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RELATION OF TREATMENT AND ECOLOGICAL EFFECTS—DISPOSAL OF WASTES TO TIDAL WATERS

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Abstract—The many ways in which tidal waters are exploited by man has led to the need for effective controls and these are reflected in national, regional and international legislation and conventions. It is argued that where wastes are discharged to tidal waters each situation should be judged on its own particular merits after adequate scientific investigation.

Details are given about the state of the North Sea which receives substantial discharges of both sewage and industrial wastes but supports one of the world's most productive fisheries. The regenerative capacity of the sea is highlighted.

The paper describes techniques employed by industry for selecting the most favourable method for disposing of wastes into tidal waters thereby minimising pollution. The problems of assessing the acute and chronic toxicity of wastes, biodegradability, bioaccumulation and monitoring the environment are described.

It is concluded that the sea is a valuable facility for the disposal of wastes but its exploitation for this purpose must be ordered and controlled if undesirable pollution and conflict with other uses is to be avoided.

INTRODUCTION

One of the major areas of public concern is the way in which the natural resources of the earth are exploited since it is constantly predicted that the demands of the increasing world population will rapidly outstrip the supply of essential raw materials and food and, at best, the standard of living and quality of life must fall. Of the natural resources available, the sea, which occupies some two-thirds of the earth's surface to an average depth of 2·5 miles, is probably the least exploited. However, as the land becomes more crowded and terrestrial resources are used up, more and more attention is being paid to the development of the sea as a source of supply.

Historically fisheries were the most highly developed and commercially important resource but their unique position is now being challenged by the exploitation of the seabed for oil and gas, essential minerals such as iron and manganese and even sand and gravel. As seawater is a complex mixture of chemicals, it is also a limitless source of elements such as sodium, chlorine, bromine, magnesium, etc. and in coastal areas seawater is widely used by industry for cooling purposes. In certain countries where the demands of the community exceed the natural supply, seawater is becoming an important source of potable water and eventually, as the economics of desalination processes become more favourable the sea could become an important source of water for the irrigation of arid regions. The sea is also the medium which permits raw materials and goods to be transported cheaply and its importance for recreational purposes is widely recognised. Finally, it may be said that to the professional scientist, naturalist and public at large, the sea is an infinite source of pleasure, study and inspiration.

It is inevitable that as the development proceeds, conflict between all the different interests must increase and in this situation discharge to the sea of substantial quantities of sewage and industrial wastes will only add to the problem because significant pollution is inimical to the rational exploitation of natural resources. Whilst the need for effective control of all man-made wastes entering the sea is generally accepted, a problem arises in striking a balance between needless pollution and extreme conservation. Any material entering the sea will have some effect, but in the present state of knowledge it is often difficult to predict with any degree of certainty whether the effect will be deleterious, either in the short term, or at some time in the future. In these circumstances, a prudent controlling authority will often err very much on the side of safety and the balance is moved towards unwarranted conservation. For the administrator it is a simple matter to set rigid stringent standards applicable to the least favourable conditions, rather than to accept the challenge of attempting to set standards for waste disposal which will allow the regenerative capacity of the marine environment to be used to a reasonable extent, yet ensuring that there is little, if any, conflict with other legitimate uses of the sea. The drawback of rigid standards is that once they are accepted it is difficult to improve them even though developing technology may make this possible. Unnecessarily stringent standards usually result in unmerited increases in the costs of manufactured goods and often substantial amounts of energy are wasted improving the quality of the discharges beyond reasonable levels. In the present situation, where inflation is rife and there is a world shortage of energy, unwarranted conservation cannot be justified or tolerated.

POLLUTION ABATEMENT

Before the recent development of sophisticated methods of chemical analysis the composition of seawater was regarded as relatively constant and dilution in the sea infinite. Furthermore, where effluents were discharged, it was recognised that many potentially toxic materials are readily broken down by marine bacteria, transformed into less toxic forms by physical or chemical processes or lost to the atmosphere. In this climate of opinion, River Boards in the United Kingdom were required to show that effluents were directly harmful to marine life before they could gain control of discharges and impose reasonable control standards.

In the present decade, the situation has changed completely because it has become apparent that in the long term the capacity of the sea to assimilate man-made wastes and render them harmless may not be unlimited. If the known effects of pollutants today are scaled up to the predicted levels for the end of the century when the world population has doubled, living standards have increased substantially and industrial activity grown to keep pace, then it is clear that without effective controls the ecological balance of the sea will become disturbed and all legitimate uses of the sea will be threatened.

Fortunately, the early appreciation of the potential dangers of pollution has led to the introduction of national, regional and international conventions and controls, with the aim of containing pollution and improving any highly polluted areas. For example, Article I of the Oslo Convention states "The Contracting Parties pledge themselves to take all possible steps to prevent pollution of the sea by substances that are liable to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the sea".

The objectives are clearly stated but, as with the Paris Convention, the International Convention for the Prevention of Pollution by Ships (1973), etc, these objectives are stated in biological terms, whilst effective control of pollution can only be achieved by completely banning discharges, or setting precise standards in physical and chemical terms for all potentially harmful materials. The Annexes to the Conventions give some guidance since they usually provide lists of substances which are prohibited, those requiring special care and criteria in general terms governing the granting of permits and consents. It is obvious, however, that only after adequate scientific investigation can each case be judged on its own particular merits. If deleterious effects on the environment are to be avoided, then it is necessary to know:

(1) the permissible concentration and form in seawater of all toxic materials;
(2) the permissible loads;
(3) the area where discharge or dumping will be carried out;
(4) the method of discharge or dumping.

As the quality of the receiving water is of prime importance in deciding acceptable levels for potential pollutants, the present state of the sea will be discussed before outlining techniques employed both in setting acceptable standards for marine discharge and minimising harmful effects.

PRESENT STATE OF THE OF THE SEA

One of the most intensively studied areas is the North Sea which receives substantial discharges of sewage and industrial wastes from the highly developed countries which border it. The effects of man's activities on its resources, particularly fisheries, was the subject of a North Sea Science Conference held at Aviemore, Scotland in 1971 under the auspices of NATO. The outcome of the Conference was elegantly summarised by the chairman, Dr. E. Goldberg[1] who stated that the North Sea constitutes only one fourthousandth of 1% of the world's oceans, yet it yields 5% of the world's fish supply. The conflicts arising from the utilisation of resources were sought but so far there is no evidence of a link between pollution and deleterious effects upon the major fisheries. At the Conference it was stated that over the past two decades the yield of fish has increased by at least a factor of three. Recent statistics from ICES,[2] whilst they show a slight downturn in recent years due to overfishing, record an increase in the yield of fish from 1·7 million tonnes in 1962 to 3·0 million tonnes in 1972, the peak being 3·6 million tonnes in 1968. These figures are scarcely indicative of a highly polluted sea. A further report[3] of the ICES Working Group for the International Study of the Pollution of the North Sea supports the thesis that, at the present time, there is relatively little pollution of the North Sea. For example, one of the conclusions from the survey of fish and shellfish in 1972 is: "In the light of the low and uniform level of metals, organo-chlorine pesticides and PCBs found in the baseline survey, the meeting of analysts (January 1973) consider that little would be gained from a repitition of the 1972 International Fish and Shellfish survey of the North Sea as a whole in the immediate future. This recommendation is based on the low concentrations found in relation to the levels which are currently known to present a hazard to human health and/or marine life".

The report[3] also records the known input of pollutants into the North Sea. The figures given below are conservative estimates because of the general lack of data.

Table 1

		Preliminary data of atmospheric input
BOD	(tonnes per year $\times 10^6$)	(tonnes per year)
Organo-chlorine pesticides	0·66	
PCBs	6·56	
Zinc	40,000	100,000
Copper	5700	13,000
Manganese	61,000	6000
Lead	3600	15,000
Mercury	140	?
Cadmium	112	230

These are very substantial loads and serve to illustrate the fact that the regenerative power of the sea is very large. The fact is also recorded[3] that marine dumping activities in the North Sea are of relatively minor importance in terms of pollutant input.

It is of interest that as in the North Sea, the yield of edible fish from the Baltic Sea has increased substantially in recent years, although the Baltic is often assumed to be one of the most polluted seas in the world, largely because of the slow rate of exchange of water with the North Sea. Svansson[4] records that from 1930 to 1970 the total catch of herring and cod increased nine times from 50,000 tonnes/year to 450,000 tonnes/year. Including sprats and flounders the total catch in 1970 was 700,000 tonnes.

The increased yields from both the North and Baltic Seas are the result of improvements in fishing methods and today fishery scientists are far more concerned with the immediate problems of overfishing than with the effects of pollutants. On the credit side, it is known that nutrients and even biodegradable organic substances which are discharged to the sea, may have a stimulating effect on primary productivity and fisheries.[5] Providing there is no serious imbalance such pollutants are beneficial and it could well be that these beneficial effects often outweigh any harmful effects of heavy metal ions and other persistent pollutants. Obviously much further research is required if we are to understand the combined effects of many of these pollutants in the natural environment. This view is clearly supported by the Analysts Working Group of ICES and is expressed in their conclusion[3] "Considering that chemical manpower and expertise available in pollution studies is very limited, the Analysts wish to emphasise the importance of directing part of these analytical facilities towards supporting studies both short and long term, which are needed to provide the realistic assessment of the biological significance of the levels of pollutants found in the base-line survey".

Whilst it is highly desirable that there should be effective controls to prevent needless pollution, the present condition of the seas with high regenerative capacity, suggests that it is not in the public interest to introduce punitive and stringent controls. Such stringent controls should only be introduced where they are found to be necessary after critical scientific investigation.

CONTROLLING AND MINIMISING POLLUTION

The objectives of control measures have been defined as avoiding hazards to human health, preventing harm to living resources and marine life, damage to amenities or interference with other legitimate uses of the sea. These objectives may be achieved by imposing physical and chemical standards based on laboratory experiments and following field investigations, selecting the most favourable method and avenue for dispersal or dumping.

LABORATORY INVESTIGATIONS

(1) *Chemical analysis*

The first essential for control purposes is a knowledge of the volume and composition of the waste material. For this a representative sample is required, so that all major and minor constituents may be identified by chemical analysis. Whilst the chemical composition of a waste may be defined it does not necessarily follow that the form of the constituents will remain the same when discharged to the sea.

(2) *Acute toxicity to marine organisms*

Techniques are well established for measuring in the laboratory the acute toxicity of wastes to marine organisms and from a knowledge of the concentration which kills 50% of the organisms in 96 hr (LC_{50} for 96 hr) it is possible to set the minimum dilution of the waste to avoid immediate harm in the receiving water. It is common practice to allow a reasonable margin of safety because it is impossible to reproduce in the laboratory, field conditions. In fact, the validity of using the results of laboratory tests for assessing what happens in the sea is often open to question but a good working relationship has been established in freshwater; the absence of fish from certain rivers has been shown to be directly related to concentrations of pollutants just exceeding the acutely toxic concentration measured in the laboratory.

Measurements of acute toxicity only permits the avoidance of catastrophic effects and much lower concentrations of persistent toxic materials may be harmful over longer periods. Thus, if a waste is found to be highly toxic to marine organisms, the specific toxic substance should be identified and its persistence measured.

BIODEGRADABILITY AND PERSISTENCE

Toxic materials may be broken down by marine bacteria or they may be transformed by physical and chemical processes into less toxic forms so that in the longer term there will not be any harmful effects. Measurements of biodegradability of organic constituents may be conveniently carried out using standard BOD (Biochemical Oxygen Demand) tests or respirometers. The effectiveness of biological breakdown can often be assessed chemically but further measurements of the acute toxicity of a treated sample may be necessary to find out if the breakdown products are also toxic. The classical example is the breakdown of DDT to the more toxic form DDE but in practice this is a rare phenomenon.

Seawater is a complex mixture of chemicals, particulate matter and living organisms. Thus, the form of waste constituents may not only be changed biologically on discharge to the sea but also by adsorption, chelation, chemical oxidation, photochemical reactions etc. Our understanding of these processes is very limited and for this reason the results of laboratory tests on pure substances can often be misleading. For example, copper added as copper sulphate to Brixham seawater was found to be lethal to the clam *Venerupis decussata.* Mortalities commenced within 10 days when the clams were exposed to 0·1 ppm and within 40 days when exposed to 0·01 ppm. Mortalities of the clams ceased when they were returned to clean seawater. However, exposure of clams to 0·1 to 0·01 ppm copper in the presence of 1·0 ppm EDTA did not cause mortalities, even after 76 days' exposure

CHRONIC TOXICITY

If acutely toxic substances are persistent then it is likely that even at sub-lethal concentrations they may be chronically toxic or if bio-accumulated they may be harmful to predators, particularly those at the top of food chains. Chronic toxicity may be defined as any deleterious effect of sub-lethal concentrations on the vital functions of organisms which may impair survival. Many research workers have proposed methods of assessing chronic toxicity by examining physiological responses to sub-lethal concentrations but so far none of the methods appear to have gained universal acceptance. In the laboratory it is relatively easy to produce a dose/response curve showing impairment of function against concentration but deciding what level gives a significant harmful effect is very difficult. A nil effect is unacceptable since this merely reflects the sensitivity of the test method. The expert may make a subjective assessment of significance but he may be wrong. In the last resort we must either accept his valued judgement based on experience or purely arbitrary standards.

BIOACCUMULATION

Problems of the bioaccumulation of persistent toxic materials found in the sea at low concentrations are well understood, for example, methyl mercury, some chlorinated hydrocarbons, organo-chlorine pesticides. However, bioaccumulation is not always a harmful phenomenon, it is in fact, a natural process and aquatic organisms would not exist if this were not so.

Animals may be exposed to low concentrations of persistent toxic materials in experimental tanks in the laboratory and the rate of uptake followed by sacrificing animals and analysing the complete animals or specific organs for the toxic material. The rate of loss of accumulated material may also be measured by analysis of some of the animals returned to normal seawater. Thus, where exposure to toxic materials is intermittent an assessment of the likely effects may be made, for example, dumping from ships.

Although the chemist can demonstrate in laboratory experiments and from measurements in the field that bioaccumulation occurs, the biological significance of the phenomenon is often obscure. Whilst it is often stated that many heavy metal ions are harmful because they are bioaccumulated, this may not be true. Many estuaries in south-west England are rich in heavy metals derived from old mine workings but there is little evidence of harmful pollution as these estuaries support an equally wide range of species of animals and plants as less unpolluted estuaries. Their abundance suggests they have readily adapted to the "polluted" environment.

FIELD SURVEYS

(1) *Minimising the effects of liquid wastes discharged through pipelines*

The most advantageous position for a submarine outfall is generally the shortest distance from the shoreline where adequate dilution and dispersal of the waste can be obtained. When the effluent is less dense than seawater usually the best method of disposal is to release the effluent from a diffuser section of pipeline on the seabed, since the effluent rising to the surface will entrain seawater and form a diluted field of effluent at the surface which subsequently will be diluted much further by turbulent diffusion, including tidal currents. If there is insufficient mass transport of the diluted effluent away from the outfall, the effluent on discharge will entrain diluted effluent and locally the concentration will rise. This frequently happens in restricted waters such as estuaries and may give rise to serious pollution. In the open sea this rarely occurs.

If the effluent is denser than seawater, it is obviously desirable to make the discharge at the surface so that, as the waste sinks towards the seabed, seawater becomes entrained and a substantial dilution is achieved. Unfortunately, discharge by pipeline direct into surface waters is usually impracticable and in these circumstances the most advantageous method of dispersal is at velocities greater than 10 ft/sec through jets inclined at 45° to the seabed so that the effluent is drawn into and dispersed widely by the overlying waters. If the dense undiluted effluent is allowed to pool on the seabed, it will probably promote a density current and move offshore along the slope of the seabed, becoming dispersed and diluted in the process. However, a dense layer of waste on the seabed would adversely affect bottom living fish and their food and the application of such a method of disposal is limited.

The programme for a typical field survey aimed at finding the best position for an outfall would normally include:

(a) Measurements of the topography of the outfall area by echo sounding and transit sonar to eliminate difficult or impossible routes for a pipeline on the seabed. This becomes unnecessary where the pipeline is constructed in a tunnel below the seabed.

(b) During neap and spring tides, measurements of current velocities along each possible route for the pipeline so that the less advantageous positions are eliminated. Following this, recording current meters can be laid at carefully selected positions on the preferred route and current velocities recorded for at least one month. From the current data, tidal excursions and residual currents can be calculated which enable predictions to be made of the eventual dilutions and dispersal of the effluent.

(c) Measurements should be made of salinity and water temperature and water samples should be taken for analysis of suspended matter, nutrients and other constituents which may be indicative of other sources of pollutants. Changes in salinity in coastal waters can be used to calculate the diffusion coefficients for effluents as the dispersal of freshwater is likely to be similar to that of buoyant effluents.

(d) Measurements of the likely dilution and dispersal of effluents in the surface waters of the sea can most readily be followed by labelling a patch of seawater with a tracer dye Rhodamine B, and subsequently sampling the patch and measuring concentrations. Not only does this give the rate of change in concentration but the movement of the patch under the influence of wind and tide can readily be followed and the likelihood of contamination of local beaches avoided.

(e) If the discharge is likely to contain substantial quantities of particulate matter which will be deposited on the seabed, it may be necessary to carry out experiments with wastes labelled with radioactive tracers to assess the likely rate of deposition and the ultimate fate of the materials. Radioactive silver 110 introduced as silver amine, has currently been used for this purpose as the metal is readily adsorbed on particulate matter and it is readily detected.

From the information gathered during the field survey it is possible to select the preferred position for the outfall and to calculate the dilution which will be achieved any distance away from the outfall.

An example of the initial dilution of a buoyant effluent discharged into UK coastal water from a submarine pipeline where the minimum depth of water was 10 metres is shown in Fig. 1. From the figure it sill be seen that initial dilution of the waste depends largely on the number and size of ports through which the discharge is made and the rate of discharge of the waste. Thus, the optimum method of dispersing the waste can be selected.

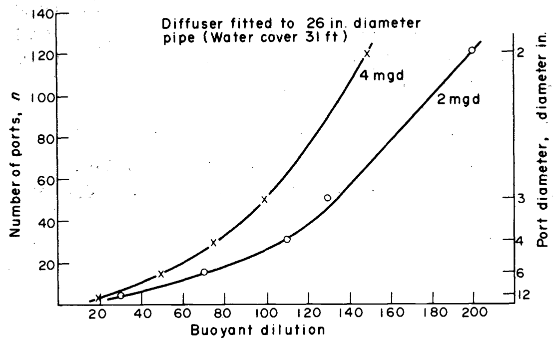

Fig. 1.

(2) *Minimising the environmental impact of wastes dumped from ships*

Dumping from a moving ship is often a much more satisfactory and safer method of disposing of liquid wastes, than discharging from a submarine pipeline lying on the seabed. This is so, because the waste can be distributed over a large area of the sea and where wastes are heavier than seawater they are more rapidly diluted and dispersed by entrainment as they sink towards the bottom. The position selected for dumping can also be well away from areas of high commercial value for fishing and well away from areas used by the public for recreational purposes.

The order of magnitude of the initial dilution of the

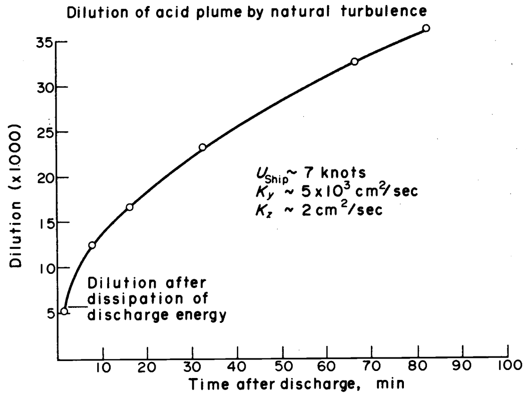

Fig. 2.

waste in the wake of the ship is roughly the ratio between the volume of waste discharged to the volume of water disturbed by the passage of the ship in a given time. However, the final dilution depends not only on the potential and kinetic energy of the discharge from the moving ship but also the degree of natural turbulence of the sea.

The extent of dilution is best illustrated by example. Consider a 1000 ton ship travelling at 7 knots discharging its load over a period of two hours into the North Sea. As shown in Fig. 2 the immediate dilution of the waste three hundred metres behind the ship is of the order of 5000 times, but within the hour the dilution rises to 30,000 times. With dilutions of this order and by the intermittent nature of these operations, dumping at sea has much to offer for the safe disposal of many wastes.

MONITORING

(a) *Onshore*

For effective control it is necessary that the discharge rate and composition of all wastes should be measured and that controlling authorities should be responsible for verifying the validity of data.

(b) *Offshore*

Changes in the concentration and distribution of pollutants are frequently measured in water, sediments, animals and plants but such information is of limited value unless the biological consequences are understood. Some form of ecological monitoring is preferable but ecological monitoring suffers from the grave defect that it is almost impossible to differentiate between natural changes and those resulting from man's activities. In practice, natural changes are always so much greater; where discharges of pollutants have a catastrophic effect ecological surveys are often unnecessary as the cause of change usually becomes obvious.

Ecological monitoring is often stated to be of greatest value for the detection of long term trends. Normally five years' results are necessary for significant changes to be detected but ten years' results are required to quantify such changes; few workers are prepared to state the time required to identify the cause of change.

CONCLUSIONS

The sea is a valuable facility for the disposal and dumping of wastes but its exploitation must be ordered and controlled if undesirable pollution and conflict with other uses is to be avoided. The sea has a large capacity for diluting and transforming wastes, toxicity thereby being greatly reduced, but exact knowledge of the fate and possible harmful effects of persistent substances is often lacking. In these circumstances we often err on the side of extreme safety and it could well be that further research will show that some of the standards applied to marine discharges are far too rigorous. On the other hand we must remain vigilant and untoward effects can best be avoided by well-directed scientific investigation prior to discharge and subsequently adequate chemical and biological monitoring of the receiving waters.

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