Discharge of Sewage from Sea Outfalls

Supplement to Progress in Water Technology

DISCHARGE OF SEWAGE FROM SEA OUTFALLS

Proceedings of an International Symposium held at Church House, London, 27 August to 2 September 1974

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Foreword

Enjoyment of the various pleasures that are afforded by bathing beaches and neighbouring coastal waters is among the most popular means of relaxation of people the world over. Yet, as is all too well known, this enjoyment and other related amenities are often spoiled by pollution arising from unsuitably sited or overloaded sewage outfalls. In general there is no major technical difficulty in preventing such adverse effects, but opinions differ as to the best way to proceed. Without going into all details of the argument, controversy arises mainly on two issues.

Firstly, there are those who believe that discharge of sewage without biological treatment, even some considerable distance offshore, is an unsavoury practice, inconsistent with modern man's technological ability and resources, and potentially dangerous to health. Others feel that it is perfectly proper to do this, since natural processes of self-purification and dispersion in the sea will, given good outfall design, ensure that no adverse effects result and that some advantage will accrue from the lower costs; moreover, the need to sacrifice valuable land for the siting of treatment works becomes unnecessary.

Secondly, there are those who consider that, because sewage can contain pathogenic micro-organisms, disposal schemes should be designed to prevent the degree of microbial contamination exceeding a chosen standard, one expressed in terms of numbers of coliform bacteria being most often suggested. Others contend that because no causal exposure–effect relationship has been established between numbers of these organisms in bathing waters and incidence of disease, and because of various practical difficulties in monitoring contamination, such a requirement would be counter-productive.

In the early sixties the then Department of Scientific and Industrial Research recognized that to resolve arguments such as these a much better understanding was needed of the behaviour of sewage and its constituents when released to the sea. The Department therefore set up a Coastal Pollution Research Committee to advise on an appropriate programme to be carried out by the Water Pollution Research Laboratory. A great deal was learned as a result of this work and of parallel activities in other parts of the world and in 1972, after about 10 years' effort, those most closely involved at the Laboratory, in consultation with the Committee, decided that the time was opportune to see whether some agreement could be reached among the professionals involved in various countries, as to the technical facts underlying the political issues. The idea was thus conceived of holding an International Symposium in which the leading protagonists of particular view points would present the scientific grounds for their contentions. Once embarked on this idea it was but a short step to decide that other important issues, such as the assessment of bacterial mortality in the sea, should be included.

The reader must judge for himself the success of the venture. My personal impression is that the quality both of the papers and of the discussion is certainly sufficiently high to have made the exercise thoroughly worthwhile and to reflect credit on all those who contributed to it.

As to the organization of the Symposium and the preparation of these Proceedings, I know that my former colleagues at WPRL and other participants will heartily support my view that by his untiring efforts, unflagging enthusiasm, and inspiration, the lion's share of the credit must go to Mr. A. L. H. Gameson and with it our grateful thanks.

A. L. Downing
(formerly Director,
Water Pollution Research Laboratory)

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London

Introduction

The original aim of the Symposium was to get full discussion of papers by leading protagonists on three important but unresolved topics: microbial standards for bathing beaches, the treatment of sewage before discharge to the sea, and the various mechanisms to which microbial mortality in the marine environment has been attributed. The scope was then extended to cover almost all aspects of the discharge of sewage from sea outfalls, though (even with 42 papers) full justice could not be done to the subject; for instance, there was too little on ecological effects and virtually nothing on outfall construction. Nevertheless, it was felt better to cover some major aspects as thoroughly as possible, rather than to attempt to cover the whole field uniformly. Papers were by invitation—after seeking the advice of about 100 specialists of international repute.

The programme was approved by the Coastal Pollution Research Committee of the Water Pollution Research Laboratory, and organization of the Symposium was little affected by the transfer, on 1st April 1974, of the Laboratory from the Department of the Environment to become the Stevenage Laboratory of the new Water Research Centre (outside the Civil Service). The main financial burden for the Symposium was borne by the Department.

Despite various difficulties, such as the late submission of many of the manuscripts, it was possible —through the ready collaboration of her Majesty's Stationery Office—to circulate preprints of each paper prior to the holding of the Symposium, and it was gratifying that (with a single exception) each was presented by an author. These two factors undoubtedly contributed greatly to the success of the Symposium in which there were some very spirited and rewarding discussions.

I take this opportunity of thanking the Authors for their unfailing courtesy over the past 18 months, the Chairmen for ensuring that the sessions ran to time and that the discussions took place in an orderly fashion, Mrs. Lena Jeger for her stimulating Opening Address, and the rest of the 218 participants (from 24 countries, plus W.H.O. and the World Bank) for their gracious co-operation and exemplary attendance, no paper being given to an audience of less than 100.

Editorial comment

In editing the papers, an attempt was made to introduce some degree of uniformity in the lay-out of tables, diagrams, reference lists, etc., so as to lighten the task of participants in reading so many papers in advance of their presentation. English spellings are used except in papers by American authors. Metric units are employed almost exclusively, the main abbreviations being s(econds), min(utes), m—metres or meters, l.—litres or liters, g—gram(me)s, t(onnes) = 10^6 g, and the prefixes n, μ, m, c, and k denoting multiples of 10^{-9}, 10^{-6}, 10^{-3}, 10^{-2}, and 10^3 respectively.

References in each paper are numbered in order of their first occurrence in the text (or relevant tables or diagrams); where several occur together, they are usually presented in chronological order. In the reference lists they are expressed in the format laid down in the 4th edition of the *World List of Scientific Periodicals* (Butterworth, London, 1964). The help is gratefully acknowledged of Mrs. I. N. Ward in checking, so far as was practicable, all these references, and of Messrs. D. Munro, A. R. Agg, A. W. J. Bufton, G. Stanfield, and D. J. Gould in editing and proof reading. Mr. Gould was also responsible for the detailed organization of the arrangements in Church House and gave invaluable assistance throughout, and Mr. Munro prepared the Subject Index.

Authors were normally given 20 min in which to present their papers (which were taken as read), and an edited summary of the opening remarks will be found immediately following the text of each paper. Contributors to the discussions were invited to hand in their contributions in writing (and most did). These have been edited—sometimes severely, as an attempt has been made to keep individual contributions down to a maximum of 300 words, although several submissions exceeded 2000 words. The Authors subsequently provided written replies conforming with what they had said at the time. To ensure speedy publication, the contributors were not sent the edited versions of their submissions; although all the edited material relating to each paper was checked by the Authors, I naturally take full responsibility for any misinterpretation or omission of the discussion material submitted. Papers were generally presented and discussed in pairs, but the discussions have been separated wherever practicable; these will be found at the end of each paper and are followed by the Authors' replies. Reported speech and English spellings are used throughout. The discussion of Papers 5 and 6, 9–11, 17 and 18, and 32–34, however, could not be treated so simply, and the Authors' replies are included within the general discussions. The numbering of the many additional literature references arising from the discussions continues from the reference list of the relevant paper, or of the final paper in the case of the general discussions. These references, some of which I have added myself where they seemed appropriate, have not been checked as thoroughly as those in the main reference lists.

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January 1975

Erratum

All references to Rapp. P.—V. Réun. Cons. int. Explor. Mer, 1975, **167** are incorrectly dated; although the volume was not published until 1975 it is dated December 1974.

Opening Address

Mrs. Lena Jeger, *M.P.*

In welcoming the Symposium participants, Mrs. Jeger said that the subject to be discussed was one very relevant to the United Kingdom because those countries (usually islands) with the longest coastlines in proportion to their areas were historically the most abusive of the sea, and this sea-girt isle was no exception. It was gratifying that there was an increasing understanding of the marvellous but finite self-cleansing powers of the oceans: legislation and public concern were accelerating in nearly every country, and there was a fashionable interest in the environment which would pass if it were only a fashion. The three main necessities for implementation for effective control of marine pollution were the right machinery for enforcement, scientific man-power (for research, monitoring, and policing), and public interest and support which would inspire and compel government policy—and pay for it.

There had recently been massive re-organization of the water industry in England and Wales, on the principles that water management needed a national council, and that there should be delegation to authorities based on watersheds and not on local government boundaries. (There would, of course, be greater problems where national boundaries were involved.) The present gathering showed no shortage of world experts but, to cross new frontiers of knowledge, many countries (and certainly the U.K.) needed a restructuring of faculties in the universities, with straddling of old disciplines, and this called for fragmentation and re-assembly. New career structures inside and outside laboratories were needed, but British government scientists were disgracefully underpaid and it was a miracle that so many talented and devoted scientists remained in the service. The same applied outside, right down and up the line: new dignity was needed for the sewage workers and managers—and a career structure, since no army could work without its non-commissioned officers.

Most democratic governments acted in response to pressures, and only rarely took initiatives. These pressures (rational and irrational) could often be generated by scientists like Bronowski and Cousteau with a gift for communication. Some did not try hard enough—leaving it to the science writer who often did a good job which many scientists were too busy or too inarticulate to do—but in the urgency of the present situation (particularly in the context of the Symposium) Mrs. Jeger believed the public wanted to know and understand, and was capable of digesting much more scientific sales-talk than it got, and turned to science fiction despite the abundance of interesting science fact. A scientific truth which could not be clearly stated might not even be true. Mrs. Jeger had been lucky, as an arts student struggling with the use of the subjunctive in Icelandic sonnets, to have been at a college (Birkbeck) where the science faculty included Blackett and Bernal who accepted (at the cost of leisure) the social duty of communication to students in other faculties—apparently without any diminution in their scientific achievement.

Too often the attempt to engage science with politics avoided a definition of either. This led to difficulty —unless politics were considered to mean the whole body of public opinion and understanding. The scientist and politician who wanted to get something done had sometimes, ironically, to keep clear of what C. P. Snow called 'the corridors of power', which swarmed with the ineffectually ambitious, and where much time was wasted. Politics had been described as the art of the possible—more often it was the art of the unexpected. Political decisions required innovation of ideas and education in them.

Lest her audience thought she was forgetting about the sea, Mrs. Jeger gave a relevant example. British politicians and civil servants—semi-literate about pollution—devised rules and standards (very variably implemented) for water quality in rivers, but these standards did not apply to estuaries or to coastal discharges, and the Working Party of which she had been Chairman had found* a move of polluting industry to the river mouths and the sea shore to escape the laws of the politicians. Sewage and trade waste from about 6 million people was discharged to the sea or estuaries with little or no treatment, about two-thirds of the coastal authorities discharging at least some untreated sewage to the sea. There was uncertainty about the long-term effects of highly toxic and persistent substances originating in industrial and chemical wastes and discharged with the sewage. The Working Party had concluded that crude sewage should be discharged only after screening or comminution, and only through diffusers on long outfalls. Seeking to agree about how to treat the oceans of the world—whether to pollute the sea or farm it, whether to enjoy it or abuse it—could well be the most immediate growing point of international co-operation, and any responsible scientist and politician must want this above all else.

* MINISTRY OF HOUSING AND LOCAL GOVERNMENT and WELSH OFFICE. 'Taken for Granted. Report of Working Party on Sewage Disposal'. H. M. Stationery Office, London, 1970.

Mrs. Jeger ended by referring to a non-scientific non-political extract from John Keats's last sonnet:

> The moving waters at their priest-like task
> Of pure ablution round earth's human shores . . . .

Oil slicks, dumping of chemical wastes with unknown results, anxieties about nuclear wastes and industrial rubbish, now made these lines seem idle nostalgia. Nevertheless she believed—especially at the present important gathering—that the poets, the scientists, and even the politicians could come together, and that the moving waters could resume their task of 'pure ablution round earth's human shores'.

Contents

The Discharge of Sewage from Sea Outfalls into the North Sea

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This paper presents in general terms some of the major factors which have a bearing on the discharge of sewage from outfalls into the North Sea. A brief description will be given of the relevant topographic, climatic, and hydrographic features which may affect the distribution of sewage, and of those uses of the sea which may be directly or indirectly affected. The aim of the paper will be to summarize many of these factors briefly; more detailed considerations of some aspects are the subject of other papers presented later at this Symposium.

Topography

For the purposes of this paper, the North Sea is defined as that sea area lying south of latitude 59° N and bounded by the Orkney Islands and the east coast of Britain on one side, and the coast of Norway and continental Europe on the other. The southern boundary is taken as the Straits of Dover. The Baltic Sea is excluded from these considerations and for this purpose a line has been drawn across the Skagerrak from Kristiansand in southern Norway to Hanstholm in northern Denmark.

The main features of the bottom topography are shown in Fig. 1. Generally, the depth of the North Sea decreases from the north towards the south, although extensive shallow areas, such as the Dogger Bank, occur in relatively deep water. Depths greater than 50 fm (91 m) are found in the northern part,

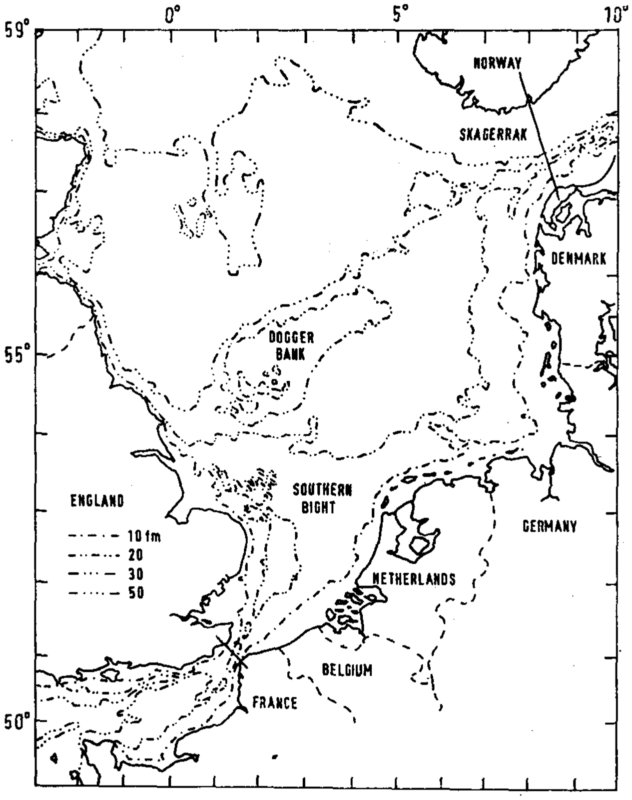

FIG. 1. Topography of the North Sea

including the area of the Norwegian Deeps adjacent to the south coast of Norway, where depths may exceed 150 fm (274 m). Extensive shallow areas of less than 10 fm (18 m) depth are found adjacent to the coasts of Denmark, Holland, Belgium, and the larger estuaries of Britain, such as the Firth of Forth, the Wash, and the River Thames. Most of the central northern part of the North Sea is between 20 and 30 fm (37–55 m) deep, the area of this depth approaching the coast of north-east Britain relatively closely.

The sea bed varies considerably, consisting mainly of sand, mud, or gravel or mixtures of them. Sand and gravel deposits are worked commercially in parts of the southern North Sea, and areas of mud occur in many of the estuaries as well as in well defined areas of deeper water[1]. In some places, usually near to rocky coasts, rocky outcrops occur. Sand is found on littoral beaches along many coasts of the North Sea, where it provides important recreational areas. The nature of the sea bed, and particularly its roughness, affects the turbulence of the water, which is important when considering the mixing characteristics of an area. Detailed consideration of this topic is outside the scope of this paper.

Climatic Conditions

Details of the climatic conditions prevailing in the North Sea are summarized by Hohn[2], whose data have been used extensively in the present paper. The North Sea is dominated by prevailing winds which bring humid conditions free from extremes of temperature. However, the North Sea is a transition area between oceanic and continental weather systems, the North Atlantic weather systems being modified by those of the continent. In winter, the lowest average temperatures occur on the eastern side of the North Sea (2–3°C) whilst those on the western side are about 5°C. In summer there is a gradient of average air temperature from the north (where it is about 13°C) to the south-east (where it reaches about 17°C). The mixed weather systems lead to a high frequency of winds, the average wind force and storm force frequency increasing from south-east to north-west. The average wind force is about 3 (Beaufort scale) in summer and 5–6 in winter.

Cloudiness and humidity are common in all seasons, but in coastal regions the effect of the land mass is to reduce cloud cover. In all months, the average frequency (days/month) of cloud cover of 8/10 or more in the southern and central North Sea is between 40 and 60 per cent, and in the northern North Sea between 50 and 70 per cent. The frequency of days with cloud cover of 2/10 or less is between 10 and 20 per cent. Clear weather occurs most frequently in the northern area from April to August, and in the remaining areas in April or May.

The frequency of precipitation is greatest in November and December and lowest in May to July. In the southern and eastern area the frequency (days/month) in the summer is about 8–10 per cent, but in many coastal areas precipitation is less as a result of the influence of the land mass. Eastern coastal regions of Britain are protected from the prevailing south-westerly wind and tend to have a lower rainfall.

Hydrography

The hydrographic features of an area play a predominant part in the fate of a waste released from a coastal discharge. The distribution of the waste will initially be influenced by (among other things) the tidal streams and in the long-term by the residual currents. Other hydrographic factors such as the effect of wind, the turbulence of the water mass, density gradients, and the differences in current velocity and direction at different depths all influence the dilution and transport of waste. Unfortunately, most hydrographic observations have until recently dealt mainly with those areas of the North Sea away from the coasts, although it is near the coasts that most discharges occur. The hydrographic characteristics of coastal waters vary widely, depending upon, for instance, topography, depth of water, and nature of the sea bed, and it is not possible to describe these features in any detail; some attention will, however, be given to this factor in subsequent contributions of a more specialized nature.

Much of the North Sea, except on part of the eastern side, is subjected to clearly defined tidal streams, in contrast with other seas such as the Baltic and Mediterranean, which, because of their restricted contact with the North Sea and the Atlantic Ocean, have only limited water movements associated with the tides. Little information is, however, available in a synoptic form illustrating the tidal streams in coastal waters, but some indication of the magnitude of the tidal streams throughout the North Sea, including coastal regions, can be inferred from consideration of co-tidal charts, from tables showing the mean range of tidal heights at selected coastal stations, and from current speeds shown at fixed stations on navigational charts.

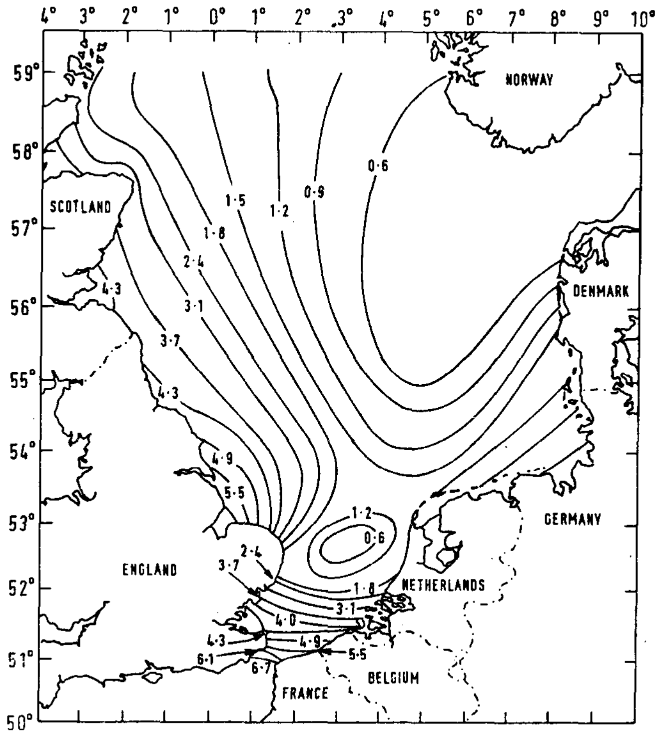

FIG. 2. Co-range chart of North Sea, showing range of mean spring tides (metres)

Co-tidal charts also show, by means of co-range lines, areas of the North Sea having the same range of tidal heights. Figure 2 shows the co-range lines for the North Sea. The salient features of this figure are the relatively small range of tides in the north and east, and the high range of tides in the south and west. Of particular note is the small range of tides adjacent to the entrance to the Skagerrak, and in the area between England and Holland. These areas surround the so-called amphidromic points. These observations are supported by examination of the range of tides predicted in tide tables at selected coastal stations (Fig. 3); for instance, the ranges of mean spring tides at stations in the Orkney Isles, in southern Norway, and in Denmark lie between 0·6 and 1·7 m, whereas on the coasts of Belgium, France, and the east coast of Britain the range of mean spring tides at 10 stations is between 1·9 and 6·6 m. The mean range of spring tides on the Dutch coast adjacent to the amphidromic point is about 1·7 m, but the range increases moving north-eastwards until, in the estuaries of the Elbe and the Weser, a tidal range of 3·2–4·0 m is recorded.

Where there is a large rise and fall of tide it may be inferred that there are strong tidal streams. This is borne out by examination of the tidal streams marked at selected stations on navigational charts (Fig. 3). The conditions of mixing and dispersal of wastes from coastal discharges are therefore likely to be more favourable on the western and southern coasts of the North Sea, than on the Norwegian, Danish, and Dutch coasts.

In addition to the immediate dilution and dispersal of a waste, broader hydrographic considerations have a bearing on the long-term distribution of wastes and their soluble components. This will be particularly important for conservative substances, i.e. metals, and nutrients such as nitrates and phosphates. The circulation pattern of the North Sea is complex[3–5], varying with depth and with the season, but its main characteristic is an anticlockwise pattern of movements. High-salinity water enters the North Sea from the Atlantic between the Orkneys and Norway and by the Straits of Dover. Run-off from the land produces estuarine and coastal water masses of lower salinity along the British coast and the coasts of the Low Countries, Germany, and Denmark. An outflow of low-salinity water from the Baltic enters the North Sea by the Skagerrak and flows northwards along the south Norwegian coast. It has been estimated[6] that about a third of the total volume of the North Sea is displaced each year by inflow from the Atlantic.

The layering of water in the North Sea, resulting from the density differences due to the salinity and/or temperature characteristics of each water mass, has an important effect on the biological processes of the sea, and on the rate of mixing and dispersal of wastes. The influence of air temperature on surface water temperature is greatest in the shallower coastal regions. According to Hohn[2], in winter the

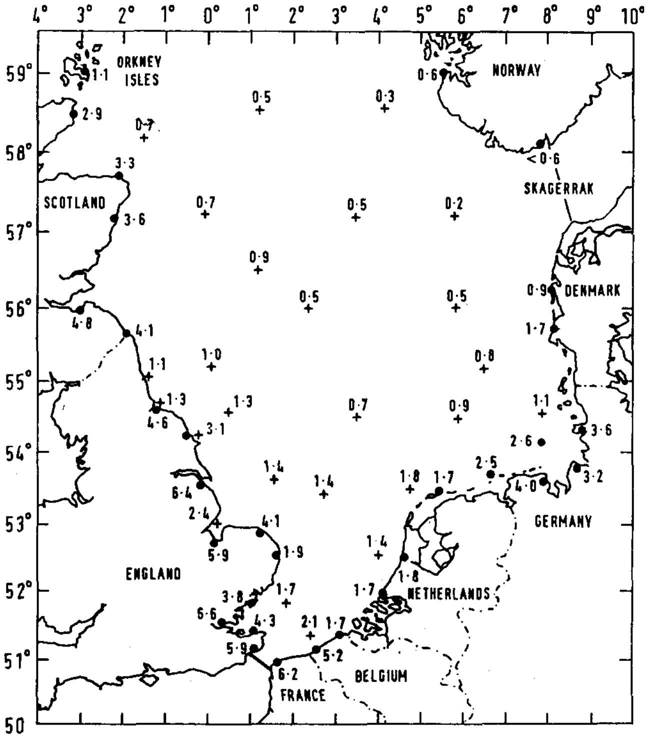

FIG. 3. Tidal range and current velocities in North Sea at mean spring tides. Range (metres) at coastal stations shown by circles, maximum velocity (knots) by crosses (*1 knot = 0·515 m/s*)

temperature of the deeper northern parts is about 7–8°C, whilst those of the shallower eastern side range from 2 to 5°C. In summer, maximum temperatures in the eastern area reach 16–17°C, and in the western area 13–15°C, but in shallower coastal regions of the southern North Sea, particularly where there are exposed banks or restricted circulation, temperatures in excess of 20°C often occur.

The North Sea, which is heterogeneous with regard to density, has been divided into several regions by Dietrich[7]. Except close to estuaries, the coastal regions of the North Sea together with the whole of the Southern Bight and the German Bight are homogeneous with regard to temperature and salinity all the year round. Adjoining this region and extending north and west, the sea is layered for part or whole of the year as a result of its temperature structure.

Adjoining the Norwegian coast, in the Norwegian Deep, stratification due to salinity differences occurs, there being a strong bottom layer with regular changes in salinity as a result of the entry of deep Atlantic water. Between the Norwegian Deep and the thermally layered area is found a transition zone where the water column is only weakly stratified.

In addition to this general structure, marked salinity gradients occur in most of the larger estuaries and in adjoining waters. Where there is marked stratification, whether due to salinity or to temperature differences, vertical mixing is reduced, and the dilution and dispersal of low-density wastes discharged from pipelines are markedly reduced, and furthermore their transport may be influenced mainly by the movement of the surface water. The stability of the water column also has marked effects upon the productivity of the waters.

In considering the long-term effects of sewage disposal into the North Sea, reference must be made to the significance of mineral nutrients which are present in sewage. Nutrients are important in that they are required by phytoplankton at the bottom of the food web. In some circumstances excess nutrients are undesirable because they may lead to excessive growth of phytoplankton, which can lead to deoxygenation of sea water or to the production of undesirable toxic species of phytoplankton. The distribution of the major nutrients, nitrates and phosphates varies with time, position, and depth, but the best assessment can be made when the numbers and activities of planktonic organisms are at a minimum. According to Johnston[8] the North Sea may be divided into several clearly defined areas. The coastal waters of the United Kingdom, Holland, Belgium, Germany, and Denmark are relatively low in free inorganic nutrients, but there is evidence of enrichment from land run-off and sewage outfalls, particularly in the southern North Sea. The nutrient regimes of Norwegian waters are complex due to the influence of the Baltic, fresh-water run-off, the entry of deep Atlantic water, and the complex salinity-temperature structure. The north central area of the North Sea is rich in nutrients derived from the oceanic water, but, because of layering, only those nutrients in the surface waters are utilized. The south central North Sea is shallow and well mixed and has intermediate levels of nutrients.

In considering the nutrient input from rivers and coastal discharges, the high productivity of estuaries and coastal waters suggests that locally the quantities of nutrients thus discharged are probably significant. However, the total amount of nutrients entering the North Sea from these sources, when compared with that entering from other sources, appears to be of little significance except perhaps locally. It has been calculated[9] that of the total input of nitrogen, about 79 per cent enters with the inflow of Atlantic water, 17 per cent is derived from rivers and discharges, and the remainder comes from precipitation. In a more recent and probably more comprehensive survey of discharges made by the International Council for the Exploration of the Sea[10], sewage outfalls are shown to contribute only about 7 per cent of the total input. Of this amount, about half is discharged into the shallower southern part of the North Sea adjacent to dense areas of population, most of it through the larger river systems.

Effects of Discharges from Coastal Outfalls

The main effects that have to be considered when sewage is discharged into coastal waters are those influencing amenities and fisheries. Amenity considerations, which include those related to health, will be discussed in some detail later. Briefly, the coastal waters of the North Sea are used extensively for recreational purposes because of their close proximity to large areas of population. Bathing beaches are found widely distributed along all coasts of the North Sea, wherever conditions are suitable. However, because of the relatively low water temperatures and the incidence of wind, rain, and cloud in northern areas, the most important recreational areas are found in the southern part of the North Sea. Nevertheless, during the summer periods some beaches in all areas are subject to very heavy use. The main features of coastal discharges which may adversely affect these activities incude the presence of floating solids and surface slicks, the discoloration of water, and the psychological effect where discharge points are obvious. The public health aspects of sewage discharges and their effects on bathing must also be taken into account.

In addition to bathing, other water-sports such as skin-diving, boating, and water-skiing are important recreations for a large number of people, and the recreational value of beaches and other coastal areas to biologists, naturalists, bird-watchers, etc., are being increasingly recognized; all these activities can be affected by ill-sited outfalls.

According to the survey of discharges made by the International Council for the Exploration of the Sea[10], most of the sewage entering the North Sea is untreated before discharge, although there are regional variations; for instance, about 60 and 80 per cent respectively of discharges from the cities of Rotterdam and London are treated before discharge.

The main effects that sewage discharges may have on fisheries occur in coastal waters. Within recent years, trawl fisheries have moved into shallow coastal waters, and the physical presence of pipelines or discharge points, including any buoys used to mark them, are serious obstructions which must be avoided. However, probably the main effect of coastal sewage discharges is upon shellfisheries. Molluscan shellfisheries of high commercial value, for species such as oysters, mussels, cockles, clams, etc., occur mainly in the estuaries of eastern Britain, the Low Countries, and Denmark[11]. Many of these species become actively polluted by faecal bacteria at considerable distances from the points of discharge, and the risks of illness following consumption are particularly high because, in many countries, such shellfish are eaten raw or only lightly cooked. Where commercial shellfish beds are polluted by sewage, extra burdens are placed on the industry, for such shellfish have to be relaid in clean areas—which are not always available or convenient—or be sterilized or subjected to a process of purification in tanks before sale.

Molluscan shellfish may also become unacceptable as a result of the accumulation of biotoxins. These toxins are produced by certain well-defined species of dinoflagellates, a microscopic group of planktonic organisms. Although these organisms are widely distributed in small numbers, when conditions become suitable (high temperature and excessive nutrient) they may multiply rapidly, and the concentrations of toxin in filter-feeding molluscs may become unacceptable to man. Biotoxin accumulation has occurred in Norwegian fjords[12], off the north coast of Britain[13], and in Holland[14]. There is some evidence that, in the first of these cases, the development of dinoflagellates was associated with excessive nutrients derived from the discharge of sewage effluents. Although the precise conditions which precipitate development of large numbers of dinoflagellates are not known, the discharge of sewage effluents into restricted coastal waters adjacent to molluscan shellfish is a cause for concern.

Fisheries for crabs and lobsters are found in coastal regions of east Britain and of Norway. Such areas have hard bottoms of rock or mixtures of shell, sand, and gravel. The location of sewage discharges, particularly of untreated sewage, in positions which will allow the settlement of organic matter will clearly alter the nature of the bottom and make the habitat unsuitable for these species. Fisheries for shrimps occur in the shallower coastal regions where the bottom is softer. These fisheries may also be affected by gross pollution of coastal regions.

Juvenile stages of certain fish, notably the flatfish, sole and plaice, are found in very large numbers in many coastal and estuarine areas[11]. These areas provide shelter and a substrate bearing suitable food for small fish before they migrate into deeper waters. Two other important factors are temperature and salinity. The high water temperature which occurs in summer in many shallower coastal waters allows rapid growth of juvenile fish and encourages the production of benthic food organisms, whilst the low salinity, particularly in estuarine areas, cannot be tolerated by many of their predators. Thus coastal and estuarine waters, although yielding relatively few fish of commercial size, are nevertheless of importance for several valuable offshore fisheries.

Recent years have seen the development of long sea outfalls discharging untreated sewage at considerable distances from the coast. Economically such schemes are particularly attractive for large urban catchments, and very substantial flows may result. In addition to the interference that this may bring to fishing activities, and to the effect on the sea bed of any deposited material, fish and shellfish are very susceptible to pollutants contained in sewage. In northern Europe, sewage from large urban areas usually contains a substantial proportion of industrial wastes, and the quantities of metals contained in the effluent may in some localities be significant, leading to the accumulation of unacceptable levels in commercial species of fish and shellfish as a result of their incorporation in the food web.

Discussion

From this brief review, it is evident that the North Sea, and particularly its coastal region, has a wide range of uses, many of which can be affected by the discharge of sewage from coastal outfalls.

The use of coastal regions for recreation is particularly great in the southern North Sea, mainly because of the proximity of areas with a high density of population there. With increasing leisure, many more people spend their holidays in coastal areas, which are thus becoming of increasing economic value. It is therefore important that sewage discharge into coastal waters should be undertaken in such a way that the value of these areas is not reduced. The value of the fisheries of the North Sea is expanding each year, and, with a rising demand for fish from traditional fishing areas, increasing amounts of fish and shellfish are being taken from the shallower coastal waters. Shellfish of high value, some of which are of particular importance because they can be cultivated, are the species mainly at risk from coastal discharges. Coastal discharges may affect fisheries in many ways, including alteration of the habitat, pollution by faecal bacteria, and the risk of the development of species of plankton whose toxin may be transmitted to man. Further away from the coasts the long-term effects of increased nutrient supplies associated with sewage discharges cannot be ignored.

Despite the risks that sewage outfalls might pose, the observed effects in the North Sea are less than expected because of the tidal regime and the free exchange of water with the Atlantic Ocean. In those areas where there are vigorous tidal currents, i.e. on the British, French, and Belgian coasts, the dispersion of wastes from coastal outfalls is rapid, whereas on the eastern side, where tidal currents are relatively weak, the mixing and dispersal of wastes from coastal discharges is less effective.

Although the discharge of sewage can lead to undesirable effects near to outfalls, in view of the large exchange of water with the Atlantic it seems unlikely that sewage discharge will in the long run lead to a general deterioration of conditions throughout the North Sea. However, care is needed to ensure that the capacity of coastal waters to receive sewage wastes is not exceeded.

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