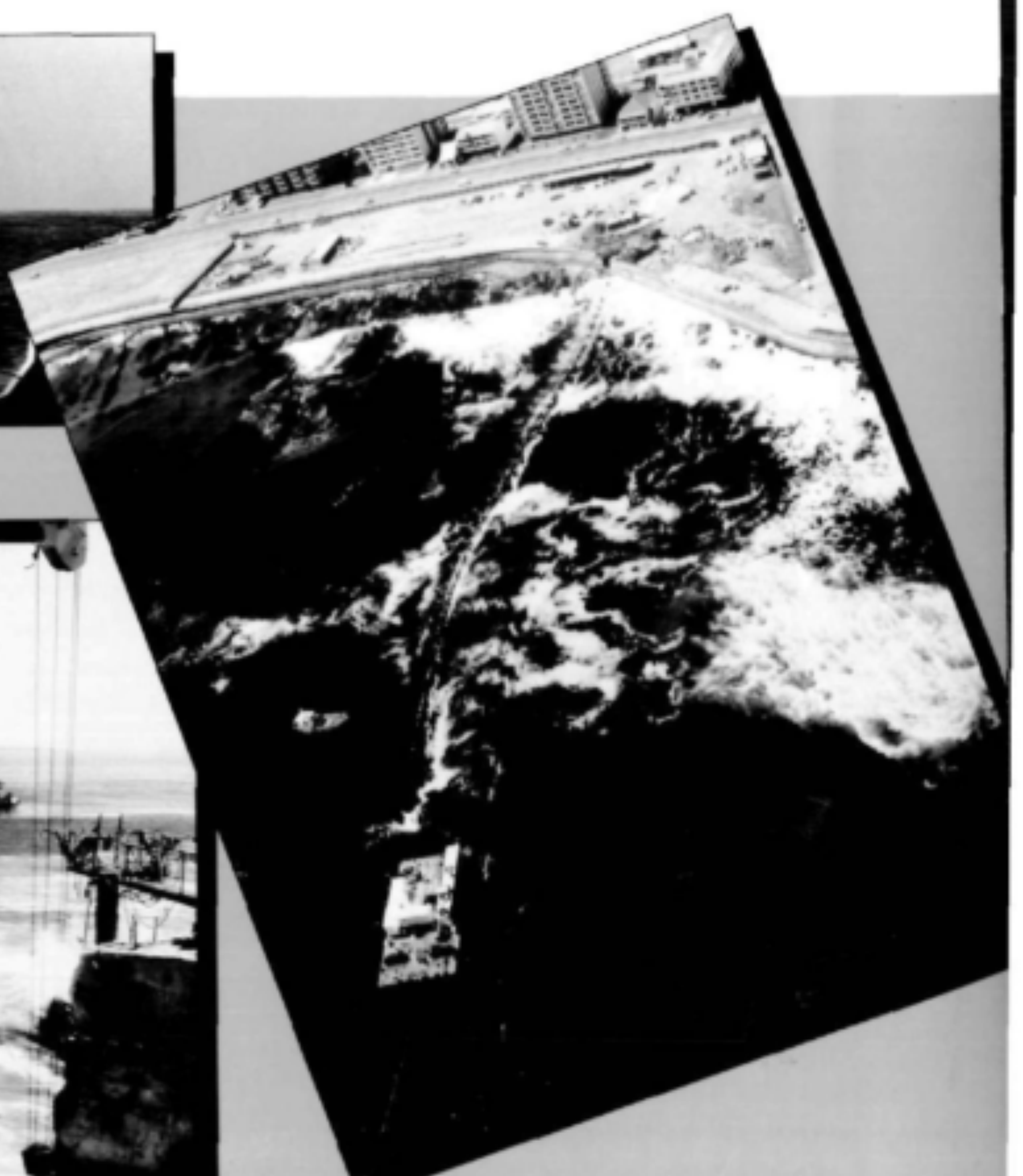
Guide for the Marine Disposal of Effluents through Pipelines



GUIDE FOR THE MARINE DISPOSAL OF EFFLUENTS

THROUGH PIPELINES

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FOREWORD

The disposal of domestic and industrial effluent to coastal waters has been receiving increasing attention in many parts of the world in recent years. Several coastal communities in South Africa have traditionally used the coastal waters adjacent to urban areas for disposal of their domestic and industrial waste water. These disposal practices have varied widely, from surf zone discharges of raw municipal sewage or industrial effluent to discharges of effluent through well designed offshore pipelines fitted with hydraulically efficient diffusers operating in water depths of more than 20 metres.

In recent years a very significant increase in population and attendant development along coastal areas has taken place, particularly in the Natal area and along the False Bay coastline.

More and more agencies are looking at the marine disposal option for the discharge of domestic and industrial effluents that result from increased coastal development. This is because of the known assimilative capacity of the ocean, the often limited space available for conventional sewage treatment facilities and the economic advantage for the coastal community.

Proper design of marine disposal systems is of the utmost importance since the marine flora and fauna, the sea water and the sea bed itself must be adequately protected. Under the most adverse oceanographic conditions an acceptable quality in terms of chemical, biological, bacteriological and physical criteria in designated areas of the sea, the sea bed or along the coastline must be maintained at all times.

The purpose of this guide is to collate as much information as possible in one volume to assist the designers of ocean outfall systems in meeting all the relevant criteria for proper design.

The reader should note that the guide is not a design manual, and should not be used as such. In this respect, therefore, it is recommended that the relevant expertise be consulted when specific designs of marine outfall sewers are required. The guide provides a great deal of technical information, however, and will be of considerable use to those considering the marine disposal option and to those engaged in the planning, design and operation of outfall sewers.

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PART 1 : INTRODUCTION

CHAPTER 1

PURPOSE OF THE GUIDE

by J E McGlashan

1.1 Introduction

The Water Research Commission has been involved in sponsoring research into the effects of the disposal of municipal waste water to the marine environment since 1980. This research has been directed primarily at establishing suitable and economical disposal routes for coastal communities for waste that would otherwise be disposed of on land or by incineration. Provided that marine disposal of waste water can be achieved without pollution of the marine environment, this route will, in many cases prove to be more economically viable than other disposal alternatives.

Encouragement of development of coastal areas by the Government in terms of its National Physical Development Plan has resulted in an increased awareness of the marine disposal option and, as a result, several organisations are involved in co-ordinating, financing or undertaking research in this area.

Discharge of waste water to the ocean results in dilution, dispersion and purification of the waste water. The degree of dilution and dispersion, however, depends on topographic and oceanographic conditions pertaining to the discharge site and will only be satisfactory if a properly designed system is used.

For the design of such a system, a thorough knowledge of the sea-bed topography and oceanographic data such as wind, waves and current data are essential. This basic data, coupled with theoretical dilution predictions for various pipeline and diffuser configurations and various chemical, biological and health constraints can be used to produce a number of different designs for a particular discharge. One of the most important aspects of such a design is to ensure that under the most adverse oceanographic conditions an acceptable quality of sea water, in terms of chemical, biological, bacteriological and physical criteria, is ensured in designated areas of the sea, the sea bed or along the coastline.

The purpose of this publication, therefore, is to collate as much information as possible in one volume, to assist the designers of an ocean outfall system. At present, the only South African guide available for the design of marine disposal systems is that published by the Natal Town and Regional Planning Commission in 1969 with the title "The Disposal of Effluents into the Sea off the Natal Coast" (Natal Town and Regional Planning Report, Volume 14). While this publication serves as a valuable and authoritative work in this field, there is a need for a new guide owing to the very sophisticated degree of specialisation reached in many of the areas involved and the substantial advances in mathematical modelling techniques and in computerisation. This new Guide is meant to serve alongside the 1969 Guide. Two other publications of note should be included at this stage. They are the proceedings of a workshop held in South Africa in May 1983 and published as the South African National Scientific Programmes Report No. 90 (1984) entitled "Pipeline Discharges of Effluents to Sea", edited by Lord, Anderson and Basson, and the South African National Scientific Programmes Report No. 94 (1984) entitled "Water Quality Criteria for the South African Coastal Zone" edited by J A Lusher. Both publications are particularly relevant to the designer of an ocean outfall system and should be used in conjunction with this Guide.

Also complementary to this Guide are two reports submitted to the Water Research Commission by the Division of Earth, Marine and Atmospheric Sciences and Technology of the CSIR in terms of contractual obligations.

The first of these is the report by Toms and Botes (1988) "Measurements of Initial Dilution of a Buoyant Effluent" and submitted as WRC Report No. 160/1/88. The second report is by Fijen (1988), "A Review of Marine Disposal Practice in South Africa" submitted as WRC Report No. 213/1/88. Both publications will be of particular value to the designer.

1.2 Use of this Guide

The Guide is divided into six parts, each with several chapters.

Part 1 serves as an introduction to the marine disposal of effluents through pipelines and touches on other disposal options.

Part 2 reviews the South African perspective with respect to oceanography of South African coastal waters and the physical, chemical and biological aspects. Also included in Part 2 is a brief review of existing and future coastal development in South Africa.

Part 3 deals with effluent characteristics (domestic and industrial) and the question of pollution and risk.

Part 4 consists of six chapters and deals with the detailed design of an ocean outfall. This section of the guide commences with the planning of the design, and continues with site and effluent investigations, design criteria, outfall hydraulics and diffuser design to ensure the desired dilution.

Part 5 deals with structural design considerations and construction techniques.

Part 6 concludes the Guide with post construction monitoring requirements. This includes environmental monitoring, pipeline stability and pipeline performance.

1.3 Definitions

1.3.1 Ocean outfall

An ocean outfall is a submarine pipeline originating on shore, which conveys municipal and/or industrial effluents to submerged discharge points located on or near the sea bed beyond the surf zone.

1.3.2 Initial dilution

Initial dilution is the process that commences the moment the effluent leaves a port of a diffuser, continues while the effluent rises (in the case of a buoyant effluent) and mixes with the surrounding sea water and becomes progressively more diluted as it moves further away from the point of discharge. It is considered to terminate either when the mixed effluent reaches the water surface or when the mixed effluent becomes stable at some intermediate water depth and levels out parallel to the surface due to the mixed effluent attaining the same density as that of a layer of colder sea water near the bottom (Grace, 1978).

1.3.3 Secondary dilution
(or subsequent dilution)

Secondary dilution is the process that commences once the mixed effluent reaches the sea surface or an intermediate equilibrium level and involves the physical spreading of the effluent into the surrounding sea water by diffusion. The process of secondary dilution is strongly influenced by prevailing ocean currents which tend to carry the effluent cloud with it in a process known as advectia (Grace, 1978).

1.4 References

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CHAPTER 2

EFFLUENT DISPOSAL OPTIONS

by J E McGlashan

2.1 Introduction

The geographical location of South Africa and the favourable ocean currents in the area make marine disposal along the 2 954 km coastline a very attractive option for municipal and industrial effluents. The South African subcontinent has nothing but vast ocean between it and the Antarctic. To the east of the country, some 7 500 km across the Indian Ocean, lies the western freeboard of Australia and to the west, some 6 000 km across the Atlantic Ocean, lies Brazil. Together with the generally favourable ocean currents, this makes marine disposal particularly attractive.

The main concentrations of urban and industrial development along the coast are situated at Cape Town, Port Elizabeth, East London, Durban and Richards Bay, and all but one of these centres use the marine disposal option for the disposal of untreated effluents. Several other options are available to coastal communities, however, and these include land disposal, incineration and reclamation.

2.2 Choice of Disposal Option

The choice of disposal option is governed by a number of factors:

(i) **Legislation** controlling water pollution in South Africa, in particular the Water Act (Act No. 54 of 1956) which is administered by the Department of Water Affairs and Forestry. Two basic requirements of the Act impinge on the choice of a marine disposal option or land-based option and these are that all public water abstracted for industrial or municipal use shall be returned to the stream of origin, and all effluents must be purified to prescribed standards. Any industry or local authority which is supplied with fresh water and wishes to discharge effluents to sea requires authority for such discharge through an exemption permit issued in terms of the Act.

(ii) **The type of effluent** for disposal. Whereas domestic sewage (settled or unsettled), certain industrial effluents and mixed domestic and industrial effluents can be considered for discharge to sea, other industrial effluents cannot be considered because of the toxic nature of the effluents. Indeed, many toxic industrial effluents can only be disposed of by special techniques. For the purpose of this Guide, however, only those effluents that may be safely disposed of to the marine environment are considered.

(iii) **The general physical constraints** of a particular option such as the limited space available for treatment and disposal on land or the general oceanology of the coastal waters, including geology and hydrography, currents, tides and the sensitivity of the marine environment.

(iv) **The economics** of the various options which naturally embraces all of the engineering decisions and requirements.

(v) **The degree of treatment required** before disposal to the ocean, to land or by incineration.

2.2.1 Treatment/reclamation

Domestic sewage and many industrial effluents can be reclaimed and renovated to any desired quality. Treatment of these effluents to remove the pollutants and to render the effluents fit for drinking purposes or any lesser quality requirements, effectively eliminates the need to discharge the bulk of the effluents. With the growth in urban and industrial complexes and the increase in the demand on the limited fresh-water resources in South Africa, direct and indirect reuse of effluent will become more and more of a reality. Coastal cities presently discharging effluents to sea may need to reclaim these effluents for reuse and discharge only concentrated portions of the original effluent.

Reclamation, therefore, has the effect of reducing the amount of effluent to be discharged but it increases the concentration of the effluent derived from the renovation process. A cleaner effluent implies a dirtier and more concentrated residue, and disposal of this residue to the marine environment will require a system designed specifically for such disposal.

2.2.2 Land disposal

In view of the requirements of the Water Act to return all public water abstracted for municipal or industrial use to the stream of origin, land disposal for the purposes of this Guide, only has bearing on the effluents produced in the process of treating municipal and industrial effluents to the required standard before returning them to the stream of origin. Municipal sewage treated at a sewage works to meet the required standards will produce screenings, grit and sludge, the nature and quantity of which will depend on the catchment, the type of industry within the catchment and the treatment process. Screenings can be highly offensive and are normally disposed of by burial or incineration. Grit can be similarly buried or spread on land. Sludge, however, presents a problem since it is produced in relatively large quantities and consists of most of the settleable solids in the sewage and some 60% of the suspended solids. It is a highly concentrated and offensive material and will generally need to be stabilised to render it inoffensive before it can be disposed of on land. If not disposed of in liquid form on land it will need to be thickened and dewatered before disposal. Depending on the nature of the raw incoming sewage to a sewage works and the method of removal of the sludge, the volume of sludge produced ranges from 1% to 3% of the incoming flow. A typical 100 000 m^3/d sewage works will, therefore, produce 1 000 to 3 000 m^3 of wet sludge per day.

Typically, before disposal on land, sewage sludge (raw primary or secondary sludge) will be thickened (by gravity thickening, dissolved air flotation thickening or by centrifuge thickening), followed by stabilisation (e.g. anaerobic digestion, aerobic digestion, thermal treatment or lime stabilisation), after which it will need to be conditioned (chemically or thermally) for dewatering (mechanically or on drying beds), whereafter it may be disposed of on land. Numerous treatment alternatives are available to process the sludge for a particular disposal method or to prepare the sludge for some form of beneficial utilisation in agriculture and horticulture.

2.2.3 Incineration

The objective of an incineration system is to destroy completely all the combustible elements, while minimising combustion imperfections and heat losses. Incineration is a high technology process and is now only considered in special circumstances where alternative disposal is not possible. It gained favour in many countries abroad in the years prior to the fuel crisis for the disposal of sewage sludge. Sewage sludge is difficult to combust completely because it is not homogeneous and it contains high levels of inert material and water.

Factors which have made incineration of sludge less attractive in recent years, apart from the fuel crisis, are the difficult nature of sludges produced from advanced treatment processes which are more difficult to dewater and thus require more energy to evaporate the excess water, and the increasing concern for air pollution. Incineration can significantly contribute to air pollution because of incomplete combustion and the formation of intermediate combustion products. As a result of this, incinerators must be equipped with scrubbers to meet air quality standards. Plants in other parts of the world and in South Africa have been closed down due to fuel requirements and air pollution problems.

2.2.4 Marine disposal

The ocean, if viewed as an environmentally acceptable option to which waste may be discharged may offer a reliable, low-cost option for coastal communities. Each environmental medium - the ocean, land, and air - has its own particular characteristics to absorb these wastes and its own particular needs for its protection. Risks of adverse environmental effects on the ocean are minimal when the waste discharged has low levels of toxics and can be diffused by currents. Provided that the quality of the sea water does not deteriorate beyond acceptable levels due to the disposal of wastes into the ocean, then the ocean can safely be viewed as a disposal option. The land has long been used for the disposal of a variety of wastes, and in some instances has suffered irreversible harm. Strict control and responsible management of waste disposal to the ocean, whether by dumping at sea, surf zone discharges or discharge through deep sea outfall sewers, will ensure protection of this medium and prevent health hazards, loss of amenities and deleterious effects on the marine fauna and flora.

2.2.4.1. Dumping at sea

Dumping at sea involves the physical transportation of waste material to a designated and licensed disposal site in the ocean. Transportation is usually by means of a ship or barge into which the waste is loaded and then released from the vessel at the designated dumping site.

The nature of the waste dumped (usually heavier than sea water) and the prevailing currents in the area will determine the movement of the discharged material once it has left the vessel. These factors will determine whether the waste will rapidly settle to the sea bed or be diffused over a wide area and hence spread itself on the sea bed. In the United Kingdom and elsewhere in the world, extensive use is made of the dumping of treated and untreated sewage sludge in the ocean. In South Africa, dumping of sewage sludge does not occur although the option has been considered by coastal communities as a possible alternative for sludge disposal.

Waste material that is dumped at sea in

various parts of the world include harbour dredgings, industrial wastes and radioactive wastes in liquid and containerised form.

2.2.4.2 Surf zone discharges

Surf zone discharges occur at numerous points along the South African coastline. The majority are discharges of treated sewage or industrial effluents which comply with the requirements of the General Standard. The remaining discharges are of untreated sewage and industrial effluents, the effects of which are regularly monitored so as to ensure that no gross pollution occurs. No doubt these discharges will be upgraded in time, especially in those cases where the discharges increase substantially in volume.

As the name implies, surf zone discharges are discharges into that region of the sea which, together with the region just seaward of it, is known as the nearshore region. Water movements in this region are caused primarily by wave action. Effluents discharged directly into this region, therefore, become part of this body of water and move with it.

Discharge to this zone are by pipelines which terminate in the surf zone, sometimes via a diffuser, or by watercourses such as canals and storm-water courses.

2.2.4.3 Ocean outfalls

An ocean outfall is the term used to describe a system whereby effluents are discharged to the ocean. An ocean outfall system may consist of a shore based plant, such as a sewage treatment plant, a pump station or a holding tank, a pipe or outfall resting on or under the sea bed to convey the effluent some distance away from the shore, and a means of diffusing the effluent into the ocean.

Ocean outfalls are used for the disposal of treated and untreated sewage, industrial effluents, sewage sludge and storm water. These effluents can be positively or negatively buoyant. The outfall is usually thousands of meters in length and terminates at a water depth of tens of meters. A diffuser is the last section of the outfall and has a number of discharge ports along its length from which the effluent is discharged. These ports are spaced along the diffuser to maximise the initial dilution in the ocean and may be staggered to discharge alternately to the left and to the right of the pipeline.

A buoyant effluent discharged from the diffuser through the discharge ports (e.g. sewage, storm water and most industrial effluents) will tend to rise and mix with the ambient sea water through which it is rising. The initially highly concentrated buoyant effluent discharged from the port thus becomes progressively diluted with sea water and thus more dense during its upward movement. This movement continues to the sea surface, or to some intermediate level where stratification of the sea water prevents the now diluted and denser effluent from rising any further due to little or no density difference existing between the effluent and surrounding sea water.

Initial dilution of the effluent is considered to terminate when it reaches either of these two levels. Thereafter, the process of diffusion takes place in which the diluted effluent is carried with the prevailing currents, and further dilution takes place as a result of eddy diffusion. Certain effluents, such as sewage with its microbial population, are further reduced in concentration by natural processes such as die-off or disappearance of the bacterial and viral populations.

An effluent that is negatively buoyant in sea water would not tend to rise due to the negative buoyancy and would need to be jetted out of the discharge ports to make use of the kinetic energy to enable active mixing with sea water to take place, aiding dispersion.

Unsettled sewage, i.e. raw sewage which still contains its settleable solids load, may be regarded as a buoyant effluent since the density of unsettled sewage is virtually the same as settled sewage.

Whether settled or unsettled, raw sewage will need to be processed before discharge through an ocean outfall system. After screening of the sewage to remove coarse material, two components in particular need to be removed, the first is grit which would otherwise accumulate as sediment in the outfall and thereby affect the efficiency of the system, and the second is floatable material. This material will rise to the surface and form a slick that would be at the mercy of the wind and waves and could, therefore, be blown shorewards. It would also be unsightly in the ocean and serve to attract scavengers such as seagulls.

Methods are available to remove these materials and include grit channels and classifiers. For the removal of floatable material, settling basins and screens may be used (these would invariably also remove a portion of the settleable solids). In order to operate effectively, an ocean outfall system would need to be designed for the specific effluent to be discharged.

PART 2 : THE SOUTH AFRICAN PERSPECTIVE

CHAPTER 3

REVIEW OF GENERAL OCEANOGRAPHY OF SOUTH AFRICAN COASTAL WATERS

3.1 Geology and Hydrography

by R H De Decker and M W Woodborne

3.1.1. Introduction

The continental shelf off South Africa is one of the most variable in the world. As a result, the details of its geology and hydrography change considerably as one moves around the margin and local factors vary in their importance. One of the few global phenomena to affect the margin is the series of major fluctuations of sea level that accompanied the Ice Ages or glacials during the last two million years. For most of each glacial, the sea level lay about 130m below its present level, because much of the evaporated sea water became trapped as snow and ice in the polar regions and was unable to replenish the sea. The consequence, for the continental shelves of the world, was that the coastline, during each glacial, lay along the 130 m isobath (depth contour). However, because the bathymetry of the South African margin is so variable (see subsequent section), the horizontal distance that the glacial coastline lay seaward of the present coastline was equally variable.

At the end of the Last Glacial, which ended about 20 000 years ago, the "latest" post-glacial rise in sea level, termed "the Flandrian Transgression", began to reflood that part of the continental shelf that had become exposed during the previous fall in sea level. River valleys that had extended their courses to the Last Glacial coastline were flooded and when the coastline reached its present position the former valleys, termed "palaeovalleys", were infilled with sediment transported by the river (termed "fluvial" sediment).

Any coast-parallel dune cordons that formed on the coastal plain as sea levels fell during the start of the Last Glacial usually contained fragments of shell made of calcium carbonate, mainly the mineral calcite. As the sea level continued to drop, the older dune cordons were left farther and farther inland, where they were affected by rain, which is always slightly acidic. As a result, some of the shell fragments dissolved slightly, enriching the pore waters between the grains in dissolved calcium carbonate. On evaporation of the pore water, however, a calcite cement was precipitated between the previously loose (or "unconsolidated") grains. In this way, cordons of originally unconsolidated dune sand were transformed into calcite-cemented sandstone. Because such sandstones or "arenites" contain substantial quantities of calcium carbonate, they are termed "calcarenites". As a result of this process, the Flandrian Transgression, in certain areas, was confronted with a series of resistant calcarenite cordons, which it had to destroy on its way back to the present coastline. The original size of such cordons is best seen onshore between Wilderness and Knysna, and many of the so-called "reefs" near this part of the coast are coast-parallel "stumps" of eroded dune cordons.

During the Flandrian Transgression, the high-energy surf-zone advancing steadily landwards between the 130 m isobath and today's coastline, deposited either "well-sorted" sands (with a narrow range of sizes) or even gravels. As such sands were left behind by the landward-advancing surf-zone they were equally steadily covered by greater and greater depths of water and were thus gradually protected from disturbance by wave action. Given a local supply of silt or clay ("mud" being a "sack" term for silt and clay), for example off a major river, such sands can be covered by a layer of first silt and finally clay as the water became deep enough to allow the grains to settle to the sea floor. This creates a "fining-upward sequence" that is typical of sediments deposited in the wake of a transgression. However, if no major river reaches the coast, locally, then the sand laid down by advancing surf-zone is not covered by younger mud and one finds vast areas of the shelf, particularly on the eastern Agulhas Bank, that are covered by drowned surf-zone sand. Because the sands are today far removed from the present surf-zone, they are termed "relict" sands, because they are relicts of an earlier surf-zone that has long since left the scene. In contrast, sand in today's surf-zone is termed "modern" as it is still within its formative environment.

Having focused mainly on former sea levels below that of today, one should realise that sea level, at times, was higher than that of today. On attacking a rocky coastline over geological periods of time, wave erosion associated with a temporarily stable interglacial sea level, is able to undercut cliffs and to cause cliff retreat, leaving a *wave-cut platform* in its wake. This will be exposed during any subsequent drop in sea level, but, if the following rise in sea level does not quite return to the same level at which the cliff was eroded, then the wave-cut platform of an earlier interglacial will remain exposed above present sea level. A good example of this is the extensive Green Point Common at the foot of Signal Hill in Cape Town. Flights of such wave-cut platforms are preserved in Namaqualand (where the gravels on them are mined for diamonds) and in the immediate hinterland of Algoa Bay.

3.1.2 Geology of South Africa's coastal plain and inner-shelf

3.1.2.1 Bedrock geology

Unlike the English Channel, recently the focus of attention as the "Chunnel" was completed, where the sea drowns rock formations extending from England right across to France, the onshore geology of South Africa, in general, does not extend very far seawards. Along much of our coastline the onshore formations are covered by younger rocks seaward for about 10 km.

Given the present, geologically temporary, position of the sea level, the pre-Mesozoic (older than 125 million years) outcrop off our coastline is narrow (< 10 km) between the Orange River and Elands Bay. Precambrian rocks (>600 million years old) crop out between the Orange River and the Olifants River, ranging from the highly resistant Namaqualand Gneiss, similar to granite, to the very soft Nama schists, originally mudstones, found immediately north of the Olifants.

Resistant Palaeozoic sandstones of the Table Mountain Group, intermediate in age between the Precambrian and Mesozoic rocks, are found between the Olifants and Elands Bay.

The pre-Mesozoic outcrop is generally much broader, although to highly variable extent, between Elands Bay and Cape Infanta (east of Cape Agulhas). Shales and sandstones of the Precambrian Malmesbury Group crop out on the floor of St Helena Bay, between Dassen Island and Robben Island and in the eastern part of False Bay. Similar shales of the Palaeozoic Bokkeveld Group are found between Cape Hangklip and Danger Point and between Cape Agulhas and Cape Infanta. The more resistant Cape Granite, of early Palaeozoic age, crops out between St Helena Bay and Dassen Island, between Robben Island and Hout Bay and in the western part of False Bay. Table Mountain Group sandstone crops out again between Hout Bay and Cape Point, in unusual dagger-like ridges southwest of Cape Hangklip and Danger Point and in an unusually wide (40km) outcrop between Danger Point and Cape Agulhas. Only off Cape Agulhas is there an extensive outcrop of pre-Mesozoic rocks in the Agulhas Arch, where mainly Table Mountain Group sandstone is found SSE of Cape Agulhas up to 200 km offshore. Similar pre-Mesozoic arches are found under the Agulhas Bank off other capes like Cape Infanta, but they are buried by younger (Mesozoic) sediments.

Along the south coast, east of Cape Infanta, which itself consists of Table Mountain Group sandstone, all the capes as far east as Cape Recife are of the same resistant sandstone. The intervening Bokkeveld shales generally lie well below sea level and are covered by Quaternary (<2 million years) calcarenites, which form cliffs, themselves, along much of the coastline, for example between Cape Infanta and Still Bay. The pre-Mesozoic outcrop between Plettenberg Bay and Cape St Francis (the Tsitzikamma coast) is a narrow, but unusually long outcrop of Table Mountain Group sandstone.

The east-west-striking ranges of the Cape Fold Belt, dominated by Table Mountain Group sandstone, are not found north of Kleinemonde near Port Alfred and narrow outcrops of pre-Mesozoic Karoo Sequence sediments (shales and sandstones) are found northwards to Mbotyi in the Transkei. Palaeozoic Natal Group sandstone and Basement granite line the coast between Mbotyi and Scottburgh (southern Natal). Most of the Natal coastline consists of Quaternary formations with no pre-Mesozoic outcrop whatsoever.

3.1.2.2 Modern surficial geology (Sediments)

Sand, consisting chiefly of quartz and subordinate quantities of shell fragments, dominates the inner shelf seawards from the surf-zone to wave base, defined as the depth of water equivalent to half the wavelength of the average deepwater wave. Waves being by nature variable, the actual depth of wave base will vary continually. However, off the Orange River, deltaic sand normally extends to 40 m, beyond which mud is found. Thus, given a full range of grain sizes, as off the Orange River, sand grades to silt near the 40 m isobath. Recent studies have shown that the extensive mudbelt that stretches from just north of the Orange River southwards to St Helena Bay, is only silty near the Orange Delta. For most of its length it is rich in clay, which has a deeper wave base of about 70 m under the same wave conditions. The seaward limit of this mudbelt is about 120 m.

Helpful terms have been coined for inner-shelf sand and mud zones, namely the Nearshore Modern Sand Prism and the Shelf Modern Mud Blanket. Off South Africa, the thickness of the Shelf Relict Sand Blanket that underlies the Shelf Modern Mud Blanket and overlies most of the middle and outer shelf seawards to the shelf break, is usually less than 1-2 m thick. As a result, bedrock often crops out seaward of the Mud Blanket. In contrast, the two modern deposits, flanking the coast, are often tens of metres thick. However, their thicknesses are highly variable and detailed shallow-seismic profiling is essential prior to any engineering operations.

In general, the Nearshore Modern Sand Prism is thickest off sandy coastlines and thinnest off rocky coastlines, any beach being merely the landward feather edge of the prism. A local source, such as the Orange River, obviously nourishes the prism and longshore drift then distributes sand along the coast from the major sources. Apart from the Modern Mud Blanket south of the Orange, there is a similar one stretching from the mouth of False Bay eastward past Cape Agulhas and Cape St Blaize to Cape Seal near Plettenberg Bay. This has already been encountered by the Mossgas pipeline that crossed the Mud Blanket en route to Vleesbaai. The bearing strength of the relatively narrow Mud Blanket was considerably lower than that of the Shelf Relict Sand Blanket on which it rested for most of its course.

Off the west coast, between the Orange River and Cape Point, the relict sand consists of drowned surf-zone sand under the modern mud and immediately seaward of it. Farther out to sea, but still on the middle shelf, it is overlain by a shelly gravel, about 10 cm thick that is difficult to penetrate with coring devices and could give the impression of bedrock when a drill refuses to penetrate farther. This "false bedrock" problem is so severe that it hampers the extensive diamond-prospecting operations on the middle shelf. As a result, De Beers Marine have gone to considerable expense to modify former drilling ships, from the Gulf of Mexico, to penetrate to true bedrock. In places, a semiconsolidated kaolinitic clay overlies bedrock and is extremely difficult to penetrate with conventional methods. The shelly gravel is usually overlain by less than a metre of unconsolidated foraminiferal ooze, consisting chiefly of the sand-size shells (or tests) of the planktonic foraminifera that rain down on the sea floor from the middle shelf out to the shelf break, down the continental slope to the upper continental rise. In places, the shelly gravel is overlain by less than a metre of *Greensand*, consisting of sand-size pellets of an intergrowth of the dominant green mineral, glauconite and a minor amount of the phosphate mineral, francolite. Extensive deposits of this Greensand are found on the middle to outer shelf, particularly off Saldanha Bay.

On the western Agulhas Bank, between Cape Point and Cape Agulhas, there is no information, to date, on the stratigraphy of the surficial sediments, but *Globigerina Ooze* dominates the middle and outer shelf, patches of Greensand having been mapped near the shelf break. Due to the pipelaying activities associated with Mossgas, the eastern Agulhas Bank's surficial stratigraphy is quite well known. Drowned surf-zone sand of the Shelf Relict Sand Blanket on the middle shelf consists of quartz and significant amounts of shell fragments. On the outer shelf, however, the proportion of quartz dwindles rapidly seawards, so that the outer shelf sand consists predominantly of coarse relict shell fragments, intermixed with foraminiferal tests. The powerful

Agulhas Current apparently hinders the development of a modern *Globigerina Ooze* on the outer shelf.

Off the east coast, the above scenario is only valid in coastal embayments of varying scales. For example, off the Tugela River, there is a relatively small Modern Mud Blanket. An even smaller patch is located off the Mzimvubu River in a smaller embayment. In general, the northward longshore drift, driven by swells from the Southern Ocean, distributes sand along the Nearshore Modern Sand Prism. However, the powerful Agulhas Current sweeps most modern mud southwards from the mouths the numerous summer-flooding rivers along the shelf to be deposited either on the outer shelf off Algoa Bay or in the adjacent ocean basin, the Natal Valley. In addition, the Shelf Relict Sand Blanket is also swept along, generally southwards, by the Agulhas Current. Unusual asymmetric submarine sand-dunes, up to 17 m high, have been surveyed using echosounders and side-scan sonar. Eddies, often very unstable in their position and strength, can, at times, reverse the transport direction of these sandwaves. Practical experience of similarly active, but tidal, sand-dunes in the English Channel off NE France and The Netherlands is relevant when planning pipelines in such areas. The relict sand in the dunes consists predominantly of coarse shell fragments, like those on the eastern Agulhas Bank. Bearing in mind that this ocean-current-dominated shelf off our east coast appears to be unique and that the velocity of the Agulhas Current increases seawards across the shelf, note that an unusual relict gravel characterizes the outer shelf immediately landward of the shelfbreak along the seaward edge of the belt of mobile submarine sand-dunes. This gravel consists of white, calcareous nodules built by coralline algae. Being plants requiring light, these *algal nodules* formed during glacial regressions, when they were covered by wave-agitated shallow water, hence their rounded shapes.

The surficial sediments likely to be encountered during pipelaying operations on the shelf around South Africa are thus highly variable in their thickness, texture, composition and present dynamic environment. Short pipelines will be laid entirely within the Nearshore Modern Sand Prism, but the longer pipelines, exemplified by the Mossgas pipeline, extend, for the most part, across the much more variable Shelf Relict Sand Blanket and usually have to cross the obstacle of the Modern Mud Blanket, with all its attendant engineering problems.

3.1.2.3 Physiography of the coastal zone

Our tourist literature emphasises the beauty of the South African coastline. This aesthetic reaction is derived from the great variety of coastal physiography, which, in turn, implies that the landfall of any pipeline must be individually surveyed as local conditions vary considerably.

There are certain types of coastline that pose major problems for the installation of pipelines. Cliffs of resistant, usually geologically old, bedrock are a major problem, for example the cliffs of the Tzitsikamma coast between Plettenberg Bay and Cape St Francis. According to the resistance, locally, of the rock type there may or may not be a wave-cut platform, attracting various levels of development requiring effluent outfalls. The Cape Peninsula is a case in point. Wave-cut platforms are not found along the granite coastline between Bantry Bay and Hout Bay and are poorly developed along the sandstone coastline between Kommetje and Cape Point. In contrast, the extensive wave-cut platform of Sea

Point and, particularly, Green Point Common, north of the Sea Point Contact, where the resistant Cape Granite gives way northwards to the less resistant Malmesbury Group greywackes (muddy sandstones), has attracted a considerable urban population. This has created the well-known dilemma for coastal engineers, whether to site a sewage works on the populated wave-cut platform or whether to excavate the bedrock of the inner shelf to protect it from the high energy of the wave environment responsible for cutting the platform in earlier times. The situation is exacerbated by the near absence of a Nearshore Modern Sand Prism, chiefly due to the lack of major rivers along the isolated, narrow Cape Peninsula.

In general, the cliffed coastline of South Africa is almost uninhabited. Certain stretches of the Namaqualand coastline house isolated diamond-mining or fishing communities, but even these cluster in small embayments between the major cliff zones. The Cape Peninsula's Atlantic coastline has already been discussed, but its False Bay coastline illustrates the same points, the higher the cliffs the less the development and the less need for major outfalls. A detail of the False Bay coastline is that the east and west shores consist of geologically old formations (Malmesbury, Cape Granite and Table Mountain Sandstone), whereas the northern coast, between Swartklip and Mnandi, is formed of cliffs cut in geologically young, variably consolidated *aeolianites* (the geological term for "dune-rock"). The remaining relict coastal dunes on the southern Cape Flats, especially in and around Mitchell's Plain, are but a remnant of a much larger glacial-period dunefield. The same argument follows for all the remnant relict dunefields, along our coastlines, the eroded, drowned stumps of which are found as aeolianite reefs on the inner shelf. These present obstacles to pipelaying activities, but they are, fortunately, easily detected with shallow-seismic and side-scan-sonar surveys.

Between False Bay and Cape Agulhas, there are extensive stretches of a narrow wave-cut platform cut across resistant Table Mountain Sandstone and backed by steep mountains (former cliffs). The coastal resorts of Betty's Bay, Kleinmond, Hermanus and Gansbaai are built on this platform, the rocky edge of which forms cliffs, 20 m high at Hermanus and Gansbaai. Between Cape Agulhas and Cape Recife, high cliffs of resistant Table Mountain Sandstone are found on the individual capes that characterise the south coast, but high aeolianite cliffs also occur along certain stretches, between Cape Infanta and Ystervark Point (just west of the Gouritz River) and between Wilderness and Knysna. Due to the milder climate and the fine local scenery, the sandstone capes often attract urban development, e.g. at Mossel Bay on Cape St Blaize. East of Mossel Bay there is a high (150 to 200 m) coastal platform, bevelled chiefly across Table Mountain Sandstone. This platform is fringed by high coastal cliffs between Groot Brak and Wilderness, between Knysna and Cape Seal, south of Plettenberg Bay and between Keurboomstrand and Cape Francis, east of Plettenberg Bay along the Tzitsikamma coast. These latter cliffs are the most formidable in South Africa, but have attracted only minor holiday resorts to date.

Along the east coast, Woody Cape, on the eastern edge of Algoa Bay, is cut into aeolianite, but most of the coast of the Ciskei and the southern Transkei is cut into Karoo-age rocks younger than those of the Table Mountain Group that dominate the south coast. The Palaeozoic

Natal Group sandstone and the underlying Basement granite forms thew coastline of the northern Transkei and Natal's misnamed "South Coast". Convex, grass-covered hillsides form much of the coastline from Cape Padrone to Amanzimtoti, cliffs only being a feature in the Port St John's region. Between Amanzimtoti and Durban, aeolianite cliffs are found again, along the seaward flank of an extensive ridge.

Having dealt with "hard" coastlines, we turn now to "soft" coastlines. Much of the coast between the Orange River and the Olifants River is semi-arid and, therefore, little sediment is available for the formation of dunes. In addition, the strong, prevailing southerly winds blow sand, at the mouths of particularly the ephemeral rivers, into narrow plumes of dunes moving inland obliquely from the coast. In many parts of northern Namaqualand, however, an older generation of decalcified, loose dune sand overlies a succession of gravel-bedecked wave-cut platforms or "terraces", the famous diamondiferous "raised beaches". Between the Olifants and Berg Rivers, there are longer stretches of beaches, flanked by relatively low barrier dunes. This is best seen beside the log-spiral St Helena Bay, the dunes increasing in height northwards towards Cape Deseada, a headland of Table Mountain Sandstone. The coastal plain inland of St Helena Bay is wide and lowlying, perhaps one of the widest in South Africa. It is underlain by the less resistant shales of the Malmesbury Group. To the south, between Dwarskersbos and the mouth of the Berg River, the coast is actively prograding, one of the few places in South Africa, a succession of beach ridges being the evidence.

West of St Helena Bay to Cape Columbine and southwards past the mouth of Saldanha Bay to the tip of the Langebaan Peninsula, the coast is rocky (Cape Granite), but farther south to Table Bay the coast, again underlain by Malmesbury shales, is sandy, the two types of coastal dunes (coast-oblique plumes and coast-parallel barriers) both being prominent. The plumes start just north of Yzerfontein and just north of Duynefontyn, near the Koeberg Power Station. Two peculiarities characterize this region. The coastal plain inland (NE) of Saldanha Bay is underlain by a highly resistant calcrete horizon, which forms low cliffs capped by dune plumes beside the bay. In addition, between Matroos Bay and the Koeberg Power Station there is an unusual section of sandy cliffs, the base consisting of decalcified older dunesand capped by intermittently calcretised calcareous dunesand. This cliff reveals the sequence that underlies the major dune plume between Duynefontyn and the new town of Atlantis.

The shore of the log-spiral Table Bay is, generally, lowlying, although, like beside St Helena Bay, the barrier dunes increase in height downdrift towards Bloubergstrand, which is more exposed to the coastal winds. The only significant beaches on the Cape Peninsula's Atlantic coast are at Hout Bay and between Noordhoek and Kommetje. At Hout Bay the beach is backed by low barrier dunes and the small Disa River, the southerly wind stripping sand off the NW end of the beach to form a small plume that transports sand to Sandy Bay near the pocket beach of Llandudno. "Long Beach", south of Noordhoek, is distinctive in being flanked by an extensive and seasonally ephemeral backshore lagoon. Here, a very lowlying coastal plain extends across the Cape Peninsula to Fish Hoek on the False Bay coastline. Drilling has shown that this fault-controlled lowland is underlain by up to 100 m of unconsolidated sediments, unusual for the South African coastline.

The northern shore of False Bay has two stretches of sandy coastline, in the northwest near Muizenberg and in the northeast near Strand, again underlain by Malmesbury shales. Both areas support large populations on their coastal plains, but local drainage from high-rainfall areas in the nearby mountains has formed extensive vleis due to ponding behind coastal dunes. A well-developed wave-cut platform, covered by a veneer of sediment, extends from Strand and Gordon's Bay to the local foothills. Remnants of this platform are seen at Kommetje, Green Point Common and on the northern flank of Blouberg and can probably be correlated with one of the lower and younger terraces of Namaqualand.

Between Cape Hangklip and Cape Agulhas, the long beaches and the dunes associated with the estuaries of the Bot and Klein Rivers are aligned parallel with the oncoming southwesterly swell, so that longshore drift is minimal. The dunefield south of the Klein estuary covers most of the hinterland of Walker Bay. East of Cape Agulhas, towards Cape Infanta, we encounter another extensive coastal plain. In this case, the plain is underlain by the less resistant shales of the Bokkeveld Group, this pattern continuing eastward to Cape St Francis. Farther east to Cape Padrone, mudstones of Cretaceous age often underlie the coastal plains inland of the major bays. In general, the barrier dunes are relatively low, but reversing, coast-parallel winds create transverse dunes with their crests perpendicular to the coast. The Alexandria Dunefield beside Algoa Bay is the most extensive of this type and has been studied intensively recently. Plettenberg Bay, in contrast, is backed by a simple, vegetated barrier dune, as is St Francis Bay. The hinterland of Algoa Bay, like that of northern Namaqualand, preserves a flight of wave-cut platforms, most of which are protected by heavily calcretized sediments. They are best observed between Port Elizabeth and the Sundays River, the Alexandria Dunefield and its older (Tertiary and Pleistocene) equivalents obscuring the platforms farther east.

Sandy coastlines are less extensive along the east coast until Mtunzini is reached north of Durban. From Mtunzini northwards to the Mozambique border at Ponta do Ouro, we find the most extensive coastal plain in South Africa, that of Zululand. The long beaches are characteristically backed by vegetated barrier dunes up to 200 m high, often ponding large rivers so that large coastal lakes are formed, Lake St Lucia being the prime example. Seaward-dipping strata of Cretaceous, Tertiary and Quaternary age underlie this wide plain.

Having stressed the variability along our coastline, let us turn again to a common denominator. In a period concerned with the possibility of "global warming", with its associated rise in sea level, albeit less than one metre, we should remember that in geologically recent times, 20 000 years ago, sea level was as much as 130 m below present sea level. This caused all our coastal rivers to incise their beds more deeply as they sought to adjust to the lower base-level. This incision varied in its effectiveness due to variations in the resistance of the underlying bedrock and in the local rainfall regime. At the end of the last glacial period the Flandrian Transgression then reflooded the newly-incised valleys, so that all our estuaries sit atop sediment infilling palaeovalleys of variable depth. Bigger palaeovalleys can be expected when the rivers are large, when rainfall is high and when bedrock is less resistant. However, some surprises may be encountered. For example, the Berg River has a smaller palaeovalley than that beneath Verlorevlei inland of Elands Bay on the west coast. Clearly, today's semi-arid climate must have given way to a wetter climate during the glacial period and, perhaps, the Berg River may, previously, have reached the sea via Verlorevlei.

3.1.3 Hydrography

3.1.3.1 Bathymetry of the South African coastal zone

The bathymetry of the South African margin is very variable and will be discussed, as above, moving from the west coast to the east coast. Between the Orange River and Hondeklip Bay in Namaqualand, the shelf is up to 180 km wide. The shelfbreak lies in a depth of 200 m off the Orange, but deepens to 500 m to the south. The inner shelf bulges seaward off the Orange River, where a submarine delta has developed and has prograded over a rocky Precambrian basement. South of the Orange, where sand blankets the delta front off the mouth, the 10 km-wide, seaward convex, inner shelf is usually rocky with isolated patches of sediment, up to 30 m thick, out to a depth of 70 m. A Shelf Modern Mud Blanket, up to 60 m thick, lies along the boundary between the middle and inner shelf in depths of 70-120 m, seaward of which the middle and outer shelf have a relatively thin veneer (0-3 m thick) of sand and gravel (the Shelf Relict Sand Blanket). The Tertiary limestones and phosphorites forming the bedrock of the middle and inner shelf often crop out with a relief of several metres.

Between Hondeklip Bay and the tip of the Agulhas Bank, the continental slope becomes steeper and both submarine slumps and canyons become important. The largest canyons are the Cape Canyon off Saldanha Bay and the Cape Point Valley. The shelf break is deep, in the vicinity of 400 m and this section of the shelf is at its narrowest (60 km) off Cape Point. The chief feature of the outer shelf is Childs Bank off Hondeklip Bay and a Pleistocene delta lies on the middle shelf off the Olifants River. The generally rocky inner shelf widens to about 30 km south of Elands Bay and fringes the coast as far as Cape Agulhas. The rocky bottom within this wide inner shelf is generally of high relief (several metres) and geological mapping is possible, because the various rock types have each have a distinctive signature. Shales of the Malmesbury and Bokkeveld Groups have a relatively subdued relief, whereas Table Mountain Sandstone strata produce very uneven relief, probably much like the scenery in the Cape of Good Hope Nature Reserve. Cape Granite, in contrast, is characterised by isolated drowned *tors* (vertical-sided tall boulders, like those along the coast south of Simon's Town).

East of Cape Agulhas, the Agulhas Bank narrows eastward from a width of 200 km to about 20 km east of Port Elizabeth. The shelfbreak is generally about 200 m deep and the continental slope is relatively steep. Volcanic pinnacles (the Alphard Banks) penetrate the Alphard Rise on the middle shelf south of Cape Infanta and ridges (eroded stumps) of aeolianite form distinctive topography southwest of Cape St Francis and off the Wilderness-Knysna coastline. The eastward longshore drift has formed unusual submarine spit bars on the downdrift (eastern) sides of Cape Infanta and Cape Seal (Robberg), the sediment being up to 30 m thick. In general, rocks constituting the shoreline of the south coast do not extend far onto the inner shelf, which is therefore far less well-defined morphologically than its west-coast equivalent.

Between Port Elizabeth and Durban on the east coast, the shelf is extremely narrow (10 km) and the shelfbreak is very shallow (100 m). Undulating topography along the outer shelf is due to submarine sanddunes travelling south, driven by the powerful oceanic Agulhas Current (2,5 m/s). The steep slope is characterised by both submarine canyons and submarine slumps, particularly off major rivers like the Mzimvubu at Port St Johns. At intervals, eroded aeolianite stumps form hazardous reefs, such as Aliwal Shoal, which also confine a Nearshore Modern Sand Prism to the inner shelf. North of Durban past the mouth of the Tugela River, the shelf widens to 60 km in the Natal Bight and the more gentle continental slope is cut by the Tugela Canyon. North of Cape St Lucia, the shelf is at its narrowest (1 km) and the shelfbreak is shallowest (70 m). The steep continental slope is cut by innumerable submarine canyons, because the glacial coastline here lay below the shelfbreak and the palaeovalleys extend right across the shelf to the heads of these submarine canyons.

The bathymetry of the South African continental margin thus covers the full spectrum from the anomalously deep shelf off the Olifants River to the narrow, shallow shelf beside the coastal plain of Zululand. Detailed surveys are therefore required to characterize the seafloor prior to any pipelaying operations.

3.1.4 Site selection considerations

3.1.4.1 Planning and geological investigations

With a general understanding of the geology of the coast and continental shelf, it remains to gather detailed geological information on the proposed site for the pipeline route. To this end detailed geophysical surveys, as alluded to above, and seabed sampling, are required.

A detailed marine geophysical survey is the basis of any geological investigation of a proposed marine outfall site. Firstly, a regional survey is required in order to determine the nature of the seafloor at the proposed site and surrounding area. After a suitable route has been identified and an appropriate pipeline has been designed, a second, more detailed, survey (termed "route survey") is conducted to determine the precise nature of the seabed along the pipeline route, primarily for installation purposes.

Paramount in the considerations of the appointed geologist is **risk reduction**, both in the cost of the undertaking and in the environmental impact of the pipeline, over the lifetime of the pipeline. Anywhere along our high-energy coastline, it is considerably cheaper to base the pipeline route selection and design on accurate, detailed and pertinent baseline geological information, than to incur the high cost of either over-engineering or under-engineering the solution in its absence.

Having identified a potential site for a pipeline route, baseline geological and oceanographic data should be gathered over a period of time incorporating the seasonal spectrum of sea conditions encountered at the site. More often than not, this has not been the case and pipeline design has largely been based on empirical data and information collected immediately prior to emplacement of the pipeline. However, careful analysis of the geological response to a variety of hydrodynamic processes provide a vital input to the successful design, placing and continued existence of a pipeline.

3.1.4.2. Survey strategy

The objectives of the geophysical survey must be clearly defined before an effective survey strategy can be planned. This phase of the investigation should be undertaken in consultation with all the parties involved in order to ensure that their specific requirements are correctly interpreted. This will affect the choice of survey equipment and the manner in which the survey is executed. In addition, there are other considerations such as bedrock structure, sediment distribution, seafloor physiography and general wave conditions that will determine the optimal orientation and spacing of the survey lines. For example, at Green Point in Table Bay, the dominant NNW structural trend of the Malmesbury Group bedrock dictates that survey tracks be run in a N-S direction in order to obtain optimal sonographic resolution of the bedrock morphology and structure.

3.1.4.3 Geophysical survey equipment and results

As mentioned previously, the marine geophysical survey is an important part of the geological investigation of any site. The standard geophysical survey involves the use of side-scan sonar, seismic profiling and bathymetric survey equipment to provide information on the surficial geology, stratigraphy and seafloor topography respectively. Although these techniques have been standard for the past 20 years, significant technical advances have been made. The techniques applied and the relevance of the interpreted information is discussed below.

3.1.4.3.1 Side-scan sonar - (surficial geology and physiography)

As a means to obtain detailed information on the nature of the seafloor surface, side-scan sonar imagery remains the optimal tool. It provides what is effectively described as an "aerial photograph" of the seabed. The system comprises a towfish that continuously transmits a narrow swath of sound onto the seafloor on either side of the survey vessel and a recorder that prints the relative intensity of the reflected signals from the seafloor below the towfish. Current systems have a capability to produce isometric sonograph records, with inherent range and speed distortions being corrected electronically.

Several transmission frequencies are available depending on the requirements for the survey. A 50 KHz low frequency, long-range scanner capable of effectively scanning 600 m to either side of the ship's track (depending on the water depth) may be used for large scale regional surveys. A 100 KHz frequency towfish set at 100 m scan range is normally used for routine regional survey work. Localized surveys, requiring detailed resolution of seafloor features are run at closer scan ranges of up to 25 metres on each side, using transmission frequencies of 500 KHz. A comprehensive survey would be one that has at least 100% overlap of the data between survey tracks. In this way seabed features will be scanned from two directions, allowing a much greater accuracy in the interpretation.

A sonograph mosaic is generally produced by combining the isometric records of adjacent lines, using the data from one insonification direction only (assuming 100% overlap of the data). The mosaic is then interpreted for bedrock structure and physiography (represented as increasing relief in metres), sediment distribution and sediment texture. Features of the order of tens of centimetres can be identified and interpreted from the records.

The sonograph map, derived from the interpretation of all the side-scan sonar records (as opposed to interpreting the mosaic only), forms the basis of the geological interpretation of the seabed and subbottom. It must be emphasised that the map of the seabed remains a sonographic map, and becomes a geological map only once the interpretation has been verified by diver-geologists, or by remote sampling methods.

3.1.4.3.2. Bathymetry - seafloor topography

Closely related to the interpreted sonograph map, is a bathymetry map of the study area. The bathymetry map is compiled by contouring tide-corrected depth soundings recorded on a precision echo-sounder. The contour-interval is generally at 1-m depth intervals or less. The sonograph map forms the basis for the bathymetry, allowing the geologist to impart a geological interpretation (or bias) to the isobaths, thereby enhancing the value of the bathymetry map and improving the result beyond anything possible by computer-aided contouring alone. The resultant map shows the seafloor topography in great detail. Apart from its inherent geological value, this information also provides the basis for wave refraction analyses.

3.1.4.3.3 Seismics (sediment thickness and stratigraphy)

Sediment is much preferred to exposed bedrock for laying pipelines. Where pipelines are to be entrenched in sediment, such as those in Richards Bay on the Natal North Coast and in Hout Bay and Camps Bay in the Cape Peninsula, particular detail is required of the thickness and stratigraphy of the unconsolidated sediment cover and also the physiography and lithology of the underlying bedrock. When techniques such as directional drilling are to be considered, as used in the Mossgas Pipeline shore-crossing at Vlees Bay, an accurate interpretation and mapping of the sedimentary stratigraphy from the seismic records is an essential ingredient for success.

In order to obtain this stratigraphic detail, a high resolution seismic profiling system (3.5 to 12 KHz "Pinger") with resolution of better than 1.0 m is generally required. Since frequency and resolution are positively related, in order to obtain this detail, one has to forego the transmitting energy that may be required to penetrate through the overburden to, and into the bedrock. Traditionally, the solution was to collect both high resolution (pinger) and medium resolution (boomer or sparker) seismic data together. However, the newest seismic technique ("Chirp" seismics) allows a whole range of frequencies to be transmitted simultaneously , and then analyzing the incoming signals. Filtered, the frequencies giving optimal penetration and resolution are then printed.

3.1.4.3.4 Navigation

No amount of detailed marine geophysical data gathering will suffice if the navigation is not up to the standard that is required for the project. In general, positional accuracy of less than a metre is theoretically possible for line-of-sight trisponder type navigational systems using microwave frequencies, eg. Microfix, Del Norte, Syledis, MRD-1 tellurometer. The absolute accuracy will obviously be dependant on the geometry of the shore-based stations, sampling frequency of the equipment and the spatial stability of the antenna on the survey vessel.

Satellite based navigational equipment (Global Positioning Systems, or GPS) are readily available and are both easy to operate and more cost effective than the trisponder type of systems. However, these systems are not capable of providing real-time position fixing required for detailed surveys, and are also subjected to selective degradation of the satellite signal which may effectively reduce the accuracy of GPS to the order of tens of metres. However, Differential GPS systems that utilise co-ordinated ground stations to update satellite fixes are becoming locally available. Differential GPS has positional accuracy to within metres and can provide real-time navigational information. The availability of the system however remains vested with the owners of the satellites and on the availability of the satellites themselves.

3.1.4.4 Verification of interpreted geophysical data

An integral part of geophysical data interpretation is its verification by means of seabed sampling. In order to quantify the geological significance of the various features interpreted from the geophysical records, it is necessary to verify the interpretation utilising diver-geologists in conjunction with specialised equipment and techniques for grab-sampling, coring and seafloor photography. Sediment and bedrock sampling are best done subsequent to the data interpretation, when diver-geologists can collect samples at exact, predetermined localities and generally verify the interpretation of the sonograph as to the nature of the seabed.

In situ underwater mapping and sampling by diver-geologists provides the optimal means of verifying the surficial geology and physiography interpreted from the geophysical records. Excavations at selected localities or trench exposures, allows the diver geologist to obtain detailed information to verify the interpreted sedimentary stratigraphy. Verification by diver-geologists offers advantages lacking in other approaches: personal perspective and geological insight. Bedrock structure is geologically meaningful only after the lineaments identified on the sonograph records have been interpreted by a diver-geologist on the seabed. Sonographically, bedding planes, foliations, faults and joints are similar, but have totally different implications for the coastal engineer siting a pipeline route.

Seafloor sediment samples, using either a Van Veen or Shipek grab can be obtained to determine the sediment composition and texture. Sediment textural and compositional maps produced from the samples obtained are part of the data gathering phase that the geologist follows to obtain a full understanding of the type of environment he is dealing with.

Sediment thickness can be verified using standard water-jet probing techniques. Sediment stratigraphy can be investigated using various coring techniques, the suitability of which will be determined by sediment texture and degree of induration. Box, piston and gravity coring techniques can be used in "soft" muddy sediments. In areas of sandy and gravelly sediment a vibrocorer would be required. These corers are capable of obtaining 3 m - 5 m long cores up to 10 cm in diameter without destroying the sedimentary stratigraphy. In cases where it is necessary to obtain bedrock samples, a combination vibrocorer/rock drill may be required. Conversely, standard percussion or rotary drilling techniques may be required.

3.1.4.5 Sediment dynamics

Perhaps the most important aspect to be considered by the engineer siting his marine pipeline is the question of sediment mobility on the seafloor, for this carries the implication of the hydrodynamic regime extant in the area under consideration. Whilst it is prudent to establish the thickness of sediment covering the bedrock, it is of greater significance to the understanding of sediment mobility to understand the sedimentary stratigraphy. This is interpreted from the nature and aspect of the reflective surfaces that are often found within the sediment body. These internal reflectors (or horizons) may indicate changes in sediment texture, compaction, induration or some other feature that causes partial reflection of the transmitted signal. A detailed interpretation of these reflectors supported by coring and diver geologist observations will give some indication of the sedimentary facies that have been deposited and the nature of the depositional environment in which the sediments occur. This gives the marine geologist an insight into the sediment mobility, frequency of sediment transport, transport direction, and the hydrodynamic regime of the area.

Where the sediment overburden needs to be investigated it may be necessary to routinely inspect a series of previously emplaced stakes in order to quantify the sediment movement in the area. Sedimentary bedforms forming as a result of oscillatory movement due to wave action or formed by rip, tidal or geostrophic currents are important indicators of sediment movement. These may be monitored over time using side-scan sonar equipment or divers to establish the rate and volume of sediment movement.

3.1.4.6 Geotechnical information

Whilst the geological information is important baseline data for the engineer, it is in fact the geotechnical properties of the seabed that concerns him in the design of the pipeline. It is important to keep in mind the difference between the geotechnical information - and the manner in which it is obtained, and the geological information that the engineer obtains from the geologist. The geotechnical data is not always directly obtainable from the reinterpretation of the data supplied by the geologist. The main function of the geological data is to provide the engineer with an understanding of the geological environment in which the pipeline will be placed and the dynamics of the environment. This will influence the location, design and installation considerations. The geotechnical data provides the engineer with information required to determine his design specifications for the pipeline.

The timeous acquisition of accurate, detailed baseline geological data and supplementary geotechnical input will provide the engineer with the information he requires to make an informed decision on the most cost-effective solution for the successful design and emplacement of a marine pipeline.

3.1.5 Acknowledgement

Section 3.1 of Chapter 3 was compiled in consultation with dr J Rogers of the Marine Geoscience Unit, University of Cape Town. His input is gratefully acknowledged.

3.2 Physical Aspects

by J L Largier

3.2.1 General considerations

Pollutants released into the sea are dispersed by a wide spectrum of fluid motions. These dispersive motions are either advective or diffusive. Advection, the average velocity over a given time or space scale, is usually the result of larger scale currents. Diffusion (or mixing), the random to-and-fro motion (turbulence) is due to smaller scale movements which cause a pollutant to spread out irrespective of any net transport of water. Analogous with molecular diffusion, a coefficient of turbulent diffusion - eddy diffusivity - may be defined and can be evaluated for a predetermined scale of resolution. While the near-field diffusion is largely a function of the structural design of an outfall, the advection and far-field diffusion are a function of the location of an outfall with respect to ambient fluid motions. These environmental conditions into which an outfall is introduced will be discussed in this section.

As a boundary to active transport of pollutants by currents, fluid boundaries or interfaces passively obstruct, redirect or inhibit transport in a given direction. Penetration of these boundaries occurs via special mechanisms. Upward exchange across the air-water boundary is considered to be less important but it is partially covered in the following subsection on weather. Without significant-sized open-mouthed estuaries the coastal boundary is effectively impermeable. Fluid- fluid interfaces between different water types will be included in this section. A complete review of pollutant transfer and transport processes is given by Kullenberg (1982).

In the ocean, four layers can usually be identified. The homogeneous surface mixed layer (extending to 10-100 m depth) is dominated by atmospheric forcing. The pycnocline, a layer of rapid density change between warm surface water and cool deep water, is found at the base of the mixed layer. It occurs at a depth predicted in models presented by Kraus (1977). Turbulence and associated vertical transport of pollutants are inhibited in the pycnocline, owing to its stable stratified character. The sub-pycnocline deep-water layer is weakly stratified by input of heat from the overlying warm water. Internal gravity waves are important and may easily break down into turbulence in this deeper layer. The bottom boundary layer (10-30 m thick) is dominated by friction forces. The rough sea bed exerts a drag on any movement of water. This usually results in turbulence and mixing in the boundary layer (sediment and particle-pollutants, which may be resuspended by an active boundary layer.

Particle-pollutants will have a given density in water and will tend to collect on the surface (if buoyant) or on the bottom (if negatively buoyant). In exceptional circumstances these particles may collect on the pycnocline. In contrast, solute- pollutants form part of the water and rely on turbulent exchange which is active in the surface and deep layers but is suppressed in the pycnocline. This turbulence, required for vertical transport of solute-pollutants, is generated by vertical velocity shear at the surface, the bottom and across the pycnocline.

3.2.2 Coastal and shelf regions

Moving seawards from the coast one can identify various zones as a function of dominant dynamics. In the surf zone a system of breaking surface gravity waves, non-breaking infra-gravity waves, edge-waves, mean longshore drift and rip currents disperse pollutants. Although the nearshore zone, which includes the surf zone, is also affected by fresh water run-off, small-scale topography, coastline features and local winds, it is dominated by wave-driven dynamics. Extending further offshore one can find the outer limit of the coastal zone which is characterised by a single mixed layer. In other words, the surface and bottom stresses are sufficient relative to the potential stratification (i.e. input of buoyancy) that the surface and bottom mixed layers merge into a single mixed layer. At the seaward boundary of this coastal zone, density fronts (i.e non-horizontal surfaces of equal density) will inhibit exchange of coastal pollutants (e.g. from outfalls) with the open sea. In general, water from this coastal zone can only move further seaward along the lines of equal density. In parallel with this, one can identify the coastal-boundary zone in which wind effects are dominant and effects due to rotation of the earth may be neglected. Within this zone, wind not only moves the water but also tilts the pycnocline resulting in coastal upwelling or downwelling. The width of this coastal boundary zone is scaled by the internal Rossby deformation radius R_i :

$$R_i = (g\Delta\rho H/\rho)^{1/2}/f$$

where

- g = acceleration due to gravity
- $\Delta\rho$ = the density difference across the pycnocline
- H = a vertical depth scale
- f = the Coriolis parameter ($\sim 8 \times 10^{-5}\ s^{-1}$ around southern Africa).

Beyond the coastal zone rotation effects become important and water movement is dominated by regional current systems. The shelf zone is characterised by shallow depths (< 300 m) and usually extends beyond the coastal-boundary zone. Pollutants associated with one particular outfall are seldom of concern beyond the edge of the continental shelf. Open ocean pollution studies are concerned with the combined effect of all pollution sources on a regional or global scale.

3.2.3 Forcing mechanisms

The movement and structure of the sea are continually subject to a variety of forces which drive the water on time-scales increasing from a few seconds (surface waves) through a day (tide and rotation effects) or a few days (synoptic weather effects) to months (seasonal) or even longer (interannual variation, for example, El Nino - Southern Oscillation). Passive responses from bottom or side-wall friction, bathymetry and coastline features contribute to the complexity of marine hydrodynamics.

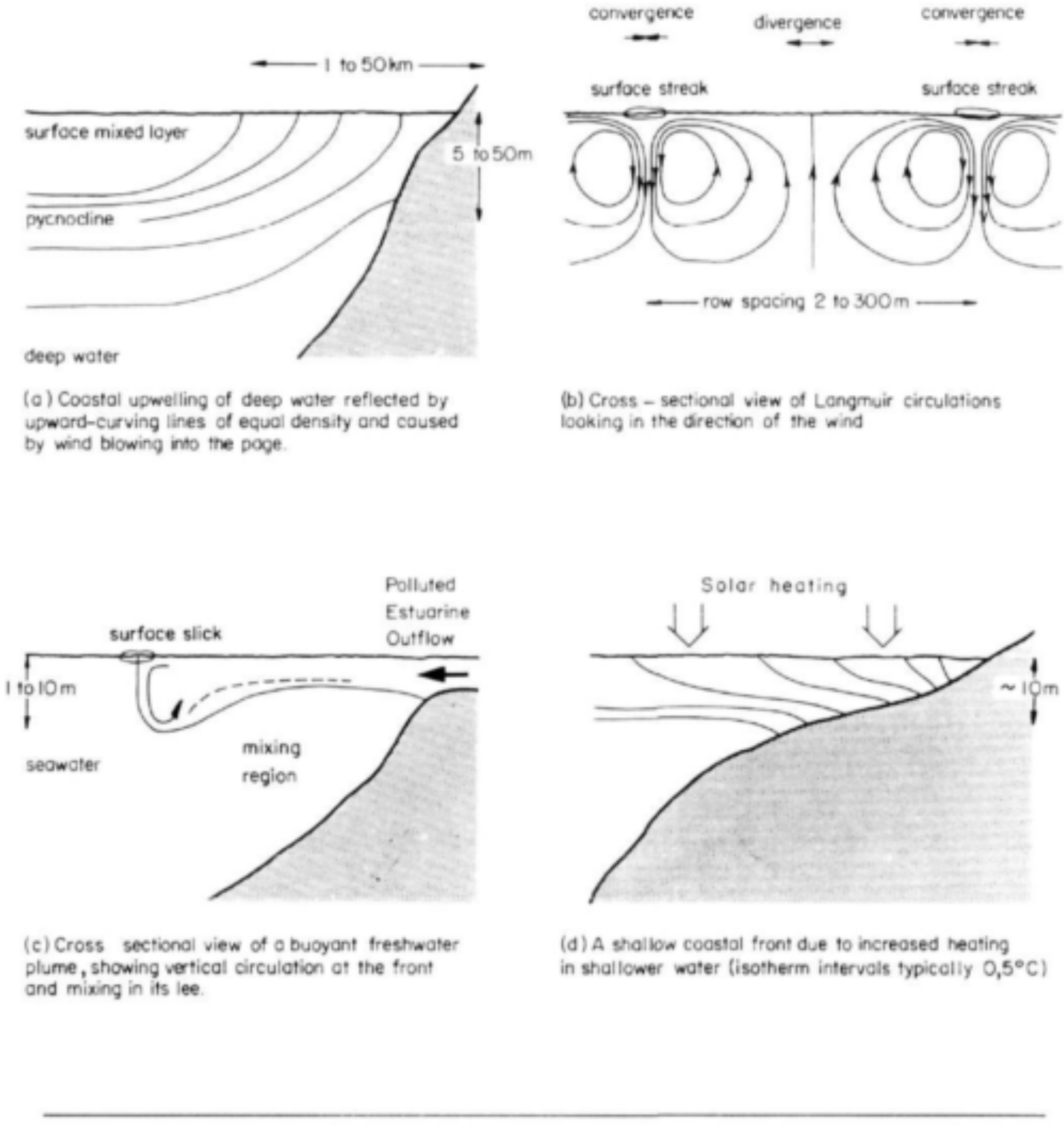
Of the above, wind effects are the most important. While this section will consider mainly the response of the ocean to wind forcing, Section 3.3 discusses wind from the meteorological angle (e.g. availability and suitability of data). In the vicinity of the wind, the immediate surface waters tend to move with the wind but due to the effect of the earth's rotation the surface mixed layer has a net displacement to the left of the wind direction (in the southern hemisphere). (In Section 3.3.4, the effect of coastal topography on local winds is discussed). Spatial variation in wind strength, or land boundaries may result in convergence or divergence of the surface layer transport. Along lines of convergence, surface water will sink, a process referred to as downwelling. Along lines of divergence, deeper water will be upwelled to the surface. Upwelling often occurs at the coast when a wind blows with land on its right-hand side (Figure 3.2.1a). Associated with this vertical transport at the coast is an onshore flow of deeper water and an offshore flow of surface water. The pycnocline is elevated near the coast and may break the surface and form a density front which prevents free horizontal exchange. Further special wind-driven phenomena include Langmuir circulations, inertial oscillations and shelf waves. Langmuir circulations (or windrows) take the form of alternatively counter-rotating helical vortices aligned parallel to the wind (Figure 3.2.1b). The surface exhibits alternating lines of convergence and divergence, corresponding to a significant system of vertical exchange in upper layers. The vertical dimensions are typically half the horizontal dimensions (which may be as large as 100 m). On a larger scale, wind also drives currents which rotate (with a period of about 21 hours at 35 ^{0}C) under the restoring action of the earth's rotation. Shelf waves, which may be generated by wind, are particularly interesting in that the associated oscillatory currents are not necessarily locally generated. Propagating along the coast, with the coast on the left-hand side, these large-scale waves are often remotely generated in a windier area further upstream. Although the surface elevation signal (< 10 cm) is not dramatic, the pycnocline elevation (often over 10 m) can be quite significant.

Compared to wind-driven dynamics, tidal currents are unimportant on the southern African coastline. Tidal ranges are small (between 0 and 2 m) and tidal phase is almost synchronous along the coast. Fresh- water outflow from the coast is also of limited effect, and density fronts due to river outflows are only of local consequence. However, a pollutant introduced into this locally contained fresh- water plume (e.g. an estuarine outfall) will suffer from a severe decrease in dispersion (Figure 3.2.1c). Diurnal heating may have an important effect, particularly in shallow water. Warm coastal systems (e.g. a kelp bed) may trap pollutants inshore of a thermal density front (Figure 3.2.1d). Further vertical exchanges are inhibited during the day by the increased stratification due to diurnal heating of the surface - this effect would be less important in winter. Land and sea breezes, particularly intense drainage winds, may either disturb ambient wind-driven processes or drive further local processes.

The remaining driving force of consequence is that owing to adjacent oceanic systems. The hydrodynamics of the shelf zone are significantly influenced by the strong Agulhas current, which flows polewards along the east and south-east coasts of southern Africa, and the extensive Benguela drift on the west coast of southern Africa, which is dominated by the wind-driven upwelling and circulation. These aspects are expanded upon in the following section.

3.2.4 Oceanographic regions around southern Africa

Within the oceanic setting provided above one can discuss five overlapping geographical regions of the coast (Figure 3.2.2). Caution must be shown, however, in interpreting this regionalisation: although the properties discussed are characteristic of the regions, it is not difficult to find exceptions or contradictions. Schumann (1986), in a report on oil pollution, provides a similar introduction to the coastal ocean dynamics of southern Africa. A more complete guide to the coastal currents is given by Harris (1978). In addition, more recent



(a) Coastal upwelling of deep water reflected by upward-curving lines of equal density and caused by wind blowing into the page.

(b) Cross – sectional view of Langmuir circulations looking in the direction of the wind

(c) Cross sectional view of a buoyant freshwater plume, showing vertical circulation at the front and mixing in its lee.

(d) A shallow coastal front due to increased heating in shallower water (isotherm intervals typically 0,5°C)

Figure 3.2.1 Four dynamical effects which effect the dispersion of pollutants

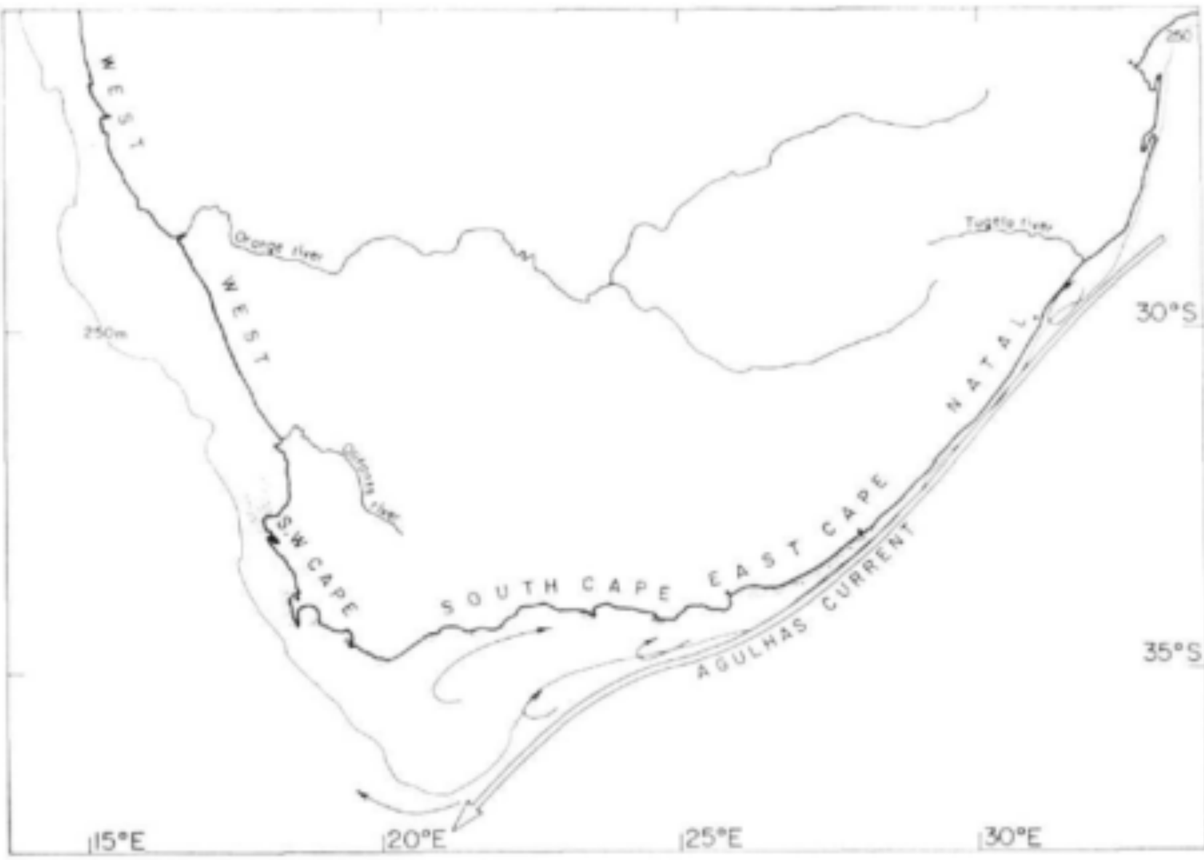


Figure 3.2.2 The five loosely-defined geographical regions of the SA coast. Coastal upwelling areas are dotted - the denser areas are centres of upwelling. The Agulhas Current roughly follows the edge of the continental shelf and it spawns cyclonic vorticity towards the coast.

specialist reports are referenced in each section below. It should be stressed that in convective-scale (~ 1 - 10 km) coastal processes (which are of relevance to outfall studies), currents are extremely variable and localised. Flow patterns observed 10 km upstream or downstream may not be applicable to a particular spot, and supplementary regional surveys are normally essential for site-specific information. The descriptions below should, therefore, be seen as background situations.

(i) **The Natal Coast**

Characterised by a narrow shelf, this region is dominated by the proximity of the Agulhas current. Where the current is close to the coast (e.g. St Lucia and Port Edward, about 5 km), the coastal currents move southward with the Agulhas. In the Natal bight, or in the event of a current meander, the Agulhas separates from the coast and the coastal flow takes the form of counter-currents, transient eddies and generally variable conditions. These intermittently northward and southward flowing coastal currents are a result of meteorological or tidal forcing or dynamic instabilities in the Agulhas current. On a local scale, pollutant input to the nearshore zone may be exported by rip currents within the breaker zone. Pollutants further offshore in the coastal zone could be transported into deeper water as a result of strong horizontal shear between the Agulhas current and the coast but could equally be reflected onshore by spin-off eddies and detraining filaments. A comprehensive but somewhat outdated report of effluent disposal on the Natal coast is given by Natal Town and Regional Planning Commission (1969). More detail on the shelf circulation was provided by Pearce (1979) and Schumann (1986). In addition to this, a book edited by Schumann (1987) presents a comprehensive collection of coastal studies off Natal.

(ii) **The East Cape Coast**

In this region the shelf widens and the Agulhas current gradually separates from the coast. The dominant feature of this region appears to be the upwelling of cold (10 ^{0}C) water in the wedge between the current and the coast. Further west this cold water is found as a continuous bottom mixed layer, superimposed by a warm mixed layer of shelf and Agulhas current water. Recorded currents in this wedge (water depth ~ 100 m) indicate south-westward flow but it is suspected that the inshore zone would be characterised by north-eastward counter-currents which would reinforce the net north-eastward longshore drift found nearshore. A local but comprehensive study of the coastal currents off East London has been reported by Schumann (1985). The shelf-zone dynamics are still clearly controlled by the Agulhas current.

(iii) **The South Cape Coast**

As soon as the Agulhas current separates from the coast, cyclonic (i.e. clockwise) vortices develop on the horizontal shear between the current and shelf waters. Warm surface plumes, typically 20 to 50 m thick, move over the Agulhas bank. The consequence of this simultaneous input of both warm and cold water is the maintenance of two clear layers separated by an interfacial pycnocline. This stable pycnocline may extend inshore to a water depth of 20 or 30 m. Solute pollutants released into either of these layers will tend to remain in that layer. If released within the mixed coastal zone, then, in the absence of up/downwelling, the pollutants will equally well remain there. Moving further west, the Agulhas current forcing weakens and wind forcing becomes more important. The combination of these two forces produce complex current patterns. A net easterly longshore drift is reinforced by a surface layer easterly counter-current which is hypothesised in the absence of wind forcing. The bottom layer continues in a southerly and westerly direction. Towards the west and during winter the stratification tends to break down and the coastal zone may extend to the 100 m isobath.

(iv) **The South-western Cape Coast**

This region is characterised by wind-driven coastal upwelling. East of Cape Agulhas patches of cold water transiently break the surface during easterly winds. West of Cape Agulhas the summer wind field is dominated by intense south-easterlies. From Cape Agulhas to Cape Point, upwelling occurs regularly but it decays as soon as the wind changes. North of Cape Point the upwelling plumes remain intact for the windy summer season, only decaying in autumn. In addition to the upwelling density front, which traps pollutants inshore, these upwelling centres develop a strong surface layer current towards the north-west. The core of this current is usually offshore of the upwelling front. Coastal currents are most likely to go westward or northward in summer and to be slack or confused in winter. These upwelling fronts may be local (50 m offshore) or regional (up to 50 km offshore). False Bay (Gründlingh and Largier, 1988) and Table Bay (Van Ieperen, 1971) display wind-driven circulations which are not clearly resolved. Coastal bays, however, are usually poor sites for dispersion owing to limited exchange with the adjacent ocean. Boyd *et al*. (1985) have discussed the area east of Cape Town. Andrews and Hutchings (1980), Nelson and Hutchings (1983) and Shannon (1985) have reviewed the Benguela upwelling system. The currents are essentially wind-driven throughout this region. Density structures and topographic/coastline features perturb these wind-driven currents.

(v) **The West Coast**

This region is characterised by steady winds and steady upwelling. Currents are generally northwards. The situation is seasonally modulated with the southerly shift of trade winds in summer. This region is also covered in the review by Shannon (1985). The coastal longshore drift will be northward.

3.2.5 Conclusion

In conclusion, the reports by Harris (1978) and Schumann (1986) contain most of the empirical data and provide the most comprehensive account of inshore and coastal currents. For more specific localised data there is no substitute for a dedicated data collection exercise.

3.3 Meteorological aspects

by I T Hunter

3.3.1 Introduction

When waste material is to be disposed of in the coastal ocean the immediate question is whether the local dispersive processes are efficient enough to prevent the build-up of unacceptable concentrations. Ideally, thus, a long-term, three-dimensional picture of water movement is required. This is seldom available along the South African coastline. Fortunately, local wind is usually a major dispersive factor except at places where the Agulhas current is close inshore, for example, along the Natal South coast. It has thus become common practice to link local winds and currents during a variety of wind conditions, and to then use the nearest source of long-term wind data to provide long-term predictions of dispersion. As will be seen in the discussion below, this method is not without its pitfalls.

3.3.2 Availability of long-term coastal wind data

The only sources of accurate long-term coastal wind data along the South African coast are the major coastal airports. Although numerous lighthouses have made meteorological observations for many decades, accurate instrumentation has never been provided, and the tables that are available are based on synoptic readings only.

3.3.3 Suitability of long-term coastal wind data

Although none of the airports mentioned above are more than a few kilometres from the coast, comparisons with actual coastal data show that the airport site may be totally 'decoupled' from coastal air flow at times. This usually occurs with rapid nocturnal cooling overland resulting in a calm, stable layer a short distance from the coast. It is thus to be expected that the number of calm conditions measured at an airport site will be a significant overestimate of those actually prevailing at the nearby coast. Figure 3.3.1 shows how a land-based wind measurement may underestimate conditions offshore. Land breeze conditions, such as that depicted, provide an important offshore flow in the winter, along much of the South African coastline. The available long-term sources of coastal wind data do not reflect this phenomenon adequately. Furthermore, with the increased surface roughness, peak wind speeds recorded even slightly inland may be markedly lower than those over the adjoining coastal ocean.

As mentioned above, the lower accuracy, long-term wind data available from lighthouses is based only on certain synoptic times. The South African Weather Bureau has, for example, wind distributions for Cape Point lighthouse based on the years 1960 - 1970. However, the basis of these distributions are the three synoptic hours, 08:00, 12:00 and 20:00. One would expect a severe underestimate of those conditions which often prevail overnight, for example, there may be a moderation in wind strength as cold air drains down from the surrounding mountain peaks.

3.3.4 Other factors

Local wind-generated currents are not a simple function of wind speed. The stability of the surface air layer over the ocean plays a major role in deciding how efficiently momentum is to be transferred to the ocean surface. For example, in a locality such as Hout Bay in the winter, the surrounding mountains become a source of cold katabatic flow overnight which causes a layer of very stable air to form over the waters of the bay. Measurements on the Cape south coast have shown that this cold air may undercut even a moderate to fresh synoptic flow.

As far as topographical distortion of flow is concerned, the coastline around the Cape Peninsula is a good example of why wind extrapolations, over even a short distance, should not be attempted. Thermal effects, including lowering of upper inversion levels may also play a major role in producing local 'jets' and 'shadows'.

Apart from the cross-coast wind components associated with land and sea-breezes, prevailing winds around the South African coastline tend to be parallel to the coast. On the Cape west coast when high summer temperatures contrast with low sea temperatures due to upwelling, the sea-breeze component is enhanced, causing a net onshore flow. Much of the remaining coastline comes under the thermal effect of the Agulhas Current so that the offshore flow associated with the land-breeze is enhanced, particularly in winter. Cut-off low pressure systems may be responsible for strong onshore flow conditions lasting several days, particularly on the south and east coast. This same system may also be responsible for intense localised upwelling on the Cape south coast.

3.3.5 Conclusion

Due basically to lack of suitable data, the meteorologist cannot provide detailed wind information for sites along the South African coastline. It should be clear from the above, however, that even one year's

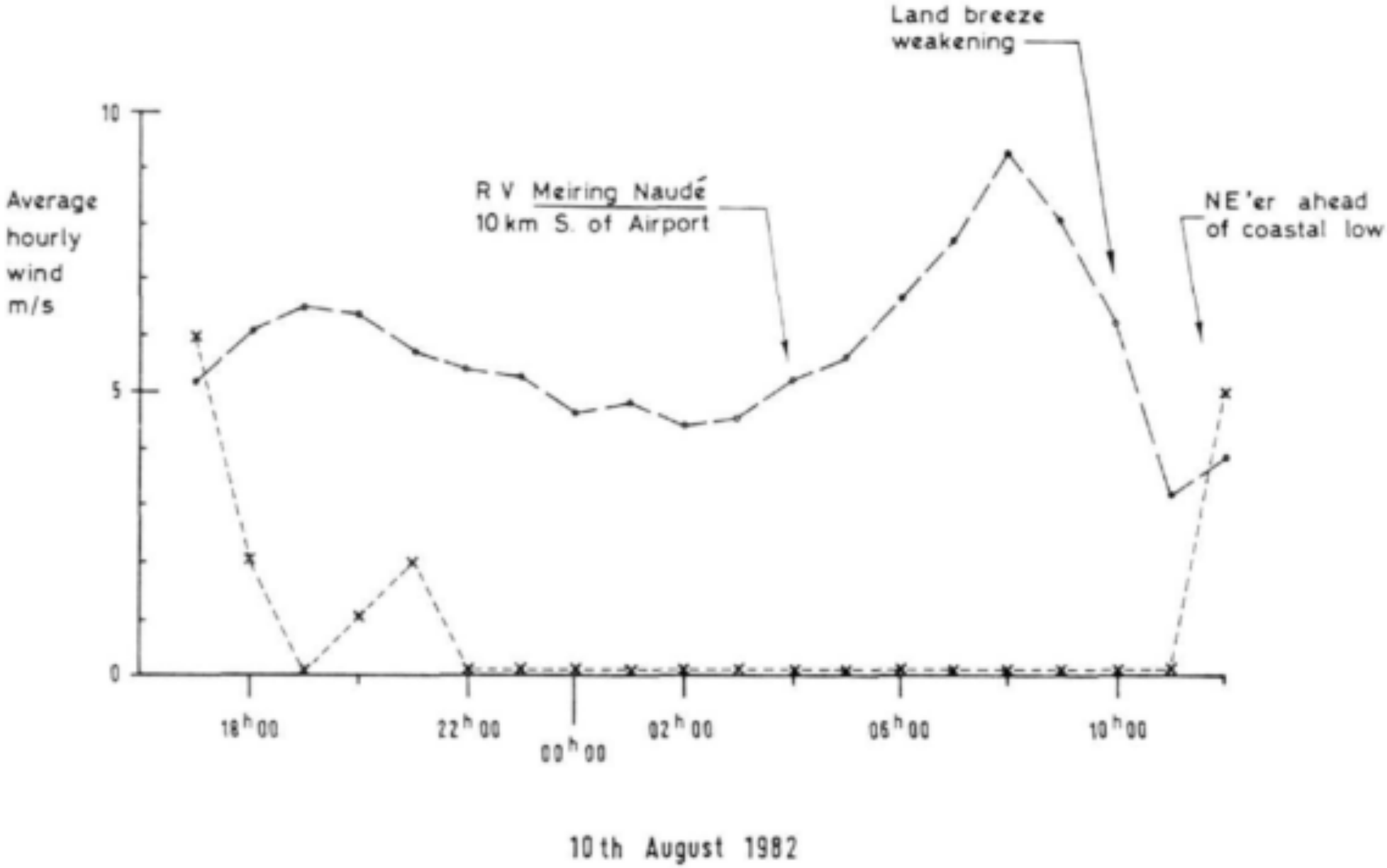


Figure 3.3.1 H F Verwoerd Airport vs R/V Meiring Naudé - hourly averaged wind speed

on-site data is worth more than several decades of extrapolated data. This does not solve the problem of long-term dispersion prediction, however. One possible solution is to relate the various dispersion patterns to sea-level pressure features, and use the long-term information on the latter.

3.4 Chemical Aspects

by H F-K O Hennig

3.4.1 Major chemical constituents of sea water

The sea contains numerous chemical constituents in dissolved and undissolved form and is the receiver of materials that are washed off the land masses surrounding it. The sea also receives materials which are exchanged between the atmosphere and it, and between the ocean floor and the sea.

The major dissolved components of sea water are given in the table below (Smith, 1974; James, 1978).

Element	Ion	Average concentration	
		g/kg	%
Chlorine	Cl^-	19,873	56,7
Sodium	Na^+	11,05	31,6
Magnesium	Mg^{2+}	1,326	2,7
Sulphur	SO_4^{2-}	0,928	2,7
Calcium	Ca^{2+}	0,422	1,2
Potassium	K^+	0,416	1,2
Bromine	Br^-	0,065	0,2
Carbon	HCO_3^-	0,028	0,1

Plus small amounts of silicon, dissolved oxygen, nitrogen and carbon dioxide, and traces (< 1 mg/l) of 73 other trace elements.

3.4.2 Salinity

The salinity (a measure of the salt content of sea water) in a typical coastal water lies in the range 32 to 35,5 g/kg. Salinity is expressed as parts per thousand, thus it ranges from 32 to 35,5 parts per thousand. Detailed values of the salinity of sea water around the South African coastline may be obtained from the South African Data Centre for Oceanology (SADCO). Mean salinity values for the west, south and east coasts of South Africa are:

West coast	$34,7 \times 10^3$ mg/l
South coast	$35,1 \times 10^3$ mg/l
East coast	$35,2 \times 10^3$ mg/l

Water quality criteria for the South African coastal zone (Lusher, 1984) require that for all marine biological purposes the salinity of sea water should lie within the range 33×10^3 to 36×10^3 mg/l. In estuaries, non-natural influences should not change the salinity beyond the range recorded over an extended period.

Brackish water is the term used to describe water that has a salinity of less than 17×10^3 mg/l.

The salinity of sea water varies with the depth due to evaporation and precipitation but remains relatively constant in the deeper waters.

3.4.3 Density

The density of sea water is primarily a function of salinity and temperature and is measured in g/cm^3. Typically sea water will have a density of 1,025 g/cm^3 and for convenience is expressed as 25 i.e. (1,025 - 1,000) x 1 000.

The higher the salinity, the denser the sea water will be. The higher the temperature the lower the density.

3.4.4 Colour and clarity

The clarity of water is measured by means of a Secchi disc, a white disc 300 mm in diameter, which is lowered in the horizontal position into the water. The 'Secchi depth' is the depth at which the disc disappears from view. The Secchi depth of the clearest ocean water can be as much as 40 m, whereas estuarine waters may have Secchi depths of the order of 1 m. The clarity of coastal waters are typically much lower than the waters of the open ocean. Both colour and clarity are detrimentally affected by discharges from marine outfalls.

3.4.5 Dissolved gases

The most important dissolved gases in sea water are nitrogen, oxygen and carbon dioxide. Nitrogen is a nutrient and will be considered in the next section. Dissolved oxygen is required by plants and aquatic animals for respiration, and carbon dioxide for photosynthesis. Oxygen concentrations in the ocean vary from place to place. The abundant supply of oxygen at the ocean/atmosphere interface results in high dissolved oxygen levels in the upper layers of the ocean. The solubility of oxygen is dependent on salinity and temperature of the water. The higher the salinity or the higher the temperature, the lower the solubility.

3.4.6 Nutrients

The breakdown of organic matter by bacterial action releases inorganic components essential for plant nutrition into the marine environment. These include nitrogen, phosphorus and some trace metals. Nitrogen and phosphorus are present in sewage, urban runoff and the major constituents of agricultural fertilisers which are eventually washed into the sea. Nitrogen and phosphorus stimulate benthic algae and phytoplankton growth. Nutrients, however, generally only result in undesirable biological effects in enclosed coastal waters. In open coastal waters, nuisance levels of excess nutrient induced biological growth occur rarely due to the rapid dispersal of the nutrients.

Water quality criteria for the South African coastal zone (Lusher, 1984) present narrative, rather than numerical criteria for nutrient concentrations: Waters should not contain nutrients and other biostimulants from land-based sources in concentrations that are capable of causing excessive or nuisance growths of algae or other aquatic plants or deleterious reductions of dissolved oxygen.

3.5 Biological Aspects

by J E McGlashan

3.5.1 Marine plants

Marine plants range from the microscopic single- celled organisms, such as diatoms, to the larger organisms like kelps. They are to be found near the surface of the sea for they rely on sunlight for photosynthesis, the process whereby energy from the sun is utilised to produce organic matter from inorganic nutrients. Phytoplankton form the base of the food chain in the sea since they are consumed by herbivorous zooplankton which convert the food into animal tissue. Phytoplankton (plants) and zooplankton (animals) are drifters and most are completely at the mercy of the prevailing currents. Benthic seaweeds are plants attached to the seabed in the shallow intertidal and subtidal photic zones of the oceans. Many microscopic algae attach themselves to the surfaces of rocks, sand and marine organisms.

3.5.2 Marine animals

Marine animals can be divided into three major categories: Zooplankton, nekton and benthos. Most zooplankton, like phytoplankton (plants) are drifters that drift in the prevailing currents. Together with phytoplankton they form the most abundant life form in the ocean and live predominantly near the ocean surface where they feed on phytoplankton. Amongst the great variety of zooplankton in the ocean are single-celled protozoa, crustacea, jellyfish, segmented worms and the larval forms of (among others) molluscs, crustacears and fish.

Nekton consist of large free-swimming animals which can control their direction and speed such as fish, squid, turtles, sharks, dolphins and whales. The nekton search for their food, which may be zooplankton, phytoplankton or other nekton.

Benthic animals are those animals which live on the ocean floor. Most are invertebrates which may be attached to the floor, such as sponges and corals, animals which move about the floor such as crabs and snails, or animals which burrow into the floor such as worms. Since the animals which burrow into the sea floor are less mobile, they are an important indicator of pollution in the area.

3.5.3 Trophic levels

Phytoplankton are the food source for consumers. They convert inorganic nutrients into organic material by means of the process of photosynthesis. The amount of available sunlight and nutrients will control the process whereby organic material is produced and oxygen released into the sea water. Due to the effects of turbidity and the amount of turbulence in the water, sunlight can only penetrate to a certain depth in the ocean, thereby limiting the depth at which organic matter can be produced by the phytoplankton. Temperature of the water and seasonal variations naturally also play a role in the rate of primary production.

The abundance and variety of organisms in a particular area depends largely on their habitat. Changes in conditions in the area will result in different distribution of species and in the total number of individual organisms. Under conditions of upwelling, when the nutrient rich lower waters of the oceans are brought to the surface, planktonic life thrives and multiplies rapidly. The nutrients brought up from the deep waters have collected there as a result of dead and decaying forms of life and waste products which decompose, releasing the nutrients back into the sea water.

In the complex food chain in the ocean, herbivorous zooplankton feed on the phytoplankton, and in turn are consumed by carnivorous zooplankton. The zooplankton are consumed by the higher order small predators such as herring which in turn are consumed by larger predator fish. Man, at the top of the scale, consumes the fish.

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CHAPTER 4

COASTAL DEVELOPMENT IN SOUTH AFRICA

by J M Jordaan and M du Toit

4.1 Existing Development

4.1.1 Historical background

In his presentation to a workshop on pipeline discharges of effluents to sea, Viljoen (1984) described the historical development as follows:

"All over the world coastal cities developed as fortresses and later as commercial gateways at strategic locations to serve specific hinterlands along transportation axes. This pattern also developed in southern Africa, but with two major differences.

Whereas the world's ports developed almost exclusively at river estuaries with these waterways as the backbone of the transportation system to the interior, only one harbour in the Republic of South Africa is truly river-based and the water transport mode is non-existent. Furthermore, South Africa has more than half of its economic activity concentrated in one overpowering metropolitan complex on a high plateau some 1 500 m above sea level and 700 km from the coast.

Fortunately, however, the port cities are well situated and strategically placed to serve their respective hinterlands. For decades these harbours primarily handled the import of capital goods in the early developmental phases (Cape Town to Kimberley and Durban to Johannesburg) as well as creating opportunities for exporting primary agricultural products such as wool (Port Elizabeth).

As the country developed, the export of other mass cargo became possible (East London grain terminal) and the import of semi-processed raw materials stimulated manufacturing industry (Port Elizabeth motor industry).

While import substitution developed on a vast scale, the competitive advantages of some of the coastal cities changed and declined until their export function has now become their real competitive advantage.

After the Second World War it became evident that the capacity of the harbours would soon become insufficient and their capacities have since been greatly increased by enlargement and modernisation as well as containerisation. However, due to physical limitations and harbour-bound development over many years, South Africa could not compete in a new world trade structure based upon modern mass- handling and transportation techniques resulting in surprising economies of scale and low unit tariffs.

South Africa's economic future will be determined amongst others by her capability to continue to exploit her mineral resources, to beneficiate them and to market them competitively on world markets. To this end it was essential to develop two completely new harbours, Richards Bay on the east coast, and Saldanha on the west coast. These two deep-water harbours are the latest addition to our strategic gateways to the world as well as to the whole of southern Africa in the bid to remain internationally competitive."

4.1.2 The national and regional development concept

Viljoen (1984) also referred to the National Physical Development Plan (NFDP): The NFDP, first published in 1975, propagated the concept of regional development not only to assist spatial planning of the country, but also to direct the translation of such guidelines into co-ordinated development strategies.

Within the framework of the regional development concept, three future metropolitan complexes have been identified, namely Richards Bay, East London and Saldanha. All three are situated on the coast. Both Richards Bay and East London are associated with the neighbouring states with the highest needs to create employment.

A further five industrial development points with future coastal impacts have also been declared, namely Tongaat, a deconcentration point south of Durban, a Natal South Coast centre, a Pondoland (Transkei) point, and George. The deconcentration point Atlantis on the developing West Coast axis to Saldanha, also has an important coastal component. In addition Mossel Bay will develop on its own account as a result of exploitable gas strikes.

4.1.3 Physiography of the southern African coastline

As described in Section 3.1 the nature of the southern African coastline is complex and variable from a physiographic point of view. Extreme coastal formations, such as dune fields, cliffs, bays, reefs, promontories and estuaries will be found. These features not only interact with the nearshore oceanographical environment to produce the ambient conditions such as longshore currents, eddies, rip currents, surf, upwelling and undertow, but determine the demographic development of each stretch of coastline, in as much as it is either hospitable or inhospitable to development. Inhospitable coastline formations are found in the Transkei Wild Coast, the stretch of the Garden Route near Tsitsikamma, the Cape Peninsula, the West Coast north of Vredendal, and the East Coast north of St Lucia estuary.

On the other hand, extremely favourable and hospitable coastal formations are found along the Natal South Coast as far as Port Edward, the Natal North Coast as far as Richards Bay, the East London, Port Elizabeth, Plettenberg Bay, Mossel Bay and Wilderness regions, the Cape Flats (False Bay), and Langebaan-Saldanha- Velddrift area. Accessibility and a coastal road and railway play an important role in settlement patterns. Accessibility is also ideal for the siting of industrial plants close to the coast and, therefore, the marine disposal of effluents.

4.1.4 Existing coastal development

- High population density, urban

- Major harbour and port cities:
  Saldanha, Cape Town, Mossel Bay, Plettenberg Bay, Port Elizabeth, East London, Durban, Richards Bay.

- Minor harbours and towns:
  Port Nolloth, Alexander Bay, Koeberg, Langebaan, Hout Bay, Fish Hoek, Simonstown, Mitchells

Plain, Hermanus, Gansbaai, Knysna, Wilderness, Jeffreys Bay, Port Shepstone, St Lucia.

- Ribbon development:
  Natal South and North Coasts.

- Predominantly rural:
  Transkei, Ciskei and Zululand.

- Sparsely inhabited or uninhabited:
  West Coast, Agulhas, East Coast (St Lucia-Kosi Bay).

- Industrialised:
  Cape Town, Port Elizabeth, East London, Durban, Richards Bay, Natal South and North Coasts.

- Special developments:
  Koeberg (nuclear plant)
  Mossel Bay (offshore oil drilling)
  Cape Town Harbour (tanker terminal)
  SA Defence (Langebaan, Saldanha, Cape Infanta, St Lucia).
  Bulk ore terminals (Saldanha, Richards Bay).

4.2 Future Development

4.2.1 Introduction

With the development of Saldanha Bay and Richards Bay for the export of iron ore and coal, two new growth centres were established. In addition, two minor development centres are being formed close inland from the coast, namely Tongaat, Sundumbili and the Isethebe area for KwaZulu in Natal, and the Atlantis-Mamre-Koeberg area on the west coast. Mossel Bay is expected to grow from a minor port into a major port with the exploitation of the oil-gas resources off the coast. East London, the only riverine port city can be expected to grow to support the Border and Ciskei development area. The rapid expansion of coastal manufacturing, processing and economic activities in these several areas can be expected to escalate industrial effluent and sewage handling demands on an unprecedented scale in the near future.

Future industrial development is planned to concentrate in regions based on priority needs, and more likely in a few growth potential centres rather than in a more diffuse form. Government would have thus more effectivity in allocating scarce resources on a limited scale to a point where private sector enterprise can be mobilised to develop it further. This conforms to short-term goals of creating regional growth points well away from present metropolitan centres, but having the capability to become future metropolitan areas within their own right.

4.2.2 Population and industrial growth areas

The following is a list of population growth and industrial growth areas, areas of population migration to the coast, industrial resettlement areas and coastal areas with perennial flow.

(i) Population growth areas:
  Cape Flats (False Bay east of Mitchells Plain)
  West Coast (Atlantis, Mamre)
  Saldanha
  Richards Bay
  Natal North Coast: Richards Bay to Umhlanga Rocks
  Garden Route area

(ii) Industrial growth areas:
  Durban harbour
  Richards Bay
  Mossel Bay
  Tugela and the interior of the North Coast
  Natal

Cape Town to Paternoster along the West Coast.

(iii) Population migration to the coast (growth):
   Richards Bay
   (Empangeni-Mtubatuba)
   Mossel Bay
   Cape Infanta
   Cape Agulhas
   Cape Flats east of Mitchells Plain
   Koeberg-Atlantis
   Saldanha
   Plettenberg Bay
   Wilderness

(iv) Industrial resettlement to the coast:
   Richards Bay
   Mossel Bay
   Saldanha
   Koeberg-Atlantis
   Paardeneiland (Cape Metropolitan).

(v) Areas of perennial river flow:
   Certain parts of the coast are characterised by perennial rivers lending themselves to ample water supply for processing purposes and a ready disposal point in or near the river mouths. These are the Great Berg River, the Klein Brak River, the Breë and Krom Rivers, the Bot River, the Buffalo River, the Great Kei River and the Mhlatuzi River (Richards Bay).

4.2.3 Development growth

The growth of future development along the South African coastline is likely to follow a set pattern. It is strongly differentiated, firstly according to population density and secondly according to the physiographic nature of the coastline. These factors will, therefore, determine the pollution potential of the coastline at various locations, and in turn the corresponding need for effluent disposal by means of ocean outfalls.

The following table lists coastal stretches, taken clockwise around the subcontinent, and gives an indication of the development trends and the possible pollution hazard as a result of those trends.

Coastal stretch	Remarks
Kosi Bay to St Lucia estuary. No effluent pollution hazard.	Pristine.
St Lucia estuary (inclusive) to Richards Bay (exclusive). Careful control of development hazards necessary.	Undeveloped but has potential. Attractive.
Natal North Coast - Richards Bay to Durban (inclusive). Population pressure, also industrialisation increasing. Effluent problems in future.	Rapidly developing but not saturated. Burgeoning urbanisation centres.

Coastal stretch	Remarks
Natal South Coast, Durban to Port Edward. Uniform population and industrial loading of coastline. Coping with effluent disposal. Ocean receptive. Control needed.	Highly developed but still balanced due to large number of smaller centres (favourable current and wind).
Transkei Coast (Port Edward to Kei River mouth.) No effluent pollution hazard.	Pristine coastline, harsh. Will not favour development.
Border: Kei River mouth to East London. Careful control of development hazards necessary.	Ciskei a strong development area. Will lead to limited coastal development.
East London to Cape Recife (Port Elizabeth) inclusive. Strict enforcement of guidelines necessary.	Developing. Near saturation at harbour cities.
Cape Recife to Cape Seal (Plettenberg Bay). No effluent pollution hazard.	Light, balanced development.
Plettenberg Bay to Mossel Bay (Cape St Blaize) inclusive. Proper effluent control required.	Large development potential of Mossel Bay including industrial and residential around gas recovery project.
Cape St Blaize to Cape Agulhas. Slight effluent pollution hazard in areas e.g. George, Knysna. Control necessary.	Pristine, but with areas designated for development.
Cape Agulhas to Cape Point. Effluent pollution hazard in False Bay areas, and harbour and estuaries (Hermanus, Gansbaai, Bot River). False Bay coastline not very receptive.	Pristine and scenic with local development.
Cape Point to Cape Columbine (Laaiplek). Serious pollution hazard if not strictly controlled (Table Bay, St Helena Bay, Saldanha, Camps Bay, Koeberg). Measures taken.	Heavy and rapid development scheduled, especially harbours. Strong conservation pressure.
Cape Columbine to Orange River mouth. Largely no pollution hazards.	Pristine, except for railway. Low development potential.

Coastal stretch	Remarks
Walvisbaai to Swakop River mouth. Bay pollution from fish canneries.	Harbour and city complex.

4.3 References

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PART 3 : EFFLUENT, POLLUTION AND RISK

CHAPTER 5

EFFLUENT CHARACTERISTICS

By A G S Moldan and J A Lusher

5.1 Domestic Sewage

Sewage may be defined as "the waste waters of a community" which include excreta and all other wastes from domestic processes. In certain cases trade effluents may also be combined in greatly varying proportions with domestic sewage prior to discharge. Ground water infiltration also finds its way into most sewerage systems.

The mixed sewage conveyed to a sewer outfall varies considerably in composition and flow, depending on a number of factors. For design purposes, domestic flow rates are assessed as 160 litres per capita per day in the South African context. A peak factor of three times these average daily flow rates may be applied to account for flow variation.

Recognising that the composition of sewage discharges is highly variable, an approximate guide to the characteristics generally encountered in South Africa is shown in Table 5.1 below.

TABLE 5.1 : General characteristics of sewage (IWPC, 1984)

Determinants			Average concentration
pH			7,3 - 7,4
Dissolved O_2			0 - 2 mg/l
Faecal coliforms			10^6 - 10^8/100 ml
Conductivity			60 - 70 mS/m
OA			60 mg/l
BOD			350 mg/l
COD			600 mg/l
NH_3 - N			40 mg/l
Kjeldahl N (TKN)			65 mg/l
Total phosphorus (as P)			13 mg/l
Suspended solids			350 mg/l
	(usually 60 -80% settleable)		
Oil/grease			60 mg/l
Metals (very variable)			
	Major inputs:	Pb	< 100 μg/l
		Cu	< 200 μg/l
		Zn	< 500 μg/l
		Fe	< 3 000 μg/l
Others:			
	Pesticide residues		< 20 μg/l
	Usual range		0,1 - 5 μg/l

From a human health point of view pathogenic micro-organisms included in a sewage discharge reflect the general health of the community. Municipal sewage might contain many pathogens, most notably *Salmonellas, Vibrio cholerae*, bacillary dysentery organisms, amoebic dysentery cysts, viruses, and *Ascaris* and *Taenia* eggs. Tests for total coliforms and faecal coliforms, and less often faecal streptococci, serve as indicators of the concentrations of sewage present in polluted water.

Numbers of coliforms in ordinary domestic sewage usually range between 10^6 and 10^8 per 100 ml, while concentrations of faecal coliforms amount to between 10 and 100% of the total coliforms. Enteric virus concentrations can vary from zero to many plaque forming units per 100 ml in ordinary municipal sewage.

The physical and chemical characteristics of sewage are also relevant : The settleable solids and colloidal material contained in sewage are generally widely dispersed when discharged to sea, but under conditions of reduced circulation, such as encountered in enclosed bays, these materials may settle out in the vicinity of the outfall. Being of organic origin, these particulates may exert an oxygen demand on the surrounding waters. This is generally of little consequence, however, in well oxygenated, open marine waters.

The chemical constituents which may be of environmental significance include organo-chlorine pesticides, trace metals, and the nutrients, nitrogen (in the organic and ammoniacal form) and phosphorus (mainly as phosphate). The nutrients are generally of little concern when discharged to open waters. Phosphorus, like nitrogen is ubiquitous in the natural environment. However, the discharge of phosphorus in combination with sufficient concentrations of other nutrients, to enclosed bodies of water, may stimulate plant life, leading to a deterioration of the aesthetic quality of the water by eutrophication. Trace metals and organic pesticides, discharged in sufficient quantities in sewage, may have an impact on the biota in the area of discharge. The implications of this are discussed in Chapter 6.

Generally, the composition and character of each sewage discharge differs so widely that an individual assessment needs to be undertaken for each situation.

5.2 Industrial Effluents

Industrial effluent characteristics are highly variable, being dependent on the raw material utilised in the plant, the type of process employed and the degree of effluent treatment. The main type of industries that discharge effluents to sea along the South African coastline include:

- Fishmeal and other fish processing plants
- Pulp and paper mills
- Fertiliser plants
- Petroleum refineries
- Fruit and vegetable processing plants
- Textile mills
- Aluminium production plant

5.2.1 Fish processing plants

Due to the nature of their activities, fish processing plants are usually situated on sheltered portions of the coastline where tidal flushing is reduced. Highly organic effluents are discharged into these areas during the processing of fish into fishmeal, oils and canned products. Fishmeal and oil producing plants in South Africa discharge an average effluent volume of 12,9 m^3/t of fish processed, with an average composition of 14,54 kg/t COD, 5,88 kg/t suspended solids, 0,36 kg/t nitrogen and 1,51 kg/t fats.

5.2.2 Pulp and paper mills

The characteristics of the effluent discharged from these plants are dependent on the type of raw material and the in-house processes used. The pulping process produces a far more noxious waste than that from the paper production process. A pulping plant situated in Richards Bay, on the Natal coast, using mainly pine and eucalyptus in a sulphate or kraft pulping process produces an effluent volume of 40 m^3/t of pulp produced. The average loads in the effluent expressed per air-dry ton of final product, are in the order of: COD 70 - 90 kg/t, TSS 15 kg/t, pH 2 - 4 and temperature 50 - 55 ^{0}C. Chlorinated organic compounds formed in the bleaching process are a significant cause for environmental concern in the discharge of pulp mill effluents.

5.2.3 Fertiliser plants

Phosphate fertiliser is produced by a series of phosphogypsum ore treatments followed by production of phosphoric acid. The waste constituents are dependent on the quality of the ore. One fertiliser plant, situated in Richards Bay, discharged approximately 6 500 tons of gypsum as a 10% slurry daily at the end of 1986. This waste contains sulphuric and hydrofluorosilicic acids, resulting in a greatly reduced pH (1 - 2). Other contaminants include trace metals such as copper, mercury, cadmium, lead, cobalt and chromium. Fluoride and phosphate are also discharged as components of the effluent.

The nitrogenous fertiliser, limestone ammonium nitrate on the other hand, is produced using the raw materials, ammonia, nitric acid and limestone. This process results in an effluent discharge in the order of 1 200 m^3/d, with a total nitrogen concentration (free and saline ammonia and nitrate) typically varying between 1 200 mg/l and 2 000 mg/l.

5.2.4 Petroleum refineries

The petrochemical industry can be subdivided into a number of production stages. These are crude distillation, cracking, reforming, visbreaking, petrochemical production, lubrication oil manufacturing and coke manufacturing.

Phenolic wastes are discharged from almost all steps of processing. After the crude oil fractionation, waste waters also contain sulphides, ammonia chlorides and mercaptans. Concentrations of phenols in flows from crude distillation may be 50 - 200 mg/l, cracking 20 - 100 mg/l and petrochemical 5 - 50 mg/l. Associated components of waste streams are BOD (up to 800 mg/l), suspended solids (300 mg/l), oil and grease (500 mg/l) and sulphides (60 mg/l). Benzines, toluenes and xylenes are also products of petroleum and petrochemical production, especially from cracking, reforming and visbreaking processes. Their concentrations may vary between 20 and 100 mg/l.

Waste flows may be considered to be in the order of 45 litre per barrel of crude distilled.

5.2.5 Fruit and vegetable processing plants

Effluents produced by the fruit and vegetable processing industry are highly variable, with the components and strengths depending largely on the type of fruit or vegetable being processed, the end product and the degree of screening.

Generally, the only chemical that is used in this process in significant amounts is caustic soda (NaOH) which is used in the peeling process and discharged with the effluent. Waste waters from this industry are high in COD and suspended solids. Depending on the process, the COD concentration may vary between 800 and 3 300 mg/l and the suspended solids 230 to 1 000 mg/l. The normal effluent flow rates for this type of industry in South Africa range from 200 to 1 500 m^3/d.

5.2.6 Textile mills

Textile mills discharge several different effluent streams from the various in-house processes, including alkaline wastes, chlorine wastes, acidic wastes, detergent wastes, fibrous suspended matter wastes and dye wastes.

A major textile mill situated close to East London produces a combined average saline effluent flow of 52 000 m^3/month. This effluent contains an average composition of 800 mg/l COD, 110 mg/l suspended solids and a pH of 10,1. The high pH value is due to the large quantities of caustic soda (26 500 litres monthly) that are used in the cloth washing process.

5.2.7 Aluminium production plant

The only aluminium producing plant operating in South Africa is situated at Richards Bay. This plant discharges in the region of 23 000 m^3 of effluent per month. The major contaminant in this effluent is fluoride which is released at concentrations in the order of 43 mg/l. Other components include suspended solids (40 mg/l), phenols (0,1 mg/l), ammonia (4,5 mg/l) and sulphides (0,2 mg/l).

5.3 Pretreatment of Effluents

Certain effluents cannot be discharged directly to sea. They will require some form of pretreatment in order to minimise or eliminate their impact on the marine environment.

The selection of treatment methods for municipal and industrial wastes prior to discharge needs to be based on the particular quality criteria and assimilative capacity of the receiving waters. The dilution and dispersion characteristics of the discharge pipeline, together with the subsequent dilution due to the ambient currents in the area need to be taken into account when assessing the requirements for effluent pretreatment. The economics of the various treatment options is another important factor that requires consideration.

If the requirement is to reduce the concentration of harmful components in the effluent to acceptable levels, the dilution and dispersion achieved by a properly designed pipeline may be considered as a viable treatment technique. A properly designed pipeline should ensure that the quality of the receiving waters is maintained in a state where concentrations of potentially harmful substances are kept below levels which could effect the natural ecological balance.

On the other hand, in certain areas, such as semi-enclosed bodies of water where flushing action is reduced, the total loading of certain components of the effluent on the receiving waters may be too high. In these cases the dilution characteristics of the pipeline will not be sufficient and some sort of effluent pretreatment must be considered.

The minimum basic pretreatment requirement for all domestic sewage and certain industrial wastes is the removal of coarse solids and floating material. A grit chamber should also be installed to remove grit and thus reduce the risk of blockage of the pipeline.

Methods of treating sewage in order to reduce the effects on the marine environment can vary from full-scale conventional treatment at a land-based sewage works, to the provision of only coarse screening and the removal of grit and grease. The selection of the treatment required is dependent on the quality of the sewage and the characteristics of the receiving waters, with an assessment being made for each case. For example, if raw, unsettled sewage is discharged into a zone where currents or tidal movements are greatly reduced, the suspended matter will deposit in the vicinity of the outlet, blanketing the bed and giving rise to anaerobic conditions. In cases like this, the bulk of settleable material should be removed before discharge to sea.

If conventional sedimentation is adopted, this will bring about a reduction in the heavy metal content of the effluent. The biochemical oxygen demand of the discharge will also be reduced due to sedimentation. However, due to the normal rate of dispersion and the degree of dilution in the sea, biochemical oxygen demand is unlikely to cause any significant oxygen depletion.

Many methods are available for the pretreatment of industrial effluents. As with the pretreatment and discharge of sewage, the selection of the method is dependent on the characteristics and quality of effluent to be discharged in each case.

5.4 References

IWPC (1984) *A Guide to the Design of Sewage Purification Works, Johannesburg.*

CHAPTER 6

POLLUTION AND RISK

By D J Livingstone

6.1 Characterising Pollution

Sea pollution, in the widest sense of involving any impurity, comprises the addition of anything at all that impinges upon the marine environment. Such addenda range naturally from rain water to drowned animals, soil and tree-trunks discharged into the sea by rivers in flood; and the sea has coped with this load for many millions of years.

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

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

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

6.1.1 Aesthetic considerations

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

(i) Will the outfall be sited remote from recreational/residential/sea-food industry areas? (Has the local Medical Officer of Health been consulted?)

(ii) Will the outfall be in or near a bay where the incoming tide can back-up the effluent or delay its dispersal in the open sea?

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

(iv) Is there a river-mouth or other water-way nearby? (Discolouration or turbidity generated by natural terrigenous waters will not serve to mask a faulty discharge; to the contrary, human nature will tend to blame any opacity on the proximate outfall. Conversely, an adjacent water-way carrying its own pollution load can incriminate an efficient works and outfall).

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

It cannot be too strongly emphasised: if the public can actually see or smell pollution, worse is invariably inferred regarding the risk to human health. Intelligent siting of a discharge pipe as a permanent sanitary feature on the coast, along with expert design criteria, can prevent costly procedures in the future such as the reconstruction or extension of an initially badly planned outfall.

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

6.1.2 Investigatory protocols

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

Initially, as wide a spectrum of tests as possible should be performed on the composition of the effluent, and on the anticipated discharge- affected area prior to construction or functioning of the outfall. Findings on the works effluent provide data for calculating and predicting dilutions, while the environmental surveys provide the background against which changes consequent upon development can be measured. (For an approach to such an investigation, see Reports 1983 and 1984).

In the marine environment, physical, biological and chemical measurements should be made along the shore, in the waters in the vicinity of the proposed discharge site and on the sea sediments in the area. The spectrum of surveillance should include:

(i) Physical oceanography and modelling of the target area which will be affected by the discharge.

(ii) Microbiology on effluents which include sewage (indicator organisms; parasite ova; other bacteria; viruses; coliphages; meio-fauna and benthic macro-fauna).

(iii) Chemistry (salinity; settleable solids; dissolved solids; KjN; COD; OA; pH; temperature; particle size; carbohydrates and other nutrients; petrochemicals; radiochemicals; toxic metals; chlorinated hydrocarbons and PCBs; any other deleterious substances).

(iv) Toxicity testing of the effluent to sensitive marine organisms.

(The investigations emphasised above represent the bare minimum of tests which can later comprise the routine protocol for regular monitoring. Obviously, if an effluent includes the discharge from e.g. a nuclear power station, tests for radiochemicals and water temperatures would be essential components in the subsequent routine).

Chapter 15 deals extensively with environmental monitoring and includes, *inter alia*, sampling strategies, chemical parameters and benthic community surveys.

6.2 Risks from Pollution

Risk is commonly assumed to mean the health-hazard presented by a marine discharge to humanity, but it also entails the risk to the marine biota and possible endangerment of economic assets and resources in the vicinity of the discharge.

6.2.1 Economic risks

The disaffection or alienation of residents, tourists and developers at a coastal resort because of an aesthetically unacceptable local marine discharge has been outlined (see above). However, an effluent may be invisible or macroscopically unobtrusive yet be of such an unwholesome nature that the marine fauna are adversely affected causing a depletion in the numbers of harvestable sea foods. Fishing grounds can be destroyed by a poisonous effluent; marine molluscs can accumulate substances or entities harmful to humans, or disappear from areas in which they once flourished. An excess of nutrients can also affect the sea and its sediments to the detriment of the biota and the food chain. Should an economically viable fishing or shellfish industry be eliminated by a noxious discharge in the vicinity, or should sea water intakes for processing plants be threatened, the economic consequences to the neighbourhood will obviously be serious.

6.2.2 Public health risks

Possibly as a result of humanity's relatively long association with epidemics and diseases capable of being categorised, and the accumulation of evidence - since the 19th Century - that microbial inceptors are the causative agents in most of these morbidities, speculation on health risks related to sea pollution is still mainly focused on the microbiological. Before examining this particular aspect more closely, it is as well to note that other components have more recently become the subject of scrutiny. For example, radioactive or thermal discharges from power stations, effluents from petrochemical factories, wastes rich in carbohydrates or which include toxic compounds in minute quantities can interfere with the metabolism of the adjacent biota causing unwelcome blooms, tainting or death with uncharted long-term effects in the food chain up to and including man (Brown, 1987).

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

(i) Sea bathing is in itself intrinsically hazardous: the risks of tissue-insult to various organs and autoinfections of mucus membranes (eyes, ears, nose, throat, etc.), of trauma (skin abrasions, cuts, broken bones, boating and board injuries in boisterous surf), even of drowning remain present to varying degrees.

(ii) Of all the illnesses human flesh is heir to - including waterborne diseases - the majority are contracted on land, by humans in contact with one another or animals on land, or from eating and drinking on land.

It is often difficult to maintain a balanced view on matters involving the environment: witness the amount of media coverage and public outrage devoted to discoloured coastal waters compared with, say, the prevailing numbness or indifference that greets the road-mortality statistics. A common practice when bacterial indicators of sea pollution are being assessed is automatically to ascribe to the indicators an additional role: that of presaging infective agents. This approach is far from proven in fact. The epidemiological data are deficient: the possibility of pathogens being present is no more than a coincidental inference when these micro-organisms have not actually been demonstrated and the indicators have. Many factors require consideration. For example, even at major resorts, with thousands of bathers entering the sea daily, holiday catering facilities cannot be excluded in the usually mild, self-limiting episodes of transient gastro-enteritis some vacationers succumb to (Moore, 1948; Mackenzie and Livingstone, 1983). Generally, too many germs have to be ingested - more than are normally present in a mouthful or two of aesthetically acceptable sea water - to produce a minimum infective dose (Moore, 1948; Mackenzie and Livingstone, 1968; Barrow, 1981; IAWPRC, 1983). A classic case described by Moore (1948) was the paratyphoid B outbreak in England popularly ascribed to sea bathing: the infective agent was in fact transmitted by bacteriologically contaminated ice-cream. Another difficulty relevant to micro-organisms with a particularly dramatic potential is exemplified by the rapid loss of virulence in haemolytic streptococci when released into the environment, reported by Perry *et al.* (1957).

Apart from surprisingly few well-authenticated cases involving grossly (i.e. macroscopically) polluted coastal waters (Anon, 1987b), and some particular localised instances (e.g. Cabelli, 1979), not many attempts to connect several ailments and infections with sea bathing can withstand rigorous scrutiny (Moore, 1971). Moreover, the extraordinary robustness of the healthy human constitution cannot be lightly discounted when a perspective is sought on the dangers of accidentally swallowing undesirable microbes in polluted sea water. The Illustrated London News (Horsford, 1987) commissioned a survey of London's leading gourmet restaurants. In each case, a small sample of the "speciality of the house" was surreptitiously obtained and submitted to a diagnostic laboratory for a total viable organisms count on one gram of the sample (a common public health criterion for foodstuffs). Some of the bacterial results (per gram) were: 12×10^6 in the foie gras, 34×10^6 in the paté de turbot, 4×10^6 in the steak tartare, $2,5 \times 10^6$ in the ratatouille and 9×10^6 in the salads and strawberries. These restaurants are well patronised by satisfied customers, the waiting list for table-bookings appears to be endless. Reverting to the marine environment, the epidemiological difficulties of demonstrating the sea to be a major vector or agent for disease transmission are formidable, despite global escalation of coastal development and population settlement.

Clearly, more epidemiological data are required before aesthetically acceptable sea water, which nevertheless includes microbial indicators of lowered water quality, can be labelled a health-hazard. However, in the case of edible shellfish, these animals are filter-feeders and efficient concentrators of bacteria, viruses, metals and pesticides, and as many precautions should be taken in their cultivation and harvesting as would be deemed necessary for any foodstuff. Here, common hygienic principles again apply: marine molluscs which are often consumed raw should not be cultivated or harvested in the vicinity of any waste-water discharge; in the absence of proven purification facilities, such practices should be prevented.

6.2.2.1 Epidemiological considerations

Epidemiology has been loosely described as the science of epidemics. More correctly it is defined as "the study of factors influencing the frequency and spread of disease" (Bullock and Stallybrass, 1983). In the isolation, identification - and in some cases enumeration - of microbes in the sea, it is obviously necessary that the water scientist or researcher specifies the objectives: is the work performed in order to measure water quality, or is it in pursuit of epidemiological considerations? Although there is some overlap, both objectives do not coincide. The former requires the employment of indicator-bacteria; the latter specifically targeted micro-organisms implicated in disease; although the recovery of a pathogen from a polluted site proves nothing more than that it is already circulating in the adjacent population. The risk of an infective agent in contaminated sea water causing disease must be weighed against the likelihood of the same disease being acquired by other routes (Moore, 1971). As an example, Hutzler and Boyle (1980) report that less than 1% of the total incidence of infectious hepatitis can be attributed to waterborne transmission generally (i.e. not confined to swimming). The authors go on to state that the incidence is greatly reduced by improving personal hygienic principles.

Gunnerson (1974) emphasises the need for more epidemiological investigations to evaluate bathing water standards (e.g. the EEC standards logically demolished by Gameson, 1979), but warns of the high costs of data collection. In South Africa, a year long marine epidemiological pilot survey was made involving underprivileged Transvaal children of all races on holiday at various charitable institutions in Durban. Initially, 241 children were screened on arrival at the coast: ENT swabs were cultured, and stool and urine samples subjected to microscopy and cultured. In all, 358 children were regularly tested after sea bathing - some experienced nearly three months of almost daily exposure to the sea - at three bathing sites including a tidal pool. Weekly clinical assessments were also made on all the children. Microbiological tests for *Escherichia coli*, ova of *Ascaris* and *Taenia* species, *Staphylococci aureus*, salmonellas and shigellas, were regularly performed on the recreational waters. Despite fluctuations in the water quality (at times seriously polluted by bacterial criteria: 90 Ml/d raw sewage were being discharged at the harbour mouth with the outgoing tides in that area), no correlative trends could be established between sea bathing and ENT or urinary tract or gastro-intestinal infections and infestations. No cases of hepatitis manifested themselves during the survey nor in the follow-up period (Livingstone, 1990).

Barrow (1981) reports the findings of a survey in which gastro-enteritis, upper respiratory infection and "total illness" were related to bathing: the bathers had fewer illnesses than the non- bathers. Barrow goes on to label microbial standards for bathing waters as irrelevant to public health. Gameson (1979) is similarly critical. At this point, it is salutary to add: the relatively modest expense of monitoring an effluent target area on the coast for pollution or to measure water quality will escalate prohibitively if unrealistic "health standards" based on dubious reasoning or guesswork have to be met prior to or after discharge.

The question of the minimum infective dose (m.i.d.) - the smallest number of a specific micro-organism required to effect clinical illness - is not without relevance in waterborne diseases in humans. Usually, large numbers of organisms (implying large quantities of sea water) have to be ingested to produce the illness. Obviously, such data are fairly uncommon as they require pure cultures (the microbial dose determined in advance) and human volunteers. Using such methods, the m.i.d. required to effect clinical salmonellosis using various serotypes in humans ranged from 125 000 to 16 000 000 via the oral route, and as low as 25 bacteria via the antral (maxillary sinus) route, in which the volunteer's antrum apparently acted as a living incubator to produce the dose that eventually effected a classical salmonellosis (Mackenzie and Livingstone, 1968).

Although it has not been possible to correlate the occurrence of pathogens in sea water with epidemiological evidence of an increased health risk from shellfish consumption, according to Fox (1985), oysters and mussels constitute food that is often consumed raw or partially cooked. Strict public health criteria for food should, therefore, be applied to these comestibles.

6.2.2.2 Microbial indicators

The human gut is host to between 400 and 500 species of bacteria (Pownall, 1986), and it is generally recognised that there is no ideal indicator organism (Report, 1976; Geldreich, 1977; Waite, 1985). Coliforms are not confined to colons; indeed, Waite (1985) questions the whole concept and validity of total coliform numbers. However, as these organisms do not occur naturally in sea water, it could be argued that they provide an approximate indication of the invasion of the saline medium by terrigenous or fresh (not necessarily sewer) water. Based on a summary of several workers, Prescott *et al* (1946) concluded that 95% of coliforms in faeces are *E. coli*. Gastro-intestinal microbes thrive in the dark at a constant temperature of 37 °C, in a highly nutritious matrix. The average weight of moist faeces excreted daily by the average individual is 100 g, some 20% to 30% of which is composed of undigested food residues, the remainder of water and bacteria (McCoy, 1971). *E. coli* is regarded as the most characteristic of the normal inhabitants of the healthy individual - their numbers approach 10^9/g of faeces. In fresh water, the time of survival of these organisms may be measured in weeks; in sea water, the period is measured in hours (McCoy, 1971) or days. In general, 50% to 60% of the daily faecal load is present in the crude sewage between 06:00 and 12:00.

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

Because indicators are usually present in far greater numbers than the pathogens, and because the demonstration of pathogens often requires sophisticated techniques and manipulations, the presence of the indicators is frequently taken to infer the presence of the pathogens (i.e. the attendant "health-hazard"). It is not always recognised that *E. coli* - normally a commensal in the mammalian and avian bowel - is also a pathogen, being a common cause of urinary tract infections and a secondary invader of skin and tissue lesions, while some serotypes cause "summer diarrhoea" in children.

In selecting a microbiological system, the aim should be clearly defined:

(i) If the detection of general increments of terrigenous water is required, the presumptive coliforms and the salinity should be monitored (many of the coliforms occur in soil and natural fresh water, but not in undiluted sea water).

(ii) If the objective is to detect sewage pollution with some degree of its intensity, the *E. coli* index scaled in orders of magnitude (i.e. up to 10, 11 - 100, 101 - 1 000, >1 000 organisms per 100 ml), plus the salinity, should be perfectly adequate. (The *E. coli* count on most raw sewages ranges between 10^6 and 10^8 per 100 ml; the salinity of clean South African coastal waters is between 34 ‰ and 36 ‰).

(iii) If the aim is water quality gradation or to establish a comprehensive background in a target area or to measure the more detailed aspects of coastal developmental impact and changes (see Reports 1983 and 1984), the addition of other indicators such as parasite ova, salmonellas, *Staph. aureus*, etc., to the *E. coli* index and salinity can prove useful. (*Staph. aureus* occurs as a naso-pharyngal commensal in about half the healthy population according to Moore, 1971; and is excreted by 25% of normal individuals according to McCoy, 1967).

(iv) In special cases such as epidemiological surveys, and if the considerable expense involved is regarded as warranted, viruses, mycobacteria, protozoan cysts, *Candida* yeasts, etc., can be pursued by sophisticated staff in appropriately equipped laboratories.

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

6.2.3 Risks from toxic substances

by A D Connell

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

(i) radionuclides;

(ii) metals and other inorganic materials;

(iii) persistent organics (in particular halogenated organics); and

(iv) petroleum hydrocarbons and petrochemicals.

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

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

Critical levels for a number of toxic substances, including toxic trace metals, organic compounds and others (e.g. ammonia and chlorine) are listed in Lusher (1984). Further data can be found in such sources as USEPA (1976) and California (1983). The USEPA recommended levels take into account not only levels for protection of marine communities, but also the protection of human consumers of edible marine organisms. Rapid and sensitive toxicity testing techniques are referred to in Section 6.2.3.1 below for test substances for which data are not available. Where several toxicants occur together at relatively high concentrations, their effects should be considered collectively: Together they might act synergistically or antagonistically. In practice, the results have generally proved toxicants to be additive.

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

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

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

6.2.3.1 Toxicity testing

Toxicity testing of effluents can be useful in several ways with regard to disposal of effluents to sea. Firstly, toxicity tests can be used to check the dilution requirements of an effluent in order to render it harmless to the test organism, thus providing a valuable guide to the design engineer regarding the dilution capabilities required in the design of the pipeline. An example of this was the Richards Bay pipeline where the maximum fluoride level in the boil over the pipe diffusers was set at 5 mg/l, the level indicated in toxicity tests to be safe for a sensitive species of crustacean reared through several generations in sea water containing elevated levels of fluoride (Connell and Airey, 1981).

A second use of toxicity tests in relation to pipelines, would be to assess the toxicity of effluent in an existing pipeline to establish the number of dilutions necessary to render the effluent harmless in a specific test with a suitably sensitive organism. This figure is then compared with the measured dilution capability of the pipeline. To further evaluate this information, environmental surveys of the area of discharge should be conducted to assess whether any impact can be detected and measured, particularly within communities of marine organisms impacted by the effluent. In this way valuable information can be gathered on the function of the pipeline, and this knowledge can be used to more realistically evaluate future pipelines in similar areas.

Toxicity testing can also be useful in assessing the options available regarding pretreatment of effluent before discharge. Pilot plant effluents, or effluents from "sister" plants can be evaluated by toxicity testing to monitor the effectiveness of the pretreatment options.

Toxicity testing can also be used to measure the quality of any water body. By comparing the results with controls of clean seawater zones of poor water quality can be identified, particularly in embayments and harbours. Salinity constraints must be taken into account in selecting an organism for toxicity testing in estuaries where undiluted waters are being tested.

Toxicity testing techniques most suited to such evaluative studies, using locally available species include:

(i) Ultra short term, 10 minute exposure of the sperm and eggs of sea urchins (*Parechinus* in the Cape, *Echinometra* in Natal) to dilutions of effluent, followed by mixing of the two and allowing fertilisation to proceed for 10 minutes before stopping the experiment with formalin. Development of the hyaline membrane is then assessed by counting under a microscope. The method is well described by Dinnel (1984).

(ii) Development of mussel embryos from fertilisation to D- larva, which takes 24 hours for *Perna perna* at 26 ^{0}C. At present, in Natal, this type of test is only satisfactorily performed when ready-to-spawn mussels can be collected in the field, usually May to October.

(iii) Development of eggs and larvae of marine fishes, when these are allowed to hatch and develop in low concentrations of effluent. Such studies are usually of less than two weeks duration. The experiment is usually terminated when the yolk sac has been fully absorbed, as first feeding of fish larvae is difficult in the laboratory, and mortality becomes unpredictable. In Natal the domino fish

Dascyllus trimaculatus has been used successfully in such tests (Connell, 1983) but other suitable species may be available, or pelagic eggs could be collected with nets at sea.

(iv) Microcosm studies in flow-through apparatus using mud from an estuary, spiked with the amphipod *Grandidierella* as described by Connell and Airey (1981). These microcosm studies are usually multi-generation, over three months or more, and are used to study long-term effects of certain effluents or toxicants. A similar test but using raw sea water containing planktonic larvae, and allowing these to establish benthic communities, is described by Hansen and Tagatz (1980).

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PART 4 : PRELIMINARY OUTFALL DESIGN

CHAPTER 7

PLANNING THE DESIGN

by G Toms and A P M Fijen, with contributions to 7.2(i) by J A Lusher

7.1 The Need for a Design Strategy

A potential discharger of effluent to sea by submarine pipeline faces a daunting series of challenges from the initial concept through to the final construction stages. Engineering difficulties in design and construction are complex and from the outset these must be considered alongside sensitive environmental aspects. A large number of specialists in vastly varying disciplines from pipeline materials experts to marine biologists must be consulted. They participate in the design process in a logical order as part of a co-ordinated, well planned design strategy.

The purpose of this chapter is to outline the main components of such a strategy. This is done with the South African situation in mind. The chapter will be structured to address the questions that a potential discharger, entering the design process for the first time, would be likely to ask:

* Who should I consult?
* What are all the aspects of the design?
* What data is required?
* How long will the complete design take?
* What will it cost?

Before embarking on the complete design process itself, it is important to realise that certain critical stages will be reached when the marine disposal option will be questioned and could be eliminated. One of these stages is reached at the end of the preliminary design phase. On completion of the preliminary design phase, the detailed design commences.

7.2 Who to Consult?

The point has been made that the design process is complex and requires careful co-ordination. Potential dischargers, typically municipalities or industries, would require guidance in this respect, and it would be prudent for a consultant and/or environmental specialist to be appointed to undertake the co- ordination. This should be done as early as possible in the design process. The specialist involved should have a sound knowledge of environmental and coastal engineering and should be well acquainted with the numerous regulations governing the discharge of substances to the marine environment.

A number of regulatory bodies must be consulted in order to obtain the necessary authority for the discharge of effluent to sea. Depending on the nature and locality of the proposed discharge, these include:

(i) **The Department of Water Affairs and Forestry**

The Department of Water Affairs and Forestry administers the Water Act (Act No. 54 of 1956). No legal standards specifically designed to apply to ocean pipeline discharges exist in South Africa. This means that concepts originally developed to control discharges to water courses inland have been carried over, with little modification, to the marine area. The legal requirements are embodied in section 21 of the Water Act and in terms of this, the Minister of the controlling department may, in terms of subsection 4, exempt any person from the requirements of subsection 1, namely to purify the effluent to be discharged to a standard to be determined by the Minister in consultation with the South African Bureau of Standards and to return it to the source from whence it came. This source specifically includes "sea".

In practice, in most instances in which it is reasonable to expect an effluent to be purified, the Minister has required the standard to be the General Standard of Government Notice 991 of 18 May 1984 to be imposed since this standard has been well tested for inland disposals and the supposition is that it is the easiest to apply to marine disposal. However, cases in which it is not reasonable to expect full purification are increasing rapidly, particularly with industrial effluents, and then the regulatory agency faces a dilemma: Since standards must be sought, what standards, if any, shall apply?

The answer in the recent past has been to involve as many expert authorities as possible, particularly those concerned with the environment, fisheries protection and health, as well as the South African Bureau of Standards. After considering possible objections and requirements, a compromise is reached and this then becomes the prevailing "standard". There is a growing body of opinion that this procedure must be replaced by consideration of marine water quality criteria prevailing at the point of discharge and the extent, if any, to which they are vitiated. As with standards, this concept still requires the exemptee to exercise proper control.

Exemptions permits have been considered in the light of Water Quality Criteria established as guidelines for the discharge of effluents to sea by the scientific community under the auspices of the South African National Committee for Oceanographic Research (SANCOR). These guidelines are contained in SANCOR Report No. 94 (1984) entitled "Water Quality Criteria for the South African Coastal Zone" (Lusher, 1984).

(ii) **The Department of Environment Affairs**

In terms of the Sea Fisheries Act, 1973 (Act No. 58 of 1973) it is an offence for anyone to discharge anything to sea which might be injurious to fish, fish food or seaweed or which may upset the ecological balance in the area. The Sea Fisheries Research Institute must be consulted in order to determine whether the substance to be discharged will have a detrimental effect on the marine environment.

Any person wishing to build a structure, including a pipeline, below the high-water mark, requires authority from the Department of Environment Affairs in terms of the Seashore Act (Act No. 21 of 1935).

(iii) **The Department of National Health and Population Development**

The discharge of effluents to the marine environment invariably has health implications which necessitate consultation with the Department of National Health and Population Development.

(iv) **Local and provincial bodies**

In many instances it will be necessary to consult with the local and provincial authorities concerned.

Since the discharge of effluents to the marine environment is primarily a matter concerning the Department of Water Affairs and Forestry, that Department should be approached in the first instance to assist in the co-ordination and involvement of the other bodies concerned.

As the design evolves so other bodies should also be consulted. With respect to regulatory and environmental issues, particularly concerning discharges into environmentally sensitive areas, it would be prudent to establish a steering committee with representation from a wide range of organisations. Such a committee could typically be constituted as follows:

Chairman:
- Prospective discharger

Supported by:
- Specialist engineering/ environmental consultant(s)

Invited participants:
- Department of Water Affairs and Forestry
- Sea Fisheries Research Institute (Department of Environment Affairs)
- Environmental Conservation Branch (Department of Environment Affairs)
- Local health authorities
- Local tourism authorities
- Ratepayers representative
- CSIR

7.3 What are all the Aspects of the Design?

The answer to this question will depend on the nature of the problems associated with a particular disposal scheme.

The design of a submarine outfall sewer generally consists of two phases: The preliminary design phase and the detailed design and construction phase. The preliminary design phase is shown in the flow-chart in Figure 7.1. Each of the constituents of the flow chart will be described in more detail in Chapters 8 to 12.

At the end of the preliminary design phase an assessment of the feasibility of the scheme must be made. At this stage cost comparisons with other options may prove that the ocean outfall option is too costly. If, however, the decision is taken to proceed, then the detailed design and construction phase commences.

7.4 What Data Collection is Required?

When an agency is considering a proposal for discharge in a new area it is important to recognise that a considerable data collection effort will almost certainly be required. The types of data required can be identified from Figure 7.1 as falling into two groups:

(i) Site characteristics (Chapter 8)

(ii) Effluent characteristics (Chapter 9)

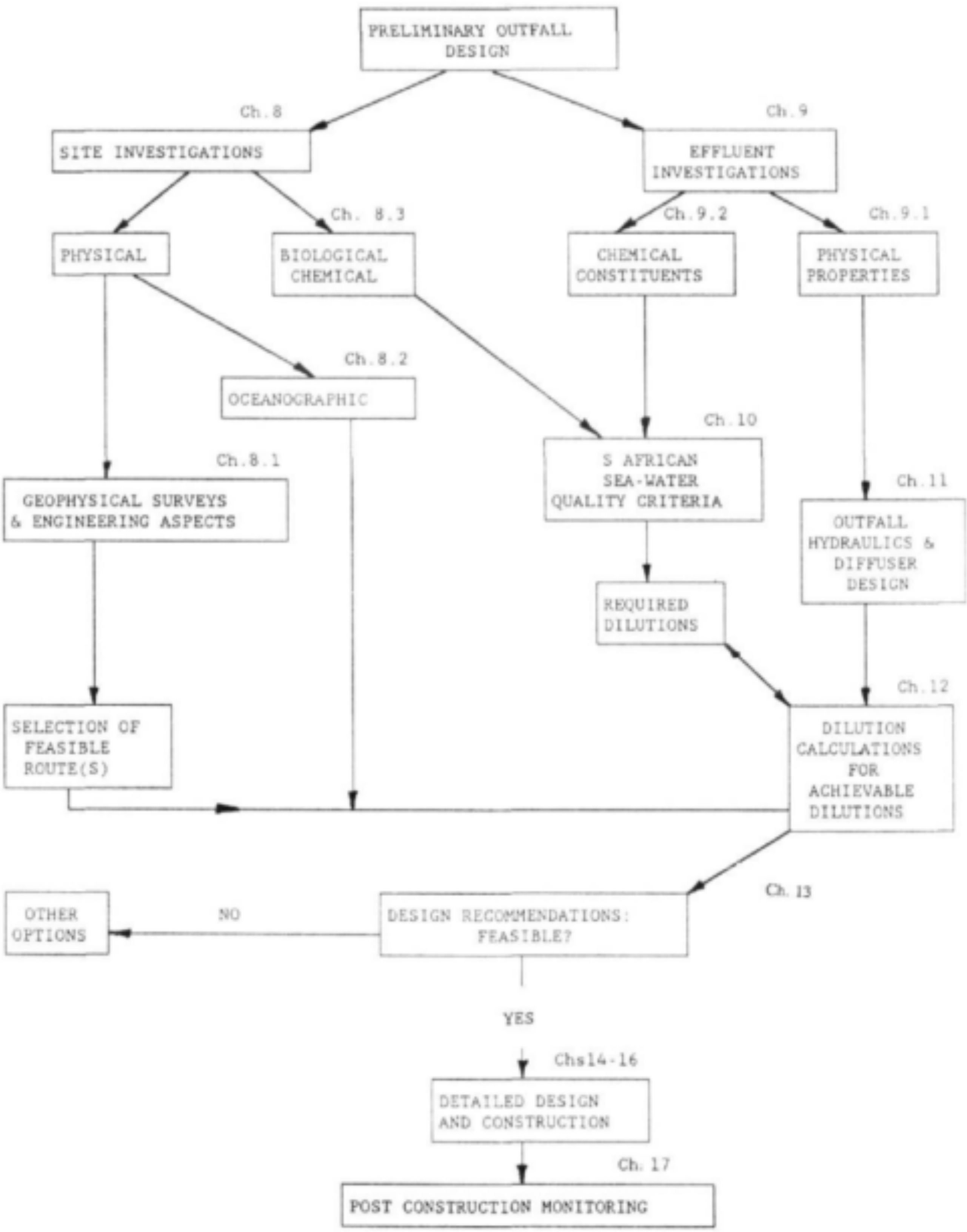

Figure 7.1 : Flow chart - Preliminary outfall design aspects.

The data collection to establish effluent characteristics, which is vitally important at an early stage, is the more straight forward of the two data collection efforts. The aim is to establish as accurately as possible the effluent constituents and physical properties. The former will affect the required degree of dilution and the latter will determine the outfall hydraulics and diffuser design.

Data collection to establish site characteristics is very time- consuming and costly and it is important to recognise this in planning the design schedule and estimating costs! The data collection to establish site characteristics will typically fall into three main categories:
Figure 7.1

(i) Physical data for the determination of the geophysical and engineering constraints of the site selection (Chapter 8, Section 8.1).

(ii) Physical data for the determination of the oceanographic characteristics of the site. These involve surveys (at sea) of currents, stratification, winds and waves (Chapter 8, Section 8.2).

(iii) Biological and chemical data for the establishment of design criteria and background levels (Chapter 8, Section 8.3).

The oceanographic data could take 6 to 24 months to collect depending on the size of the outfall scheme. Reasons for this duration are the fact that seasonal influences on the data can be great and should be detected. Remember that it is often preferable to conduct the oceanographic data collection ((ii) above) after the site selection ((i) above). Naturally in certain areas (such as close to harbours, etc.) a good deal of data already exists and, therefore, the collection effort for acquiring new data could be reduced accordingly. It may be prudent that some data collection, such as wave and wind data, should be continued throughout the subsequent detailed design and construction activities.

Finally, it will be recognised from subsequent chapters that the data collection work requires specialised equipment and knowledge. It would be wise to appoint specialised contractors for this work.

7.5 How Long Will the Complete Design Take?

From the initial concept to the end of the preliminary design activities, which will enable the feasibility of the scheme to be assessed, will take from 6 to 24 months, depending on the size of the scheme and the extent of relevant oceanographic data that exists upon which to base the preliminary design. Normally these activities take 12 to 18 months.

For the detailed design and construction a further 6 to 12 months would be needed. This will depend on the "timing" of sensitive construction features, such as jetty construction and pipe laying, with known calmer periods of the year (for example, November-January for the Cape, June-August for Natal).

The entire process from the initial concept to commissioning of the pipeline is likely to vary from 1 to 3 years.

7.6 What Will it Cost?

It will be obvious that the cost of an ocean outfall scheme depends on many factors relating to the scheme such as: Pipeline length, pipe size, pipe material, specific site conditions, construction methods etc.

NO. OPERATING AGENCY PLACE	TYPE OF EFFLUENT	AVERAGE QUANTITY [m3/day]	PRETREATMENT BEFORE DISCHARGE	PIPELINE MATERIAL WALL THICKNESS IN [mm]	PIPELINE LENGTH IN [m]	MAIN PIPE INSIDE DIAMETER IN [mm]	DIFFUSER CHARACTERISTICS: INSIDE DIAMETER IN [mm]	LENGTH IN [m]	NUMBER OF PORTS AND PORT SIZE IN [mm]	PORT CONFIGURATION	END CONFIGURATION	WATER DEPTH AT DIFFUSER IN [m]	YEAR OF CONSTRUCTION AND COST OF PIPELINE	MONITORING	COMMENTS
NATAL:															
1 Mhlatuze Water Board Richards Bay Buoyant line	Municipal and industrial (pulp mill + alum. smelter + fluorine effluent)	128,000	40 mm. bar screen, and mixing with seawater. Total intake of seawater about 46000 m3/day for the dense pipeline	HDPE , 40 concrete weights at regular intervals	4950	920	920 530	460 180	69x75 37x75		Closed	30	1984 R35 million for both pipelines	Annual diving surveys and regular environmental monitoring	
2 Mhlatuze Water Board Richards Bay Dense line	Industrial (mainly gypsum)	84,400		HDPE , 40 concrete weights at regular intervals	3830	820	820 630	40 120	6x75 14x75	45°	Closed	25	1985		This effluent is a dense effluent with a specific weight of about 1.06 g/cm3
3 Durban Corporation Umlaas Southern Works	Municipal and industrial	140,000	Screening, grit removal, primary sedimentation	Steel , 14 concrete encased	4200	1370	1370 1150 920	164 119 163	7x152 2x152+ 7x203 15x203+2x254		Closed with one port i.d. 300	60	1968 R6.12 million for both pipelines including ancillary work on shore.	Biennial diving survey and regular environmental monitoring	
4 Durban Corporation Bluff Central Works	Municipal and industrial	70,000	Screening, grit removal, primary sedimentation	Steel , 14 concrete encased	3200	1230	1230 1000 776	117 158 170	6x203 5x203 7x203+ 1x254		Closed with one port i.d. 300	55	1969		
5A Saiccor Umkomaas old pipeline (pre 1987)	Pulp mill effluent (mainly lignins)	70,000	Settling ponds and 1-inch bar screen	Mild steel rubber lined concrete encased	2310	914	914	112	15x102+ 18x114+ 15x127		Closed with one port i.d. 150	22	1967 about R1 million	Regular diving surveys and environmental monitoring	
5B Saiccor Umkomaas new pipeline (post 1987)	Pulp mill effluent (mainly lignins)	70,000	Settling ponds and 1-inch bar screen	stainless steel,10 concrete encased	3000	900	900	490	21x100+ 13x125+ 8x150+ extra 8x150	45°	Stainless steel door can be opened +1x200 port	30	1987 about R27 million		The extra ports are "scavenger" ports, to reduce settlement in the pipeline
6 SA Tioxide Umbogintwini	Titanium dioxide factory (mainly sulphuric acid)	2,500	Settling pond and coarse screen	Polyethylene, 25 with mild steel and concrete encasing, 50	1700	200	200	300	Originally 24x50 At present open end		Closed	30	1983 about R2.9 million	Regular diving surveys and environmental monitoring	Pipeline discharges a dense effluent Diffuser is made of mild steel
7 AECI Umbogintwini	Calcium chlorides Sodium sulphates	2,000	Lime addition then settling ponds	Mild steel, 12 rubber lined, and concrete encasing, 50	1700	200	NO DIFFUSER SYSTEM, OPEN END DISCHARGE					33	1966 Unknown	Regular diving survey	This is the old SA Tioxide pipeline. First discharge was short surfzone pipe
EAST CAPE:															
8 Port Elizabeth Municipality Fish water flats	Municipal	40,000	Effluent treated to general standard, with bacter. exemption	Asbestos-cement,58 concrete encased	170	1700	There is a discharge box at the end of the pipeline with 8 openings 450x450 mm. discharging horizontally					L.W.-2m.	1976 about R1 million	monthly bacteriological monitoring on beaches	
CAPE:															
9 Cape Town Municipality Green Point	Mainly municipal less than 1% industrial	34,000	Screening, maceration, hypochlorate addition	HDPE , 50 concrete collars at regular intervals	1700	700	700 630 500 355	12 40 40 40	4x125+ 4x125+ 4x150+ 4x150		Closed with sludge opening	28	1985 about R7.8 million	Regular diving surveys and environmental monitoring	
10 Cape Town Municipality Camps Bay	Municipal	1,800	Screening, maceration	HDPE , 23 with mild steel encasing and grout in between	1350	354	354 285 222 143	17 24 12 12	3x92+1x102+ 1x102+1x115 +1x115+ 1x115		Closed	24	1977 about R12 million	Regular diving surveys and environmental monitoring	
11 Fedmis Milnerton	Effluent from fertilizer factory (mainly ammonium salts)	1,000	Settling ponds	HDPE , 12 concrete encased	330	141	141	10	Originally 12x72 At present 2x72		originally open, now closed	5.5	1966 Unknown	Regular diving survey	Diffuser is constructed in stainless steel
12 Caltex Oil Milnerton	Oil refinery effluent	2,000	Skimming, settling, some chemical treatment	Mild steel , 6	520	203	200	28	5x100		Closed, but can be opened	11	1965 Unknown	Regular diving survey	Diffuser is flushed of any settled material once a week

Table 7.1 : Offshore pipelines discharging effluent beyond the surfzone.

The data collection exercise can vary from R100 000 to R600 000 depending on the nature and extent of information already available (1989 costs).

A summary of the existing ocean outfalls in South Africa, including construction costs, is given in Table 7.1 (Fijen, 1988).

At the end of the preliminary design phase it should be possible to make an accurate estimate of the construction costs of the proposed pipeline.

7.7 References

FIJEN, APM (1988) A review of marine disposal practice in South Africa. WRC Report No. 213/1/88. Pretoria.

LUSHER, JA (ed.) (1984) Water quality criteria for the South African coastal zone. SA National Scientific Programmes Report No. 94. CSIR, Pretoria.

CHAPTER 8

SITE INVESTIGATIONS

by G Toms and W A M Botes

This Chapter will describe the following in more detail:

(i) **Geophysical surveys** and engineering aspects for selection of a feasible route (Section 8.1).

(ii) **Oceanographic surveys** to establish the sea-water properties which influence effluent transport and mixing (currents, salinities etc.). (Section 8.2).

(iii) **Biological and chemical surveys** that characterise the region and establish background levels that can be used with the South African Water Quality Criteria (Lusher, 1984) (Section 8.3).

8.1 Selection of a Feasible Route

The requirements for a feasible outfall pipeline route can be summarised as follows:

(i) Avoidance of irregular, rocky sea bed.

(ii) Suitable accessibility from shore.

(iii) Optimal siting with respect to drainage or pumping of effluent to enter the outfall (Section 8.1.2).

(iv) Avoidance of disturbance of environmentally sensitive areas (Section 8.1.3).

How these requirements can be investigated is outlined below.

8.1.1 Geophysical surveys

The major tools available to the designer to ensure avoidance of irregular, rocky sea-bed features are geophysical surveys; that is, hydrographic, sidescan sonar, seismic and diving surveys of the sea bed. In all cases, prior to the commencement of any survey, all sources of existing geophysical data relating to a prospective site should be reviewed to avoid duplication. Published depth charts ("fair-charts") are available from the Hydrographer's Office of the South African Navy while, especially close to harbours, other sea-bed data are often available from the South African Transport Services or the CSIR (EMATEK).

Hydrographic surveys detect the sea water depths using echosounders often operated from a ski-boat (Figure 8.1). In calm conditions an accuracy of ± 20 cm can be achieved. Depths are recorded as the ski-boat travels predetermined parallel lines normally perpendicular to the coast. To review a general area, lines at 100 m spacing would be required whereas within a specific favoured route 25 m spaced lines may be preferred at a later stage. Efficient position fixing is essential and this is often achieved with electronic systems consisting of a master unit on board and several shore stations.
Corrections for tidal height and swell interference are also necessary. Data loggers, computers and plotting facilities are available to prepare contoured plots or a map of spot depths soon after the survey (Figure 8.1).

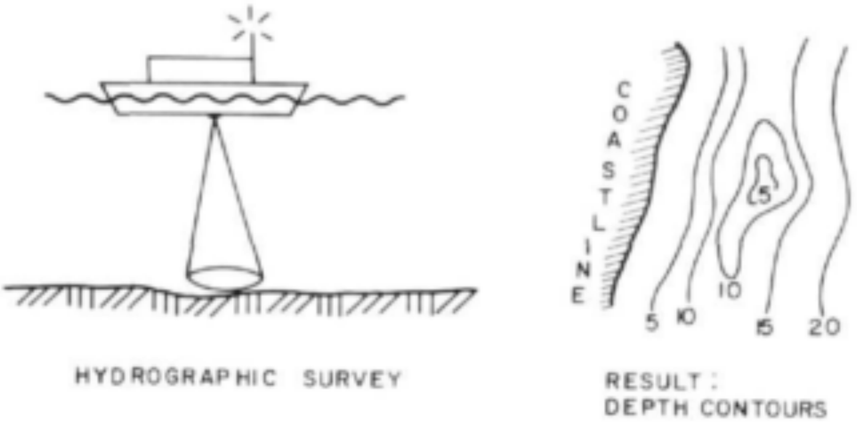

Figure 8.1 : Hydrographic survey. Result : contour plan.

Sidescan sonar surveys detect the surface texture of the sea bed and in so doing allow areas of sand, gravel or rock to be mapped (Figure 8.2). A skilled interpreter can also detect features such as wrecks, anchors or other pipelines in the survey area. The instrument is called a sidescan sonar since it operates by transmitting a very narrow sound beam, normally with a spread angle of 1,20 to

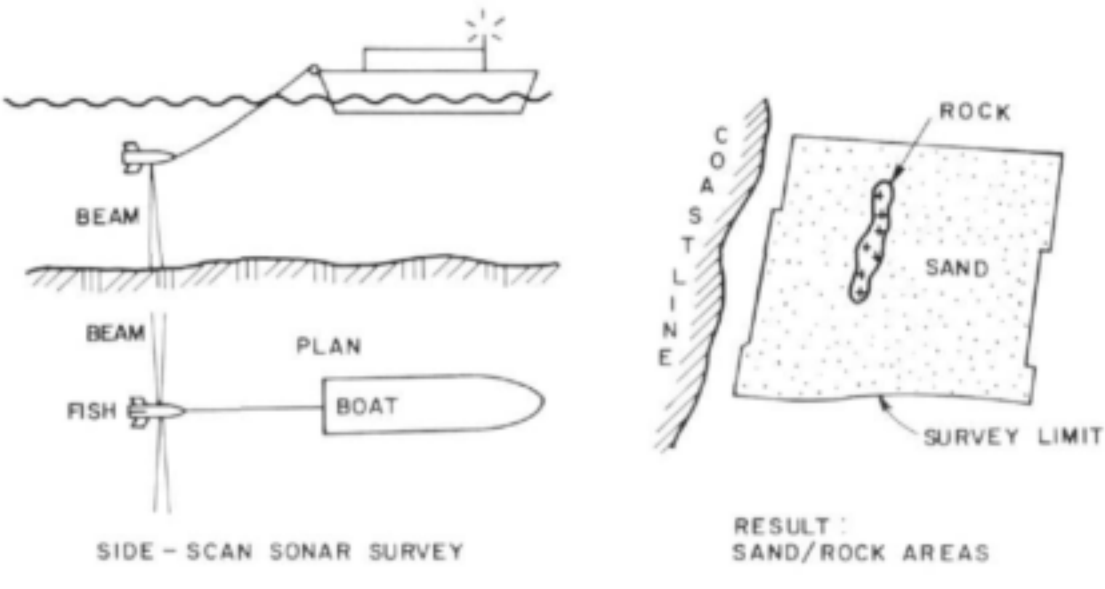

Figure 8.2 : Sidescan sonar survey. Result : sand/rock areas.

either side of a sound source. This sound source, called the "fish", is towed below the water surface behind a survey vessel. The fish also receives the sound waves reflected from the sea-bed features and transmits these to the vessel where they are plotted. As the fish is towed along a co-ordinated survey line, a map of the sea-bed reflections is produced covering a strip up to 250 m wide on either side of the fish's path. Corrections for distortion due to swell, ship speed changes, course variations, turning etc. can be done manually or by sophisticated equipment. The composite result from a number of overlapping lines is equivalent to an aerial photograph of the sea-bed features. Shadow-lengths behind sea-bed obstructions can be used to interpret the height of the obstruction or outcrop.

Seismic surveys are conducted to obtain information from beneath the surface of the sea bed (Figure 8.3). Typically, a sound source or transducer is towed behind the survey vessel either on a surface float or below the surface. The transducer beams sound down into the sea bed and sub-bottom features reflect the sound back towards the surface. Reflected sound waves are received on a hydrophone array which is also towed from the boat. (A hydrophone is a sensitive underwater microphone). The received sound is then transmitted from the hydrophone to a plotter on the survey boat as the boat travels along a co-ordinated predetermined path. Of all the geophysical surveys this is normally the most expensive and time-consuming as well as the most difficult to interpret. Various sound sources can be used depending on requirements concerning the depth of penetration below the sea bed, the degree of accuracy of plotting the depth of sub-bottom features and the

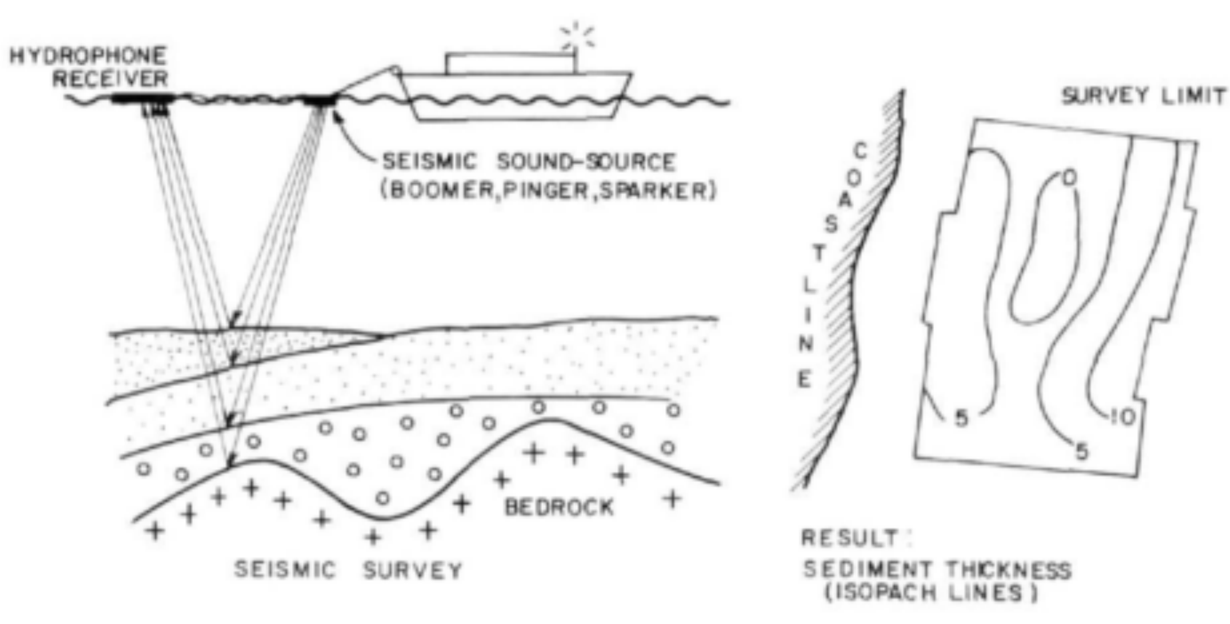

Figure 8.3 : Seismic survey. Result : sediment depths.

resolution. In general, the greater the required penetration, the higher the power of the source and the lower the frequency of the sound wave, and unfortunately the less the resolution of the resulting plot. The following summarises some properties of the better known sound sources:

Pinger

- 3 to 5 m depth penetration with 0,5 m resolution.
- Very useful for mapping soft, superficial sediment thicknesses.

Boomer

- 30 m depth penetration but 2 to 3 m resolution.
- More useful for deeper reflectors.

Sparker

- Up to 2 km depth penetration but poor resolution.
- Used in gas/oil strata detection.

Naturally, a pinger survey or a combination of pinger and boomer surveys is sufficient for detecting the depth of sediments into which an ocean outfall can be founded since only the top 3 m is really of interest.

Due to the effort and complexity of the seismic surveys it is wise to narrow down route options using **hydrographic and sidescan sonar** surveys. These will allow one or several suitable corridors to be selected within which seismic work can be done. Following the seismic survey (or occasionally in place of it in the case of a shorter or smaller outfall), **diving surveys** can be done to provide confirmation of sea-bed features, the retrieval of outcropping rock samples to be tested for hardness (dredging or blasting), and the resistance to penetration of the surface sands. This latter survey is usually done by divers operating water-jet probes up to 3 m long. In soft surface sediments these will easily penetrate completely but should such a layer be only 1 m thick overlying harder gravel or rock these probes will detect this. Such 'probing' surveys are particularly useful close inshore where, due to shallow depths or the presence of breaking waves, the geophysical survey cannot be done. This 'gap' between the beach and nearshore geophysical surveys is the problem area for reliable route selection and often diving surveys are the only source of information available in that area. Figure 8.4 shows a typical result of a detailed geophysical survey conducted for the Richards Bay outfalls in 1982 (CSIR, 1982).

8.1.2 Engineering considerations

In the selection of a feasible pipe route, engineering considerations, apart from the availability of a rock free sandy corridor at sea, must be taken into account. These will include suitable accessibility from the shore to the submarine corridor, the availability of an adjacent foreshore area for construction facilities and optimal location of the sea route in relation to the natural land drainage route which would minimise effluent pumping requirements. Naturally each of these considerations should be thoroughly investigated, the first two in discussion with potential outfall contractors and the latter in discussion with a local consultant or the authorities responsible for drainage in the area or effluent delivery. Proposed outfall construction techniques which may require a temporary pipe launching jetty to be constructed could also have a profound effect on the choice of a feasible pipe

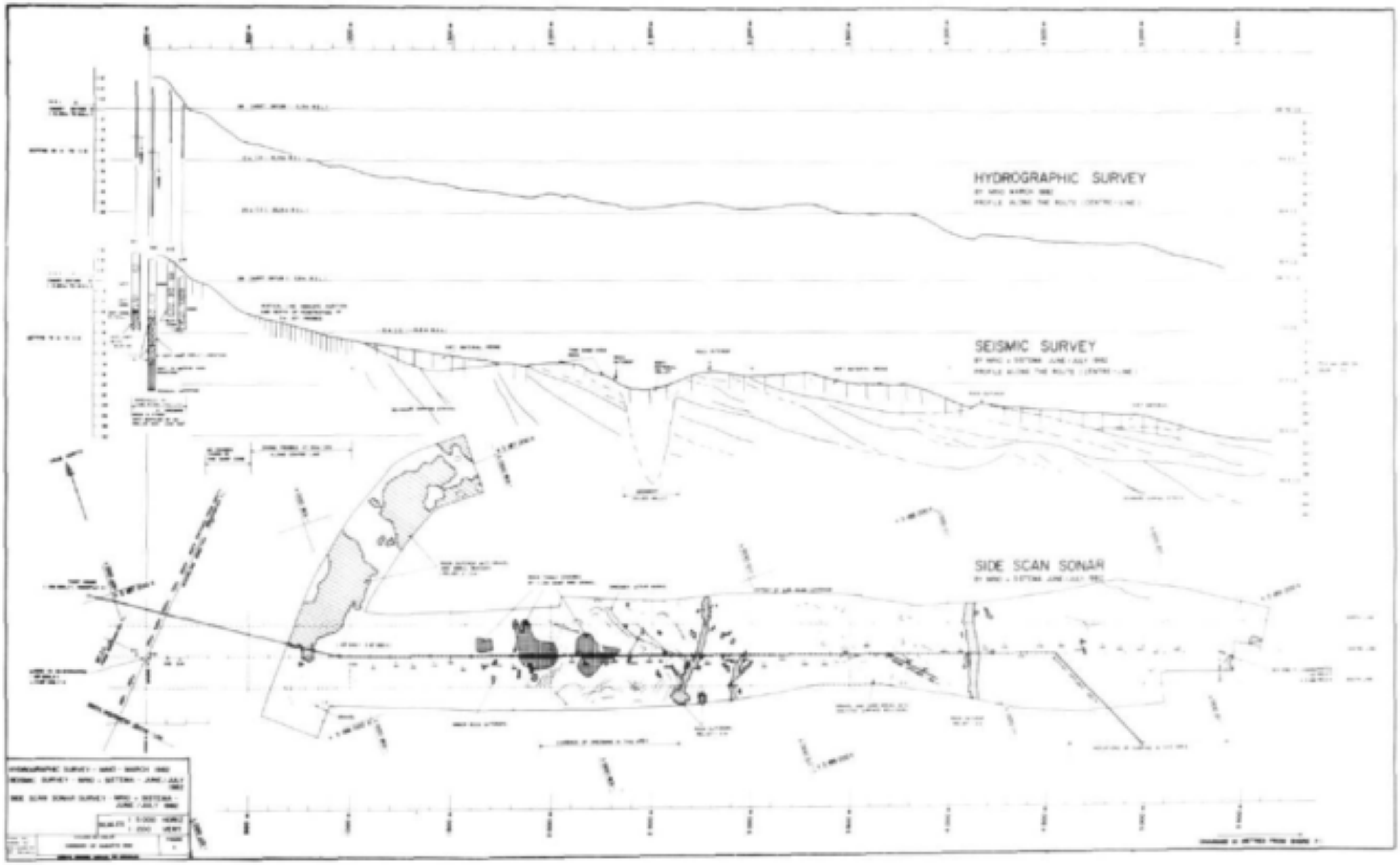

Figure 8.4 : Richards Bay surveys.

route. Also important is the need to avoid harbour entrance channels, popular ship anchoring areas, fish trawling grounds and dredging or nearshore mining activities. These could all result in structural damage to the pipe after installation. There are many examples of this occurring in the past.

Finally, wave attack angles should be considered in specific cases. Laying the pipe perpendicularly to approaching wave fronts will minimise associated wave forces on the pipeline if it is exposed on the sea bed.

8.1.3 Other considerations

Having discussed the engineering requirements at sea and on land the other considerations influencing the selection of a route for an ocean outfall pipeline include aesthetic and ecological aspects.

Aesthetically, it is desirable to be able to bury the outfall pipe as it crosses beach areas and to ensure that any auxiliary buildings such as pumping, screening or degritting works are as unobtrusive as possible.

Ecological aspects will naturally be a major consideration in the design and location of the outfall pipeline. They can influence the path of the outfall route directly, for example, to avoid trenching the pipe through a sensitive reef.

8.2 Establish the Oceanographic Properties of the Site

Assuming that a specific route has been selected the oceanographic properties of the sea that would influence the dilution of effluent released from the diffuser, and its subsequent transport and dispersion away from the diffuser, need to be established. Such properties include currents and stratification. Winds, in many cases an important driving mechanism for nearshore currents in South Africa, are also recorded. Waves are recorded since wave properties will influence the detailed design and construction activities.

Before embarking on any measurement programme it is imperative to ensure that all existing data for a specific area has been thoroughly researched and documented.

8.2.1 Currents

The measurement of currents at sea is complicated by the strongly varying nature of currents from location to location and with depth and time. Local effects due to wind forcing in shallow water can be dominated by, or can predominate over, other influences which move water. Such water movements include the Agulhas current flowing down the east coast from the northern Indian Ocean or, closer to shore, deflected surf zone longshore wave currents or rip currents. Currents vary with water depth at some locations in both speed and direction and currents measured during a particular wind condition may be unrelated to that condition since they may still be subject to the inertia of a previous wind forced circulation. All these and other effects require that any current measurement programme is carefully designed to avoid bias. For example, around any prospective outfall discharge, a grid of current sampling stations must be set up such that measurements can be made at various depths and locations. The measurement programme must also be arranged to adequately reflect seasonal and other cyclical current trends and have a typical duration of 12 to 18 months.

Ideally, continuously recording current

meters moored at at least three depths in the water column at each grid location would completely and adequately describe the current field. However, constraints which prevent this are many, among them being costs of meters, reliability of meters near the surface, and logistical difficulties in operating several dozen simultaneously recording current meters. Compromises are therefore made, producing information which although not ideal, is sufficient for most design procedures. The compromise measurement programme typically consists of:

- Several moored continuously recording current recorders (close to the bottom).

- Current profiling from a survey boat at regular intervals (weekly, monthly) on each grid point.

- Regular surface and subsurface current measurements using drogues, dye or drift cards.

Each of these current measurement techniques will be briefly discussed below.

(i) **Moored continuously recording current meters** are self contained recorders that measure the current speed and direction at a specific location (Eulerian data). The information is measured and recorded by the instrument typically at 15-minute or 30-minute intervals. Information is stored on cassette tapes or solid state memory for later analysis. Moored current meters use a variety of methods for sensing speed and direction and it is important to understand the limitations and performance of each type when designing the current recording programme.

Rotor-type meters measure the current speed by the accumulated number of rotations of a rotor in a specified time interval. Directions are sensed by a large vane orientation with respect to an in-built magnetic compass. Savonius rotor meters are the most common in use in South Africa. Such meters are used at typically a 15-minute sampling rate and are exchanged monthly or two-monthly due to limited tape storage capacity, battery life or the presence of marine growth on the rotors. A serious limitation of such meters is their inability to distinguish between ambient currents which act in one direction and would transport effluent away from the outfall and orbital currents beneath waves which are ineffective in transporting effluent out of the area due to their oscillatory nature. These oscillating orbital motions beneath passing waves are considerable and even in depths of 40 m they can mask the ambient current information as shown in the following table, which shows maximum horizontal orbital velocities (cm/s) at the sea bed:

Wave		Wave height (m)			
Depth	Period				
(m)	(s)	1	2	3	4
20	14	31	64	97	131
30	14	23	46	69	92
40	14	18	36	54	71

An illustration of a commonly used savonius rotor meter, the Aanderaa RCM4, and a typical mooring configuration is shown in Figure 8.5, along with other current meters.

In South African coastal waters on the south and west coasts the ambient currents are not dominated by a strong

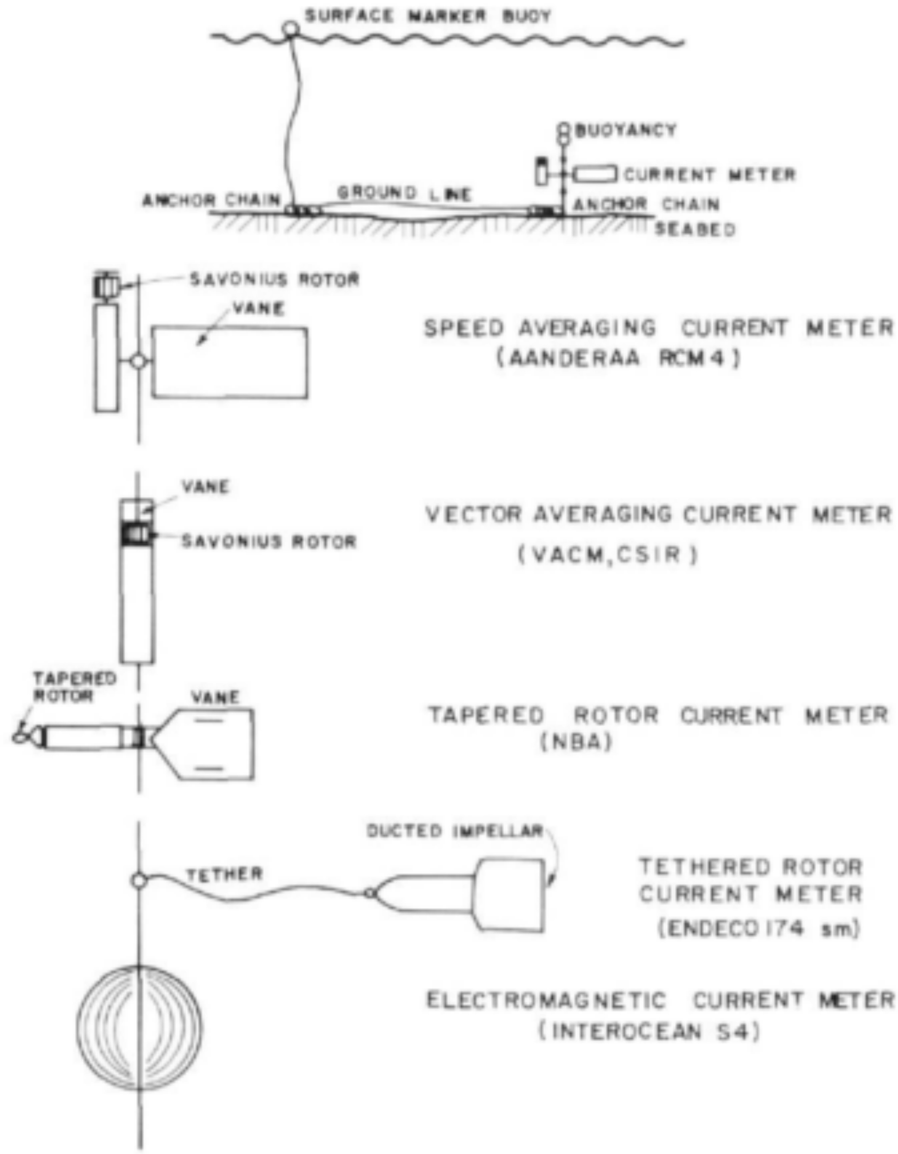

Figure 8.5 : Illustration of some continuously recording current meters.

flowing ocean current but by slower variable wind driven currents often in the range of 5 to 25 cm/s. This fact coupled with the considerable orbital motions caused by long (> 12 s) swells approaching these coasts has necessitated the use of improved rotor or other types of meters. Improvements of the rotor response and the rapid detection of rotor speed (e.g. every half a revolution) in the Vector Averaging Current Meters (VACM) are proving partly successful in avoiding wave interference as are the tapered rotors mounted horizontally on torpedo-shaped bodies (e.g. NBA) or the tethered rotor meters such as the Endeco 174. These are illustrated in Figure 8.5. One disadvantage of all rotor-type current meters, however, is the susceptibility to marine growth on the moving parts which naturally hampers operations. On the east coast this is more severe, sometimes being problematic after only several weeks.

Electromagnetic meters make use of the principle of Faraday's Law of electromagnetic induction. An electromagnetic field is produced around a sensor and the water flowing past the sensor is the moving conductor. Electrodes placed on opposite sides of the sensor then detect the potential difference between them and in the meter this is converted to a current speed. By arranging two pairs of electrodes at 90^0 to each other two current components can be deduced which are converted, via a magnetic compass in the instrument to a resultant current speed and direction. The great advantage of these meters is their ability to rapidly detect and memorise current vectors (e.g. at 1 s intervals) allowing averaging over 1-minute intervals or more to eliminate orbital velocity influences on the currents. A further advantage is the lack of moving parts and therefore susceptibility to marine growth or wear. Disadvantages include the great cost of these instruments. Often, conversion of measured data into a usable format has proved difficult in the past, but recent advances in data capture such as the ability to off-load data directly onto a personal computer (Interocean S4) have solved this. Other meter types such as the acoustic and tilting meters are little known in South Africa and rarely used.

Despite their disadvantages rotor type meters such as the Aanderaa RCM4 are used on the east coast and the NBA on the south and west coasts. In interpreting the results, great care is taken to recognise and take into account the interference from wave action. Naturally this interference decreases with depth and such continuously moored current meters are only used close (1 to 2 m) to the sea bed in water depths beyond 30 m where a reasonable indication of ambient bottom current vectors can be achieved.

Typical results from moored continuously recording current meters, after analysis are shown in Figure 8.6. These include a time-series plot, current rose and scatter diagram.

(ii) **Current profilers**. Due to difficulties in sampling currents with moored recorders it is normal practice to employ an extensive direct current sampling programme from a survey boat on predetermined grid locations around an outfall. Direct sampling allows currents to be detected throughout the water depth. The profiler current meter is lowered to a specified depth and the survey boat is allowed to drift during the current measurement. Accurate position fixing of the survey boat with electronic equipment (e.g. tellurometer) is essential since the ship's drift vector must be vectorially subtracted from the measured velocity to produce the true ambient current vector. Figure 8.7 illustrates the procedure further. Currents are sampled throughout the depth at approximately 5 m depth intervals. Also shown in Figure 8.7 is the typical analysed result from such recordings.

(iii) **Surface and subsurface current recordings** are made by direct measurements by tracing the movement of floats (Lagrangian) in the current field at or near the diffuser. Floats consist of either drogues or drift cards. Dye patch observations are also sometimes used.

Drogues are surface or subsurface floats identified by a flag number which drift with the current. Figure 8.8 illustrates surface and subsurface drogues. The subsurface drogues are used up to 10 m below the surface. Drogue pairs (surface

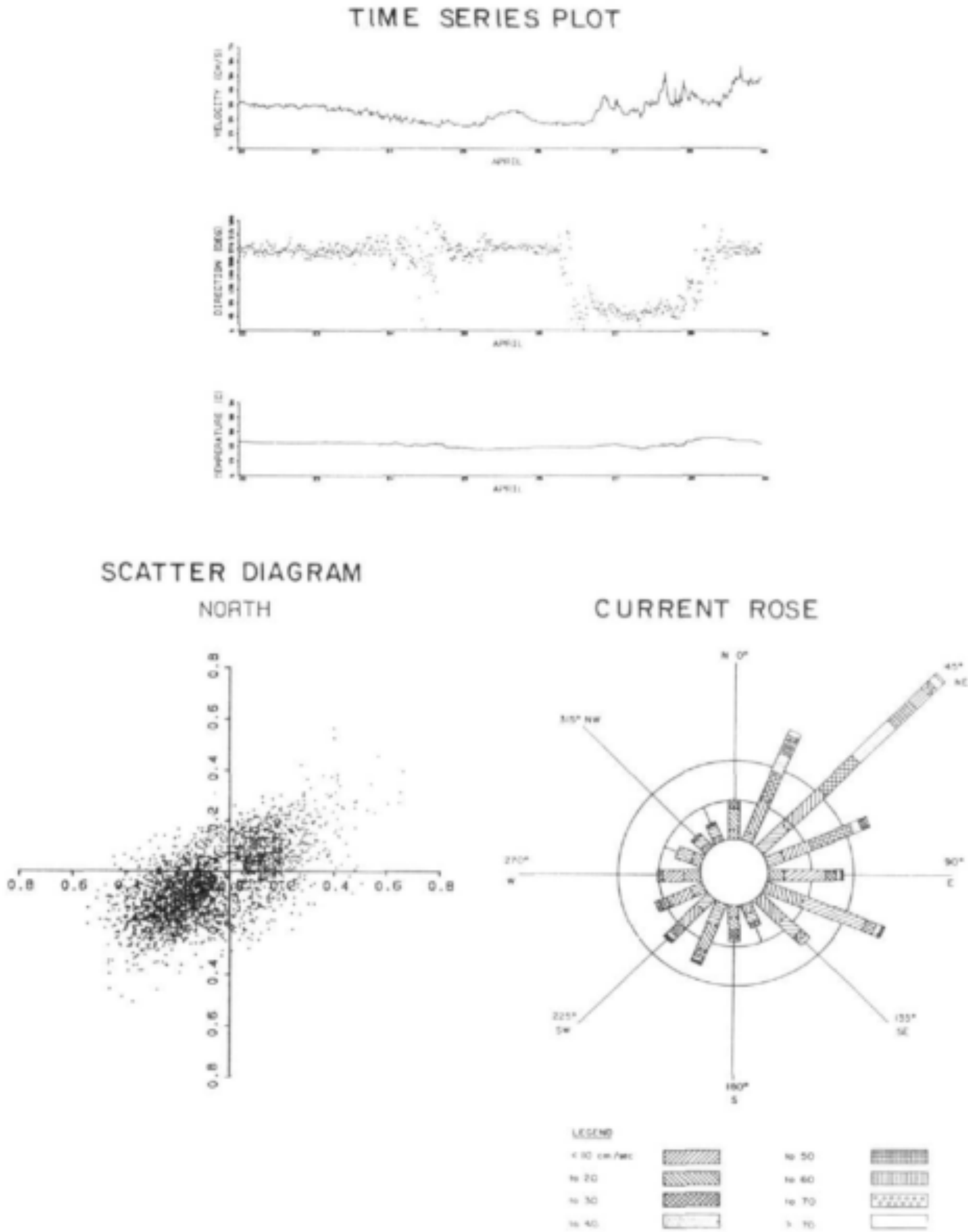

Figure 8.6 : Typical results from a continuously recording moored current meter.

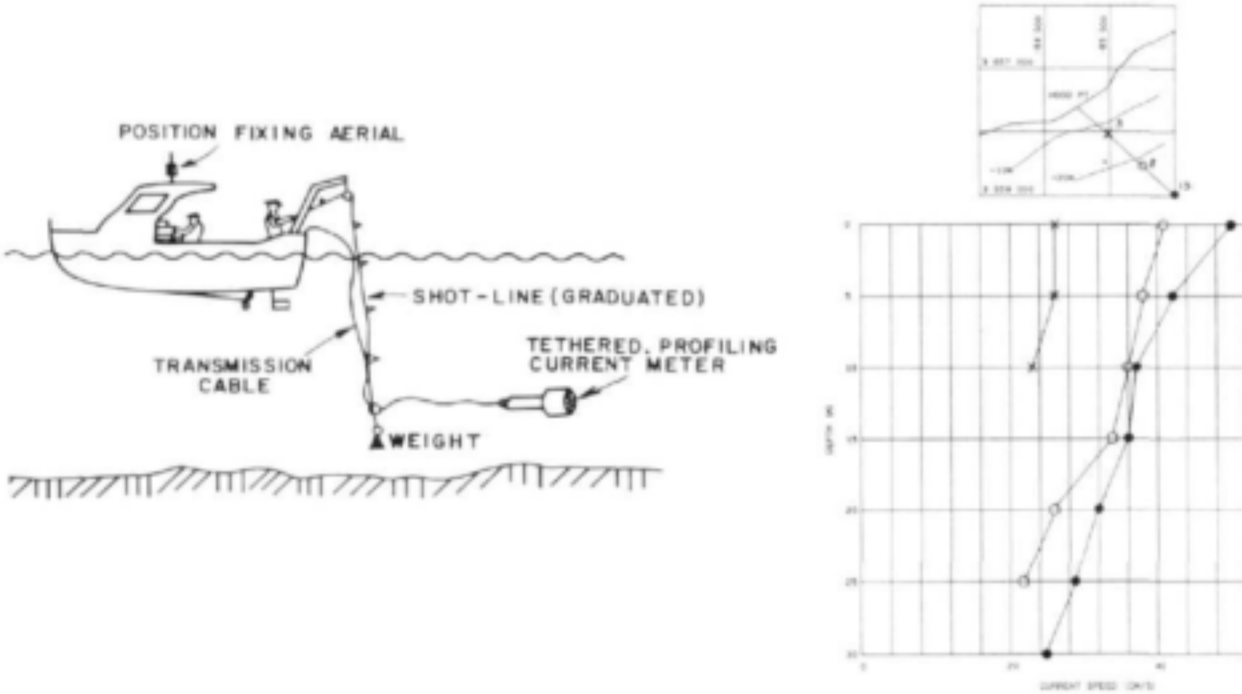

Figure 8.7 : Typical results. Profiling current meter.

and subsurface) are released at strategic locations around a proposed pipeline diffuser to detect the probable current pattern which transports the effluent away from the outfall. The drogues are tracked by a survey boat which visits each drogue several times during the drift period (several hours to one day). Locations and times are then recorded and plotted on a map of the area to provide surface and subsurface current vectors for the particular day of observation. Vectors from various drogues are then combined to produce a good indication of the general current pattern on that particular day.

Radio drogues have recently been developed that transmit a signal to the shore at a predetermined frequency for each drogue. At three shore stations directional receivers are tuned to receive this signal and thereby provide an accurate intersection of the drogue's location. These drogues are more expensive than the normal floats described above but they allow great savings in time and effort. After initial deployment they can be tracked over large distances up to a range of about 50 km for a week or more without expensive boat work. Vectors obtained with these radio drogues are also superior in indicating current patterns due to the longer tracks thus produced. Figure 8.8 also shows the radio drogues and an example of a measured result. In the design of drogues the influence of the wind on the above-water part and the influence of the current on the nylon line connecting the float to the vane of a subsurface float has to be minimised to ensure that current measurements are not seriously affected (Botes 1988).

Drift cards are plastic cards typically 10 x 15 cm^2 which are dumped 200 at a time at a specific location. The fate of

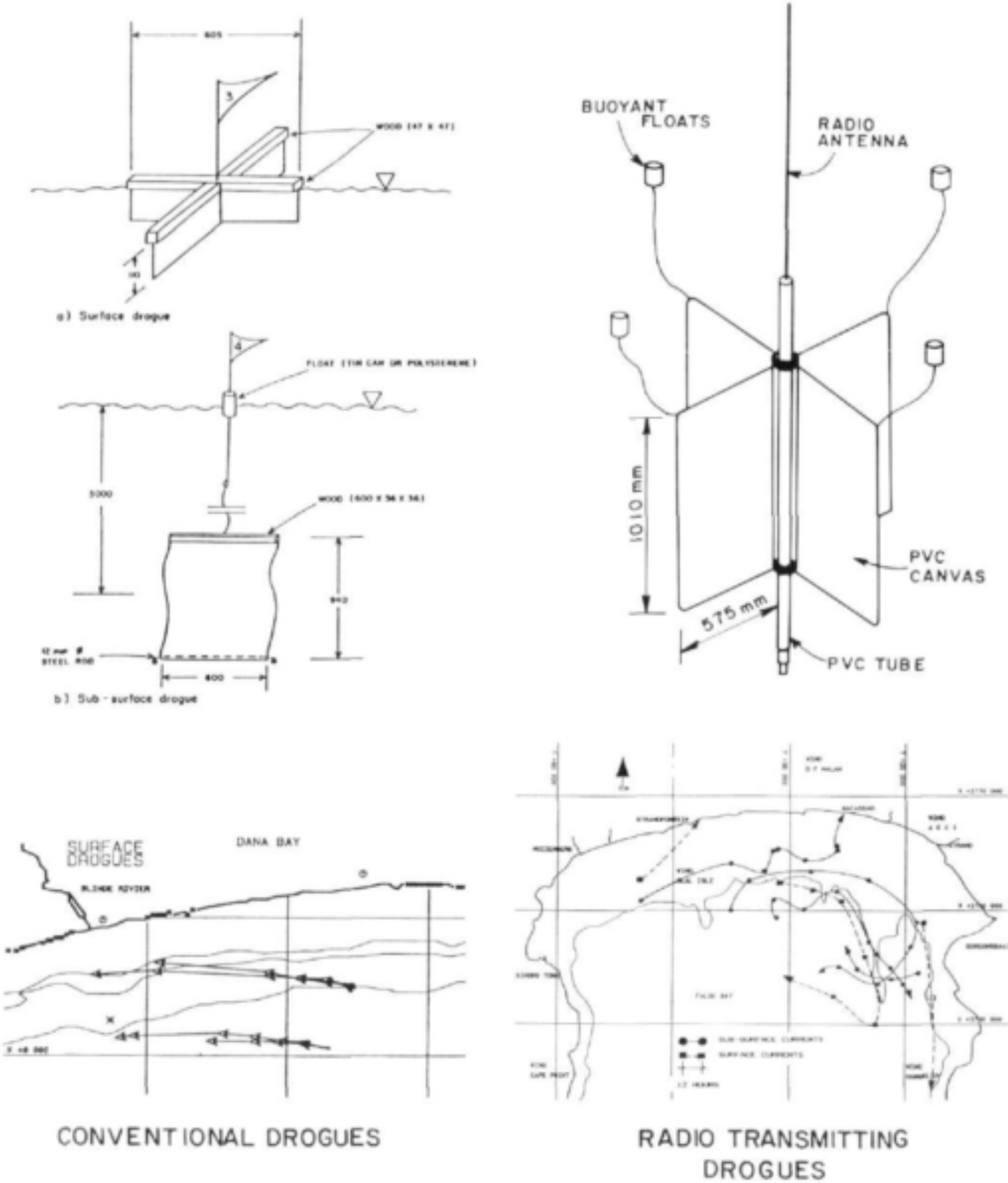

Figure 8.8 : Drogue measurements for determining surface currents.

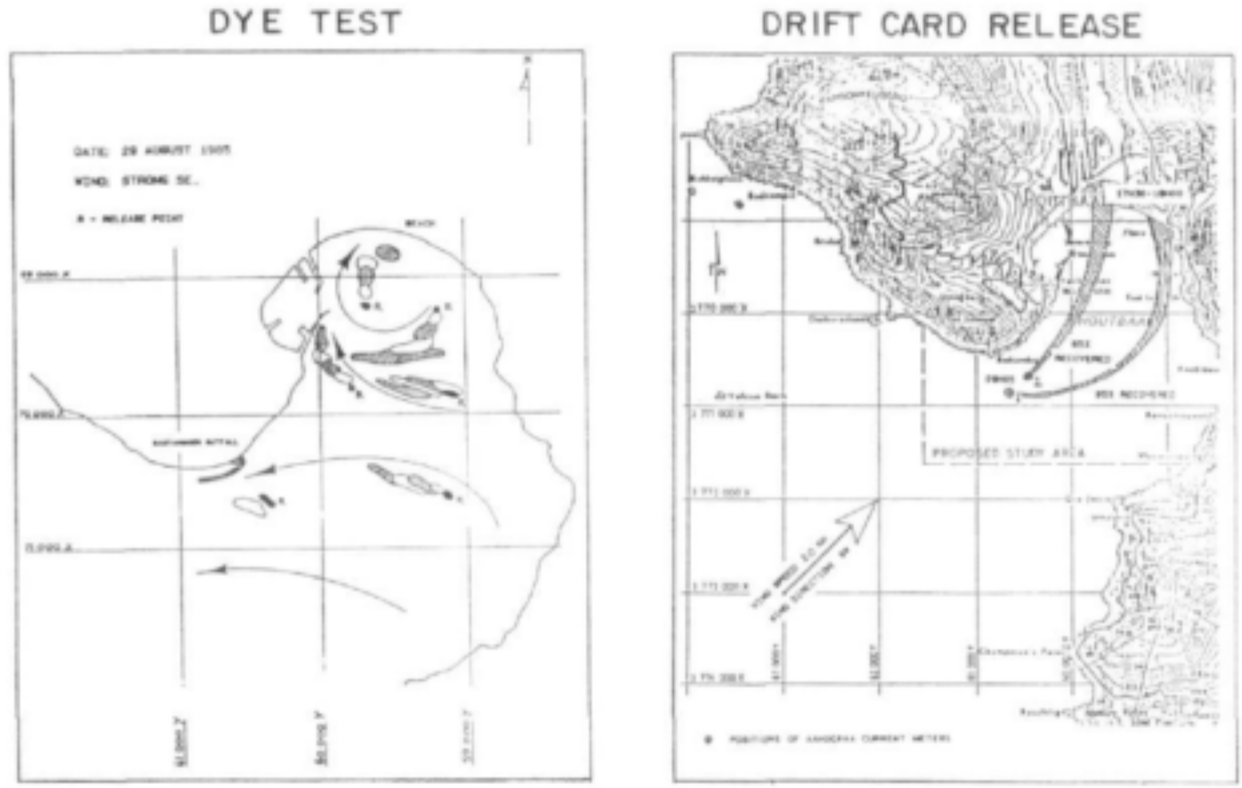

Figure 8.9 : Surface current patterns measured using drift cards and dye.

the cards is recorded by the location and time of their deposit on the shoreline. This is used as a crude but effective way of predicting what the fate of effluent released at the same location would be. Cards of various colours can be dropped from different proposed outfall locations. The results are meaningful but with obvious limitations. A plotted result is shown in Figure 8.9.

Dye patches provide another method of detection of surface current patterns. An amount of concentrated dye such as Rhodamine B is released at a specific location or at several locations in an area of interest. Dye patch movement and spreading is then monitored by aerial photography or by tracing the perimeter of the patch with the survey boat. A plotted result is also shown in Figure 8.9.

8.2.2 Stratification

Stratification is the term used to describe the phenomenon of denser sea water underlying lighter sea water thereby causing a vertical density gradient in the water column. These can inhibit dilution by suppressing the buoyancy of a rising plume of effluent above the diffuser but they can also be seen as beneficial in the sense that effluent may be prevented from surfacing and being visible.

Causes of stratification in South Africa's coastal waters are typically warming of the surface waters by radiation, upwelling of colder less saline (denser) deep ocean water (particularly on the west coast) and the movement of warmer more saline (less dense) water towards the coast due to a passing ocean current (an east coast

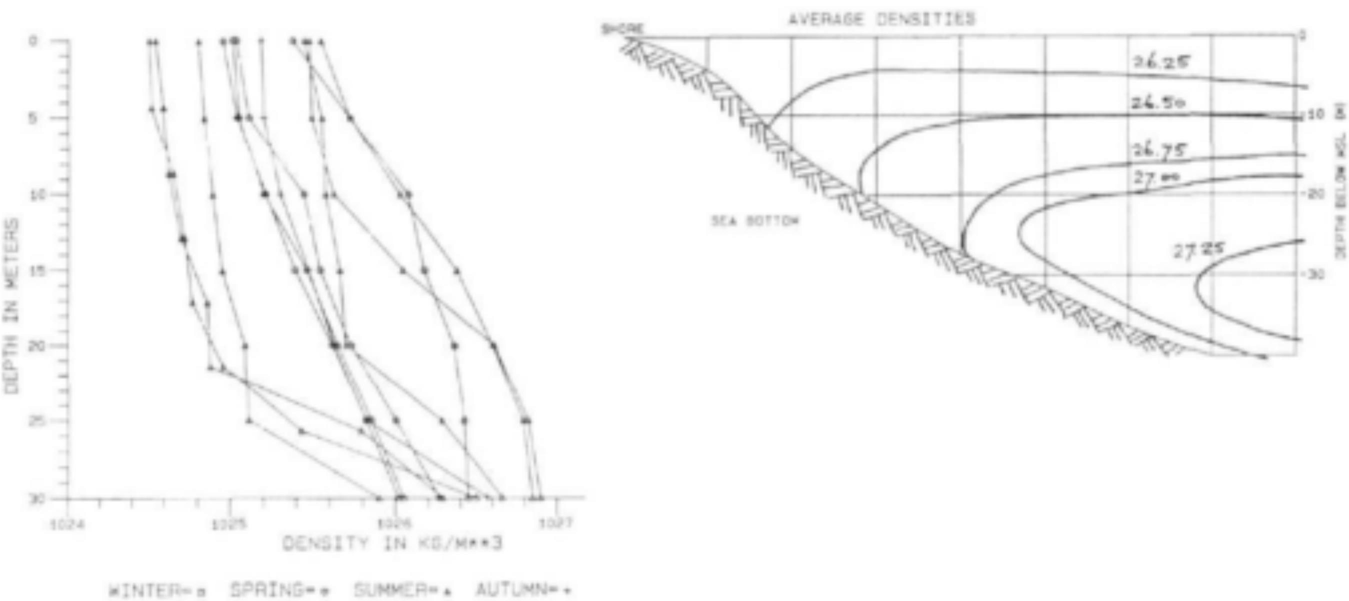

Figure 8.10 : Stratification measurements.

phenomenon). Completely mixed water columns (zero stratification) are normally present after high wave or storm events. Salinity differences due to fresh water from rivers fanning out to sea are rare on the South African coast and are very localised even around the major rivers.

In order to detect stratification in the water column, both temperature and salinity profiles should be measured since sea- water density is a function of both properties. Standard equipment is used and values are measured from a survey boat. The stratification measurements should also be done on a similar grid as for the current measurements. It is convenient to attach the small temperature and salinity probes to the current profiler to maximise the information obtained from each measured profile. Figure 8.10 shows some ways to present measured stratification data.

8.2.3 Winds

Wind is a particularly important phenomenon to investigate since it is often the wind field which governs the behaviour of currents within several kilometres of the coastline in a prospective discharge location. Winds exert a stress on the water surface which is passed down through the water column by shear between the moving surface water and the lower layers. In the absence of stronger ocean currents, wind forcing dominates. Understanding and statistically describing the wind field will lead to a better description of the current field in such cases.

Winds are measured by automatic wind recorders connected to data loggers. Wind speed and direction at almost any predetermined sampling interval can be digitally recorded, transferred to a personal computer and processed in a very straight-forward way. Ideally, several such recorders should be operated around a proposed outfall area to avoid biased results brought about by sheltering or deflection of winds by topographic features. The data can be plotted as time-series or as wind roses for each location as seen in Figure 8.11.

8.2.4 Waves

Waves are not very important in determining the behaviour of effluent

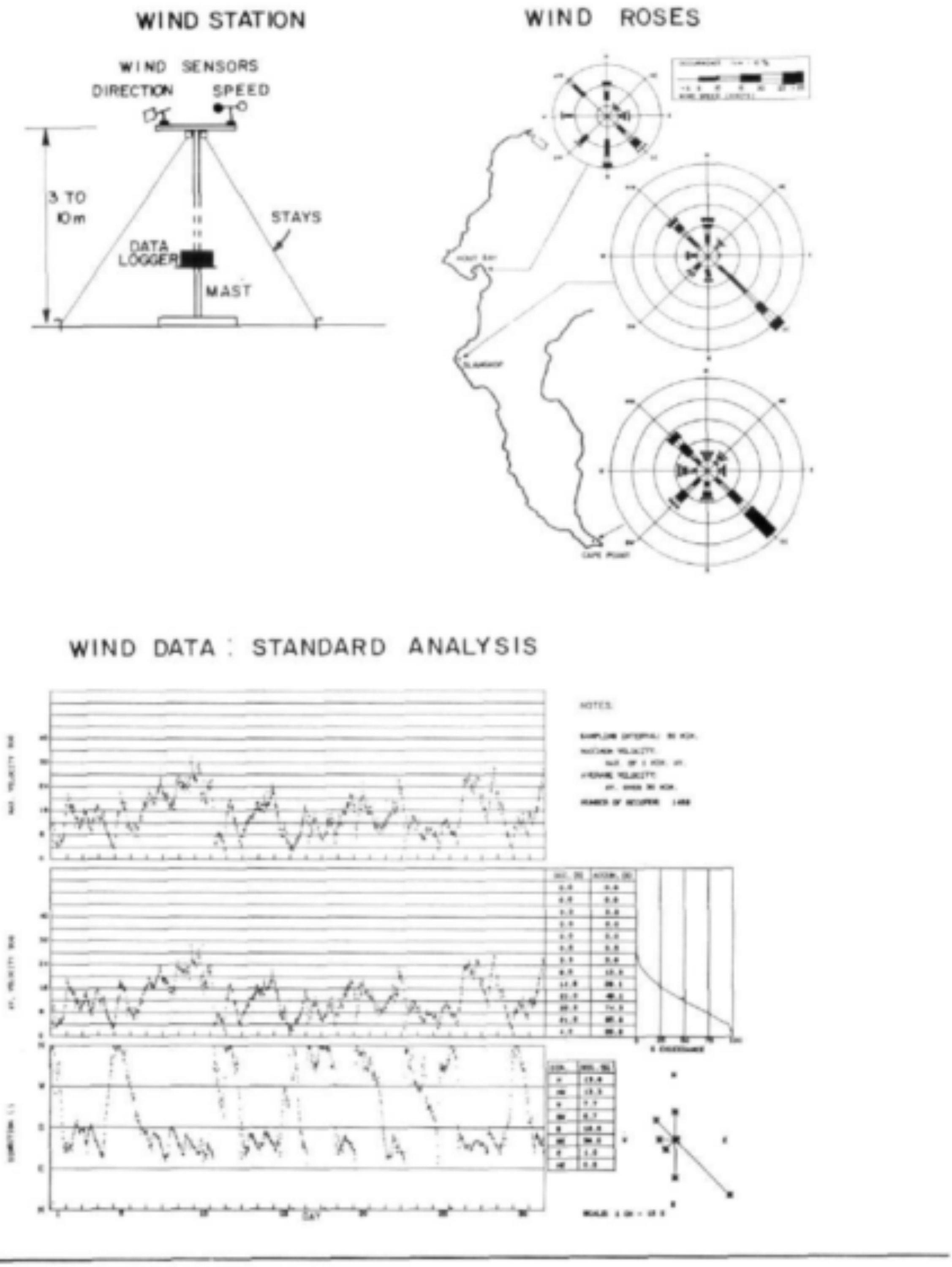

Figure 8.11 : Wind recordings.

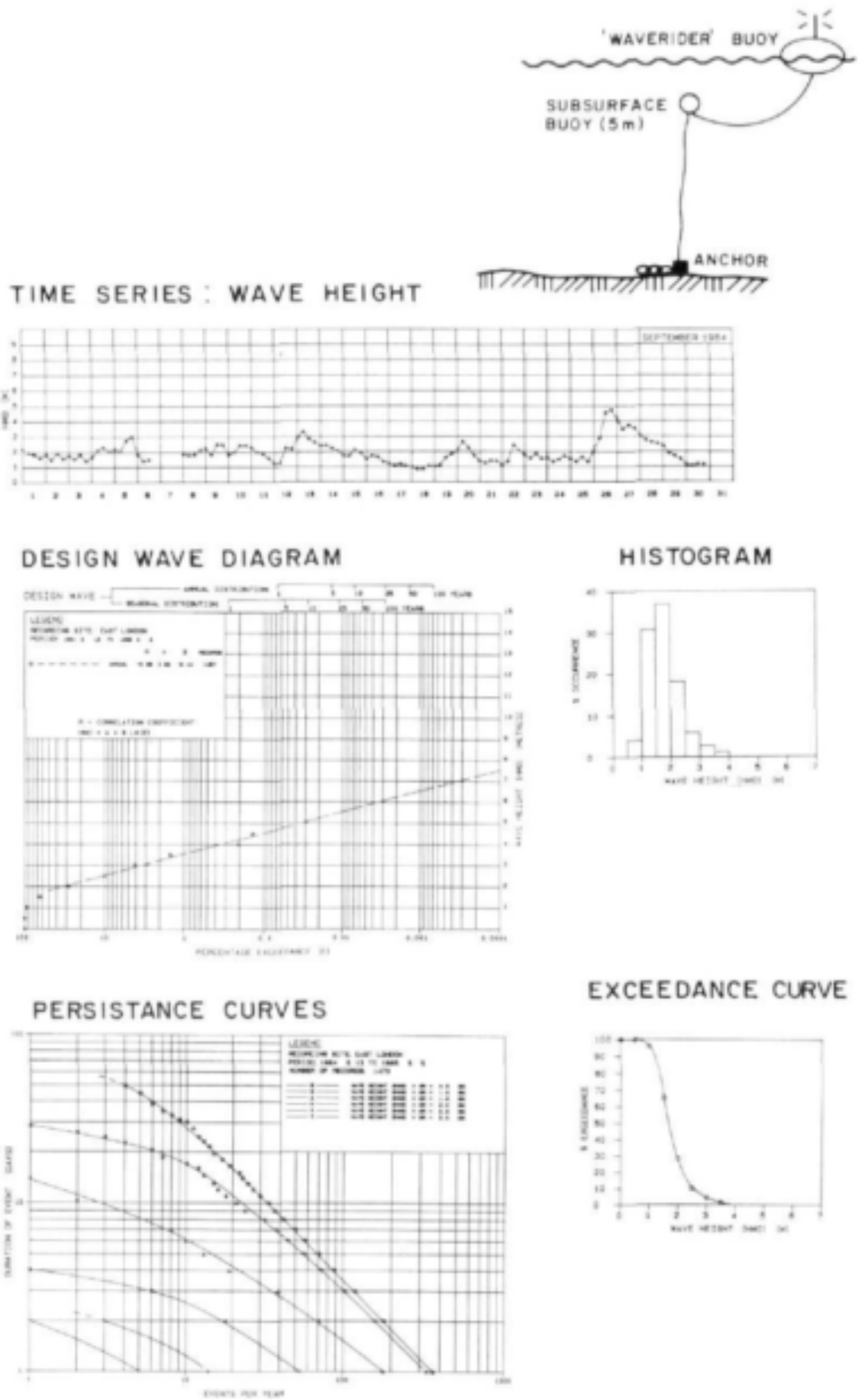

Figure 8.12 : Analysed wave recordings.

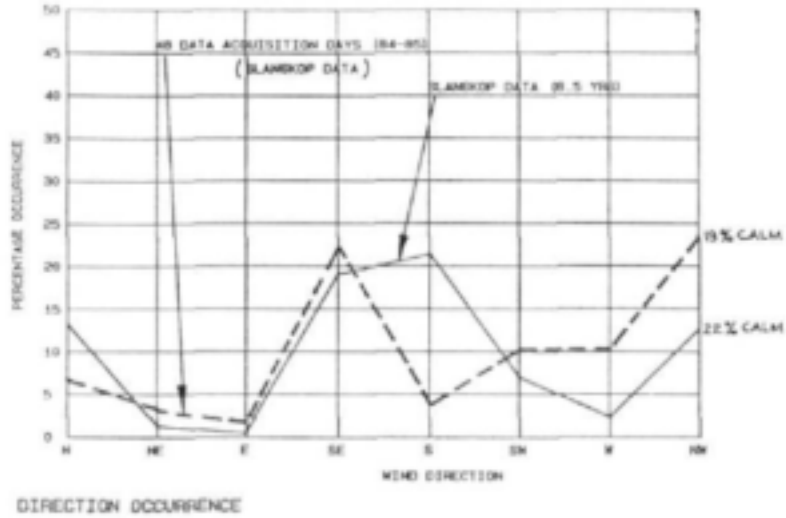

Figure 8.13 : Reliability of weather coverage.

discharged well beyond the surf zone but any data collection exercise prior to the construction of an outfall should include the collection of wave data over as long a period as possible for use in the detailed (structural) design of the scheme. This is achieved by a standard procedure of mooring a wave measurement buoy (e.g. Waverider) at a representative location along the pipe route. The buoy samples the relative elevation of the sea surface on which it floats at 0,5 s intervals for normally four 20 min. periods each day (at 6 hour intervals). The data are transmitted by the buoy to a shore station receiver where it is digitally recorded. The data are typically presented as time-series plots of wave height and period, histograms of wave height, exceedance curves and persistence curves; examples of which are shown in Figure 8.12. The persistence curves are of particular use in construction since they can show the likely duration of calm or storm conditions which can also be plotted seasonally. To detect seasonal variations at least one full year's data is needed but for statistical confidence in estimation of the design wave recording periods well beyond one year are preferred.

8.2.5 Data interpretation

The lengthy data collection phase of the feasibility study should be followed by thorough data interpretation to convert the measured data to a form suitable for outfall design. Before doing this, however, the reliability of the data measured directly at sea should be examined with respect to any bias towards specific weather conditions. This can be done by referring to a nearby weather station or wind recorder which has been operating for many years. The distribution of wind conditions at that weather station on the direct measurement days at sea can be compared with the distribution of wind conditions, of the long-term data series for that station. Biases in the data can be revealed and where applicable corrected. Such a check is shown in Figure 8.13.

The current data required for the diffuser design is in the form of statistical data for current speed and direction over the diffuser. A representative mid-depth current can be used and this can be gained from the moored current meter and profiling data.

The current data required for the transport of the effluent away from the diffuser is best obtained from drogues, drift cards and dye measurements. These must be summarised to provide the best estimate of the surface current patterns. These patterns can be correlated with causal wind conditions and adjusted to correct for any bias present as described above. Figure 8.14 shows a resulting summary from over 60 days measurement off East London (CSIR, 1988).

When good quality moored current meter data at the site are available on the measurement grid then these can be used directly in the dilution calculations as will be explained in Chapter 12. Also, good quality profiling data can be used directly in initial dilution calculations, also explained in Chapter 12.

8.3 Establish Biological and Chemical Properties of the Site

This is done for two reasons. Firstly to establish baseline data against which post installation performance of the outfall can be compared and secondly to highlight sensitive areas and other ecological characteristics of the region which should be taken into account in the design or in

PATTERN	TYPE	NUMBER OBSERVED	AVERAGE VELOCITY cm/sec	PERCENTAGE OCCURRENCE
	Southwesterly	41	46	64
	Southwesterly with small eddy near coast	15		
	Northeasterly	18	31	24
	Northeasterly with small eddy near coast	3		
	Onshore	7	12	8
	Offshore	4	11	4

Figure 8.14 : Surface current patterns off East London.

the designation of design criteria (Chapter 10).

Surveys done at sea and on the coast could include surveys of water chemistry, sediment chemistry, meiofauna (in the sediments), macrofauna (on sediments and reefs) and macroalgae (kelp, seaweed).

An assessment of the assimilative capacity of the area involved must be established by means of chemical analyses of the sea water and of the beach and sea-bed sediments, and biological analyses based on sampling, identification, counting and comparing the animals in the beach and sea-bed sediments.

Chemical analyses performed on the water and sediments would include dissolved oxygen, organic content, salinity, trace metals, nitrogen, ammonia and pH. The chemistry of the sediments and the numbers and variety of animals living in them are sensitive measures of the available organic material. Levels higher than a critical level established for any parameter will serve as a clear indication of enrichment, usually from pollution.

Plant and sea life counts, their nature and occurrence in the area may also need to be done to serve as background data once the pipeline has been commissioned and post-discharge monitoring has commenced. Monitoring of the marine environment after commissioning of the pipeline is dealt with in detail in Chapter 15.

8.4 References

BOTES, WAM (1988) Lagrangian current measurements by using radio transmitting buoy. CSIR Report EMA-T 8811, Stellenbosch.

CSIR (1982) Richards Bay ocean outfalls. Engineering design aspects **2**, CSIR Report C/SEA 8231/2. Stellenbosch.

CSIR (1988) East London outfall studies Report No. 5. Dilution calculations and evaluation of effects. CSIR Report C/SEA 8847. Stellenbosch.

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CHAPTER 9

EFFLUENT INVESTIGATIONS

by G Toms and A P M Fijen

9.1 Physical Properties

The physical properties of the effluent that require definition are those which influence the engineering design of the scheme with respect to flow delivery and the physical behaviour of the effluent after release from the diffuser or pipeline into the sea. These include:

- flow rate
- density (specific gravity)
- temperature
- suspended solids content

The **flow rate** should be specified as peak flow (m^3/s) and minimum, average and maximum daily flows (m^3/d). Variations in the flow for WWF or DWF (Wet or Dry Weather Flow) due to infiltration of storm water should be investigated or estimated. Seasonal variations should also be documented since, for certain industrial flows, these could be dramatic (e.g. fruit processing).

The peak flow and variations in daily flow are important for hydraulic design of the scheme, for sizing pumps, reservoirs, pipelines etc. In discharging to sea the hydraulics of the submerged diffuser section will require that the pipe and all discharge ports flow full. This may be difficult during periods of low flow. To achieve this, for smaller unsteady flows, it is customary to collect effluent at a shoreline pump station and discharge for short periods at a rate sufficient to flush the diffuser when enough effluent has been collected. For larger flows where such intermittent pumping is not necessary the pipeline hydraulics should be calculated to maintain a minimum flow in the pipeline to avoid deposition of solids even at low flow periods.
For water quality (dilution) calculations it is important to quantify the mixing that a proposed scheme or diffuser will achieve. The mixing is dependent on the discharge and the higher the discharge, in general, the worse the mixing. For dilution calculations, therefore, the peak flow rate is important.

It will also be important to cater for any changes that are likely to take place during the lifetime of the scheme.

The **density** of the effluent is a vitally important parameter required for the correct prediction of dilution since it is the buoyancy of the effluent relative to the surrounding sea water which will dictate the dilution rate. Indirectly, therefore, it dictates the diffuser design. Should the effluent be more dense (heavier) than sea water a completely different design philosophy will be used to design the diffuser than the traditional methods when discharging the more common buoyant effluents. It is also important to consider density variations.

The **temperature** of the effluent, apart from affecting the density, will also influence the designers choice of pipe material (as will pH). A high temperature (above 45 ^{0}C) weakens the radial strength of a high density polyethylene pipe (HDPE) and therefore it is important to investigate likely maximum effluent temperatures.

The **suspended solids** content of the effluent must be well understood. Very high suspended solids content could lead to a slurry-type effluent with an associated high specific gravity causing the effluent to become more dense than sea water. Also, suspended sediments or rock particles can seriously abrade the pipe or the impellers of pumps.

Finally scale forming effluents, foaming effluents (pulp mill wastes), corrosive effluents and effluents containing wood chips, vegetable pips etc. can all result in physical difficulties in the pipe or diffuser which must be taken into account when designing a pipeline.

9.2 Chemical Constituents

Important effluent constituents and properties that need to be specified are concentrations or loads per unit time of the following:

Nutrients (nitrogen, phosphorus)
Ammonia
Toxic inorganics (metals, etc.)
Organic compounds (pesticides etc.)
Microbiological parameters, viruses
Fish tainting substances
Radioactive substances
Colour
Foaming properties
pH, COD etc.

The concentrations and the variations and increases in concentration during the lifetime of the outfall (30 years) are important to quantify.

CHAPTER 10

DESIGN CRITERIA : REQUIRED DILUTIONS

by G Toms and A P M Fijen

Design criteria for marine discharges are defined in Lusher (1984) as:

"those limits which must not be exceeded in order to maintain the chemical, physical or biological characteristics of a selected portion of the sea or estuary".

In keeping with the analogy to a traditional engineering design a set of "limits" to which the marine environment can be "stressed" is precisely what is required in the design process. However, the variability and complexity of the marine environment, its various uses to man and its ability to deal with limiting contamination inhibits this rather simplistic approach.

In Chapter 7 it is recognised that a number of organisations are involved in establishing the precise design criteria for a particular proposed discharge. Normally after the formation of a Steering Committee on which are represented the bodies listed in Section 7.2, the design water quality criteria can be decided upon.

10.1 The South African Water Quality Criteria for the Coastal Zone

As a guideline to facilitate this process a report was compiled by a panel of South African scientists and engineers and published in 1984 (Lusher, 1984) with the title: "Water Quality Criteria for the South African Coastal Zone".

This report outlines an approach for simplifying the establishment of criteria for a specific proposal using the concept of "beneficial use" areas. Limits are proposed for effluent contamination of waters according to their beneficial use. For example it is sensible that sea-water areas where aquaculture is practised have stricter criteria than sea-water areas used for mining. Within each beneficial use area criteria or limits are imposed. The water- quality criteria and the recognised beneficial uses are shown below:

Recognised beneficial uses

- Maintenance and preservation of ecosystems.
- Direct-contact recreation.
- Migration of aquatic life.
- Collection or culture of aquatic life for food.
  - Filter feeders.
  - Non-filter feeding edible organisms.
- Collection of aquatic life for uses other than food.
- Supply of desalination and potable water recovery.

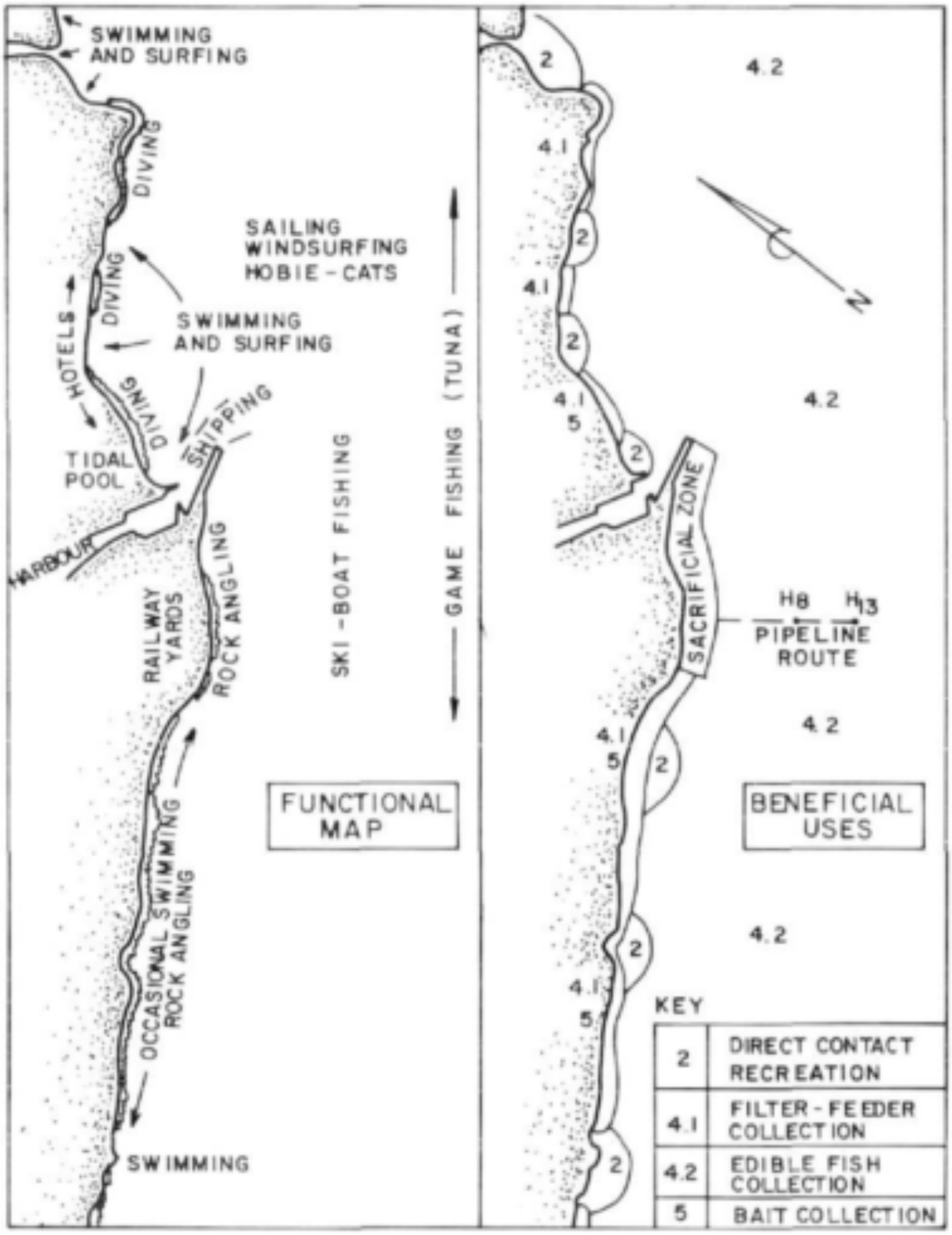

Figure 10.1 : Demarcation of beneficial uses for East London.

- Recovery of minerals.
  - Evaporation.
  - Mining.
- Use of sea water for industrial purposes.
  - Food processing.
  - Cooling water.
  - Washing water.

- Miscellaneous uses.

List of water quality criteria

- Aesthetic criteria and physical hazards

- Conservative materials and properties:
  pH.
  Dissolved oxygen.
  Salinity.
  Turbidity and colour.
  Suspended solids.
  Temperature.

- Nutrients and biostimulants :
  Nutrients and other biostimulants.
  Ammonia (expressed as nitrogen).

- Toxic inorganic materials.

- Organic compounds and cumulative materials.

- Microbiological parameters.

- Fish-tainting substances.

- Radioactive substances.

While the new criteria provide an invaluable guide in the establishment of design criteria a good deal of consultation is still required on a case-by-case basis. One of the difficulties that still exists relates to the interpretation of the more narrative criteria such as those for aesthetic considerations and nutrients where limiting levels are not given. Another difficulty relates to the assignment of limits for compounds or elements not described in the report. Similar difficulty exists for assessing complex mixtures of effluents which could lead to synergistic effects. To partly solve these problems, toxicity testing as described in Chapter 6, Section 6.2.3.1 is used. Levels of dilution required to prevent detrimental effects on an indicator organism are determined by this means.

The water quality criteria and toxicity testing described above provide guidance to the Department of Water Affairs who will lay down standards for the specific discharge case being considered. These standards will then be written into the permit as part of the permit conditions.

A good example of the application of the beneficial use concept is the recently designed East London outfall. Figure 10.1 shows the beneficial use demarcations agreed in consultation between the various bodies involved (CSIR, 1988).

10.2 Required Dilution

Dilution is a measure of the degree of mixing that takes place between the effluent discharged from the diffuser and the surrounding sea water. For example, a dilution of 100 indicates 1 part effluent and 99 parts of sea water in every 100 parts of the mixture. The final concentration of the effluent is thereby reduced to one-hundredth of the original concentration.

The required dilution for any particular constituent of an effluent is calculated with the following relationship:

$$\text{Required dilution} = (C_e - C_s)/(C_l - C_s)$$

where

C_e = concentration of constituent in the effluent

C_s = background concentration in the sea

C_l = concentration not to be exceeded in the sea

For example if there are 5 000 parts per million of a constituent in the effluent, and there are 10 parts per million naturally present at sea then for a limiting concentration in the sea specified by the design criteria as 60 parts per million the required dilution would be:

$$(5\ 000 - 10)/(60 - 10) = 100$$

The designer is required to compute the required dilution for each constituent of the effluent and to repeat this for each beneficial use area that will be exposed to the effluent. Such a calculation can often be simplified by recognising the fact that specific constituents will control the design such that if they are diluted sufficiently then all other constituents will be accommodated in the design.

Standards specified for an outfall recognise the need to define a 'mixing zone' which is a zone near the diffuser within which rapid mixing of the effluent with the surrounding sea water takes place. Consequently criteria are set only at the edge of this mixing zone and not within it. Figure 10.2 describes the dimensions of the mixing zone for an outfall diffuser as recognised in South Africa.

This approach will result in the establishment of required dilutions for specific critical areas that are impacted by the effluent. Typically such areas will be at the edge of the mixing zone, at nearby reefs or at adjacent shorelines used for swimming or shellfish collection.

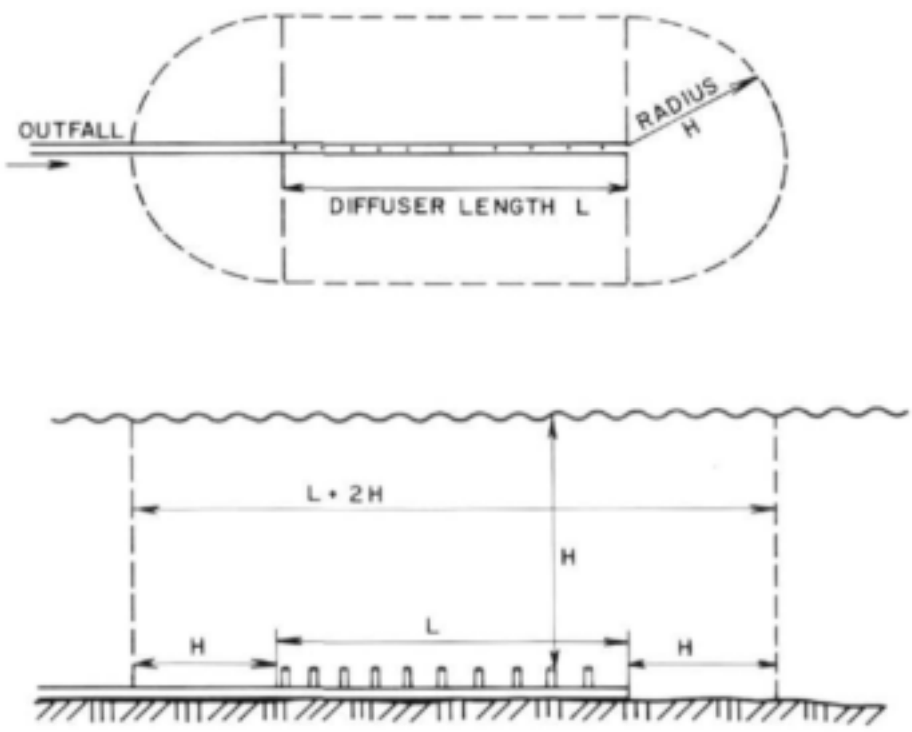

Figure 10.2 : Mixing zone dimensions.

The above description of required dilutions relates to non- decaying or conservative effluent constituents. If an effluent contains constituents which are subject to decay due to settlement, changes in chemical form, or, in the case of micro- organisms, die-off, then the accompanying reduction in concentration caused by this decay is catered for by an equivalent decay dilution, that is :

Required dilution =

$(C_e - C_s)/(C_1 - C_s)$(Decay dilution)

For example if $C_e = 10^7$ organisms/100 ml and $C_1 = 10^2$, $C_s = 0$ and the decay dilution is 100, then the required dilution will be 10^3. This matter is further explained in Chapter 12.3.

10.3 References

CSIR (1988) East London outfall studies Report No. 5. Dilution calculations and evaluation of effects. CSIR Report C/SEA 8847, Stellenbosch.

LUSHER, JA (ed.) (1984) Water quality criteria for the South African coastal zone. SA National Scientific Programmes Report No. 94. CSIR, Pretoria.

CHAPTER 11

OUTFALL HYDRAULICS AND DIFFUSER DESIGN

by G Toms and A P M Fijen

The hydraulics of the outfall pipe and diffuser system need to be investigated in order to decide on the best pipeline and diffuser arrangement for the most effective dilution of the effluent. Generally an outfall is several kilometres long and the length of the diffuser section 50 to 500 m at the seaward end of the outfall.

11.1 The Main Pipe

The purpose of the main pipe is to deliver effluent from the pump station or collection reservoir out to the diffuser. The pipe should flow full during discharge times and a sufficiently high flow velocity should be maintained to avoid deposition of settleable solids or sediments in the pipeline. The flow velocity should not result in excessive head loss in the system.

11.1.1 Discharge rates and pipe size

In practice, effluent discharge rates vary considerably with time especially for sewage flows and some industrial flows (like canning factory effluents which are seasonal) . A minimum flow velocity of 0,70 m/s should be maintained in the main pipe, even at low flow periods. Peak sewage flows, which can be 1,5 times the average for a large population (100 000 people) or as much as 3,5 times the average for a small population (2 000 people), should be used for estimating peak head losses in the pipe and for sizing pumping systems. The average flow rates are normally used for the selection of the pipe diameter.

11.1.2 Head losses

The maximum head loss in the main pipe will be a function of the peak flow and the frictional resistance of the pipe's inside wall. To cut down on head loss HDPE pipe is often used. Frictional resistance will increase with time due to 'ageing' of the pipe and possibly also due to scaling where the effluent forms a hard deposit on the pipe wall.

11.1.3 Pumping

The effluent is supplied to the outfall either by gravity, or more commonly, by pumps. The siting of the pump station should allow for some initial pretreatment of effluents like sewage where maceration, degritting and coarse and fine (5 mm) screening should be done. For smaller outfalls with variable flows, such as the sewage flow from a small coastal catchment, it is good practice to operate the outfall on an intermittent pumped discharge. Effluent is collected in a small sump or reservoir and a pump is triggered to empty an amount out of the sump when the effluent reaches a predetermined level. The pumping mode is then an on/off mode, with a predetermined volume being discharged over a specific period of pumping, and no discharge whilst the pump is switched off.

For example, at Camps Bay near Cape Town, a pump empties a 13 m^3 sump over a period of about 5 minutes and is idle for about 30 minutes per cycle in low flow periods. The pump is idle for 5 minutes per cycle in peak flow periods. In pumped schemes anti-surge or water-hammer devices are fitted to prevent damage to the outfall and the pumps. These may be surge towers or air vessels.

11.1.4 Pipe profile

The profile of the main pipe is important since sludge or sediments will deposit and collect in low points and air in the high points. A gradually declining grade is therefore necessary.

11.2 The Diffuser

The diffuser is the seaward section of the outfall through which effluent is discharged through a series of discharge ports distributed along its length.

The main requirement of the diffuser is to distribute the effluent release in order to maximise effluent dilution in the surrounding sea water. Hydraulically, this translates into the following two main requirements:

- to ensure a good flow of effluent through all the ports at all times of discharge and to attempt as uniform a port-flow distribution along the diffuser as possible; and

- to ensure that a minimum flow velocity in the pipe in the diffuser section is maintained so as to avoid settlement of suspended solids.

The diffuser design must also ensure that blockages of ports by effluent particles does not occur, that deposition of solids adjacent to the pipe is avoided and that ingress of sand into the diffuser is prevented. Where possible, ports should be removable so that they may be removed from time to time for cleaning or replacement purposes.

11.2.1 Diffuser diameter

Due to the release of effluent through the successive ports, flow in the diffuser naturally decreases towards the seaward end. It is common practice to compensate for this by tapering the diffuser, that is, by reducing its diameter at sections between ports where the flow velocity drops below the 0,7 m/s required to prevent settlement of solids. It is generally impractical to taper the diffuser all the way to the end to ensure that the flow velocity near the last few ports remains above 0,7 m/s. Some deposition can therefore be expected at the end of the diffuser. For this reason a flap or removable flanged end is fitted on the pipe to allow occasional flushing of the diffuser with the end open or for pigging purposes (artificial scouring by an abrasive ball being forced through the outfall).

11.2.2 Port flows

A general rule to satisfy the first requirement above is that the downstream discharge area at any cross-section in the pipe or diffuser is not more than 0,7 times the cross-sectional area of the pipe at that section. This is called the 'area ratio' principle. For example at the start of the diffuser section :

$$\sum_{j=1}^{n} a_j < 0{,}7A$$

where

A = cross-sectional area of the outfall pipe

a_j = cross-sectional area of the j-th port
n = number of ports.

This equation can be used to calculate the number of ports that must not be exceeded on a pipeline of internal diameter 800 mm and port sizes of 100 mm as follows:

$$n < \frac{0,7(\pi/4)(0,8)^2}{(\pi/4)(0,1)^2} \approx 45$$

To ensure that the ports flow full and to prevent sea-water intrusion into the pipe, the densiometric Froude number at the port, F, should be greater than 1. If F<1 then sea water is likely to infiltrate into the outfall.

$$F = u/\{gd(\Delta\rho/\rho_s)\}^{1/2}$$

where

u = port exit velocity (m/s)
$\Delta\rho$ = q_s - q_e
ρ_s = density of sea water (kg/m^3)
ρ_e = density of effluent (kg/m^3)
d = port diameter (m)
g = gravitational acceleration (m/s^2)

11.2.3 Sea-water infiltration

Sea-water infiltration into an outfall can occur if very low effluent flows are permitted to occur. Such infiltration is undesirable since, apart from disturbing the desired diffuser hydraulics and port flows, it can be accompanied by ingress of sediments which can eventually settle out in the pipe. In pipeline outfalls laid on the sea bed, ingressed sea water is relatively easy to purge at higher effluent flows. However, in tunnelled outfalls where sea bed ports are connected via shafts (or risers) down to a pipe buried several meters below the bed such purging is often very difficult to achieve. This has been a frequent problem in the United Kingdom where such tunnelled outfalls are more prevalent. Consequently, considerable research work has been done to prevent sea water infiltration in the United Kingdom with the design of non-return flaps on discharge ports and other preventative measures (Charlton *et al.*, 1985).

11.2.4 Port diameters

Port diameters should be kept small to improve dilution but large enough to prevent blockages. They are typically in the range of 100 mm to 200 mm for South African outfalls. It is unwise to use a port diameter smaller than 75 mm. For medium to large pipes (>300 mm inside diameter) the general rule is that the port size should not exceed 25 per cent of the pipe size. To assist with more even flow distribution, downstream port diameters are generally made progressively larger.

11.2.5 Port spacing

The port spacing should be such that effluent plumes rising from adjacent ports do not merge before reaching the sea water surface (in the case of buoyant effluents). This will be achieved if ports are spaced at distances greater than one third of the water depth.

11.2.6 Port configuration

Various different diffuser port designs are used, even on the 12 existing South African outfalls. These vary from simple holes drilled into the pipe wall, to complex hairpin risers that turn the flow

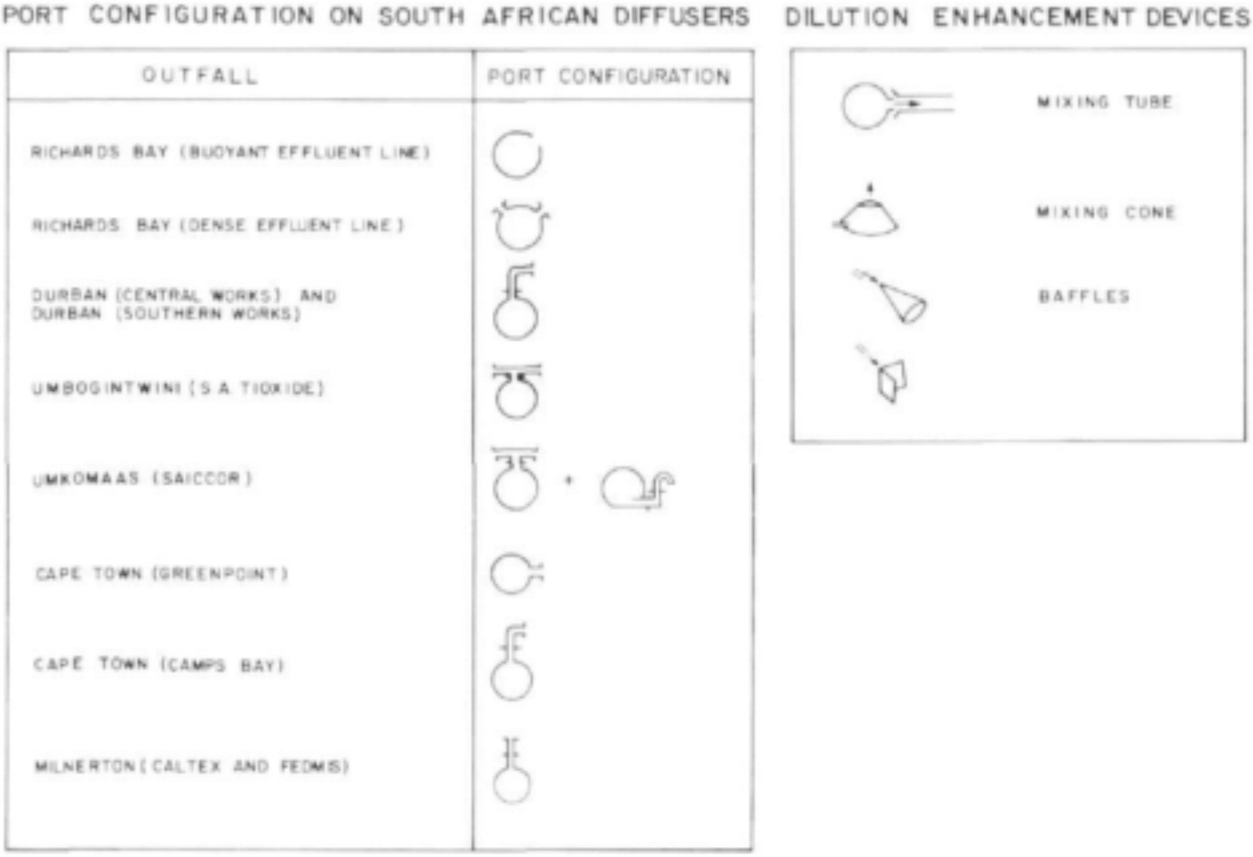

Figure 11.1 : Diffuser port configurations.

downwards, or T-ports that deflect the flow sideways in opposite directions. In fact, there is little evidence to show that any one port design is superior to another, particularly for buoyant effluent discharges in deep water where the dilution occurs predominantly in the buoyant plume rising to the surface and not close to the ports. The general rule should be that the port configuration should be simple. Flanged elbow ports or simple oblique ports are often preferred since this allows a plate to be bolted to the ports during flushing of the main pipe. These ports are often staggered so that successive ports discharge to opposite sides of the diffuser. Figure 11.1 illustrates these two simple designs as well as some of the other designs presently in use in South Africa.

Research has been done (Sharp, 1979) on the design of ports to enhance dilution by accelerating the drawing-in of sea water into the emerging port flow. Such ports, however, have proved largely ineffective. One reason for this is that while dilution is slightly improved close to the port exit, the diluted effluent plume then becomes less buoyant at the start of its rise to the surface. Consequently, dilution during buoyant rise of the plume is reduced which almost completely negates the earlier improvement. The difficulties in installing and maintaining such enhancement devices (against marine growth and structural damage) do not warrant their use in most cases. Some of these devices are illustrated in Figure 11.1 but in general, they are not recommended for use in South Africa.

11.2.7 Hydraulic analysis and head loss of the diffuser.

A thorough hydraulic analysis is required to compute the flow velocities from each port, the variation in flow in the diffuser pipe and the head loss over the diffuser. It is often required to perform these computations many times to cater for variations in total flow rate and for different diffuser arrangements. For these reasons computer programs are indispensable.

In solving the hydraulics of a submerged manifold, such as a diffuser (Rawn *et al.*, 1960) the key lies in the fact that the flow "q" through a port can be given as a

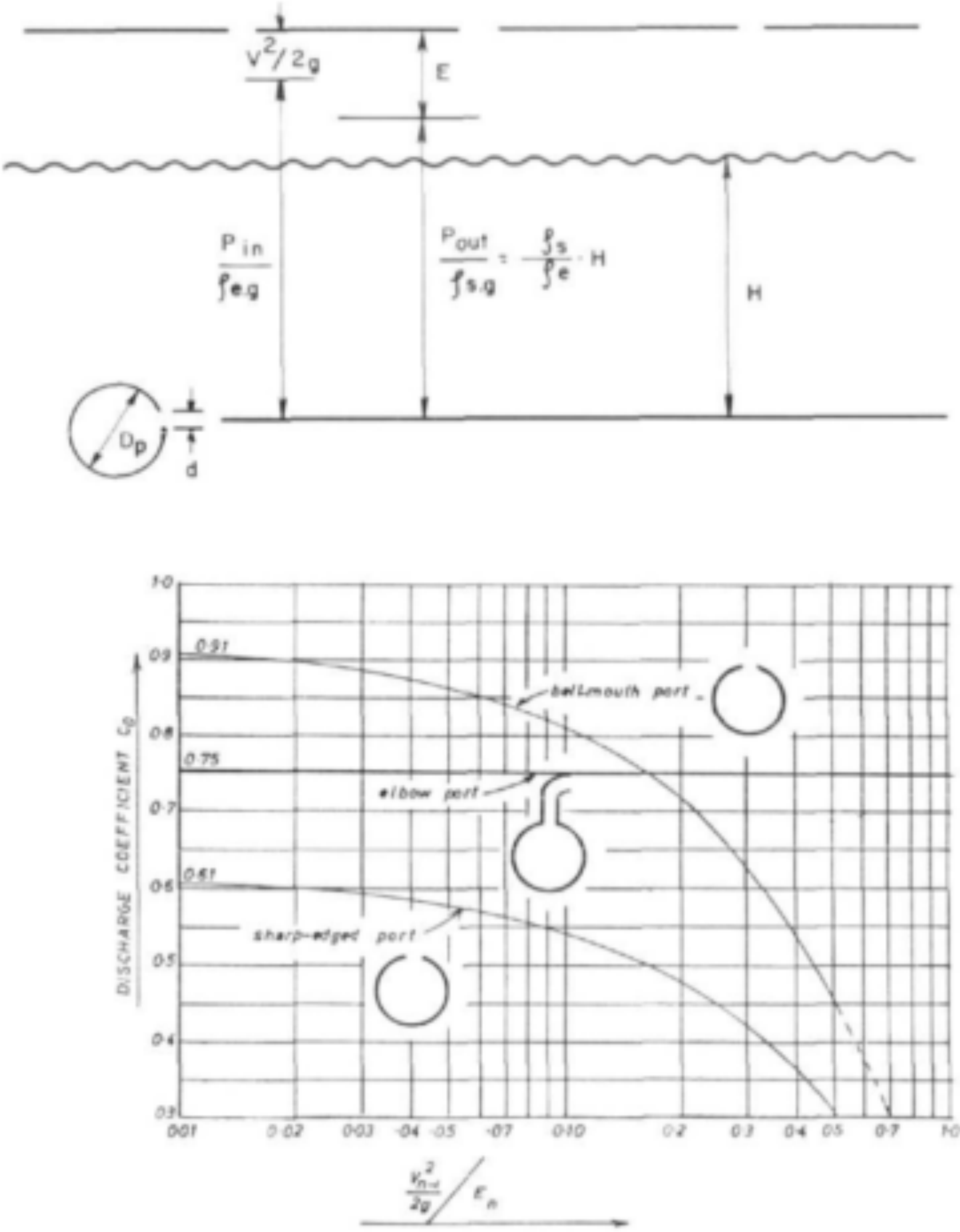

Figure 11.2 : The hydraulics of port discharge.

function of the total net available energy "E" in the pipe. "E" is the difference in head between the inside and the outside of the pipe (Figure 11.2).

$$q = C_D a(2gE)^{1/2} \quad \text{or}$$

$$u = C_D(2gE)^{1/2} \ ; \ \text{and}$$

$$E = (V^2/2g) + (p_m/g\rho_e) - (H\rho_s/\rho_e)$$

where:

C_D	=	discharge coefficient for port
a	=	cross-sectional area of port (m^2)
p_m	=	static pressure head inside pipe (m)
H	=	water depth (m)
V	=	flow velocity in main pipe approaching the port (m/s)
E	=	total available head to force flow out of the port (m)
u	=	port exit velocity (m/s)
ρ_e	=	density of effluent (kg/m^3)
ρ_s	=	density of sea water (kg/m^3)
g	=	gravitational acceleration (m/s^2)

The discharge coefficient C_D is a measure of the losses, contractions and flow non-uniformities in the main pipe caused by the port. As such, C_D is itself a function of the flow velocity (V) in the diffuser pipe. For increasing diffuser pipe flow it should be progressively more difficult to attract flow into the port and C_D decreases as V increases. Laboratory experiments have shown that for a sharp edged port in the side of a diffuser pipe (Fisher *et al.*, 1979):

$$C_D = 0{,}58 - 0{,}63(V^2/2gE)$$

But for a round edged port:

$$C_D = 0{,}975(1 - V^2/2gE)^{3/8}$$

For specific port designs, especially one of complex geometry, for example a set of ports on a riser typically from a tunnelled outfall, laboratory tests should be performed to establish the relationship between C_D and the ratio between velocity head and total energy head.

For the 'elbow' ports of the Durban outfalls, the value of C_D was found to be a constant 0,75 (CSIR, 1964). These results are shown in Figure 11.2.

In Figure 11.3 a definition sketch is given for the hydraulic analysis which proceeds from the downstream port, 1, to the most upstream port, n. Between any two ports j-1 and j the total energy head E is increased by the friction loss from j to j-1 and by a term to compensate for the slope of the diffuser:

$$Q_j = Q_{j-1} + q_j$$

$$E_j = E_{j-1} + \underset{j \rightarrow j-1}{\text{friction loss}} + \underset{j \rightarrow j-1}{\text{slope compensation}}$$

This provides a method whereby, starting with an assumed E value at the seaward port, the above equation can solve the diffuser hydraulics up to a point where E_n is reached. At E_n, q_n is computed and $Q_n = q_n + Q_{n-1}$ is compared with the design flow into the diffuser. The calculation is iterated with successive assumptions for E_1 until satisfactory agreement is reached at Q_n.

Figure 11.3 also shows the typical results from the diffuser hydraulics calculations.

The head loss over the diffuser is generally low for a buoyant effluent diffuser with low exit velocities and can be simplified as:

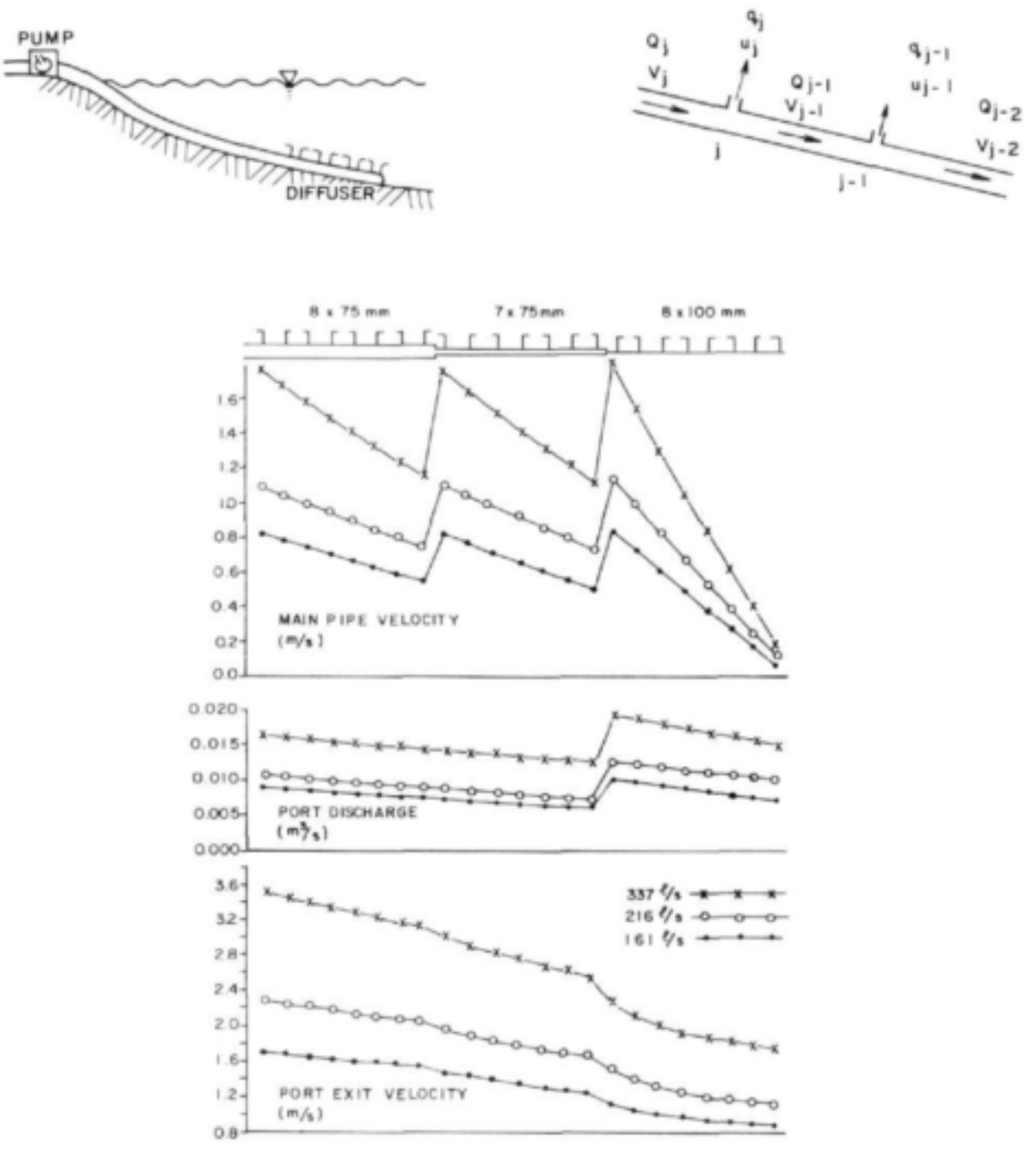

Figure 11.3 : Diffuser hydraulics.

$$(h_L)_{diffuser} = \sum_{j=1}^{n} h_{fj} + E_1 + \{(\rho_s - \rho_e)/\rho_e\}(h_1 - h_n)$$

where

h_{fj} = friction head loss between ports j and j-1 (m)

$h_1 - h_n$ = total fall in bed level along the diffuser (m)

E_1 = energy head available at the seaward port (m)

$$= (u_1)^2/\{2g(C_D)^2\}$$

In a buoyant outfall u_1 will typically be not more than 2 m/s. Therefore with C_D = 0,9; E_1 = 0,25 m.

For a dense effluent outfall where higher jet velocities are required, u_1 can be as much as 15 m/s, then E_1 will be 14 m and the diffuser head loss will be a major factor to overcome in the design. With such high exit velocities, an effort will have to be made to keep C_D as close to unity as possible by avoiding sharp edged entrance losses.

The last term in the equation which caters for the diffuser slope, is likely to be a minor addition to the total head loss over the diffuser. Some typical values demonstrate this:

$h_1 - h_n$ = 5 m
ρ_s = 1 025 kg/m^3
ρ_e = 1 000 kg/m^3

then

$$\{(\rho_s - \rho_e)/\rho_e\}(h_1 - h_n) = 0{,}125 \text{ m}$$

With this in mind a simple approximation to the total head loss of an outfall $(h_L)_{tot}$ can be given by:

$$(h_L)_{tot} = \lambda(L_{tot}V^2/2gD_p) + \{u^2/2g(C_D)^2\}$$

= friction loss + jet loss

where

λ = Darcy-Weisbach friction factor in main pipe
L_{tot} = length from the pump house to the end of the diffuser (m)
D_p = main pipe diameter (m)

11.3 References

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CHAPTER 12

DILUTION CALCULATIONS : ACHIEVABLE DILUTION

by G Toms and A P M Fijen

Achievable dilutions from a marine outfall are determined by three mechanisms : initial dilution, subsequent dilution and decay dilution.

Initial dilution is the dilution that the effluent undergoes under direct influence of the exit velocity from the diffuser port and the buoyant rise of the effluent away from the outfall. The initial dilution phase is finished when both the jet momentum and buoyancy are spent or the effluent reaches the water surface. Typically, the initial dilution takes place within the mixing zone and dilution levels at the edge of the mixing zone are then taken as initial dilution levels.

Subsequent (or secondary) dilution is the further dilution that the effluent undergoes as it is transported away from the mixing zone.

The final mechanism that reduces the concentration of some non-conservative constituents in the effluents is biological and chemical decay.

Therefore, in predicting the total reduction in concentration of an effluent from the outfall to some distant target location, the combined product of reduction due to initial dilution, subsequent dilution and decay should be used as will be shown at the end of this chapter.

It is not the purpose of this chapter to theoretically describe all these processes and provide lengthy descriptive formulae. The principles of the phenomena involved and some of the more simple and popular (desk-top) dilution formulae will be given while some techniques for more sophisticated solutions will be mentioned.

12.1 Initial Dilution

12.1.1 Concepts

Figure 12.1 provides sketches of the initial dilution process for different types of effluent. Initial dilution is achieved by the entrainment of surrounding ambient sea water into the discharged effluent. This process takes place due to jet entrainment close to the port outlet and buoyant entrainment during the plume's rise to the surface. Naturally in the case of an effluent that is heavier than sea water, buoyant entrainment is non-existent and is substituted by negatively buoyant entrainment when the discharged jet collapses to the sea bed.

For a buoyant effluent, the buoyant entrainment is by far the most predominant diluting mechanism. Jet velocities at the ports are typically 1 to 5 m/s and jet entrainment is far less significant.

However, for a dense effluent the jet entrainment is relied upon to provide the dilution and jet velocities of 10 to 15 m/s are then used.

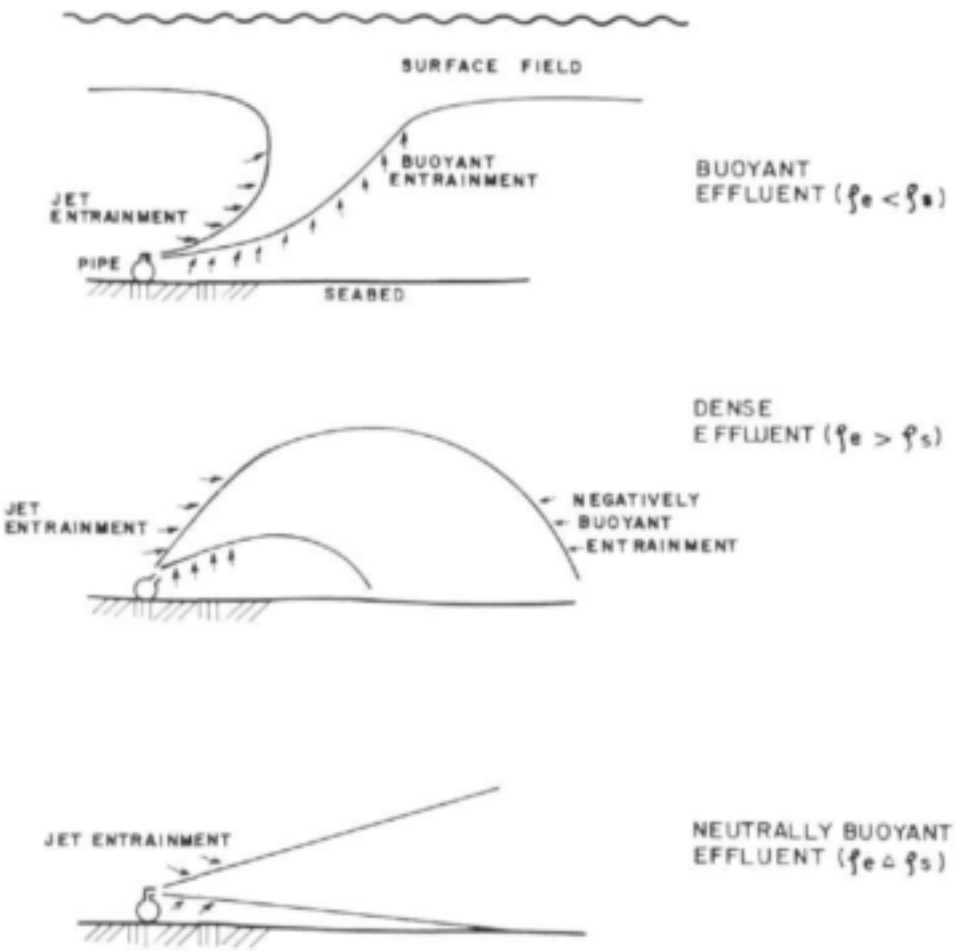


Figure 12.1 : Effluent behaviour during initial dilution.

Figure 12.2 illustrates the behaviour of a buoyant effluent undergoing initial dilution. This behaviour is dramatically affected by the properties of the water column above the diffuser.

In stagnant, unstratified (uniform) water the effluent always rises to the surface where it spreads laterally forming a 'surface field'. In the presence of stratification the buoyant plume rise is inhibited, often to the extent that the buoyancy is spent before the effluent plume can reach the water surface and a 'submerged field' is formed. Due to the shorter distance over which buoyant entrainment then takes place, effluent in a submerged field is less diluted than in a surface field. The advantage of a submerged field is that the effluent will not reach the surface, and aesthetically this may be a better solution. In deep water outfalls it is often the case that the designer can seek-out common stratification depths, for example where thermoclines frequently occur, and ensure that discharge is made below these thermoclines. In moving water the current deflects the jet downstream forcing greater entrainment over a longer path

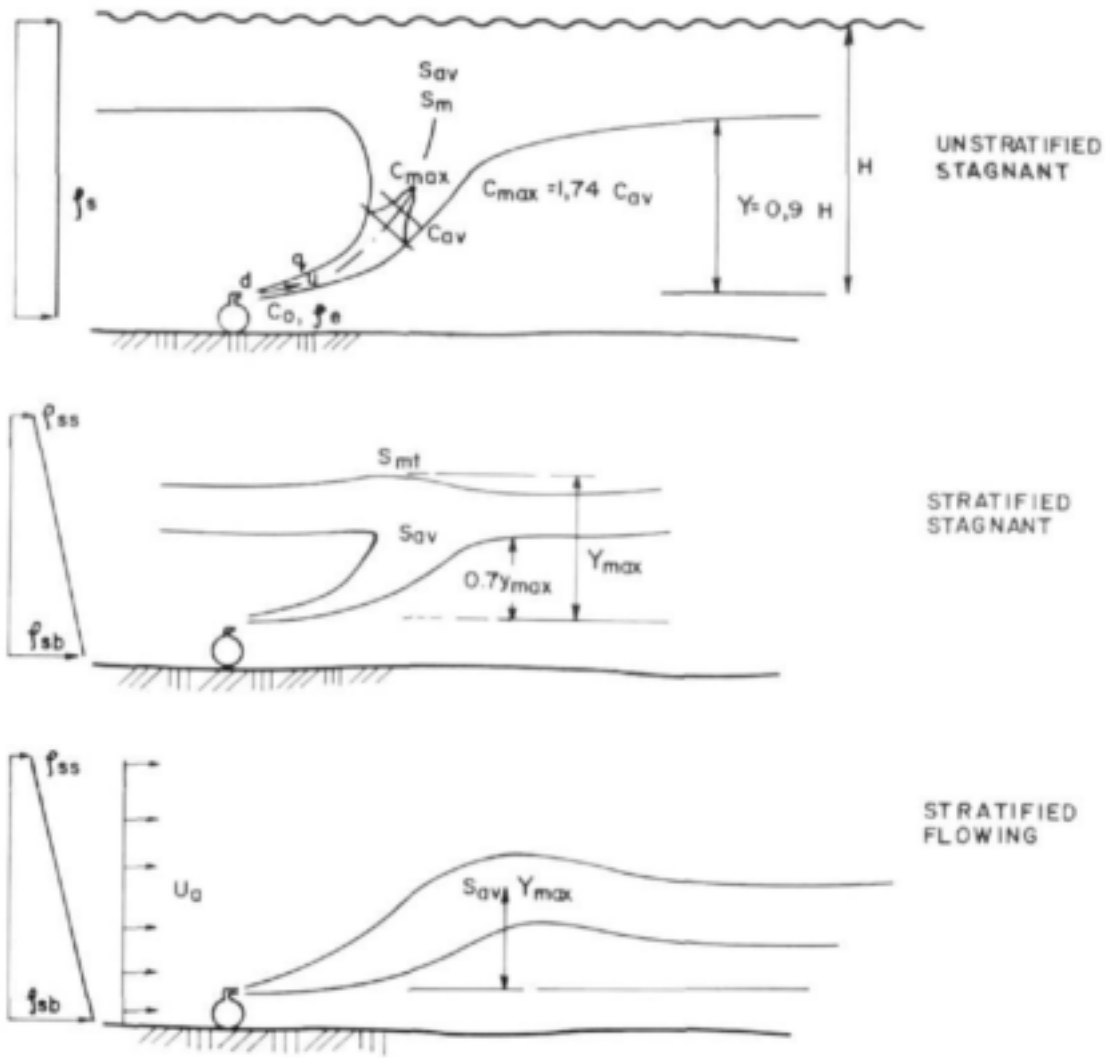


Figure 12.2 : Initial dilution of a buoyant effluent.

length, with resulting increase in initial dilution. The real situation at sea for an operating outfall is that a combination of currents and stratification is always present and that true stagnant unstratified conditions (zero current, zero stratification) never exist.

A dense effluent, discharged through high velocity jets at the sea bed will be less sensitive to stratification than to ambient current speed and direction. Currents deflect the jet path considerably and enhance dilution accordingly. The angle of the jet relative to the current direction is an influencing factor as is its angle to the horizontal.

12.1.2 Calculations

12.1.2.1 Buoyant effluents

In a sophisticated approach to the design of a new outfall pipe, where good field data of current and stratification profiles of the site is available, a computer program is used to calculate the initial dilution and the full buoyant effluent plume behaviour. The program (EPA, 1979) is based on a numerical method for solution of the simultaneous equations for conservation of mass, momentum and buoyancy along the path-length of the rising plume. Entrainment is described by an entrainment coefficient in an assumed entrainment relation. Such a program allows the designer to predict a direct range of probable dilutions and rise-heights as well as their statistical occurrence. This method is the ideal and in most outfall studies should be the designer's goal.

Desk-top methods are however available which allow simplified effluent behaviour to be described and dilutions to be assigned.

Such calculations are excellent for providing a 'feel' for the likely performance of an outfall at an early stage in the design. In deriving the formulae, use has been made of empirical relationships often involving the dimensionless Froude Number F of the jet emerging from the port. Use is also made of the terms S_m and S_{av}. S_m is the term to describe the minimum dilution in the effluent field and S_{av} to describe the average dilution. At a cross-section through the rising plume, as shown in Figure 12.2, the concentration profile has been measured as bell-shaped and the centre-line concentration C_{max} is 1,74 times the average concentration C_{av}.

$$S_{av} = 1{,}74S_m$$

S_{av} is used more often since S_m is a very localised dilution applicable only on the centre line of the effluent plume.

In Figure 12.2, Y is the rise height (m) of the effluent measured above the port, d is the port diameter (m) and H the water depth (m) to the port centre line (Roberts, 1977 and 1984), then:

(i) **Stagnant-uniform conditions** (Figure 12.2 top)

For $Y/dF \geq 25$

$$S_{av} = 0{,}186F(Y/dF)^{5/3}$$

For $Y/dF < 25$

$$S_{av} = 0{,}186F\{1{,}6 + 5(Y/dF) + (Y/dF)^2\}^{5/6}$$

If S_{av} is taken at the base of the surface field, a surface field thickness is needed to compute Y. A surface field thickness of 10 per cent of the depth H is assumed (although there are conflicting findings ranging from 10 per cent to 40 per cent): $Y = 0{,}9H$ (Koh, 1983-1).

Fieldwork has confirmed that the dilutions thus predicted are underestimated by a factor of 2 to 3 in extremely calm sea conditions (although not completely stagnant) and these formulae are therefore considered very conservative (Toms and Botes, 1988).

(ii) **Moving stratified conditions** (Figure 12.2 bottom)

The water column properties are described using two parameters (Koh, 1983-2); U_a for the average current speed over the depth (m/s) and G as a linear stratification parameter:

$$G = -(g/\rho_{sb})\{(\rho_{ss} - \rho_{sb})/H\}$$

where

ρ_{ss} = sea-water density at the surface (kg/m^3)

ρ_{sb} = sea-water density at the bed (kg/m^3)

Also used is a relative buoyancy parameter g' where

g' = $g\Delta\rho_a/\rho_a$ and

ρ_a = average sea-water density (kg/m^3)
= $(\rho_{ss} + \rho_{sb}) / 2$

$\Delta\rho_a = \rho_a - \rho_e$

ρ_e = density of effluent (kg/m^3)

The formulae for the 'rise height' Y_m (m) and S_{av} the submerged field average dilution are:

$Y_m = 2{,}3(g'\rho/U_a)/G^{1/3}$ and

$S_{av} = 0{,}71(U_a/\rho)(Y_m)^2$
(Wright, 1984).

If Y_m exceeds 0,9H then this latter value must be used to compute S_{av} which will then be the average surface field dilution.

12.1.2.2. Dense effluents

Figure 12.3 illustrates the two types of dense jets discharging in stagnant water. The formulae given below (Roberts and Toms) show the terminal height dilution on the centre line S_t, the impact dilution S_i (at the collapse of the plume to the sea bed) and the terminal rise height Y_t for two discharge angles:

For stagnant conditions:

	S_t	S_i	Y_t
Jet at 60°	0,38F	1,03F	2,08dF
Jet at 90° (vertical)	0,19f	0,51F	2,22dF

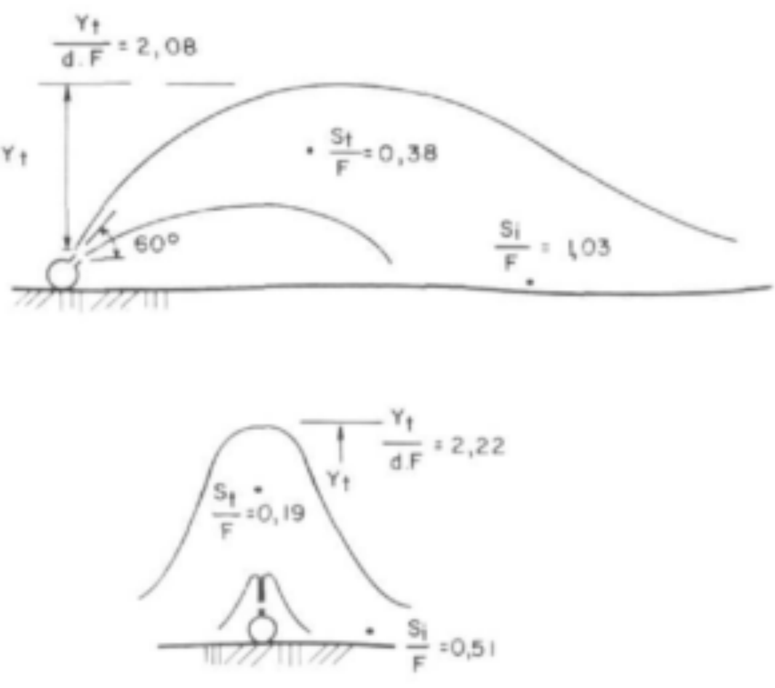


Figure 12.3 : Initial dilution of a dense effluent.

In a current, the dilution relationships are dependent upon the current speed and direction but the exact description is beyond the scope of this guide. As an indication however the following formulae are applicable
for a 60° jet discharging at velocity u perpendicular to a cross-flow velocity of U_a m/s:

$$S_t/F = 0{,}8(u_rF)^{1/2}$$

$$S_i/F = 2(u_rF)^{1/2}$$

$$Y_t/F = 2{,}5(u_rF)^{-1/3}$$

where

$$u_r = U_a/u \text{ (m/s)}$$

As an example the following case is given:

d = 0,075
F = 100
u = 15 m/s

U_a = 0,5 m/s

	S_t	S_i	Y_t
Stagnant 60°	50	100	15,0 m
Stagnant 90°	20	50	16,5 m
Crossflow 60°	150	365	12,5 m

12.1.3 Special cases

(i) Merging plumes

When ports are closely spaced (<H/5) in a diffuser discharging buoyant effluent then the individual effluent plumes will merge before surfacing. If such merging takes place close to the diffuser (for very closely spaced ports) then the merged plumes form a line-plume (or rising curtain of effluent) along the diffuser.
The case of a line-plume is a special case that has been studied extensively, since, on the larger US outfalls there has been a preference for closely spaced ports to economise on diffuser length. When diffuser length is critical a large number of closely spaced ports of small diameter perform better than fewer wider spaced ports of larger diameter. For a line plume formed by merging jets the following relationship can be used (Roberts, 1977):

Stagnant unstratified conditions:

$$S_m = 0{,}38(Y/q_e)(g'q_e)^{1/3}$$

where

q_e = Total pipe flow/diffuser length (m/s)

In moving unstratified conditions, with current U_a m/s crossing the diffuser at 90° to the pipe axis:

$$S_m = 0{,}58(U_a/q_e)Y$$

For moving stratified conditions the relationship for S_m and the variation with angle to the current is best shown graphically (Roberts, 1977). This, however, is beyond the scope of this guide the reader is referred to the specific literature. In South Africa no line-plume diffusers have been constructed to date.

(ii) Current parallel to diffuser

In the case of merging jets in a current parallel to the diffuser, it was found (Roberts, 1977) that the dilution was about 25 per cent of the dilution achieved with a current at 90° to the diffuser. For non-merging (widely spaced) jets this reduction in dilution should not occur since the plumes will remain separated irrespective of current direction, especially when elbow ports are used which discharge to opposite sides of the diffuser.

12.2 Subsequent Dilution

12.2.1 Concepts

Subsequent dilution, sometimes termed secondary dilution, is the further dilution that takes place as effluent from the surface or submerged field is transported away from the mixing zone in the direction of the current. The behaviour of the effluent in this phase of dilution is completely dependent on the characteristics of the receiving waters, namely, advection, diffusion and dispersion and is beyond the control of the designer.

Advection is the direct transport of the effluent field at a velocity equal to the mean ambient velocity. Diffusion occurs as molecular and turbulent diffusion, which describe random spreading due to concentration gradients and oceanic turbulence. Dispersion is the forced spreading due to spatial velocity fluctuations and the accompanying shear between adjacent water bodies moving at different speeds. This shear effect results in eddy entrainment which introduces uncontaminated sea water into the effluent field, increases turbulence levels in the field and creates opportunities for molecular diffusion to take place across concentration gradients. This capture of water into the field and its subsequent mixing results in an ever increasing field size and a reduction in effluent concentration.

Oceanic features contributing to diffusion and dispersion are wind-driven currents, ocean currents, waves and tides as well as other phenomena such as upwelling and density currents. These are all responsible for turbulence at a vast range of scales resulting in eddies of minute dimensions to large ocean circulation cells (several hundreds of kilometres across). The rate of spreading of an effluent field will depend on the size of the field relative to the scale of the mixing mechanisms (eddies) acting on it. All eddy sizes up to a certain size will entrain sea water into the effluent field. The critical size will be the eddy size which transports the effluent field without causing entrainment or distortion. Such

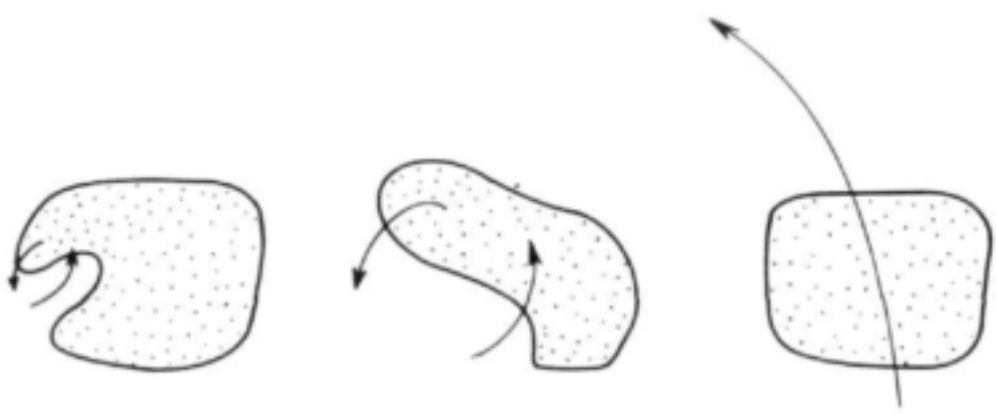


Figure 12.4 : Eddy entrainment scales.

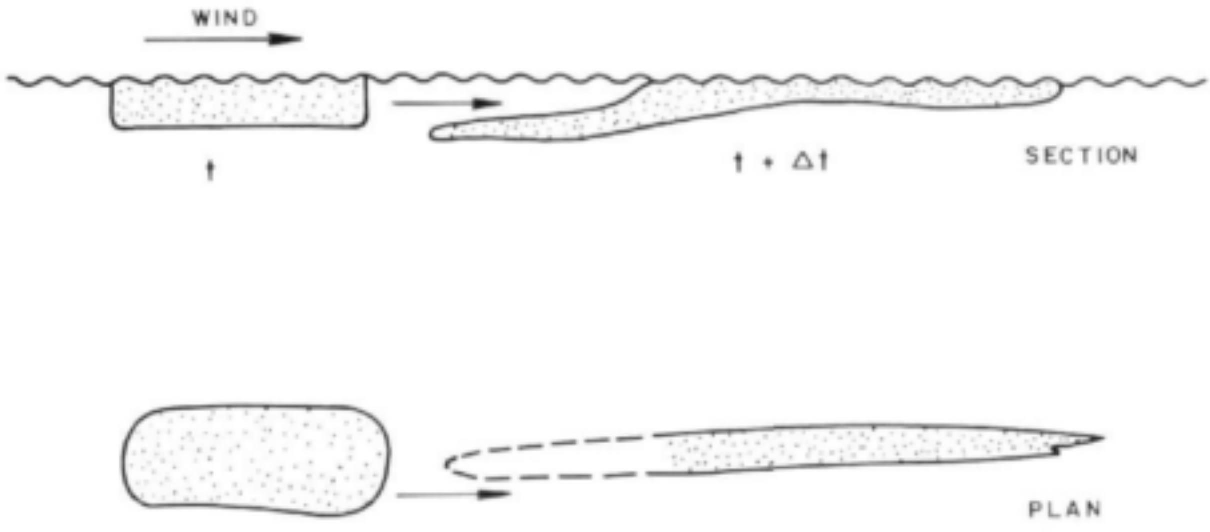


Figure 12.5 : Wind shear on the surface field of a buoyant effluent.

a size is of the order of the size of the field itself as shown in Figure 12.4. As the field grows in size due to entrainment it will also be subjected to an increasing range of eddy sizes beyond the previous critical size. It is for this reason that diffusion coefficients, which describe the rate with which an effluent plume spreads out, are not constant but functions of the size of the field on which they are active.

One of the dominant shearing mechanisms in South Africa's coastal waters is surface winds. These winds transport surface water in the direction of the wind causing a drag on the more sluggish subsurface water. Observations of surface dye patches deployed in ocean outfall studies around the South African coastline have repeatedly indicated distortions of the patch caused by wind shear as shown in Figure 12.5.

12.2.2 Dispersion and diffusion coefficients

The diffusion coefficient is a measure of the rate of spreading of an effluent field mainly due to turbulent entrainment. The dispersion coefficient however expresses the dispersive properties of the velocity field acting on the effluent. The true situation at sea which results in effluent dilution is a complex combination of these two effects.

The diffusion coefficient for a patch of effluent growing in size under the influence of eddies can be written as:

$$K = \alpha(L_*)^{4/3}$$

where

- K = diffusion coefficient (horizontal, uniform in all directions (m^2/s)
- α = diffusion constant ($m^{2/3}/s$)
- L_* = characteristic length scale e.g. patch diameter (m).

This is the well-known four-thirds law of diffusion which was shown by Okubo (1974) to adequately describe normal patch diffusion and dispersion at sea as

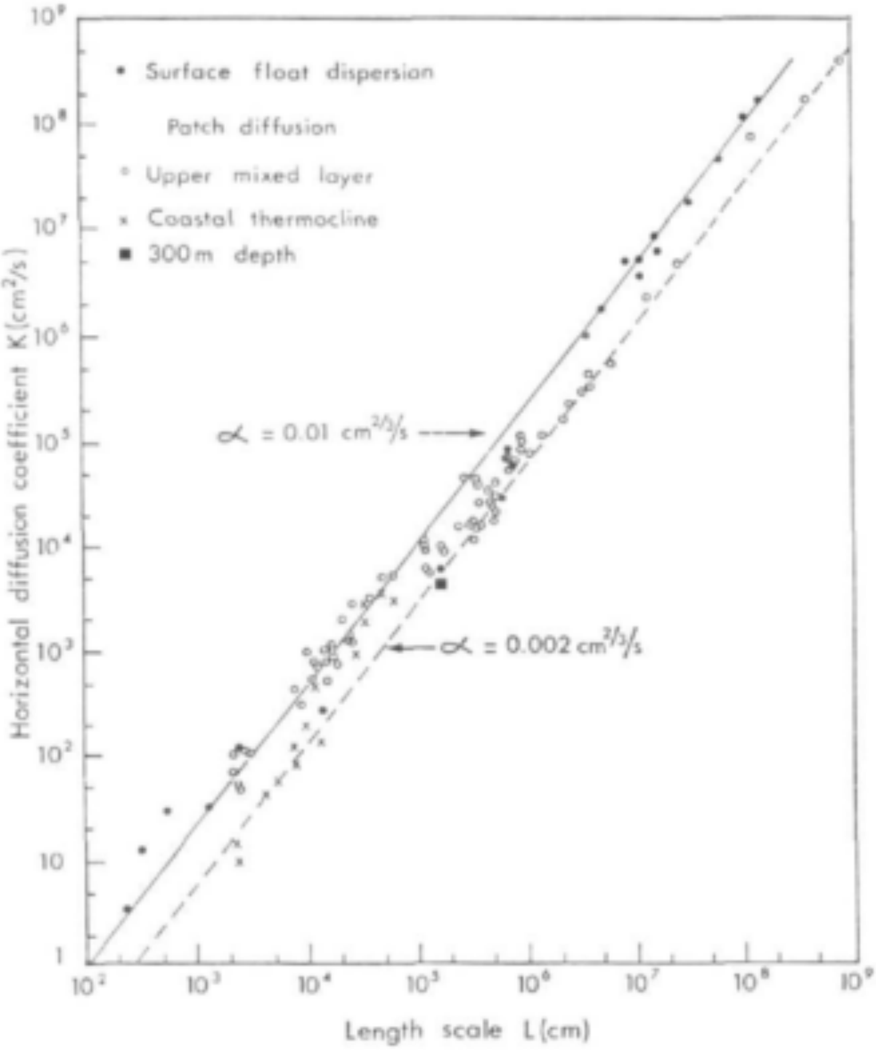


Figure 12.6 : Results of oceanic diffusion experiments (Okubo, 1974).

shown in Figure 12.6. The factor a is a constant for any one situation but it will vary in time and location depending on wind, wave and all other turbulence inducing effects condensed into this a-value. Okubo's results showed a to vary from 0,002 $cm^{2/3}/s$ to 0,01 $cm^{2/3}/s$.

In the presence of strong dispersive shear (wind) currents or high waves, K can be called a dispersion coefficient and the value of a will then be significantly larger. Indeed measurements off Natal in 1969 (Natal Town and Regional Planning Commission, 1969) showed a to vary up to 0,3 $cm^{2/3}/s$ longitudinally (in the direction of flow) and 0,2 $cm^{2/3}/s$ laterally (at 90° to the flow direction). The use of the lower values given by Okubo (0,002 to 0,01 $cm^{2/3}/s$) will result in an under prediction of the growth and hence a low estimation of the dilution of the effluent patch.

The above discussion related only to horizontal spreading in two dimensions. Vertical spreading also takes place due to vertical diffusion. Vertical diffusion

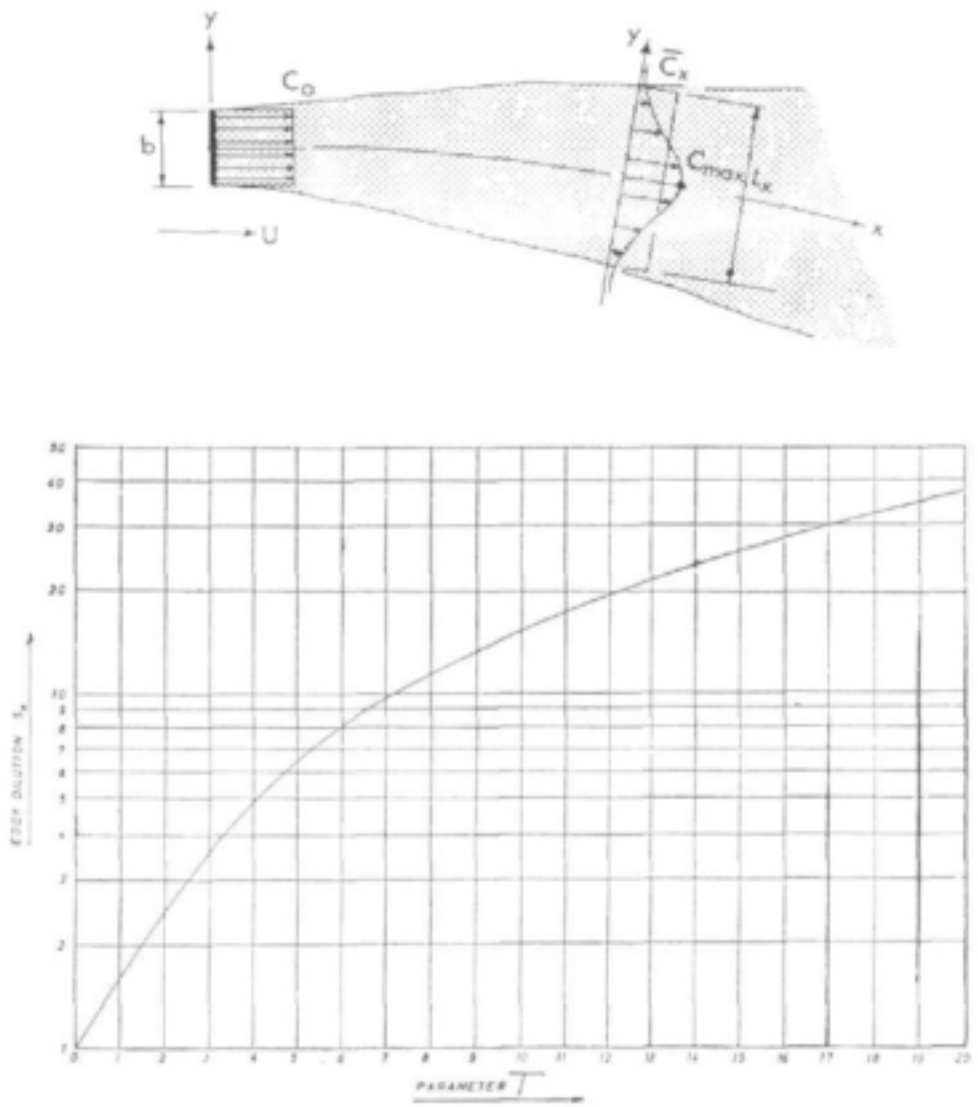


Figure 12.7 : Definition - Brooks' simplified solution procedure.

coefficients are reported to be several orders of magnitude lower than horizontal diffusion coefficients, based on sparse measurements reported in the literature. Measured values of the vertical diffusion coefficient vary up to a maximum of $4 \times 10^{-3} m^2/s$ while horizontal diffusion coefficients are typically from 2×10^{-2} m^2/s to 20 m^2/s (Bell, 1985).

12.2.3 Simplified solution procedure

A much simpler calculation procedure, which allows a conservative first estimate of shoreline concentrations, is given by Brooks (1959). Brooks assumes that only lateral diffusion acts on an effluent plume being swept downstream in a steady uniform current. The effects of longitudinal and vertical diffusion and dispersion are ignored.

The situation being described is shown in Figure 12.7 which shows a surface field equivalent to an initial width (at right angles to the current) $L_* = b$ (m) widening as it is transported downstream in a uniform cross current velocity U (m/s). The concentration in the initial surface field is C_o.

At a distance x meters downstream, in the direction of flow, the following is shown by Brooks (1959):

$(C_{max})_x = C_o \mathrm{erf}[\ ]$ where

$[\ ] = \{1,5/[(1 + 2T/3)^3 - 1]\}^{1/2}$

$T = 12K_o t/b^2$

$L_x = b(1 + 2T/3)^{3/2}$

$(C_{av})_x = (C_{max})_x/1,5$

$(C_{av})_x$ = average effluent concentration x metres downstream.

$(C_{max})_x$ = centre line effluent concentration x metres downstream.

C_o = initial effluent concentration at x = 0.

K_o = initial value of lateral diffusion coefficient (m^2/s) at x = 0.

t = time taken to reach location x metres downstream (s).

b = initial width of field at 90^0 to flow direction at x=0 (m)

L_x = width of field at 90^0 to flow direction x metres downstream (m).

$$\mathrm{erf}(a) = (2/\pi^{1/2})\int_o^a e^{-t^2}\,dt$$

= error function

In applying this simplified diffusion equation to an outfall situation, the concentration C_o can be taken as the average concentration in the effluent field after initial dilution; b can be taken as the length of the mixing zone along the pipeline axis (L + 2H) - see Figure 10.2 - and K_o can be derived from:

$$K_o = \alpha b^{4/3}$$

The parameter T is plotted in Figure 12.7 (Pearce, 1976) which gives a quick answer for the secondary dilution S_e ($= C_o/(C_{max})_x$) from the mixing zone to a destination x metres away. For an a-value of 0,01 $cm^{2/3}/s$ (0,0005 $m^{2/3}/s$) as a conservative estimate of the lateral diffusion constant, T, for use in Figure 12.7, becomes:

$$T = 0,006x/Ub^{2/3}$$

The following table provides an idea of the sensitivity of S_e to the initial field width b.

Travel time (t)		Subsequent dilution (S_e)	
(h)	(s)	b = 35 m	b = 700 m
1	3 600	2	1
3	10 800	7	1,4
10	36 000	3	3
20	72 000	9	7

It is clear that for a longer diffuser (i.e. larger b) the subsequent dilution is far less effective. This is because the eddies "eating" into the edges of the widening plume take longer to affect the centre line concentration. For this reason the secondary dilution is also very sensitive to the current direction. For a current at an angle θ to the diffuser, the projected initial field width becomes

$$b = (L + 2H)\mathrm{Sin}\ \theta.$$

As h decreases a stage is reached where b equals twice the water depth. The rapid increase in secondary dilution S_e with decreasing θ represents one of the drawbacks in this theoretical approach, (the effect can be seen in the above table with H = 17,5 m and L = 665 m where 35 m represents a θ of 0° and 700m a θ of 90°). If the current is parallel to the diffuser (θ = 0°) in the case of merging plumes, as discussed in 12.1.3, then the initial dilution is about 25 per cent of that in the case of θ = 90°. Recent work (Roberts, 1988) indicates that this reduction can also be applied to the non-merging plumes in the case of θ = 0°. This 75 per cent reduction in dilution will compensate to a certain extent for the somewhat exaggerated S_e value for θ = 0°.

e.g.
L = 665m
H = 17,5m

t = 20 h : θ = 90° S_e = 7
θ = 0° S_e = 24
t = 10 h : θ = 90° S_e = 3
θ = 0° S_e = 9

The shortcomings of the simplified approach described here are many. Among the most significant of these are:

(i) **The assumption that longitudinal mixing is negligible** is very unrealistic, particularly in coastal wind-driven currents with strong shear in the upper layers which disperse a surface effluent field in the direction of the wind.

(ii) **The assumption that vertical mixing is negligible** is also unrealistic because of the influence of waves, upwelling, stratification, topographic features, entrainment on the underside of the spreading plume, etc.

(iii) **The travel time to shore** is often far higher than the normally used simplified travel time determined as the offshore distance divided by the onshore current speed. Onshore currents are often short-lived and are intermediate phases during a reversal of parallel-to-shore currents. Path lengths to shore and consequently travel times are therefore much longer than this simplified travel time.

(iv) **Surf zone interference** is an additional effect that improves the dilution by increased mixing and deflection of the plume path in an alongshore drift.

The above demonstrates the careful approach and sound engineering judgement that is needed to estimate secondary dilution using the Brooks method.

Due to the fact that onshore currents, although far less frequent, are more critical for shoreline contamination than parallel-to-shore currents (shorter travel time), diffusers may be laid parallel to shore or in a 'Y' configuration pointing offshore. This is at the discretion of the designer but most diffusers are left in the direction of the pipe axis perpendicular to shore for convenience of installation and maintenance.

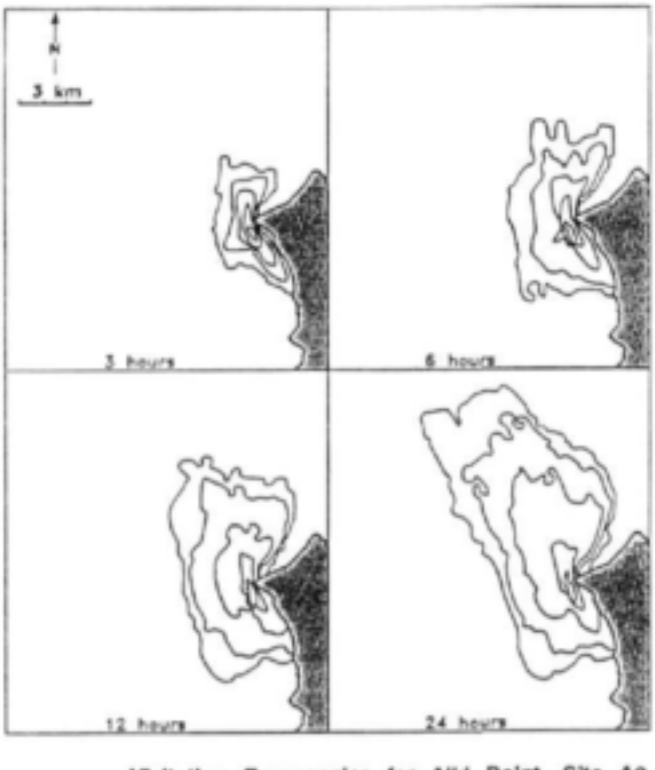
12.2.4 Alternative solution procedures

Due to the shortcomings (i) to (iii) above, in the simplified solution procedure, much work has been done recently to investigate a more suitable solution method.

One method is to solve the full three-dimensional differential transport diffusion equations numerically. Such models are extremely complex and still rely on a 'choice' of diffusion coefficients for the three directions. Often depth averaged two-dimensional finite difference models are applied in cases where the coastal hydrodynamics can be accurately generated. (For example in areas that are tidally dominated.) However, diffusion coefficients in the two horizontal directions are still required as input. Due to the South African conditions (straight coastlines, wind-driven currents, the lack of dominant tidal currents and three-dimensional effects) the solution procedures are very complicated and such models have therefore not been applied in this country yet.

The recent improvement of current measurement techniques in shallow water has brought about the development of models which use the measured current meter data to advect and disperse the effluent away from the mixing zone. There are many variations on this technique and it is beyond the scope of this report to describe these in more detail. One such method, however, is worthy of description due to its simplicity. This is the so-called **'visitation frequency'** method (Roberts, 1988; Csanady, 1983):

"Puffs" of effluent are patches of effluent that are generated by a release of effluent from the diffuser over a time-step Dt such that a continuous release is composed of a series of consecutive "puffs". A puff is allowed to travel for a specific time using the real measured current data. Consecutive puffs each travel for an equally long time but starting Dt later in the current record. This process is repeated until the whole period for which current data is available is covered. The "visitation frequency" for a specific grid



Visitation Frequencies for Alki Point, Site A2.
Contours are 0, 1, 5, 20, and 50 percent.

Figure 12.8 : An application of the visitation frequency method (Roberts, 1988).

square of the ocean is then the frequency with which a particular square is exposed to the centre line of movement of the effluent puffs. Simply by drawing contours of visitation frequency for a specific travel time will provide a very useful indication of the extent of the waste field within this time. Travel times can be extended or the discharge location changed to examine at which location the shoreline contamination is within reasonable limits. The shoreline concentrations can still be checked using the Brooks procedure but now a much more realistic travel time has at least been used. Figure 12.8 demonstrates an actual result which shows the usefulness of this technique.

12.3 Decay

Certain constituents of an effluent can be of a non-conservative nature meaning that their concentrations will not only be reduced by dilution but also by "decay". The decay of constituents can be due to:

- die-off of micro-organisms (e.g. in sewage)
- deposition or solubility of suspended solids
- satisfaction of oxygen demand
- chemical changes in sea water

A relationship for the decay rate of a substance should be derived such that the reduction in concentration during the travel time to a target area can be computed.

When considering the marine discharge of sewage in particular, strict criteria usually limit the number of faecal coliforms. Much work has been done to adequately describe the decay rate of faecal coliform in sea water. Decay is due to a combination of several factors, including osmotic shock as a result of rapid salinity changes, the ultraviolet component of solar radiation, sedimentation, predation by other organisms, etc. The solar radiation effect is known to be a predominant decaying mechanism for faecal coliforms.

The first order decay equation applied to describe the die-off process is given by:

$$c = c_o e^{-kt}$$

where c_o is the concentration of faecal coliforms in the effluent at the mixing zone (assuming no decay over the short travel time from the diffuser to the mixing zone) and c is the concentration downstream after a travel time t (h). To adequately describe the reduction, use is made of the so-called T_{90}-value. T_{90} is the time taken for 90% of the coliforms to die. The k-factor is related to T_{90} as follows:

$$\text{At } t = T_{90}$$
$$c/c_o = 0{,}1$$

$$\text{then } 0{,}1 = e^{-kT_{90}}$$

$$\text{or } k = 2{,}303/T_{90} \quad (h^{-1})$$

In an Australian test to measure T_{90} it was found that T_{90} varied considerably with the time of day due to its dependence on solar radiation (Caldwell-Connell, 1979). A typical range of T_{90} values generally in use is from a conservative estimate of 60 h (night time travel) to a rapid die-off estimate of 1,5 h (mid-day travel). Because of the exponential nature of the decay equation it is extremely sensitive to the choice of T_{90}, as illustrated in the table below:

If c_o = 10^5 coliforms/100 ml
and t = 8 h (travel time to shore)

T_{90} (h)	c (at the shore)
1,5	< 1
4	10^3 / 100 ml
10	1,6 x 10^4 / 100 ml
60	7,4 x 10^4 / 100 ml

Typically T_{90} is chosen in the range 4 to 10 h and the value of 10 h is recommended although this is a very conservative choice.

Computation of the decay of micro-organisms in sea water, in the way described above, can be criticised for a number of reasons. This criticism mainly involves the applicability of the approach:

- Does the decay rate of faecal coliforms match the decay rate of pathogenic bacteria and viruses, since it is these organisms which are of main concern in sewage effluent?

- Is the measurement of faecal coliforms by culturing colonies from surviving bacteria not miscalculated by the lack of response from 'dormant' but not dead bacteria?

- Is the decay rate affected by the dilution rate?

These and many other questions are constantly being studied, but the procedure described here provides a standard method of quantifying the decay process to some extent and serves as a useful, albeit an inexact tool for the designer. The sensitivity of the final result to the chosen T_{90}- value is of concern since designs can be 'forced' to achieve criteria simply by reducing the chosen T_{90}- value, and there is insufficient proof to justify or reject such a decision with confidence. The value to be used by the designer should be agreed upon by all parties concerned at the outset of the design.

12.4 Total Dilution

For any specific discharge proposal the dilution at a point distant from the outfall is given by:

$$S_{tot} = S_i S_e S_d$$

where:

S_{tot} = total dilution
S_i = initial dilution in the mixing zone
S_e = subsequent dilution
S_d = equivalent decay dilution

The concentration of a substance at the target location is then equal to the sum of the concentration already in the sea water (before discharge) plus c_o/S_{tot}.

12.5 Feasibility Recommendations

Using all the techniques described in Chapters 7 to 12 the designer can address the feasibility of the marine outfall option. Various diffuser designs, current and sea conditions, effluent flow rates and pipe routes can all be examined in such a way as to establish the shortest pipe length that will satisfy the required dilution or concentration levels. The main factor affecting the economic feasibility will generally be the distance the diffuser must be offshore to achieve the required dilution.

An assessment of the feasibility of any design is very dependent on two important descriptions:

(i) A thorough description of the effluent.
(ii) A thorough description of the receiving waters.

It will be clear that a feasibility assessment may result in a positive or in a negative recommendation and it is important to accept that a good deal of work needs to be done to provide such an assessment. There can be no guarantee of success at the outset of the assessment, however, but what can be guaranteed by this approach is that if an outfall is designed in this way and is found feasible, then the impact on the marine environment will be within acceptable limits.

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PART 5 : DESIGN AND CONSTRUCTION CONSIDERATIONS

CHAPTER 13

STRUCTURAL CONSIDERATIONS

by K S Russell and J D Pos

13.1 Depth of Burial of Pipelines in Surf Zone

Waves approaching the shore become unstable and eventually break, dissipating their energy in the process. The type of wave breaking depends on the bed slope and the deep water wave steepness H_o/k_o. The most common breaker types are spilling and plunging. Waves breaking as plunging breakers lose a substantial portion of their energy at the breaker point, whereas spilling breakers gradually lose their energy across the breaker zone. The differentiation between spilling and plunging breakers is not very clear cut and it is possible to observe waves breaking as partly spilling/partly plunging with an associated dissipation rate somewhere between the extremes as observed for spilling and plunging breakers.

Although many attempts have been made to determine the exact breaker location theoretically, the best information to date is still of empirical nature. The width of the breaker zone depends on incident wave height and the sea-bed profile and can vary between virtually nothing and more than a kilometre. Typically the median width is of the order of a few hundred metres along the South African coastline.

Sediment is entrained in the violent surf zone by orbital motion over the bed forms, by bulk erosion due to the fluctuating pressure at the bed and due to the excessive turbulence due to wave breaking. This sediment in suspension can be transported out of the area under consideration by residual currents. In this way onshore or offshore transport of sand can take place with a predominance for onshore transport during periods of low wave attack and with offshore transport more prevalent and during periods of high storm waves. Obliquely incident waves can generate longshore currents in the coastal zone extending to about twice the breaker zone width with the strongest currents in the outer part of the breaker zone. These currents cause the longshore transport of sand. The net transport direction over a year will depend on the variability in the direction of wave attack over a year. Typical values for the magnitude of the net longshore transport could fall between nought and few million cubic metres per year with an expected median of the order of hundreds of thousand cubic metres per year (e.g. Durban 650 000 m^3/a, Richards Bay 800 000 m^3/a).

Gradients in the magnitude of either on-offshore or longshore transport cause accretion or erosion. As a result substantial variations in the bed level in the coastal area can be observed even over a short time span such as days or even hours. The envelope of all beach levels recorded over an extended period, say one year, is called the dynamic swept prism and is indicative of possible variations in sea-bed level. The dynamic swept prism normally extends from the backshore through the breaker zone to a water depth of approximately 15 m. The difference between the upper and lower envelope of the dynamic swept prism could be as high as 4 m for South African conditions and normally occurs in the surf zone.

It is normal practice to divide the nearshore zone into two areas when determining the elevation of an ocean outfall, namely, the breaker zone and the area seawards of it. It is customary to bury the pipeline to such an extent inside the breaker zone that its crest elevation is below the design lowest sea-bed level. Outside the breaker zone it is sufficient, according to the Natal Town and Regional Planning Commission (1969), to bury the pipeline in the sea bed to half the pipe diameter, provided that sandy conditions occur.

Tests done in the Delft Hydraulics Laboratory for the outer area of a sewer outfall at The Hague in the Netherlands indicated that if the pipeline is buried to a depth of two-thirds of the pipe diameter, possible scour holes under the pipeline will not increase in size but will fill up (DHL, 1966). For this reason a depth of burial of two-thirds the pipe diameter is recommended, rather than the value of one-half the pipe diameter quoted above.

It is felt, however, that the use of the breaker line to distinguish between these two zones is not a conservative enough practice. Although the water movement outside the breaker zone is clearly less turbulent than inside the breaker zone, it is still possible for large sediment movement to take place. To illustrate this point reference is made to the study by Swart (1974) of onshore-offshore sediment movement. Swart found that the bed profile could be divided into three clearly definable areas, each with its own particular sediment transport mechanism, namely :

(i) **A backshore area**, landwards of the point of maximum wave run- up, where sediment movement normally takes place in the form of slumping due to undercutting.

(ii) **The actual developing profile** (D-profile), between the point of maximum wave run-up and a limiting depth h_m in the seaward direction, within which sediment movement takes place very actively as both bed load and suspended load, with a predominance for the latter, and where sea-bed changes are frequent and often dramatic.

(iii) **A transition zone** seawards of the limiting depth h_m, which normally has a rather smooth transitional slope between the developing profile and the original profile and where sediment transport normally takes place as bed load.

Swart used numerous data sets from both laboratory experiments and observations in the field to determine empirical relationships for the calculation of these profile limits.

With this background it is suggested that the dividing point between complete burial and partial burial be chosen at the seaward limit of the developing profile. Swart found the expression by which this seaward limit can be obtained to be:

$$h_m = 0{,}01(T_p)^2 \exp[\ ]$$

$$[\ ] = 4{,}347(H_{so})^{0{,}473} / \{(T_p)^{0{,}894}(D_{50})^{0{,}093}\}$$

where

T_p	=	peak wave period
H_{so}	=	deepwater significant wave height
D_{50}	=	median particle diameter

In the design of a pipeline in Richards Bay, for example, it was found that h_m varies between 3,3 m and 9,4 m below actual water level. The mean value was 4,2 m and a depth of 7 m below actual water level was exceeded only 3 per cent of the time.

13.2 Wave Force on Pipelines and Risers

by J D Pos

13.2.1 Determination of design wave conditions along pipelines

Determination of the wave forces on the pipeline first requires an estimation of the design wave conditions along the pipeline. Assuming a deterministic approach, the usual procedure is to determine the 1 in 1, 1 in 10, 1 in 50 and 1 in 100-year maximum wave heights and the associated mean wave directions and wave periods at regular intervals along the pipeline route.

Ideally the design wave data would be derived from at least a few years of wave data from a Waverider buoy, or preferably a directional wave buoy, moored close to the proposed pipeline site. Alternatively deep-sea wave data for the area concerned can be used. A wave refraction analysis is then needed to relate the design wave conditions at the buoy position or from the deep sea to predetermined positions along the pipelines and to determine the design wave directions at each position.

Voluntary Observing Ship (VOS) data for the portion of ocean adjoining the pipeline site can be used for determining the deep- sea direction of the design waves. This information is needed for the application of the results of the wave refraction analysis. VOS data for 1960 to the present are available for the South African coastline.

13.2.2 Wave orbital kinematics

Once the design wave conditions have been determined, a suitable higher order wave theory must be used to calculate the resultant wave orbital velocities and accelerations on or near the sea bed. Theories such as Stokes V, Dean Stream Function and the NRIO's Vocoidal wave theory have been used extensively. However, it is recommended that expert advise be sought when selecting an appropriate higher order wave theory. Particle orbits and variation of particle velocity amplitudes with depth are shown in Figure 13.1.

An alternative approach, which by-passes the need to determine design wave heights and the use of higher order wave theories, is to determine the design wave bed kinematics directly from records of a bottom mounted orbital velocity current meter. A few years of data would again be needed in order to obtain statistically reliable data. Alternatively, orbital velocity data collected over a shorter period can be considered with simultaneously recorded wave data to establish a statistical relationship between measured and calculated wave kinematics.

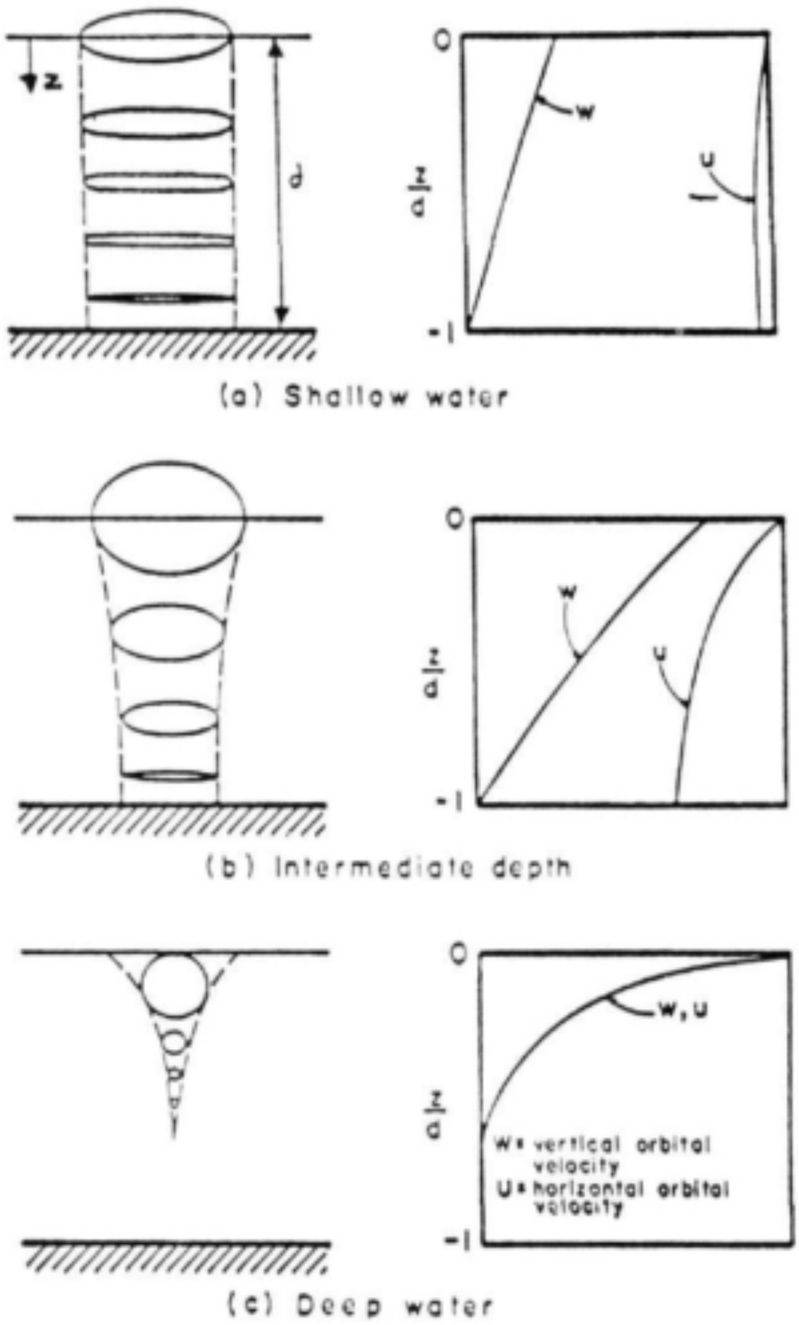

Figure 13.1 : Particle orbits and variation of particle velocity amplitudes with depth.

13.2.3 Calculation of wave forces on pipelines

The wave induced horizontal forces on a bottom mounted pipeline are most commonly calculated using the Morison equation, namely :

$$F_H(\text{total}) = F_H(\text{inertial}) + F_H(\text{drag})$$

where

$$F_H(\text{inertial}) = C_M M_{disp} U \sin\alpha$$

and

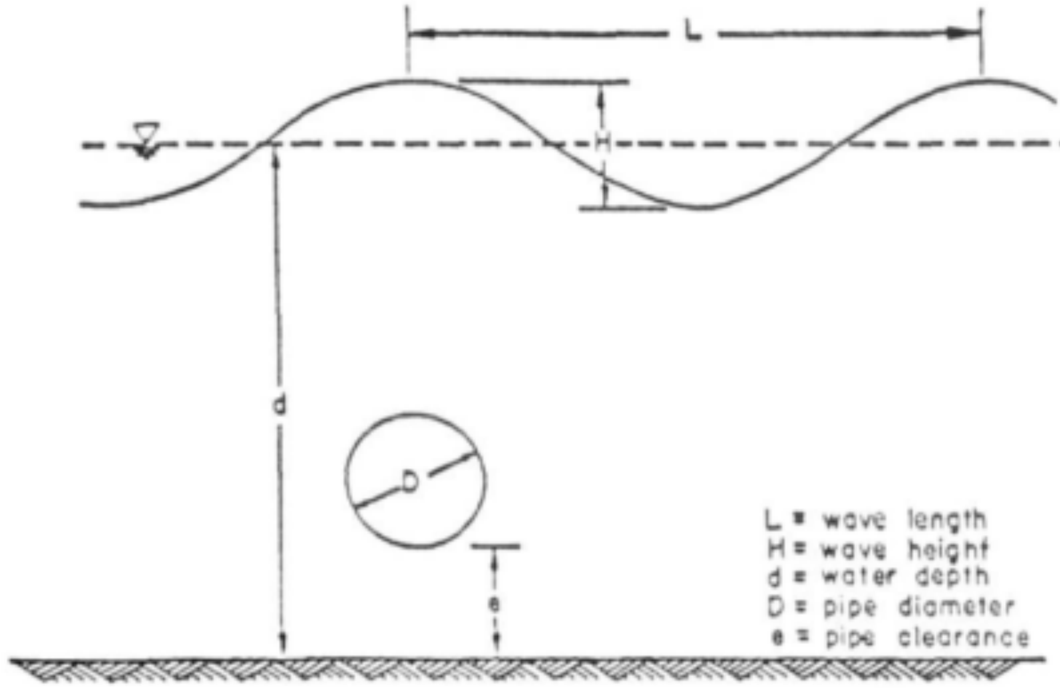

Figure 13.2 : Definition sketch for pipeline at a distance "e" from the bed.

$$F_H(\text{drag}) = 0{,}5C_D\rho DU\text{Sin}\alpha\,|U\text{Sin}\alpha|$$

where

- F_H = the horizontal force perpendicular to the pipeline per metre length
- M_{disp} = the mass of water displaced by the pipe per metre length
- ρ = density of water
- D = diameter of pipe
- C_M = mass or inertia coefficient
- C_D = drag coefficient
- U = horizontal orbital velocity as a function of time
- $\dot{U}$ = horizontal acceleration as a function of time
- α = angle of inclination of the wave orthogonals (direction of propagation)relative to the pipeline axis.

It should be mentioned that the maximum values of F_H(inertial) and F_H(drag) do not occur simultaneously and can, therefore, not be simply added to obtain the maximum value for F_H(total). The full force time functions must, therefore, be added to arrive at an economic and safe design.

A bottom mounted pipeline is also usually subjected to a wave induced vertical lift force usually calculated as follows:

$$F_L = 0{,}5C_L\rho D(U\text{Sin}\alpha)^2$$

where

- F_L = the (vertical) lift force per metre length
- C_L = lift coefficient

In the presence of a current (ocean current or littoral current) the horizontal current velocity at the relevant depth "u", can be added to the orbital velocity U, that is, "U" in the above equations is replaced by "u + U" (this assumes that there is no interaction between waves and currents).

For a bottom mounted pipeline (see Figure 13.2) the Morison equation force coefficients (C_M, C_D and also C_L) are functions of Reynolds number, Keulegan-Carpenter number, relative roughness k/D (ratio of height of roughness "k" to pipe diameter "D") and relative clearance e/D (ratio of height of gap between bottom of pipe and bed "e" to pipe diameter "D"). The Reynolds number R_e is defined by :

$$R_e = UD/\nu$$

where

ν = coefficient of kinematic viscosity.

The Keulegan-Carpenter number "KC" is defined by

$$KC = UT/D$$

where

T = wave period.

For pipes mounted well clear of the bed the Morison equation force coefficients are also a function of V/U, that is, the ratio of the vertical orbital velocity "V" to the horizontal orbital velocity "U". The force coefficients can also change significantly as a result of marine growth on the pipe and possible scour or sand build-up along the pipeline.

From the above it is evident that an exhaustive review of the available literature on forces on pipelines will have to be undertaken to select the appropriate force coefficients commensurate with the pipeline configuration under consideration. Factors, such as the effective eddy shedding on the lift forces will also have to be considered. Sarpkaya and Isaacson (1981) provide a comprehensive set of Morison equation wave force data. For example for $R_e = 10^6$, KC = 40, e/D = 0,2, k/D = 0 and V/U = 0 they state that $C_D = 0{,}82$, $C_M = 1{,}84$ and $C_L = 0{,}35$.

Since every pipeline configuration is unique the appropriate force coefficients required need to be carefully selected.

13.2.4 Calculation of wave forces on vertical risers

As for bottom mounted pipelines, the wave induced horizontal forces on a vertical riser are most commonly calculated using the Morison equation, namely:

$$F_H(\text{total}) = F_H(\text{inertial}) + F_H(\text{drag})$$

where

$$F_H(\text{inertial}) = C_M M_{disp} \dot{U}$$

$$F_H(\text{drag}) = 0{,}5 C_D qDU|U|$$

where

F_H = the horizontal force per metre length

M_{disp} = the mass of water displaced by the riser per metre length

D = diameter of riser.

In the presence of a current with velocity u, the total force on the riser can be found again by replacing "U" in the above equations by "U + u".

For a vertical riser the Morison equation force coefficients (C_M and C_D) are functions of Reynolds number R_e, Keulegan- Carpenter number KC, relative roughness k/D and the vertical to horizontal orbital velocity ratio V/U. For long risers the effects of eddy shedding and the variation of wave orbital kinematics with depth will have to be taken into account.

Guides to the appropriate Morison equation wave force coefficients are given in CERC (1984) and by Sarpkaya and Isaacson (1981).

13.2.5 Determination of anchor weighting along pipelines

Pipelines laid on the sea bed are generally weighted in order to resist movement of the pipeline due to wave induced forces, that is, to ensure adequate stability. This weighting can take the form of a continuous concrete coating or regularly spaced concrete anchor blocks. The minimum anchor weighting "W" required at a particular position along a pipeline to prevent sliding is calculated from :

$$F_H(max) = f(W - F_L)$$

where

- $F_{H(max)}$ = design horizontal force per metre length of pipe
- f = friction coefficient between the pipe and the sea bed
- W = anchor weighting per metre length of pipe
- F_L = lift force associated with $F_{H(max)}$

For a flexible pipeline design $F_{H(max)}$ may be calculated using for instance, a 1 in 1 - year maximum wave, while for a rigid pipeline design (steel pipe with concrete coating) $F_{H(max)}$ is calculated using a 1 in 50 or a 1 in 100-year maximum wave depending on the design life of the structure. For a flexible pipeline design movements and strain for 1:10, 1:50 and 1:100 year maximum waves must be calculated at regular intervals along the pipeline to ensure that these are within specified limits. The movements of those sections of a flexible pipeline which pass close to rock outcrops particularly need to be limited.

The design of the anchor weights for a flexible outfall design must be such that their frictional resistance is maximal, the pipe is well clear of the bottom to reduce vertical and horizontal forces, and the laying of the pipeline causes no undue problems. At Richards Bay star-shaped anchor weights were used.

13.3 Wave Forces on Construction Jetty

13.3.1 Determination of design wave conditions along jetty

To determine the wave forces on the jetty the design wave conditions along the jetty must be estimated. The procedure followed would be as described previously in Section 13.2.1 for the pipeline design. An important consideration, however, is that due to the fact that the jetty traverses the surf zone, the larger waves will break before reaching the jetty. As a first estimate, a wave will break when its height H_b = 0,78d, where d is the water depth. H_b, however, depends on the local conditions, particularly the bottom slope and as a result can vary between about 0,5 and 1,0. Under breaking wave conditions the jetty will be subjected to wave impact forces.

13.3.2 Wave orbital kinematics

Once the design wave conditions have been determined a suitable higher order theory is needed to calculate the resultant wave orbital velocities and accelerations adjacent to the jetty from the sea bed to above the sea-water level (SWL). Wave theories such as Cnoidal, Stream function or Vocoidal would be suitable for this purpose. However, it is again recommended that expert advice is sought when selecting an appropriate higher order wave theory. A good guide to higher order wave theories is given by Sarpkaya and Isaacson (1981).

13.3.3 Wave forces on slender piles

The section of pipeline traversing the surf-zone is normally laid from a pile jetty. The jetty is usually constructed from pipe or "H" piles driven into the sea floor at prescribed longitudinal and lateral spacing. The piles are bolted together with steel beams which support the crane rails. The pipeline can be laid from this open pile jetty if conditions are relatively calm, or alternatively steel sheet pile walls can be driven alongside the pile jetty and the sheet piles bolted to the tubular pile jetty structure. The pipeline is then laid in the trench excavated between the sheet piles. The horizontal wave forces exerted on the slender pipe or "H" piles supporting the jetty are calculated using the Morison equation, described in Section 13.2.4, integrated over the full length of the pile from the sea bed to above the SWL. Detailed information on the design of slender piles is given in CERC (1984), while guides to the appropriate Morison equation force coefficients are given both in CERC (1984) and by Sarpkaya and Isaacson (1981). For slender piles lateral forces due to vortex shedding and wave impact forces should also be taken into account.

13.3.4 Wave forces on vertical sheet pile walls

For the design of a vertical sheet pile wall it is usually assumed that the sheet piles

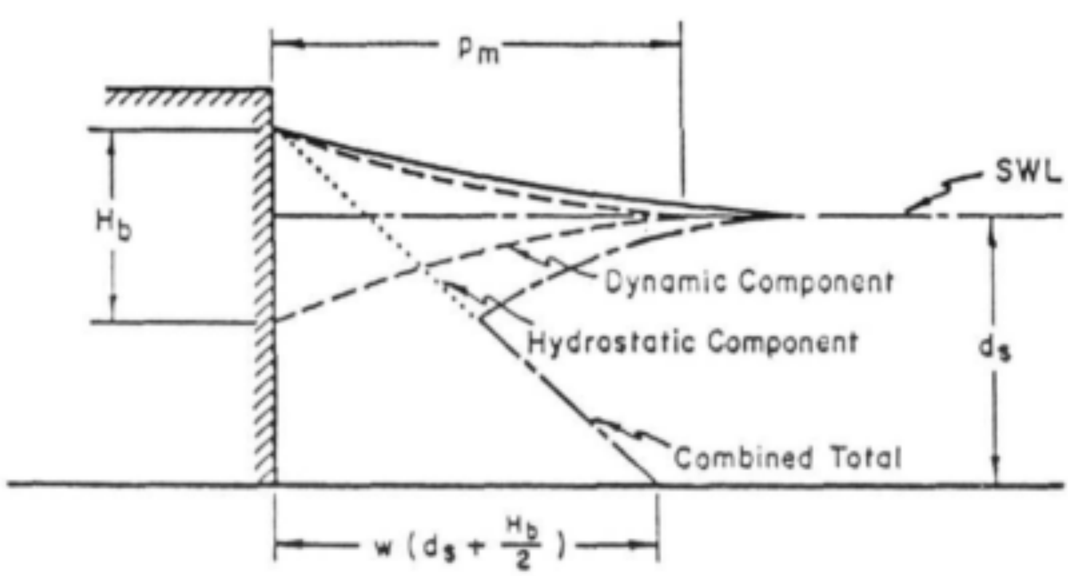

Figure 13.3 : Minikin wave pressure diagram.

are subjected to breaking wave forces. For a first design the Minikin Method (see CERC, 1984) could be used. The maximum pressure P_m on the wall due to breaking waves (see Figure 13.3) is assumed to act at the SWL and is given by:

$$P_m = 101w(H_b/L_D)(d_s/d_L)(d_L + d_s)$$

where

P_m = the maximum dynamic pressure
H_b = the breaker depth at the toe of the wall
d_L = the depth one wavelength in front of the wall
L_D = the wavelength in water depth d_L
w = the unit weight (N/m^3 or KN/m^3)
= ρg where ρ is the mass density (kg/m^3) and g is the gravitational acceleration.

The distribution of dynamic pressure is shown in Figure 13.3. The pressure decreases parabolically from P_m at the SWL to zero at a distance of $H_b/2$ above and below the SWL. The force represented by the area under the dynamic pressure distribution is :

$$R_m = P_m H_b/3$$

that is, the force resulting from the dynamic component of pressure. The overturning moment about the toe is :

$$M_m = R_m d_s$$

that is, the moment resulting from the dynamic component of pressure.

The hydrostatic contribution to the force and overturning moment must be added to the results obtained from the above equations to determine total force and overturning moment (see Figure 13.3).

Forces calculated using the Minikin method are known to be very conservative, and for a more economical design more advanced force calculation methods should be used. Also the effect of wave angle should be taken into account since most jetties will be orientated approximately normal to the wave crests.

13.4 Stresses During Construction

Pipelines are likely to be subjected to greater stresses during laying than the stresses experienced due to wave loading over their design life. It is thus necessary to ensure that the strength design of the pipeline is adequate to withstand the expected construction stresses.

The type of stresses likely to be experienced by a pipeline are dependent on the method of construction employed. For example, for flexible pipelines which are floated out to the site and sunk into position, and for flexible pipelines which are laid from a lay barge, the pipeline catenary between the surface and the bed can be subjected to severe loading. More rigid pipelines, constructed in sections on the shore and then pulled into position along the sea bed, need to be designed to withstand the high pulling forces.

13.5 References

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CHAPTER 14

CONSTRUCTION TECHNIQUES

by W J Brewster

Outfalls on the South African coast can be expected to have a length in the range 500 m to 5 km and diameters from 200 mm to 2 m. These basic dimensions are determined from hydraulic and dispersion calculations, and when established largely dictate the choice of pipe material, the structural design of the pipeline and the installation method.

Other important considerations are the type of effluent, the nature of the sea bed, the sea conditions and the availability of suitable onshore fabrication areas.

14.1 Materials

Most marine effluent outfalls are constructed from the following materials :

- Concrete
- Asbestos cement
- Steel
- Glass reinforced pipe
- Unreinforced plastic
- Reinforced plastic
- Cast iron

14.1.1 Concrete

Reinforced concrete pipes, either standard or specially made with rubber seal joints, are commonly used for outfalls. Since the joints can only withstand limited deflection, firm support is required under the pipeline. This can take the form of a prepared bed or alternatively the pipeline or the joints can be founded on pile supports.

Continuous concrete pipelines have been constructed using longitudinal prestressing and special joints capable of transferring tensile forces.

14.1.2 Asbestos cement

Standard asbestos cement pipes may be used for outfalls, and as with concrete pipes, particular attention must be paid to the method of support.

14.1.3 Steel

Steel is used principally for the longer outfalls. Various types of joining methods are possible but the choice will usually determine the installation method. Linings are required to resist the effluent and external coatings to resist sea water. Concrete encasement is normally provided to protect the coating and to add mass to the pipeline for stability purposes. Special support of the pipeline is usually only necessary on very weak materials or where the joints have substantially less resistance to bending or longitudinal tension than the steel pipe itself.

14.1.4 Glass reinforced pipe

The use of glass reinforced pipe in outfalls is usually restricted to transporting very aggressive effluents. Joints can be a problem and the material is most often used in the form of liner pipes within a steel or concrete sleeve.

14.1.5 Plastics

These are usually selected for their resistance to attack either by the effluent or sea water. High-density polyethylene (HDPE) and polypropylene are probably the most common. Pipelines from these materials can be used as liners inside sleeve pipes or by themselves with suitable anchoring methods.

14.1.6 Cast iron

Pipes made from this material have frequently been used in the past to construct outfalls. Firm support particularly at the joints is required. Longer life can be achieved by special linings and coatings.

14.2 Installation Methods

Ocean outfalls rarely extend into depths greater than 50 metres and this depth will generally be found within 10 km of the shore along the South African coastline. Possible installation methods appropriate for these criteria are :

Bottom tow
Off-bottom tow
Surface tow
Assembly on sea bed
Lay-barging

Most of these methods are only suitable for certain pipeline materials and diameters, and in addition the choice will be restricted by prevailing environmental conditions.

14.1.1 Bottom tow

In this method the pipeline is assembled onshore and is pulled into position on the sea bed by winching from a barge or vessel anchored offshore. To keep the pulling loads and the stress in the pipe to acceptable limits it is usual to seal off all openings in the pipeline and to keep the inside full of air. The method is usually applicable to steel pipelines due to the comparatively high tensile stresses during pulling but it has on occasion been used for prestressed concrete pipes.

For steel pipes with normal wall thickness, 300 mm diameter is a significant division. A pipe of less than this size will not float when filled with air but above this size it will. The submerged weight of the pipeline is critical to the installation method. It must be sufficiently heavy to withstand current and wave forces during the pull but not so heavy that the pulling load and pulling stress exceed acceptable limits. For design purposes it is usually assumed that the critical combined current and wave forces for a return period of 1 in 1-year are applicable. For steel pipe sizes above 300 mm additional weight must be added to the pipeline to meet this criteria. This can be done by increasing the wall thickness of the pipe or by adding a concrete coating. The latter solution is usually more economic and the concrete serves to protect the anticorrosion coating against damage both during installation and in the permanent installation.

If the submerged weight empty is unnecessarily high for the 1 in 1-year wave and current forces, it may be reduced by attaching floats to the pipeline onshore and removing them after the pull has been completed.

The pipeline is normally assembled onshore in as long lengths as possible to reduce the number of welds or other connections during the pulling operation to a minimum. This is to minimise the cost when employing very expensive marine equipment and also to reduce the weather risk. Each length in turn is transferred onto a launchway, connected to the previous section and the completed section is pulled seawards by the offshore pulling winch for a distance equal to the length of the pipe string.

For ease of working the assembly area must be reasonably level, although a longitudinal fall seawards of up to 10 degrees is acceptable. The pipe strings are normally made up straight but the launchway can be provided with vertical and horizontal curves to achieve the most economical solution of the problem of transferring the pipeline sections from the assembly area to the sea bed. Minimum radii of curvature are calculated and specified for the pipelines such that the allowable steel and concrete stresses are not exceeded.

Lateral movement of the pipe strings onto the launchway is usually achieved by rolling the strings over concrete plinths but for very large diameter pipes rail mounted bogies are sometimes used.

Longitudinal movement of the completed pipeline down the launchway is usually over fixed rollers or rail mounted bogies to reduce the force necessary to overcome friction which for the nonsubmerged pipe would otherwise be very high.

The profile of the sea bed must be such that the combined stress in the pipe wall due to the pulling load, the external water pressure and the radius of curvature does not exceed the permitted value. If necessary the sea bed profile must be modified to suit the allowable radii. The sea bed material should preferably be sand or silt and areas of hard material should be avoided if possible by selecting a suitable route. The alignment of the pipeline should preferably be straight since horizontal curves are difficult to control using the bottom tow method and can involve relocation of the main pulling anchor spread.

14.2.2 Off-bottom tow

In this method the pipeline which is usually steel or reinforced plastic is made up onshore into large lengths and ballasted to a slightly positive buoyancy. Short lengths of chain are then attached at intervals and the pipeline launched. Due to the action of the chain the pipeline section takes up an equilibrium position a few metres above the sea bed with part of the chain resting on the bed. The section is then towed into position by a tug and lowered to the sea bed by removing the buoyancy floats.

The towing force required is very low for this system and in theory the method can be used for very long lengths of pipeline. In practice, however, the installation is influenced by currents and the method is usually restricted to small diameter pipelines or bundles of pipelines laid in deep water without a connection to the shore.

14.2.3 Surface tow

For this method the pipeline must be buoyant during the tow but have some means of reducing the buoyancy so that the pipeline can be made to sink. For steel pipelines with concrete weight coating, buoyancy tanks or floats are provided and after the pipeline section has been towed into position it must either be lowered from the floats or the floats must be flooded or released progressively.

The method is not suitable for large diameter rigid pipelines owing to the risk of buckling during sinking. It requires extreme care during the sinking and very calm conditions are required.

For flexible pipelines made from HDPE or polypropylene the surface tow is the preferred method. The pipeline is assembled in sections onshore, the weight collars fitted and the pipe section launched into sheltered water. The sections should generally not be longer than 1 000 m and the required number can be assembled and stored floating if a suitable site is available. They can also be flooded and stored underwater if this seems more appropriate.

The tow to the site of the pipeline is relatively easy although certain precautions must be taken. The sinking process requires calm conditions with minimal currents. It consists basically of allowing water to enter the pipeline at one end and releasing air at the other. The air must initially be pressurised. The pipeline adopts an S-curve configuration during installation.

The stresses in the pipe wall must be controlled very carefully by keeping the internal water surface at the correct depth and by maintaining a minimum laying speed. Sections of pipeline on the sea bed are usually joined by fitting purpose made spool pieces with flanged joints. The sinking stresses impose limits on the number of concrete collars which can be attached to the pipe prior to sinking. If this mass is insufficient for the stability of the pipeline on the sea bed then additional collars or parts of collars can be attached by divers after the sinking operation is complete.

14.2.4 Assembly on sea bed

The method is usually confined to outfalls in sheltered areas and which are made up of short lengths of rigid pipe such as concrete, asbestos cement, steel or cast iron. The joints are a source of weakness and flexibility and tolerance of angular misalignment are usually necessary. A firm foundation is necessary and this can range from piled supports at each joint to a prepared crushed rock bed. If piled supports are used these can sometimes be designed to accept environmental loads but pipelines on prepared beds are usually installed in excavated trenches and backfilled.

It is sometimes possible to install small diameter pipelines of this type using divers and without special equipment or expensive temporary works, but generally this is not the case. For larger diameter pipes underwater gantries can be used to line-up and join pipes but calm conditions are necessary. The use of divers can be minimised by automation but the cost of special equipment can be very high.

In general it is preferable to support pipe sections during installation off the sea bed thus avoiding vertical motion due to wave or swell action on the surface. The effects of wave currents and inertia can be very considerable and the horizontal forces from these can be very high on large pipes.

It is usually convenient to cross beach and surf zones with a trestle or jetty as a working platform but in water depths greater than 10 metres it will probably be more economical to continue with a jack-up or self elevating platform.

14.2.5 Laybarging

The laybarge is a floating piece of construction equipment on which pipe sections are joined together and payed out onto the sea bed as the barge moves progressively forward on its anchors. Some kind of pipe ramp is usually required off the stern of the barge to prevent overstressing of the pipeline. The method is used almost exclusively for long welded steel pipelines and due to the high cost of mobilising and operating the equipment this method is normally uneconomical for the comparatively short pipelines required for outfalls. An offshore laybarge cannot operate in shallow water and shore approaches or surf zone crossings have to be constructed by a bottom tow operation. This can be done either by keeping the laybarge anchored offshore and pulling the newly assembled pipeline ashore with a land based winch or by assembling the pipeline onshore and pulling it offshore either with a winch from the laybarge or more usually a special pulling barge. To continue with pipeline installation the laybarge picks up the seaward end of the pipeline, removes the pulling head and joins on new pipes progressively.

PART 6 : POST CONSTRUCTION MONITORING

CHAPTER 15

ENVIRONMENTAL MONITORING

by A D Connell and T P McClurg

15.1 Introduction

Environmental monitoring is an essential part of both the planning and the operation of any ocean outfall, for the verification of the adequacy of the design, environmental protection and public health related concerns.

The assimilative capacity of the discharge area should have been roughly assessed in the early stages of planning and site selection in order to determine the amount and type of effluent that can safely be discharged. Subsequent monitoring provides the confirmation (or otherwise) of the adequacy of the safety factors applied in the design stages, provides a measure of the environmental impact of the discharge, if any, and supplies valuable information and experience in ocean outfall design.

Three aspects of the marine environment are generally of concern, namely :

(i) **water quality**, including chemical, physical and bacteriological aspects;

(ii) **sediment quality**, including physical and chemical aspects; and

(iii) **the biota** - in this category are included aspects of the pelagic fauna and flora, the benthic communities, and the accumulation of chemical substances in organisms through exposure to elevated levels in the environment. Benthic community studies could also extend to meiofauna of beaches or the fauna and flora of rocky shores if such areas fall within the zone of influence of the ocean outfall.

The intensity of effort involved in environmental impact monitoring is obviously related to the scale and composition of the discharge, the sensitivity and ecological or sociological importance of the area in which the discharge is to be located.

The following comments on post-discharge monitoring would presuppose a data bank of information on conditions prior to discharge, be they chemical, bacteriological, physical or biological.

15.2 Sampling Strategies

The strategy adopted will depend on the scale and composition of the discharge and the goals of the monitoring programme. A standard grid of stations is generally adopted, on a 9 x 5 or 10 x 5 grid of 250m squares, the longer side set parallel to the prevailing currents (usually parallel to the coast). A full set of samples from the grid thus provides a "snapshot" of conditions prevailing, and, in the case of the biological samples and sediments at least, integrated over a period of time prior to sample collection.

Sampling does, however, need to be reasonably flexible. Any changes encountered need to be quantified, both in terms of the degree of change and the area affected. Thus it may be necessary to deliberately concentrate on a particular quadrant where perhaps dominant currents have consistently moved effluent over one area of the sea bed.

More information on water sampling techniques will be found in Watling (1981).

15.3 Chemical Parameters

15.3.1 Water chemistry

If there are no existing pipelines or other sources of pollution in the area, general data on water quality in that area will be sufficient as background data. Other activities which might affect background water quality include dredge spoil dumping and tidal discharge from harbours. River discharges might also play an important role in bacteriological quality of waters in their vicinity.

In the planning stages it must be recognised that the discharge of effluents containing substantial levels of heavy metals or persistent chemicals which can lead to problems of direct toxicity or accumulation in food chains, would not be permitted. In continuous large volume discharges, however, small quantities of certain of these compounds or elements will be discharged, but they will be released at relatively low concentrations. Since changing wind, current and wave patterns can and will render meaningful sampling of the water column difficult, it is usually preferable to study levels in sediments and shellfish, the former to indicate the predominant transport direction if such trends are discernible, and the latter to indicate the bioavailability of the compounds present in the effluent. Mussels and oysters have been used in such studies, and can be moved from clean sites beyond the influence of the outfall, to moored cages in the vicinity of the pipeline.

Chemical analyses should be confined to those parameters relevant to a particular pipeline. A conservative element or compound, if any can be identified which can act as a tracer, might prove to be particularly useful.

15.3.2 Sediment chemistry

The sediments must be sampled in order to determine any changes in the chemical concentration or any organic enrichment due to the accumulation of pollutants.

Usually this is achieved by simply subsampling the sediments retrieved by grab during biological sampling. In poor weather, or in the absence of grab samples, use may be made of a simple core dredge to scoop sediment from the sea bed. In areas where location is critical, or undisturbed cores are required, diver collected samples would be most suitable.

Standard methods for the chemical analysis of marine sediments have been described by Watling (1981). Apart from the specific parameters of interest, effort should always be made to measure the particle size distribution and levels of easily oxidisable organic matter in all sediment samples. These two parameters have a strong modifying effect on other parameters and are essential in interpreting trends. For example, finer sediments, by virtue of their greater surface area per unit volume, tend naturally to adsorb higher concentrations of metals and organics. It follows that without knowledge of particle sizes any upward trend in metals or organics cannot be conclusively attributed to increased population loads. At the very least the sediments must be subjectively categorised.

15.4 Toxin Levels in Biological Tissues

Methods of sampling for certain organisms such as mussels and oysters, and the analytical techniques involved, are given by Watling (1981).

A useful technique for gauging the amounts of biologically available metals involves the transfer of bivalve molluscs from clean areas to localities in the vicinity of the outfall where they can be hung from surface or subsurface buoys.

Fishes, particularly those types that associate closely with the sea bed, such as soles, plaice and flounder, are also useful for monitoring toxicant levels. At Richards Bay, in addition to trace metals and pesticides, the tissues are analysed for fluoride. The fishes are collected by beam trawl, and the composition of beam trawl hauls over standard distances has made a useful addition to the records of benthic organisms in the area.

15.5 Benthic Community Surveys

15.5.1 Marine communities available for sampling

Field surveys of biological communities comprise an integral part of most pollution impact studies. They provide a means of verifying environmental predictions based on laboratory toxicity experiments and dispersion calculations. They also provide a means of detecting damage at the ecosystem level. Unfortunately such surveys are usually expensive and tend to have many weaknesses. To be most cost- effective the surveys should be very carefully planned.

Generally three types of marine community are available for sampling in pollution impact assessment.

(i) **The flora and fauna** which settles on introduced artificial substrates.

(ii) **The pelagic biota** (plankton and nekton) associated with the water column.

(iii) **The benthos** - those organisms associated with, or living on, the sea bed.

The use of artificial substrates has considerable potential in determining biological impact. The idea is that any new substrate, such as an asbestos panel, a tray of sand or a length of rope introduced to the sea will be colonised by species from the surrounding populations, either by larval settlement or by direct migration. The colonisation process will be impeded or disrupted in a pollution stressed environment resulting in impoverished fauna, the degree of impoverishment bearing a rough relationship to the degree of stress. This approach suffers two potential shortcomings. First, natural temporal and spatial variation in the settlement of larvae may hamper the interpretation of results. Second, logistical problems may be encountered in establishing and maintaining artificial substrates in the field. On the positive side, it allows fairly precise control over the location and timing of measurements and tends to focus attention on a key process in the development of marine communities, namely larval recruitment and development.

Pelagic biota are obviously important, especially for commercial fisheries, and need to be protected. However, the effective use of pelagic organisms in impact assessment is difficult to achieve. Pelagic populations tend to fluctuate very widely and are difficult to quantify. Plankton is inherently patchy and is locally influenced by the prevailing currents and oceanographic conditions. The nekton also fluctuates widely in composition and abundance and contains some groups (e.g. fishes) which may actively select or avoid a locality. This natural variation makes it difficult to link cause and effect when considering the effects of pollution on pelagic organisms. Pelagic biota have consequently not been widely exploited in marine pollution assessment.

Most pollution studies have concentrated on the benthos as it is easier to sample quantitatively and has the distinct advantage of including mostly sedentary species which cannot simply move away from stressful conditions. Sensitive species may be eliminated while the more opportunistic ones may proliferate. The result will be a change in community structure which may relate to the degree of stress. The benthos suffers two main disadvantages. Firstly, it only reflects conditions near the sea bed. Secondly, natural spatial and temporal variations in the composition and abundance of fauna tend to be wide and may mask the effects of pollution. This variation must be accounted for in the design of field surveys so that statistically verifiable results may be obtained.

If the general physical and biological conditions in the area to be studied are not known, a pilot survey should be made which may include direct underwater observations by divers. Preliminary qualitative sampling will give some idea of the types of animals to be sampled and the patchiness of both organisms and sediment. Measurements of physical parameters, such as currents, salinity and temperature may reveal trends or gradients which may need to be accounted for in the layout of stations. For example, if there is a predominantly southward current one may want to increase sampling density to the south. The final number and disposition of stations will be based largely on common sense and is likely to be a compromise between the statistical requirements for intensive sampling and the realities of expensive sea-time and time consuming analyses. To be most cost-effective the survey should be aimed at a level which will give a statistically verifiable result for the least effort. Benthic environmental surveys clearly require careful planning and should entail the early interaction of a benthic ecologist and statistician.

15.5.2 Sampling methods

Having decided where to sample, the question of how to sample arises. Numerous dredges, corers and grabs have been devised to remotely sample benthic fauna and the choice will depend very largely on the facilities available, the size of the sampling platform, water depth, sediment type, etc. Holme and McIntyre (1971) provide a detailed review of marine benthic sampling methods. The van Veen grab with a "bite area" of about 0,1 m^2 is probably the most widely used. However, it tends to be less effective in the harder sandy substrates where the Smith-McIntyre grab operates well. There is no single sampling size which is appropriate to all quantitative biological surveys. Large numbers of small samples are preferable for the purpose of spreading the samples over a wider area and so reducing error variance. However, edge effects of the sampler become increasingly significant with smaller samples. A good compromise appears to be about 0,1 m^2 sediment surface area per grab. The number of samples required to give an acceptable estimate of the diversity and abundance of the population will depend on patchiness and the associated variation between samples. A species-area curve may be obtained by pooling successive samples and determining the number of species in the pooled samples. The number of samples required to secure a reasonably high percentage of available species can then be determined.

15.5.3 Determining the effects of pollution

There are three distinct approaches which may be taken to determine whether a benthic community has been affected by pollution. Firstly, one may compare the fauna statistically with that occurring in an unpolluted control area. Secondly, one may look for gradients in faunal parameters, such as diversity or abundance, which may relate to the incidence of pollution. Thirdly, one may compare the results of surveys made at the same stations before and after the pollution event. Most studies rely on the latter two approaches in evaluating pollution impact. The first approach should only be used with extreme caution since natural variability between geographically separated populations may lead to erroneous conclusions.

In applying the "before and after" approach it is usual to maintain a fixed set of sampling stations. However, in cases where there is a high degree of patchiness, or where difficulty is experienced in returning accurately to the same sampling point, a modified approach involving a randomised sampling pattern may be adopted. Gilfillan (1986) has recommended such an approach for monitoring the impact of the Richards Bay marine pipelines.

A variety of criteria are used in making comparisons between benthic faunal communities. Most relate to community structure and include total abundance, number of species, diversity and evenness. Each of these parameters has some value in assessing community change, the Shannon-Weiner measure of diversity being particularly widely used (see Gray, 1981, for a detailed review of methods for comparing benthic marine communities). These community parameters should only be used in a comparative way for they have little meaning in isolation. They may be ambiguous in that totally different species compositions may yield identical values. To measure absolute difference between communities, a multivariate statistical approach is required. Two broadly distinct multivariate techniques have evolved, namely classification and ordination. Both require the use of computers.

15.5.3.1 Classification

Classification, or similarity analysis aims at measuring the relative similarity of the fauna at all stations and classifying them into groups. The end result of a classification is usually expressed as a dendrogram which graphically represents the affinities between samples and groups of samples. Samples with high faunal affinity will be clustered together.

The most widely adopted measure of similarity appears to be the Bray-Curtis index (Bray and Curtis, 1957). Sneath and Sokal (1973) provide a comprehensive revue of the classification concept in their detailed treatise on numerical taxonomy.

15.5.3.2 Ordination

The principle of ordination is similar to classification in that it aims at delineating groups of samples or stations with high affinity. The end product is a graph, usually two-dimensional, in which similar entities are grouped near each other, while dissimilar entities are located far apart.

There are a variety of methods which can be used for ordinations. In South Africa success has been achieved with detrended correspondence analysis (Hill, 1979) while Field *et al.* (1982) express a preference for multi-dimensional scaling as described by Kruskal and Wish (1978). Gauch (1982) provides a useful review of the subject.

Although classification and ordination produce similar end products, they achieve it by different means. The complementary nature of the two methods is stressed by Field *et al.* (1982), who suggest that confirmation of a result may be achieved by applying both techniques to the same data set.

15.5.3.3 Explanation of observed trends

Having generated a dendrogram or ordination, the next step is to seek an explanation for any observed trends. This will usually entail a search amongst physical or environmental parameters, including exposure to pollution, for patterns which may corroborate the biological trends. A link can thus be established. It can be seen that accurate documentation of environmental parameters is very important. These should not only include pollution related measures (e.g. toxic metals, pesticides, total organic carbon, pH, dissolved oxygen, etc.) but any other parameters which might account for natural biological variation (e.g. currents, salinity, temperature, sediment type and light penetration). Experience, common sense and availability of resources will dictate the choice of parameters to be measured. Important parameters should not be missed, yet one should guard against making unnecessary measurements. One parameter which should always be included in any benthic survey is sediment type. Grain size and sediment texture are key factors in the development of benthic communities. At the very least the sediment should be subjectively categorised.

15.6 Other Parameters

The bacterial quality of surface waters over the diffuser, and along the beaches, has been discussed in Chapter 6 and when relevant should form an integral part of the monitoring programme.

Meiofauna studies on sandy beaches adjacent to pipeline discharges can provide useful data in certain circumstances. However, the analysis of such samples is a specialised task, and a good deal of data is needed on local meiofaunal communities before meaningful comparisons can be made.

A number of studies have been made into the subject of the health of fishes near ocean outfalls. Examination of liver tissue can give an early indication of changes in the health of fish. In southern California, liver cell enlargement (hypertrophy) and increased vacuolation has been correlated with DDT concentrations in the liver (Rosenthal *et al.*, 1984).

The incidence of parasites in fishes has also been linked to pollution. However, parasitism is a density dependent occurrence, i.e. the more dense the host the higher the incidence of parasitism. It is, therefore, impedent to select a comparison population with a similar field density to the population in the vicinity of the pollution source.

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CHAPTER 16

PIPELINE STABILITY

by K S Russell

16.1 General Design Aspects

Movement or displacement can result from an unstable sea bed, erosion of the sea bed material undermining the structure or from insufficient anchorage to resist the hydrodynamic forces due to wave and/or current action. Other causes identified have been due to snagging by ships anchors and indeed buoyancy due to air or foam intrusion into the pipeline.

The pipeline route should be subject to extensive and detailed survey, including geophysical investigation to evaluate the condition and stability of the sea bed. The selected route should avoid installation across unstable side slopes as these will be subject to slippage or slumping.

Across the surf zone it is essential to determine the envelope of movement of the sea bed profile. In the active coastal zone in South Africa, vertical movement on the sandy beaches may be 4 to 5 m requiring temporary works with jetties and sheet pile trenches to ensure that the pipeline is buried or trenched at a depth below the minimum predicted profile. It is normal to place sleeves, encased in concrete to ensure structural integrity and anchorage weight, through which the pipeline can subsequently be installed. Alternatively, smaller diameter pipelines can be installed by directional drilling techniques. Directional drilling involves drilling a pilot hole in a loop from the beach to a position beyond the active surf zone. The drill diameter is successively increased by reaming until the continuous pipe can be inserted and a sub-bottom connection secured at the exit point.

Erosion of the bed material and subsequent undermining of the structure is mainly due to currents, often coupled with wave induced currents. The normal pattern for pipelines laid directly on the sea bed is to find deposition against the pipe in the direction facing the current with erosion on the down drift side. For pipelines on areas underlaid by rock, erosion of the sediment may leave them perched or spanning across rocks or rock sills and liable to failure. Corrective measures employed in Durban was to drape the pipe with fine fishing nets, to encourage sand trapping and to protect the pipe with fine dump material overlaid with rubble.

The design philosophy with marine structures, including pipelines, is to ensure integrity of the structure throughout its design life expectation. This can be achieved by trenching the pipeline in an excavated or dredged trench and backfilling with suitable material. On a sandy sea bed the pipeline may be laid directly on the sea bed and subsequently trenched using a special travelling trencher mounted on the pipe. A variety of travelling trenching devices have been developed using either (1) mechanical, counter-rotating cutter heads to cut under the pipe, (2) high pressure water jets to loosen the material coupled with a dredge suction to remove the material, or (3) fluidisation of the sediments by injecting large quantities of water which decreases the density and causes the pipe to settle under its own weight.

If burial of the pipeline can be achieved and ensured for the lifetime of the installation then there is no need to be concerned with the stability against wave forces beyond those which occur during construction and prior to backfilling. It will be necessary to ensure that the backfill material itself is suitable and stable and that any rock protection or armour is adequate to ensure stability under wave action.

Many pipelines laid on the sea bed have been protected directly by rock backfill and armour. The design of such protection is in the form of an inverted filter, geo-textile material covering the pipe and adjacent area overlaid with layers of filter stone, increasing in grading size and overlaid with rock armour. The rock size of the armour layer is determined by calculation of the hydrodynamic forces due to waves and currents on the submerged rock.

16.2 Design Philosophy

For pipelines laid directly and fully exposed on the sea bed there are basically two approaches to the design philosophy. The "rigid" design approach, where the pipeline weighting or anchorage system is designed, with a suitable factor of safety, to resist the maximum combined hydrodynamic force to which it will be subject during its life expectation of some 25 to 50 years. This approach is the historical design concept and applies to conventional material used in construction - iron, steel and concrete. The introduction of plastic materials - polyvinyl chloride (PVC), high-density polyethylene (HDPE) and fibreglass reinforced pipe (FRD) - has lead to the "flexible" pipe design procedure. There is no "design code" for flexible pipelines, present design is based mainly on experience gained in Scandinavia with certain force coefficients as defined by Det norske Veritas publication RULES FOR SUBMARINE PIPELINE SYSTEMS (1981), superseded by *on-bottom stability design of submarine pipelines* (1988). In this procedure it is accepted that the pipe may move, the anchor weighs are determined on the basis of a once-a-year maximum wave height. However, such a design should only be considered acceptable when it can be proved that, for the design life wave conditions (i.e. 1:25 to 1:50 year maximum waves), the pipe will remain functional. That is, it will not move more than a few metres and the bending moments and strain will not exceed accepted values, applicable to the end of the design life period. It is also essential to consider the sea bed geological properties. Obviously, design for movement on a rocky sea bed would be unacceptable due to damage to the concrete anchor blocks on rock and subsequent loss of anchorage weight and stability. Abrasion of the plastic material against rock outcrops due to movement should also be considered.

The pipeline at Green Point, Cape Town, designed according to the "flexible" design procedure, was extensively damaged in the storm of May 1984 due to movement and resulting loss of anchorage. The replacement of the pipeline was undertaken by excavation of a trench in the rock (Malmesbury scale), backfilled and surfaced with tremie concrete. The Richards Bay pipelines, also designed according to "flexible" design procedures but lying on a predominantly sand sea bed, have been successfully operating since 1984. The Richards Bay pipelines cross a reef at two locations. These reef areas have been excavated adjacent to and below the pipe invert, additional weighting was provided to prevent movement, with transitional weighting on the adjoining sections to avoid "rigid" focus points for strain and subsequent buckling.

For such "flexible" designs there are also numerical techniques to calculate the displacement of the pipeline under hydrodynamic loading and the cumulative displacement under a prescribed storm condition - as indicated the design should only be considered acceptable if this movement is limited and does not hazard the function and operation of the pipeline. A number of questions remain however on the actual movement of such flexible pipelines in prototype conditions and very little accurate field monitoring data of installed pipelines exists.

Ocean pipelines, normally extending a number of kilometres to sea, are vulnerable to snagging by ships anchors. Such pipelines are often located at major harbour cities for disposal of industrial and domestic effluents. It is not always possible to ensure that pipelines are in areas where anchorage of ships is prohibited, while ships in heavy seas often drag their anchors for considerable distances before the situation is brought under control. On a sandy sea bed, ploughing by anchors of large ships such as tankers and ore carriers has been reported to extend beyond a metre below the sea bed. Burial or backfilling and armour protection of the pipeline obviously minimised the hazard. In certain designs, where there is a high likelihood of snagging by anchors, pipelines have been designed to withstand point loading due to ship anchors.

16.3 Pipeline Survey

Marine pipelines should be regularly surveyed to check their stability, especially after the occurrence of extreme sea state conditions. The survey of a pipeline requires high- precision position fixing of the survey vessel, coupled with accurate vertical definition.

There are a variety of electronic systems available for position fixing at the sea surface. For pipelines which extend some kilometres offshore, microwave or alternatively laser systems are highly suitable. The accuracy for the microwave system depends on the distance offshore and the configuration of the shore beacons which control the angles of interception. If three beacons are deployed the accuracy of the fix can be determined from the triangular interception of the three beams. Accuracy of $\pm$ 1 m can be obtained up to a 10 km range. The range of most laser systems is limited to 5 km and accuracies are of the order of $\pm$ 0,5 m. With the motion of the boat, the antenna or reflector is constantly moving and an accuracy of $\pm$ 1 m is the best which can realistically be achieved.

Echo sounding is the most accurate depth measurement, providing a continuous record or profile of the seabed under the survey vessel. By undertaking a fine grid of survey lines, parallel and perpendicular (across) the pipeline it is possible to build up a clear impression of the sea bed and of sediment accretion and erosion adjacent to the pipeline. Vertical accuracy by echo sounder is $\pm$ 1 % of the depth or 20 cm in 20 m water depth. With high precision equipment and constant calibration checks this could be improved to $\pm$ 0,5 %. For such high resolution survey the spacing of the survey lines is critical and intervals between lines of 10 m to 25 m is normal.

Side-scan sonar provides a strip plan of the sea-bed over which the profiler is towed. Successive parallel survey lines can, after correction for distortion, be assembled to form a mosaic of the sea bed. Side scan sonar is less accurate than echo sounding but provides a more comprehensive "picture" of a pipeline and the adjacent sea bed. Side-scan survey is particular useful in identifying sea bed features such as rock outcrops, reefs and adjacent obstructions which may hazard the pipe.

For buried pipes seismic or sub-bottom profilers can be used to determine the depth of burial below the sea bed. The use is limited to burial in sediment. The accuracy is also limited by the resolution and quality of the reflected signals.

16.4 Measurement of Pipeline Movement

The accuracy of locating the pipeline is determined by the combined accuracy of the survey fixing and echo sounding. As a result the best accuracy for locating a position on the sea bed will be in excess of 1 m. While successive surveys would determine gross movements of the pipeline, movements of less than some 2 metres could not be resolved with any degree of confidence. The basis for the design of the flexible pipelines was that movement of the pipe under maximum wave loading (i.e. 1:25 - 1:50 year maximum wave) would not exceed more than a few metres.

To resolve minor but critical movement of the pipeline, fixed reference marks can be established adjacent to the pipeline. At Richards Bay a total of 20 such reference marks have been established at intervals of some 200 m extending from chainage 1150 m to 5400 m.

These reference marks are referred to as jet pipe markers (JPM) and consist of scaffolding pipe which have been air jetted into the sea bed at some 4 m from the pipeline. The JPM's were placed to the southern side of the pipeline as the major wave loading is from SW and pipeline movement would be to northward. Measurements of the distance to the adjacent anchor block from the JPM have been undertaken since 1985 during the annual diving inspection. Measurements at all reference marks has consistently indicated variations of $\pm$ 0,2 m which is without doubt the reading error as diving is normally in extremely poor visibility. However, during the diving inspection of August 1988 the section at chainage 1300 m was found to have moved from 5,1 m to 11,1 m. This displacement was as a result of the floating of the pipeline (7 May 1988) due to the pumping of foam from the fertiliser factory. The pipeline was displaced when it re-settled on the sea bed but was otherwise undamaged.

It is essential to build up long term records of movement of installed pipelines as this will contribute to future design an improved safety for future installations.

CHAPTER 17

PIPELINE PERFORMANCE

by G Toms

Monitoring the effects on the marine environment after construction of a pipeline is fairly standard practice; measurement of the actual dilutions that are achieved with a new outfall, are however, much less common. Such dilution studies have only been carried out on two outfalls in South Africa to date: the Camps Bay outfall near Cape Town which discharges municipal effluent and the Fedmis outfall in Milnerton which discharges industrial effluent.

The purpose of these studies are partly of a research nature, with the aim of validating the prediction techniques for initial dilution and partly to evaluate compliance of the outfall with the criteria set by the controlling authority.

This type of pipeline performance test is generally carried out in the following way: A dye material (Rhodamine B) is introduced into the effluent stream of a marine pipeline. The dye marked effluent is discharged through the diffuser ports and becomes visible as a series of red plumes on the surface of the ocean. Later, the individual surface plumes merge and the red effluent field is transported and diluted further under the influence of the local currents. Rhodamine dye has the advantages that it is clearly visible and its concentration can be accurately measured with a fluorometer, even at very low concentrations of around 10^{-10}. During the dilution process therefore, samples of the spreading effluent patch are collected from a vessel and stored in glass bottles (500 ml). These samples are collected in quick succession from the centre of the patch for the duration of the test. At the same time samples are also collected from the effluent as it enters the pipeline or, if that is not possible, from the diffuser ports by a diver as it emerges from the ports. The samples are then stored in the dark, since the Rhodamine concentration diminishes under the influence of ultraviolet rays, for later laboratory determination of concentration.

Comparison of the concentrations of dye in the diluted effluent with the concentration of dye just before discharge will give a good indication of the dilution that can be achieved in the field during a particular sea condition. The dilutions thus obtained are minimum dilutions since the samples were collected from the centre of the patch. It will obviously then also be necessary to describe the sea conditions at the time of the test by measuring the salinity and temperature stratification of the water column as well as the wind and current characteristics.

Aerial photographs can also be taken at regular time intervals, of the spreading dye/effluent patch. These will give valuable information on the behaviour and ultimate fate of the patch.

Investigations of this kind are expensive, especially since they should be repeated under various conditions in the ocean. They are invaluable, however, in assisting in an understanding of the processes and mechanisms of effluent discharges and of the real, on-site dilutions that can be achieved. The results presented in the WRC Report No. 160/1/88 have assisted in furthering our knowledge and in updating the prediction techniques for achievable dilutions (Toms and Botes, 1988).

Pipeline performance tests have a certain structural significance as well. It is probably one of the easier methods to establish leaks in a pipeline or to establish whether blockages have occurred in any diffuser ports. The presence of red dye along the main pipeline immediately shows the presence of a leak and the first appearance of red plumes on the surface will indicate which diffuser ports are blocked, if any.

17.1 References

TOMS, G and BOTES, WAM (1988) Measurement of initial dilution of a boyant effluent. WRC Report No. 160/1/88. Pretoria.

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