pollution sources. Can be microscopically confused with certain marine and freshwater saprophytes.
Clostridium perfringens	Anaerobic bacterium. Too ubiquitous in the soil and river waters of this coast. Spores are known to survive for months, even years, and can be transported to sites remote from source in high-energy coastal waters. Has been recovered three years later from the vicinity of a discontinued discharge.
Entamoeba histolytica	Protozoan. Morphological distortion of cysts occurs rapidly in seawater. Requires sophisticated cultural techniques.
Giardia intestinalis (*lamblia*)	Flagellated protozoan. (See comment for *Entamoeba*.)
Mycobacterium tuberculosis	Mycobacterium. Found only in the harbour-mouth sediments in this survey in the early 1960s. Requires sophisticated cultural techniques of four or more weeks duration.
Streptococcus faecalis	Gram + streptococcus. Usually occurs in smaller numbers and with a longer survival time than *E. coli* I. Numbers appear to fluctuate widely in domestic waste effluents. Possibly occurs in greater numbers in certain animals than in humans. Indicative role approximately echoes but does not supersede *E. coli* I in marine waters.
"Total viable organisms"	All culturable Gram + and - bacteria. Extreme variability of numbers even on a divided sample. Includes, indiscriminately, some of the marine saprophytes. The procedure is without any value in testing seawater for pollution.

Table continues

Table 3.1 continued

Vibrio cholerae/parahaemolyticus	Vibrios. Detected only in the harbour (probably from oriental fishing boats) in the early years. More common off waterways recently. Survival time too lengthy (some serotypes able to proliferate in high saline waters particularly estuaries). Very large numbers could acquire an indicative role as evidence of a local epidemic.
Viruses	Enteric viruses are common in sewage works effluents. Found close to beach discharges but appear to be uncommon at any distance. Of major public health significance in shellfish harvested for human consumption raw. Costly and sophisticated cultural techniques several weeks long presently required. Any indicative role is at least rivalled by the bacteriophage of *E. coli*.

Total coliforms - These organisms were routinely enumerated in the investigation as this index provides a fair, if non-specific, general indication of waterborne terrigenous increments. However, total coliforms are not specific enough when faecal pollution is under consideration. Owing to the physical nature of the Natal coast, well-known for its frequency of high-energy events, the use of coliforms or so-called "faecal" coliforms is comparatively valueless in effluent work; and if a water standard is to be based on *E. coli* I, it must be ensured that it is indeed this particular organism of faecal pollution that is being evaluated and not Irregular VI, the 44,5 °C (Eijkman) positive thermotolerant coliform which is not necessarily of faecal origin.

Presumptive *E. coli* ("faecal" or thermotolerant coliforms) - This group usually includes, indiscriminately, *E. coli* I which is incontrovertibly of faecal origin, Irregular II, of doubtful habitat, and Irregular VI, usually of non-faecal origin and capable of proliferation in jute, rags and hemp (Windle Taylor, 1958; Wilson and Miles, 1964; Wilson *et al.*, 1984), and, in Natal, in the marginal vegetation of rivers (Brand, 1966; Brand *et al.*, 1967). The Irregular VI group is probably comprised of a saprophytic or adaptive variant of *Klebsiella aerogenes* (Windle Taylor, 1958; Brand, 1966); further identification, however, was not pursued as such speciation was considered irrelevant in the context of this survey's objectives. An example of the necessity for differentiation between *E. coli* I and the Irregulars (which together comprise the presumptive *E. coli* group) follows: a mill on the Mgeni River 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 (Livingstone, 1969):

Presumptive *E. coli* or "faecal" coliforms	$2,3 \times 10^8$ per 100 m*l*
E. coli I	0 per 100 m*l*
Irregular II	$1,5 \times 10^8$ per 100 m*l*
Irregular VI	$8,3 \times 10^7$ per 100 m*l*

Subsequent investigations showed that, in fact, no direct faecal contamination of the river could be attributed to the mill, and that the presence of no other sewage organisms could be demonstrated from the mill's water circuits. (The waste rags were steamed before processing.)

3.1.2.1 Systematics and nomenclature of the genus *Escherichia*

Modern water-pollution scientists may, perhaps understandably, occasionally experience dismay at the confusion attending the systematics of the Enterobacteriaceae family, the coliform-dysentery-typhoid group of bacteria, particularly the genus *Escherichia*. The seventh edition of *Bergey* (Breed *et al*., 1957) offers *E. coli* with four appended variants (*communis*, *acidilactici*, *neapolitana* and *communior*) along with *E. aurescens*, *E. freundii* and *E. intermedia*. The eighth edition of *Bergey* (Buchanan and Gibbons, 1974) suggests *Escherichia* is a single genus with only one type-species, namely *E. coli*. The considerable number of biochemical and serological and other divergencies exhibited by different strains of *E. coli* are regarded as constituting mere variants of the single genus (or species), similar to the unnamed serotypes reported by Kauffmann (1954). This may eventually prove to be correct, while continuing to allow the differences to be presently reflected by differences of nomenclature, otherwise the identification *E. coli* would invariably have to be followed immediately by an unwieldly formula of the particular variant's carbohydrate utilization, chemical behaviour, response to antibiotics, etc. The ninth edition of Bergey (Krieg and Holt, 1984) re-expands the *E. coli* group slightly to include *E. adecarboxylata* and *E. blattae*; however, Wilson and co-workers (1984) do not accept this innovation. There may be historical and geographical reasons for much of the confusion: the USA expended about three-quarters of a century in pursuit of "fecal coliforms" as a water quality criterion, and more recently alternative indicators to *E. coli* are introduced almost annually from that country. Moreover, the Irregulars (variations within the genus *Escherichia*) are not at all common in the northern hemisphere (McCoy, J H, pers. comm.*).

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Whatever the taxonomic variations (or the names attached to the variants), it is as well to recapitulate here that all members of the family Enterobacteriaceae are interrelated, that the transition from genus to genus is gradual, that differences between species are similarly fluidic and by no means sharply defined.

For the purposes of this survey, the systematics have been anchored firmly in classical waters (Wilson and Miles, 1964; Brand, 1966; Brand, P A J, pers. comm.*), and the classical differentiation and nomenclature retained. To summarize: all presumptive coliforms exhibiting thermotolerance (fermenting lactose in bile-salts media at 44,5 °C), were classified as presumptive *E. coli*; further differentiation into *E. coli* I and the Irregulars II and VI was made from the organisms' respective capacities to produce indole or utilize citrate salts.

Until these designations are unequivocally superseded, this nomenclature will be adhered to; in any event, the supercession, if it occurs, will not amount to more than a change of nomenclature.

3.1.3 Indicators selected for this survey

Indicators finally selected therefore, as the basis for the water classification system, were:

E. coli I - This organism is an indicator of definite and fairly recent faecal pollution. Its only limitation as a source indicator is that a reduced number of the bacilli may survive for more then 24 hours in local seawater (Livingstone, 1978). In view of the frequency of high-energy events and the current dynamics in the region, the complete and consistent absence of *E. coli* I from any particular beach is not usual.

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Parasite Units - These were measured as numbers of the ova of *Taenia* and *Ascaris* species, and proved useful in plume tracking, apart from their role as a quantitative measure of the grosser degrees of sewage pollution. These entities can remain in seawater for several hours before becoming unrecognizable, about 5% of the eggs surviving 30 hours (Livingstone, 1978); other species of ova proved to be relatively much shorter-lived and were consequently excluded as indicators.

Coagulase positive, mannitol positive staphylococci (*S. aureus*). - These organisms were recorded on a present- or absent-in-the-sample-basis. However, their presence in local seawater, despite their halotolerance, is rare in comparison with their occurrence in local inland waters. The organism would appear to indicate very recent specific pollution, possibly of a non-faecal nature. Common in the respiratory tract of man, the organism is also to be found on the skin and in the faeces of about 30% of normal individuals (Wilson *et al.*, 1984). Some significance may or may not be attached to the isolation of these bacteria near relatively stagnant or stored seawater, for example harbour-mouths and canal-mouths experiencing tidal damming effects, river-mouths and unchlorinated tidal swimming pools. The staphylococci are present, however, in appreciable numbers in polluted rivers examined by the writer and others (Wilson and Miles, 1964). The organism has been reported as succumbing fairly rapidly in polluted seawater (Anon, 1956).

Salmonella typhi, salmonellae and shigellae - Isolation of salmonellae from polluted waters proved to be a relatively straightforward and speedy process, and was therefore extensively used in the work (Livingstone, 1964). The organisms probably do not live for more than a day or two at most in seawater, claims to the contrary probably result from the use of laboratory cultures. Shigellae, the causative organisms in a variety of dysenteries, which are known to be less hardy than salmonellae, probably survive for mere hours; consequently, shigella isolations from seawater, uncommon though they are, were included for evaluating high degrees of pollution brought about by proximity to a contaminative source.

Salinity - This single measure of a purely physical nature was included in order to indicate the degree of dilution of the saline medium by fresh water. "Clean" (ie: undiluted) seawater on the Natal coast exhibits a salinity (measured as conductivity) of 35 - 36 $^{o}/_{oo}$, or even higher: accretions of fresh water, if present in sufficient quantities, depress this figure. Samples with a salinity reading below 34 $^{o}/_{oo}$ were relegated in the classification system whatever their bacteriological content, such samples being regarded as "polluted" by fresh water, in its widest sense.

3.1.4 Sampling bias and sampling stations

Normally, sampling of the surf was not biased or selected for favourable or unfavourable conditions; nor for seasonal variation of beach use; nor to accommodate vagaries of wind, tide or current. (Wind, tide and current were, however, recorded while sampling; these factors affected some of the beaches during the early period of surface sewage-plumes; and continue to influence stations adjacent to waterways by transporting indicators along the shore.) If schedules permitted, sampling of aesthetically repellant surf discoloured by suspended silt following a flooding event was postponed: such waters inevitably yielded depressed salinities throughout the surf-zone which was not a fair reflection on the normally prevalent conditions. (Such episodes of discolouration were observed to occupy from 2-6 weeks, on average, per annum.) Sampling was usually performed in the early morning to allow as much time as possible for the ensuing laboratory procedures. It is possible that the early morning regimen obviates to some degree the lethality of ultraviolet effects on the bacteria near the sea surface (ie: sampling later in the day could result in reduced microbial indices due to more lengthy exposure to sunlight).

Both bathing and non-bathing beaches (eg: Stations 6 and 10) were included in the survey for comparative purposes. Possibly due in some measure to the turbulent nature of the local surf which affords good mixing characteristics, increased numbers of bathers produced little or no increase in bacterial numbers (D J Livingstone, 1966: unpublished data; D J Livingstone and M M Calder, 1988: unpublished data); however, a few dozen early morning fishermen (implying discarded bait and, possibly, defecation) close to a sampling station appeared to effect a measurable increase in the *E. coli* I index (Livingstone and Calder, 1986).

Factors influencing the establishment of beach sampling stations were: proximity to shore-based sanitary features (eg: pipes, drains, rivers, canals) and to amenities (eg: bathing beaches, tidal pools); and accessibility.

During the deep-sea work, all waste-pipe discharges on the research vessel - particularly from the galley - were halted while the ship was on station for the collection of samples.

3.2 METHODOLOGY

The procedures, methodology and techniques employed in implementing the survey, and outlined briefly here, have been described in detail (Livingstone, 1964; Brand and Livingstone, 1965; Livingstone *et al.*, 1968; Livingstone, 1969; Livingstone, 1982; Livingstone and Calder, 1983). The methods were adopted and standardized in 1964, and have been used since, with minor changes, to allow comparison of past and future results.

3.2.1 Sampling

Water samples were collected in sterile 250 m*l* glass containers, 2 m from the side of a boat or, in the surf zone, 2 m seawards from the lip of a newly broken wave. A sample-stick with bottle-holding attachment was used. Effluents from sewage works were sampled on site. (All sampling bottles included a small crystal of sodium thiosulphate to neutralize any free chlorine present, a particular necessity in effluent sampling.)

For all surface investigations, the water layer between the surface and 0,15 m depth was sampled. In depth work and sediments, standard National Institute for Oceanography (United Kingdom) all-plastic sampling bottles and cone-dredges were used.

3.2.2 Total coliforms

Two 100 m*l* samples of water, or of appropriate dilutions in sterile water, were membrane-filtered. The membranes (Oxoid or Gelman

Sciences) were resuscitated for 1 h at 37 °C on pads impregnated with resuscitation broth (Oxoid Division, 1961), then transferred to pads impregnated with MacConkey membrane broth (Oxoid) for a further 17 h (total incubation, 18 h). 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 m*l*.

Alternatively, M-Endo-LES agar (Difco) was employed for culturing the membranes, and colonies exhibiting the characteristic metallic sheen were treated as presumptive coliforms (Lichtigfeld and Melmed, 1982).

3.2.3 Total presumptive *E. coli*

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

Alternatively, standard M-FC agar (Biolab) (without rosolic acid) was used for culturing the membranes, and all blue colonies were treated as presumptive *E. coli* (Grabow *et al.*, 1984).

3.2.4 *E. coli* I, Irregular II and Irregular VI (Difco Laboratories, 1953, 1962; Taylor, 1958; American Public Health Association, 1960; Oxoid Division, 1961; Wilson and Miles, 1964; Wilson *et al.*, 1984).

A representative number of yellow (on MacConkey) or blue (on M-FC) colonies from the membranes of the presumptive test were subcultured into tryptone broth (Difco) and incubated at 44,5 °C for 24 h. From these tubes, subcultures were made in Koser's citrate medium (Difco) with 0,5% of brom thymol blue indicator solution (brom thymol blue, 1,6 g; n-NaOH, 1,3 m*l*; absolute alcohol, 20 m*l*; distilled water to make 50 m*l*), and incubated at 44,5 °C for 96 h. The tryptone broth cultures were tested for indole production with Kovac's reagent:

44,5 °C	Indole	Citrate	Organism
+	+	-	*E. coli* I
+	-	-	Irregular II
+	-	+	Irregular VI

From these results, a differential *E. coli* I, Irregular II and Irregular VI count per 100 m*l* was calculated.

3.2.5 Parasite units

Normally, 250 m*l* of the sample were examined. The sample was allowed to stand for 20 min, and the supernatant, except the last 10 to 20 mm, was carefully drawn off with a small water-vacuum pump and discarded. The retained portion was shaken well, and centrifuged in 15 m*l* tubes at 3 000 rev/min for 3 min. All the *Ascaris* and *Taenia* ova in the whole deposit were counted under the microscope, and the numbers recorded.

3.2.6 Coagulase positive, mannitol positive staphylococci (*S. aureus*)

Two 25 m*l* aliquots of a water sample were membrane-filtered. Membranes were cultured on *Staphylococcus* medium No. 110 (Difco) at 37 °C for 43 h. 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 dehydrated diagnostic plasma (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. Results were recorded as present or absent in 50 m*l*.

3.2.7 *Salmonella typhi*, other salmonellae and shigellae (Livingstone, 1964).

Normally, 250 m*l* of the sample were added directly to 6 g of selenite brilliant green broth (SBG, Difco); the broth so formed was divided into two 125 m*l* subsamples and to one of these about 0,6 g (ie: about 0,5%) dulcitol was added. In the case of sediments, 10 g was added to 250 m*l* of broth. In the case of bivalves and crayfish, 10 g of the flesh was used. Both halves of the sample were incubated at 37 °C for 20 h, and each was then subcultured on two plates of a modified SS (Difco) agar, in which the lactose was increased to 1,5%, and 1,5% of saccharose, not normally present, was added. A selection of the clear colonies on these plates was 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 the modified SS agar and tested against appropriate polyvalent antisera (Burroughs-Wellcome). All salmonellae and shigellae were submitted elsewhere for independent confirmation and serotyping.

Results were recorded as present or absent per 250 m*l*, or per 10 g.

3.2.8 Salinity

During the early years, salinity was determined by the standard titration technique using $AgNO_3$, with K_2CrO_4 as the indicator; later, the conductivity method described by Grasshoff (1976) was employed using a simple laboratory conductivity meter equilibrated against a "Standard Seawater" instead of a complex salinometer. Results were reported as $^o/_{oo}$ to two decimal places.

3.2.9 Supplementary tests (Adapted from Nupen *et al.*, 1983)

During the modified effluent discharge to sea experiment (between October 1980 and May 1983, see Chapter 2: PHYSICAL CONSIDERATIONS and Chapter 4: RESULTS AND DISCUSSION), intensive surveillance of the submarine discharge area for enteroviruses and bacteriophages took place. The refrigerated (4 °C) viral samples were despatched in cold bags to the Division of Water Technology, CSIR, Pretoria, while the coliphage tests were performed locally.

3.2.9.1 Viruses

Using an Amicon ultrafiltration unit (Model 2000), 10 *l* samples were filtered through an Amicon XM membrane. After filtration, the membrane was eluted by using 4 x 5 m*l* aliquots of 0,5% Hank's lactalbumin acetate as the eluent. Viruses present in the 20 m*l* concentrate were evaluated by a quantal response technique which determined the number of 50% tissue culture infective doses ($TCID_{50}$) per m*l*. The remainder of the concentrate was inoculated into confluent layers of vervet monkey kidney cells in a Roux flask to determine the presence of a smaller number of infectious doses than 10 m*l*.

3.2.9.2 Coliphages

Bacteriophages of *Escherichia coli* B (coliphages) were enumerated by adapting the double agar-layer method of Adams (1959) modified by Grabow and his co-workers (1978). A layer of the base medium (agar 13 g, tryptone 13 g, NaCl 8 g, glucose 1,5 g, sterile water 1 *l*) was poured into the base of a 150 mm petrie dish and allowed to set. Superimposed on this were: 10 m*l* of water sample, 0,5 m*l* of a broth containing *E. coli* B stock culture, and 25 m*l* of the surface medium (agar 6 g, tryptone 10 g, glucose 3 g, sterile water 1 *l*). This was swirled to mix, covered and allowed to set. Plaques were counted after 16 to 18 h incubation at 37 °C. Results were expressed per 10 m*l*.

3.3 FACTORS AFFECTING INDICATORS

3.3.1 Precision of determination of *E. coli I* counts (Livingstone *et al.*, 1968)

It was considered advisable to determine the degree of precision - the reproducibility of repeated measurements on the same sample (measured by standard deviation) - inherent in the membrane filtration method. Counts were therefore performed on 30 subsamples from each of eight samples collected from waters and effluents where the known *E. coli* I index ranged from units to tens of millions. Of the 30 membranes set up, faulty counts arising from technical errors, breakages, drying up of membranes, etc., were discarded, as were those membranes on which two or more types of organism were demonstrable from a single colony (ie: "mixed" colonies). The first 20 counts from the remainder were employed for calculating the standard deviation (SD) and the coefficient of variation on each series.

Results of the comparison are presented in Table 3.2, followed by the statistical analysis in Table 3.3. A graphic rendition of the results appears in Fig 3.

Apart from Subsample A with its single digit range, which perhaps understandably yielded a coefficient of variation of 55%, the average of coefficients of variations was in the region of 10%. This finding validates the accuracy and reliability of the *E. coli* I methodology employed.

3.3.2 "Nonculturable *E. coli*"

In the preceding section (3.3.1), it could be regarded as an unusual phenomenon if a *constant percentage* of the *E. coli* I populations present in all 160 subsamples proved to be sublethally impaired cells, viable but unculturable, allowing the culturable percentage a reciprocal constancy. To expect some sort of, at least, sequential "fade" is perhaps not unreasonable as the procedures on each sample occupied about two hours in the laboratory; however, no such "fade" occurred: the last sub-sample result more or less agreed with the first sub-sample result.

Nevertheless, in recent years, some attempt has been made to cast doubt on the validity of standard bacteriological cultural methods for recovering indicator organisms in the aquatic environment: it has been reported a proportion of "*E. coli*" (among other microbes) undergoes a "non-recoverable" stage while remaining viable, thus compromising "faecal coliform" indices. Xu and co-workers (1982) incubated various laboratory-reared strains of micro-organisms for two weeks in various saltwaters (5-25 $^{o}/_{oo}$ NaCl) and sterilized Chesapeake Bay water (salinity 11 $^{o}/_{oo}$) for 24 and 96 h, and 13 days, at temperatures of 4-6 °C, 10 °C and 25 °C. Using direct microscopic examination of fluorescent antibody and acridine orange stained cells, they reported that a significant proportion of the nonculturable cells remained viable, whereas their most probable number

TABLE 3.2

E. coli I/100 *ml* in twenty subsamples from each of eight samples

Sub-sample:	Sample							
	A	B	C	D x 10^3	E x 10^3	F x 10^3	G x 10^6	H x 10^6
1	3	52	104	5,40	13,60	269,0	1,460	75,20
2	6*	62	100+	5,60	12,24	268,0	1,182+	81,00
3	4	64	128	5,40	14,24	235,0	1,440	73,00
4	2	48+	104	5,30	12,52	285,0	1,440	70,00
5	3	54	120	5,10	13,10	268,0	1,800*	66,40
6	<1+	48	160*	5,70*	14,56	282,0	1,600	65,00+
7	2	48	120	4,60	14,70	276,0	1,236	73,00
8	2	53	130	5,20	12,58	276,0	1,800	67,00
9	3	66*	132	4,50+	12,92	286,0*	1,760	71,00
10	2	52	120	5,10	14,62	256,0	1,650	75,00
11	3	56	138	4,90	13,28	262,0	1,480	65,00
12	4	58	120	5,30	14,42	272,0	1,552	65,00
13	4	54	104	5,40	14,34	248,0	1,528	75,00
14	2	50	160	5,50	14,56	230,0	1,352	80,00
15	2	62	152	5,50	15,08*	224,0+	1,304	83,00*
16	4	48	120	4,85	12,54	250,0	1,384	78,00
17	3	64	152	5,60	11,08+	278,0	1,740	78,00
18	5	62	160	5,50	12,78	228,0	1,630	76,00
19	1	56	104	5,30	12,74	250,0	1,630	73,00
20	<1	58	150	5,50	14,76	274,0	1,264	81,00

Range per sample: + = Lower; * = Upper

TABLE 3.3

Statistical analysis illustrating the reliability and reproducibility of *E. coli* I/100 m*l* (membrane counts on waters of differing pollution levels)

Sample	Mean	SD	% Coeff. of Var.	Range (per 100 m*l*)	95% confidence limits (2,1 x SD)
A	2,75	1,52	55	<1 to 6	0 to 6
B	55,75	6,42	11	48 to 66	42 to 69
C	128,9	20,84	16	100 to 160	85 to 173
D	5,26 x 10^3	331,7	6	(4,5 to 5,7) x 10^3	4 563 to 5 957
E	13,53 x 10^3	1,10 x 10^3	8	(11,08 to 15,08) x 10^3	(11,22 to 15,84) x 10^3
F	261,2 x 10^3	19,8 x 10^3	8	(224 to 286) x 10^3	(219,6 to 302,8) x 10^3
G	1,51 x 10^6	0,189 x 10^6	13	(1,82 to 1,8) x 10^6	(1,115 to 1,909) x 10^6
H	73,53 x 10^6	5,75 x 10^6	8	(65 to 83) x 10^6	(61,45 to 85,61) x 10^6

(MPN) estimates and plate counts exhibited reductions in microbial numbers. Grimes and Colwell (1984) reported similar results using washed cells from laboratory cultures in similar saltwaters.

It must at once be acknowledged that these reports have relevance to the cultivation and harvesting of shellfish for human consumption: vigilance is required to ensure the bivalves are not exposed to possibly contaminated seawater. However, any relevance to the monitoring of indicators in the sea could be regarded as questionable.

Natural seawater is a physiologically balanced dilute solution of several salts, some dissolved gases and traces of a vast number of organic compounds. ZoBell (1946) lists 41 elements in natural seawater, observing that the salts in natural seawater are essential to maintain marine biological activity. Conversely, it could be argued these components play a significant part in limiting the survival of sewage bacteria in the intrinsically hostile marine environment. Moreover, lowered salinity is universally recognized to benefit the survival of coliforms (Carrington, 1980). Salt water of >3% salinity is not the natural milieu for this group of organisms, the physiological salinity of their mammalian hosts being of the order of 0,9%, while that of inland waters (in which the free-living coliforms appear to survive almost indefinitely) is usually much less.

Other microbiologists have expressed grave reservations about the validity of using laboratory-reared pure cultures of bacteria in die-off studies (Kott, Y, pers. comm*): old laboratory strains tend to produce breeds of microbes that may metabolize differently from natural strains. It could be added, autoclaved seawater, or salt waters manufactured in the laboratory eliminate or preclude all the oceanic entities involved in competition with and predation of the interlopers, such as marine bacteria and protozoa and the voraciously scavenging zooplankton. The laboratory ambience itself excludes most solar radiation, and if the test microbes are in refrigerators or incubators, all of it.

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Finally, the history of using bacterial criteria to grade waters as safe for drinking or recreational purposes spans nearly a century. There has not been a mysterious and persistent percentage of morbidity among consumers and bathers when such waters have been classified fit for their respective uses following the application of routine bacteriological methods of scrutiny. While it is reasonable to assume that numbers of domestic wastewater microbes do indeed maintain viability for a time in seawater yet cannot be demonstrated on culture plates, for all practical monitoring purposes (apart from shellfish) the phenomenon appears to be of marginal significance.

3.3.3 Survival of certain entities in seawater

3.3.3.1 Coliforms (Adapted from Livingstone *et al.*, 1968)

Six coliform populations in freshly collected raw sewage, (ranging between 68,5 x 10^6 and 1,57 x 10^6/100 m*l*) were inoculated into natural seawaters contained in the microcosms of laboratory flasks, away from direct sunlight. Approximately 20% of the bacteria proved to be unculturable after 24 h. Three of the six mixtures exhibited an increase in the coliform index after 15 minutes, and this phenomenon was echoed by a fourth mixture after 30 minutes, suggesting the break up of bacterial aggregates in the early stages before decreases commenced. It is also probable the added sewage initially made nutritive material available to the organisms.

The sewage plume at the harbour-mouth (Station X) was also tracked and sampled during overcast conditions using sodium fluorescein and small surface-current drogues to mark the plume. Samples were taken from a small dinghy at the marker floats at fixed intervals of time. The coliform counts were related to the salinity measurements. Dilution effects became apparent within a few minutes: dilution of the plume by 98-99% was paralleled by a 99% decrease in the coliforms. After 20 minutes (and moving 716 metres) from the discharge point, the figures started to diverge: the concentration of the plume calculated from the salinity was 2,9% while that of the coliforms was 0,4%, suggesting factors other than dilution and dispersal had started to operate.

3.3.3.2 *E. coli* I (D J Livingstone, M M Calder and A D Connell: unpublished data)

Under varying conditions of sun and shade, four litres of primary tank effluent (PTE) were added to approximately 2 x 10^3 *l* of natural seawater contained by a flexible tank suspended in a larger rigid tank of seawater. Continuous agitation was applied to the mixture. In one experiment, the PTE was peculiarly clear in appearance and odourless, and proved to contain far fewer *E. coli* I/100 m*l* than is usual for PTEs. In this test the survival of the *E. coli* I numbers was 33,39% after six hours. It is possible this "weaker" effluent afforded an acclimatization component to the organisms prior to their inoculation into seawater. The salinity range in this investigation was 32,50 - 33,35 $^{o}/_{oo}$. In subsequent experiments, the survival rate of *E. coli* I ranged between 0,01% in sunny conditions and 0,25% in the shade, after six hours.

3.3.3.3 Parasite ova (Adapted from Livingstone, 1978)

It was found that 10-20% of parasite eggs from raw sewage did not survive initial contact with seawater, consequently samples from the sewage plume at the harbour-mouth several metres from the point of impact were collected, and various parasite ova were recovered for examination. The concentrates were placed in wet chambers with a drop of 1% eosin dye (as a supravital stain) and counted microscopically every hour. Criteria for viability were: morphology, but not size (swelling occurred in some species); rejection of the supravital stain; embryonation, discernible in some species. Results appear in Table 3.4.

The time the helminth ova spent in the sewage system prior to contact with seawater was uncertain, and this, along with laboratory manipulative procedures (centrifugation, etc), may have influenced their respective times of decay. Causes for the loss of viability under the investigated conditions were probably due to osmotic effects following the erosion or lysis of the protective sheaths possessed by some of these ova and, possibly, subsequent bacterial invasion.

TABLE 3.4

Observed loss of viability of certain helminth ova in seawater

Hours	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	After 30
Enterobius vermicularis																										
Run 1	8	1	0																							
2	3	0																								
3	1	0																								
4	3	1	0																							
Total	15	2	0																							
% Viable	100	13	0																							
Hookworm species																										
Run 1	11	8	4	3	3	0																				
2	4	0																								
3	3	1	1	0																						
4	7	3	0																							
Total	25	12	5	3	3	0																				
% Viable	100	48	20	12	12	0																				
Trichocephalus trichiuris																										
Run 1	3	3	2	0																						
2	5	5	5	4	4	3	1	0																		
3	4	3	3	0																						
4	3	2	2	1	1	0																				
Total	15	13	12	5	5	3	1	0																		
% Viable	100	87	80	33	33	20	7	0																		
Ascaris lumbricoides																										
Run 1	18	17	17	17	17	14	12	6	6	6	6	5	4	4	2	0										
2	12	12	12	11	11	10	10	10	10	10	10	9	9	9	8	7	5	4	4	4	3	3	2	2	2	2
3	15	13	12	11	9	9	9	7	7	7	7	7	6	6	6	5	3	2	1	1	1	0				
4	25	23	23	23	18	16	15	11	11	11	10	7	3	0												
Total	70	65	64	62	55	49	46	34	34	34	33	28	22	19	16	12	8	6	5	5	4	3	2	2	2	2
% Viable	100	93	91	89	79	70	66	49	49	49	47	40	31	27	23	17	11	9	7	7	6	4	3	3	3	3
Taenia species																										
Run 1	13	13	13	13	12	9	9	8	8	6	6	5	4	4	3	0										
2	6	5	5	5	5	5	5	5	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	2
3	5	5	5	5	5	5	4	4	4	4	4	4	4	3	3	1	1	1	0							
4	8	7	6	6	5	3	3	2	2	2	1	0														
Total	32	30	29	29	27	22	21	19	18	16	15	13	11	10	9	4	4	4	3	3	3	3	3	3	3	2
% Viable	100	94	91	91	84	69	66	59	56	50	47	41	34	31	28	13	13	13	9	9	9	9	9	9	9	6

Although some of the *Ascaris* and *Taenia* spp. ova survived in seawater for times in excess of 24 hours, their decay through rapid sedimentation in the open sea can be reasonably expected to take place in view of their comparatively much greater density.

3.4 A SYSTEM OF CLASSIFYING SEAWATERS

A system of grading seawater quality employing the indicators selected for the purpose was evolved (Livingstone, 1969) to assess any improvement or deterioration of the local surf affected by domestic wastewater discharges, and the procedure is in use to the present day. Classification is based on a planned system of adverse scoring, each indicator selected and scored basically on a value of 4 (the value for 101 - 1 000 *E. coli* I/100 m*l*). Once the bacterial and salinity measurements are available, classification is a simple, straightforward and speedy arithmetical calculation. The design of the system accords the same basic score of 4 to indicators of particular pollution significance, even if the recovery of such indicators is not common.

The rationale in the final selection of indicators is outlined briefly:

- *E. coli* I for its historical status, relative hardiness and numbers;
- parasite ova for the relative speed with which these entities succumb to sedimentation as surface wastewater plumes become diluted;
- coagulase + mannitol + staphylococci which are common enough respiratory tract, skin and bowel commensals, and which (despite their halotolerance for NaCl) succumb fairly rapidly in the open sea, with marked frequencies of recoveries near relatively stagnant or stored seawater, ie: the harbour-mouth, canal-mouths experiencing tidal damming effects, river-mouths, unchlorinated tidal baths etc;
- salmonellae which are not as common but which can be regarded as occurring in an approximate proportion to *E. coli* I in sewage whether the sewage is raw or treated and massively diluted;
- *Salmonella typhi* for its numerical rarity; and
- shigellae, for their apparent sensitivity to seawater.

The closer the sampling site to the source of sewage pollution the greater the possibility of isolating more than one, or all of these indicators, probably in the above order: their frequency of occurrence and numbers governed by proximity to the discharge point and efficacy of the sewage treatment process.

3.4.1 Evaluation of indicators

Salinity is included in the system to indicate dilution of the saline medium.

This method of adverse scoring, which reduces the data on the various indicators for every sampling station to a comprehensible system of classification, is presented in Table 3.5.

TABLE 3.5

Evaluation of indicators

Indicator	Degree	Value
E. coli I/100 m*l*	<1-10	1
	11-100	2
	101-1 000	4
	>1 000	8
Parasite units/250 m*l*	1-7	4
	>7	8
Coagulase and mannitol positive staphylococci/50 m*l*	Present (+)	4
Salmonellae/250 ml	Present (+)	4
S. typhi/250 m*l**	Present (+)	4
Shigellae/250 m*l*	Present (+)	4
Salinity	<34 $^{\circ}/_{\circ\circ}$	4

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

3.4.2 Classification of seawaters

The classification of the seawaters by their indicator values appears in Table 3.6.

TABLE 3.6

A system of classifying seawaters by indicator value

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

Although this system employs stringent criteria for classifying recreational waters of a very high standard, it has been designed to detect even small changes in that quality. And while the standards required for water to be rated as Class I are rigorous, Class II is also perfectly acceptable for recreation, and completely in accordance with Public Health principles (Richter, M B, pers. comm; Mackenzie, C R, pers. comm*).

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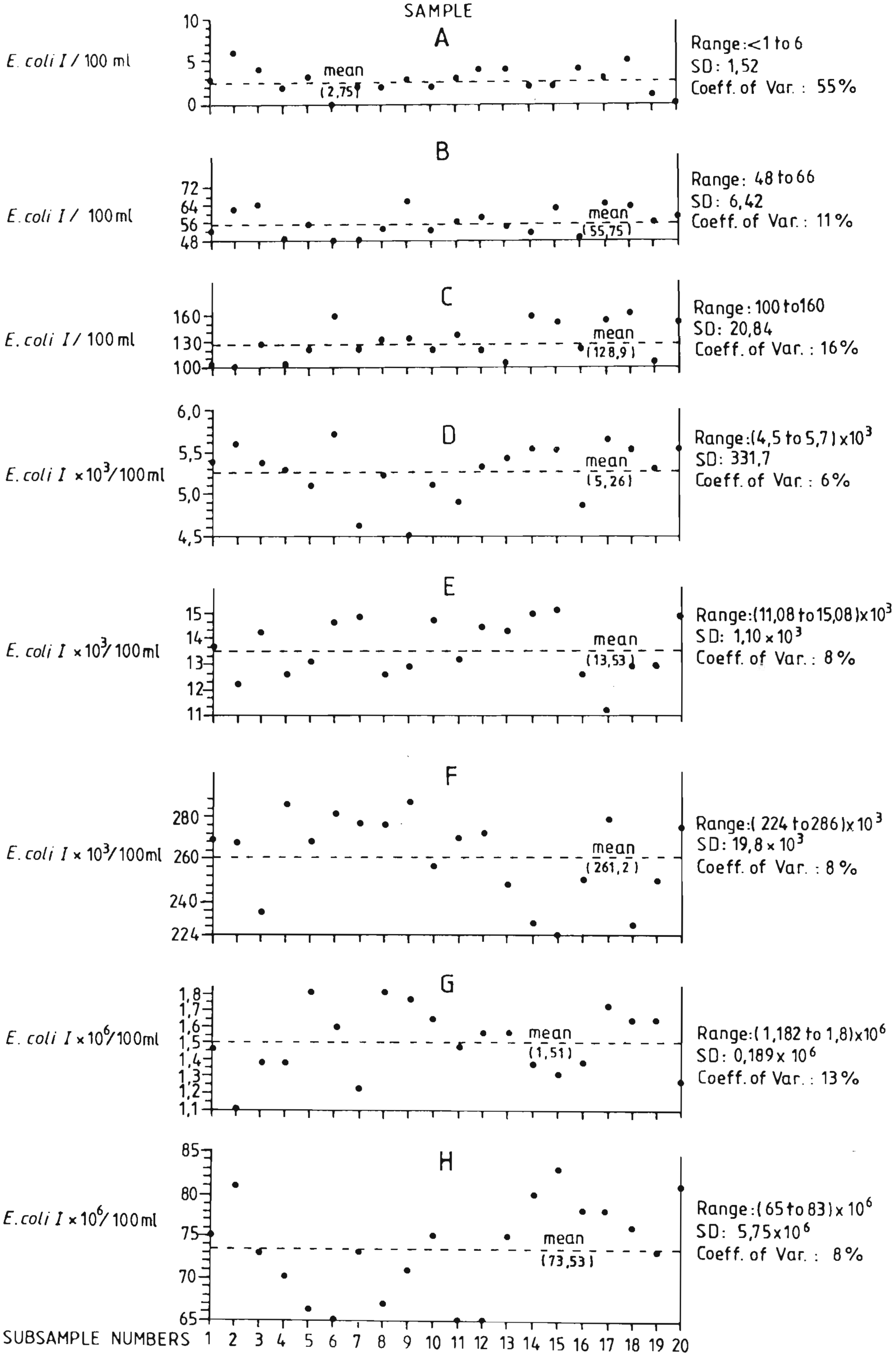

Fig 3 Numbers of *E. coli* I counted by the membrane filtration technique on 20 subsamples from each of eight samples (SD: standard deviation)

CHAPTER 4 : RESULTS AND DISCUSSION

4.1 BACKGROUND TO THE RESULTS

At the start of this survey, when the polluted nature of the local surf became apparent, the search for clean coastal seawater to serve as the baseline criterion was extended south to Park Rynie (see Fig A4.1 in the Appendix) with due note taken of all possible contributory features such as rivers and estuaries, canals and pipes, sewers and tidal pools. In all, 47 sampling stations were assessed in 1964 and 1965, stretching from the Mgeni River to Park Rynie, and the waters graded by their indicator values and classified according to the system described in Chapter 3 : INDICATORS AND METHODOLOGY.

Table 4 presents these results, along with the 1967 gradations of Stations 1-26 (which constituted the actual coastal geographical extent of the survey). This was the last full run before the commissioning of the submarine outfalls. Inset in Table 4 is an extract from a bacteriological survey executed on the Port Elizabeth surf in 1965, applying the same system of indicator valuations and classification, which also revealed the close correlation between the microbial state of the proximate sea and the observable shore-based features and constructs (Livingstone, 1969).

4.1.1 Recapitulation of the survey area

The location of the sampling stations in this survey (see Fig 1 in Chapter 1, Figs 2.4 and 2.5 in Chapter 2, and Table 4) is briefly recalled here to aid topographical orientation of the subsequently presented results:

Station 1 is at the mouth of the Mgeni River.
Stations 1a-8 span the northerly bathing beaches.
Station X is at the site of the harbour-mouth sewer discharge which stopped in November 1969.
Station 10 is at the base of the CWO.
Station 12 is near the whaling factory which closed in October 1975.

TABLE 4

Water quality classifications of the sampling stations by indicator values, with actual or potential polluting features in their vicinities, prior to the submarine outfalls

1964-65 (Average of three runs)								Contamination Code: se: sewage; sw: stormwater; iw: industrial waste	1967							
Station number	*E. coli* I	Parasite units	C+M+ Staph.	Salms./Shigs.	Salinity	Ind. total	Class		Station number	*E. coli* I	Parasite units	C+M+ Staph.	Salms./Shigs.	Salinity	Ind. total	Class
								Mgeni River mouth, open: se; sw; iw.								
1	8	4	.	8	4	24	IV		1	8	4	4	4	4	24	IV
1a	8	4	.	4	4	20	IV		1a	8	.	.	4	.	12	III
2	2	.	.	.	.	2	I	Pipe 2.1: se; sw.	2	8	.	.	4	.	12	III
3	4	.	.	4	.	8	II	Pipes 3.1, 3.3, 3.4: se; sw.	3	8	.	.	4	.	12	III
4	4	4	.	8	.	16	III		4	8	.	.	.	.	8	II
5	1	.	.	.	.	1	I	Pipes 5.1, 5.7: se; sw.	5	8	.	.	.	.	8	II
6	4	4	.	4	.	12	III	Pipe 6.1: se; sw.	6	8	4	.	.	.	12	III
7	2	4	.	4	.	10	III	Pipes 7.3, 7.4: se; sw.	7	8	4	.	.	.	12	III
8	4	4	.	4	.	12	III	Pipe 8.1: se; sw.	8	8	.	.	4	.	12	III
X	8	8	4	12	4	36	IV	Major sewer: se; sw; iw.	X	8	8	4	4	4	28	IV
								Harbour mouth, open: se; sw; iw. (Flowing into the harbour: *Mbilo* and *Mhlatuzana Rivers*, open: se; sw; iw.)								
9	2	.	.	.	.	2	I		9	1	.	.	.	.	1	I
10	4	.	.	.	.	4	I	Pipes 10.5 to 10.7, 10.9, 10.10: se; sw; iw.	10	4	4	.	.	.	8	II
11	4	.	.	.	.	4	I	Pipes 11.2, 11.3, 11.5 to 11.7, 11.9 to 11.15, 11.17, 11.20, 11.21, 11.23: se; sw; iw; whaling effluents.	11	8	4	.	4	.	16	III
12	8	4	.	.	.	12	III	Pipe 12.1: major sewer: se; sw; iw.	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	8	.	20	IV	Unchlorinated tidal swim-pool; chlorinated in 1966.	15	4	.	.	4	.	8	II
16	2	.	.	4	.	6	II		16	2	.	.	.	.	2	1
17	2	.	.	4	.	6	II		17	1	.	.	.	.	1	I
18	4	.	.	4	.	8	II		18	1	.	4	.	.	5	II
19	1	.	.	4	.	5	II		19	8	4	4	4	4	24	IV
								Mlaas Canal (Mlazi River), open: se; sw; iw.								
20	8	4	4	8	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		22	8	.	4	.	4	16	III
								Reunion Canal, open: se; sw; iw; petro-chemical waste.								
23	2	.	.	4	.	6	II		23	8	4	4	4	4	24	IV
24	2	4	.	4	.	10	III		24	8	.	.	.	4	12	III
								Sipingo River, usually closed: se; sw; iw.								
25	1	.	.	4	.	5	II	Unchlorinated tidal swim-pool.	25	8	4	4	4	4	24	IV
26	1	.	.	8	.	9	III		26	8	4	4	4	4	24	IV
								Mbokodweni River, open: se; sw; iw.								
27	2	.	4	4	4	14	III									
28	2	.	4	.	.	6	II	Pipes 27.1, 27.2: iw.								
29	1	.	.	.	.	1	I									
30	2	.	.	.	.	2	I									
31	1	.	.	.	.	1	I									
32	1	.	.	4	.	5	II	Chlorinated tidal swim-pool.								
								Manzimtoti River, usually closed: se; sw; iw.								
33	1	.	.	.	.	1	I									
								Little Manzimtoti River, open/closed 50%: se.								
34	1	.	.	.	.	1	I									
35	2	.	.	.	.	2	I	Unchlorinated tidal swim-pool.								
								Lovu River, usually open: se; iw.								
								Msimbazi River, closed: se; iw.								
36	2	.	.	.	.	2	I									
								uMgababa River, usually closed: se.								
37	2	.	.	.	.	2	I									
								Ngane River, usually closed: se.								
38	2	.	.	.	.	2	I									
39	4	.	4	.	4	12	III									
								Mkomazi River, open: se.								
40	4	.	4	.	.	8	II	Unchlorinated tidal swim-pool. Chlorinated later.								
41	2	.	.	.	.	2	I									
								Mhlongwana River, closed.								
42	2	.	.	.	.	2	I									
43	2	.	.	.	.	2	I									
								Mahlongwa River, usually closed.								
								Mpambanyoni River, open.								
44	8	.	.	.	4	12	III	Chlorinated non-tidal beach swim-pool.								
45	4	.	.	.	.	4	I	Chlorinated tidal swim-pool.								

Port Elizabeth: 1965

P1	1	.	.	.	.	1	I
P2	1	.	.	.	.	1	I
Swartkops River							
P4	8	.	.	4	.	12	III
Wool-washing factory drain							
P6	8	.	4	4	.	16	III
Main sewer outfall: se; sw; iw.							
P10	8	4	4	4	.	20	IV
P10a	8	8	4	.	.	20	IV
Two beach drains: sw; iw.							
P12	8	8	4	.	.	20	IV
Harbour							
Oceanarium							
P16	2	.	.	.	4	6	II
P17	1	.	.	.	.	1	1

Stations 12 and 13 bracket the Finnemore Place sewer which closed in 1979.

Stations 14 and 15 are bathing beaches, with a tidal pool at Station 15.

Station 16: some bathing occurs here.

Stations 19 and 20 bracket the mouth of the Mlaas Canal; after the Natal Floods in September 1987, the mouth of this waterway relocated north to between Stations 18 and 19 for about a year before reassuming its original position.

Stations 22 and 23 bracket the Reunion Canal which drains an oil refinery campus.

Station 25 is at the usually sand-plugged mouth of the Sipingo River where some bathing occurs; and there is a tidal pool in the vicinity.

Station 26 is a bathing beach.

(Sampling stations not listed above were sited at what was considered to be judiciously selected coastal intervals so that no extensive gaps were left in the coverage of the inshore waters.)

4.1.2 Types of sampling runs and frequencies

Generally, five types of sampling runs were made differing in the extent of the terrain surveyed:

Full runs: these covered all 28 sampling stations. In the first phase of the survey, prior to the installation of the undersea outfalls, every beach station was examined at least four times to establish the background, after which there was a pause while the works were being constructed and the pipes pulled out to sea. Full runs recommenced in 1970, and in that year and the following one, five full • runs were executed. From 1972-1974, six full runs were made. Towards the end of 1974, the Steering Committee, financially restricted, resolved that the sampling stations should be reduced in number to sixteen essential localities, consequently no full run was performed in 1975, but five attenuated runs were performed from October 1974 to August 1975. In January 1976, the author believed it was important to reinstate the full sampling run by extending one of the attenuated runs annually in order to maintain the integrity of the data bank, and this practice was eventually ratified by the Committee, and has continued to date.

Attenuated runs: these were designed to cut transport and laboratory costs while covering key stations and selected bathing beaches, and comprised Stations 1, 3, 5, 6, 8, X, 10-15, 19, 20, 22 and 23 (sixteen in all). The complete spectrum of indicators was nevertheless employed. As previously noted, these runs started in 1974, and between that year and 1978 eight attenuated runs were made. From 1977-1980 the sampling pattern was one full run and two attenuated runs annually. In 1981-1982 the frequency was raised to three attenuated runs (along with the annual full run). In 1983 this was reduced again to one attenuated run and one full, but these were supplemented by two modified effluent runs. 1984 and 1985 saw three attenuated runs (along with the annual full run). In 1986, two attenuated runs were made, with one modified run and the usual full run; similarly, in 1987, two attenuated runs supplemented by a modified run, as well as a special run covering all the bathing beaches, with the annual full run, were made. In 1988, three attenuated runs, a modified effluent run and full run completed the survey.

Modified effluent discharge runs: these were performed on selected Bluff area beaches in addition to the previously mentioned runs to test for any impact of the modified effluent on the section of the surf-zone closest to them; they consisted of Stations 9-15, 19, 20, 22 and 23 (eleven in all). These runs commenced in November 1980, and fell approximately into an annual pattern: in January 1981, February 1982, January and May 1983, August 1984, June 1986 and 1987, and May 1988.

Deep-sea runs: these were made on a grid of sampling stations over the terminal diffuser section of each outfall, and beyond, as well as a control station (h3) between the two pipelines (see Fig 2.4). Each sea station actually comprised four sampling points: surface; "mid", approximately 20 m deep; "depth", approximately 5 m above the seabed;

and the bottom sediments. The first deep-sea runs over the SWO and the CWO pipelines were made in July and August 1970 respectively; and follow-ups were performed in January and November 1971. Thereafter, the efficiency of the outfalls was monitored from the shore until the modified effluent discharges commenced. The CWO was examined in April and December 1980; then in February, May, June, July, September and October 1981; and in January and April 1982; thereafter, once a year to date. The SWO was surveyed in October 1980; then in May, July, September and December 1982; then, once a year to date.

Special runs: these included the intensive surveys on the key Stations 1, X and 19 (see Tables A4.1 - A4.3 in the Appendix), and on the works effluents (primary tank effluents and sludges) as well as the final mixes at the Southern Works. Other surveys comprised testing all the pipes, drains, canals and waterways, including the lower reaches of the Mgeni River, employing the full spectrum of indicators during the time when the works and the outfalls were under construction; runs relating the coliform index to tides; fortnightly *E. coli* I runs on the 28 stations between March 1970 and November 1971; several regular surveys on certain stations (eg: Stations 15 and 26) for limited periods; and extensive bacteriological testing of beach sands (with meagre and inconclusive results). These latter runs are considered only marginally relevant to the main purpose of the survey and the findings are therefore not detailed here. A special run was made on all the bathing beaches in December 1987 to check their condition a few months after the Natal Floods and the results are included (all had re-attained Class I water quality). Other special runs included utilizing shellfish as *in situ* monitors for salmonellae along the Bluff beaches, with negative findings except in the vicinity of the canals; and viral and coliphage runs with very similar results.

4.1.3 Test aliquots

In water: all bacilli were measured per 100 m*l*; parasite unit numbers (ova of *Ascaris* and *Taenia* spp.), salmonellae and shigellae per 250 m*l*; staphylococci per 50 m*l*; viruses per 10 *l*; coliphages per 10 m*l*.

In seabed sediments and sands: all results were per g.; except viruses which were initially tested per 16 g, then per 100 g (and which all yielded negative findings).

In works effluents: test aliquots were the same as in water; except for staphylococci in 0,5 m*l*, and viruses per litre of sludge.

4.1.4 Indicators at the works

The range of indicators at the works was wide; extremes measured were:

Total coliforms/100 m*l*	5,5 x 10^5	-	80,4 x 10^8
Presumptive *E. coli*/100 m*l*	3,8 x 10^5	-	44,1 x 10^8
E. coli I/100 m*l*	2,9 x 10^5	-	35,3 x 10^8
Irregular II/100 m*l*	1,0 x 10^5	-	8,8 x 10^8
Irregular VI/100 m*l*	>1	-	1,8 x 10^7
Parasite units/250 m*l*	0	-	113

Staphylococci in 50 m*l* and salmonellae in 250 m*l* were usually present, shigellae in 250 m*l* rarely.

The extremely low indices (obtained from the primary tank effluent at the Southern Works) were measured in April 1984; in January and February of that year the two cyclones struck Natal ending the drought, and the stringent water restrictions obtaining were lifted. Such low concentrations of bacteria were not encountered prior to April 1984, nor since; the range of indices usually being of the order of 10^6 - 10^7.

4.2 DEPICTION OF THE RESULTS

The results have been translated to visual depictions wherever possible: each station has been graded from Class I - Class IV from its indicator values. However, Tables A4.1 - A4.3 in the Appendix list the August 1968 - November 1971 results on Stations 1, X and 19, regarded as key stations, and have been included as examples of the application of the indicator evaluation and classification system. (All data, including figures, amplifying or illustrating themes and issues raised that might be regarded as peripheral to the main impetus of the text, which may nevertheless prove useful as an adjunct to the findings have been diverted to the Appendix.)

4.2.1 Beach runs

Figs 4.1 - 4.7 present averages of indicators and classifications on the full beach runs, and of the total indicator values for each of the 28 sampling stations surveyed. The upper half of each of these figures depicts the averaged levels of the *E. coli* I $\log_{10}$ indices in red, and the salinities in green; the remaining indicators (parasite units, *S. aureus*, salmonellae and shigellae) as averaged indicator values in blue; while the classifications appear as bold interrupted black vertical lines. The lower half of each figure similarly shows the sum of averaged indicator values (*E. coli* I in red, salinity in green, and the remainder in blue), the total of the values appearing as the vertical axis.

The eight page Fig 4.8 commences with averaged classifications for every beach station during the runs of 1964 and 1965, the full run (the last before the commissioning of the outfalls) in 1967, and averaged classifications for the three key stations in 1968 and 1969. Thereafter, every run including attenuated runs (which included all the parameters), the shore features and changes in these, and the major climatic events are chronicled.

Figs 4.1 - 4.7 and Fig 4.8 can be referred to in conjunction with Fig 4.9 which is an isogram depicting the full run classifications of the waters at the 28 stations during the 25 years of the survey.

> Fig 4.1 (1964-1967): this graphic represents the full run averaged results in the years prior to the commissioning of the submarine outfalls (Station 1 is at the mouth of the Mgeni; Stations 1a-7 near the main northerly bathing beaches; Station X was the site of the harbour discharge; Station 12 the whaling factory, with the Finnemore Place surf-zone pipe between Stations 12 and 13; Stations 14 and 15 are bathing beaches; between Stations 19 and 20 lies the Mlaas Canal; between Stations 22 and 23 is the Reunion Canal.) The effects from the discharge at Station X are manifest; while the classifications showing

unsatisfactory waters at the Mgeni mouth and near the Mlaas Canal was to be repeated with varying regularity throughout the survey.

Fig 4.2 (1970-1971): the dramatic improvement following the commissioning of the deep-sea pipelines is unequivocal; this period included the time when, due to a mechanical failure at the Central Works, untreated effluent was discharged via the CWO which stems from Station 10.

Fig 4.3 (1972-1976): this period covered the progressive closure of the minor beach outfalls (see pp 128 and 129 in Chapter 6: CONCLUSIONS AND EXTRAPOLATION), while floods occurred in March 1976.

Fig 4.4 (1977-1981): during this phase the sewer between Stations 12 and 13 was closed in February 1979; a drought commenced in December 1979 and water restrictions were imposed; the experimental discharge of modified effluent from the CWO was initiated prematurely in October 1980, then stopped in February 1981, then officially sanctioned in June 1981; flash floods occurred in August 1981 with no overall alleviation of the drought.

Fig 4.5 (1982-1986): in 1982 the experimental discharge was switched from the CWO to the SWO, and the final date of the experiment (which proved a success) was at the end of May in 1983; in January and February of 1984, two cyclones struck Natal ending the drought.

Fig 4.6 (1987): this is the full run of November 1987 and graphically depicts the effects of the Natal Floods which occurred in September; although the region of the canals was very severely affected, the relegation of many of the bathing beaches from Class I to Class II is here evident, and was due mainly to depressed salinities.

Fig 4.7 (1988): the last full run of the survey in August of that year showed all the bathing beaches had reverted to Class I, but the Mlaas Canal area, which is usually polluted, still demonstrating some after-effects of flooding.

4.2.2 Deep-sea runs

Figs 4.10 - 4.12 illustrate the results of the deep-sea work over the outfalls, in the discharge target areas. After these areas were surveyed in 1970 and 1971 (with an extra northerly station - b3 - at the CWO) with negligible results, it was concluded the pipelines were discharging efficaciously with better than predicted dispersal characteristics, with barely any possibility of the discharged material traversing the intervening 3-4 km of open sea to the nearest beach. During the modified effluent discharge experiment, deep-sea monitoring was reinstated, and has continued to date.

> Fig 4.10 (CWO): this graphic shows contact with the discharged effluent in the water columns was intermittent, even at the central station of the target area, d3; the gradations accorded the samples did not approach the Class IV level expected in close proximity to the sewage. In August 1970, Class III water was measured on the surface at d3, but this may be attributable to other causes which will be discussed. Both Class III waters measured at depth at c3 confirm the predominantly north-easterly flow of the ocean current near the seabed. A certain amount of expected scatter occurred and was detected, usually at depth, at a few other stations, but these cannot be regarded as indicating any definite pattern or trend.
>
> Fig 4.11 (CWO): these measurements of *E. coli* I/g of sea sediment show only modest accretions of the bacilli, even close to the pipe. It may be of interest to note that the only result in excess of 1 000 *E. coli* I/g occurred when the discharge of modified effluent was not taking place.
>
> Fig 4.12 (SWO): the picture presented here is unambiguous: occasional contact with the discharge occurred, at depth, at the central station m3; and, further diluted and further out to sea, at m4. These results in the vicinity of a submarine pipeline discharging an excess of 100 x 10^3 m^3/day imply exceptionally good mixing and dispersal by the sea in the area, and validate the design of the outfall's diffuser section.

Fig 4.13 (SWO): the *E. coli* I/g results depicted in this figure again reveal the essentially hostile environment the seabed presents to sewage bacteria; none of the results even approached 1 000/g.

Annual deep-sea runs continued after the modified effluent disposal experiment with little variation in the picture already determined, and are consequently not detailed here.

4.2.3 Viruses and coliphages

Results on the virus and coliphage testing during the modified effluent experiment appear in Figs A4.2 and A4.3 in the Appendix. Along with the works effluent and the deep-sea stations, three beach stations - 10, at the base of the CWO, and 19 and 20 on either side of the Mlaas Canal mouth - were surveyed. Apart from the expected regularly positive findings at the works and near the canal, the paucity of positive results out to sea (especially in the sediments) and at Station 10 suggests the relatively negligible contribution these microorganisms afford in monitoring sea pollution: their role is easily superseded by more accessible indicators. (However, the public health implications of viruses in edible marine molluscs is not denied.) Testing for viruses and coliphages continued after the completion of the modified effluent disposal experiment with similarly meagre results which have not been included here.

4.2.4 Marine life on the pipes

Both outfalls are videod along their whole lengths every second year using underwater cameras (Macleod, D C, pers. comm.*). The films reveal a healthy and vigorous growth of marine fauna and flora on each outfall, particularly near the diffusers: an abundance and variety of fish are to be observed in their vicinities.

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4.3 DISCUSSION

4.3.1 The surf-zone

The sudden and dramatic improvement of water quality in the surf-zone following the closure of the harbour sewer and the commissioning of the submarine outfalls is evident from the results. The beneficial effects increased as the minor outfalls along the beaches were progressively stopped. Temporary adverse effects were measured following major meteorological events. Early in the survey, the Mgeni River and the canals were identified as secondary contaminative foci (after the sewer at Station X was stopped) and have continued in this role to date.

4.3.2 The outfalls

This pair of notable engineering constructs affected the whole region beneficially as soon as Durban's waste waters were diverted into them for deep-sea discharge. Operating at approximately half of their designed capacities (with consequently lessened diffuser velocities), both pipelines have exceeded their initially calculated dilution and dispersal characteristics. Effluent did not reach, and is not reaching the shore in measurable amounts.

Three practical limitations of sea work are:

> Drifting of the research vessel off station due to variations in winds and currents, at times requiring start-up and repositioning.
>
> The small bacteriological returns compared with the time and skills needed in processing sediments.
>
> The possibility of contamination of the sampling milieu by the ship. (Despite restrictions on the discharge of waste while the vessel is stationary, control of galley washings, deck hosing, spitting, and even seasickness, is not always complete. There is also the possibility of contamination from other vessels that have recently traversed the target area.) Surface contamination can be inferred at Station d3 in August 1970 (see Fig 4.10).

Offsetting these limitations is the fact that no evidence of gross pollution approaching the levels of sewage was detected at any of the sea or sediment stations during the survey.

4.3.3 The modified effluent discharge

In conjunction with the microbiology, several disciplines were involved in monitoring the effects of the modified effluent discharge; all branches of this surveillance yielded favourable results (Butler and Sibbald, 1983; Connell, 1983; Livingstone and Calder, 1983; McClurg, 1983; Nupen *et al.*, 1983; Richardson, 1983a, 1983b; Stanton *et al.*, 1983a, 1983b).

The altered nature of the discharges produced no deleterious effects on the target area; nor were any adverse conditions measured in the adjacent surf-zone as a result of the effluents. Undoubtedly, the pipelines are more than adequately fulfilling their designed functions and purpose.

4.3.3.1 Seabed sediments

An interesting impression is conveyed by Grabow (1987) in a review article in which he relayed opinions on the importance of sediments in polluted marine environments with regard to health-related micro-organisms: enteric viruses, apparently, may be ten times or more as high in marine sediments than in the overlaying water because, it is reputedly believed by some, the sediments provide a beneficient environment for both viruses and non-marine bacteria. This may be true in some parts of the world in more quiescent waters, or where the sheer weight and intensity of accumulated waste material has altered the nature of the seabed obliterating the indigenous biota, but such conditions do not occur off Durban. Reference to the *E. coli* I indices/g (see Figs 4.11 and 4.13) and the meagre virus results (see Figs A4.2 and A4.3 in the Appendix), even at sediment stations close to the diffuser sections of both outfalls, reveal the local state of affairs on the seabed. Moreover, Schleyer and Roberts (1987) found numbers of free-living organisms of the order of 3,23 x 10^9/g in surface sediments offshore of Durban. Apart from the high-energy dynamics affecting the local waters and seabed, it is improbable that such an alien matrix as a marine sediment would provide a beneficial resting place or culture milieu to allochthonous micro-organisms: competition and predation from the indigenous organisms would patently be fierce. The chances for protracted survival of biological entities from domestic wastewater must therefore be fairly slender in an arena of such physiological contention.

4.3.4 Validity of sampling frequencies

In the contemporary mode of the modern statistical approach that has become an article of faith in several aspects of the biological sciences, the implicit demand requiring analyses of an inordinate number of samples, it could be argued that more frequent sampling would have produced results of greater statistical validity in this survey. Such an approach requires close analysis in its turn. The testing of vast tracts of sea for wastewater indicators, remote from any pollution source is patently absurd, except to serve as controls; sampling regimens require intelligent spatial consideration, particularly with modern outfalls incorporating diffusers of sophisticated design affording rapid entrainment of seawater, fast dilution and dispersal. Careful selection of sampling points closely interrelated with shore-based sanitary features (including waterways), the behaviour of tides, longshore and ocean currents, wave patterns and meteorological conditions, coupled with more than one parameter can afford a valid enough picture without endless duplications of bacteriological tests. The quantum leap in perceptions regarding the microbial state of the surf off any coastal city's beaches, after even one test run, from a prior state of complete absence of knowledge, becomes immediately palpable (eg: see the 1967 run in Fig 4.8; or the 1970 run). Analysis of variance of the data was considered to be unnecessary owing to the unequivocal nature of the results.

This survey spanned a quarter-century, during which approximately 100 samples per annum were examined, each subjected to a multiplicity of tests (other surveys were in progress concomitantly), and it provides a solid enough background against which future changes consequent upon development can be measured. More frequent repetitions of microbial procedures, provided coastal features remain unchanged, would add little to an already comprehensively ascertained picture: changes on the shore were invariably reflected by changes in the sea. Conversely, when microbial changes were detected in the sea, there invariably existed a reason: climatic, topographical, or produced by the hand of man. This reciprocal equation is, as this survey has proved, inevitable and incontrovertible.

4.4 SUMMARY

Given the range of indicators and disciplines involved, the spectrum of investigative procedures and the time-span covered, the sea off Durban - a city that combines the roles of Africa's busiest port, major industrial centre and prime holiday resort - possibly ranks among the more rigorously researched and biologically monitored marine regions on the planet. If global climatic changes occur, this survey constitutes a possibly valuable historical record. In any event, a microbial marine data baseline has been acquired against which developmental changes occasioned by escalating socio-demographic stress to the region can be measured.

Other possible scenarios in which this survey may prove useful are a pipeline break; or the closure of one or both of the existing outfalls following advances in disposal technology; the present damming of the Mgeni River; or the cleaning up of the canals; or a decimation of the population. Changes could even include a third (intelligently sited!) outfall: it has been fairly demonstrated the discharge area is dynamic and resilient enough to deny the accumulation of deleterious matter; no threat to the marine biota in the target area has been discerned; and no adverse effects originating from the pipelines have proved measurable in the adjacent surf-zone. Unfavourable results throughout the survey have been shown to derive from disposal or drainage features on the shore, including watercourses; temporarily inauspicious results have been precipitated by climatic events flushing terrigenous detritus into the sea.

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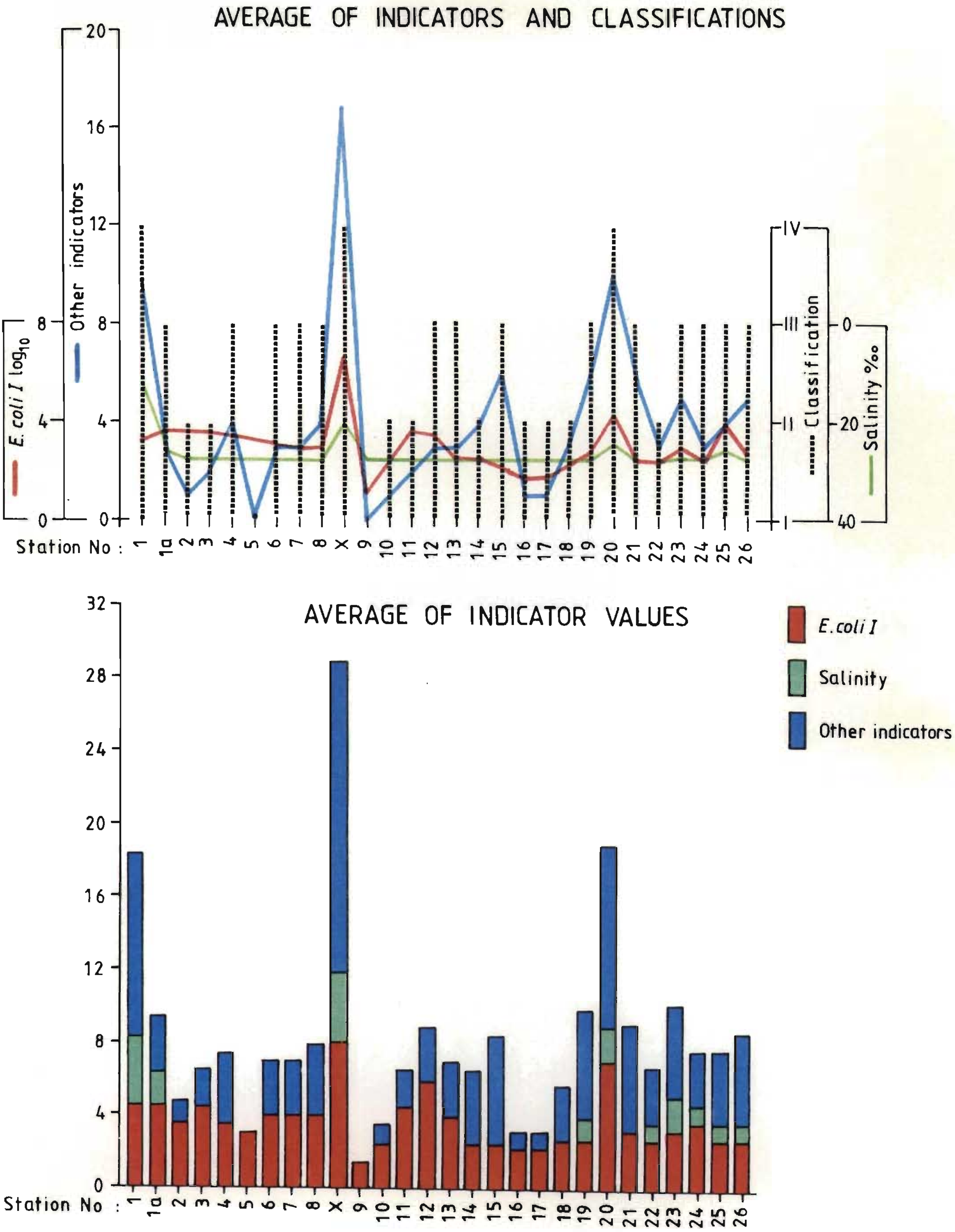
1964 to 1967



AVERAGE OF INDICATORS AND CLASSIFICATIONS

AVERAGE OF INDICATOR VALUES

Fig 4.1 Indicators and classifications prior to the submarine outfalls

1970 to 1971

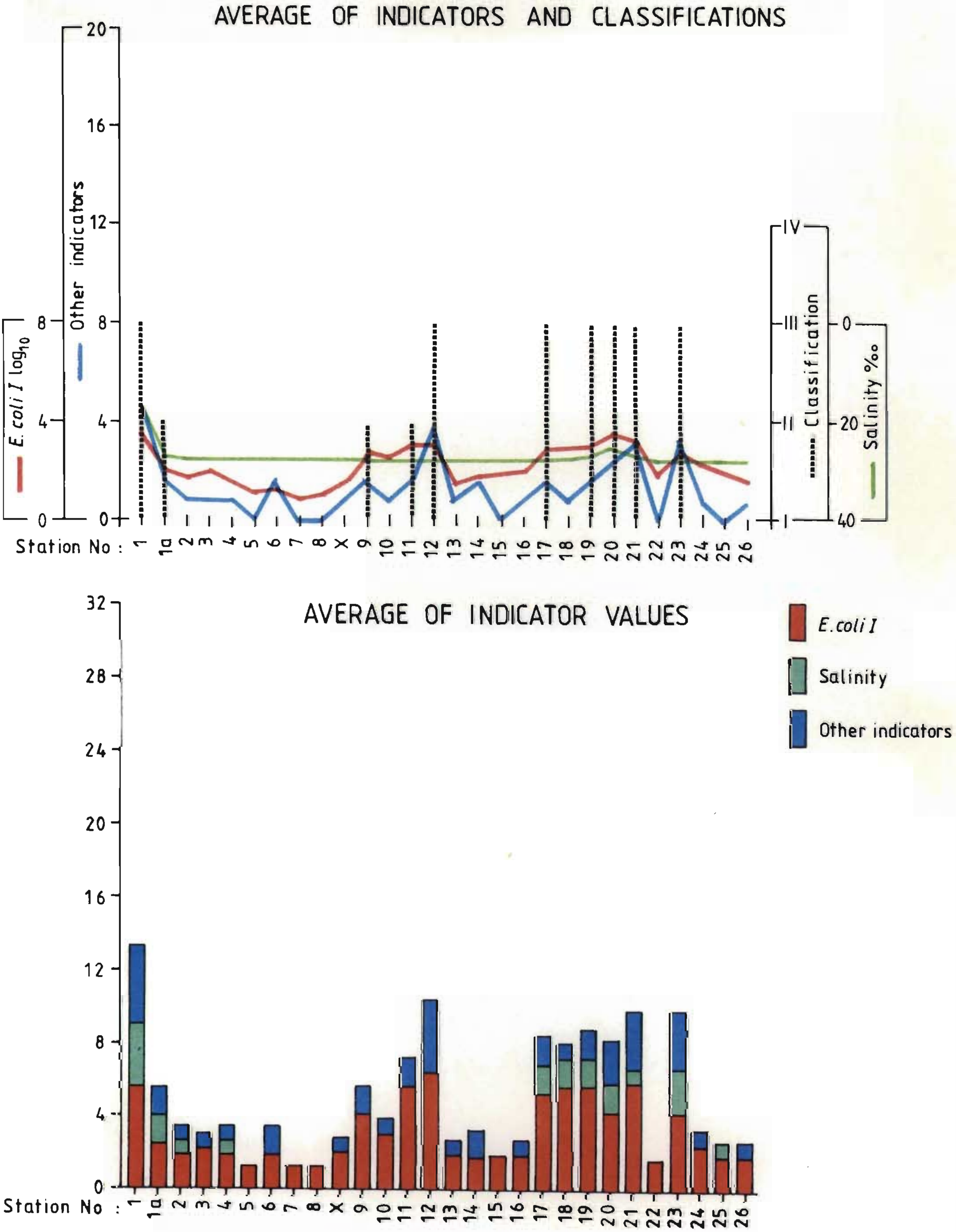


Fig 4.2 Indicators and classifications: 1970 to 1971

1972 to 1976

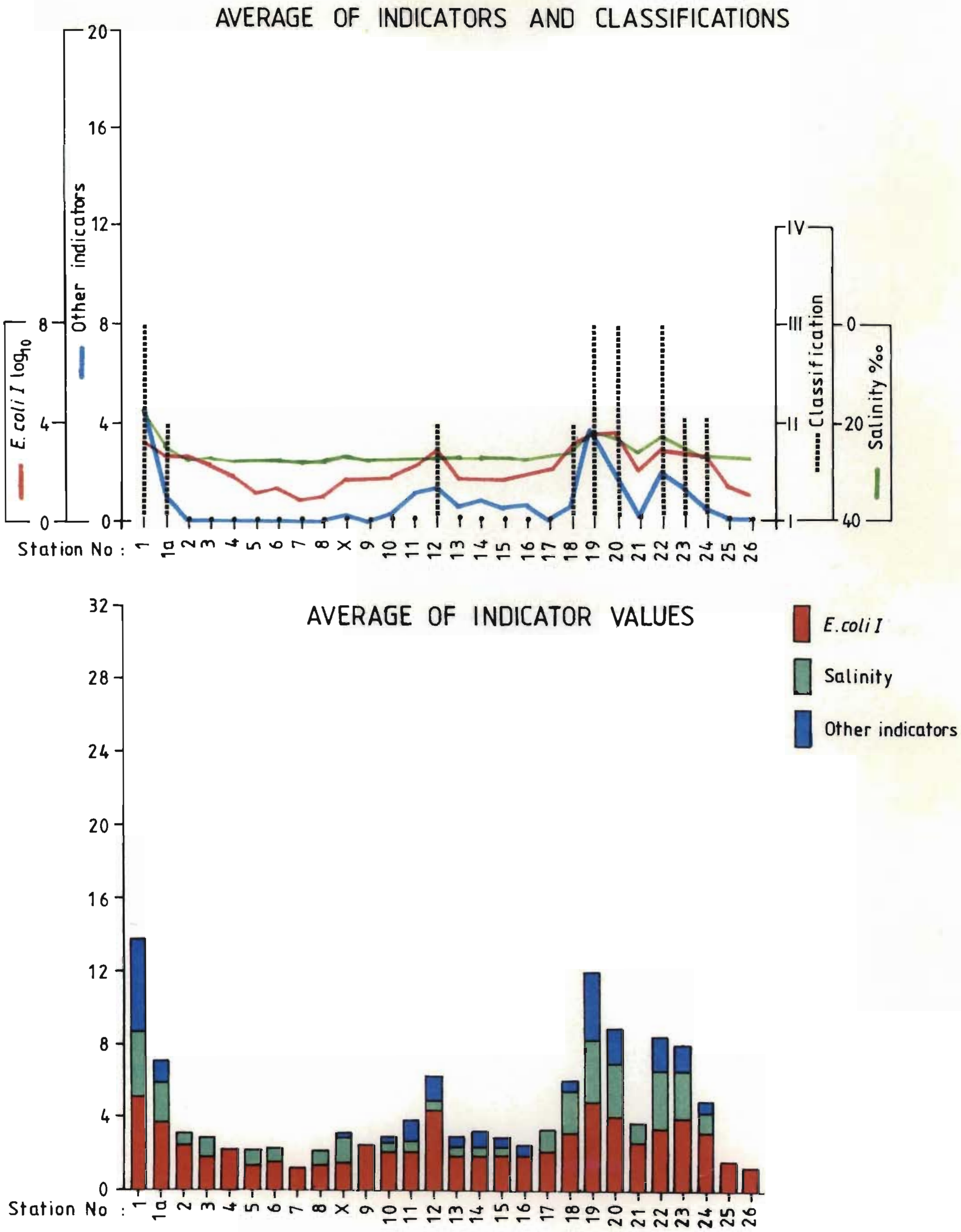


Fig 4.3 Indicators and classifications: 1972 to 1976 (omitting 1975)

1977 to 1981

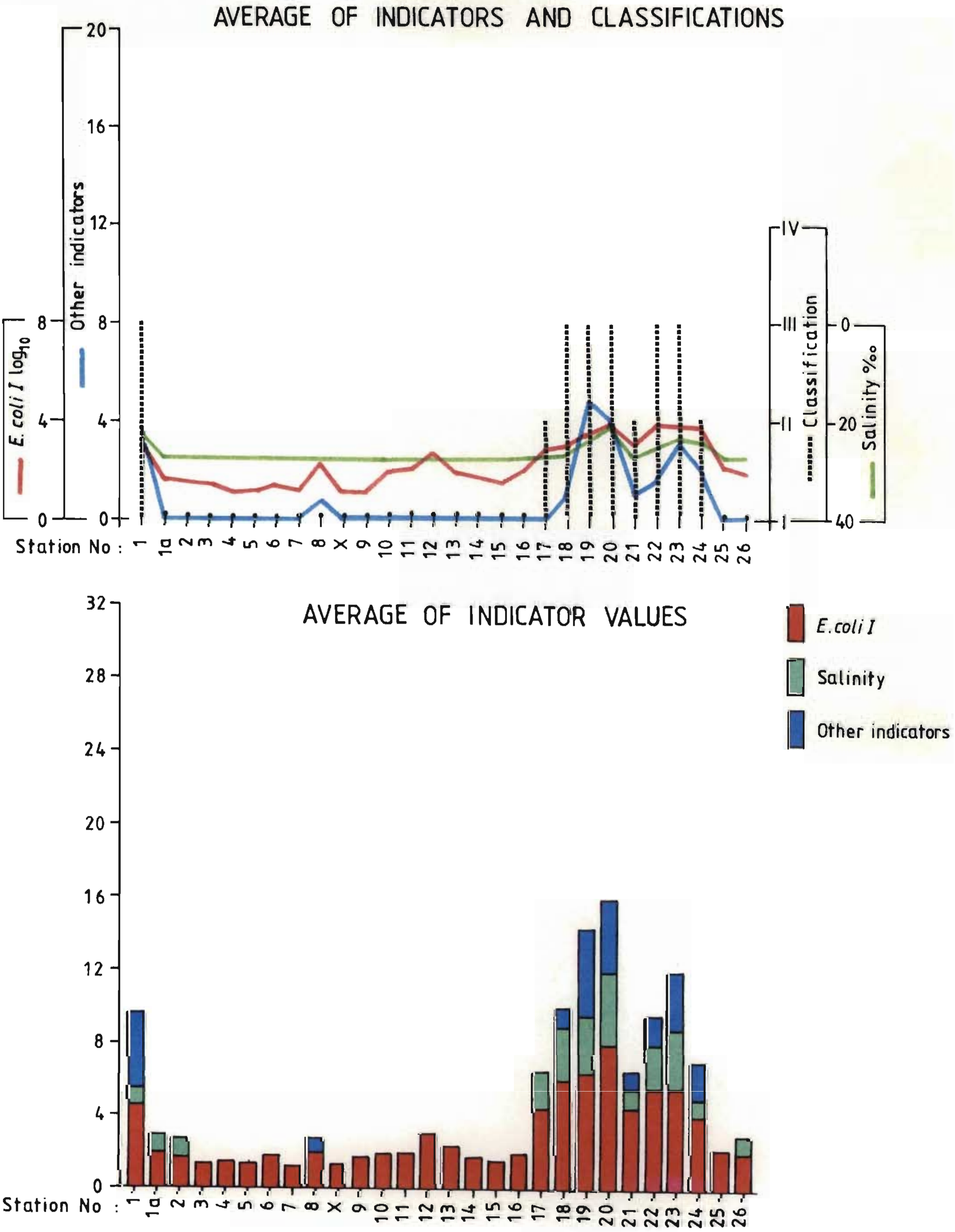
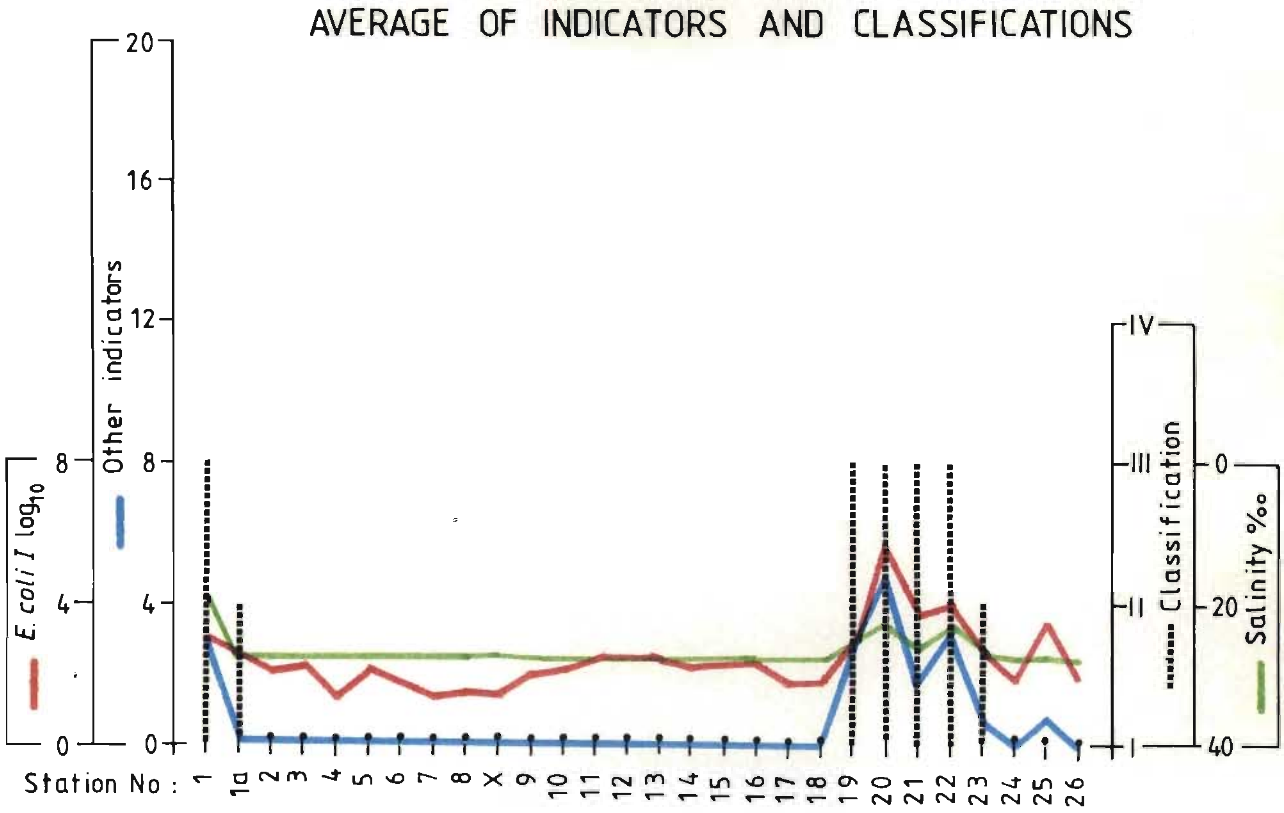


Fig 4.4 Indicators and classifications:
1977 to 1981

1982 to 1986



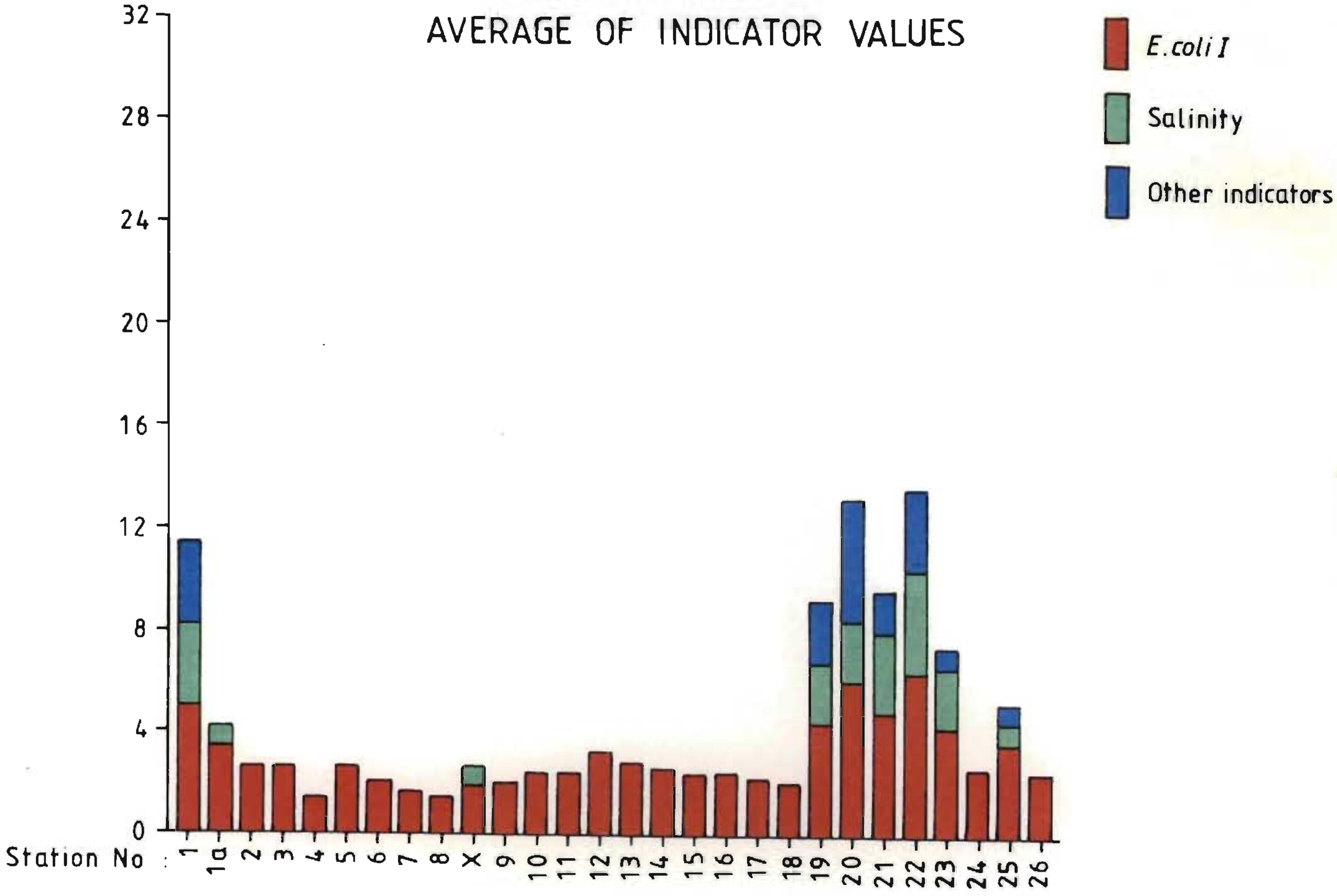


Fig 4.5 Indicators and classifications: 1982 to 1986

1987

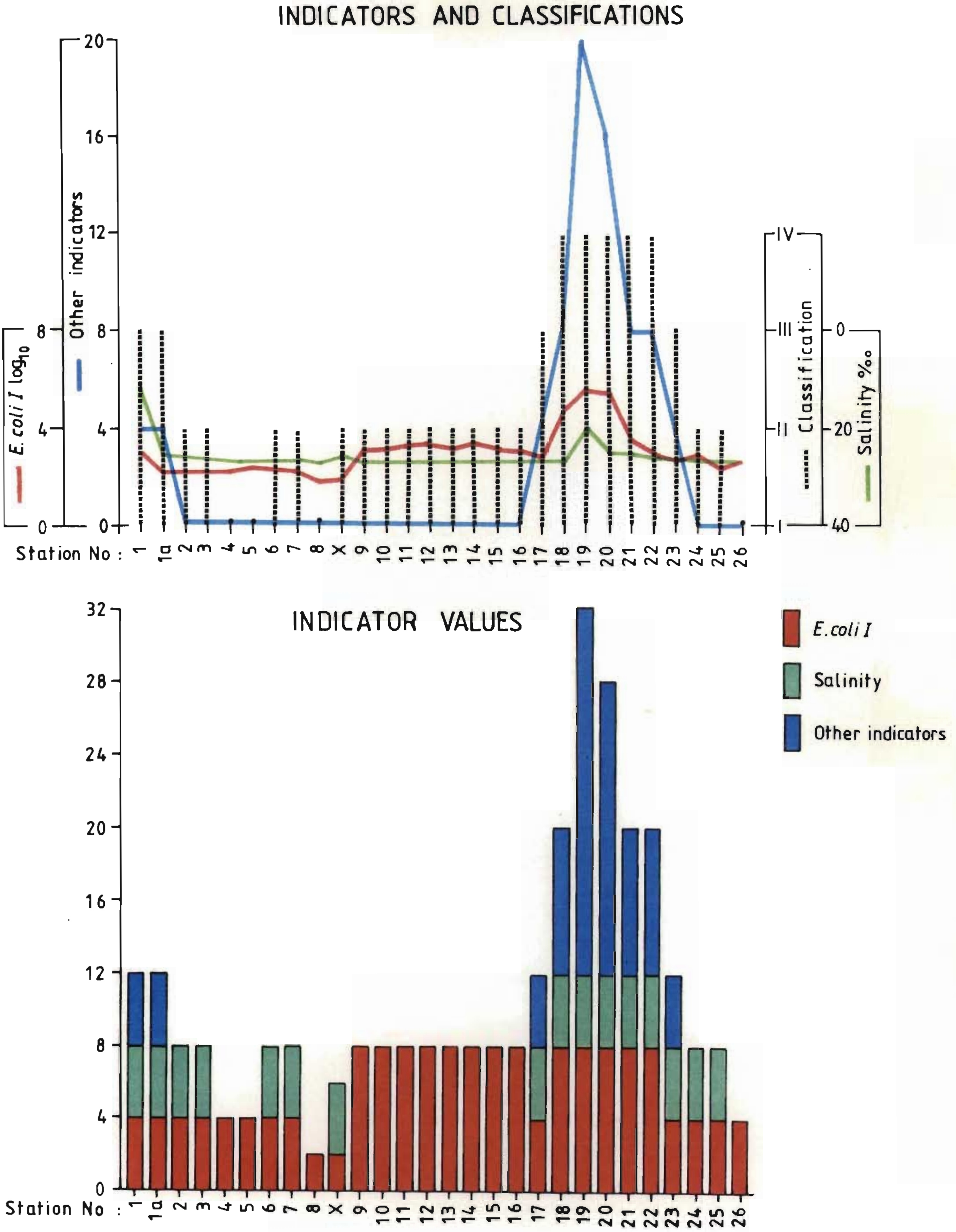
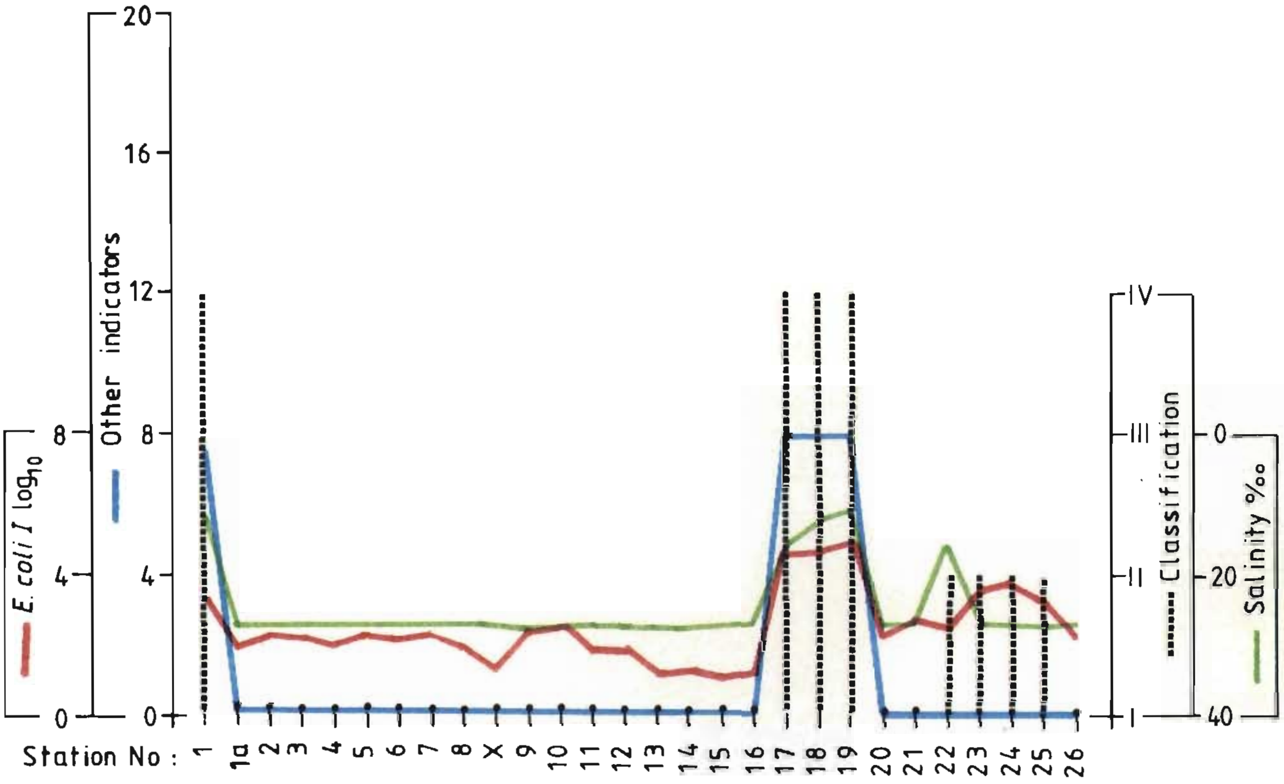


Fig 4.6 Indicators and classifications in 1987: the year of the Natal Floods

1988

INDICATORS AND CLASSIFICATIONS



INDICATOR VALUES

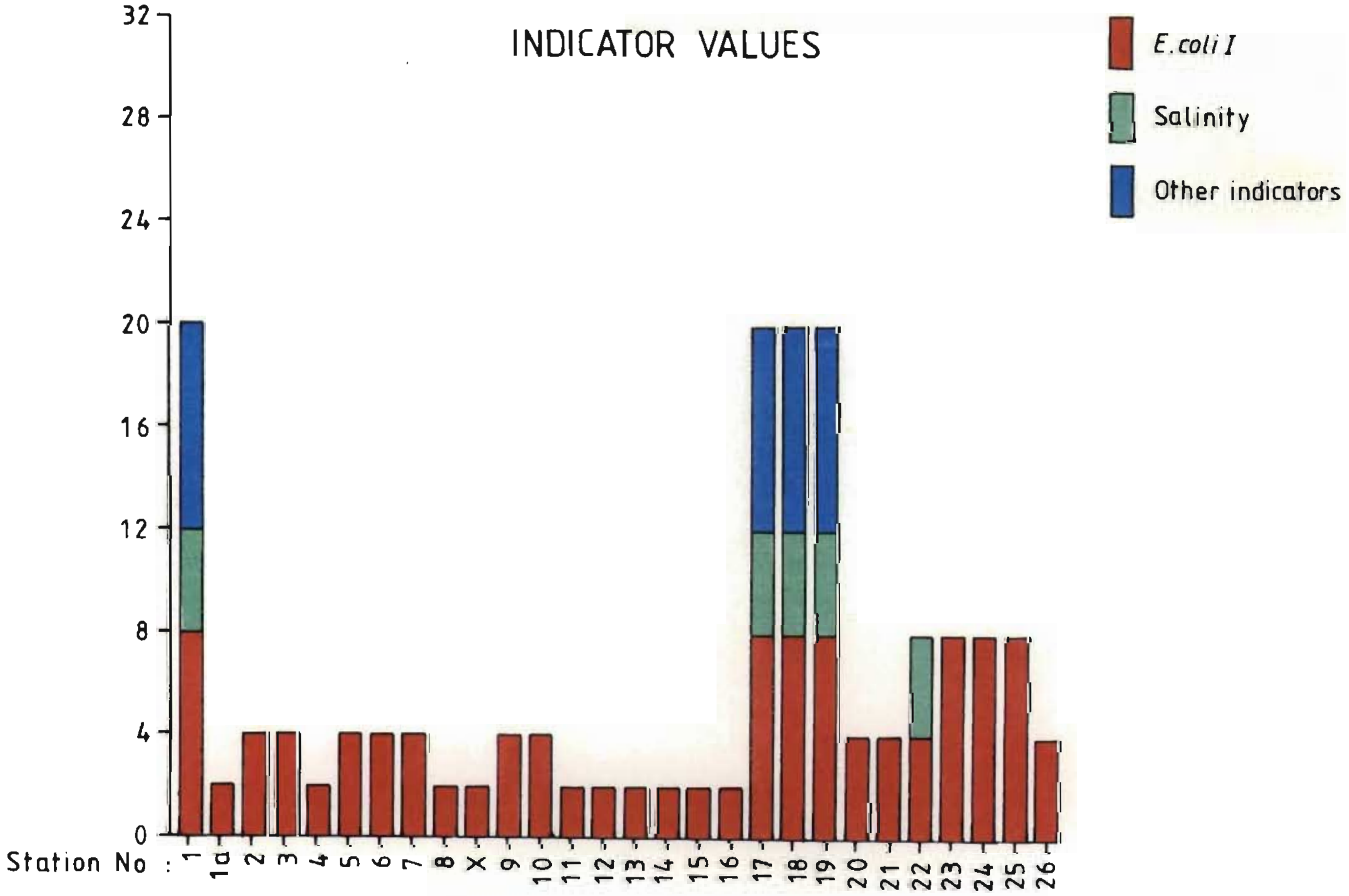
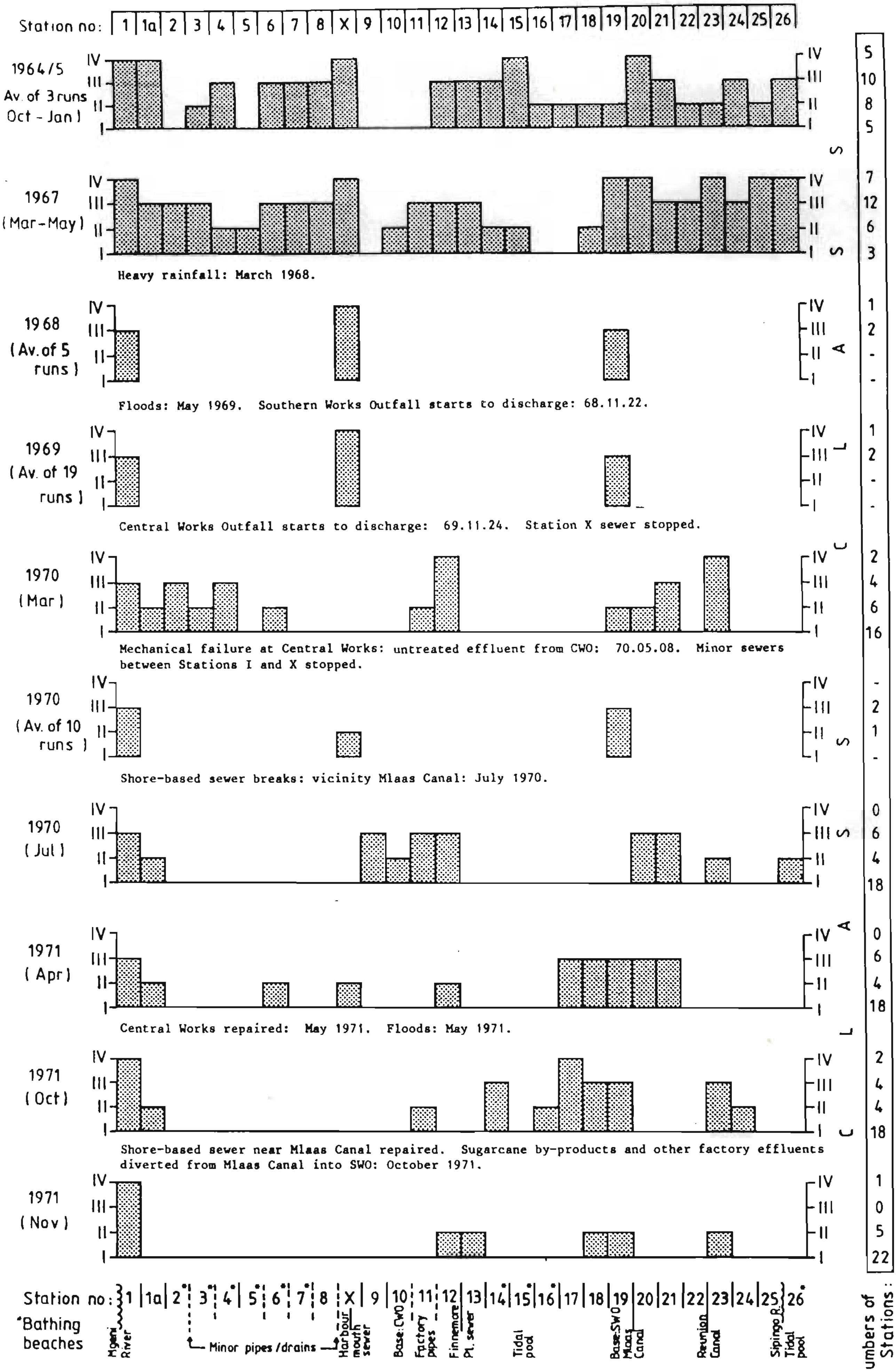


Fig 4.7 Indicators and classifications in 1988: the last year of this survey



Heavy rainfall: March 1968.

Floods: May 1969. Southern Works Outfall starts to discharge: 68.11.22.

Central Works Outfall starts to discharge: 69.11.24. Station X sewer stopped.

Mechanical failure at Central Works: untreated effluent from CWO: 70.05.08. Minor sewers between Stations I and X stopped.

Shore-based sewer breaks: vicinity Mlaas Canal: July 1970.

Central Works repaired: May 1971. Floods: May 1971.

Shore-based sewer near Mlaas Canal repaired. Sugarcane by-products and other factory effluents diverted from Mlaas Canal into SWO: October 1971.

Fig 4.8 Classification of the surf waters, with shore features and an outlined chronology of events

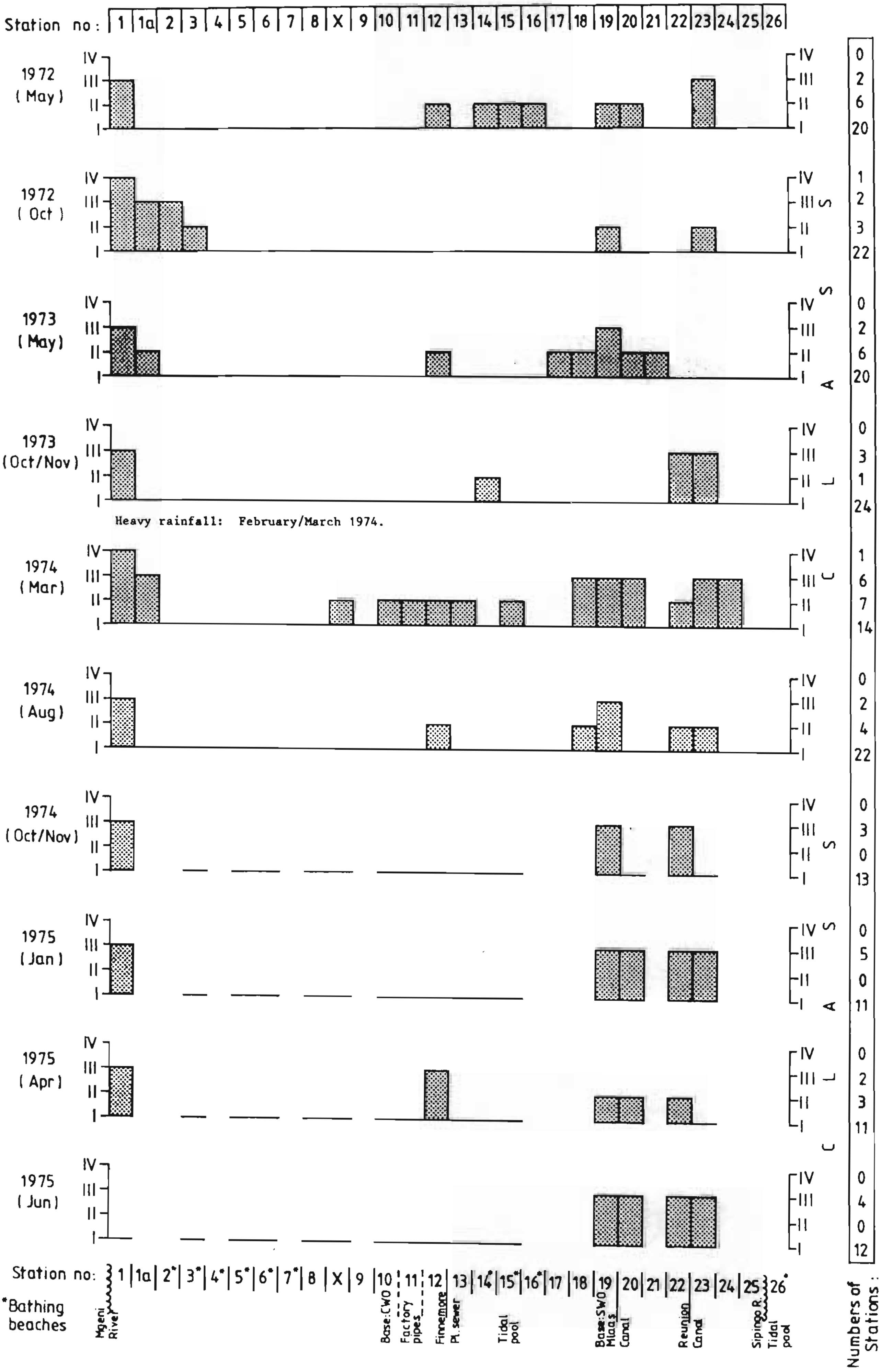
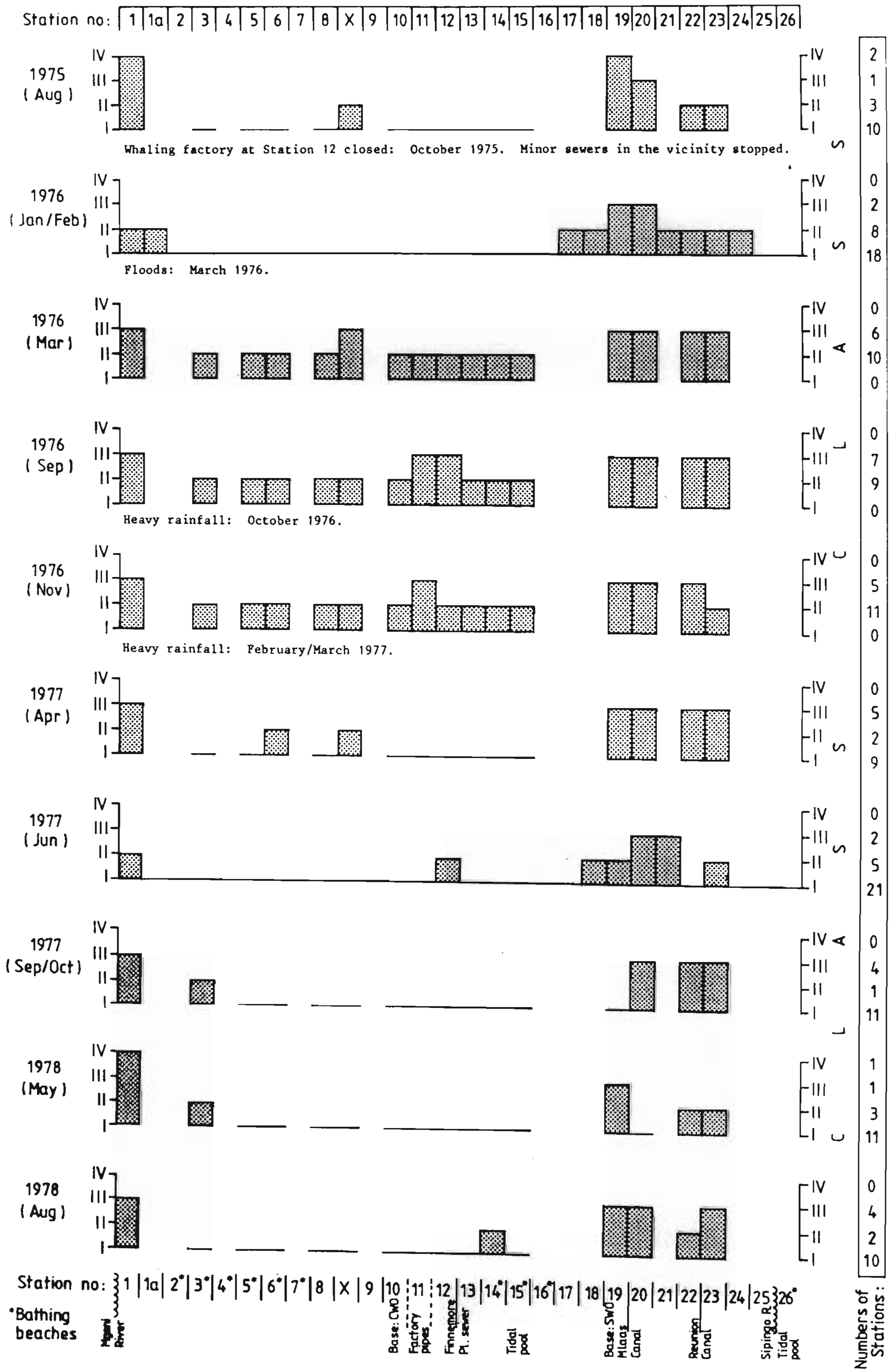


Fig 4.8 Continued



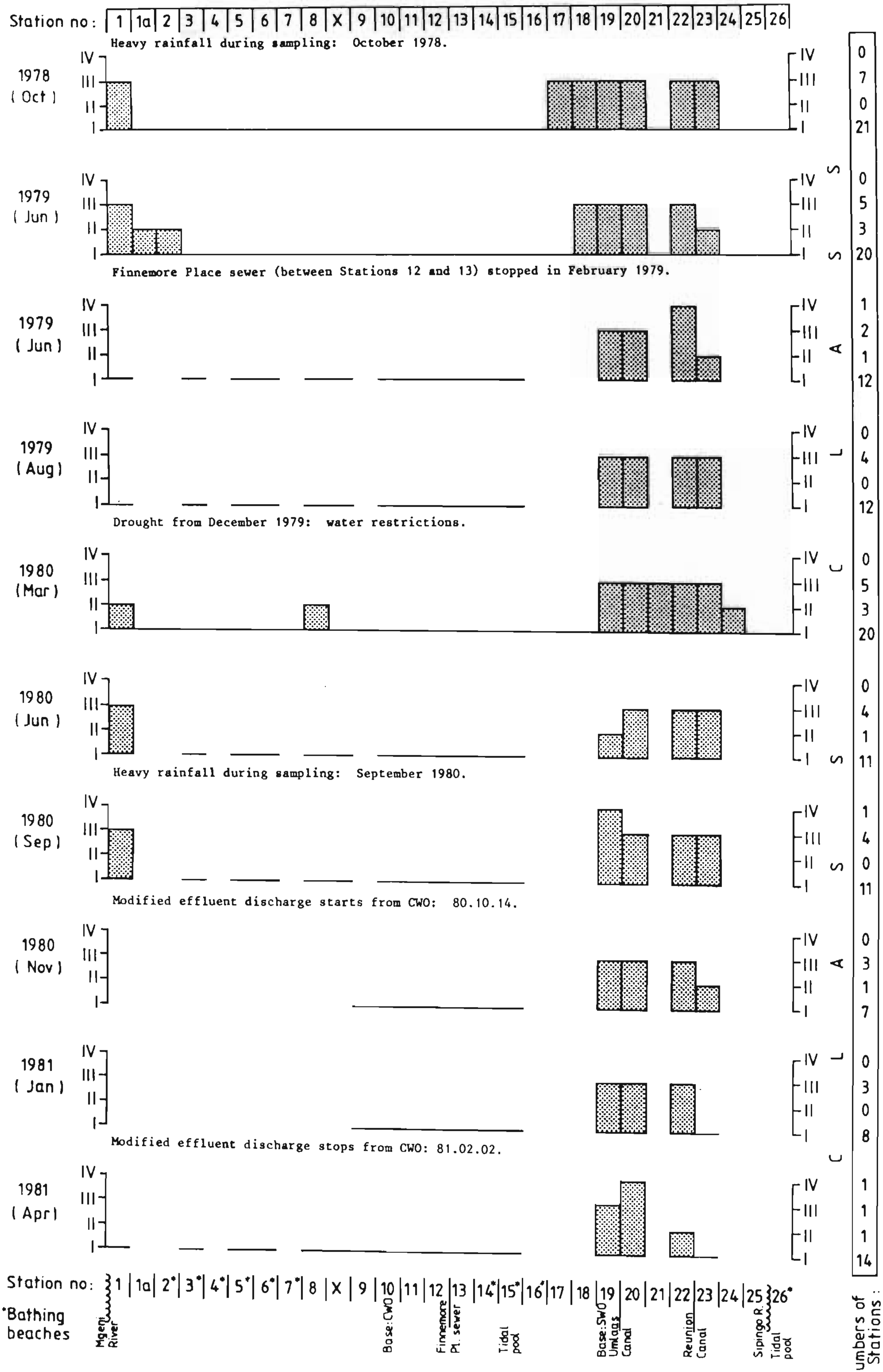
Whaling factory at Station 12 closed: October 1975. Minor sewers in the vicinity stopped.

Floods: March 1976.

Heavy rainfall: October 1976.

Heavy rainfall: February/March 1977.

Fig 4.8 Continued



Heavy rainfall during sampling: October 1978.

Finnemore Place sewer (between Stations 12 and 13) stopped in February 1979.

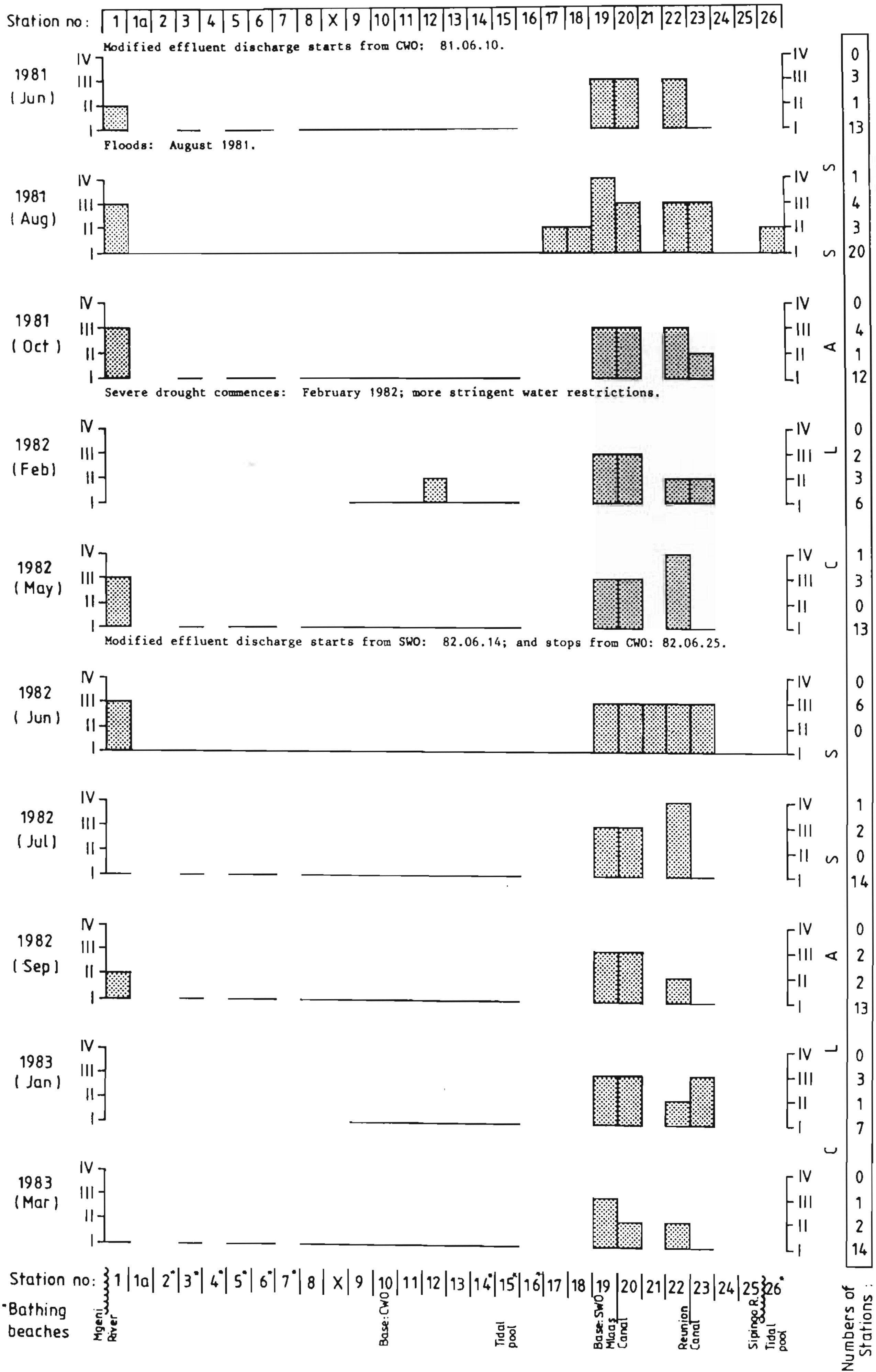
Drought from December 1979: water restrictions.

Heavy rainfall during sampling: September 1980.

Modified effluent discharge starts from CWO: 80.10.14.

Modified effluent discharge stops from CWO: 81.02.02.

Fig 4.8 Continued



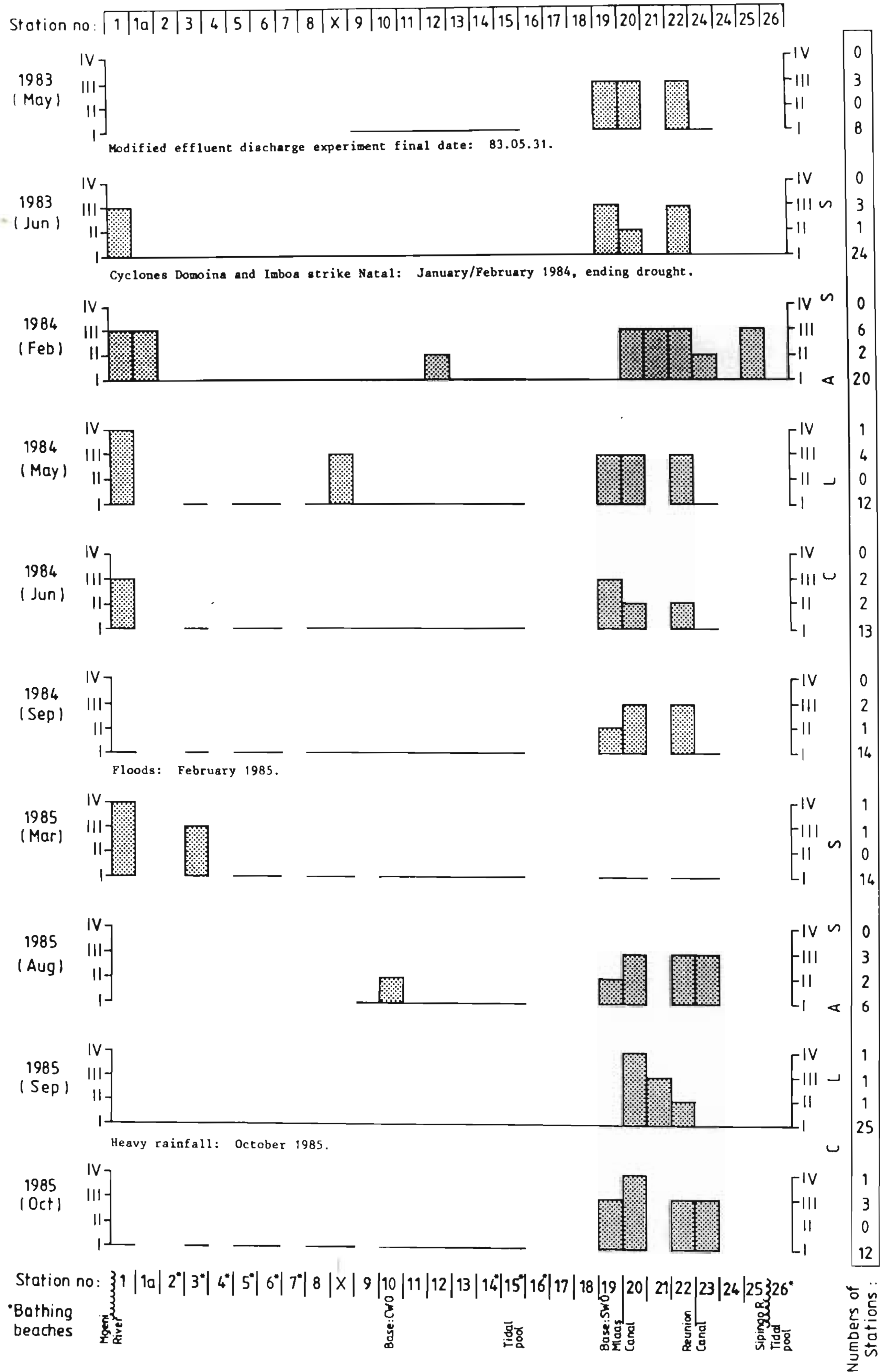
Modified effluent discharge starts from CWO: 81.06.10.

Floods: August 1981.

Severe drought commences: February 1982; more stringent water restrictions.

Modified effluent discharge starts from SWO: 82.06.14; and stops from CWO: 82.06.25.

Fig 4.8 Continued



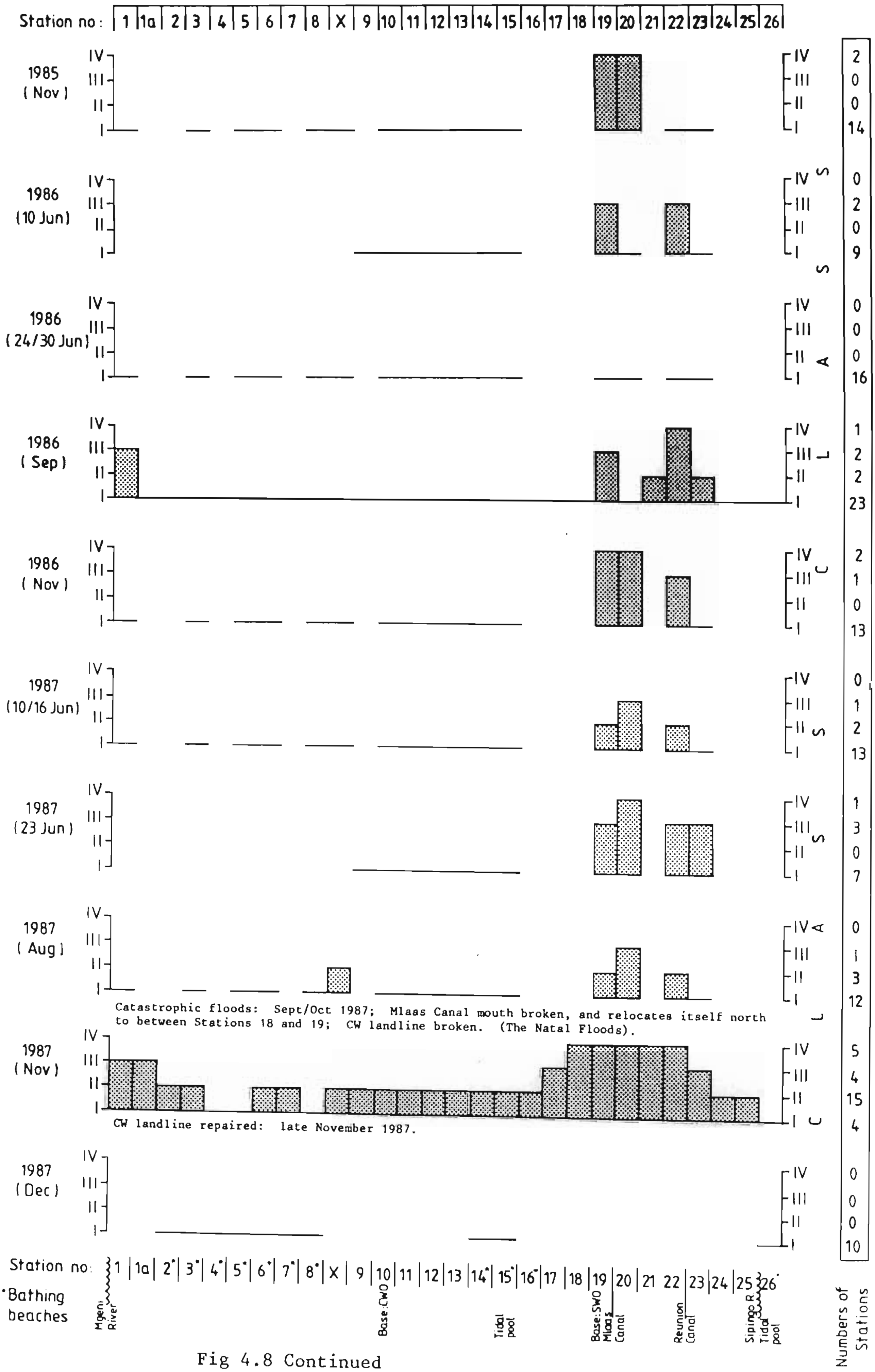
Modified effluent discharge experiment final date: 83.05.31.

Cyclones Domoina and Imboa strike Natal: January/February 1984, ending drought.

Floods: February 1985.

Heavy rainfall: October 1985.

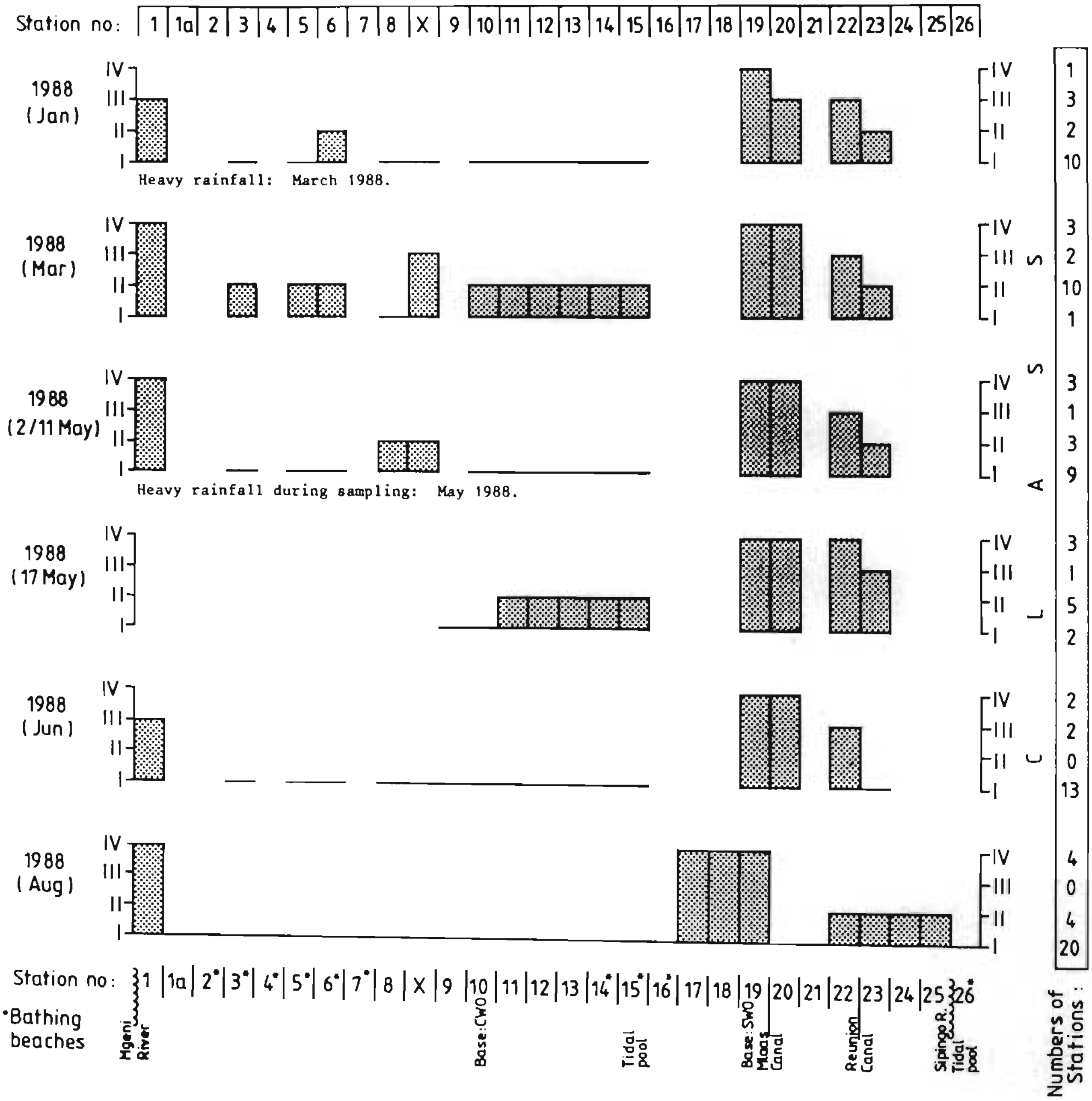
Fig 4.8 Continued



Catastrophic floods: Sept/Oct 1987; Mlaas Canal mouth broken, and relocates itself north to between Stations 18 and 19; CW landline broken. (The Natal Floods).

CW landline repaired: late November 1987.

Fig 4.8 Continued



Heavy rainfall: March 1988.

Heavy rainfall during sampling: May 1988.

Fig 4.8 Ends

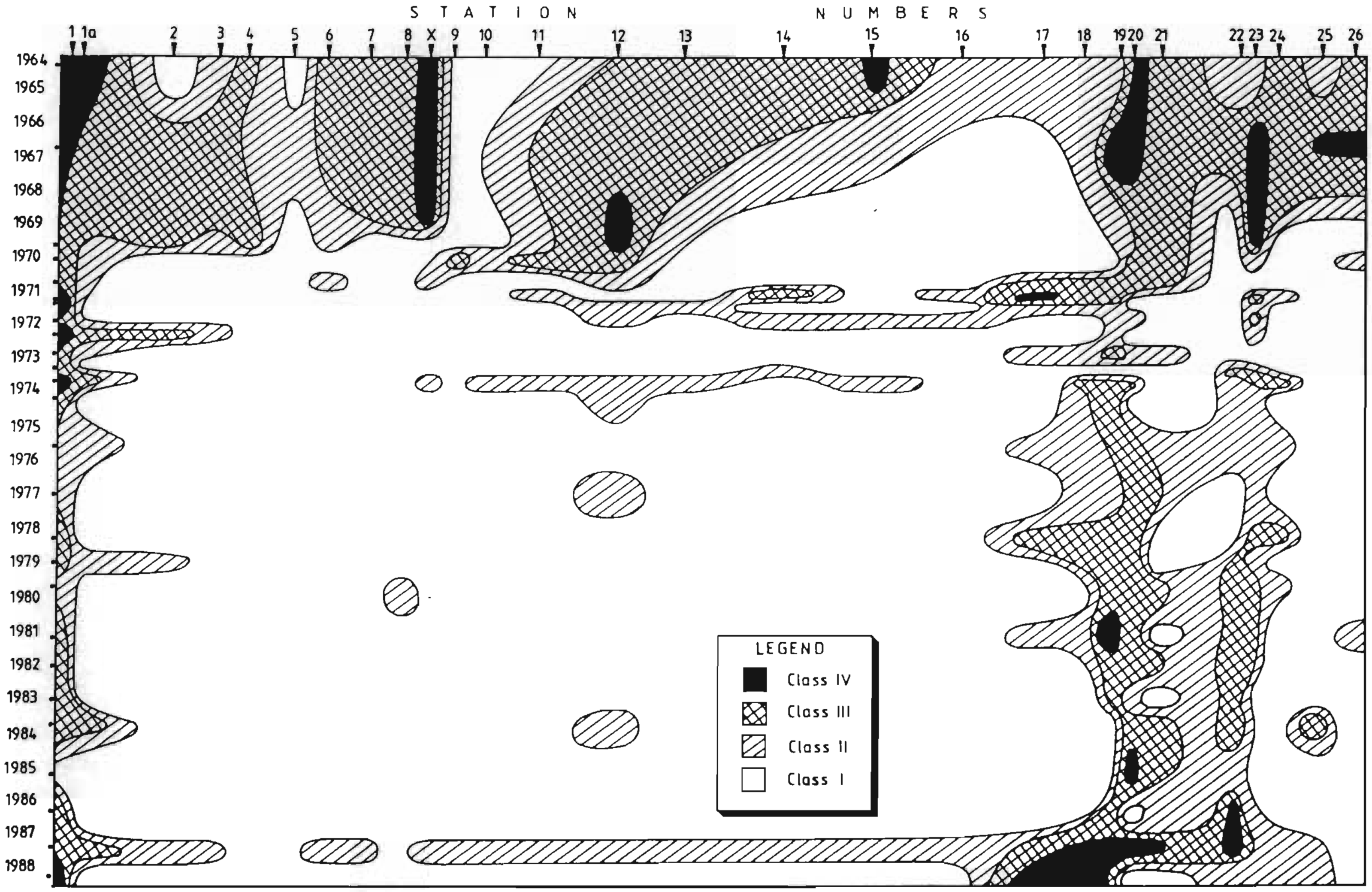


Fig 4.9 Isogram depicting classification of the surf-zone at the 28 sampling stations in space/time. (Horizontal axis showing the stations approximately distanced; vertical axis the years.)

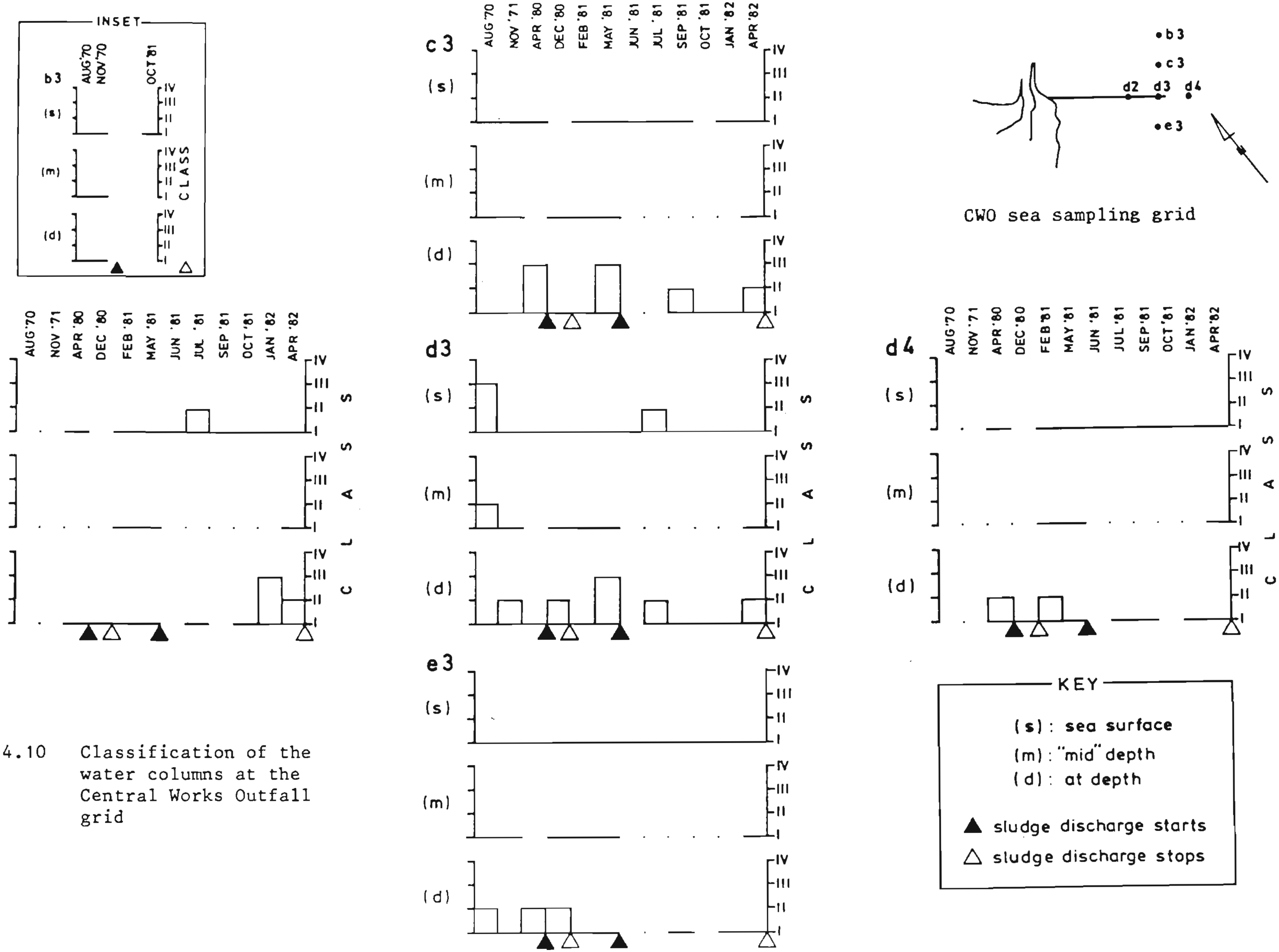


Fig 4.10 Classification of the water columns at the Central Works Outfall grid

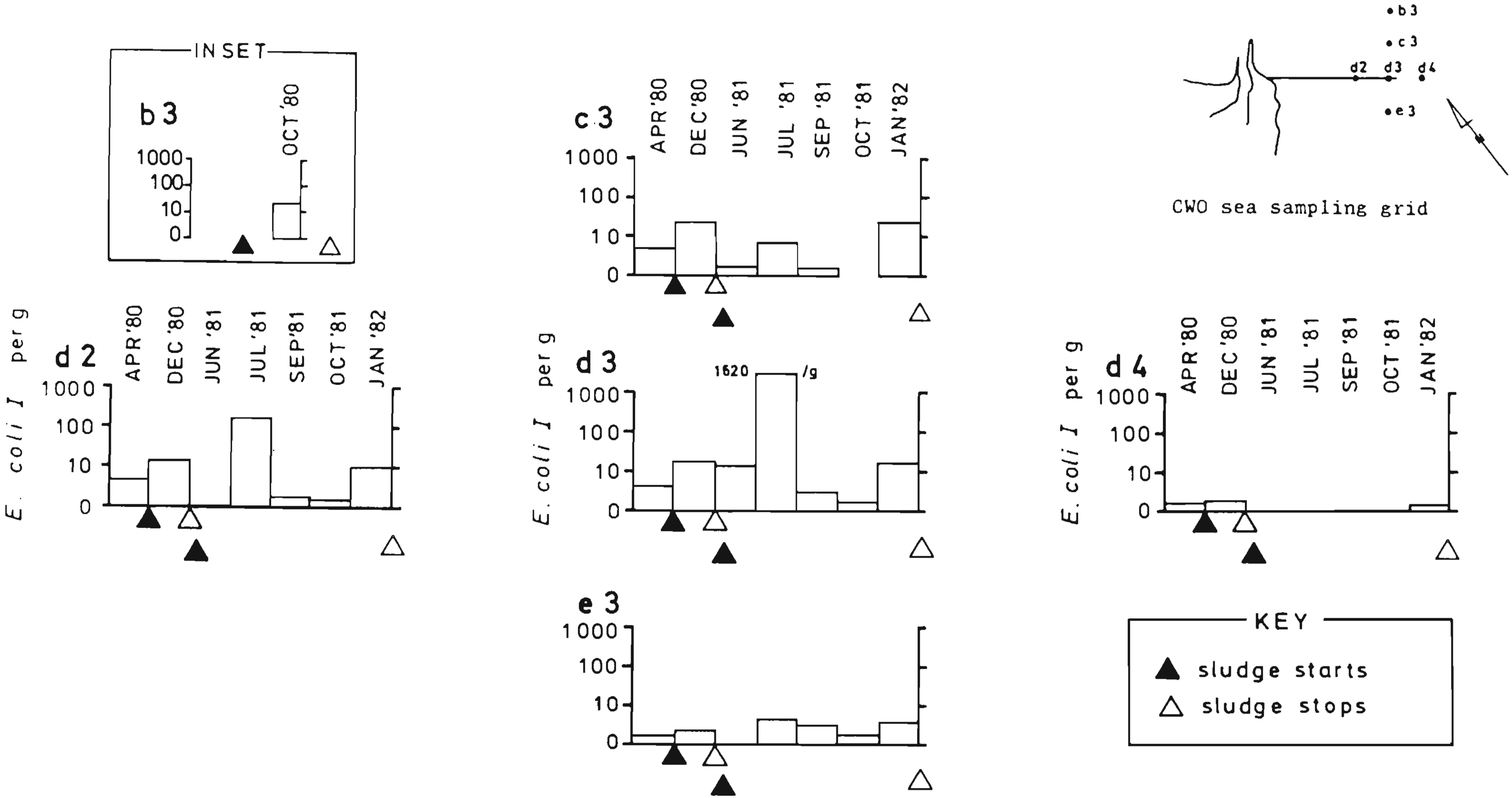


Fig 4.11 *E. coli* I/g on sediments from the Central Works Outfall grid

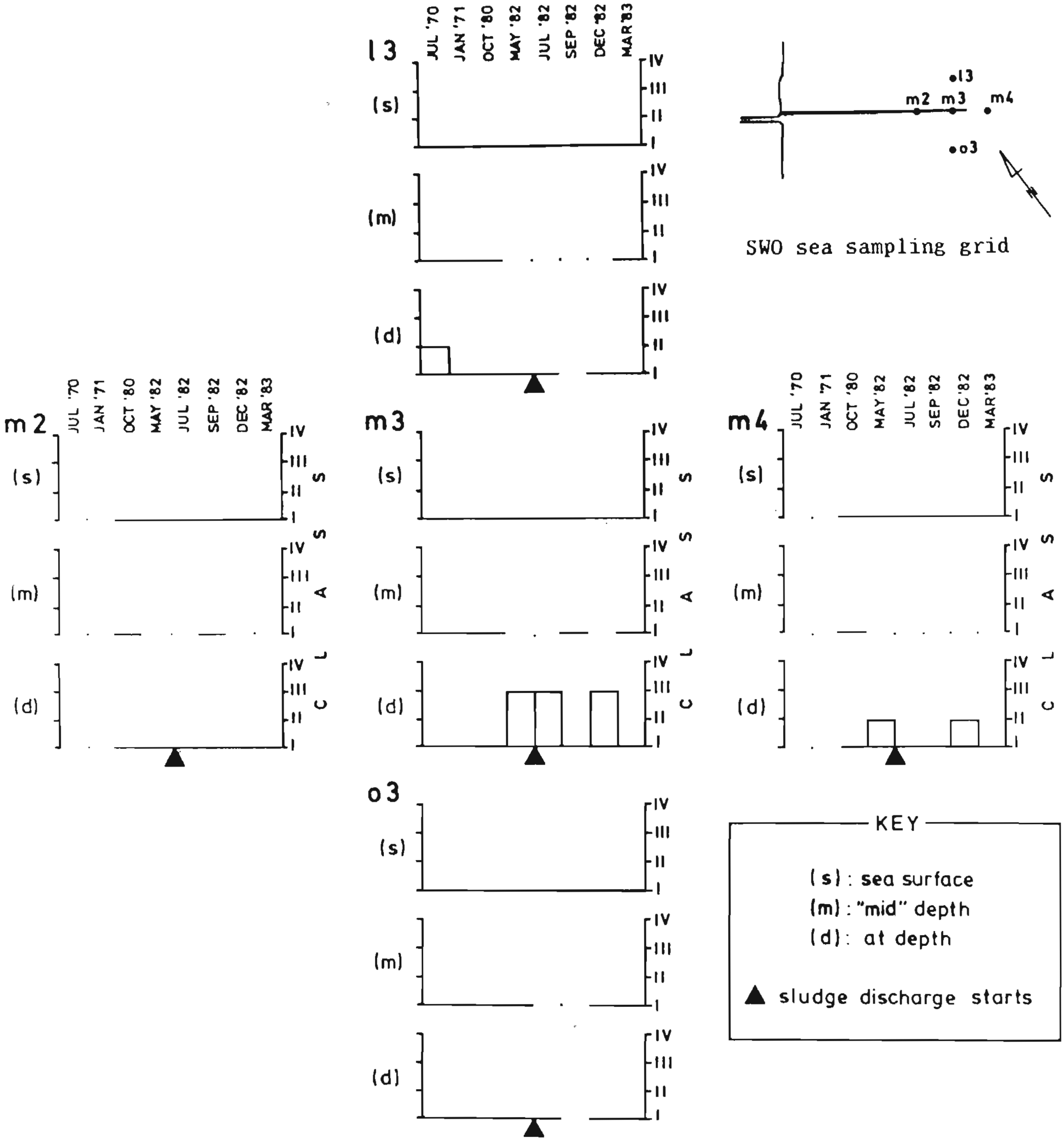


Fig 4.12 Classification of the water columns at the Southern Works Outfall grid

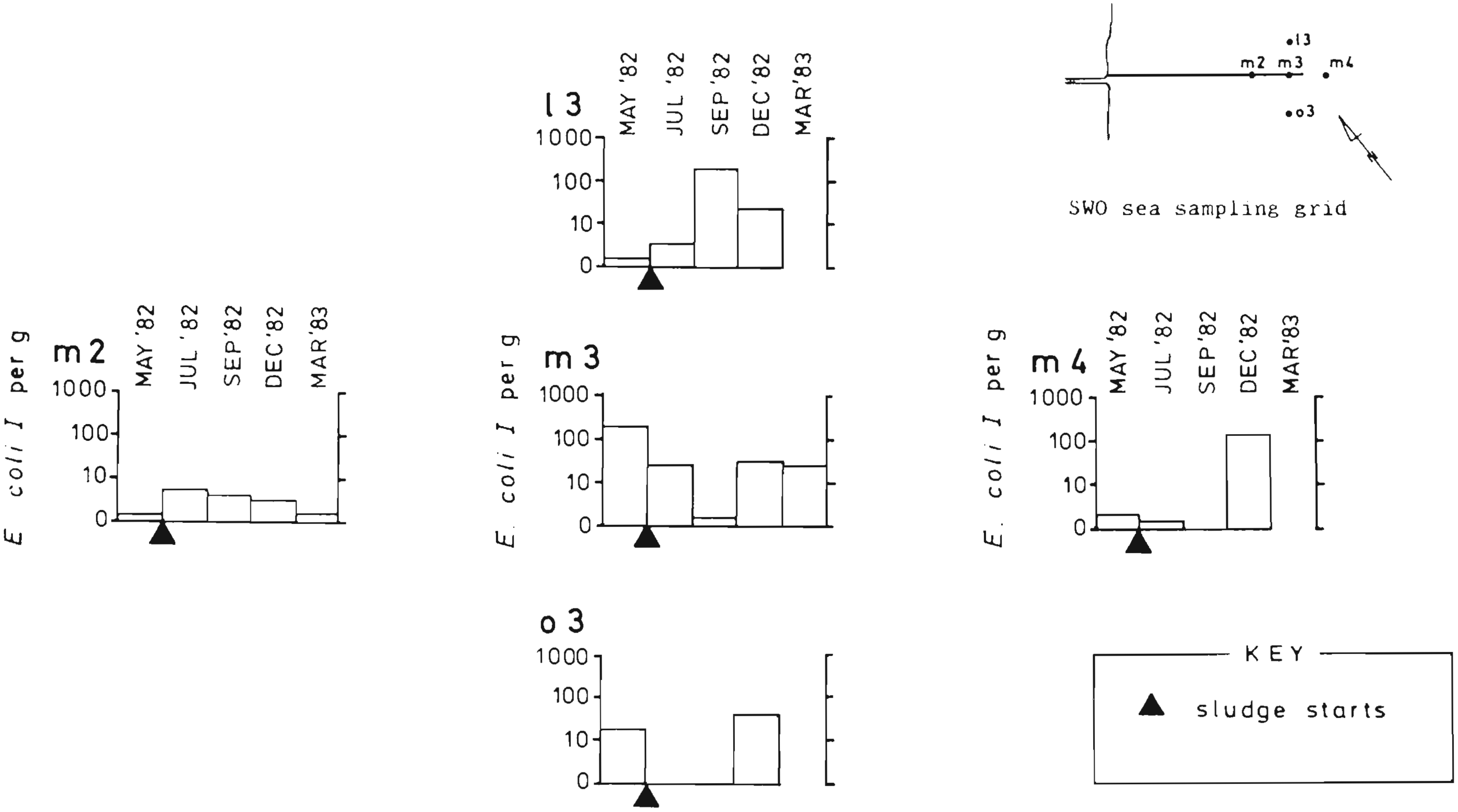


Fig 4.13 *E. coli* I/g on sediments from the Southern Works Outfall grid

CHAPTER 5 : MARINE POLLUTION AND ASSOCIATED RISKS

5.1 RISK: A PERSPECTIVE

In the context of marine pollution, risk is commonly assumed to mean the actual or potential health hazard presented by a wastewater discharge to humanity, but it also includes an actual or potential threat to the marine biota and possible endangerment of economic assets and resources in the vicinity of a discharge, or from the discard of waste materials in the marine environment.

5.2 ECONOMIC RISKS

The dissatisfaction or alienation of residents, tourists and developers at a coastal resort because of an aesthetically unacceptable local marine discharge has been outlined in Chapter 1: INTRODUCTION (1.2 Characterizing Marine Pollution). However, an effluent may be invisible or macroscopically unobtrusive yet be of such an unwholesome nature that the marine fauna are adversely affected causing a depletion in the numbers of harvestable sea foods. Attempts to sterilize effluent by chlorination may produce similarly lethal effects on marine or estuarine biota. Fishing grounds can be destroyed by a poisonous effluent; marine molluscs can accumulate substances or entities harmful to humans, or disappear from areas in which they once flourished. An excess of nutrients can also affect the sea and its sediments to the detriment of the biota and the food chain. If an economically viable fishing or shellfish industry is eliminated by a noxious discharge in the vicinity, the economic consequences to the neighbourhood will obviously be very serious.

5.3 PUBLIC HEALTH RISKS

Possibly as a result of humanity's relatively long association with epidemics and diseases capable of being categorized, and the accumulation of evidence - since the 19th Century - that microbial inceptors are implicated in most of these morbidities, speculation on health risks related to sea pollution is still mainly focused on the microbiological.

Before examining this particular aspect more closely, it is as well to note that other components have more recently become the subject of scrutiny. For example, radioactive or thermal discharges from power-stations, effluents from petrochemical factories, wastes rich in carbohydrates or which include toxic compounds in minute quantities can interfere with the metabolism of the adjacent biota causing unwelcome blooms, tainting or death, with uncharted long-term effects in the food chain up to and including man (Brown, 1987); certainly, the bioaccumulation of PCBs in aquatic living matter implies dire consequences for the future.

In examining possible health hazards presented by microbes from the discharge of effluents into the sea, two obvious factors provide a background to the overall perspective, and warrant concise recapitulation here:

> Sea-bathing is in itself intrinsically hazardous: the risks of tissue-insult to various organs and autoinfections of mucus membranes (eyes, ears, nose, throat, etc), of trauma (skin abrasions, cuts, broken bones, boating and board injuries in boisterous surf), even of drowning remain present to varying degrees.
>
> Of all the illnesses human flesh is heir to - including waterborne diseases - the majority are contracted on land, by humans in contact with one another or animals on land, or from eating and drinking on land.

It is often difficult to maintain a balanced view on matters involving the environment: witness the amount of media coverage and public outrage devoted to discoloured coastal waters compared with, say, the prevailing numbness or indifference that greets the road-mortality statistics. A common practice when microbial indicators of sea pollution are being assessed is automatically to ascribe to the indicators an additional role: that of presaging infective agents. This approach is far from proven in fact. The epidemiological data are deficient: the possibility of pathogens being present is no more than a coincidental inference when these microorganisms have not actually been demonstrated and the indicators have. Many factors require consideration. For example, even at major resorts, with thousands of bathers entering the sea daily, holiday catering facilities cannot be excluded in the usually mild, self-limiting episodes of transient gastro-enteritis to which some vacationers succumb (Moore, 1954a; Mackenzie and Livingstone, 1983). Generally, a very large number of infective agents have to be ingested - more than are normally present in a mouthful or two of aesthetically acceptable seawater - to produce an infective dose (Moore, 1954b; Mackenzie and Livingstone, 1968; Barrow, 1981, International Association on Water Pollution and Control, 1983). A classic case described by Moore (1954a) was the paratyphoid B outbreak in England popularly ascribed to sea bathing: the infective agent was in fact transmitted by bacteriologically contaminated ice-cream. Another difficulty relevant to microbes with a particularly dramatic potential is exemplified by the rapid loss of virulence of haemolytic streptococci when released into the environment (Perry *et al.*, 1957).

In a recent report (Dewailly *et al.*, 1986), windsurfer championships were held in a Quebec bay on the St. Lawrence river, over nine days. On average, competitors participated in seven three-hour races and fell into the water 18 times. The "faecal coliform" density of the competition water was "estimated" to be 1 000/100 m*l*. Symptoms (gastro-enteritis, skin irritation, otitis and conjunctivitis) were elicited by questionnaire: no clinical nor microbiological diagnoses were made. Out of 79 competitors, 45 reported at least one symptom although 17 did not specify the date of occurrence. As might be expected, those falling most often (in excess of 30 times) reported all the symptoms; those falling less: fewer. After subjecting the human organism to such a stressful episode involving longer than a week of hectic activity and exposure to sun, wind and insult to tissue from several impacts in the polluted baywaters of a modern city, combined with the presently not fully understood physiological aspects of human competition, some surprise could fairly be expressed that the reported ill-effects warranted mere subjective answers on a question-sheet. Another account with some similarities (Anon, 1987a) cites snorkelers participating in a race in the Bristol docks, England, 25% of whom contracted a stomach infection within 48 hours. (Apart from the questionable wisdom of holding a swimming competition in an industrial harbour, this report does not elaborate on what the snorkelers had for lunch.) Obviously, recreational sites should be selected with caution.

Vague and emotive claims on waterborne infections can be contested from the point of view of the paucity or absence of sound epidemiological investigations related to them, but they remain a tempting media event.

Apart from surprisingly few well-authenticated cases involving grossly (ie: macroscopically) polluted coastal waters (Anon, 1987b), and some particular localised instances (eg: Cabelli, 1979), not many attempts to connect several ailments and infections with sea bathing can withstand rigorous scrutiny (Moore, 1971). Moreover, the extraordinary robustness of the healthy human constitution cannot be lightly discounted when a perspective is sought on the dangers of accidentally swallowing undesirable microbes in polluted seawater, or from other sources. A prominent British periodical commissioned a survey of London's leading gourmet restaurants (Horsford, 1987). In each case, a small sample of the "speciality of the house" was surreptitiously obtained and submitted to a diagnostic laboratory for a total viable organisms count on one gram of the sample (a common public health criterion for foodstuffs). Some of the bacterial results (per gram) were: 12 x 10^6 in the *foie gras*, 34 x 10^6 in the *pate de turbot*, 4 x 10^6 in the *steak tartare*, 2,5 x 10^6 in the *ratatouille*, and 9 x 10^6 in the salads and strawberries. These restaurants are well patronised by satisfied customers: the waiting lists for table bookings appear to be endless.

Reverting to the marine environment, the epidemiological difficulties of demonstrating the sea to be a major vector or agent for disease transmission are formidable despite global escalation of coastal development and population settlement. It may be surprising to learn, J A Wakefield (1988), Founder Chairman of the British Coastal Anti-Pollution League, states unequivocally the sea provides the fastest most efficient treatment of sewage that is known, provided discharge is effected through properly designed outfalls, and is attended by careful monitoring.

5.3.1 Edible shellfish

Clearly, more epidemiological data are required before aesthetically acceptable seawater, which nevertheless includes microbial indicators of lowered water quality, can be labelled a health hazard. However, in the case of edible shellfish, these animals are not only filter-feeders but efficient concentrators of bacteria, viruses, metals and pesticides; and as many precautions should be taken in their cultivation and harvesting as would be deemed necessary for any foodstuff. Here, common hygienic principles apply: marine molluscs which are often consumed raw should not be cultivated or harvested in the vicinity of any waste-water discharge; in the absence of proven purification facilities, such practices should be prevented. It could be added, clinical acumen is indispensable in the diagnoses of alleged shellfish poisoning: paralytic shellfish toxins are potent neurotoxins produced by several species of dinoflagellates ingested by these bivalves (Kodama and Ogata, 1988).

5.3.2 Epidemiological considerations

Epidemiology has been loosely described as the science of epidemics. More specifically it is defined as "the study of factors influencing the frequency and spread of disease" (Bullock and Stallybrass, 1982). In the isolation, identification and - in some cases - enumeration of microbes in the sea, it is obviously necessary that the water scientist or researcher defines the objectives: is the work performed in order to measure water quality, or is it in pursuit of epidemiological considerations? Although there is some overlap, both objectives do not coincide. The former requires the employment of indicator-bacteria; the latter specifically targeted microorganisms implicated in disease, although the recovery of a pathogen from a polluted site proves nothing more than that it is already circulating in the adjacent population. The risk of an infective agent in contaminated seawater causing disease must be weighed against the likelihood of the same disease being acquired by other routes (Moore, 1971). As an example, Hutzler and Boyle (1980) report that less than 1% of the total incidence of infectious hepatitis can be attributed to waterborne transmission generally (ie: not confined to swimming). The authors go on to state the incidence of hepatitis is greatly reduced by improving personal hygienic principles.

In their review of several epidemiological surveys, Pike and Gameson (1970) concluded the probability of contracting serious enteric disease from bathing in aesthetically acceptable water is so minor as to be epidemiologically not demonstrable. McCoy (1976) maintains water has never been implicated as a primary cause in salmonella infections: the main source of infection being the consumption of infected food and milk, and outbreaks usually originate from catering establishments, hotels and hospitals.

Gunnerson (1974) emphasizes the need for more epidemiological investigations to evaluate bathing water *standards* (eg: the EEC standards severely criticized by Gameson (1979)), but warns of the high costs of data collection. In South Africa, a year long marine epidemiological pilot survey was made involving underprivileged Transvaal children of all races on holiday at various charitable institutions in Durban (Mackenzie, C R: pers. comm.*). Initially, 241 children were screened on arrival at the coast: ENT (ear, nose, throat) swabs were cultured, and stool and urine samples subjected to microscopy and cultured. In all, 358 children were regularly tested after sea bathing - some experienced nearly three months of almost daily exposure to the sea - at three bathing sites, including a tidal pool. Weekly clinical assessments were also made on all the children. Microbiological tests for *Escherichia coli* I, ova of *Ascaris* and *Taenia* species, *Staphylococcus aureus*, salmonellae and shigellae, were regularly performed on the recreational waters (D J Livingstone: unpublished data). Despite fluctuations in the water quality (at times seriously polluted according to bacterial criteria: 90 x 10^3 m^3/day raw sewage were being discharged at the harbour-mouth with the outgoing tides), no correlative trends could be established between sea bathing and ENT or urinary tract or gastrointestinal infections and infestations. No cases of hepatitis manifested themselves during the survey nor in the follow-up period; all the children appeared to be healthier after their holiday at the seaside (D J Livingstone: unpublished data).

In another survey (D J Livingstone: unpublished data), five scientists camped on the banks of a Natal estuary for four days to study the chemistry and fauna of the estuarine waters. On the second day, bacteriological

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samples were collected from seven sampling stations approximately 1,5 km apart in the estuary, including from the bank of the scientists' camp. During the period, all five of the team were in frequent physical contact with the estuary which involved total immersion at least once a day, while their work brought them into daily intimate contact with the water. One shaved in the estuarine waters daily; the others did not shave during the period.

Three were in the habit of smoking while performing wet experiments from the bank and a small boat. Bilharzia was not considered to be a hazard, and no snails were discovered on the aquatic plants. The only precautions taken against infection were the use of clean stored tap-water for drinking and cooking, and as a final rinse after washing the eating-utensils. From the samples collected on the second day, the waters were found to be bacteriologically contaminated with sewage (from a town upstream): all stations yielded an *E. coli* I index in excess of 3 000, *S. aureus* were recovered from every station, while salmonellae were demonstrable from all the samples except from the river-mouth. A searching health questionnaire was prepared and followed up daily in the first week after the scientists' return to Durban, and thereafter weekly for five weeks. The questionnaire can be summarized briefly here:

> Urinary tract infection (frequency, burning, backache?)
> Gastro-intestinal tract infection (diarrhoea, nausea, cramps, constipation?)
> ENT and eye infection (pain, inflammation, abnormal discharges?)
> Cutaneous infection (eruptions, itches, rashes?)
> Loss of general well-being or weight?

Diagnostic laboratory procedures were available if indicated, but these proved unnecessary: all the replies were negative. Despite bathing and working in polluted estuarine water, all members of the team continued to enjoy excellent health during the six-week follow-up period.

Barrow (1981) reports the findings of a survey in which an attempt was made to relate gastro-enteritis, upper respiratory infection and "total illness" to bathing: the bathers all had fewer illnesses than the non-bathers.

Barrow goes on to label microbial *standards* for bathing waters as irrelevant to public health. Gameson (1979) is similarly critical. At this point it is salutory to add: the relatively modest expense of monitoring an effluent target area on the coast for pollution, or to measure water quality, will escalate prohibitively if unrealistic "health standards" based on dubious reasoning or guesswork have to be met prior to or after discharge.

5.3.3 "Health standards"

The question of the minimum infective dose (m.i.d.) - the smallest number of a specific micro-organism required to effect clinical illness - is not without relevance in waterborne disease. Usually, large numbers of organisms (implying large quantities of seawater) have to be ingested to produce the illness. Obviously, such data are fairly uncommon as they require pure cultures (the microbial dose being determined in advance) and human volunteers. Using such methods, the m.i.d. required to effect clinical salmonellosis using various serotypes in humans ranged from 125×10^3 to 16×10^6 via the oral route, and as low as 25 bacteria via the antral (maxillary sinus) route, in which the volunteer's antrum apparently acted as a living incubator to produce the dose that eventually effected a classical salmonella infection (Mackenzie and Livingstone, 1968).

On viruses, Shuval and co-workers (1986) state the vast majority of infections with enteroviruses leads to benign short episodes of acute illness, or to subclinical infections with little impact.

There can be little doubt that standards pertaining to comestibles have proved to be possibly the greatest single advance in public health or preventative medicine achieved by humanity: sound epidemiological evidence supports these standards. Health standards designed for recreational waters, unsupported by sound epidemiology, can and should be vigorously challenged: the spectacle of microbiologists bypassing clinicians and seeking to censor or restrict public behaviour from the pinnacle of a few laboratory tests is unedifying. Infection does not result from the presence of a few pathogens. Nevertheless, the proliferation of recommended or actually promulgated health standards continues apace.

The Commission of the European Communities (1976) directive on microbial standards for bathing waters is summarized in Table 5. The United Kingdom has had to comply, and is adopting the "I value". Moore (1977) expressed himself as unconvinced about the EEC standards, and called for a fundamental rethink on policies that reflected certain American enthusiasms he believed to be questionable.

TABLE 5

EEC microbial standards for bathing waters

	G value	I value
Total coliforms/100 m*l*	500 (80)	10 000 (95)
Faecal coliforms/100 m*l*	100 (80)	2 000 (95)
Faecal streptococci/100 m*l*	100 (90)	-
Salmonellae/*l*	-	0 (95)
Enteroviruses/10 *l*	-	0 (95)

Numbers in parentheses are the percentages of samples in which the counts must not be exceeded. Tests for faecal streptococci, salmonellae and enteroviruses are required only when inspection of the bathing area shows that they may be present or that the water quality has deteriorated.

G = guideline; I = mandatory

The USA has certainly rethought the matter, and appears to have terminated its long-standing affair with "fecal coliforms", replacing it by embracing enterococci, at least in the marine environment. Cabelli and co-workers (1982) aver a relationship exists between the mean enterococcus density in marine bathing waters and the "swimming-associated risk" rate of gasteroenteritis: morbidities were ascertained from beach interviews conducted by graduate students with swimmers who had immersed their heads; each interview was subsequently followed up telephonically (Cabelli, V J, pers. comm.*). Wakefield (1988), commenting on Cabelli's theory, remains unconvinced: "... this relationship is tenuous and in the League's (the British Coastal Anti-Pollution League) view not to be taken seriously ..."; while Fattal and co-workers (1986) found no statistical difference between swimmers and non-swimmers for highly credible enteric symptoms in their study of enterococcal densities in beach waters. Nevertheless, Cabelli's influence has made itself felt and the Environmental Protection Agency's (EPA of the USA) (1986) health standard for marine recreational water is:

> "Enterococci not to exceed 35/100 m*l*" (the criteria are calculated as the geometric mean of not less than five samples equally spaced over a thirty day period).

In South Africa, Lusher (1984) more conservatively recommends:

faecal coliforms should not exceed: 100/100 m*l* in 50% of samples,
400/100 m*l* in 10% of samples,
2 000/10 m*l* in 1% of samples.

Arising from the work embodied in this monograph, it is submitted that a simplified standard confirming the safe and efficient marine disposal of domestic wastewater off Durban and similar high-energy coastal regions could read:

E. coli I : $\leqslant$ 1 000/100 m*l*
salinity : $\geqslant 34\ ^{o}/_{oo}$

within the surf-zone adjacent to the discharge.

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5.3.3.1 Shellfish

No direct correlation has been proved between occurrence of pathogens in seawater and epidemiological evidence of an increased health risk from shellfish consumption, according to Fox (1985). Nevertheless, oysters and mussels constitute food that is often consumed raw or partially cooked: strict public health criteria for food should therefore be applied to these comestibles.

5.3.3.2 Beach closure due to bacterial "standards"

A clean and non-toxic environment is every individual's birthright, and indeed, part of every individual's responsibility to safeguard and propagate. Nevertheless, in the absence of sound epidemiological data, the concept of bacteriological health standards for sea bathing is not advocated: the sea is not a common comestible, and too many variables are involved. The biologically possible should not be automatically promoted to the biologically probable, and from thence to legislation. Responsibility for the closure of a bathing beach for health reasons should rest with the local medical officer of health. Only such officers, when provided with the data on adjacent coastal pollution measurements, have the expertise and specialized knowledge relating to parochial disease incidence to take such decisions.

5.4 RISKS FROM TOXIC SUBSTANCES (This section authored by Connell, A D*)

Toxic substances are an important component of environmental pollutants which should be identified in relation to effluent disposal to sea. They include:

radionuclides
metals and other inorganic materials
persistent organics (in particular halogenated organics)
petroleum hydrocarbons and petrochemicals

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In addition to these, there are the indirectly toxic materials which have to be considered and they include organic materials that during rapid degradation in confined areas or systems with poor circulation can cause oxygen depletion, nutrients which - in excess - can cause undesirable changes, and thermal effluents which - in excess - can also be lethal to the biota. These and organisms potentially pathogenic to man have already been referred to in varying detail.

In weighing the potential impact of a substance it is necessary to identify the most likely targets in a particular area of discharge. In heavily peopled areas the most affected may be the human population. Risks related to human health, livelihood and food sources such as shellfish may be the most important, but other serious considerations should include marine resources, intertidal communities and all forms of marine life, eggs, larval and juvenile stages in vital breeding areas, as well as critical habitats such as estuaries and coral reefs.

Critical levels for a number of toxic substances, including toxic trace metals, organic compounds and others (eg: ammonia and chlorine) are listed by Lusher (1984). Further data can be found in such sources as the United States EPA (1976) and State Water Resources Control Board (1983). The EPA recommended levels take into account not only levels for protection of marine communities, but also the protection of human consumers of edible marine organisms. Rapid and sensitive toxicity testing techniques are referred to in McGlashan (in press) for testing substances for which data are not available.

Where several toxicants occur together at relatively high concentrations, their effects should be considered collectively: together they might act synergistically or antagonistically. In practice, the results have generally proved toxicants to be additive.

Bioaccumulation along food chains has, so far, been positively identified for a relatively small group of toxicants. These include dichlorodiphenyltrichloroethane (DDT), PCBs and Hg (Swartz and Lee, 1980). However, bioconcentration, particularly by filter-feeding bivalve molluscs, is a well known phenomenon which can result in consumers ingesting high concentrations of trace metals, radionuclides or organic compounds. Perhaps the best known example of this is zinc in oysters. It is generally expedient to measure levels in accumulator organisms, and to use these data to assess whether the levels being discharged are excessive (Preston and Portmann, 1981). Another direction of control-monitoring might be on levels of toxicants - particularly pesticides - in eggs or tissue of fish-eating birds from areas where determining the levels in other accumulator organisms is not possible or appropriate.

Recent research and careful assessment of the extensive literature on the trace metals have led many to the conclusion that, provided these substances are not discharged in excessive amounts, the trace metals are not of particular concern in the marine environment. The single exception is mercury: because of its ability to retain the methylated form in seawater (albeit at very low levels) and its high fat solubility in this form, bioaccumulation of Hg occurs when it is introduced into food chains. However, Hg, like all the major elemental trace metals, has been present in seawater for many millions of years, and marine animals have the ability to deal with these toxicants by way of their metallothioneins (Bascom, 1984). Unfortunately, the same is not true of the synthetically formulated compounds such as the tributyl tins which have had a serious impact on oyster culture in Europe (Thain and Waldock, 1986) resulting largely from the use of such compounds in anti-fouling paints.

The extremely durable organic compounds, particularly the chlorinated hydrocarbons such as DDT, dieldrin and BHC, and the polychlorinated biphenyls (PCBs), are not commonly present in substantial amounts in effluents, but they are potentially so important that they should be included in assessments of effluent quality. Their presence in the South African marine environment is caused by widespread low-volume usage coupled with their remarkable persistence.

5.5 THE RISK FROM POLYMERS

Environmental pollution from polymeric substances, at this stage of the planet's evolution (or entropy), presents a risk currently directed mainly at the marine biota. The facts are alarming. The world's merchant fleet alone dumps 6 x 10^6 plastic containers in the sea every day, or 7 x 10^6 kg of plastic trash annually (Anon, 1988). Every year, one hundred thousand whales and dolphins and one million seabirds are destroyed along with unknown numbers of turtles and fish as a result of plastic discarded in the world's oceans, often in the form of finely meshed nylon drift-nets. Random counts have shown an average of 4 x 10^3 plastic "particles" for every km^2 of the sea surface. The durability of polymeric shopping bags, for instance, has been estimated at 600 years (Anon, 1988). It would appear the risk from discarded plastic in the sea poses a greater and more immediate threat to the health of the planet's aquatic environment (and therefore eventually to humanity) than any other substance.

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CHAPTER 6 : CONCLUSIONS AND EXTRAPOLATION

6.1 CONCLUSIONS

Ideally, humanity should pump nothing at all into the sea: many industrial wastes exhibit at least a potentially injurious impact upon marine ecologies, and any environmental degradation will eventually rebound to the detriment of man. The problem of waste disposal remains, and the ocean presents as a tempting receiving milieu. With circumspection and strict limitations regarding quantities and the nature of the discharges, the deep sea disposal of ecologically harmless effluents is an aesthetically acceptable feasible proposition, as can be seen from the present study.

6.1.1 Shore-based sanitary features

Among the several conclusions arising from this survey, the most fundamental is the indispensability of noting the correlative situation of sanitary (disposal and drainage) features on the shore. Such an inventory constitutes a vital dimension in understanding the presence, location and movement of demonstrable pollutants in any investigation of the littoral zone. For example, during the early months of bacteriological surveillance at Durban, the elevated levels of indicators found at times in the vicinity of Stations 9, 10 and 11 appeared to constitute something of an anomaly: these stations were south of the harbour-mouth discharge point (Station X), were in the "shadow" of the harbour's south pier, while the prevailing longshore current was (and is) towards the north. Although the Finnemore Place sewer (between Stations 12 and 13) lay to the south, it was felt this outfall's discharge was too remote and too modest in size to impinge so directly on these three stations. Five unobtrusive beach pipes had been observed near the old disused whaling factory at Station 10 (which was subsequently razed and rebuilt as the Central Works) where several people lived. A dozen pipes were also noted in the vicinity of Station 12, at the then functioning new whaling factory (see Fig 2.5 on page 41 and Fig 4.1 on page 91). All the pipes were seen to discharge intermittently on to the beach or into the surf. It was decided to sample and examine these minor effluents; subsequent testing proved many of the pipes to be contaminated with faecal material, blood, offal and/or cetacean bowel-washings. The probable cause of the elevated microbial counts in the adjacent surf-zone thus became apparent.

6.1.2 Oceanography and meteorological events

Similarly, it is concluded that a sound knowledge of the physical coastal dynamics (current directions and velocities along with dilution and dispersal characteristics, wave and wind action) is an essential component in any marine pollution survey if the biological findings are to attain coherence and intelligibility. Formidable precipitation events may also exert marked if short-term effects on the water quality of the littoral, not only by dilution from rainfall and elevated river flows but by pollution from stormwater drains.

6.1.3 The submarine outfalls at Durban

It must be stated the shore-based location of the Southern Works outfall (near Station 19) is less than ideal, sited as it is in the contaminative ambience of the Mlaas Canal mouth. It is obvious this situation was dictated by costs: the CW landline runs in a straight line from the Works along the north bank of the Mlaas Canal. Until all pollution upstream in the Mlaas is stopped, the often unsavoury macroscopic appearance of the surf in the vicinity of the canal mouth (along with the Class III or IV gradation frequently accorded the water samples from this locality) may at times be erroneously attributed to the adjacent deep sea outfall. This factor highlights the importance of aesthetics in marine disposal planning.

However, with due regard to the ocean dynamics in the region, and in terms of the diffuser sections at the ends of each outfall, the siting, design and function of the Durban pipelines is excellent. Dilution and dispersion of the effluents is effected swiftly and efficiently far out to sea with no measurable deleterious consequences on the surf-zone bordering the target area.

6.1.4 Indicators of domestic wastewater in the sea

In considering presumptive *E. coli* (or thermotolerant or "faecal" coliforms), no member of this group of bacteria occurs naturally in seawater, consequently the group as a whole is of considerable value in tracking and assessing increments of terrigenous water in the saline medium. However, this assembly of microbes - although it includes *E. coli* I, the prime indicator of faecal pollution - also embraces the Irregular organisms some of which are not of faecal origin and capable of proliferation in the marginal vegetation of warm-water rivers. The group as a whole is therefore of limited value in confirming the presence and assessing degrees of sewage pollution in Natal's marine environment.

The incidence and substantiality of *E. coli* I as the preferred indicator of faecal pollution are confirmed by the present survey. To some extent, the inclusion of corroborative indicator organisms is justified if their presence can be rapidly and inexpensively ascertained; they appear to reinforce the status of *E. coli* I as the pre-eminent indicator in any marine programme designed to detect domestic wastewater, while the presence of corroborative organisms has a psychological impact on coastal management authorities. A possible drawback to the inclusion of such supplementary organisms is that their recovery and identification may require sophisticated bacteriological and manipulative skills.

The measurement and incorporation of depressed salinity levels to indicate dilution of the recipient marine matrix by non-saline water has proved to be a major parameter in the measurement of seawater quality during the whole extent of this survey.

6.1.4.1 "Health risks"

The assumption: indicator x = pathogen y = disease y* is a shaky one; morbidity does not depend on the presence of microbes alone, and no incontrovertible evidence on implied microbial risk appears available that can withstand rigorous epidemiological scrutiny. The recovery of a pathogen from the sea proves no more than that it is circulating in the adjacent population. However, in the case of filter-feeding bivalves (which concentrate micro-organisms and metals), it is recommended these molluscs should not be harvested for raw consumption by humans if the mussels and oysters are found within a 5 km radius of a polluting source or waterway on the Natal coast.

6.1.5 The future

Based on intimate association with this sector of the littoral zone for more than a quarter-century, the most serious aspect of marine pollution confronting humanity and the marine ecology in the future will be the escalating levels of non-biodegradable polymeric substances ("plastics"). Should global warming effect a rise in sea-levels, it is predicted this problem will be exacerbated by the sea's embrace of more land along with further stores of discarded polymeric waste materials.

6.2 EXTRAPOLATION

William of Ockham's famous injunction, referred to in Chapter 1 : INTRODUCTION, affirms: "entities are not to be multiplied beyond necessity." This elegant principle of scientific economy has proved to be unshakable since the 14th Century. The present text will therefore be concluded with an attempt to simplify the system of water-quality gradation that has been applied with some success in the waters off Durban for the duration of the survey.

In Fig. 6.1, the distribution of *E.coli* I $\log_{10}$ numbers is plotted against a range of salinity values for the nearly 2 500 seawater samples tested at Durban. It can be observed that these means decrease progressively as the salinity attains the level of clean seawater (35 $^{o}/_{oo}$ and above) suggesting some correlation between the two values. Such a conclusion appears to be empirically reasonable. Table 6 lists three gradation systems using: the *E. coli* I index alone; the method presently employed at Durban; and a new system propounded here comprising the *E. coli* I index with the same orders of magnitude and their respective scores, with the same provision for the addition of four adverse points when the salinity is <34 $^{o}/_{oo}$, but with different total evaluations.

TABLE 6

Comparison of three systems for classifying seawaters incorporating adverse scoring for microbial indicators, and including depressed salinities in two of the systems

	E. coli I only	Durban system	*E coli* I + salinity
Indicator:	Score:	Score:	Score:
E. coli I index <1-10	1	1	1
10-100	2	2	2
101-1000	4	4	4
>1000	8	8	8
Parasite units/250 ml 1-7		4	
>7		8	
Staphylococci/250 ml		4	
Salmonellae/250 ml		4	
Shigellae/250 ml		4	
Salinity <34°/oo		4	4

E. coli I only		Durban system		*E coli* I + salinity	
	Class:		Class:		Class:
1	I	1-4	I	1-2	I
2	II	5-8	II	4-5	II
4	III	9-16	III	6-8	III
8	IV	>16	IV	12	IV

In Fig. 6.2, the three systems have been comparatively applied to the full beach runs of 1987 (the Natal Floods year) and 1988. It can be seen that the top horizontal strip (*E. coli* I alone) in each year is clearly divorced from the pair below, being over-strict, depicting no Class I waters at all in 1988, whereas in fact some of these samples yielded *E. coli* I indices ranging from 12 to 60 which is negligible in marine coastal terms, particularly when adjacent to a large industrial city. The bottom strip for each year, comprising *E. coli* I and salinity, although stricter than, is much closer in its classifications to the middle strip which depicts the same waters subjected to all the indicators of the present gradation system: the Class IVs coincide; and if some Class Is have been downgraded to Class II, and a few Class II waters have had to be relegated to Class III, the differences are by no means extreme.

Comparing this second pair again, Fig. 6.3 presents adjacent isograms of the averaged annual results for every station over the quarter-century under review (the present system on the left; the *E. coli* I and salinity system on the right). Careful study reveals that the *E. coli* I index plus salinity system offers a reasonable (if often stricter) approximation to the present system of water quality classification.

This simplified alternative (or possibly a near-variant) employing just the two parameters - the *E. coli* I index and salinity of $<34\ ^{o}/_{oo}$ - is not only more readily and economically accessible to microbiologists working at the coast, it could prove equally useful to coastal management authorities as has the more complex system that has been successfully applied in this microbial study of water quality in the marine environment off Durban from 1964 to 1988.

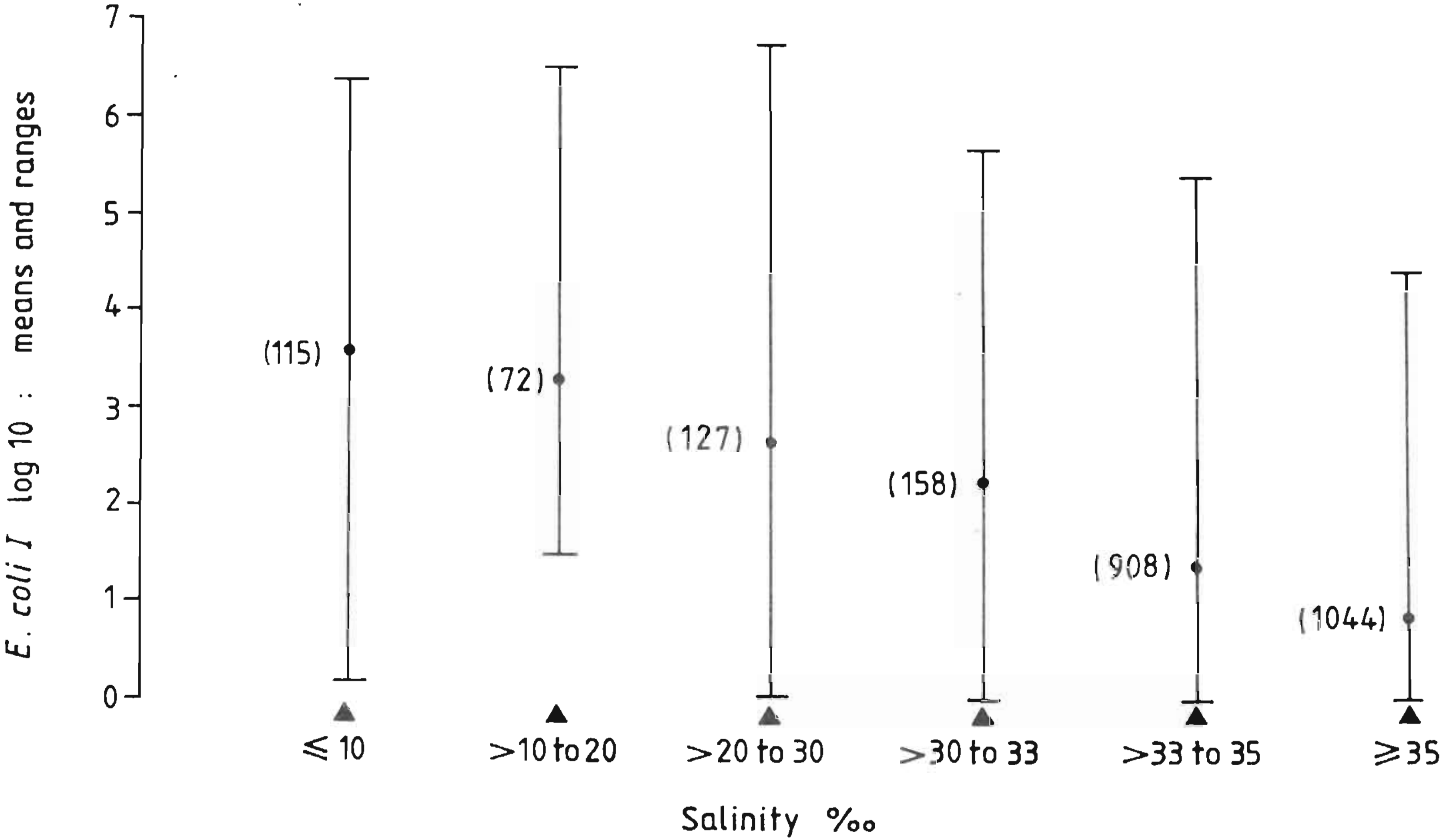

Fig 6.1 Means and ranges of *E. coli* I $\log_{10}$ determinations on seawater (numbers of samples per range in parenthesis) distributed according to salinity levels

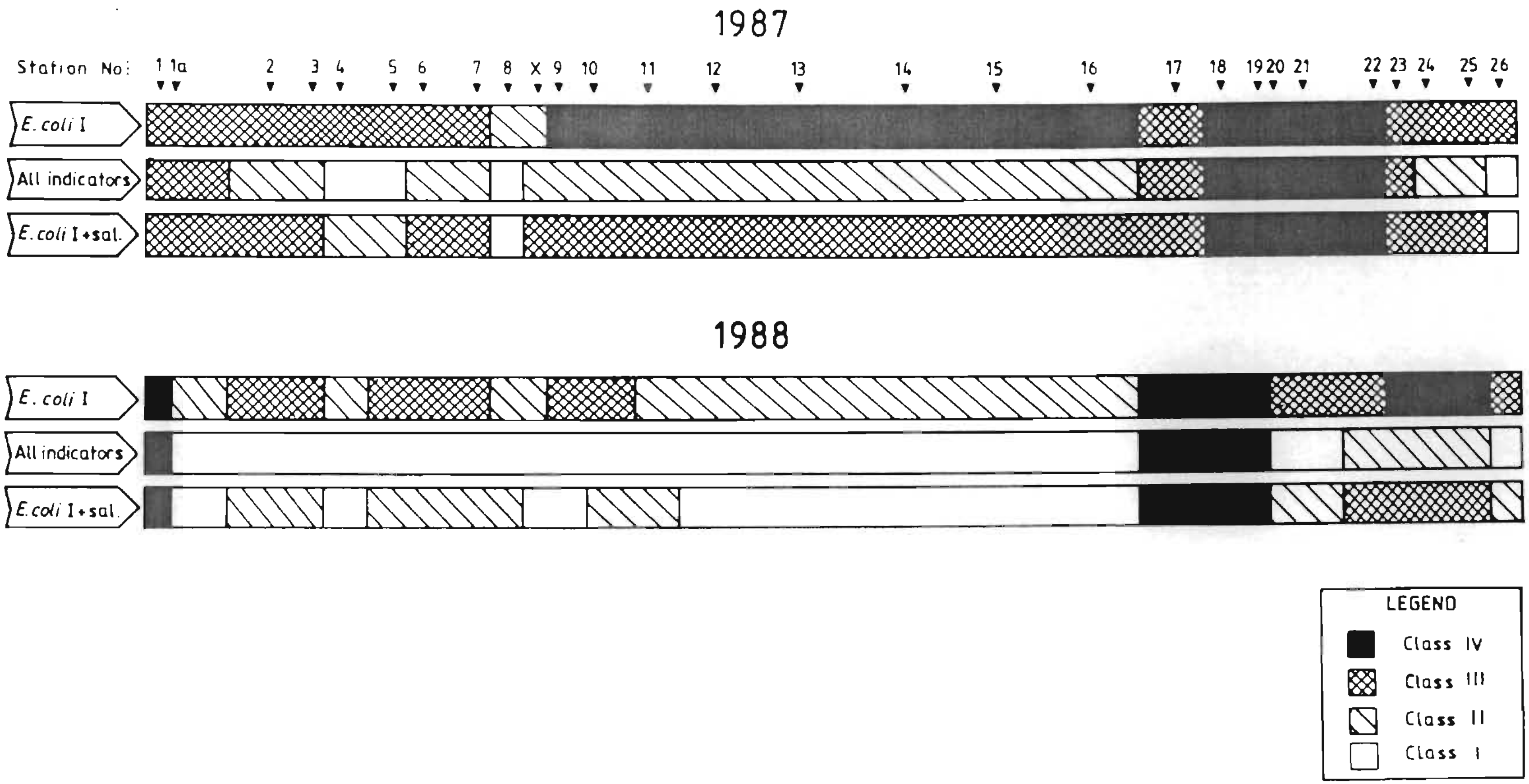

Fig 6.2 The 1987 and 1988 full beach runs, each illustrated by comparing three classification systems

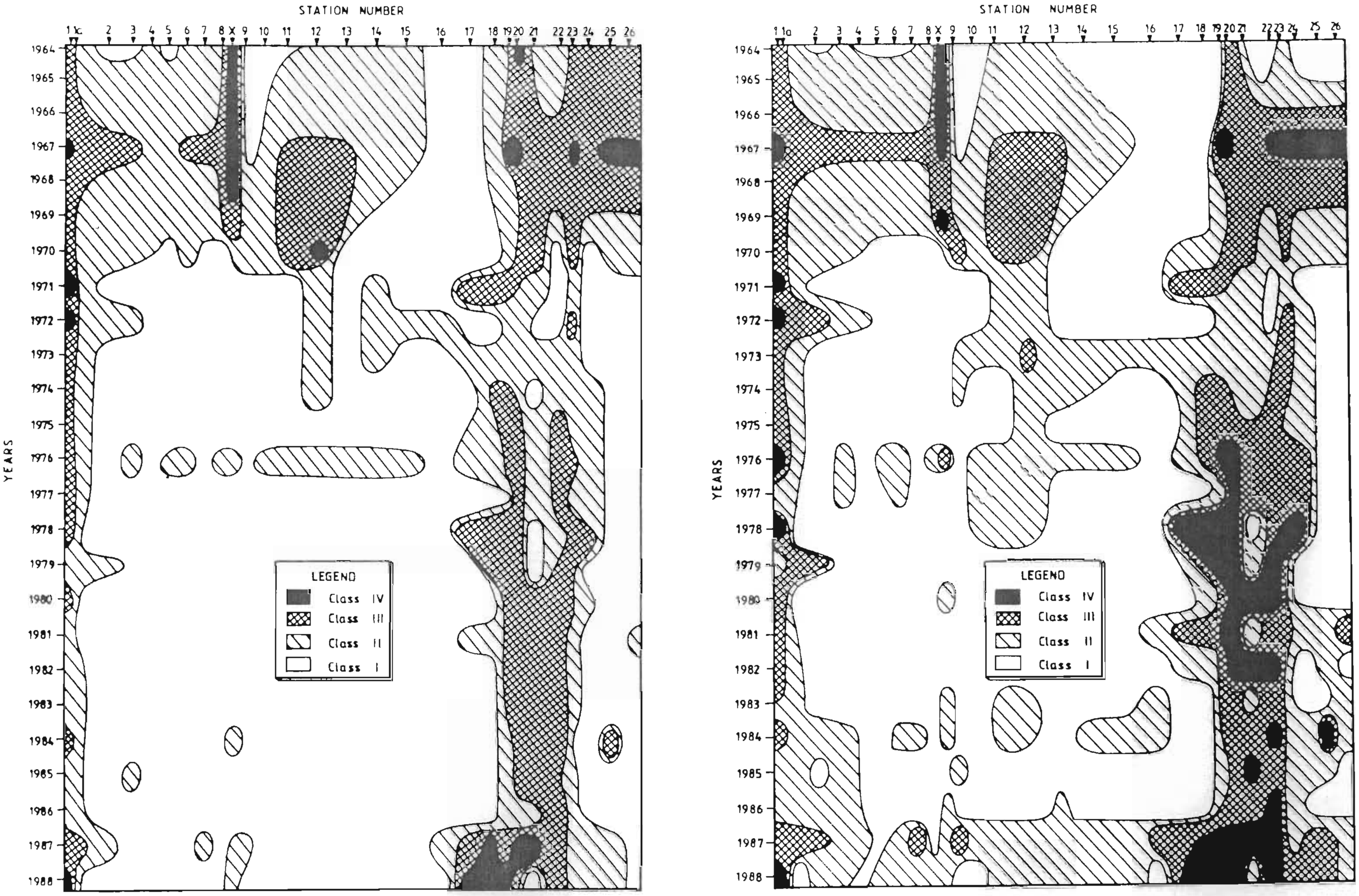

Fig 6.3 Isograms comparing two seawater quality classification systems on averaged annual results of all stations; LEFT: using all indicators, RIGHT: using *E. coli* I indices and salinities

APPENDIX

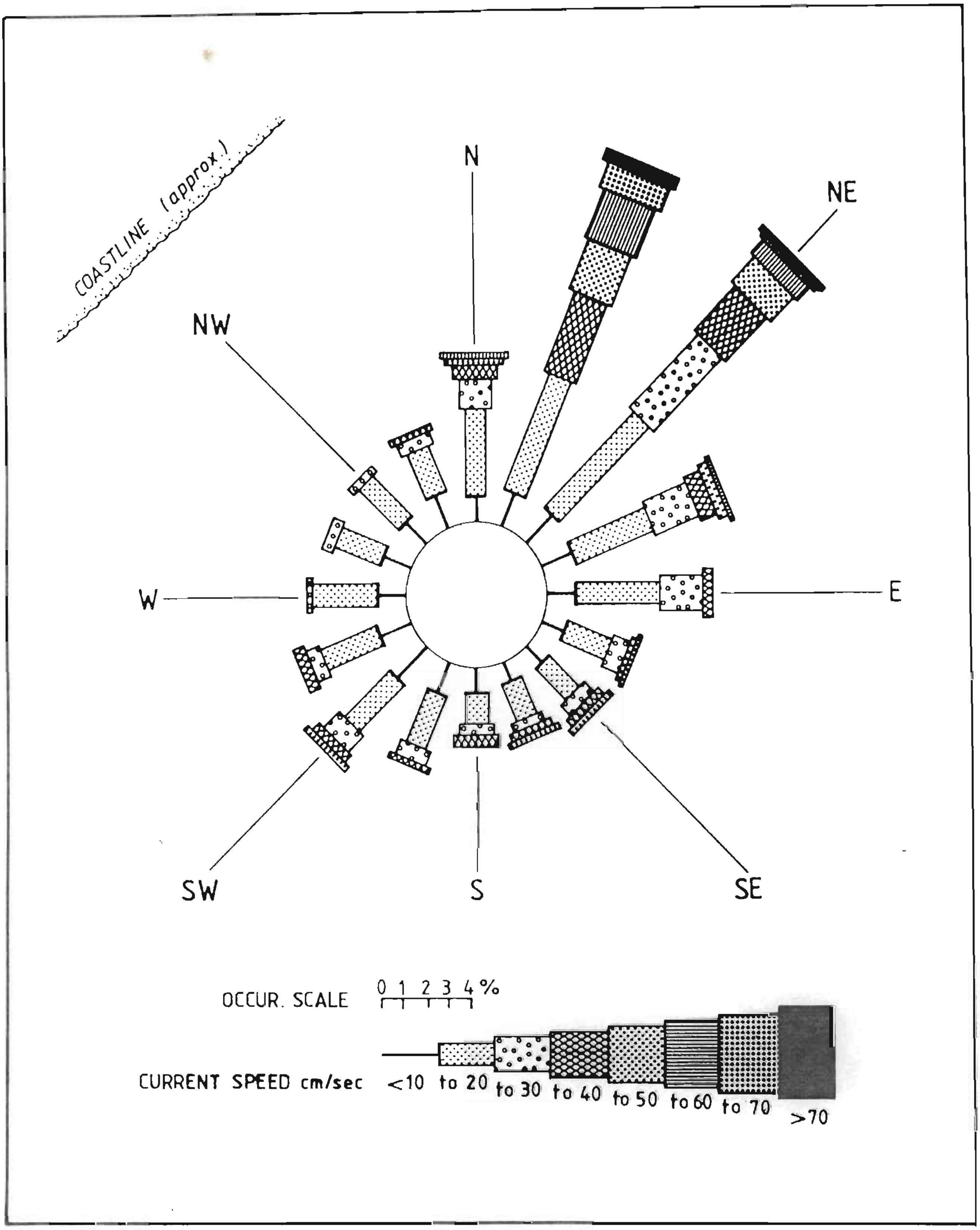

Fig A2.1 Current direction, speed and frequency of occurrence at the CWO

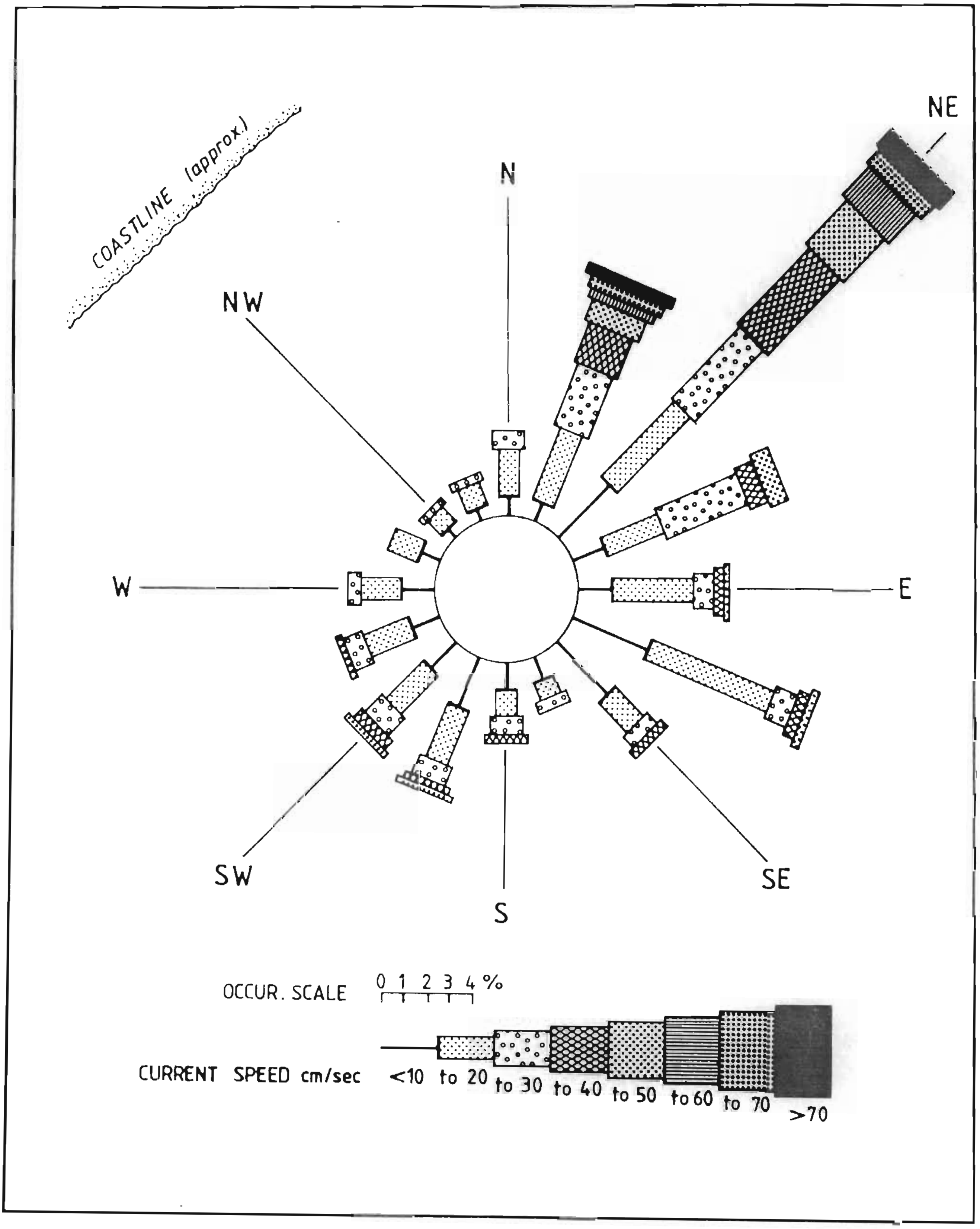

Fig A2.2 Current direction, speed and frequency of occurrence at the SWO

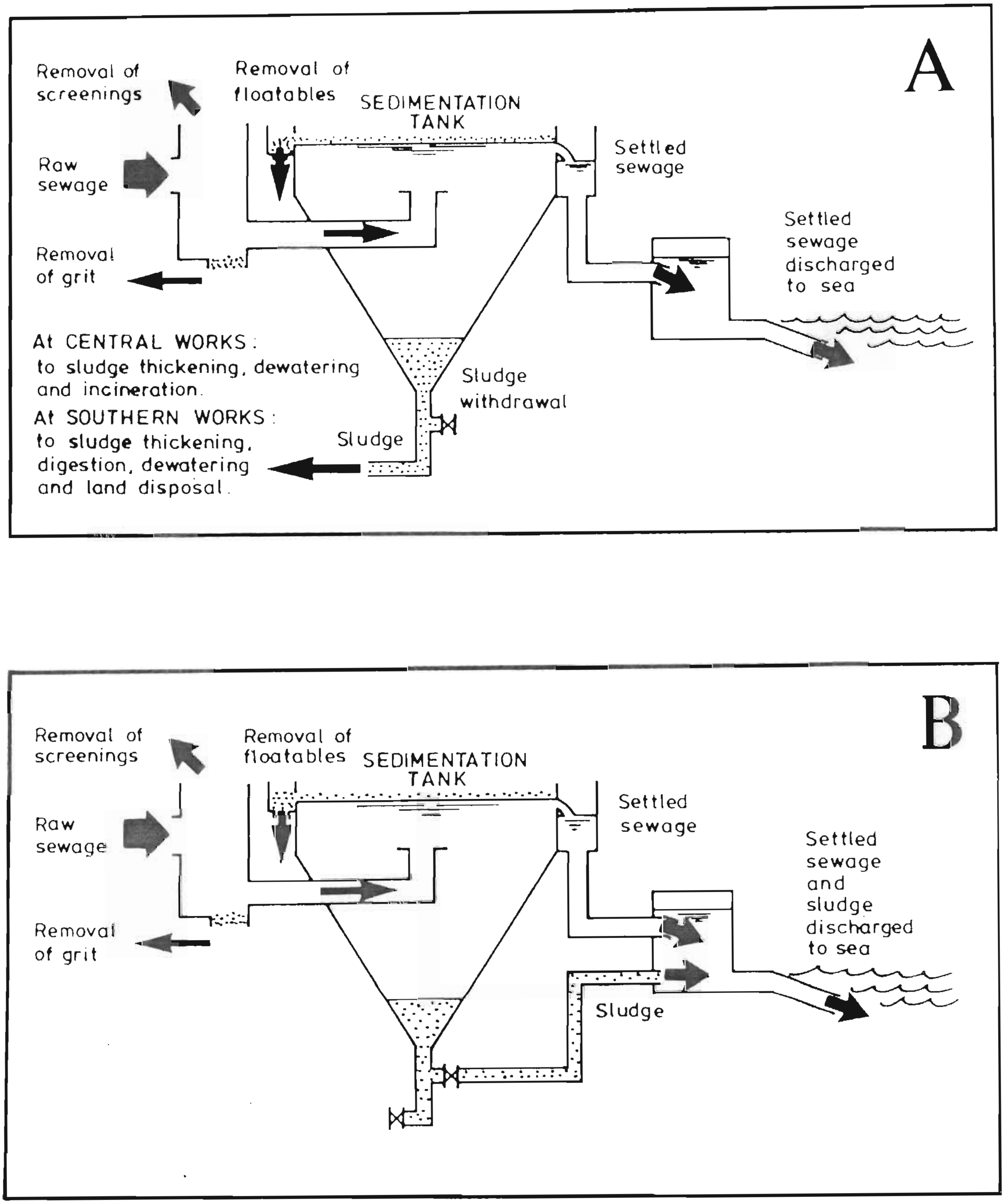

Fig A2.3 Diagrammatic representation of both Central and Southern Works; A: conventional primary treatment; B: primary treatment modified by the reintroduction of sludge to the discharge

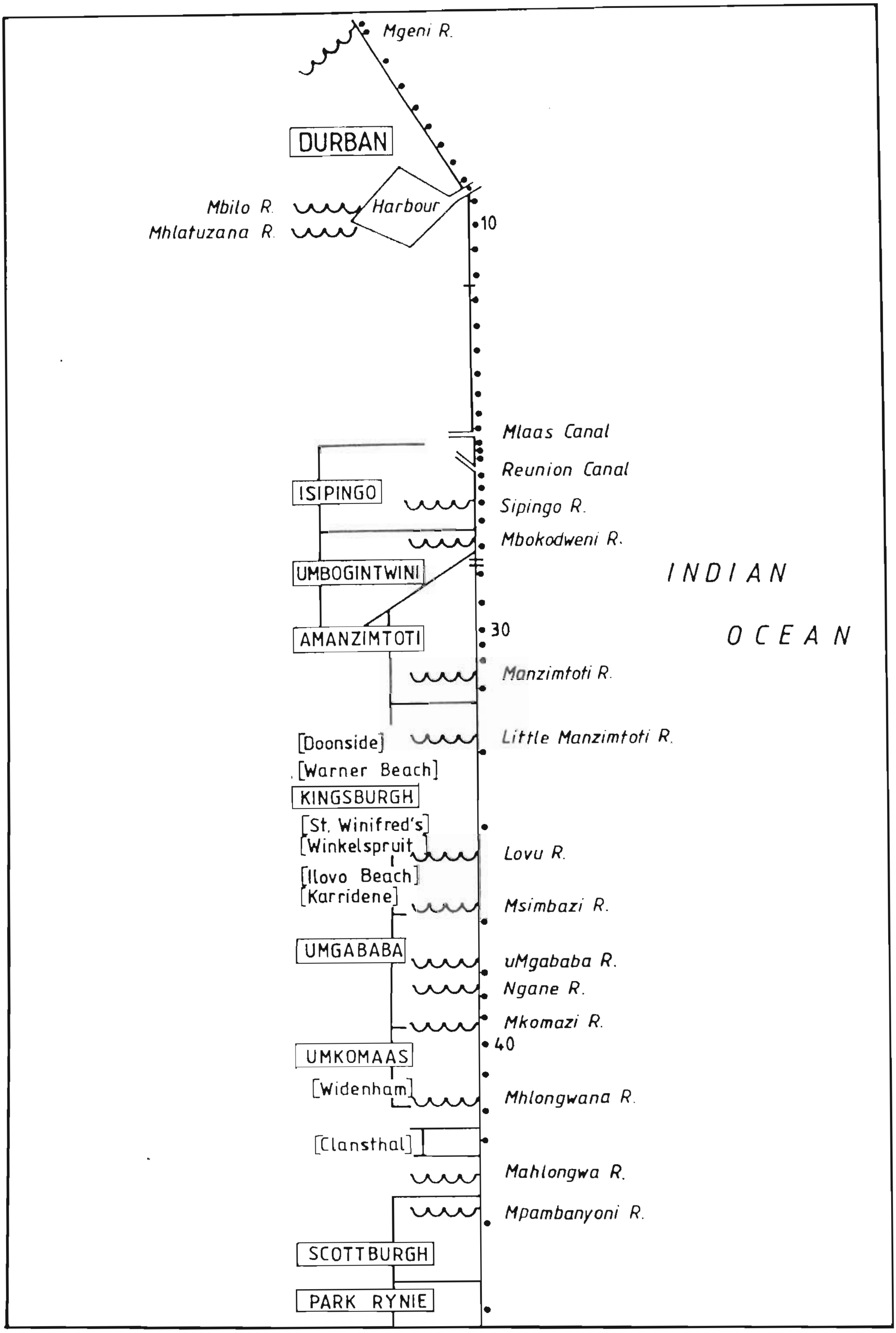

Fig A4.1 Schematic representation of the coast from the Mgeni River to Park Rynie depicting waterways and sampling station sites

TABLE A4.1

Results and classification of Station 1 : 1968 to 1971

Date	Time	HW	LW	Total Coliforms/ 100 mℓ	Presumptive *E. coli*/100 mℓ	*E. coli* I/ 100 mℓ	Irreg. II/ 100 mℓ	Irreg. VI/ 100 mℓ	Parasite Units/ 250 mℓ	C+M+ Staph/ 50 mℓ	Salmonellae/ 250 mℓ	Shigellae/ 250 mℓ	Salinity °/oo	Wind (from)	Current (to)	Indicator value	Class
68.09.17	0745	1343	0716	$27,28 \times 10^6$	$4,6 \times 10^6$	0	$3,2 \times 10^6$	$1,38 \times 10^6$	0	+	+[1]	0	0,67	Nil	Out	13	II
68.10.07	0755	0401	1001	75 500	7 000	0	6 000	1 000	1	+	0	0	25,03	N	Out	13	II
68.10.21	0755	0307	0909	119 000	45 000	27 000	18 000	0	0	+	+[2]	0	19,70	Nil	Out	20	IV
68.11.04	0755	0308	0906	157 000	18 000	3 600	9 000	5 400	0	+	0	0	17,62	NE	Out	16	III
68.12.09	0800	0555	1154	645 000	300 000	30 000	180 000	90 000	0	0	+[3]	0	1,25	NE	Out	16	III
69.01.13	0730	1103	0402	$2,3 \times 10^6$	540 000	54 000	54 000	432 000	0	0	+[4]	0	4,42	SW	Out	16	III
69.01.27	0725	1105	0330	108 000	36 000	10 800	21 000	3 600	0	+	0	0	15,71	SW	Out	16	III
69.02.10	0735	0834	0153	1 000	1 000	0	1 000	0	1	0	0	0	34,75	NE	In	5	II
69.03.10	0730	0707	1319	$4,65 \times 10^6$	$1,425 \times 10^6$	285 000	997 000	142 500	2	+	+[5]	0	1,02	SW	Out	24	IV
69.03.24	0730	0630	1248	361 500	68 000	6 800	54 400	6 800	0	+	+[6]	0	3,19	Nil	Out	20	IV
69.04.21	0735	0544	1158	39 000	10 000	4 000	6 000	0	0	+	0	0	6,76	Nil	Out	16	III
69.05.05	0730	0527	1138	18 000	3 000	1 500	1 500	0	0	+	0	0	28,94	Nil	Out	16	III
69.05.19	0730	0502	1114	400 000	7 100	1 420	4 970	710	0	0	0	0	21,57	SW	Out	12	III
69.06.09	0730	1154	0551	43 000	7 400	5 920	1 480	0	0	+	0	0	5,75	NW	Out	16	III
69.06.23	0740	0905	0307	1 330	130	52	78	0	0	+	0	0	33,99	N	Out	10	III
69.07.21	0730	0724	1329	40	20	0	20	0	0	+	0	0	34,37	N	In	5	II
69.08.04	0730	0729	1329	2 165	625	125	500	0	0	0	0	0	34.89	Nil	In	4	I
69.08.18	0735	0617	1220	204	66	33	33	0	0	0	0	0	34,51	Nil	Nil	2	I
69.09.02	0730	0643	1241	43 500	5 200	1 560	3 640	0	0	+	+[7]	0	33,70	SE	Slack	20	IV
69.09.15	0730	0521	1123	9 800	1 000	300	700	0	0	+	0	0	32,70	NE	Out	12	III
69.09.29	0725	0519	1117	73 000	10 600	5 300	4 240	1 060	0	+	0	0	24,16	Nil	Out	16	III
69.10.20	0730	1239	0611	1×10^6	230 000	115 000	115 000	0	1	+	0	0	0,09	Nil	Out	20	IV
69.11.03	0720	1130	0359	255 000	83 000	16 600	66 400	0	0	+	0	0	0,32	NE	Nil	16	III
69.12.01	0730	0757	0133	138 500	72 000	7 200	57 600	7 200	0	+	0	0	1,44	NE	In	16	III
70.01.19	0720	0226	0822	165 000	164 000	0	82 000	82 000	0	+	0	0	< 0,10	S	Out	9	III
70.02.02	0725	1237	0613	110 000	36 000	7 200	25 200	3 600	0	+	0	0	0,15	Nil	Out	16	III
70.02.16	0725	0153	0756	12 000	100	60	40	0	0	+	0	0	0,12	SW	Out	10	III
70.03.02	0625	1011	0242	52 500	11 000	6 600	3 300	1 100	0	+	0	0	0,75	SW	Out	16	III
70.04.13	0720	0733	0113	136 000	32 000	3 200	25 600	3 200	0	+	0	0	4,80	Nil	Nil	16	III
70.04.27	0720	0704	1310	126	20	0	13	7	0	0	0	0	34,54	S	In	1	I
70.05.11	0655	0644	1253	120 000	48 000	38 400	9 600	0	0	+	0	0	2,52	Nil	In	16	III
70.05.25	0720	0621	1228	54 000	3 500	1 750	1 750	0	0	+	0	0	22,78	SW	Nil	16	III
70.07.06	0715	0515	1122	12 150	2 600	2 600	0	0	0	+	0	0	22,60	S	Out	16	III
70.09.08	0700	0707	0106	278	93	56	37	0	0	0	0	0	35,19	NE	In	2	I
71.04.13	0650	0447	1101	5 000	2 320	773	773	774	0	+	0	0	6,58	SW	Out	12	III
71.10.12	0625	1108	0308	10 700	2 190	1 314	876	0	0	+	+[8]	0	0,89	Nil	Nil	20	IV
71.11.08	0610	0705	0036	11 200	2 685	1 611	1 074	0	0	+	+[9]	0	21,84	SW	Nil	20	IV

[1] *S. sofia*

[2] *S. sofia*; *S. johannesburg*; *S. typhi-murium* (phage type: 2b:u:1,8,9)

[3] *S. typhi-murium* (pht: 7)

[4] *S. typhi-murium* (pht: 1a)

[5] *S. newport*

[6] *S. typhi-murium* (untypable); *S. newington* *S. enteritidis* (pht: 13)

[7] *S. typhi-murium* (pht:1a)

[8] *S. amager*

[9] *S. eastbourne*

TABLE A4.2

Results and classification of Station X : 1968 to 1971

Date	Time	HW	LW	Total Coliforms/ 100 mℓ	Presumptive *E. coli*/100 mℓ	*E. coli* I/ 100 mℓ	Irreg. II/ 100 mℓ	Irreg. VI/ 100 mℓ	Parasite Units/ 250 mℓ	C+M+ Staph/ 50 mℓ	Salmonellae/ 250 mℓ	Shigellae/ 250 mℓ	Salinity °/oo	Wind (from)	Current (to)	Indicator value	Class
68.09.17	0820	1343	0716	255 000	81 950	57 365	24 585	0	2	0	+[1]	0	34,40	S	Nil	16	III
68.10.07	0830	0401	1001	975 000	401 500	255 000	109 500	36 500	3	+	+[1]	0	34,01	NE	Out	20	IV
68.10.21	0840	0307	0909	990 000	605 000	423 500	181 500	0	0	+	+[3]	0	33,99	Nil	Out	20	IV
68.11.04	0835	0308	0906	120 000	67 500	60 750	6 750	0	0	0	+[4]	0	34,42	NE	In	12	III
69.12.09	0820	0555	1154	$1,03 \times 10^6$	$1,001 \times 10^6$	455 000	364 000	182 000	2	+	+[5]	0	33,42	NE	Out	24	IV
69.01.13	0750	1103	0402	11 800	4 500	4 500	0	0	0	0	0	0	34,80	SW	Nil	8	II
69.01.27	0800	1105	0330	50 000	11 900	8 330	2 380	1 190	0	0	+[6]	0	33,99	Nil	Nil	16	III
69.02.10	0755	0834	0153	11 000	10 000	8 000	2 000	0	1	0	0	0	34,59	NE	In	12	III
69.03.10	0755	0707	1319	$1,44 \times 10^6$	890 000	534 000	356 000	0	1	+	+[7]	+[8]	32,34	SW	Out	28	IV
69.03.24	0755	0630	1248	730 000	410 000	410 000	0	0	0	+	0	0	33,37	Nil	Out	16	III
69.04.21	0755	0544	1158	360 000	267 300	218 700	24 300	24 300	0	+	+[9]	0	32,96	Nil	Out	20	IV
69.05.05	0745	0527	1138	875 000	390 000	273 000	117 000	0	0	+	+[10]	0	33,32	Nil	Out	20	IV
69.05.19	0745	0502	1114	710 000	407 000	370 000	0	37 000	1	0	+[11]	0	33,25	SW	Nil	20	IV
69.06.09	0745	1154	0551	34 000	10 230	9 300	0	930	3	+	0	0	33,79	NW	Out	20	IV
69.06.23	0800	0905	0307	27 300	9 700	6 790	2 190	0	0	+	+[12]	0	34,42	N	Nil	16	III
69.07.21	0745	0724	1329	$1,29 \times 10^6$	610 000	488 000	122 000	0	0	+	+[13]	0	32,70	N	Nil	20	IV
69.08.04	0745	0729	1329	$1,01 \times 10^6$	266 000	159 600	106 400	0	0	+	+[14]	0	33,42	S	Out	20	IV
69.08.18	0745	0617	1220	430 000	230 000	127 778	102 222	0	2	+	+[15]	0	33,51	NE	Nil	24	IV
69.09.02	0750	0643	1241	$1,04 \times 10^6$	630 000	441 000	189 000	0	1	+	+[16]	0	32,79	SE	Nil	24	IV
69.09.15	0745	0521	1123	440 000	310 000	186 000	124 000	0	0	0	+[17]	0	33,77	Nil	Out	16	III
69.09.29	0745	0519	1117	456 000	230 000	138 000	69 000	23 000	0	+	+[18]	0	33,73	Nil	Slack	20	IV
69.10.20	0745	1239	0611	63 000	14 000	9 800	4 200	0	0	0	+[19]	0	30,30	Nil	Nil	16	III
69.11.03	0740	1130	0359	42 000	23 000	18 400	4 600	0	0	+	+[20]	0	33,37	NE	Nil	20	IV
69.12.01	0740	0757	0133	400	100	50	50	0	0	0	0	0	34,08	NE	In	2	I
70.01.19	0735	0226	0822	1 250	296	207	30	59	0	0	0	0	33,30	Nil	Out	8	II
70.02.02	0745	1237	0613	1 550	408	163	204	41	0	0	0	0	33,77	SW	Nil	8	II
70.02.16	0745	0153	0756	225	79	55	24	0	0	0	0	0	33,99	SW	Out	6	II
70.03.09	0615	0452	1058	122	24	16	8	0	0	0	0	0	34,32	NE	Nil	2	I
70.04.13	0740	0733	0113	83	22	9	13	0	0	0	0	0	24,22	Nil	Nil	5	II
70.04.27	0725	0704	1310	115	58	0	46	0	0	0	0	0	34,47	Nil	Nil	1	I
70.05.11	0725	0644	1253	1 120	408	367	41	0	0	+	0	0	33,53	Nil	Nil	12	III
70.05.25	0745	0621	1228	132	40	28	16	0	0	0	0	0	34,39	SW	Nil	2	I
70.07.06	0845	0515	1122	157	95	76	19	0	0	0	0	0	34,35	Nil	Nil	2	I
70.09.08	0720	0613	1221	62	6	6	0	0	0	0	0	0	35,22	NE	In	1	I
71.04.13	0645	0447	1101	210	48	48	0	0	0	+	0	0	34,46	SW	Nil	6	II
71.10.12	0750	1108	0308	146	42	17	17	8	0	0	0	0	34,82	SE	Nil	2	I
71.11.08	0745	0705	1306	638	94	19	75	0	0	0	0	0	34,64	SW	Out	2	I

[1] *S. tennessee*; *S. reading*; *S.* (9,12:v:enx) new serotype, Subgenus II
[2] *S.* (- : Z10 : -)
[3] *S. newport*; *S. typhi-murium* (phage type : 2b:u:1,8,9)
[4] *S. anatum*; *S. sofia*
[5] *S. nordenham*; *S. durban*; *S. tehiongwe*; *S.* (9,12:a:1,5) new serotype, Subgenus II
[6] *S. reading*
[7] *S. reading*; *S. kentucky*
[8] *Sh. sonne*
[9] *S. typhi-murium* (untypable)
[10] *S. reading*
[11] *S. braenderup*
[12] *S. takoradi*; *S. reading*
[13] *S. reading*; *S. braenderup*; *S. bloemfontein*
[14] *S. reading*; *S. kentucky*
[15] *S. enteritidis* (untypable); *S. typhi-murium* (pht:18)
[16] *S. takoradi*; *S. worthington*; *S. reading*
[17] *S. chester*
[18] *S. chester*
[19] *S. kraalfontein*
[20] *S. cerro*; *S. elizabethville*

TABLE A4.3

Results and classification of Station 19 : 1968 to 1971

Date	Time	HW	LW	Total Coliforms/ 100 mℓ	Presumptive *E. coli*/100 mℓ	*E. coli*/100 mℓ	Irreg. II/ 100 mℓ	Irreg. VI/ 100 mℓ	Parasite Units/ 250 mℓ	C+M+ Staph/ 50 mℓ	Salmonellae/ 250 mℓ	Shigellae/250 mℓ	Salinity °/oo	Wind (from)	Current (to)	Indicator value	Class
68.09.17	0915	1343	0716	595 000	443 000	443 000	0	0	1	0	+[1]	0	34,75	S	N	16	III
68.10.07	0915	0401	1001	100	20	20	0	0	0	0	0	0	34,28	NE	S	2	I
68.10.21	0930	0307	0909	549 500	265 500	265 500	0	0	0	0	+[2]	0	31,99	Nil	N	16	III
68.11.04	0930	0308	0906	400	400	360	40	0	1	0	0	0	34,51	NE	S	8	II
68.12.09	0855	0555	1154	26 000	5 850	2 340	2 925	585	0	0	0	0	33,77	NE	S	12	III
69.01.13	0825	1103	0402	2 000	1 300	910	390	0	0	0	0	0	35,09	SE	N	4	I
69.01.27	0830	1105	0330	5 700	1 900	570	760	0	0	0	+[3]	0	34,80	SW	Nil	8	II
69.02.10	0830	0834	0153	6 940	5 850	5 200	650	0	0	0	0	0	34,89	NE	S	8	II
69.03.10	0830	0707	1319	30 000	21 000	6 300	12 600	2 100	0	0	+[4]	0	32,84	SW	N	16	III
69.03.24	0830	0630	1248	3 400	1 700	1 511	189	0	0	0	0	0	34,61	Nil	S	8	II
69.04.21	0830	0544	1158	580	520	520	0	0	0	0	0	0	33,72	NE	S	8	II
69.05.05	0825	0527	1138	3 200	1 650	825	825	0	0	0	+[5]	0	33,73	NW	Nil	12	III
69.05.19	0820	0502	1114	16 250	3 220	2 070	0	1 150	2	+	-+[6]	0	33,65	SW	N	24	IV
69.06.09	0825	1154	0551	1 000	500	350	100	50	0	0	0	0	34,30	NW	S	4	I
69.06.23	0830	0905	0307	100	60	60	0	0	0	0	0	0	34,54	N	S	2	I
69.07.21	0820	0724	1329	1 580	160	64	96	0	0	+	0	0	34,11	N	N	6	II
69.08.04	0820	0729	1329	2 600	0	0	0	0	0	0	0	0	34,59	Nil	S	1	I
69.08.18	0820	0617	1220	6 000	1 350	405	945	0	0	0	0	0	34,46	NE	S	4	I
69.09.02	0825	0643	1241	31 800	6 300	1 260	5 040	0	0	+	0	0	32,49	SE	N	16	III
69.09.15	0820	0521	1123	120 000	64 000	19 200	44 800	0	0	0	0	0	34,03	Nil	N	8	II
69.09.29	0815	0519	1117	4 400	1 200	360	840	0	0	0	0	0	34,22	S	Nil	4	I
69.10.20	0820	1239	0611	40 000	6 050	3 300	1 100	1 650	1	+	0	0	28,97	N	N	20	IV
69.11.03	0810	1130	0359	2 600	300	200	0	100	0	0	0	0	34,34	NE	S	4	I
69.12.01	0810	0757	0133	17 400	100	50	50	0	0	0	0	0	34,22	NE	S	2	I
70.01.19	0810	1428	0822	53 000	11 750	9 400	1 175	1 175	0	+	0	0	26,02	S	N	16	III
70.02.02	0825	1237	0613	15 300	4 200	2 940	1 260	0	0	+	0	0	29,28	N	SW	16	III
70.02.16	0820	1349	0756	32 100	13 550	12 195	1 355	0	0	+	0	0	31,06	N	SW	16	III
70.03.16	0820	1114	0222	900	410	328	82	0	0	+	0	0	34,40	Nil	S	8	II
70.04.13	0815	0733	1346	2 930	600	300	300	0	0	+	0	0	34,30	SW	N	8	II
70.04.27	0800	0704	1310	2 800	340	0	204	136	0	0	0	0	34,04	S	N	1	I
70.05.11	0800	0644	1253	1 775	600	540	60	0	0	+	0	0	32,39	Nil	N	12	III
70.05.25	0810	0621	1228	4 400	1 300	780	520	0	0	+	+[7]	0	33,92	SW	N	16	III
70.07.20	0710	0444	1054	658	381	229	152	0	0	0	0	0	35,52	N	S	4	I
70.09.08	0750	0707	1306	61	12	10	2	0	0	0	0	0	35,34	NE	S	1	I
71.04.26	0745	0414	1024	76 000	9 000	3 600	5 400	0	0	0	0	0	28,80	NE	S	12	III
71.10.25	0640	0625	1221	10 700	2 900	1 160	1 740	0	0	+	0	0	34,27	NE	N	12	III
71.11.22	0650	0545	1144	5 400	1 100	660	440	0	0	0	0	0	31,59	Nil	N	8	II

[1] *S. tshiongwe; S. bechuana; S. juisberg*
[2] *S. siegburg*
[3] *S. oranienburg*
[4] S. (11:-:1,5) new serotype, Subgenus II
[5] *S. enteritidis* var. *jena* (pht:14)
[6] *S. braenderup*
[7] S. (1,13,23:d:enx) Subgenus II

Date/ Sample	APR '80	JUN '80	OCT '80	NOV '80	DEC '80	JAN '81	FEB '81	APR '81	MAY '81	JUN '81	JUL '81	AUG '81	SEP '81	OCT '81	NOV '81	JAN '82	FEB '82	MAR '82	APR '82	MAY '82	JUN '82	JUL '82	SEP '82	JAN '83	MAR '83	MAY '83	JUN '83
Station 10		–		–		–		–		–		–		–			–			–	–	–	–	–	–	–	–
		–		–		Y		–		–		Y		–			–			–	–	–	Y	–	–	–	–
Sludge			X										X	X	X		X										
			Y										Y	Y	Y	Y	Y										
P. Tank			X										X	X	X		X										
Effluent			Y										Y	Y	Y	Y	Y										
b3(s)														–													
														–													
b3 sed														–													
														–													
c3 (s)	–						–		X	–	–		–			–			–								
	–				–		–		–	–	–		–			–			–								
c3 (m)																											
																			–								
c3 (d)																											
																			–								
c3 sed	–				–		–			–	–		–			–											
	–				–		–			–	–		–			–											
d2 (s)					–											–											
					–					–				–		–											
d2 sed	–				–		–			–	–		–	–		–											
	–				–		–			–	–		–	–		–											
d3 (s)					–		–						–	–		–			–								
	–				–		–			–			–	Y		–			–								
d3 (m)																											
					–														–								
d3 (d)																			–								
					–														–								
d3 sed	–				–				–	–	–		–	–		–											
	–				–				–	–	–		–	–		–											
d4 (s)					–											–											
					–					–				–		–											
d4 sed	–				–		–			–	–		–	–		–											
	–				–		–			–	–		–	–		–											
e3 (s)	–				–		–		X	–	X		–	–		–			–								
	–				–		–		–	–	–		–	–		–			–								
e3 (m)																											
																			–								
e3 (d)																			–								
																			–								
e3 sed	–				–		–			–	–		–	–		–											
	–				–		–			–	–		–	–		–											
		▲				△			▲												△						

KEY

X : virus positive
Y : coliphage positive
– : negative findings

(s) : sea surface
(m) : "mid" depth
(d) : at depth
sed : sea sediment

▲ : sludge starts
△ : sludge stops

Fig A4.2 Summary of virus and coliphage results pertaining to the Central Works Outfall

Date/ Sample	MAR '80	JUN '80	SEP '80	OCT '80	NOV '80	JAN '81	APR '81	JUN '81	AUG '81	OCT '81	FEB '82	MAY '82	JUN '82	JUL '82	AUG '82	SEP '82	DEC '82	JAN '83	MAR '83	APR '83	MAY '83	JUN '83
Station 19	X	-	-		-			X	-	X	X	X	X	X		X		-	-		-	-
	Y	Y	Y		Y	Y		Y	Y	Y	Y	Y	Y	Y		Y		Y	Y		Y	Y
Station 20	-	-	X				X		-	X		X	X	X				X	X			X
	Y	-	Y				Y		Y	Y		Y	Y	Y				Y	Y			Y
Primary Tank Effluent														X	X			X				
														Y	Y			Y				
Sludge														X	X			X				
														Y	Y			Y				
Final Mix																		X				
														-	Y			Y				
ℓ3 (s)				-								-		-		-	-		-			
				-								-		-		-	-		-			
ℓ3 (d)				-																		
				-																		
ℓ3 sed				-								-		-		-	-					
				-								-		-		-	Y					
m2 sed				-								-		-		-	-		-			
				-								-		-		-	-		Y			
m3 (s)												-		X		-						
												-		-		-						
m3 sed				-								-					-					
				-								-		-		-	Y					
m4 sed				-								-		-		-	-					
				-								-		-		-	-					
o3 (s)				-								-		-		-	-		-			
				-								-		-		-	-		-			
o3 (d)				-																		
				-								-										
o3 sed				-								-		-		-	-					
				-								-		-		-	-					

▲

KEY

X : virus positive
Y : coliphage positive
– : negative findings

(s) : sea surface
(d) : at depth

▲ : sludge starts

Fig A4.3 Summary of virus and coliphage results pertaining to the Southern Works Outfall

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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.

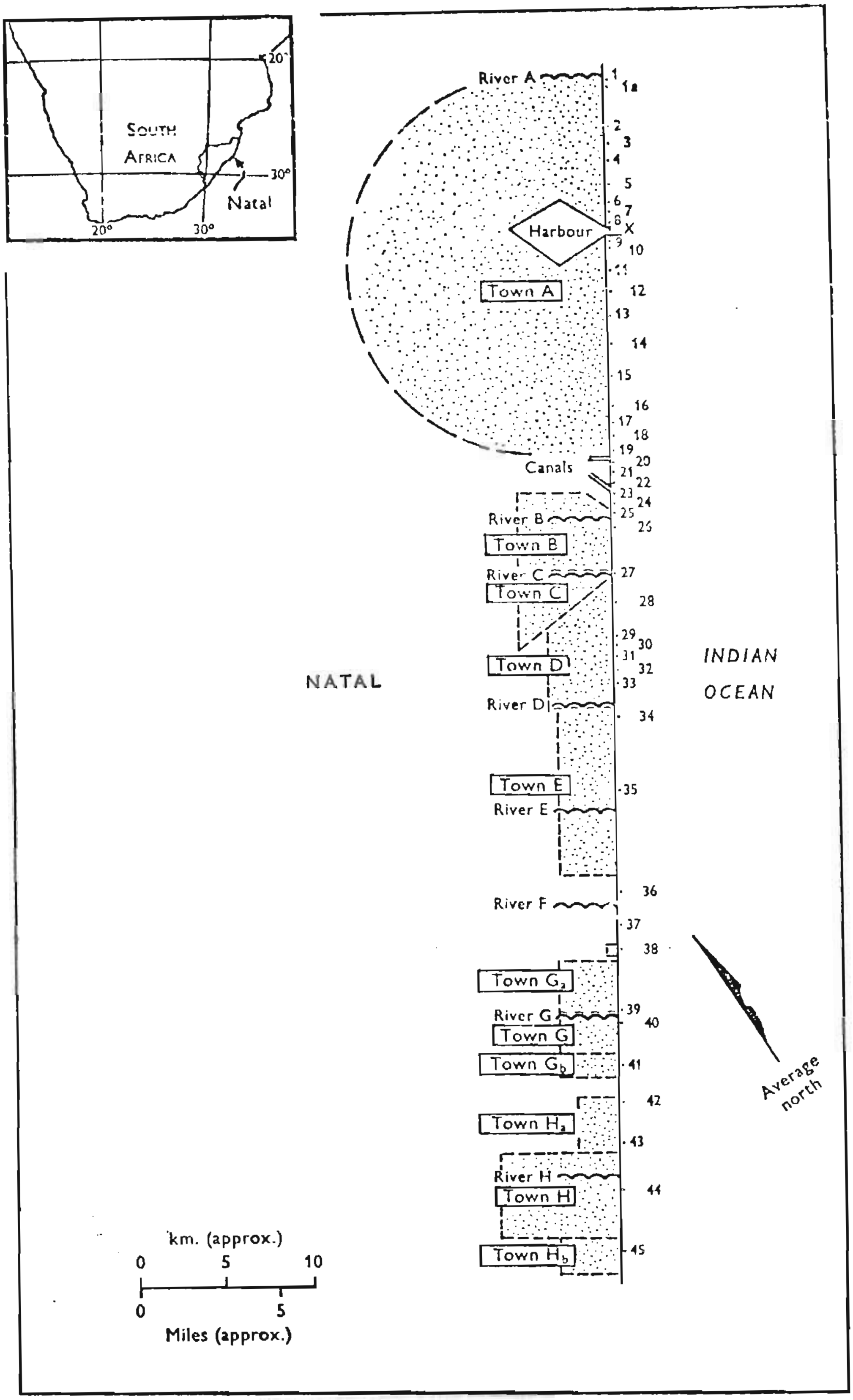

Fig. 1. Section of Natal coastline (schematic) showing sampling stations and main towns and rivers.

DESCRIPTION OF THE SURVEY AREA

Natal is 36,000 square miles in extent, and constitutes about $7\frac{1}{2}\%$ 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 ½–1 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

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* 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.

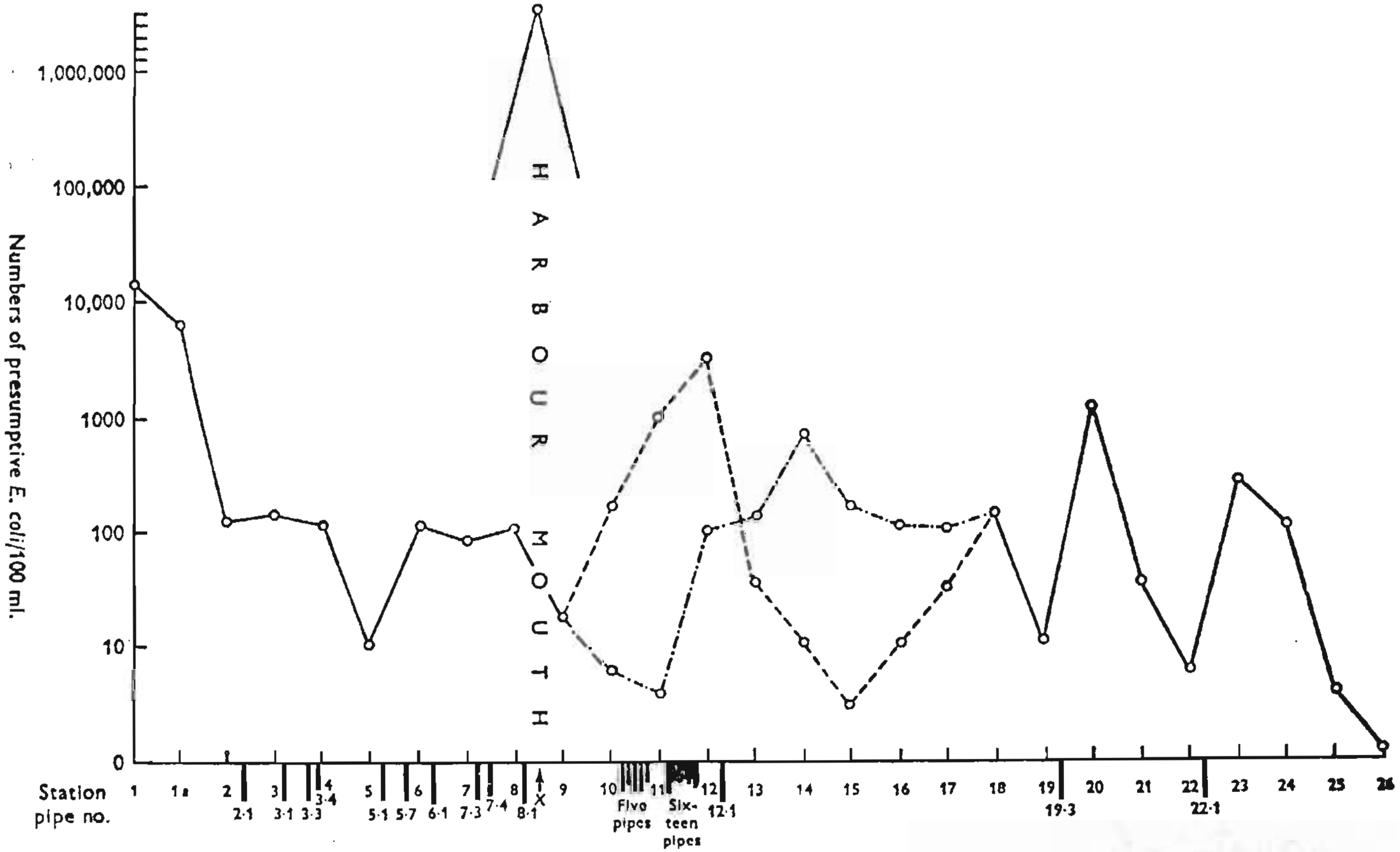

Fig. 2. Numbers of presumptive *E. coli* recovered from the surf sampling stations, showing the positions of pipes, drains and canals discharging sewage. Between stations 9 and 18: ←– – – north-going current; –· → south-going current.

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 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

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

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.

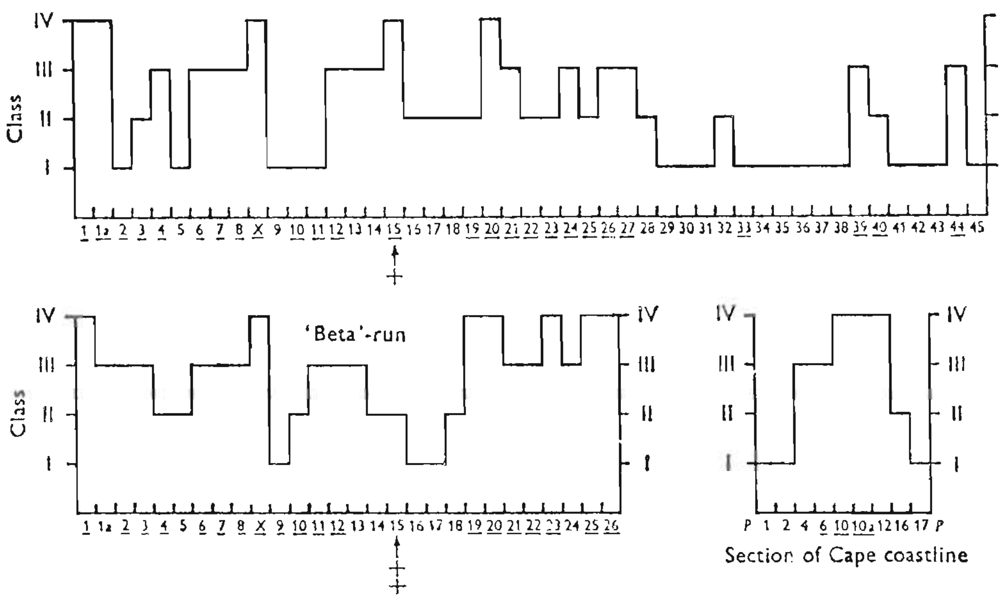

Fig. 3. Gradation of surf-waters by indicator values. Station numbers underlined indicate proximity to known sources of pollution. +, Tidal bath before chlorination; ‡ tidal bath later, chlorinated.

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.*)

	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 co.	*E. coli* I	Parasite index	C+M+staph.	*S. typhi*	Salmonellae/ Shigellae	Salinity	Total	Class
									River B mouth. Unchlorinated tidal swimming bath									
26	1	.	.	.	8	.	9	III	.	26	8	4	4	.	4	4	24	IV
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'									

Cape section

Station co.	*E. coli* I	Parasite index	C+M+staph.	*S. typhi*	Salmonellae/ Shigellae	Salinity	Total	Class
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.

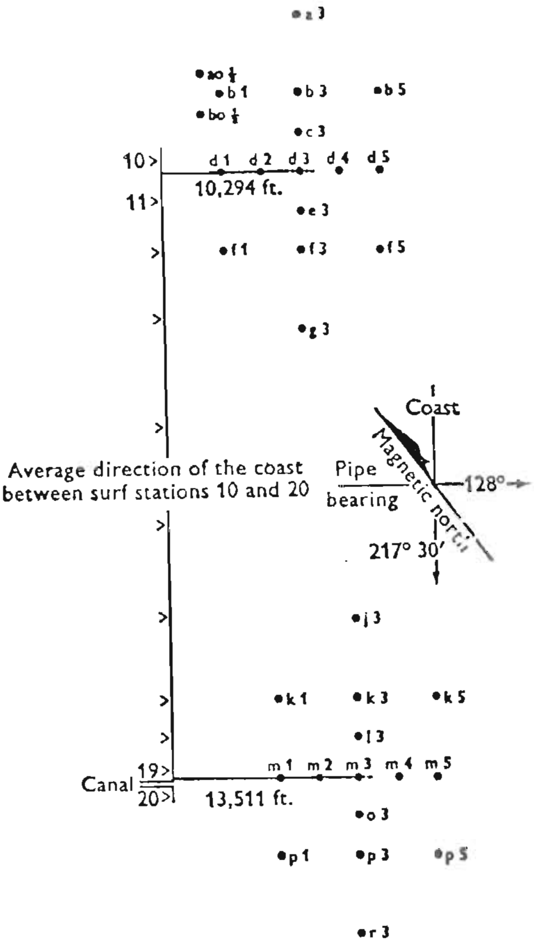

Fig. 4. Section of coast showing forthcoming submarine outfall lines with sea monitoring stations (arbitrary grid system: ½-mile units). Scale, 1:80,000.

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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An appraisal of sewage pollution along a section of the Natal coast after the introduction of submarine outfalls

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SUMMARY

A bacteriological survey 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 before the use of submarine outfalls was reported previously. In that report more than half the beaches in the region were found to be of Class IV or III quality. After the submarine outfalls became operational, ten further sampling runs were made. A considerable improvement in the sea-water quality was apparent, most of the beaches being regraded to Class II or I, notably in the bathing areas.

INTRODUCTION

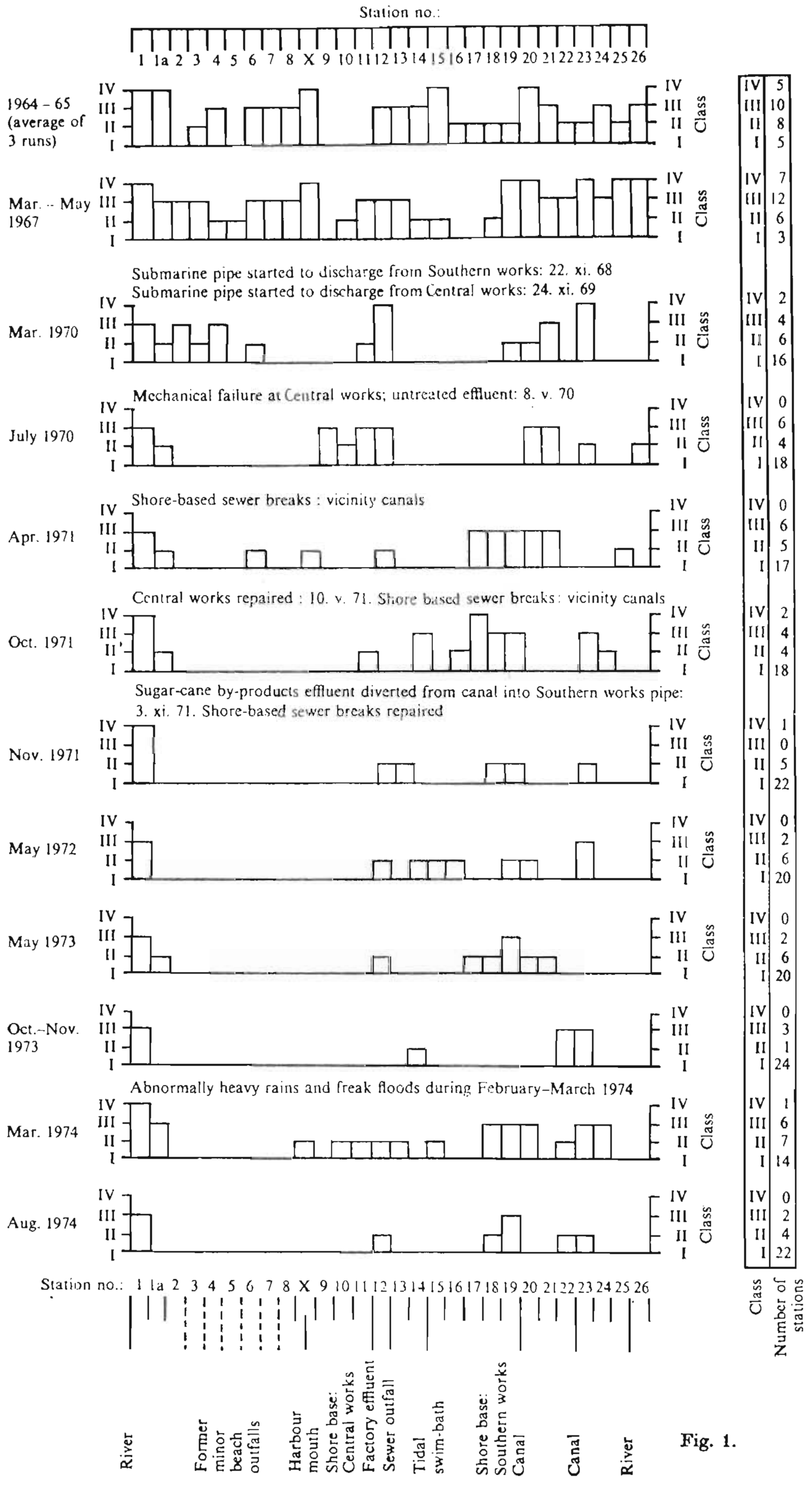
The first part of this investigation presented a description of the survey area, the bacteriological methods employed and the results obtained from the surf sampling stations, before the establishment of two submarine pipelines for conveying treated effluent out to sea for dispersal (Livingstone, 1969). A system of water quality gradation based on a method of adverse scoring for the various indicators used was also postulated. The system ranged from the evaluation of 'clean' sea water to grossly polluted. It was thought that the method, which used *Escherichia coli* I counts, parasite units, staphylococci, salmonellas and salinity, would provide an objective evaluation of any further changes in water quality when the various shore-based pipes and drains were sealed and their effluents diverted for ejection via the two submarine outfalls.

On the 22.xi.68 the submarine pipeline in the vicinity of Station 19 (Fig. 1), now referred to as the Southern Works pipeline, started to discharge. On the 24.xi.69 the pipeline in the vicinity of Station 10, known as the Central Works pipeline, started functioning. Both lines extend out to sea approximately at right angles to the coast. Further technical details on the pipelines appear in Table 1.

The present paper provides a brief digest of the changed nature of the surf waters in the region before and after the establishment of the pipelines.

MATERIALS AND METHODS

These adhered precisely to the methods previously described (Livingstone, 1969).



Submarine pipe started to discharge from Southern works: 22. xi. 68
Submarine pipe started to discharge from Central works: 24. xi. 69

Mechanical failure at Central works; untreated effluent: 8. v. 70

Shore-based sewer breaks : vicinity canals

Central works repaired : 10. v. 71. Shore based sewer breaks: vicinity canals

Sugar-cane by-products effluent diverted from canal into Southern works pipe: 3. xi. 71. Shore-based sewer breaks repaired

Abnormally heavy rains and freak floods during February–March 1974

Fig. 1.

Table 1. *Hydrographic data on the submarine outfalls*

Pipe from	Total length from shore (km.)	Length of diffuser section (m.)	Main diameter (m.)	Diameter of tapered diffuser section (m.)	Average depth of diffuser section (m. from sea level)	Average discharge Ml./d. (gal./d.)
Central Works	3·2	427	1·22	0·76	– 48 to – 53	77·40 (19×10^6)
Southern Works	4·2	525	1·37	0·92	– 54 to – 64	72·03 (18×10^6)

RESULTS AND DISCUSSION

The system of evaluating indicators and of classifying sea waters (Livingstone, 1969) was applied to the results obtained from the samples collected after the pipes started to discharge treated sewage. Fig. 1 shows the classification of these waters, an average of three runs in 1964–5 appearing first, followed by a run in 1967, before the pipelines were constructed. More than half of the beaches in the region fell into Class IV or III. These included the main swimming areas Stations 2, 3, 4, 5, 6, 7, 14 and 15 (Livingstone, 1969). Thereafter, in chronological order, the classification of the waters is depicted for ten subsequent sampling runs.

Attempts to detect the discharged effluent at sea by employing tracer dyes, and bacteriologically, failed except on one occasion during the period when untreated effluent was being discharged from the Central Works and the plume surfaced beyond the end of the pipeline at Station d3 (Fig. 4 in Livingstone, 1969) between changes of current direction.

The sensitivity of the system of measurement is reflected by the run of March 1974, when abnormally heavy rains took place. These caused localized sewer and stormwater overflows which affected the quality of the adjacent surf.

Apart from contributions of adverse hygienic significance from the river in the north (Station 1) and the pair of canals in the south (Stations 19/20 and 22/23) a general measurable improvement in the sea-water quality of this region has occurred. Many of the former Class IV and III beaches have changed to the altogether more desirable grades of Class II and I, notably in the bathing areas, after the pipelines became fully operational, thereby confirming the calculations used for designing the outfalls.

Fig. 1. Gradation of the surf water by indicator values, with the progressive chronology outlined, and certain past and present actual or potential polluting features shown.

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THE EFFECT OF SUBMARINE WASTEWATER DISCHARGE ON THE BACTERIAL QUALITY OF SURF WATERS

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ABSTRACT

A system involving enumeration of *Escherichia coli* I, parasite units, staphylococci and salmonellas, and determination of salinity, was developed for the objective assessment of bacterial water quality in the sea off Durban, South Africa. The system was used to measure the quality of the surf waters before and after the construction of two submarine outfalls. Significant improvement in the quality of the surf along the bathing beaches has been noted since the outfalls became operational.

KEYWORDS

Submarine wastewater discharge; surf waters; bacterial quality; *Escherichia coli* I; parasite units; staphylococci; salmonellas; salinity.

INTRODUCTION

In 1964 the untreated wastewater from the central area of Durban (approximately 90,000 $m^3.d^{-1}$) drained towards the vicinity of the harbour mouth, where it was temporarily stored after coarse screening, and discharged with the outgoing tide at Station X (Fig. 1). In the south, the sewered area drained to a pumping station, and this waste (some 20,000 $m^3.d^{-1}$) was ejected into the surf via an outfall between Stations 12 and 13. In addition, there were numerous minor discharges, particularly in the vicinity of Stations 10 to 12.

Owing to rapid industrial and municipal expansion, the City Council in that year initiated a programme to reticulate the whole of the city, to develop and upgrade the trunk sewer system to cope with expected future loadings, and to study the feasibility of constructing stable submarine outfalls for the efficient and safe discharge of domestic and industrial wastewater to sea.

Work on the oceanographic aspects had already been commenced in 1962 by the Council for Scientific and Industrial Research (CSIR), and experiments on the feasibility and design of the pipelines started a year or two later.

At this juncture, the National Institute for Water Research (NIWR) of the CSIR was contracted to measure the existing degree of pollution, to locate all its sources,

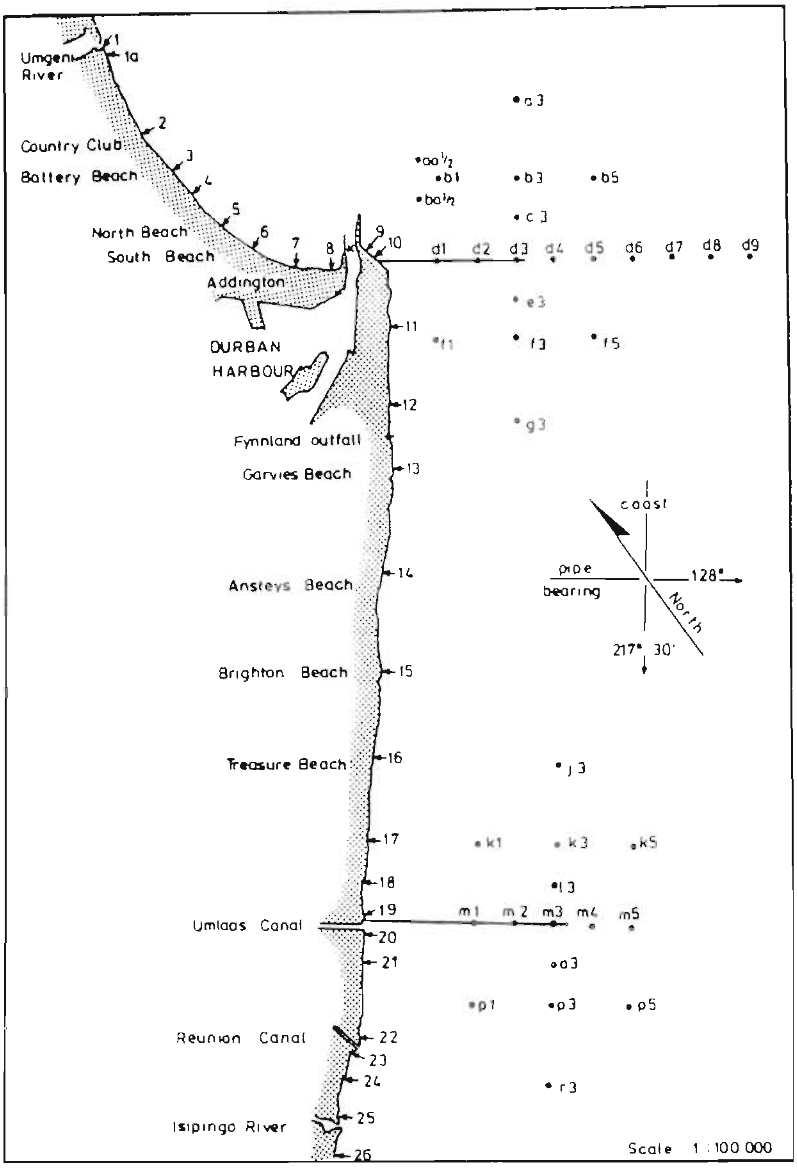

Fig. 1. Locality of the beach and off-shore sampling stations.

and to establish standards for subsequently monitoring the outfalls when they became operational. The detailed chemical and faunal picture has been fully documented (Oliff and co-workers, 1967a, 1967b), and summaries of certain of the bacteriological findings, along with a detailed description of the survey area and the bacteriological methods used, have been reported (Livingstone, 1969, 1976).

The submarine pipelines started to discharge in the late 1960's; the Southern Works outfall, near Station 19, on 1968.11.22, and the Central Works outfall, near Station 10, on 1969.11.24.

A bacteriological system of water quality gradation, based on a method of adverse scoring for the various indicators, has been in use from 1964 to the present day.

The waters are classified at approximately three monthly intervals. A limited number of stations are usually sampled but all stations are graded at least once per annum. In evolving the system, it was sought to range from the appraisal of 'clean' sea water to the grossly polluted; and the method employs the evaluation of *Escherichia coli* I counts, parasite units, staphylococci, salmonellas and salinity.

This system has enabled an objective assessment of changes in the local water quality to be made during the transition period from before to after operation of the outfalls. The system should continue to prove useful in the future for assessment of the effects of a sludge discharge experiment presently being initiated in the region.

OCEANOGRAPHY AND CURRENT DYNAMICS

The flow of the sea off Durban is dominated by the southgoing Agulhas Current, a western boundary current situated, on average, with its core about 40 to 50 km offshore. The different topography further south and the subsequent movement of the Agulhas Current inshore results in the existence of a semi-cyclonic gyre off Durban, and the flow on the shelf is then generally northwards.

Measurements over a number of years have confirmed this northward tendency, although periodic fluctuations are superimposed on this drift. Thus changes in current direction occur, with weak onshore/offshore components during the transition. The periods vary from 2 to 10 days (E.H. Schumann, 1980 - personal communication).

Closer to shore, the nearshore currents flow parallel to the coast and reverse direction, usually in association with changes in atmospheric pressure, every 1 to 3 days. The majority of these (65%) tend to be northgoing, with an average velocity of 0.3 $m.s^{-1}$. Weak onshore surface components occur 10 to 15% of the time, usually in association with the wind direction and longshore current reversals. Current velocities near the sea-bed off Durban are lower than at the surface by a factor of 0.3 to 0.4. Wave height is normally 1 to 2 m, and wave approach is somewhat oblique 50% of the time. The surf zone itself is dominated by wave action and rip currents which occur about 40% of the time (Stander, Oliff and Livingstone, 1967; Oliff, Livingstone and Stone, 1969; Oliff and Addison, 1970).

HYDROGRAPHIC DATA ON THE SUBMARINE OUTFALLS

The designed capacity of the Central Works pipeline is 136,000 $m^3.d^{-1}$, while that of the Southern Works is 227,000 $m^3.d^{-1}$. The present (March, 1981) flow through each of the pipelines is approximately 50% of their respective designed capacities. With increased discharge, increased diffuser port velocities and, consequently, increased dispersion is expected (Macleod, 1972).

Design calculations based on detailed oceanographic data had indicated that a pipeline 4 km in length at a site near Station 19, with a diffuser of 420 m length, would provide a further minimum dilution of 1,000 times at Station 15, allowing for a 5% onshore frequency in the vicinity. At all other areas the dilution would be greater (Anderson, 1967).

The dimensions and discharge depths of the two outfalls are shown in Table 1.

TABLE 1 Hydrographic Data on the Submarine Outfalls

Pipe from	Total length from shore (km)	Length of diffuser section (m)	Main diameter (m)	Diameter of tapered diffuser section	Average depth of diffuser section (m from sea level)	Average discharge ($\times 10^3$ $m^3.d^{-1}$)
Central Works	3.201	421.8	1.22	0.76	-48 to -53	77.40
Southern Works	4.198	421.8	1.37	0.92	-54 to -64	72.03

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 contexts is often of undoubted importance.) These included *Streptococcus faecalis*, *Clostridium perfringens*, *Candida albicans*, the bacteriophage of *Salmonella typhi*, and *Mycobacterium tuberculosis*.

Total coliforms are routinely enumerated in the work as this index provides a fair, if non-specific, general indication of waterborne terrigenous increments. However, total coliforms are not specific enough when faecal pollution is under consideration. Owing to the particular nature of the coastline in the area, the use of coliforms or so-called 'faecal coliforms' is comparatively valueless; and if a water standard is to be based on *Escherichia 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.

The 'faecal coliforms' usually 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 and hemp (Wilson and Miles, 1964) and, at least in Natal, in the marginal vegetation of rivers (Brand and co-workers, 1967). As an example of the differentiation applied to the present survey, a paper mill, upstream from Station 1, producing paper from rags imported from Japan and ejecting waste into the river, showed the following typical analysis on one of its felt-based effluents:

E. coli I	0 per 100 mℓ
Irregular II	150.07 x 10^6 per 100 mℓ
Irregular VI	83.38 x 10^6 per 100 mℓ
'Faecal coliforms'	233.45 x 10^6 per 100 mℓ

Subsequent investigations showed that, in fact, no direct faecal contamination of the river could be attributed to the mill, and that the presence of no other sewage organisms could be demonstrated from the mill's water circuits. Furthermore, the waste rags were subjected to an initial steaming before processing.

Indicators finally selected, therefore, were:

E. coli I. This organism is an indicator of definite and fairly recent faecal pollution. Its main limitation as a source indicator is that the bacilli can survive for more than 24 h in local sea water (Livingstone, 1978). In view of the currents obtaining in the region, the complete and consistent absence of *E. coli* I from any particular beach in this area is highly improbable.

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, about 5% of the eggs surviving 30 h (Livingstone, 1978).

Coagulase positive, mannitol positive staphylococci. These organisms were recorded on a present- or absent-in-the-sample basis. However, their presence in local sea water, despite their predilection for sodium chloride, was rare in comparison with their occurrence in local inland waters. This organism would appear to indicate very recent specific pollution, possibly of a non-faecal nature. Though common in the respiratory tract of man, the organism 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 relatively stagnant or stored sea water, for example a harbour mouth, a canal mouth experiencing tidal damming effects, river mouths and unchlorinated tidal swimming pools. These staphylococci are present, however, in appreciable numbers in polluted rivers examined by ourselves and others (Wilson and Miles, 1964). The organism has been reported as succumbing fairly rapidly in polluted sea water (Anon., 1956). For these reasons, its isolation was regarded as having distinct 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 (Livingstone, 1964). These 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. Shigellas, which are known to be much 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

The methods outlined here were adopted and standardized in 1964. These methods have continued to be used, with some minor changes, to allow comparison of past and future results.

Sampling. Water samples were collected in sterile containers, 2 m from banks of rivers and canals, the side of a boat or, in the surf zone, 2 m from the shoremost lip of a newly broken wave. A sample-stick with bottle-holding attachment was used. Effluent from pipes and drains was sampled direct.

For all surface investigations, the water layer between the surface and 0.15 m depth 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 h at 37 °C on pads impregnated with resuscitation broth (Oxoid), then transferred to pads impregnated with MacConkey membrane broth (Oxoid) for a further 17 h (total incubation, 18 h). 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 'faecal coliforms'. Two 100 mℓ samples of water, or of appropriate dilutions in sterile distilled water, were membrane-filtered. The membranes were resuscitated for 2 h at 37 °C on pads impregnated with resuscitation broth (Oxoid), then for a further 16 h at 44.5 °C in a water bath (total incubation, 18 h) 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 .

E. coli I, Irregular II and Irregular VI (Difco Laboratories, 1953, 1962; Taylor, 1958; *Standard Methods*, 1960; Oxoid Division, 1961; Wilson and Miles, 1964). A representative number of yellow colonies from the membranes from the presumptive test were subcultured into tryptone broth (Difco) and incubated at 44.5 °C for 24 h . From these tubes, subcultures were made in Koser's citrate medium (Difco) with 0.5% of brom thymol blue indicator solution (Brom thymol blue, 1.6 g; n-NaOH, 1.3 mℓ; absolute alcohol, 20 mℓ; distilled water to make 50 mℓ), and incubated at 44.5 °C for 96 h . The tryptone broth cultures were tested for indole production with Kovac's reagent.

44.5 °C	Indole	Citrate	Organism
+	+	-	*E. coli* I
+	-	-	Irregular II
+	-	+	Irregular VI

From these results, a differential *E. coli* I, Irregular II and Irregular VI count per 100 mℓ was calculated.

Parasite units. Normally, 250 mℓ of the sample were examined. The sample was allowed to stand for 30 min, and the supernatant, except the last 10 to 20 mm, 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 3,000 rev/min for 3 min . All the *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 h . 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 bromcresol purple indicator were placed to detect mannitol fermentation. Results were recorded as present or absent in 50 mℓ .

Salmonella typhi, and *Salmonella, Shigella, Proteus* and *Pseudomonas* groups (Livingstone, 1964). Normally, 250 mℓ of the actual sample were added to 6 g of selenite brilliant green broth (SBG, Difco); 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. Both halves of the sample were incubated at 37 °C for 20 h, and each was then subcultured on two plates of a modified SS (Difco) agar, in which the lactose was increased to 1.5%, and 1.5% of saccharose, not normally present, was added. A selection of 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 for independent confirmation and serotyping.

Results were recorded as present or absent per 250 mℓ .

Salinity. Salinity readings were taken on an electrical conductivity salinometer.

WATER QUALITY GRADATION

The limitations of *E. coli* I as the sole indicator in monitoring the effects of the diversion of wastewater through submarine outfalls have already been discussed. A means of measuring local water quality was therefore evolved employing a graded process whereby any quality variation of the nearshore sea water and surf as regards sewage contamination could be assessed. The system was designed to cover every possible local contingency of wastewater discharges affecting neighbouring bathing beaches on an adverse scale. Each indicator was selected and scored basically on a value of 4 (the figure for the presence of 101 to 1,000 *E. coli* I per 100 mℓ). Certain indicators regarded as of special pollution significance were given greater weight by being accorded higher values if their numbers or infrequency of occurrence were thought to warrant this. This system of scoring is shown in Table 2. Table 3 shows how the total indicator scores from Table 2 were used to divide the waters into Classes I to IV.

This system of measurement is based broadly enough to ensure that no random momentary increase or lessening of the numbers of any single indicator would dictate major reclassification of the sea water. Any important change would involve all or most of the parameters.

RESULTS AND DISCUSSION

Gradations of the surf waters in the region, from 1964 to 1980, are presented in Fig. 2. The bathing beaches are at Stations 2 to 7, 14 and 15 (Fig. 1).

Judging from the numbers and variety 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, 1954a, 1954b), to the absence of *E. coli* (Yotakis, 1959). More recently, the Council of the European Communities directive (1976) on 'the microbial standards for bathing waters' shows that the multiple-organism approach is gaining ground. This 'directive' specifies counts for total coliforms, faecal coliforms, faecal streptococci, salmonellas and enteroviruses. Unfortunately, the directive assumes the stance of a 'health standard'; whereas the actual risk to health from bathing in waters which are polluted but not aesthetically displeasing remains largely

TABLE 2 Evaluation of Indicators

Indicator	Degree	Value
Escherichia coli I per 100 mℓ	0 to 10	1
	11 to 100	2
	101 to 1,000	4
	> 1,000	8
Parasite units per 250 mℓ	1 to 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 °/oo	<34 °/oo	4

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

TABLE 3 A system of Classifying Sea Waters according to Indicator Values

Indicator values	Water quality	Class
1 to 4	Good	I
5 to 8	Fair	II
9 to 16	Poor	III
> 16	Very poor	IV

speculative or controversial (Cabelli, 1979; Gameson, 1979). The main concern in the present survey was the need to measure local water quality, and changes in that quality, efficiently and relatively speedily. However, it can be reported that there have been no cases of notifiable infections recorded from swimmers using Class I or Class II bathing areas since the outfalls became operational.

As can be seen from Fig. 2, the section of coast under review was in a grossly polluted state prior to the use of submarine wastewater discharge. More than half of the beaches in the region were Class IV or III; these included the main swimming areas Stations 2 to 7, 14 and 15.

After the submarine outfalls started to operate and the discharges ceased at Station X, there was an abrupt and dramatic cessation of salmonella isolations, a great decline in *E. coli* I numbers, and staphylococci were rarely to be found at this station. The improvement favourably affected the neighbouring stations immediately to the north. Even a year-long failure at the Central Works, during which untreated wastewater was pumped out to sea, produced little or no effect on the main bathing beaches. All the bathing beaches between the Umgeni River (Station 1) in the north and the harbour mouth (Station X) in the south reflected Class I water quality. The Umgeni River itself showed little change, usually fluctuating between Class III and IV. The bathing beaches south of the outfall near Station 13, in the vicinity of Stations 14 and 15, also showed improvement, although this was not as steadily maintained as in those to the north. This area, south of Station X, included a factory effluent at Station 12, the outfall between Stations 12 and 13, the complex of canals between Stations 19 and 20, a further canal between Stations 22 and 23, and the river near Station 25.

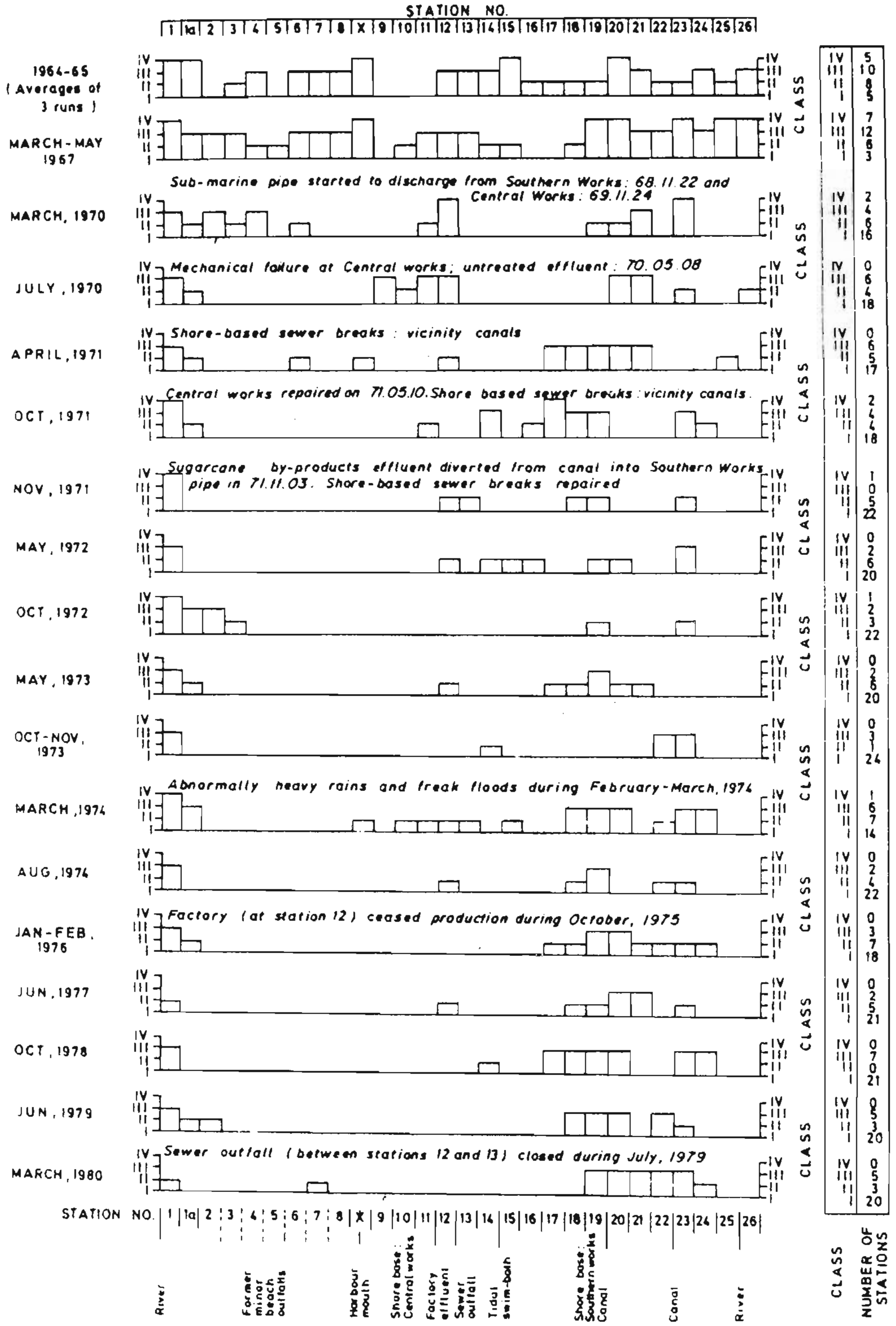

Fig. 2. Gradation of the waters by indicator values, with the progressive chronology outlined, and certain past and present actual or potential polluting features shown.

After several initial commissioning problems with the marine outfalls had been overcome, and the surf zone outfall along with the minor pipes and drains ceased discharging, the picture improved further. Attempts to detect the discharged effluent at sea bacteriologically and by employing tracer dyes, failed, except on one occasion between changes of current direction, during the period when untreated wastewater was being discharged from the Central Works. On this occasion the plume surfaced beyond the end of the pipeline between Stations d3 and d4.

The sensitivity of the system of measurement is reflected by the run of March 1979, when abnormally heavy rains took place. These caused a few remaining localized sewer and stormwater overflows, which affected the quality of the adjacent surf.

Apart from contributions of adverse hygienic significance from the Umgeni River in the north (Station 1) and the pair of canals in the south (Stations 19/20 and 22/23) where the pollution of these waterways occurs some distance inland beyond the city's jurisdiction, a general measurable improvement in the seawater quality of this region has occurred. Many of the former Class IV and III beaches have changed to the altogether more desirable grades of Class II and I, notably in the bathing areas, after the pipelines became fully operational, thereby confirming the calculations used for designing the outfalls.

It is considered that the system of grading these waters will continue to prove useful, in the light of the present background, for detecting and measuring any changes when experimental submarine discharge of sludge commences in the area.

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