# Marine Pollution – A 1988 Perspective

A G S Moldan and J H Ridder (Editors)

Proceedings of a symposium on Marine Pollution held at the Muizenberg Pavilion under the auspices of the Departments of Water Affairs, Environment Affairs and National Health and Population Development, the Water Research Commission and the Council for Scientific and Industrial Research

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## ABSTRACT

The debate over the degradation of coastal waters by sewage, oil and industrial wastes, continues. To provide a wide-ranging but concise examination of this topic, the Foundation for Research Development of the CSIR organized a one-day public technical symposium, attended by 250 people, to examine the nature, degree and control of marine pollution in South African coastal waters in the Muizenberg Pavilion on 8 September 1988. This report contains the presentations of invited speakers selected from a wide spectrum of scientific, technical and administrative backgrounds. Speakers emphasized current knowledge, perception and control measures to offer a condensed but broad perspective of the major issues and of advances made in recent years.

## UITTREKSEL

Die debat oor die agteruitgang van kuswater as gevolg van riool, olie en nywerheidsafval gaan voort. Om 'n breë maar saaklike oorsig van hierdie onderwerp te verkry, het die Stigting vir Navorsingsontwikkeling van die WNNR op 8 September 1988 in die Muizenberg paviljoen 'n eendaagse openbare tegniese simposium, wat deur 250 mense bygewoon is, gereël om die aard, graad en beheer van seebesoedeling in Suid-Afrikaanse kuswaters te ondersoek. Hierdie verslag bevat die referate van genooide sprekers uit 'n wye spektrum vanuit wetenskaplike, tegniese en administratiewe agtergronde. Hul het huidige kennis, persepsies en beheermaatreëls uitgelig en 'n samevattende, maar wye perspektief gegee van die belangrikste kwessies en van vordering wat gedurende die afgelope jare gemaak is.

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# MARINE POLLUTION AND HUMAN HEALTH; SOME PERSPECTIVES

G.S. Watermeyer

As man proceeds to multiply on planet Earth, and as his sociological make-up and herd instinct draws him to the city environs, so he exerts a defined effect on his immediate environment. When one adds to this need to congregate, an ability to develop industries, it becomes clear that the immediate environment within which Man functions must begin to show certain evidence of man's presence. Were the evidence universally advantageous to the environment, one would have little problem, but the negative influences which we observe; the destructive impacts on the wider ecosystem represent the deleterious effects of environmental pollution.

Other speakers at this conference will discuss a variety of forms of impact of pollution on aquatic life, the flora and fauna of the undersea world - suffice it to say at this stage that my main concern today relates to the demonstrable impacts of marine pollution on human health.

Much has been written and much more has been speculated on the effects of marine pollution on man - but what are the facts? Pitifully few!

We have the well-documented Minamata problem related to mercury pollution of a marine ecosystem where people utilizing the marine resource developed an irreversible nervous system disorder culminating in paralysis and insanity. We have further examples of bacterial contamination of shellfish by sewage effluent in some Mediterranean sea-coast resorts, but these are rather special cases. The run-of-the-mill user on the South African coastline faces an as yet undetermined risk to his health on our relatively open and relatively unpolluted coastline. But the future is anything but clear.

In the first instance, who knows what future urbanization and industrialization will take place in this country? Who knows what burden of pollutants will be presented to the massive aquatic environment? Who knows how to measure this burden? Who knows how to lessen the burden?

There has been a great deal of discussion around the measurement of the extent of pollution, just as there has been many attempts to measure the impact of marine pollution on human health. Most of these attempts have failed to provide conclusive results.

It follows from this argument that it is at present, in the current state of our knowledge, not possible to lay down hard criteria for pollution levels from the perspective of human health hazard - the best we can do is to suggest guidelines.

It follows also that the indicators of human health hazard from marine pollution that we have to use are at present only approximate suggestions and guidelines.

There is also another important proviso. If we are uncertain regarding measurement we should not indulge in scaremongering - if we can measure a microgram or picogram amount of a substance it does not mean that that amount represents a hazard and those scientists, pseudo-scientists and camp-followers who espouse that principle should be requested to validate their position.

I believe that this symposium seeks to achieve exactly that balanced approach that one is so desperately looking for.

# SOUTH AFRICAN COASTAL WATERS ASSIMILATION OR POLLUTION?

D.A. Lord

## INTRODUCTION

The sea - and more particularly the coastal ocean - is the ultimate repository of man's wastes. The highly dynamic nature of the southern African shoreline allows for a very rapid assimilation of many of these materials by natural processes such as oxidation, degradation, or sequestration into sediments.

However, the capacity for such assimilation is limited. Understanding this process of 'absorption' by the oceans and thereby determining their 'assimilative capacities' has been the main challenge of marine pollution research during the last few decades. There is little doubt that significant successes have been achieved in reducing the contamination of our natural waters, however these gains have in part been offset by an increase in the number of discharges and therefore the total load being delivered to the sea, further exacerbated by the increasing individual demands for higher standards of living.

Currently, approximately 800 million l/day of effluent is discharged to sea off the coast of South Africa, about 550 million l/day from deepsea outfalls, and the remaining 250 million l/day from shoreline sites (Toms 1986). The control of marine discharges is undertaken by the Department of Water Affairs, with permit conditions required in terms of the Water Act (which was initially established to control discharges to fresh water) usually being relaxed for parameters such as oxygen demand, suspended solids, and bacteria. Maintaining water quality requirements for the preservation of aquatic life is considered to be the most important objective in the control of marine discharges and this is achieved by reference to the compilation, 'Water Quality Criteria for the South African Coastal Zone' (Lusher 1984).

## DEEPSEA OUTFALLS

Deepsea outfalls have proved extremely efficient for the dispersion of those effluents which degrade readily in the sea. Deepsea outfalls are not the answer to pollution problems; rather they should be considered as the most effective way of finally discharging a buoyant material into the sea after effective treatment on land has been completed. Techniques for their most efficient design have advanced markedly, particularly with the experience gained in the design of the two Richards Bay pipelines (CSIR 1982, Toms 1986, Lord and Geldenhuys 1986), and with the proposed Hout Bay sewerage disposal system (CSIR 1986). An improvement in the water quality of Durban beaches provides one of the more convincing examples of the effectiveness of sensible land treatment coupled with deepsea discharge.

Prior to 1968, Durban did not have any wastewater works to handle sewage and trade effluent. At this time 90 million l/day of raw sewage were discharged to sea via outfall pipes along the North Pier, and approximately 20 million l/day were discharged into the surf at Fynnlands. Two main sewerage works were subsequently built along the coast, the first at the Old Whaling station on the Bluff (the Central Works) and the second on the northern banks of the Umlaas Canal (Southern Works). The effluents from these works were discharged to sea via two submarine outfalls 3.2 and 4.2 km long respectively, discharging in waters 48 m and 54 m deep respectively. Livingstone (1976) using a stringent and interlinked system of water quality gradation employing *E. coli I* counts, parasite units, staphylococci, salmonellas, and salinity to evaluate 'before pipelines' and 'after pipelines' water quality at the beach, showed unequivocally that,

a) beach water quality was only compromised by shore based discharges, and b) the two Durban deepsea outfalls are efficient and effective.

The gnawing question still remains, "How many pipelines can discharge into the sea without effects being felt". Since the Durban experience, two large polyethylene marine pipelines have been installed from Richards Bay, and further sewage pipelines are being considered along the South Coast of Natal. Clearly, the sea is not unlimited in its capacity to receive wastes even as non-refractory as sewage. Determining the upper limits of discharge to even the dynamic systems that exist off our coast, still represents a major technical challenge.

## SHORELINE DISCHARGES

In contrast to deepwater discharges, shoreline discharges to sea will always constitute an environmentally risky procedure. Detailed studies in enclosed areas such as False Bay and Algoa Bay (Lord *et al.* 1988) clearly show that shoreline discharges, which normally are of freshwater and far lighter than the seawater that they enter, stay on the sea surface close to shore, with limited dilution (1 to 2 orders of magnitude) occurring typically within only a kilometre of the discharge point.

However, these discharges to sea cannot be eliminated. Conventional stormwater discharges are at or above HWOST, and treatment of stormwater prior to discharge in South Africa is impractical. The stormwater issue can only be resolved by combining a number of common sense collection and treatment procedures, such as using unlined (i.e. pervious) stormwater channels and sumps to reduce flows and to remove suspended material, to screen stormwater before discharge, and to discharge only after all attenuation procedures have been exhausted. Possibly one of the most elegant stormwater retention and 'treatment' systems exists in the city of Canberra, Australia. By combining a series of traps, and small ponds which assist in nutrient removal, stormwater is discharged to freshwater lakes at a quality equal to the lake water itself (NCDC 1986, NCDC 1988). Such pretreatment before discharge is not applicable for discharge to sea, but the basic principles are.

In South Africa, such shoreline discharges are of greatest concern in areas of rapid urban development, and where stormwaters discharge to enclosed or semi-enclosed bodies of water, such as False Bay. Stormwater discharge from the major development at Motherwell, on the northern shore of the Swartkops River Estuary, is of even greater concern. This stormwater is channelled via a concrete canal into the middle reaches of the Swartkops River Estuary - an area of the estuary known to have reduced exchange with the sea (Lord and Thompson 1988). Interestingly, despite an extended dry spell during the period July-September 1988, flow from the canal was continuous (estimated 15-50 kilolitres per day) and of extremely poor quality (faecal coliforms $10^6$-$10^8$ per 100ml) (Scarr and Lord, unpub. data 1988). Ironically, rainfall actually improved the quality of the canal discharge by dilution. These observations on stormwater quality elicited grave concern about the ability to maintain even recently installed sewerage systems.

## THE CHLORINATED HYDROCARBONS

An important marker of widespread contamination of our environment is the presence of chlorinated hydrocarbons in marine tissues. This broad range of compounds includes in particular, the persistent insecticides such as; DDT and its metabolites, dieldrin, and lindane (or gamma-BHC), as well as industrial chemicals such as the polychlorinated biphenyls (PCBs). These compounds have very low water solubility, and consequently a strong tendency to accumulate in fatty tissue (de Kock and Lord 1987). Residues of these chemicals are now found in animals worldwide. Comprehensive studies using dolphin blubber (from animals caught accidentally in anti-shark nets off Natal during 1978 - 1987) have revealed a number of important trends (Cockroft *et al.* 1988).

Male dolphins increase residue concentrations with age. In females, a very rapid decline in residue is found after the age of sexual maturity, indicating that during lactation subsequent to her first pregnancy, a female voids herself of the major portion of her blubber residues, with estimated losses being 70% and 85% of the PCB and t-DDT loads respectively. This load is borne by the first born calf. It is unlikely that these transferred loads are toxic (ibid) to the first born pups, as successful populations of other marine mammals, specifically grey seals in the Farne Islands colony, show far higher contaminant loads and successful breeding patterns.

An important feature observed was that bottlenosed dolphins, which inhabit shallow inshore waters and feed predominantly on inshore reef and demersal fish and squid, have far higher residue levels than do the common dolphin, which forages further offshore over the entire continental shelf (Fig. 1a and b). In addition, dieldrin occurs more frequently and at higher levels in bottlenosed dolphins than in common dolphins (84% vs 34%; 0.3$\mu$g $g^{-1}$ vs 0.08$\mu$g $g^{-1}$), indicating the greater degree of contamination of nearshore waters. Using male bottlenosed dolphin tissue as the marker, these data then show that during the last decade it appears that PCB contamination of east coast waters has remained stable, whereas DDT levels have shown a recent increase. This may be a result of increased rainfall in the latter half of the 1980s, as the ratio DDE/t-DDT in animal tissue even in 1987 is greater than 0.6.

It is unlikely that these levels of contamination will decrease in the foreseeable future, as for example DDT is still in use as the most effective anti-malarial agent, and PCBs are in widespread use as heat exchange fluids. It is only a reduction or cessation of the use of these materials or their more effective disposal which will lower residue levels in biota. A spectacular success of this kind has been achieved in the Great Lakes. DDE levels (using Herring Gull eggs) have been dropping steadily since the main uses of DDT were banned in 1972 (Bird and Rapport 1986).

## PLASTICS

Plastics are in widespread use around the world. However, they do not degrade readily in the environment (the prime degradation route is via ultra-violet radiation which normally occurs only in direct sunlight). But worst of all for the marine environment, most plastics float. The world's seas and shores are littered with plastic debris (Pruter 1987, Ryan 1987a), including lost or discarded fishing nets, ropes, plastic strapping, bottles, packaging, and small beads. Concentrations are highest close to shipping lanes and to oceanic convergence zones (e.g. Carr 1987).

But the real question is; "What effects do these objects have on aquatic life, either by entanglement, or by ingestion?" The entanglement of marine animals such as seabirds, seals, and turtles can cause debilitating wounds or death. In southern African waters, it appears that this occurs sufficiently infrequently to constitute a severe problem to animal populations (Ryan 1988a); however this is considered opinion as there is simply insufficient evidence for a firmer

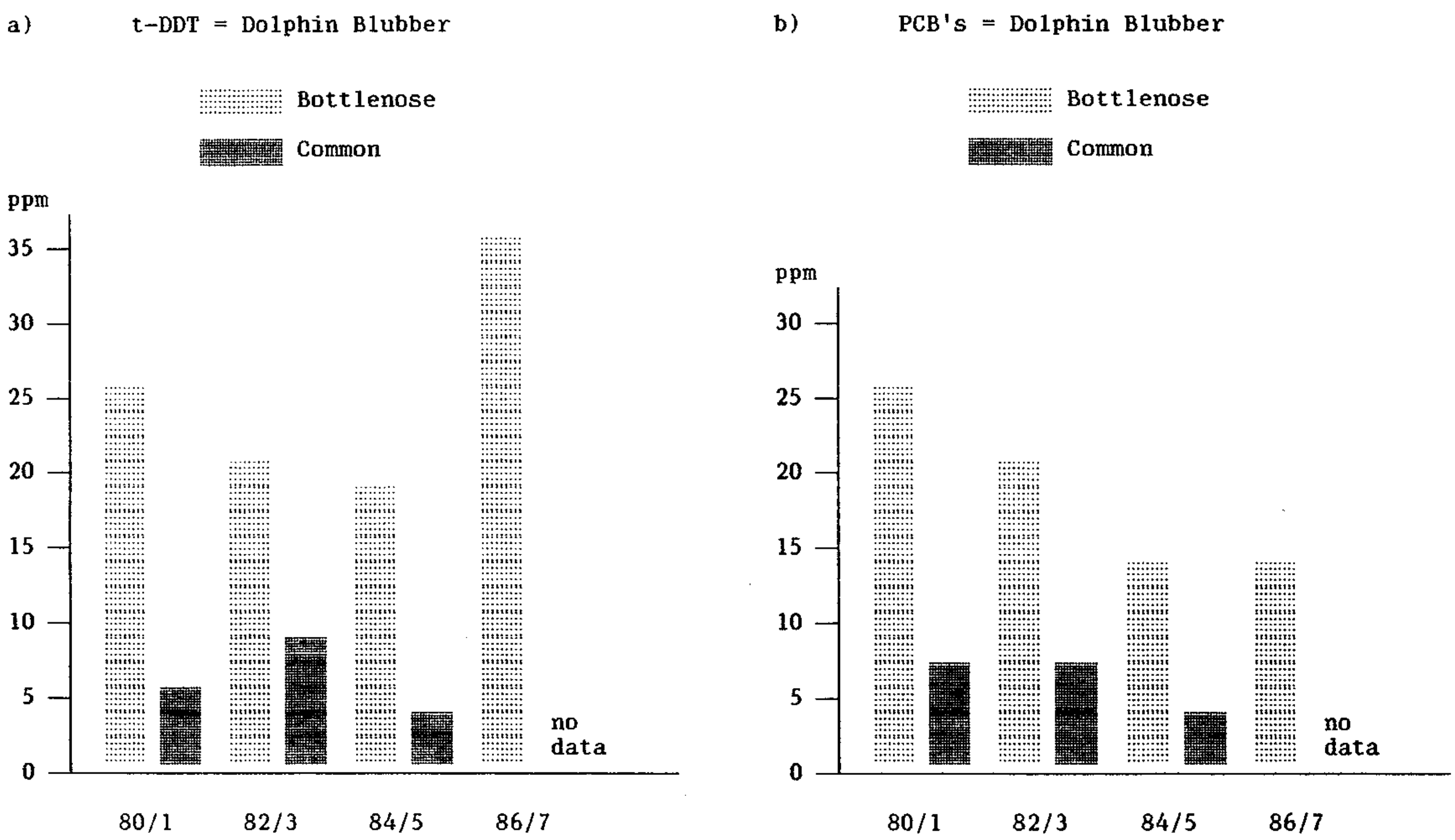


Figure 1. The occurrence of chlorinated hydrocarbon residues in the fatty tissues of dolphins caught accidentally in shark nets off the Natal coast. Bottlenose dolphins are inshore feeders, while common dolphins range over the entire continental shelf.

a) t-DDT (=DDT + DDD + DDE) residues

b) PCB residues

statement. Internationally, the opinion is growing that some animal populations are being directly influenced by entanglement, with the best documented case study being that of the Northern fur seal (Fowler 1987), where very detailed records of populations are maintained to allow for the regulation of animal harvesting.

The ingestion of plastic articles probably poses a greater threat than entanglement to particularly seabirds and possibly sea turtles. At least 50 species of seabirds are known to ingest plastic debris (Day *et al.* 1985), and a recent detailed study off southern Africa (Ryan 1987b) shows a similar pattern, with the most frequent occurrence in procellarian birds (notably the Blue Petrel, Great Shearwater, White-faced Stormpetrels and Pintando Petrels), where plastics were found in more than 80% of the birds examined. It is proposed that the birds ingested these items directly and mistakenly as food. The main effect of these plastics, apart from mechanical ulceration of the stomach wall and obstruction of the digestive tract - both of which are not considered a major threat - is considered to be the reduction in effective stomach volume, resulting in smaller meal sizes and the inability to feed efficiently (Ryan 1988b).

The reduction of plastic pollution can be undertaken in a number of ways. First, ratification and implementation of Annex V of the MARPOL convention should allow for control of materials disposed directly to sea during a vessel's operation - this being considered the major source of plastic debris in the sea. Second, the use of more rapidly degradable plastics, combined with better disposal methods on land, particularly recycling. And third, education of major suppliers and users.

## CONCLUSION

Are South African coastal waters polluted? The answer is both yes and no. There is no question that contamination at very low levels can be widely detected. This knowledge is sufficient to raise the alarm, but many reputable observers (Clark 1986) believe that this global feature is not of ecological concern (i.e. contaminant levels are too low to cause an effect) and that these residue data should rather be used to assist us in our control of particularly persistent chemicals. This may seem somewhat cavalier, but it is a difficult argument to combat in the absence of any indications of deleterious effects to plants and animals at these very low levels of contamination.

Systems of major effluent disposal to sea are being given close scrutiny, and apart from the traditional dichotomy between dischargers and regulators, the control of disposal is well regulated in South Africa. Probably the single most influential effects in the coastal zone over the next ten years will arise from the proliferation of points of runoff and discharge arising from rapid urbanization and deregulated industry. Methods for the appropriate handling of these discharges are available, but they are both expensive and require a high level of maintenance.

In essence, population density is the major factor that will affect our coastline in the near future. Maintaining water quality is going to require perseverance and initiative. We can't afford traditional and expensive treatment programmes; equally we can't afford uncontrolled and widely dispersed discharge.

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# CHARACTERISTICS OF WASTE DISCHARGES

J.E. McGlashan

## INTRODUCTION

The type of wastes discharged to the ocean varies from those of purely domestic or urban origin, through domestic plus light industry to those from large industrial plants. The degree of potential danger that these discharges pose to the marine environment varies from nothing on the one hand to a potential pollution hazard on the other - depending on the contents of the discharge, the volume or mass of material discharged and the characteristics of the receiving body of water. A purely domestic sewage that has undergone pre-treatment to remove the more obvious and aesthetically unacceptable contaminants such as floatable material will pose little or no threat to the environment. The discharge would of course be through a properly designed sea outfall that discharges the sewage at sufficient depth and distance from the coast to ensure rapid dilution and dispersion.

## SOURCES OF WASTE DISCHARGES

The input of pollutants to the oceans in the southern hemisphere can be expected to be considerably lower than that in the heavily industrialized northern hemisphere. However, the 3 000 km long South African coastline is becoming increasingly developed, supporting new towns and industries. This increase in urbanization and industrialization leads to an increase in the volumes of domestic and industrial effluents discharged to sea. These are land based discharges which, together with pollutants from marine sources (such as discharges from ships) and atmospheric sources (such as particulate matter deposited from the atmosphere), constitute the three pollutant source categories.

Land-based discharges include urban and rural runoff, direct discharges of domestic sewage and sewage sludge, rivers, seepage and industrial effluent discharges. Pollutants discharged to sea by rivers enter the river system via overland runoff. These discharges may contain nutrients such as nitrates and phosphates as well as herbicides and pesticides from agriculture.

### Land based sources

#### Urban and rural runoff

The characteristics of discharges from urban and rural runoff depend largely on the management of the catchment involved, the degree and density of urbanization, agricultural and forestry practices and land management in general. Plant nutrients and pesticides from agriculture and runoff from urban areas carrying with it indeterminable amounts of suspended solids, heavy metals, oil, grease and litter all contribute to contamination of inshore coastal waters.

Domestic sewage and industrial effluents

Domestic sewage and industrial effluents are concentrated waste discharges owing to the fact that a variety of wastes are purposely collected in a drainage or sewerage system. These include normal household wastes derived from kitchens, bathrooms and toilets, and industrial processing wastes.

Seepage

Seepage into the ocean occurs naturally and contamination of this seepage by the effluent discharged from septic tanks situated near the shore will result in contamination of the beaches and nearshore waters.

Rivers

Rivers are a major source of pollution of nearshore waters since they carry with them silt loads, material collected from runoff draining rural and urban areas and also receive the treated effluents from inland sewage works. Any waste that has been discharged to a river, whether it be uncontrolled surface runoff or point source discharges of treated or semi-treated wastes, will eventually reach the sea. However, depending on the passage to the sea, most of these wastes are likely to have been considerably dispersed in the river system. They are unlikely to be discharged as a slug to sea unless the point of discharge into the river is close to the sea.

Marine sources

Many countries use the dumping of waste at sea from ships as a major waste disposal option. However, in South Africa this practice is not heavily exploited. Wastes that are currently being dumped at sea include dredge spoils from harbour maintenance activities and shipboard wastes. Worldwide, dredged material by far accounts for the greatest amount of ocean dumped waste (190 million $m^3$ of dredge spoil dumped into the coastal waters of the USA in 1977; currently 4 million $m^3$ per annum in RSA). These materials can be polluted with organics, oils, nutrients and heavy metals and in addition carry a high suspended solids load. Oil and garbage discharged from ships at sea also contribute to the pollution load in our coastal waters.

### Atmospheric sources

Comparatively little information is available locally on the influx of pollutants to the oceans from the atmosphere. They are more difficult to quantify than pollutants reaching the ocean from other sources. The man-made pollutants reaching the oceans include fluorocarbons, fluorochlorocarbons and high molecular weight halogenated hydrocarbons.

## TYPES OF WASTES

### Municipal wastes

The sources of municipal waste or sewage as it is commonly known, are domestic dwellings, commercial buildings and both light and heavy industry within the municipal boundary. A municipality which has little or no industry will collect a sewage that is primarily of domestic origin, i.e. a sewage containing mainly bathroom, kitchen and toilet wastes.

These wastewaters usually contain most of the constituents of the water supply of the area with additional impurities from the waste producing process. Properties or characteristics of importance when assessing the strength or nature of these wastewaters include a measure of the pH, temperature, settleable solids, suspended solids, chemical oxygen demand (COD), organic nitrogen, ammonia nitrogen, nitrite and nitrate nitrogen, phosphate and synthetic detergents.

A typical raw sewage consists of 99% water and 1% solids, of which 70% are organic solids (proteins, carbohydrates and fats) and 30% are inorganic solids (grit, salts, metals).

Raw and treated sewage (unless disinfected) contains large numbers of micro-organisms such as bacteria, viruses, protozoan and helminths (worms such as roundworms and tapeworms) and therefore constitute a potential for the transmission of disease.

The composition of municipal sewage depends largely upon the catchment involved and the amount of ground water and rain water that enters the sewer (and therefore has a diluting effect). One municipal catchment may serve an industrial area with a number of "wet" industries that produce large quantities of very dilute waste which in turn would dilute the sewage. Other catchments may serve industries that produce small quantities of noxious wastes. All industrial waste discharges into municipal sewerage systems are strictly controlled by municipal by-laws.

Raw sewage discharged to sea would carry with it all the constituents derived from the domestic, commercial and industrial sources which would include matter that floats, that remains in suspension, that sinks;

matter that is dissolved in the water as well as the micro-organism populations. These constituents need not necessarily contaminate the marine environment since the forces of nature will exert a biocidal effect on the micro-organisms present, the shear dilution effect will dilute the sewage to a fraction of its strength at discharge and living organisms in the sea will filter out or consume the food contained in the discharge. Raw sewage normally contains heavy metals derived from the water supply of the area, plumbing fittings and domestic and industrial discharges. Municipal by-laws control the discharge of heavy metals from industries such as plating and metal finishing where high concentrations of metals can be expected in their discharges to municipal sewer. The concentration of heavy metals from urban waste waters are generally not high enough to be of concern.

## Municipal sewage discharged to sea

The composition and characteristics of municipal sewage discharged to sea would depend upon the degree of treatment received prior to discharge. This may vary from full treatment to the standard required in terms of the Water Act (Act No 54 of 1956) - in which case it would become a "final effluent" and no longer be "sewage" - to no treatment at all.

Discharge of sewage by deepsea pipeline would normally involve some or other treatment of the raw sewage to remove grit and sand that could otherwise block the pipe or the discharge ports, and removal of aesthetically unacceptable floating material. Further treatment is unnecessary since the sea itself absorbs and treats the discharge.

In some cases raw sewage first undergoes the process of primary sedimentation, whereby settleable material is removed before the resultant effluent is discharged to sea. The settleable material thus removed, and known as sewage sludge, must then be treated before it can be disposed off on land. The difference in characteristics of unsettled and settled sewage therefore is that in the former, settleable solids would measure about 5 ml/1, whereas in the latter this would be of the order of 1 ml/1. Discharge of sewage by short outfalls that release raw sewage either into the breaker zone or just beyond the breaker zone is a different matter however, since it is very unlikely that any treatment other than screening of the raw sewage will take place. The composition and characteristics of these discharges will not differ from that of raw sewage. This practice is most undesirable and totally unacceptable by today's standards.

## Industrial wastes

Industrial wastes originate from a variety of manufacturing operations, including refineries, fish processing, pulp and paper manufacturing, fertilizer manufacturing, fruit and vegetable processing, textile mills, aluminium production, tanneries, woolscouring, metal finishing and plating, steel production and inorganic and organic chemical production. The quantity and content of industrial wastes depend on the raw materials and processes used and on the finished product. The waste content may also be affected by the economics of by-product recovery and water and waste water management within the factory. Differences within industries make it difficult to be definitive about waste loads, and only general characteristics can normally be described. Seasonal variation is another factor which affects quality and quantity of certain industrial wastes.

Typical characteristics of some industrial wastes are as follows:

| | |
|---|---|
| Pulp and paper | High organic content<br>High suspended solids<br>Colour<br>Toxicants |
| Fertilizer | Fluorides<br>Phosphates |
| Fruit and vegetable processing | High organic content<br>High suspended solids |

## Discharge of industrial effluents to sea

Potentially toxic effluents from industry cannot be discharged to sea unless they have undergone some form of pretreatment in order to limit the impact on the marine environment. The selection of treatment methods prior to discharge must be based on the assimilative capacity of the receiving water and the dilution and dispersion characteristics of the discharge pipelines.

## Dredge spoils

Dredging has become an essential operation for the orderly conduct of marine commerce. Most of the material dredged can be classified as clean sands, gravels or silts (river borne in origin, some from sediments which have moved into the harbour by estuarine circulation or by erosion of beaches) but invariably they also contain urban or industrial wastes and solids from street runoff. Consequently they often contain objectionable toxic chemicals, heavy metals, pathogens and organic materials. Metals found in dredge spoils particularly silver, chromium, copper, zinc, tin and lead are many times higher than the background levels in uncontaminated areas around dump sites.

# PROPERTIES OF WASTES

## Physical, chemical and biochemical properties

The physical, chemical and biochemical properties of selected elements and substances found in wastes are given in this section, as well as the type of industry from which they can be expected.

### Zinc

Zinc is mainly found in the rinse solution of plating and metal processing industries and occurs in clear liquid form or slightly coloured solution and may include both soluble and dissolved zinc. Zinc sulphate (from steel galvanizing plants) is highly soluble and quite toxic to natural fauna. With dilution in sea water zinc salts, which are largely insoluble, will be formed with time.

### Copper

Copper metal is used both in industry (metal processing, electric wire treatment and electronic printed circuit industry) and for jewellery manufacture. Copper sulphate is a known algicide. Most copper precipitants will remain insoluble in a weak alkaline environment but will tend to be re-dissolved in an acidic environment such as produced in anaerobic bottom layers when mixed with biodegradable organic sediments. Copper wastes may also be found in pulp and paper mill effluents, fertilizer manufacture and petroleum refining.

### Nickel

Nickel is found in the wastes from metal processing and plating industries. The wastes appear as acid green solutions and contain $NiSO_4$ and $NiCl_2$.

### Chromium

Chromium will be found in a multitude of wastewaters since it is used in many alloys and plated metals and as an anti-corrosion inhibitor. Principle industries are tanneries, where virtually all the chromium appears in the less toxic trivalent form, electroplating and alloy industries, where the chromium appears in the toxic hexavalent form and the textile and wool dyeing industries. Receiving bodies of water usually provide a reducing environment to turn the chromium into a trivalent form and with neutral or alkaline pH will render the chromium insoluble.

## Lead

The major industries that use lead are electroplating battery production and paint production. The lead will be in the form of $PbSO_4$ in the waste discharge which is normally white and turbid.

## Tin

Tin plating is a common process in the metal processing industry. Production of cans for food preserving and canning involve large scale tinning operations. The wastes are the rinsing water and process bathspills and contain free tin and $Sn(BF_4)_2$. They are acidic in character and turbid with dissolved and floating material.

## Silver

Silver plating is used for cutlery and jewellery. It is also used in the photographic film processing industry. Because of its high value, the recovery of silver is most desirable. Waste discharges from the plating industry are mainly soluble AgCN. The wastes are alkaline, sometimes slightly turbid and without colour.

## Mercury

In most cases, mercury is or has been discharged in inorganic form or as organo-mercurials other than the hazardous methylmercury form. This means that before the mercury becomes a hazardous contaminant in fish or shellfish, it has to undergo methylation. Compared to bioaccumulation, biological methylation is a slow process.

## Persistent organic residues

Most of the organic compounds in sewage are degradable and yield simple materials such as ammonia, phosphate, water and hydrochloric acid on decomposition. These degradation products are unlikely to cause any problems in the marine environment. However, in some cases the degradation process may be slow, and intermediate compounds may be more toxic or may be bio-accumulated. The most important organic compounds are organo chlorine pesticides (DDT, DDD, Aldrin, Dieldrin, etc.), organo phosphate pesticides (Parathion, Malathion, etc.), polychlorinated biphenyls (PCBs) and chlorinated solvents (carbon tetrachloride, trichloro ethylene, etc.). Disposal of these chemicals is strictly controlled.

## Phenols and aromatic organic compounds

Phenolic compounds are prevalent in the wastes of many industries. They are toxic to marine life, create an oxygen demand and also bring about a distinct bad taste and odour to fish and fish products. Industries giving rise to phenol wastes are coke production, organic chemical production, plastics production, pharmaceuticals, gas production and oil refineries. Other aromatic compounds also bring about a distinct bad taste and odour to fish. Disposal of these wastes is also strictly controlled.

### Substances which have an effect on the oxygen balance

Discharge of any biodegradable organic wastes into the marine environment will have an effect on the oxygen balance. The main sources of such wastes are municipal and industrial wastes particularly the food and beverage industries, breweries and distilleries, paper, tanneries, sugar refineries, canning industries as well as meat packing and processing and fishmeal production.

### Persistence in the marine environment

If a substance is not readily degraded in the sea, the possibility of problems arising are increased since with time a toxic concentration may build up in the area of discharge. It is obviously unrealistic to think that we can totally eliminate even the traces of those persistent substances having toxic effects from the discharge, but it is necessary that in defining levels of concentration for such substances one also bears in mind the quantity contained in the discharge and the size and the characteristics of the receiving area.

### Toxicity

Toxicity of various elements and compounds has been mentioned previously. Most tests on the acute toxicity of substances to marine organisms are performed using standard bioassays. Testing of effluents containing a multitude of contaminants is useful in that the dilution required to render it harmless to the test organism can be checked. The engineering design of the pipeline would then ensure a safe minimum dilution to ensure no toxic effects on sensitive marine flora and fauna in the area of discharge.

### Bio-accumulation

Organisms have the ability to take up various contaminants from either the water itself or from food and other particulate matter. Organisms may also loose contaminants by degradation, excretion, or diffusion out of the organism across the gills or other membranes. The balance between the processes of uptake and loss defines the amounts of a contaminant which will accumulate within an organism.

Various bio-concentrated organic substances are generally localized within organisms, often in lipid-rich tissues such as the liver. Metals also concentrate to a greater extent in some tissues than others.

## Biochemical transformations

Waste discharges into the environment undergo various transformations. Physical, chemical and especially biological agents will interact with the various components of the waste and change the original composition by decomposition of the organic matter, by changing the physico-chemical form of elements, incorporation into living matter, adsorption into particles, adsorption onto sediments etc.

## Effects of oxygen balance

Biodegradable organics reach the ocean through the sources mentioned previously. Most organic wastes entering the ocean are biodegradable; that is, they are capable of being broken down by bacteria which use them for energy and as a source of needed organic molecules for biosynthesis.

Bacteria may be classified as aerobes, bacteria which require free dissolved oxygen in their metabolism in order to live and multiply; anaerobes, bacteria which require the complete absence of dissolved oxygen in order to oxidize organic matter and facultative bacteria, bacteria which use oxygen when it is available but which can also grow in its absence.

Since aerobic degradation of organics requires the use of dissolved oxygen, the oxygen demand in the immediate vicinity of the waste discharge will be high. However the sea is generally saturated with oxygen and bearing in mind the initial high dilution of the waste from a properly designed outfall, a transitory lowering of dissolved oxygen levels is all that will occur. In stagnant conditions and assuming a massive amount of biodegradable organic matter being discharged, a severe lowering of dissolved oxygen levels can occur resulting in mortalities of organisms in the receiving waters.

# CONCLUSION

Several sources of input of contaminants into the ocean exist, chief amongst these being aerial deposition, river and coastal runoff, dredging operations and point and non-point source discharges.

The characteristics of the more identifiable of these, such as dredge spoils and point source discharges are known and the discharges themselves can be strictly controlled.

Industrial discharges direct to the ocean and to municipal sewer for discharge to the ocean are controlled by means of municipal by-laws, permit conditions and by regulations promulgated in terms of Acts of Parliament. The controls are based on the constituents and characteristics of the particular discharge. A waste containing highly toxic material will not be permitted to be discharged to the ocean. However, a waste that contains toxic material in small quantities but which can be assimilated into the marine environment without harmful effect may be discharged. Here too a river, which will invariably contain small quantities of toxic material, will be an uncontrollable source of this material but which can be assimilated in the ocean.

These controls are designed to ensure protection of the marine fauna and flora.

# TREATMENT OF SEWAGE FOR SEA DISPOSAL

D.C. Macleod

In selecting appropriate treatment processes prior to sea disposal of sewage, the basic criterion at all times should be to achieve a least cost process for all affected bodies, taking into account environmental consequences for the land, atmosphere and marine environment.

## CONVENTIONAL TREATMENT PROCESSES

The head-of-works screening and degritting units are invariably the least attractive part of a conventional wastewater treatment works and, apart from being visually objectionable to the layman, often give rise to odour problems. Nevertheless, failure to remove screenings from the sewage flow will not only give rise to the risk that floating material will appear on the sea surface but experience has shown that, if macerators are used, the shredded material sometimes reforms into large lumps. Degritting removes the need for special flushing arrangements to cater for build-up of material in the discharge pipeline, but also removes the risk of accumulation of sediment in the vicinity of the pipeline.

Where disposal of sludge on land is essential, conventional primary treatment units have to be used. However, if it is possible for the sludge to be disposed of to sea together with the effluent, there is still an advantage in introducing primary treatment tanks which not only facilitates the removal of oils and other light floating material, but also reduces the organic material remaining in the sewage flow to relatively finely divided particles.

Secondary treatment followed by maturation ponds or advanced treatment processes such as are essential for reclamation of effluent, are not required where the disposal to sea route is being followed, although chlorination sometimes is practised.

Where it is not possible to dispose of the sludge to sea, conventional treatment processes, such as thickening, followed by dewatering, whether it be on sludge drying beds or by centrifugation or pressing and even some form of sterilization, become necessary. At the same time, when the options are being examined, it must be remembered that the final disposal route of the sludge can either be to land as landfill or as a fertilizer or through incineration. At the same time, the possibility of making beneficial use of the energy derived from the methane gas cannot be overlooked when the cost evaluation is made.

## BEST DISPOSAL OPTION

Insofar as effluent disposal is concerned, the option is influenced initially by consideration of whether the effluent is derived from domestic sewage, industrial wastes or a combination of both.

### a) Domestic Sewage

Where domestic sewage is the sole contributor, the environmental risks of effluent disposal to sea are not great, provided the design of the sea outfall allows sufficient dilution, dispersion and die-off to prevent bacterial and/or viral pollution of recreational waters and areas where harvesting of shellfish occurs.

### b) Industrial Effluent

Once industrial wastes have to be considered, however, a different picture emerges. Firstly, of course, the industrial wastes can, in appropriate circumstances, be handled in a separate reticulation system and subjected to different treatment and disposal options, with the domestic effluent being handled more easily and safely.

Secondly, the possibility exists of direct discharge to the outfall of selected industrial wastes of appropriate quality, either by pumping or tankering to holding tanks. In 1977, the savings to industry, where discharge was direct to sea outfall instead of through the Municipal sewerage system, was calculated in relation to the tariff applicable in Durban, which takes the following form:

$$\text{Tariff rate in cents per kilolitre} = X + Y\frac{A}{30} + Z\frac{B}{9}$$

A is the permanganate value, being the oxygen absorbed as expressed in ppm from acidic N/80 potassium permanganate in four hours at 27°C for settled trade effluent.

B is the volume to the nearest millilitre of settleable matter in one litre of trade effluent measured after settlement in the laboratory for one hour.

X is the cost per kilolitre of conveyance through the reticulation system and of primary treatment, less a rebate in respect of contribution through the City rates made by contributors of trade effluent to the sewerage account of the City.

Y is the cost of treatment at the Works of an effluent having a permanganate value of 30 mg/l.

Z is the cost of treatment at the Works of an effluent having a settleable solids value of 9 ml/l.

For a paper industry discharging 6,7 million m³ per annum, with an OA average of 71 mg/l and maximum 165 mg/l and suspended solids average 2 ml/l with a maximum 42 ml/l, the saving was calculated to be of the order R360 000 for the year. For a chemical industry discharging 450 000 m³ per annum, OA of the order 25 000 mg/l, suspended solids average 38,7 ml/l, maximum 245 ml/l, the saving would be R2 million for the year.

Advantages to the Municipality arising from such direct discharge are:-

(i) The Treatment Works are afforded a measure of protection from toxic substances in the industrial wastes that could have a serious effect on the secondary treatment processes.

(ii) There is a saving in cost of construction and operation of additional secondary treatment processes. It was calculated at the time, in respect of the industrial wastes bypassing the Durban Treatment Works, that the City was saved from having to construct a secondary treatment plant equivalent to that required to treat a flow of 750 megalitres per day of domestic sewage.

(iii) To this saving in additional treatment plant cost must be added the saving in capital outlay on the original Works as a result of construction of the sea outfalls for disposal of settled effluent and also the considerable saving in operating costs in relation to such secondary treatment plant, even allowing for the much reduced costs of maintenance associated with the sea outfalls and the cost of monitoring their performance in respect of the following parameters:-

Bacteriology, Chemical Quality, Viruses and Coliphages, Benthic Macrofauna, Toxic Metals, Chlorinated Hydrocarbons and Effluent Toxicity.

c) **Sludge**

The disposal of sludge to sea, as well as settled effluent, raises the problem of handling toxic metals. The following table, which represents a metal analysis at one of the Durban Wastewater Treatment Works at a time when discharge of sludge, as well as settled effluent through the sea outfall, was being considered, well illustrates the problem:

| Parameter | Concentration in ppm in | | | | | |
|---|---|---|---|---|---|---|
| | Sludge mg/kg, dry basis | | Settled Effluent (mg/1) | | Combined Effluent + Sludge (Calculated) (mg/1) | |
| | Ave. | Max. | Ave. | Max. | Ave. | Max. |
| Zinc (as Zn) | 1 051 | 2 179 | 0,32 | 0,43 | 0,51 | 0,81 |
| Copper (as Cu) | 232 | 469 | 0,08 | 0,14 | 0,12 | 0,22 |
| Nickel (as Ni) | 101 | 194 | 0,07 | 0,14 | 0,09 | 0,17 |
| Chromium (Total) (as Cr) | 96 | 227 | 0,07 | 0,11 | 0,09 | 0,15 |
| Lead (as Pb) | 198 | 455 | 0,08 | 0,13 | 0,12 | 0,21 |
| Cadmium (as Cd) | 3,1 | 7,4 | 0,003 | 0,004 | 0,004 | 0,005 |
| Mercury (as Hg) | *1 | *2 | 0,001 | 0,005 | 0,001 | 0,005 |

*Hg/1 wet basis

## CONCLUSION

It should be obvious from the foregoing that, in seeking the best disposal option, there is at all times the need for well-formulated Trade Effluent By-laws where industrial wastes have to be handled and an effective Pollution Control Inspectorate that can ensure, as far as possible, compliance with those By-laws by a process of education rather than mere enforcement and application of penalties.

In addition, an appropriate monitoring programme must be followed at the Treatment Works as well as in the sea water and sediments in respect of all the critical parameters pertaining to the sewage that is being accepted for sea disposal.

Finally, all the treatment processes examined in this paper prior to discharge to sea have been limited to cases where the receiving water is not a closed body. Where adequate water exchange does not take place, nutrient removal will also become an essential requirement.

# DISCHARGE OPTIONS AND DESIGN OF MARINE DISPOSAL SYSTEMS

K. Russell

The Seas cover 362 x $10^6$ $km^2$ or 71% of the earth's surface containing a volume of 1286 x $10^6$ $km^3$ (av. depth 3.55 km), compared with only 35 x $10^6$ $km^3$ of fresh water.

The coastline of South Africa, bounded by the Indian and Atlantic Oceans has a length of some 3 000 km. The coastal waters act as the ultimate sink for a large proportion of the waste effluents generated by the country's population of 30 million people.

The sea, a vast treatment facility with an almost unlimited resource of dissolved oxygen and energy, is consistently highly efficient in the treatment of discharged sewage effluents, provided that:

a) overloading is avoided, and

b) it is ensured that the quality of seawater does not deteriorate beyond acceptable levels.

A recent review by the CSIR of the marine pipelines in use along the South African coast indicated some 60 pipelines discharging over 700 000 $m^3$/day to the marine environment. Of these, only 33 discharge below the high water mark, while 12 major outfalls discharging beyond the surf zone account for some 605 400 $m^3$/day or 85% of the total discharge (Table 1 + 2).

**Table 1**
**Geographic distribution of pipeline discharges**

| | Offshore | Surfzone | Vol. ($m^3$/day) | % contribution |
|---|---|---|---|---|
| Natal | 7 | 7 | 515 000 | 73 |
| East Cape | 1 | 4 | 96 800 | 14 |
| South Cape | 4 | 7 | 71 000 | 10 |
| West Cape | 0 | 3 | 19 800 | 3 |
| Total | 12 | 21 | 702 600 | 100 |

**Table 2**
**Average daily discharge volumes ($m^3$/day) of different effluent types**

| Type | Offshore | Surf | Total |
|---|---|---|---|
| Domestic | 276 500 | 35 500 | 312 000 |
| Industry | 328 900 | 19 800 | 348 700 |
| Fish factories | | 14 900 | 41 900 |
| Total | 605 400 | 97 200 | 702 600 |

A widely distributed paper on human enteric viruses in sewage-polluted seawater and shellfish showed incidence of these viruses in coastal water adjacent to beach discharges or streams discharging directly to the surf zone - no incidence was related to designed pipeline discharges.

Dye tests and dilution studies at such streams indicate that low dilutions (factor 10 times) often persist for considerable distances (100 - 500 metres) adjacent to these discharges due to the trapping of the effluent in the breaker zone. The lesson would appear obvious - avoid contact with obviously polluted or aesthetically unacceptable seawater, avoid recreation adjacent to beach discharges.

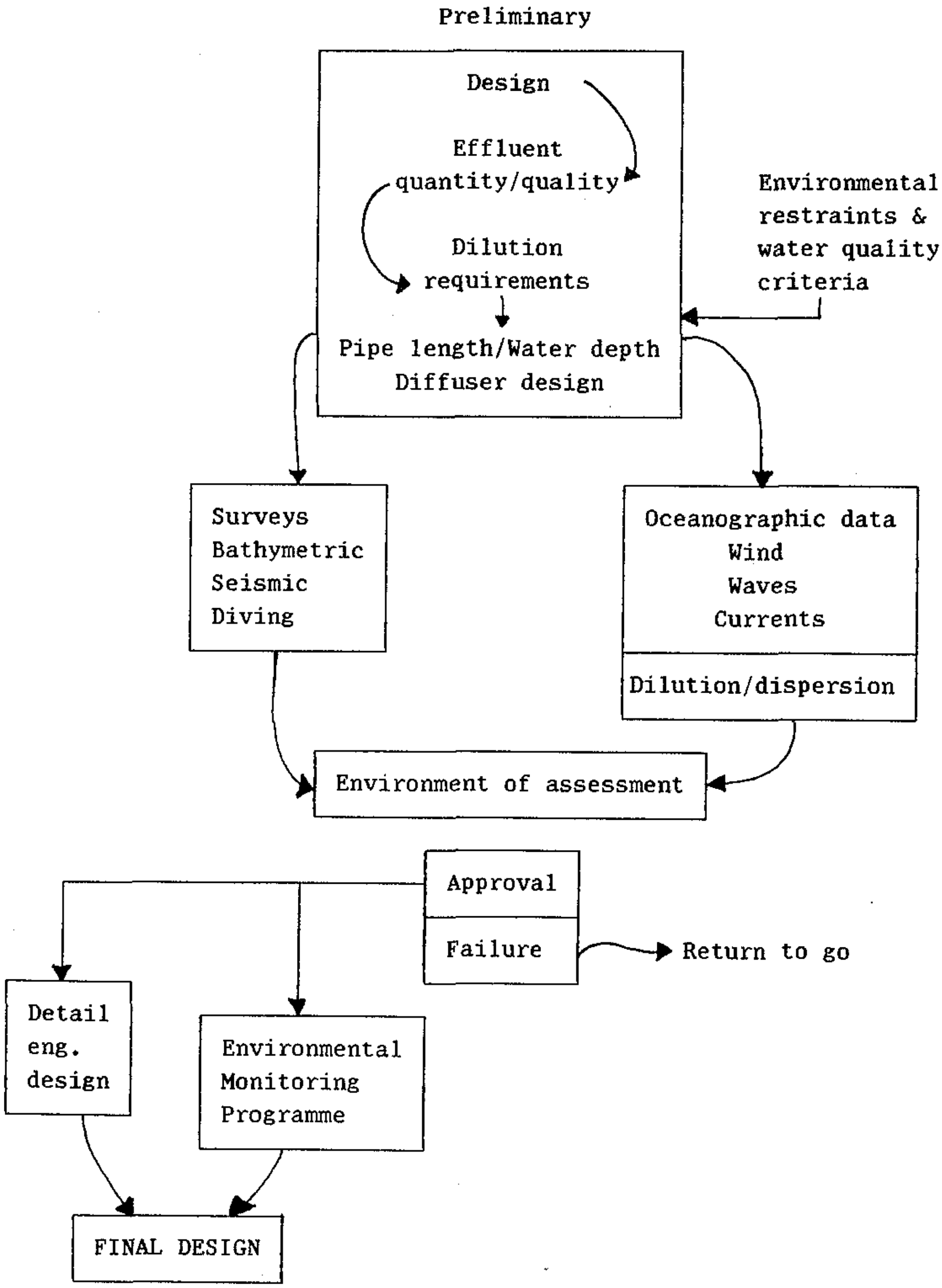
Sampling of stormwater discharges also indicates significant levels of faecal coliform bacteria in many discharges.

Pipelines discharging beyond the surf zone are designed to achieve initial dilutions (pipeline diffuser to water surface) in excess of 100 times, which with subsequent dilution due to diffusion, coupled with decay and the buffering capability of the seawater, ensures that the effluent is rapidly assimilated in the sea without significant impact.

Such pipelines, normally discharging in excess of 1 km from the coastline, maximize the dilution by proper hydraulic design and disperse the screened effluent discharge through a series of diffuser ports to ensure that acceptable conditions can be achieved. The location of the marine pipeline is of the utmost importance. Obviously an open coastline with strong longshore currents is more suitable for discharge, while closed bays and lagoons are to be avoided. Discharging into deep water (> 15 m) is preferred as stratification of the water column (especially in summer) can be utilized to advantage.

The construction of a marine pipeline for the disposal of pollutants requires not only sound engineering design of the structure but siting of the pipeline also requires close interaction and coordination with

Figure 1. Marine outfall design requirements




marine biologists and chemists responsible for assessing the environmental impact of the scheme (Fig. 1). While large quantities of waste can be absorbed by the sea, these must be introduced so that the environment is not materially polluted and so that pollution standards, in the area of the pipeline and at the adjacent beach are maintained in accordance with the public health, aesthetic, ecological and recreational considerations.

Marine outfalls are acceptable primarily because of the large dilutions which can be achieved in the disposal of waste material in the sea.

The principle aim in the disposal of effluents to sea is, that the detrimental effects be kept within acceptable limits - this can normally be achieved through adequate dilution.

The total dilution, $S_T$, after release of an effluent is given by the formula:

$$S_T = S_j \times S_e \times S_d$$

where

$S_j$ = the jet diffusion (or initial dilution) occurring between the discharge and the ambient seawater

$S_e$ = the eddy diffusion (or secondary dilution) as the effluent field moves with the current, this dilution is normally about one-tenth of that due to the jet diffusion

$S_d$ = decay depending upon the nature of the effluent and the time of transit

The jet dilution is directly dependent on the effluent density, the water depth and the design of the diffuser section. Initial dilution of the effluent occurs in the immediate vicinity of the diffuser (i.e. within a radius approximately equal to the water depth) and is caused by entrainment and mixing which in turn is dependent on the jet momentum and buoyancy of the effluent (Fig. 2).

If instead of discharging through a single outlet, the effluent is discharged through a series of smaller outlets the degree of dilution can be greatly increased. The hydraulic design of the diffuser, to optimize the size and spacing of the discharge ports so as to obtain maximum dilution with minimum loss of power (i.e. minimum pumping costs), is normally determined by computer model simulation.

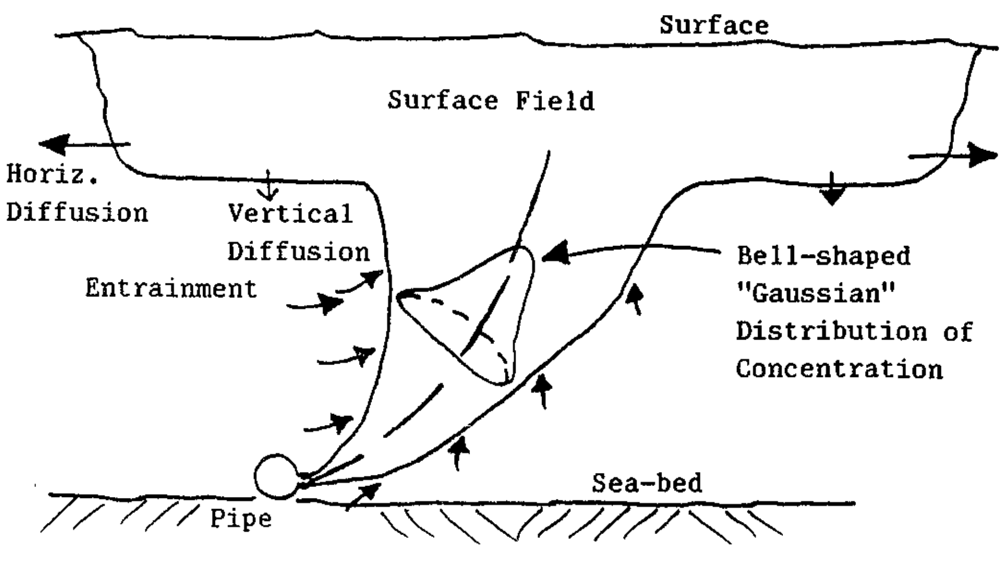



Fig. 2. A buoyant effluent rising in an unstratified stagnant ambient

Similarly, dilution occurs during transport of the waste by currents and dispersion by turbulence generated by the action of wind and waves. Thus, secondary dilution occurs as the surface "cloud" moves away from the diffuser over a distance of several kilometres, and takes place by horizontal and vertical diffusion and by eddy dispersion, causing entrainment and spreading. The eddy dilution at any point at a distance downstream of the source can be calculated according to a number of theories.

Decay is obviously dependent on the specific constituents of the effluent and must be determined experimentally.

The design of a marine outfall is basically an interactive process involving not only engineering factors but also economic, aesthetic, health, planning, sea fisheries and other social and often intangible factors. These in combination clearly indicate the need for a comprehensive Environment Impact Statement, requiring continued joint cooperation between the various disciplines involved and concerned with the design.

The South African coastal zone is subject to ever-increasing loading, however it is the diffuse sources of pollution, particularly discharges onto the beaches and into the nearshore waters, which are the problem and cause of increased concern.

# CONTROL OF MARINE DISCHARGES

H.J. Best

## INTRODUCTION

The availability of water and water pollution prevention considerations have never played an important role in influencing population movements and the siting of industrial development in the RSA. Port facilities, the availability of labour forces, commercial fishing activities and the ever-growing tourist and holiday industry have, for example, been primarily responsible for rapid population and industrial growth in coastal areas. The belief that the sea is a natural sink for the discharge of wastes might have been a contributory factor.

The direct disposal of industrial and domestic wastes to the sea along our (approximately 3 000 km long) coastline has been practised for many years. Sixty-one officially recognized outfalls presently discharge some 700 000 $m^3$ of effluent to sea daily (Fig. 1, Table 1). The average daily discharge of domestic sewage effluent varies considerably, ranging from 50 $m^3$ of septic tank effluent being discharged at Shelley Beach (Natal South Coast) to as much as 175 000 $m^3$ per day disposal of screened, degritted and "all floatables removed" combined domestic and industrial sewage beyond the surfzone at Durban. Similarly industrial effluent discharges range from as little as 6 000 $m^3$ per day discharged below LWOST from Mondi Felixton at Port Dunford to a daily peak of 95 000 $m^3$ per day beyond the surf zone from the Mondi Paper Company's pulp factory at Richards Bay.

In terms of the Water Act, 1956 (Act 54 of 1956), powers are vested in the Minister of Water Affairs to exercise control over effluent discharges to sea and, in addition, to prescribe by regulation such steps as may be necessary to prevent pollution of the sea from sources other than effluent arising from the use of water for industrial purposes.

A striking feature of the Water Act is, that the disposal to sea of effluent arising from the use of water from any source other than the sea is forbidden and that land disposal of such effluent is obligatory. Sea disposal is however from an economic and environmental point of view not always the least desirable option. Provision is therefore made for sea discharges to be authorized through exemption permits, which, if granted, are issued subject to such conditions as the Minister may determine after consultation with the South African Bureau of Standards, the Departments of National Health and Population Development, Environment Affairs and institutions such as the CSIR's Division of

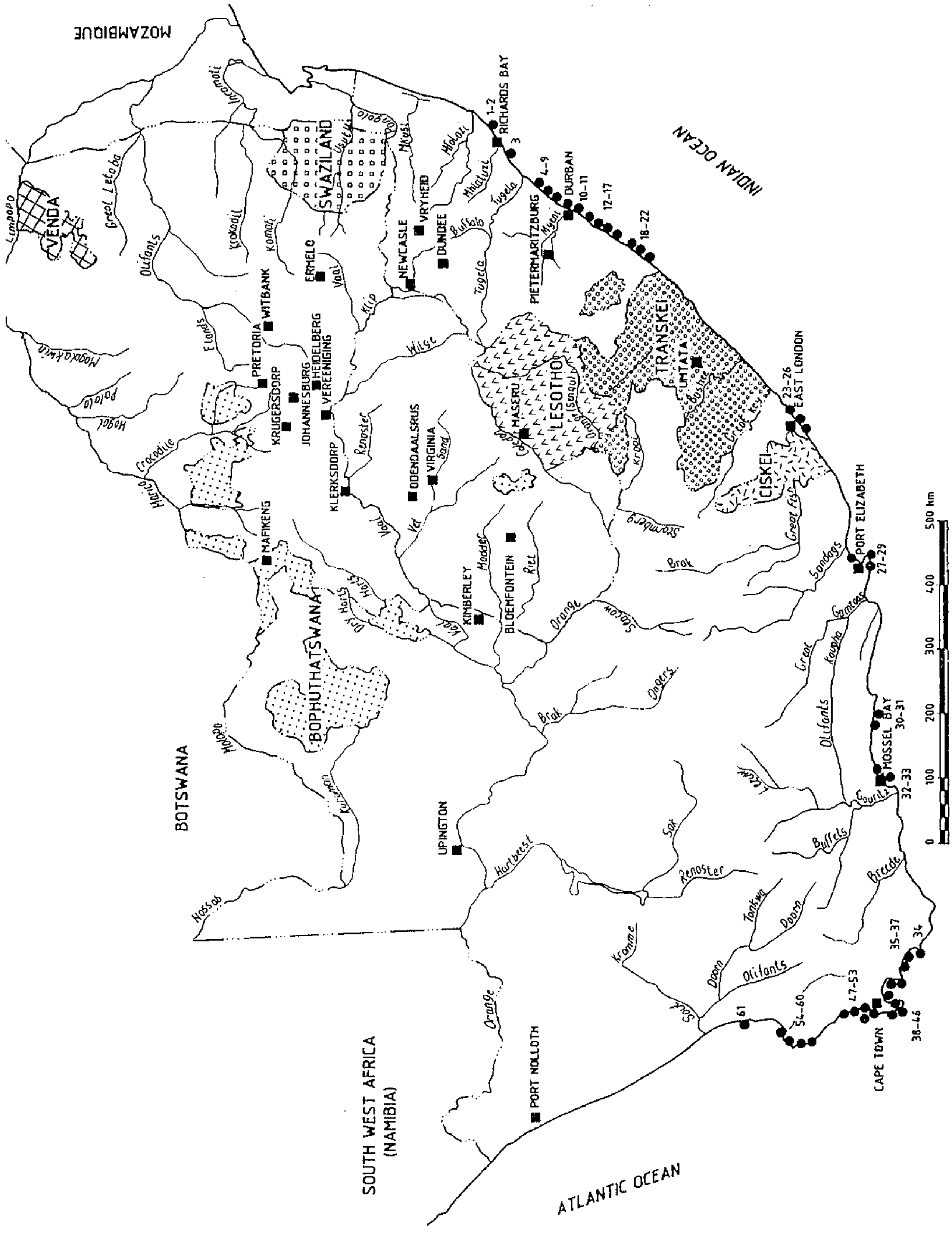



FIG. 1 SEA OUTFALL PIPELINES ALONG THE SOUTH AFRICAN COAST LINE

Earth, Marine and Atmospheric Science and Technology (EMA) and the Oceanographic Research Institute (ORI).

**Table 1**
**Direct discharges to sea along the South African coastline**

| Type of effluent discharge | Number | Average daily discharge in $m^3$ |
|---|---|---|
| Domestic sewage | 22 | 75 000 |
| Domestic sewage plus industrial effluent | 9 | 370 000 |
| Industrial effluent | 30 | 255 000 |
| TOTAL | 61 | 700 000 |

Permit conditions for each discharge are evaluated independently on their own merit as each point of discharge is unique with respect to marine fauna and flora, oceanographic and topographic conditions, the quality and quantity of effluent to be discharged as well as beneficial use areas in the vicinity of discharge.

Case by case decision making is coupled with careful monitoring, continued research and continual re-evaluation of each discharge as more information becomes available. This paper describes the requirements of the Water Act, procedures for the issue of permits, typical permit conditions and monitoring of marine discharges.

## THE WATER ACT, 1956 (ACT 54 OF 1956)

In respect of marine discharges, the Water Act contains the following basic provisions (with explanatory notes).

SECTION 21(1). Any person using for industrial purposes water, including sea water brought ashore, shall -

a) purify effluent resulting from such use to standards prescribed by the Minister after consultation with the South African Bureau of Standards. (The standards prescribed can be effluent related e.g. the present blanket effluent standards for discharge to rivers or can be industry related or receiving water quality related. The latter includes standards for discharge to sea.)

b) the effluent so purified must be returned to the source of origin of the water at the place where the water was abstracted or at such other place as the Minister may indicate.

SECTION 21(2). Unless The Minister otherwise directs, the above provisions shall not apply -

a) in respect of any septic tank or french drain system or

b) to any person who discharges effluent into a canal, sewer or other conduit controlled by the Minister or any person or local authority having the authority to treat or dispose of effluent. (The provisions of Section 21(1) can therefore be enforced by direction of the Minister in all cases where effluent from septic tanks and french drains causes pollution of the marine environment. Similarly, all dischargers to the Mhlatuze Water Board's sea outfall at Richards Bay are subject to these provisions).

SECTION 21(4)(a). The Minister may exempt a person or a category of persons from any or all of the provisions of section 21(1) subject to the conditions the Minister may prescribe. (Any industry, local authority or person which uses fresh water and wishes to discharge effluent to sea requires authority for such discharge through an exemption permit issued in terms of Section 21(4)(a). If seawater brought ashore is used and such water is contaminated in any way through such use, a permit would likewise be required.)

SECTION 21(4)(b). No exemption which may result in the discharge to sea of effluent which does not comply with the quality requirements of section 21(1)(a) shall be granted except after consultation with the SABS. (Although only consultation with the SABS is stipulated, the Water Act does not replace or override provisions of any other applicable act, ordinance, regulation or by-law. Due regard is for example taken of the provisions of the Health Act, 1977 (Act 63 of 1977), Sea Shore Act, 1935 (Act 21 of 1935) and the Sea Fisheries Act, 1973 (Act 53 of 1973) through consultation with the Departments responsible for the administration of these acts.)

SECTION 21(4)(c). Any person prejudiced by an exemption permit issued to any other party may after notice to the Minister lodge with a water court an objection against the continuation of the exemption or against any matter in connection therewith and the court may confirm or withdraw the exemption or amend any condition to which it is subject (No time limits are specified for the lodging of objections. The tendency of pressure groups to direct objections through the public media is therefore not always comprehensible.)

SECTION 21(4)(e). The Minister may at any time withdraw an exemption permit or render the continued validity thereof subject to such conditions as he may then determine, whether by the imposition of further or new conditions or by the cancellation or amendment of existing conditions. (Failure of dischargers to comply with permit conditions could for example result in the re-evaluation of the efficacy of conditions and the imposition of stricter conditions. Permission for marine discharges is never granted in perpetuity. The validity of permits can either be made to expire after intervals of time of sufficient duration to facilitate reassessment of options or permits can be withdrawn after reasonable notice should it, for example, become necessary to utilize the effluent discharged for other purposes.)

SECTION 21(5). Any contravention of or failure to comply with a condition of an exemption permit, constitutes an offence (See also section 24(2)).

SECTION 22. Whereas section 21 provides for control over effluent resulting from the use of water for industrial purposes (including the use of water for the conveyance of sewage or any other substance), section 22 provides for *inter alia* the prevention of marine pollution by other sources, including contaminated storm runoff. The person in control of land on which any activity was or is undertaken that involved or involves a substance capable of causing pollution of water on that land or any other land or the sea, is obliged to take the steps prescribed by regulation to prevent such pollution. In addition the Minister can cause the steps to be carried out by third parties and can recover the cost so incurred from the person or persons in default.

SECTION 23. Any person who wilfully or negligently does any act which could pollute sea water shall be guilty of an offence.

SECTION 24(2). The Minister may, if a condition of an exemption permit is contravened or not complied with, direct that the supply of water to the discharger be suspended or reduced to a quantity determined by him. In such an event the discharger will not be entitled to recover from the State any cost incurred in complying with the direction or any damage or loss caused thereby. (As such direction can result in the closure of an undertaking, it can be expected that the Minister will apply this power vested in him with great circumspection.)

SECTION 24(3). The Minister may direct that the manufacture, marketing or use of any substance which in his opinion could cause pollution of any water, including the sea, be terminated or restricted or subject the manufacture, marketing or use thereof to conditions determined by him.

## PROCEDURE FOR THE ISSUE OF EXEMPTION PERMITS

When all other alternative disposal routes have been investigated by the applicant and disposal to sea is considered to be economically and environmentally the preferable option, a fully detailed study of the proposed discharge needs to be made.

The applicant will normally be expected to have the following investigations carried out at his own cost:

## Oceanographic Investigation

These investigations must be conducted by renowned specialists to the approval of the Department of Water Affairs and should at least include the following:

a) chemical analysis of the effluent to be discharged and toxicity testing using the most sensitive biological indicator likely to be affected by the effluent at the proposed point of discharge. When effluent is not yet available, tests must be conducted on effluent from other sources which have similar characteristics. The toxicity testing will give an indication of the initial dilution required at the point of discharge to safeguard marine life normally present in the receiving water,

b) surveys of the direction and speed of tidal currents, wave movements and observation of the movement of sea water under different physical conditions such as changes in wind direction and speed. These are important parameters in determining the eventual dilution and dispersion of the effluent in the sea and its possible impact on beaches and other areas of beneficial use,

c) the measurement of temperature gradients in receiving waters. The presence of temperature gradients of sufficient magnitude can ensure submergence of the effluent plume,

d) topographical and geophysical surveys of the sea bed to define the most suitable site and route for the outfall pipeline,

e) assessment of the chemical quality of bottom sediments and the species diversity and number of benthic macrofauna before discharge commences.

## Environmental Impact Assessment

This assessment is closely related to the oceanographic investigation but is preferably discussed under a separate heading.

The beneficial use areas in the vicinity of the proposed outfall need to be identified and the likely impact of the proposed discharge on these areas needs to be assessed. Beneficial use can include any combination of the following:

- direct contact recreation
- maintenance or preservation of ecosystems
- migration of aquatic life

- collection or culture of aquatic life for food
- collection of aquatic life for uses other than food
- use of seawater for desalination and potable water recovery
- use of water for industrial purposes
- miscellaneous uses like aesthethics and tourism.

In the assessment, the aim should be the maintenance of an appropriate quality of sea water at each beneficial use area taking into consideration the likely dilution at each area. The appropriate quality of water should preferably be based on SANCOR'S Water Quality Criteria for the South African Coastal Zone, supplemented where necessary by additional inputs from the Departments of National Health and Population Development and Environment Affairs and institutions such as EMA and ORI.

**Engineering Investigation**

These investigations must be carried out by professional engineers experienced in the field of marine outfall pipeline design. Based on information gathered during the oceanographic surveys, the pipeline must be designed to withstand the type of effluent to be disposed of and the stresses imposed during construction, operation and the continuous movement and forces of the sea. As pipeline failures can have catastrophic environmental impacts and are time-consuming and difficult to repair under operating conditions, a conservative but safe design is an important consideration.

Interactive consultation between the Department of Water Affairs, the applicant, the scientific community and other government departments usually starts at the inception of a proposal for marine discharge and is continuous from initial investigation stages through to implementation and subsequent monitoring. Steering or Coordinating Committees representative of all the parties involved are normally formed to oversee all aspects of the discharge.

On receipt of the formal application, which must be accompanied by reports from all the specialists involved, the Department of Water Affairs proceeds to officially consult the following departments and institutions:

- SABS
- Department of National Health and Population Development on all health related aspects
- Department of Environment Affairs on all matters related to the environment in general
- EMA, ORI or other institutions on any aspect not already clear from supporting documents.

Comments received will, if necessary after further consultation and deliberation, be included in the exemption conditions.

## TYPICAL EXEMPTION PERMIT CONDITIONS

Although some permit conditions will be common to all marine discharges, most are specific to a particular outfall:

**Common conditions:**

- rate of discharge
- record keeping and reporting
- periodic inspection and survey of pipelines to ensure safety.

**Discharge and site related conditions:**

- quality of effluent that may be discharged
- pretreatment requirements
- specific requirements about health related aspects, e.g. the maximum acceptable bacterial counts at each beneficial use area; the prohibition of the collection of filter feeders in certain areas
- requirements for the prevention of undesirable aesthetic impacts
- monitoring requirements in respect of effluent quality and the condition of the marine environment with specification of extent and frequency
- special conditions related to the operation and maintenance of sea outfall pipelines and pretreatment works (where applicable).

## MONITORING REQUIREMENTS

Monitoring requirements will depend on the type and quality of the effluent discharged and will be site specific. In the case of the Richards Bay sea outfall pipelines, the following monitoring programme is conducted during May and November of each year:

a) sampling of bottom sediments from 51 fixed stations surrounding the end of the pipelines for chemical analysis of trace metals, OA and TOC (particle size). (During the November visit only 21 stations are sampled),

b) investigation of benthic macrofaunal diversity and numbers in sediment samples,

c) chemical and bacteriological analyses of water column samples from five fixed stations closely spaced around the diffusers,

d) beam trawling for one nautical mile across the sea bottom at distances five, seven and nine kilometres offshore to collect samples of fish and crustacea. These are subjected to chemical analysis for trace metal and fluoride concentrations and also provide essential data in respect of pathological features and species diversity and numbers,

e) sampling at five beach stations and six harbour stations for bacteriological analysis.

Monitoring results at marine outfalls have up till now indicated that no adverse impact could be detected in the vicinity of outfalls. Damage to marine fauna and flora, if any, was in most cases limited to small areas in the immediate surroundings of the discharge ports.

## CONCLUSION

Officials of the Department of Water Affairs subscribe to the view that it is their responsibility as administrators of the Water Act to exercise the required stewardship of the marine environment on behalf of the public. The Department however does not attempt to prevent progress or to be restrictive in its requirements. Each application for marine discharge is carefully examined to ensure that irreversible damage is not caused whilst the ocean's capacity to safely dilute, disperse and purify effluent is cautiously utilized where it can be justified on economic and environmental grounds.

# THE ASSESSMENT OF BIOLOGICAL DAMAGE RESULTING FROM THE DISCHARGE OF TOXIC WASTES INTO THE SEA

A C Brown

## INTRODUCTION

The general public only recognizes pollution damage in the sea when it is so devastating that it kills virtually everything in sight. When this occurs you do not need an expert to tell you that something is wrong. On the other hand, an ecosystem may be very sick yet look superficially healthy and it may then be difficult to persuade factory managers or local authority that serious damage is being caused. For example, pollution which kills grazing invertebrates will result in a luxuriant growth of attached algae; this may look very attractive, yet the ecosystem is seriously degraded and is doomed unless appropriate action is taken.

Another popular misconception is that only poisonous wastes damage ecosystems. In fact effluents containing nutrients or inert sediments can be just as damaging. Nevertheless, I confine myself here to the discharge of toxic wastes from factories and I want to discuss only one question: "How can we measure the damage or potential damage which they cause?"

## FIELD STUDIES

The obvious thing to do is to go to the discharge site and take a look at what is going on - but it has to be an experienced and perceptive look and it has to be quantitative. It will have to consider such things as species diversity and density and we will want to pay particular attention to species that should be present but are now absent. This may sound easy but in fact it is very complicated and it may well be impossible to reach a definite conclusion. One reason for this is the natural complexity of marine ecosystems; another is the fact that enormous fluctuations occur in the composition of communities under normal circumstances. Some such fluctuations are seasonal and can largely be predicted but others are quite unaccountable in the present state of our knowledge. It is against this constantly changing background that pollution damage must be assessed.

One of two scenarios may be presented to the pollution biologist. Firstly, he may be asked to assess damage to an area which is already being polluted - in which case he cannot be certain what the ecosystem was like in its pristine, unpolluted state. A common way of trying to get around this is to compare the polluted site with one or more unpolluted sites having similar physical conditions. However, this can give very misleading results, because no two sites ever have identical communities of marine biota to begin with. One can, in fact, find oneself in the embarrassing position of quantifying two reference sites which differ more from one another than either differs from the polluted site (e.g. Brown 1974).

A much better situation is presented when one can undertake base-line studies before discharge commences and continue monitoring afterwards. Such opportunities have become fairly common in South Africa, the best example being, perhaps, the investigation of the Richards Bay effluent pipeline (Lord and Geldenhuys 1986). But the difficulties are still enormous and answers are only likely to emerge after a number of years of study; which means committing thousands of man-hours and very large sums of money.

Even then one can be misled, as I found to my cost when studying an effluent added to a small stream running down the beach at Dido Valley (Brown 1983). The meiofauna of this beach showed consistent depression at the site of the outfall. Eventually the effluent was routed elsewhere and I determined to study the recovery of the meiofauna - only to discover that it never did recover. The perturbation of the community was due to reduced salinities associated with the fresh water stream and had nothing to do with pollution.

Another great problem with field studies is that organisms are never self-sufficient; they constantly interact with one another to produce a highly dynamic system. So it is not enough to count species and individuals - one should also test whether pollution is interfering with their interactions. Pollution may, in fact, change the dynamics of the system without having any immediate effect on community structure (Ulanowicz 1986) and such a dynamic change may be the first sign of eventual disaster. This is fairly obvious in theory but it has hardly ever been studied in practice.

A different approach is to ignore the complexity of the ecosystem and to concentrate on "indicator species", species such as the worm *Capitella capitata*, which increases in abundance under conditions of organic pollution (Patin 1982, Southward 1982); or one can consider species which are known to be the first to disappear under pollution stress (Gray and Pearson 1982). On sandy beaches one might look at the proportion between copepods and nematodes because, in general, copepods decrease in numbers in response to pollution, while nematodes may increase (Raffaelli and Mason 1981). Another technique is to consider rates of colonization of artificial substrata at set distances from the outfall. This is a promising approach and it may be noted that moored rafts are being used for this purpose in the Richards Bay study (Potter *et al.* 1987).

However, on the whole, studies of pollution damage based on field work alone, in addition to being expensive, tend to be largely inconclusive unless the damage is extreme or unless the study is continued for many years. It is small wonder, therefore, that many pollution biologists have abandoned field studies in favour of laboratory-based toxicity testing.

## LETHAL TOXICITY TESTS

Toxicity tests have advantages in that only one species and one set of circumstances are studied at a time; we no longer have to contend with the complexity of the ecosystem or with fluctuating communities - and of course we don't have to get our feet wet either. However, by doing toxicity testing we introduce a different problem and that is to relate our findings to what actually happens in the field. In fact an enormous amount of data has been accumulated from laboratory toxicity testing but most of it has no value in that it cannot be applied to any real-life situation (Clark 1986).

The earliest and most obvious toxicity test was simply to place organisms in known concentrations of effluent or toxicant and to see how long it took them to die. A slight sophistication of this procedure is to estimate the concentration which will kill 50% of a population in either 48 or 96 hours. This is the $LC_{50}$ test. Even assuming that such work has been meticulously undertaken, the concentrations of pollutant monitored and proper controls maintained, the question remains as to what the results imply. In the 1960s quite unfounded conclusions were drawn; for example, work on the mortality rates of fish led to the conclusion that "for practical purposes" a threshold of toxicity may be assumed to exist a little below the concentration corresponding to an $LC_{50}$ value of 500 minutes. Below this concentration the fish were considered to survive indefinitely (Herbert 1962). In Britain in the 1970s it was officially stated that one-tenth of the 96-hour $LC_{50}$ was a "safe level" for the discharge of an effluent (Brown 1976).

In fact, the figure chosen "for practical purposes" as a "safe level" is largely irrelevant; it is the basic reasoning which is wrong, for it ignores the fact that different organisms vary enormously in sensitivity and that the stages in the life history of a single species may also differ remarkably in their tolerances. For example, embryos of the mussel *Choromytilus* are over a thousand times more sensitive to ammonium nitrate pollution than are the adults (Currie *et al.* 1974). But in any case to test lethal concentrations is not very meaningful from an ecological point of view. What, in fact, matters ecologically is not the death of individuals but the number and fate of the survivors; what we must ultimately be concerned with is the loss of reproductive potential of a population (Brown 1984). Clearly, if a population cannot reproduce adequately, for any reason whatsoever, then it will soon cease to function as an ecological entity. The corollary is equally true: if a source of pollution does not reduce reproductive potential then it is not of any ecological importance (Clark 1986).

## SUBLETHAL TOXICITY TESTS

There is virtually no feature of an organism which may not be affected by pollution. Frequently the first sign of disturbance in animals is reduced feeding activity, either as a result of impaired chemoreception or through inhibition of ciliary beat. Digestion and absorption efficiencies may be adversely affected. There may be affects on respiration, on the heart beat and on rates of locomotion. All these changes, and others, influence the scope for growth and reproduction and hence reproductive potential. Scope for growth may be measured directly, of course, but it is too time-consuming to be recommended as a toxicity test.

What is required are simple, rapid, sublethal tests, unambiguous and conclusive, which can be related to what really happens in the field. Sometimes in the sequence of responses of an animal to pollution, there is one stage which lends itself to toxicity testing. Consider the responses of the sandy-beach whelk *Bullia* to pollution (Fig. 1). Most of these responses are gradual in their onset, but emergence from the sand, or failure to burrow after stimulation, is a clear-cut, all-or-none response which does not require complex apparatus or a great deal of time to quantify. I have therefore used it in some of my toxicity studies (Brown 1982, 1986).

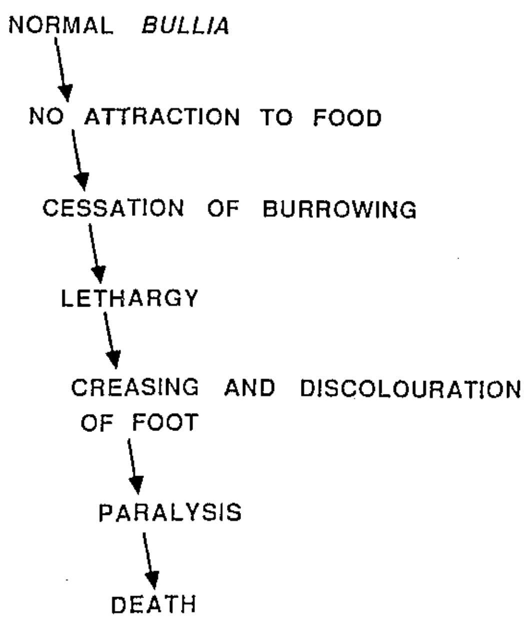



Fig. 1 Sequence of responses to increasing stress, including pollution, by the sandy-beach nassariid whelk *Bullia* (from Brown 1986).

On the whole, however, I favour the testing of developmental stages, either gametes or early embryos, because of their sensitivity to pollution and because any malfunction in this regard clearly reduces reproductive potential. Tests based on the viability of sea urchin sperm after exposure to various concentrations of pollutants have been developed by a number of workers (e.g. Kobayashi 1971, 1984, Brown and Greenwood 1978, Dinnel *et al.* 1981), while McGibbon and Moldan (1986) have introduced the useful concept of the Fertilization Inhibition Dose ($FID_{50}$). Such tests give very rapid, statistically verifiable results, are inexpensive and can be carried out routinely by a laboratory technician. If time is not an issue, even better are tests in which small marine animals are taken through several generations under polluted conditions and the number of offspring compared with a control population kept in unpolluted sea water (Lee 1977, Connell and Airey 1980), thus testing reproductive potential directly.

Such tests are meaningful, they are ecologically relevant and the results can, in principle, be related to real conditions in the field - except, unfortunately, for two important considerations. The first of these is that, in the laboratory, we will have kept factors such as temperature and salinity constant; they are not constant in the sea and their fluctuation will affect toxicity. Furthermore we have prevented our laboratory population from interacting with other species; in the field there will be all sorts of biological stresses which will affect reproductive potential. The other problem is equally serious - in the laboratory we have tested the effects of single pollutants or single effluents but in the sea pollutants never occur singly. It is common for a number of effluents to discharge in the same area. For example it may be calculated that Table Bay, with its pollution from major and minor industries, from sewage outfalls, from the docks and from the Black and Riet Rivers, is the receptacle for approximately 100 000 different chemical substances every day. This figure will increase in the event of an accident such as an oil spill, and to it must be added the background pollution derived from other areas of the coast and even from other countries. In some cases the effects of different pollutants acting together are simply additive, but they are just as likely to be synergistic and there are even cases where two pollutants have less effect than either acting singly. So it is necessary to proceed with great caution in relating laboratory-based results to a real body of water.

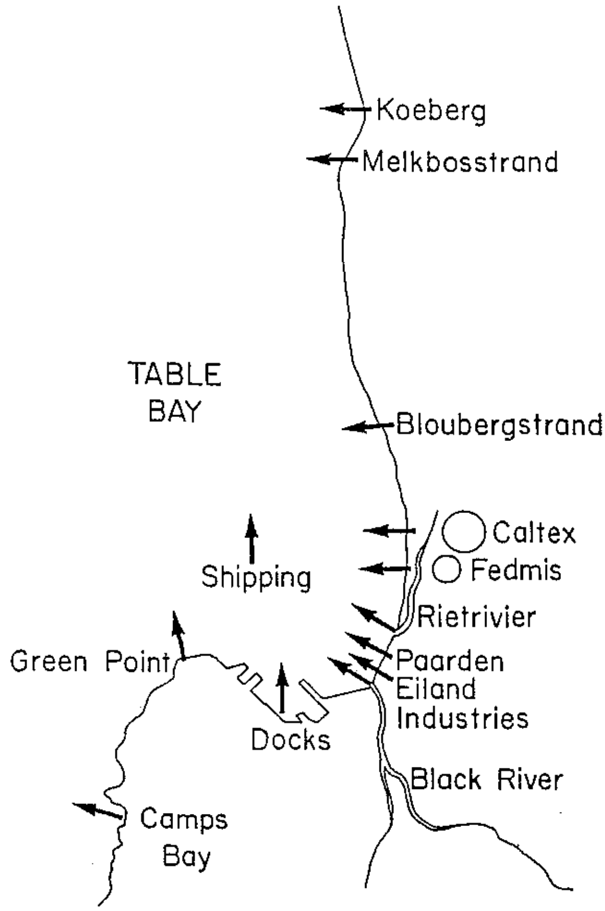



Fig. 2. Pollutants never occur singly in the sea. Discharges into Table Bay, indicated here, pollute the area with perhaps a hundred thousand different chemicals every day, in addition to bacteria, viruses and non-dissolved solids (from Brown 1987).

## BIOACCUMULATION AND CHEMICAL TRANSFORMATIONS

A different approach altogether is based on the fact that many pollutants tend to accumulate in the tissues of marine animals, so that a tissue analysis gives a good index of what the state of pollution has been over an extended period of time and may allow one to make ecological predictions (Clark 1986). Such analyses are also of importance because, in South Africa as elsewhere, many marine animals are consumed by man, so that bioaccumulation presents a potential health problem (Brown 1987). Monitoring of pollutants in marine animals has been extensively carried out in South Africa, particularly with regard to metallic compounds (Hennig 1985), and there are international programmes such as "mussel watch" and "crab watch" for monitoring bioaccumulation.

One thing that arises from such studies is that the accumulated toxin is hardly ever in the same form in which it was discharged into the sea. It has been transformed into different substances which may be less, but frequently more toxic than the original material. This is partly because the substances present in sea water react with one another and with any newly added substance, and it is partly due to transformations brought about by the organisms themselves. Far more knowledge is required concerning these chemical transformations before we can have confidence in extrapolating laboratory tests to field conditions and before predictions can be made (Platt 1984).

## PREDICTION AND PREVENTION

Although we are discussing the assessment of pollution damage, it is obvious that our aim must be the prevention of such damage. We cannot do away with all pollution, of course, but we must try to limit it to an acceptable level. The question then is what is acceptable? In this regard the concept of the "assimilative capacity" of an ecosystem may be appropriate. The assimilative capacity may be defined as a level of pollution stress from which the system will recover rapidly once the stress is removed. There are, of course, difficulties with such a concept; for example, what does one mean by "recover", and what does one mean by "rapidly". However, the concept is good in principle and can be combined with the "water quality criteria" which have been spelled out for the South African region (Lusher 1984). It must, of course, be acknowledged that even if the toxicity of an effluent is within the required limits, accidents may occur. Their impact can, however, be greatly reduced by the use of continuous automatic biological monitoring (Morgan and Brown 1988).

We also desperately need to be able to predict the toxicity of compounds and mixtures of compounds. Toxicity testing itself has predictive value but so many pollutants and new mixtures are being added to the environment each year that we simply do not have the resources to test them all in the laboratory. What is needed is an index, based on known physical properties of the compound, which will enable us immediately to predict its toxicity without the necessity of testing it. Many such attempt have been made (Koch 1983). Among the most promising are those based on water/octanol partitioning (Lord pers. comm.) and on molecular valence connectivity indices (*mc*-indices). The latter gives a measure of the complexity and degree of branching of an organic molecule and provides a good correlation with toxicity (Fig. 3) (Koch 1983, Brown 1986, Wynberg *et al.* 1989). However, these studies are still in their infancy.

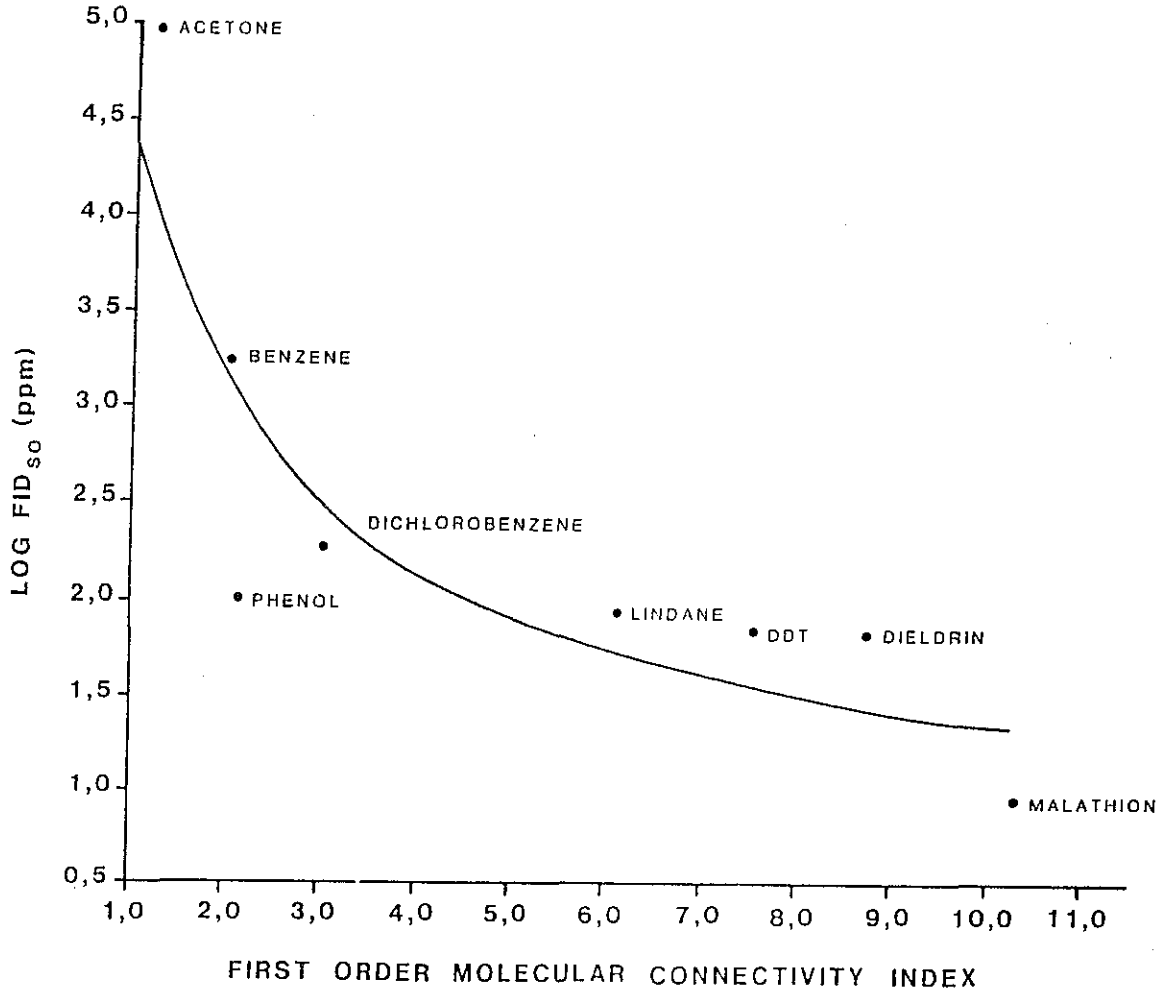



Fig. 3. Correlation between the molecular valence connectivity indices of a number of organic compounds and their toxicities in terms of inhibition of fertilization in the sea urchin *Parechinus angulosus* (from Wynberg *et al.* 1989).

## CONCLUSIONS

I have stressed the complexity of the marine environment and of marine ecosystems. I have stressed the extreme difficulty of quantifying these ecosystems in a meaningful way. I have spoken of the limitations of toxicity testing and the fact that our predictive abilities are at present tenuous. You may well get the impression that pollution biologists don't really know what they are doing - but this is only partly true. The major errors have already been made and we have learnt a great deal from them. We know where we are going, we know what is valid and what is not, we can identify the pitfalls and avoid them and, most important, we know what questions to ask. The ability to ask the right questions is critical not only in pure science but also in its application.

In conclusion, I wish to make a plea to pollution biologists to be flexible in their approach, as this is a field in which rigid, preconceived ideas spell disaster. It is no good sticking to one technique or to one point of view. One must be opportunistic, quick to avail oneself of any and all evidence that may be relevant, mixing field studies with laboratory toxicity testing, a knowledge of bioaccumulation with experiments aimed at future prediction; and we should always bear in mind that, however fascinating our work may be academically, our aim is to bring relief to a sorely stressed environment.

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# PATHOGENIC ORGANISMS IN SEWAGE DISCHARGED TO THE SEA

W.O.K. Grabow

## DISEASES ASSOCIATED WITH THE MARINE ENVIRONMENT

### Diseases caused by chemical pollutants

Marine pollution which resulted in the contamination of seafood with mercury and cadmium, led to the well-known incidents of Minamata and Itai-Itai diseases in Japan (Brown 1987a). Apart from the often devastating effects on marine life, pollution with organic chemicals such as polychlorinated biphenyls, petroleum hydrocarbons, chlorinated hydrocarbons and pesticides, may directly or indirectly have adverse effects on human health (Brown 1987a, b, Hewitt *et al.* 1988). However the incidence of human disease associated with chemical pollutants in marine environments is relatively low (Gerba and Haas 1988, Sockett *et al.* 1985).

### Diseases caused by natural toxins

Some natural inhabitants of the sea produce toxins which cause disease in man, namely, paralytic shellfish poisoning (PSP) and red whelk poisoning (Brown 1987b, Sockett *et al.* 1985). The latter follows ingestion of the salivary glands of the red whelk *Neptunea antiqua*, which contain the toxin tetramine. When bivalve molluscs feed on toxic dinoflagellate plankton of the genus *Gonyaulax*, they accumulate the toxin known as saxitoxin. PSP follows the consumption of such molluscs. Although this type of intoxication is rare, it is of concern from a public health point of view because of the high mortality rate caused by these neurotoxins, and because there is no specific treatment. Pollution of the sea with nutrients may stimulate blooms of toxic plankton (red tide) and thereby increase the risk of intoxication (Hewitt *et al.* 1988).

### Diseases caused by pathogenic micro-organisms

Sewage and stormwater runoff from residential areas contain a wide variety of pathogenic viruses, bacteria, protozoa, intestinal parasites and fungi. Theoretically these pathogens can cause many diseases. Illnesses most commonly associated with polluted marine environments include gastroenteritis and dysentery, respiratory, ear, eye and skin infections, viral hepatitis, cholera and typhoid fever (Brown 1987a, Cabelli 1983, Gerba 1988, Morse *et al.* 1986, Pain 1986, Shuval 1986, Sockett *et al.* 1985). These infections represent the great majority of human diseases associated with polluted marine environments (Gerba and Haas 1988, Sockett *et al.* 1985) and will be considered in further detail.

## INFECTIOUS DISEASES ASSOCIATED WITH POLLUTED MARINE ENVIRONMENTS

Infections are contracted either by direct exposure to polluted seawater through, for instance, bathing, diving or surfing, or by the consumption of contaminated seafood. Detection of these infections, and assessment of their public health significance, is difficult. One reason is that many people contract sub-clinical infections, which are not detectable. These people may, subsequently, infect other people who do develop clinical illness. The latter cases are difficult to relate to the original source of infection. Secondary transmission of this kind has been detected in epidemiological studies (Gerba and Haas 1988). Secondary transmission is, of course, an extended health implication which applies only to infectious diseases and not to intoxication with chemical compounds or natural toxins.

Distinction between infections caused by polluted marine waters, and infections caused by other modes of transmission such as personal contact and the consumption of contaminated food or water not related to marine pollution, is difficult and requires dedicated epidemiological studies (Cabelli 1983, Shuval 1986). Outbreaks involving large numbers of cases, are relatively easy to associate with marine pollution. The smaller the number, the more difficult it becomes to establish the association. The detection of individual cases, which obviously occur much more frequently than outbreaks, becomes virtually impossible (Brown 1987b, Shuval 1986). For the above and other reasons, the true number of infections associated with marine pollution is considered to be much higher than the number of epidemiologically confirmed cases (Brown 1987a, b, Gerba 1988, Shuval 1986).

### Recreation in polluted seawater

Associations between recreational exposure to polluted seawater and infections have been established in a number of epidemiological studies (Cabelli *et al.* 1982, Cabelli 1983, Fattal *et al.* 1987, Ktsanes *et al.* 1981, Seyfried *et al.* 1985, Shuval 1986). One study revealed statistically significant increases in the incidence of gastro-intestinal symptoms among bathers in seawater with counts of faecal coliforms and faecal streptococci as low as 10/100 ml (Cabelli *et al.* 1982). These counts are much lower than those generally considered acceptable for seawater at bathing beaches (Lusher 1984, Shuval 1986). In another study a direct correlation was detected between the incidence of various infections and the number of times board sailers fell into polluted water (Dewailly *et al.* 1986).

In most of the epidemiological studies the aetiological agents of infection were not identified. However, the clinical symptoms of the infections, particularly those of gastroenteritis, indicate that the majority of infections were caused by viruses (Cabelli 1983, Shuval 1986).

## Consumption of contaminated shellfish

Shellfish associated with the transmission of infectious diseases comprise both crustacea and molluscs (Brown 1987b). Crustacea include rock lobsters, crabs, shrimps and prawns. Molluscs fall into two groups: the bivalves, which have two shells joined by a hinge, and the gastropods, which have a snail-like shell. The bivalves include oysters, mussels and cockles, while the gastropods include whelks and periwinkles. Of all seafoods, bivalve molluscs are most frequently associated with infections because they feed by filtering large volumes of water, up to 20 litres per hour, and thereby accumulate pathogens from their environment (Brown 1987a, Lusher 1984, Sockett *et al.* 1985).

Outbreaks of shellfish-borne disease have been reported from many parts of the world. The following are some examples: it has been estimated that during the period 1918-1933 more than 100 000 cases of typhoid fever had occurred in France due to the consumption of contaminated shellfish. This estimate was considered conservative (Brown 1987a). In Australia, over 2 000 people were affected by outbreaks of oyster-associated gastroenteritis caused by the norwalk virus during the months of June and July in 1978 (Grohmann *et al.* 1980). In 1982, not an unusual year in this regard, there were 103 well-documented outbreaks in which 1 017 people in the State of New York, USA, became ill from eating clams or oysters. The most common symptoms were diarrhoea, nausea, abdominal cramps and vomiting. Both incubation period and the duration of illness were generally 24-48 hours (Morse *et al.* 1986). This clinical picture is typical of viral infection. In England and Wales, in one incident between November 1980 and April 1981, 450 people became ill with type A viral hepatitis as a result of eating contaminated cockles, while the period January to April 1986 saw more than 500 cases of viral gastroenteritis blamed on shellfish (Pain 1986).

Diseases transmitted by various types of shellfish display distinct differences. The Communicable Disease Surveillance Centre of the Public Health Laboratory Service in the United Kingdom, recorded 87 outbreaks of infectious diseases caused by the ingestion of shellfish in England and Wales during the period 1965-1983 (Socket *et al.* 1985). Of these outbreaks, 60 (69%) were caused by molluscs, 23 (26%) by crustacea, and 4 (5%) by mixed seafoods. Outbreaks transmitted by molluscs were caused by hepatitis A virus (10), small round viruses (22), unknown causes (26), paralytic shellfish poisoning (1), and red whelk poisoning (1). No bacterial diseases were diagnosed, and there is good reason to believe that the majority of unknown causes were viral infections.

Outbreaks transmitted by crustacea, on the other hand, were caused by various bacterial pathogens (20) while the cause of three outbreaks was unknown and no viral infections were recorded. Bacterial pathogens transmitted by crustacea fell into two groups. One group comprised

*Staphylococcus aureus* (8), salmonellae (3) and *Bacillus cereus* (2). Indications are that these outbreaks were due to secondary contamination of the crustacea during handling and processing and not to marine pollution. The second group consisted of *Vibrio parahaemolyticus* (6) and *Aeromonas hydrophila* (1). This group represents bacteria which occur naturally in marine environments, and the outbreaks were probably the result of insufficient decontamination of crustacea.

Another important difference is that crustacea are generally harvested from deeper waters which are to a lesser extent subject to sewage pollution, while molluscs are generally harvested from, or cultured in, estuaries and nearshore coastal waters which are to a larger extent exposed to sewage pollution. In addition, crustacea are generally cooked, while molluscs are often consumed raw, or partly cooked, steamed or fried.

In summary, the data reported by the UK Communicable Disease Surveillance Centre show that molluscs are responsible for the great majority of shellfish-borne diseases, and that the great majority of these diseases are caused by viruses which originate from sewage pollution. Similar results have been reported from other parts of the world (Gerba 1988, Shuval 1986). The predominant role of viruses in diseases transmitted by molluscs harvested from polluted marine waters, is ascribed to the fact that viruses are more resistant to disinfection and depuration processes than other pathogens (Sockett *et al.* 1985).

Data on mollusc-borne disease outbreaks recorded for ten-year intervals by the UK Communicable Disease Surveillance Centre, confirm the predominant role of viruses, and reveal an increasing incidence during the last two decades (Table 1). Since 1983 the recorded incidence of these disease outbreaks has continued to escalate (Pain 1986, P N Sockett, pers. comm.). Similar trends are being reported from other parts of the world (Gerba 1988). The increasing incidence of outbreaks is ascribed to increasing marine pollution, growing demand for seafoods, and improving epidemiological surveillance techniques.

With regard to Table 1, data on small round viruses became available only in the seventies, when electron microscopy was introduced as a tool for the diagnosis of aetiological agents. Identification of the wide variety of viruses involved in these diseases is extremely difficult because most of them cannot be detected by conventional techniques. Methods for the detection of more of these viruses are currently being developed (Gerba *et al.* 1989). The clinical symptoms of the diseases in outbreaks for which the aetiological agent is unknown, indicate that the great majority of them were caused by viruses.

The decreasing incidence of outbreaks caused by bacterial pathogens is ascribed to improved decontamination procedures which inactivate bacteria but still fail to inactivate viruses (Sockett *et al.* 1985).

**Table 1**
**Aetiology of disease outbreaks associated with molluscs in England and Wales (Sockett *et al.* 1985)**

| | Number of outbreaks | | | | |
|---|---|---|---|---|---|
| Disease | 1941-50 | 1951-60 | 1961-70 | 1971-80 | 1981-83 |
| Unknown | 21 | 14 | 6 | 10 | 13 |
| Small round viruses | 0 | 0 | 0 | 9 | 13 |
| Hepatitis A virus | 0 | 0 | 0 | 3 | 7 |
| Salmonella | 3 | 2 | 0 | 0 | 0 |
| Other bacteria | 2 | 2 | 0 | 0 | 0 |
| PSP | 0 | 0 | 1 | 0 | 0 |
| RWP | 0 | 0 | 0 | 1 | 0 |
| Total outbreaks | 26 | 18 | 7 | 23 | 33 |

PSP = Paralytic shellfish poisoning; RWP = Red whelk poisoning

## SURVIVAL OF HEALTH-RELATED MICRO-ORGANISMS

### Survival in seawater

The survival of pathogenic and indicator organisms in marine environments is subject to a variety of factors (Brown 1987b, Gerba 1988, Rao *et al.* 1986), of which the following are among the most important:

**Temperature.** Temperature is one of the most important factors. Generally organisms survive longer at lower temperatures. At temperatures below 10°C, enteric viruses may survive for several months.

**Salinity.** Most of the organisms concerned do not survive as long in seawater as in freshwater.

**Osmotic shock.** The cytoplasmic membranes of many organisms rupture upon sudden exposure to seawater with the organisms being inactivated almost instantaneously. Viruses, which do not have a cytoplasmic membrane, are affected to a lesser extent than bacteria such as coliforms. Bacterial spores, or bacteria in a dormant state, survive longer than vegetative bacteria. Gram-positive bacteria, such as faecal streptococci, survive longer then gram-negative bacteria such as coliforms.

**Microbial antagonism.** Certain marine organisms produce compounds which inactivate other organisms, including enteric viruses.

**Sunlight.** Ultraviolet light inactivates micro-organisms. Survival is, therefore longer in deeper waters or in bottom sediments than at the surface. Viruses are affected to a lesser extent than bacteria because their ultraviolet light target size is much smaller than that of bacteria.

**Adsorption to solids and sediments.** Adsorption to solids and sediments protects micro-organisms against various inactivating agents and conditions. Counts of viruses have been found to be 10 to 100 000 times higher in marine sediments than in overlaying waters.

**Ingestion by molluscs.** Micro-organisms survive longer in the tissues of molluscs than in seawater environments.

**Type of micro-organism.** For reasons such as differences in structure and composition, the survival of various micro-organisms differs considerably. As a result of their simple structure and protective capsid, viruses are generally more resistant then vegetative bacteria to adverse marine conditions.

**Dilution.** When sewage is discharged into the sea, the numbers of pathogens may be reduced to levels below minimal infectious doses which would eliminate health risks. This factor would depend on variables such as the volume of discharges, and currents.

In laboratory experiments enteric viruses have been found to survive from 2-130 days in seawater. Coliform bacteria did not survive that long. In studies on a deepsea sludge dumpsite off the Philadelphia coast, viable viruses were recovered from the sediment and crabs at the site 18 months after sludge dumping had been terminated. Calculations based on survival curves indicate that viable viruses would be present at the site for several years.

### Survival in seafoods

Pathogenic micro-organisms can survive for extended periods of time in raw or processed seafoods (Gerba 1988). As mentioned earlier, seafood may become contaminated during or after processing. Bacterial pathogens such as *Bacillus* species, certain salmonella and coagulase-positive staphylococci are particularly important in this regard. Under favourable conditions some of these pathogens multiply in raw or processed seafood. Human viruses cannot multiply in the marine environment, or in shellfish or processed seafood.

## CONTROL OF DISEASE TRANSMISSION

The first and most obvious way of preventing disease transmission is by limiting marine pollution. This can be accomplished in various ways

(Grabow 1987). Wastewater discharge by deepsea pipelines is a popular choice. The ideal solution would be not to discharge wastewater into the sea at all. Progress in water treatment technology and the growing demand for fresh water, are increasing the feasibility of advanced treatment and reuse on land. Stormwater runoff, which may contain as many pathogens as sewage, poses more difficult problems. However, by means such as the careful planning of residential areas, the maintenance of buffer zones and the construction of pond systems, the extent of pollution can be curtailed to a large extent.

Methods for controlling the spread of disease by contaminated shellfish, include the following (Gerba 1988, Sockett *et al.* 1985):

**Depuration.** Depuration is standard practice for molluscs. It involves the keeping of molluscs harvested from polluted marine environments for 36-48 hours in shore-based tanks under controlled conditions, including circulated seawater decontaminated by ultraviolet light irradiation. However, molluscs will only release pathogens under optimal conditions. Although depuration reduces health risks, it cannot guarantee a safe product. This was illustrated in 1983 by an outbreak of viral gastroenteritis among 1 300 guests attending a series of receptions in the UK. At least 40% of those attending two of the receptions became ill. The cause of the outbreak was shellfish which had been depurated for at least 72 hours in a purification system judged to be working efficiently by bacterial monitoring. Viruses are of particular concern in this regard because in contrast to bacteria they penetrate the tissues of shellfish and are released less readily during depuration.

**Relaying.** Relaying is basically similar to depuration, except that molluscs are kept in unpolluted marine environments instead of shore-based tanks.

**Heat-treatment.** Sufficient heat treatment will inactivate pathogens. However, viruses have been found to survive the commonly used methods of steaming, frying, baking and stewing. Adequate decontamination is difficult in practice because excessive heating of mollusc meat causes unfavourable changes in taste and texture. This seafood is, therefore often consumed raw or after light cooking.

**Gamma radiation.** Gamma radiation is rarely applied because available information indicates that the doses of radiation required to fully inactivate viruses cause unacceptable organoleptic changes in shellfish meat.

## QUALITY CRITERIA

Microbiological quality guidelines are being used worldwide to monitor marine pollution and contamination of seafoods, and to assess related health risks. Depending on many factors, such as the interpretation of an acceptable health risk, these criteria differ from one country to another. Generally they are based on the use of coliform bacteria as indicators of faecal pollution (Shuval 1986). This approach, which is being followed because of technical difficulties in the determination of pathogens, has shortcomings because numbers and the survival of indicators differ from that of pathogens such as viruses (Grabow *et al.* 1989).

Quality criteria are being revised regularly as more information on health risks and new technology become available. Recently criteria recommended by countries of the European Economic Community and the State of Arizona in the USA, for the first time include limits for human viruses (Grabow *et al.* 1989). A new generation of methods based on nucleic acid detection, will greatly facilitate research on, and the monitoring of, viruses in water and food (Gerba 1988, Gerba *et al.* 1989).

## SITUATION IN SOUTH AFRICA

The incidence of diseases caused by polluted marine environments and contaminated seafoods, has not yet been investigated in South Africa (Brown 1987a, b, Grabow 1987). However, there is no reason to believe that transmission of disease similar to that in other parts of the world does not take place. This possibility is supported by unconfirmed reports of infections associated with exposure to seawater (Brown 1987a).

In view of internationally recognized health implications, and increasing risks in South Africa due to factors such as massive population growth in many coastal areas and an escalating demand for seafoods, authorities have decided to make an assessment of potential health risks. The initial step consisted of a preliminary analysis of the incidence of viruses and indicators in marine discharges and of seawater and molluscs at selected sites along the coast (Grabow 1987, Grabow *et al.* 1989). The results, typical examples of which are summarized in Table 2, indicate that large numbers of human viruses and indicators of faecal pollution were discharged onshore or nearshore at certain sites. In the surfzone at these sites the seawater exceeded recommended limits for direct contact recreation, and molluscs exceeded recommended limits for human consumption. These results suggest that a potential health risk may exist in certain areas. Although a variety of viruses was detected (Grabow *et al.* 1988), counts represent an underestimate because the viruses of primary concern, such as hepatitis and gastroenteritis viruses, are not detectable by the culture methods used.

The results also reveal shortcomings in currently used quality indicator systems (Grabow 1987, Grabow *et al.* 1989). For instance, viruses were cultured from seawater which had counts of indicator organisms (per 100 ml) as low as the following: total coliforms, 7; faecal coliforms, 0; faecal streptococci, 0; coliphages, 30. By using immunological techniques, antigens of hepatitis A and rotaviruses were detected in samples of seawater which had even lower indicator counts. These results suggest that current guidelines for direct contact recreation which specify maximum acceptable faecal coliform counts (per 100 ml) of 100 in 50% of samples, 400 in 90% of samples, and 2 000 in 99% of samples, do not reliably reflect virological safety.

Table 2

**Average counts of human viruses and indicators of faecal pollution in a typical wastewater discharge, seawater and molluscs in the surfzone at this discharge site, and seawater and molluscs at a site where the seawater meets coliform limits for the harvesting of shellfish.**

| | Average count per 100 ml or 100 g | | | | |
|---|---|---|---|---|---|
| Sample | TC | FC | FS | CP | CV |
| Discharge site | | | | | |
| Sewage | $29 \times 10^7$ | $20 \times 10^6$ | $12 \times 10^5$ | $28 \times 10^4$ | $17 \times 10^2$ |
| Surf - seawater | $15 \times 10^5$ | $84 \times 10^3$ | $11 \times 10^3$ | $67 \times 10^3$ | 20 |
| Surf - molluscs | $52 \times 10^6$ | $36 \times 10^5$ | $45 \times 10^4$ | $18 \times 10^5$ | 200 |
| Harvesting site | | | | | |
| Seawater | 380 | 0,4 | 0,1 | 0,0 | 0,0 |
| Molluscs | $60 \times 10^5$ | $64 \times 10^4$ | $24 \times 10^3$ | 80 | 30 |

TC = Total Coliforms; FC - Faecal Coliforms; FS = Faecal Streptococci; CP = Coliphages; CV Cultured Viruses.

Likewise, viral antigens were detected in samples of mollusc meat which conformed to current quality guidelines. On the other hand, viruses were not detectable in many samples which by far exceeded currently recommended coliform limits. These results confirm the poor correlation in counts of indicator bacteria and viruses described in various other studies. With regard to shellfish harvesting grounds, viruses and unacceptable counts of indicator bacteria were detected in molluscs collected from areas where the seawater conformed to guidelines for shellfish harvesting which specify maximum acceptable faecal coliform counts (per 100 ml) of 15 in 50% of samples, and 45 in 90% of samples (Table 2).

## CONCLUSIONS

1. Epidemiological data from many parts of the world show that a variety of infectious diseases can be transmitted by recreational exposure to polluted seawater and by the consumption of sewage-contaminated seafoods.

2. Disease outbreaks with substantial health implications for large numbers of people have been associated with marine pollution world-wide.

3. In South Africa there is virtually no information on the incidence of diseases associated with polluted marine environments. This lack of information creates a false sense of security.

4. Results of a preliminary survey show that substantial numbers of human viruses and indicators of faecal pollution were discharged onshore or nearshore at certain sites along the coast of South Africa. Counts of viruses and indicators in seawater and shellfish at these discharge sites exceed recommended limits and suggest that a potential health risk may exist at these sites.

5. In view of the above findings and factors such as massive population growth and urbanization in many coastal areas, more details are required on the extent of marine pollution and its relation to current and future health risks. These details have enormous financial and other implications in terms of public health, the tourist and holiday industry, the seafood industry, and wastewater management in coastal areas.

6. Counts of viruses and indicators of faecal pollution revealed shortcomings in currently used quality guidelines for marine wastewater discharges (Department of Environment Affairs 1984, Department of Health 1978), seawater used for direct contact recreation (Lusher 1984), seawater at shellfish harvesting grounds (Lusher 1984), and shellfish for human consumption (Department of Health 1973). A major shortcoming of these guidelines is that they do not include limits for human viruses which are responsible for the great majority of infectious diseases concerned.

## RECOMMENDATIONS

1. More details should be obtained on the incidence and behaviour of human viruses, other pathogens, and indicator organisms in polluted marine waters along the South African coast.

2. Epidemiological data on the incidence of diseases associated with marine pollution in South Africa should be obtained.

3. Epidemiological studies should be carried out to establish correlations between the quality of seawater and infection rates in exposed people.

4. The above information should be used to revise and meaningfully implement currently used quality guidelines. These guidelines should be regularly revised and updated as new information becomes available.

5. An assessment should be made of future trends in marine pollution and related health risks.

6. Based on information presently available, the following revised quality guidelines are recommended.

**Seawater: direct contact recreation**

| | | |
|---|---|---|
| Faecal coliforms/100 ml | : | 100 (50% of samples) |
| Faecal streptococci/100 ml | : | 40 (50% of samples) |
| Coliphages/100 ml | : | 50 (50% of samples) |
| Human viruses/10 litre | : | 0 (50% of samples) |

**Shellfish meat: human consumption**

| | | |
|---|---|---|
| Faecal coliforms/100 g | : | 500 (90% of samples) |
| Faecal streptococci/100 g | : | 200 (90% of samples) |
| Coliphages/100 g | : | 10 (90% of samples) |
| Human viruses/10 g | : | 0 (90% of samples) |

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# HEALTH EFFECTS AND EPIDEMIOLOGY

J.W. Moodie


## ABSTRACT

There are always human enteric pathogens in sewage discharges. These organisms may be the ova of intestinal worms, bacteria or viruses. The dilution factor, when sewage is discharged into the sea, is immense and man must drink or inhale water or spray that originates from very close to the outfall to be infected. Conditions that promote the survival of such organisms beyond this zone would include the persistence of undissolved faecal material and the presence of surface currents and prevailing winds which may result in concentrations of organisms at a distance from the outfall.

It is important to perceive that most organisms do not in fact multiply in the marine environment and this is particularly true of viruses, some molluscs filter relatively large volumes of water and can act as concentrations of the dilute suspension of viruses in sea water. As shellfish are often eaten uncooked, diseases such as hepatitis A, hepatitis non A, non B and poliomyelitis are transmitted in this fashion.

Several surveys have addressed the risks associated with polluted recreational waters, and these have been reported for inland water in (mainly) the United States of America.

It is theoretically possible to institute an epidemic disease surveillance study and identify a control population in this country. However, as we have a high rate of pre-existing immunity to most endemic oral disease it would require a large controlled study to detect any signal that might significantly relate to polluted marine waters.

# OIL IN THE MARINE ENVIRONMENT

C.R. Camp

## WHERE IS IT COMING FROM?

Ships and, to an even lesser extent, tankships are presently not the main culprits in contributing to the total input of oil to the marine environment.

In 1985 the US Academy of Science stated that 47% of the oil entering the sea was coming from land-based sources, i.e. non-oil company controlled sources. Sewage, industrial effluents, urban and river runoff and non-tanker shipping were found to be the main contributors. In addition about 7% enters the sea from seepage through the earth's crust and sediment erosion. This input is not controllable by man.

With the reduction in oil tankship contributions, the figure of 47% arising from the non-oil company sources on land is currently estimated to be nearer 60%.

This oil is (possibly) coming from you. It is coming from unconcerned or ignorant industrialists and members of the public. For instance, used motor car oil and paraffins are still going down the drain and into the sea.

When you wash a paint brush with a solvent, where do you dispose of the contaminated solution?

## IMPROVEMENTS IN TANKSHIPS AND TANKSHIP OPERATIONS

Tankships have over the years increased in size, resulting in fewer but larger ships transporting the world's oil. This has led to a reduction in risk, or likelihood of an accident, but increases the hazard, or the resulting damage due to the greater volumes of oil involved. These more spectacular events have led to greater public awareness, reinforced by the media coverage.

With fewer ships to man, the oil industry has been able to improve training and safety standards leading to a dramatic reduction in the number of accidents.

No longer do tankships dispose of tank washings overboard. The clingage is retained and either discharged to shore at the loading port or mixed with the next cargo (also known as load on top).

All types of ships are allowed to pump oil-contaminated water overboard in minute quantities under certain conditions as laid down by the International Convention for the Prevention of Pollution from Ships (MARPOL 1973/78):

a) The effluent must not contain more than 100 ppm of oil,

b) The discharge must be automatically monitored and recorded,

c) It may only be discharged in agreed zones, normally at least 50 km from land,

d) The effluent oil content may not be discharged at a rate greater than 60 litres per nautical mile. (This would result in an invisible film of 0,1 microns thickness which is degraded rapidly.)

However, certain ships do still illegally discharge oil around our coast. 183 Illegal discharges were spotted last year by Kuswag VI patrol aircraft. This resulted in six successful prosecutions.

As with litter, it is no use making anti-litter laws unless we show people how and where to dispose of the litter. Thus the key to making MARPOL work is to have an adequate number of locations (oil-loading ports and repair yards) with slop-receiving tanks and related treatment/disposal facilities. Such facilities exist in Cape Town and Durban. Too little attention, however, appears to have been given to providing slop tanks at other ports where bunkers are taken on.

When an accident, involving one of their cargoes of ships, does occur, the International Oil Industry will call on their response teams to assist the local government authorities with expertise. In addition, 95% of all tankships are covered by a voluntary oil industry insurance under two schemes known as TOVALOP and CRISTAL.

These schemes were established to provide financial compensation to those involved in the spill control, clean up and for any consequent damage. In addition TOVALOP employ technical staff who respond to incidents and offer on-site experience and expertise. Incidentally, they have a very high regard for South African "know how" and capabilities.

In South Africa the oil industry retains an Environmental Engineer, at the moment myself, to advise them on all environmental matters including contingency planning, and through the industry my services are freely available to the authorities in cases of accidental spills.

Tankships have also incorporated improved navigational systems and superior design safety features. For example, the *Antonios G*, a fully laden 250 000 tonnes tankship was struck by a semi-submerged object during one of our freak storms and holed forward. Due to the presence of double bulkheads, none of the oil tanks were damaged. Thanks to South African expertise and equipment, the cargo was transferred to another ship within False Bay without a drop going into the sea.

**MOSSGAS**

This operation does not as yet fall under the oil industry umbrella but it is known that the operators are very conscious of the environment and that they are in continual liaison with the authorities. Naturally, following some overseas platform disasters, the public is concerned, but let me reassure you, that as in many other spheres, South Africa is different.

The products coming out of the ground at the future offshore platform are gas and a very light liquid. In case of a system or mechanical failure leading to a release of these products, the gas would disperse in the atmosphere (mainly methane) and the light liquids would evaporate. The real danger is not pollution but fire.

There is however, a need for special facilities and precautions regarding the discharge of effluent from the onshore Mossref process plant, but I am confident this will be adequately addressed by the Department of Water Affairs.

In conclusion let me reassure you, that the oil industry that I represent, does care about the environment and is putting a tremendous amount of effort and resources into improving its operations wherever possible and is continually planning for contingencies.

# BIOLOGICAL EFFECTS OF OIL SPILLS

L.F. Jackson

Major oil spills are often highly dramatic events involving fires, explosions, and loss of, or danger to, human life. As a result of the ensuing press coverage, the problem of oil pollution has attracted considerable public interest. Such spills, however, contribute a relatively minor proportion of the total input of hydrocarbons into the marine environment. Nonetheless, because of these highly visible events, oil has probably received more than its fair share of attention in relation to some industrial pollutants and synthetic products. Oil is a natural substance and can be dealt with in the biochemical sense, by many organisms, at levels one is likely to find dissolved in the water column. This is not to say that oil does not have harmful effects, but rather that they should be considered in perspective. In this context, it should also be pointed out, that marine systems have a strong capacity to recover, given the chance. Thus, although a major spill may have a devastating initial impact, it is the smaller recurrent spills, or the incidents which cause changes to the physical environment, which result in longer-term or permanent damage.

In South Africa, the level of industrialization is relatively low by comparison with most first world countries, and is concentrated around a few of the bigger cities. On the other hand, it lies on one of the major shipping routes between the Gulf oil states and Europe and America, and in 1983 it was estimated that some 14% of oil transported globally passed our coastline. This, together with the treacherous seas in the region means that oil can at present be considered as one of the more important potential pollutants of our marine environment.

Oil can affect marine organisms both physically and chemically, and the results can be lethal or sublethal. The effects of any particular spill are, however, difficult to predict, as they are dependent on the specific combination of a number of highly variable parameters at the time of the spill. These parameters include the type and volume of oil involved, the weather conditions, the interval between spillage and the impact on the community, the nature of the community affected, etc. Thus a major spill such as that emanating from the *Castillo de Bellver* off the Cape coast in 1983, which involved between 160 000 - 190 000 tonnes of crude oil, resulted in relatively minor environmental damage because the prevailing southeaster kept the oil offshore and in the north-flowing Benguela current. Under a different set of circumstances, the oil could have entered the Saldanha Bay/Langebaan lagoon complex and/or the Koeberg nuclear power station intake basin, with disastrous consequences.

In spite of these variables, it is possible to make some general predictions as to the potential effects of spills. For example, a spill of light oil will evaporate rapidly, especially in heavy weather, and leave little or no residue. Light oils, however, are also more soluble in water, so that their effects are generally at the biochemical/physiological level. These spills are unlikely to reach the shore, and the organisms most likely to be affected are planktonic species. Plankton includes a fairly high percentage of eggs and larvae of both fish and invertebrate species, many of which are much more sensitive to pollutants than the adult forms.

In contrast to the above, crude oils and heavy fuel oils, although they may have a high percentage of volatile components, do leave a tarry residue after weathering, and are therefore more likely to have physical effects. Whether or not they are stranded obviously depends on how far from shore the spill takes place, as well as on factors such as the wind and current speed and direction at the time. Physical effects include direct smothering or coating of organisms, as well as habitat alteration, and can take place both onshore and offshore.

Should the oil come ashore, physical coating and smothering of intertidal organisms will obviously take place. Oil coating the cilia, membranes and mouthparts of these animals will interfere with both feeding and respiration, and consequently may be lethal. The direct contact may also produce chemical effects, e.g. the muscles of the foot in limpets are often adversely affected, and a frequent sight after a spill is that of empty scars where limpets have lost their hold on the rock surface. Oil on the surface of rock pools will reduce both light penetration and oxygen diffusion, thereby affecting the organisms within.

As mentioned before, small recurrent spills may have more serious consequences than a single larger incident. In the same vein, the severity of an individual stranding of oil is linked to the persistence of the oil in the area. This in turn is related to the degree of wave action. Sheltered areas such as estuaries are considered to be amongst the most sensitive of environments to pollution. Oil entering an estuary tends to adhere to suspended particulates, and in the lower density water, tends to sink to the bottom. In the sheltered waters oil incorporated into the sediments will remain for many years, for example, it was estimated that oil deposited in salt marshes after the *Metula* spill was likely to remain there for up to 10 years. Clean-up operations in such habitats have unfortunately often resulted in even more extensive damage. Attempts at removal of oil from marshes affected by the *Amoco Cadiz* spill resulted in a break-down of the whole marsh drainage system as the roots of the marsh plants binding the sediments were removed. On the other hand, oil left in the sediments will leach out slowly, having sub-lethal effects on estuarine species, particularly burrowing organisms.

Offshore, those species most likely to be affected by oil slicks are plankton and seabirds, particularly penguins and diving birds. Both groups may be affected both physically and chemically.

As far as birds are concerned, physical oiling of the feathers is the most common cause of death. Oiling leads to a breakdown in the feather structure which destroys their water proofing capacity. Oiled birds entering the water therefore become wet, and rapidly lose body heat. They therefore tend to avoid entering the sea, and since they are unable to feed, die as a result of a combination of starvation and exposure. Birds may also suffer physiological and/or histopathological effects if they either inhale fumes from a slick, or ingest oil during preening or when feeding at the water surface. Finally, the hatchability of eggs may be reduced by absorption of oil from the feathers of the parent birds during incubation.

The effect of oil on the viability of eggs and/or larvae of marine species, or on other aspects of the reproductive process, is a good example of a sublethal effect that can have long-term consequences. Other life processes that can be affected at the sublethal level include respiration, moulting, behavioural patterns, neural transmission, etc. To demonstrate the potential ramifications of a sublethal effect we will look briefly at a study conducted on the effects of oil on the reproduction of the burrowing sandprawn.

Exposure of berried females showed that both hatching rates and the success of larval development were severely reduced by levels of dissolved oil as low as 2 ppm. This was related to an increase in the occurrence of abnormal eggs and larvae. The sandprawn is unusual in that it produces relatively few eggs, and that the larval phases are not planktonic. The adults only live two to three years, so that should oil become deposited in the sediment, the reduced recruitment of juveniles could lead to a decline in the population. Should they be entirely killed, repopulation of the estuary would be inhibited by the lack of a planktonic larva. The sandprawn is the dominant macrobenthic species in many South African estuaries where it serves as a prey item for several species of fish and birds. It also provides a vital link in the detrital food chain, and its burrows serve to aerate the top layers of sediment. Its demise would therefore have repercussions through the entire community.

Sublethal effects are unfortunately not easily discernable in the field, so that it is difficult to identify a community that is in a state of decline while it can still be easily remedied. This is the more so in that they are seldom subjected to a single pollutant, but rather to a mixture which may have synergistic effects. The effects of oil should therefore, not be considered in isolation, but in conjunction with other stress factors which may be at work on any particular community.

# RESPONSE TO OIL SPILLS

A.G.S. Moldan

The grounding of the *Torrey Canyon* off the coast of Cornwall in 1967 and the resulting devastation of the intertidal marine life and seabird populations caused by the release of 100 000 tonnes of crude oil highlighted the inadequacy of the existing legal, technical and organizational structures required to effectively respond to an oil pollution incident of this magnitude. Since that time tremendous advances have been made in all three fields. A number of international conventions have come into effect which facilitate the implementation of more effective pollution control measures following a marine casualty, vast investments have been made in the development of oil spill clean-up technology and most maritime states have now developed oil spill response protocols, which include the preparation of oil spill contingency plans. South Africa for its part has kept abreast with these trends by acceding to most of the relevant international oil pollution conventions, incorporating these into local statute, establishing stockpiles of oil spill response equipment and by developing comprehensive oil spill contingency plans.

These contingency plans form the core of the oil spill response strategy in South Africa. Large stockpiles of equipment and sophisticated legal structures are of little value in cases where co-ordinated plans are lacking. The ultimate goal of contingency planning is to minimize the potential for environmental damage resulting from an oil spill by predetermining the appropriate courses of action. As many of the decisions as possible concerning the response action need to be taken prior to an oil incident in order to minimize loss of time when the situation arises. This is done by:

* identifying the nature and size of the potential threat
* identifying sensitive resources at risk
* establishing priorities for their protection
* determining a strategy for protection and clean-up in specific areas
* establishing organizational structures
* establishing effective reporting and alerting procedures
* establishing availability of suitable equipment, disposal sites, etc.

## POTENTIAL THREAT

South Africa is situated on one of the world's major shipping routes, with 30% or 163 million tonnes of the Middle East oil exports presently passing the Cape of Good Hope, bound for Europe and the Americas. This represents only 25% of the oil carried around the Cape during the peak period of 1977. These changing trends are due to such factors as the closure of the Suez Canal between 1967 and 1978, the fluctuating price of oil, the exploitation of reserves in other parts of the world, changes in the international economy and the development of alternate energy policies.

In assessing the potential threat of an oil spillage from a tanker casualty off the South African coast, the number and size of tankers carrying the oil needs to be considered together with the actual volumes of oil transported. During the period 1968-1972 a large fleet of smaller tankers ranging from 37 000 to 54 000 DWT were used to move the oil. For this size of ship it is estimated that 10 000 tanker trips were required to move the $457 \times 10^6$ tonnes of oil around the Cape in 1972. The following years saw a dramatic increase in the size of tankers, with the average size increasing to about 250 000 DWT. This increased cargo capacity meant that only about 650 voyages were required to carry the $163 \times 10^6$ tonnes in 1987. This dramatic reduction in the number of laden tankers rounding the Cape reduced the likelihood of casualties. However, the volume of oil released from a casualty involving one of these larger tankers is significantly increased. This is borne out by the larger number of incidents involving tankers in the earlier days (11 in 1968) compared to the smaller number of incidents resulting in the release of greater volumes of oil in more recent years. The release of 175 000 tonnes from the *Castillo de Bellver* in 1983 and 24 000 tonnes from the *Venpet-Venoil* collision in 1977, serves to illustrate this point.

An assessment of the potential coastal pollution based on tanker routes and the oceanic environment indicates that the area faced with the highest pollution risk lies between Cape Town and Cape Recife on the South Coast. The areas of lowest risk occur on the West Coast where the tankers veer away from the coast to round the bulge of Africa, and between Port Alfred and Port Edward on the East Coast where the tanker route is well beyond the core of the Agulhas Current.

## COASTAL SENSITIVITY

During a major spill incident where large volumes of oil are likely to impact the coastline it is obviously not possible for all coastal resources to be adequately protected. It is therefore necessary to identify the resources likely to be threatened by oil and then to determine priorities for their protection.

South Africa's sensitive coastal resources have been identified, with the information presented in the form of a Coastal Sensitivity Atlas. This atlas contains 34 maps (1:250 000) and accompanying text covering almost 3 000 km of coastline from the Orange River to the Mozambique border. The vulnerability of the shoreline to oil, assessed in terms of a geomorphological classification system, is depicted as colour-coded strips along the shoreline. This information gives an indication of the potential for oil being deposited on the particular types of shoreline and its persistence once beached. Coastal resources such as estuaries, other ecologically sensitive areas, amenity areas, industrial sea water intakes, fisheries, seabirds and other resources likely to be threatened are identified by means of symbols on the maps.

Priorities for protection of these sensitive resources are then established and highlighted in the individual oil spill contingency plans, with specific action being recommended. This is probably the most important facet of the policy adopted for spill response. Only government authorities are in a position to make the necessary decisions, since the economic and environmental value to the community needs to be assessed. It is essential to take into account the desirability of protecting a particular resource as well as the extent its defence is practicable.

## STATE RESPONSE

In terms of the Prevention and Combating of Pollution of the Sea by Oil Act (6 of 1981), the Department of Transport is responsible for the prevention of oil pollution at sea while the Department of Environment Affairs is responsible for the combating of oil pollution once on the sea. In practice this means that the responsibilities are divided as follows:

### Department of Transport

Prevention : Control of shipping casualties and salvage
: Oil transhipments

Prosecutions : Illegal oil discharges

### Department of Environment Affairs

Combating : Co-ordination of clean-up and protection activities
: Control of Kuswag vessels and aircraft
: Dispersant spraying

Maintain equipment stocks

Contingency planning

## CONTINGENCY PLANS

Oil spill contingency plans have been compiled for the South African coastline including Walvis Bay, Ciskei and Transkei. For this purpose the whole coastline has been divided into 26 separate coastal zones, demarcated by local authorities boundaries, with a detailed plan developed for each zone. These plans form the basis for the oil spill response protocol and include the following information:

* legal aspects pertaining to oil spills
* liabilities, costs and claims concerning oil pollution damage
* reporting procedures
* activation of response - alert, mobilization, implementation, review, termination
* organizational structure established for the duration of an incident
* facilities and communication network
* specific protection and clean-up measures for each area
* maps indicating local authorities' areas of jurisdiction, access to the shoreline, etc.
* disposal sites for oil and oily debris
* equipment and manpower lists
* telephone numbers
* training of local authorities.

These plans have been put to use in a number of minor spill situations and have been found to work well in practice.

## RESOURCES AVAILABLE TO COMBAT OIL SPILLS

A limited stock of equipment for combating oil spills is maintained by the Department of Environment Affairs. Additionally more generalized equipment (bulldozers, pumps, straw bales, etc.) held by coastal local authorities has been identified and listed in the contingency plans. The dedicated equipment includes:

* a Partenavia patrol aircraft for coastal patrols and aerial evaluation during an oil spill
* four, 29 metre spray vessels, each with a capacity to carry 100 tonnes of oil spill dispersant
* 150 000 litres of dispersant held in tanks around the coast
* 400 metres of inflatable boom to protect estuaries and other sensitive areas
* skimmer for removing oil from water surface
* sorbent materials for removing smaller quantities of oil.

Additionally, the Department of Transport holds equipment for the transhipment of oil and the South African Transport Services has a number of booms and skimmers for removal of oil in harbour areas.

## CONCLUSION

Careful planning is essential for the preparation of any successful operation, this is especially so in an emergency situation. Response to the accidental spillage of oil is a typical example. Advance planning in the form of oil spill contingency plans has proved itself time and again to offer the most effective approach in establishing a sound oil spill response capability.

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