



United Nations Environment Programme



EP

UNEP(OCA)/MED WG.104/Inf.7
30 January 1996

Original: ENGLISH

MEDITERRANEAN ACTION PLAN

Meeting of MED POL National Coordinators

Athens, 18-22 March 1996

GUIDELINES FOR SUBMARINE OUTFALL STRUCTURES FOR MEDITERRANEAN SMALL AND MEDIUM-SIZED COASTAL COMMUNITIES

In collaboration with:



WHO

UNEP
Athens, 1996

TABLE OF CONTENTS

	Page
BACKGROUND	1
1. INTRODUCTION	3
1.1 Definition of the problem	3
1.2 Land-based treatment and marine disposal	3
1.3 Aim of the guidelines	7
2. MEDITERRANEAN CONDITIONS	7
3. ENVIRONMENTAL OBJECTIVES AND WATER QUALITY STANDARDS	9
3.1 Protecting public health and marine ecosystems	9
3.2 Water quality standards	9
3.3 Effluent standards	11
4. WASTEWATER AND ENVIRONMENTAL CHARACTERISTICS	12
4.1 Wastewater characteristics	12
4.2 Environmental characteristics	12
5. DESIGN PROCEDURE AND COMPUTATIONS	17
5.1 Pretreatment alternatives	18
5.2 Design principles	20
5.3 Computation procedure	21
6. MONITORING OF SUBMARINE OUTFALLS	23
7. CONSTRUCTION PRECAUTIONS AND MAINTENANCE	24
APPENDIX I	27
APPENDIX II	29
APPENDIX III	31
BIBLIOGRAPHY	34

BACKGROUND

Article 4 of the Convention for the Protection of the Mediterranean Sea against Pollution, adopted and signed by the coastal states of the region in Barcelona in 1976, contains the general understanding that Contracting Parties shall individually or jointly take all appropriate measures to prevent, abate and combat pollution of the Mediterranean Sea Area and to protect and enhance the marine environment in that Area. Article 8 of the Convention binds Contracting Parties to take all appropriate measures to prevent, abate and combat pollution of the Mediterranean Sea Area caused by discharges from rivers, coastal establishments or outfalls, or emanating from any other land-based sources within their territories.

Article 7.1 of the Protocol for the Protection of the Mediterranean Sea against Pollution from Land-Based Sources, adopted and signed in Athens in 1980, stipulates that Contracting Parties shall progressively formulate and adopt, in cooperation with the competent international organizations, common guidelines and, as appropriate, standards or criteria dealing in particular with, *inter alia*, the length, depth and position of pipelines for coastal outfalls, taking into account, in particular, the methods used for pretreatment of effluents.

At their fourth ordinary meeting, held in Genoa in 1985, Mediterranean governments, in their capacity of Contracting Parties to the Convention for the Protection of the Mediterranean Sea against Pollution and its related Protocols, reviewed their cooperation within the framework of the Mediterranean Action Plan (adopted in Barcelona in 1975) over the past ten years, and adopted a declaration, the Genoa Declaration on the second Mediterranean decade. A part of this declaration, they adopted ten targets to be achieved as a matter of priority. These targets include the establishment, as a matter of priority, of sewage treatment plants in all cities around the Mediterranean with more than 100,000 inhabitants and appropriate outfalls and/or appropriate treatment plants for all towns with more than 10,000 inhabitants.

Draft Guidelines for Computations concerning Marine Outfall Systems for Liquid Effluents were prepared by the World Health Organization (WHO) and submitted to the first meeting of experts on the technical implementation of the Protocol for the Protection of the Mediterranean Sea against Pollution from Land-Based Sources, held in Athens in December 1985. These guidelines contain a detailed analysis of the behaviour of wastewater discharged into the marine environment, together with a complete set of calculation procedures, both numerical and graphic, for the prediction of dilution, dispersion and decay of pollutants.

A pilot project on monitoring the efficiency of selected outfalls in the Mediterranean region was subsequently organized by WHO within the framework of the Long-term programme of pollution monitoring and research in the Mediterranean Sea (MED POL Phase II) and carried out by institutions in Egypt, Greece, Italy and Spain. This pilot project was completed by June 1989. A Consultation Meeting on Guidelines for Submarine Outfalls in the Mediterranean was subsequently organized by WHO in Madrid from 3 to 5 July 1989. The meeting noted the results of the pilot monitoring project and the information available from other studies carried out in the region. It was agreed that Mediterranean conditions and characteristics were specific and had to be taken into account when designing and constructing submarine outfalls.

The meeting discussed the draft outline of the Guidelines for Submarine Outfalls in the Mediterranean and the objectives, scope and potential users of such a document, which should be aimed to small and medium size submarine outfalls of localities with less than 100,000 inhabitants. The meeting agreed that common procedures, as were scheduled for preparation in terms of Article 7.1(a) of the Protocol, should include a description of possible types of pretreatment available before discharge, recommended quality levels for the affected region and standards for specific contaminants, together with the presentation of the calculation procedures and environmental studies necessary for predicting the dilution and spreading of the discharges. Minimum design conditions should also be given as part of the calculation procedures.

The draft prepared according to the recommendations of the Madrid meeting was discussed during a consultation meeting on programmes and measures for the protection of the Mediterranean Sea against pollution from land based sources organized by WHO in Alexandria from 5 to 9 November 1989. The meeting agreed with the general format and contents of the document and made the following recommendations:

- a) The scope of the guidelines should be kept within the terms of Article 7.1. (a) of the Protocol and should not enter into any comparison between alternative methods of treatment/disposal.
- b) Standards and criteria already formally adopted by Contracting Parties on a common Mediterranean basis should be utilized wherever available and applicable. In other cases, standards and criteria already in use in individual Mediterranean countries should be quoted as a guide.
- c) The guidelines should clearly express the benefits and limitations of submarine outfalls, the latter in particular where specific conditions or situations prevail.
- d) Construction requirements for submarine outfalls should be included as an annex, in addition to a reasonably comprehensive bibliography.
- e) The guidelines should provide adequate indication of the options and procedures to be applied in particular cases, such as significant seasonal variations in flow, the different levels of treatment prior to discharge, multiple discharges in the same area, and the existence of sensitive areas in the vicinity of the discharge point, such as **Poseidonia** beds.

The present guidelines, which have been prepared for WHO by Professor J. Ganoulis, are essentially a collation of the original 1985 draft guidelines for computations concerning marine outfall systems for liquid effluents, prepared by Dr M. Gervais de Rouville, and the 1989 draft guidelines on submarine outfall structures for Mediterranean small and medium-sized communities, prepared by Dr M.G. Mariño, together with relevant additional material. They are essentially designed to provide basic information to local Authorities and Municipalities in the Mediterranean region for the design of marine outfall structures to serve communities with less than 100,000 inhabitants, in line with the terms of Article 7.1 of the 1980 Athens Protocol.

1. INTRODUCTION

1.1 Definition of the problem

In the Mediterranean region, particularly during the last two decades, the need has been felt to combat environmental pollution caused by the discharge into the sea of various pollutants from land-based sources. The ever-increasing quantities of such pollutants discharged into the sea caused concern, which led to a number of studies with a view to defining the conditions under which wastewater containing various types of pollutants could be discharged, without damage to the marine environment.

With regard to wastes originating on land and discharged into the sea through coastal underwater outfall systems, the methodology for the computations concerning such outfalls has taken different forms, each providing specific solutions depending on the method of formulation of the problem.

The scientific rationale and the computations contained in this document match that formulation of the problem where:

- a) the characteristics of the waste are given (flow, type and content of pollutant)
- b) the waste is to be discharged into the sea in an area encompassing well-defined sensitive zones to be protected against pollution
- c) these areas are covered by standards of maximum levels of concentration for one or more of the pollutants contained in the waste.

The problem then is to define the particular features of the outfall system in such a way as to satisfy the conditions already established, i.e. to comply with the standards in force in the areas to be protected.

By taking into consideration both the quantities of the waste to be discharged and the local geographical and meteorological conditions, one can select a method which would give a solution with a smaller or greater degree of accuracy in calculating pollutant concentrations at various distances around the point of discharge.

1.2 Land-based treatment and marine disposal

As shown in Figure 1, discharge of wastewater into the sea by means of an outfall system is the last link in a chain whose first element is the source of the wastewaters: home, industrial plant, agricultural undertakings. Between the two ends, the chain comprises basically a sewerage system and one or more treatment plants.

Raw sewage is generally treated in special plants by means of various techniques. Wastewaters are then discharged into the sea through submarine outfalls. This is very useful in order to ensure adequate dilution of different pollutants and prevent adverse impacts on the marine environment.

Figure 1. Collection, treatment and marine disposal of effluents.

It is not the objective of the guidelines to present a comparison between alternative methods of wastewater treatment or between land-based treatment and marine disposal. For every specific case an optimum solution can be found as a combination of the treatment applied and the use of a marine outfall. This depends on local environmental conditions, the composition of effluents, the different uses of marine waters, and local technical and human constraints. Generally, a certain degree of pretreatment of wastewaters is absolutely necessary before discharging the effluents into the sea. For this reason a brief review of the characteristics of land-based treatment and marine disposal is given here.

A classification of different pollutants contained especially in urban sewage is presented in Appendix I. As shown in Figure 2, in primary and secondary treatment (settling and biological oxidation) the suspended solids (SS) and organic matter (BOD) are reduced by two orders of magnitude. However, bacterial concentrations are reduced by a factor of 10 only.

Since in most cases microbial pollution is the critical factor for sensitive areas, the first thing that comes to mind in order to resolve the problem is to destroy the bacteria before the effluent enters the outfall pipe, which in such case could be shorter and less costly. Furthermore, one can argue that the process already exists on paper; it is termed sewage "disinfection". Problems and issues related with disinfection are reported on Appendix II.

Figure 2. Characteristics of land-based treatment (White, 1970).

Suspended solids are extremely harmful to the marine environment. For this reason, some countries prohibit any kind of discharge without preliminary partial elimination of suspended solids. In France, for instance, after preliminary treatment (screening and removal of sand and grease) it is mandatory to eliminate, before discharge, 90% of the suspended settleable solids (or 50 to 60% of the total suspended solids). These regulations are based on the fact that such results lie within the scope of the physical process of simple gravitational settling. If better results are desired - up to 90% of total suspended solids - one must use a physico-chemical process of coagulation - flocculation of the various colloidal substances by means of flocculation catalysts such as lime, ferric chloride, aluminium sulphate, polyelectrolytes.

Biological processes (bacterial beds, biological discs, activated sludge, bacterial filters) give results at least as good on total suspended solids; they are recommended in sensitive coastal areas when most of the organic matter must be eliminated before effluents are discharged into the sea.

As shown in Figure 3, dilution of pollutants discharged by a submarine outfall takes place in two different zones: (a) the jet or near-field zone and (b) the dispersion or far-field zone.

In the jet zone, water from the ambient region is entrained by wastewater as it rises buoyantly from the discharging port to the sea surface. An important dilution up to 10^3 occurs depending on the water depth, the flow stratification and the characteristics of the diffuser. In the dispersion zone, dilution due to shear and turbulent eddies is one or two orders of magnitude less than in the jet zone. In this region, additional dilution takes place by chemical and biological interactions (e.g. bacterial decay).

Figure 3. Dilution of wastewaters from a submarine outfall.

In the case of total bacteria, the following table gives the orders of magnitude of the decrease of concentration in each phase.

<u>First Phase</u> Rising Plume	Dilution by turbulent diffusion	without diffuser with diffuser	2 to 100* 10 to 1000*
<u>Second Phase</u> Horizontal transport for 1000m	Dilution by vertical and horizontal dispersion		5 to 20
<u>Third Phase</u> Bacterial Decay	Equivalent to dilution	after 3h after 6-8h after 10-15h	10 100 1000

* Increases roughly by the power of 3/2 of the depth.

In the design of a coastal sewerage scheme, treatment plant and sea outfall are two elements of a whole which cannot be separated and must be the object of a unified study. This study must take into account the local environmental conditions and seawater quality standards which have to be met in the receiving environment.

1.3 Aim of the guidelines

Two potential users of the guidelines have been identified: administrators responsible for wastewater management of small and medium size coastal cities (less than 100,000 inhabitants) and engineers responsible for the design, construction and maintenance of small to medium size submarine outfalls.

Local Administrators can use the guidelines to decide on the alternatives of sewage disposal, and together with other sources of information and advice, to know about the advantages and needs of a submarine outfall structure. Regional or National Administrators can use the guidelines as a reference for the setting of national standards, minimum requirements for these structures, and monitoring programs design.

Engineers in charge of the design, construction, maintenance and supervision of a submarine outfall can use the guidelines as a reference and guide on calculation procedures and type and depth of needed environmental studies.

The common theory on the behaviour of sewage discharged into seawater and the wide field and laboratory experience on this subject have produced many reliable calculation procedures and prediction models for the design of submarine outfall structures which give acceptable results. Although most calculation procedures differ in less than 10-20% among them and prediction models can have a fairly good accuracy, the necessary measurement of the environmental conditions is a generally costly activity without the same degree of precision.

For the design of large submarine outfalls (flows from cities of more than 100,000-200,000 inhabitants) it is normal to have access to extensive field surveys, modelling and good expertise. On the contrary, most outfalls of cities of less than 100,000 inhabitants have to be designed and situated with few, if any, previous studies on the receiving waters conditions and project parameters, no modelling and less access by the designing engineer to specialized expertise. The guidelines are intended to complement and help the design of these latter outfalls, and are applicable to cases of sewage disposal into the sea through small or medium size structures (cities of less than 100,000 inhabitants, preferably less than 50,000).

2. MEDITERRANEAN CONDITIONS

Among the different acceptable alternatives for the disposal of urban sewage in coastal localities, reuse and discharge into the sea of complete or partially treated effluents are the two more commonly used for small and medium size towns, while septic tanks and infiltration are applied in hotels and individual dwellings. Once the decision has been made on the discharge, Mediterranean conditions make the use of outfall structures a good option because:

- a) There is a relative ease of construction due to the generally good weather during the summer and to the weak currents.

- b) Oligotrophic conditions in most open areas allow relatively high loads of domestic wastes if sufficient dilution is assured.
- c) Solar exposure and transparency of waters result in important apparent die-off of bacterial indicators and quick photolytic degradation of some non-persistent organic substances.
- d) The general absence of strong tidal currents and the subsequent lack of dispersion in the Mediterranean give great importance to attaining the maximum possible initial dilution and distance between the point of discharge and the predicted impacted areas.

For tenso-active substances and micro-organisms, especially viruses, which are the main contaminants generated by small to medium sized cities (1,000 to 100,000 inhabitants) with a high potential impact on the marine environment, the actual treatment procedures are either not generally efficient or too expensive. In addition, Mediterranean currents and tides are not sufficient for enough effluent dispersion if the discharge is made close to the coast.

Although in some cases submarine outfalls have presented low performances due to maintenance problems and damage by winter storms and sailing and fishing vessels, sound design, available protective measures¹ and regular maintenance and monitoring programs can guarantee the adequate functioning of these disposal systems, which present among their principal benefits their low operating and maintenance costs, their ability to cope with significant seasonal variations in flow and to obtain an effective dilution that is normally enough to prevent negative effects due to the discharge of organic matter and nutrients.

Because of these reasons, for most situations in the Mediterranean, sewage outfalls remain a better option and a necessity for domestic wastes under the condition that multiple discharges in the same area do not affect the background levels. Industrial discharges should always be considered for treatment, whether they are discharged through an outfall or not.

The use of outfalls as the only means for the disposal of untreated domestic sewage can however have some limitations in specific situations. The main situations which can be identified are:

- a) Multiple discharges of medium and small towns in the same area, concentrated within a short distance, as their combined effect can alter the background levels, especially regarding organic matter and nutrient build-up. In these cases, solids removal or even biological treatment can be necessary and these multiple small outfalls should be considered as part of a large discharge and treated accordingly.
- b) Shallow seas or areas where regional circulation patterns block the renewal of water, as untreated discharges can lead to build-up of contaminants and increased oxygen depletion and algae blooms occurrence. When these are the oceanographic conditions of the receiving waters, full treatment can also be necessary.

¹ **The adequate protection of the outfalls is one of the most important precautions to be observed by the designing engineer. Enough resources should be reserved to this end during the construction of the outfall as repair costs are normally high.**

- c) When shellfish farming and other aquaculture activities are important resources in the discharge area, bacterial decay cannot be assured and should not be included in the computation procedure. In these cases disinfection and solids removal should always be considered.

Furthermore, outfalls are not a definite solution but a temporary one. Loads of settleable solids, nutrients and toxic substances should be reduced through appropriate treatment whenever there is a possibility for that. Pretreatment with screen bars should always be carried out before discharge as well as the evaluation of the possibility for re-use during the planning stage.

3. ENVIRONMENTAL OBJECTIVES AND WATER QUALITY STANDARDS

3.1 Protecting public health and marine ecosystems

In order to understand the reasons that led to the development of guidelines concerning sea outfalls for wastewaters containing pollutants, it is necessary to summarize the elements of the problem. There are ecological and health considerations with a view to preserving a satisfactory level of quality in the coastal waters, taking into account the risk that the pollution of such waters involves for animal and plant species living in the sea, and for man through his use of the marine environment (bathing) and its products (consumption of marine animals). Even if less frequently, the problem can also be formulated as follows: what is the "maximum receiving capacity" of a well-defined coastal area for a specific pollutant, e.g. urban sewage, and which is the best configuration of an outfall system to meet this maximum capacity?

The risk that humans may incur from marine pollution comes primarily from two "uses" of the sea, i.e. bathing and consumption of sea products (especially if they are consumed raw, which relates mainly to consumption of shellfish). Therefore, regulations are generally formulated as two series of standards concerning "**bathing**" and "**shellfish culture**" and are based on the maximum content of seawater pollutants at levels which are considered acceptable in terms of these two risks.

3.2 Water quality standards

The distinction between environmental and human risks for different water uses should lead to the formulation of "standards", expressed in maximum receiving capacity of the seawater for specific categories of pollutants most frequently discharged into the marine environment along with the sewage.

Water quality objectives for the protection of beneficial uses of the marine environment have been seen as necessary by most Mediterranean countries. Bathing water and, to a lesser extent, shellfish growing waters quality criteria have been issued by these countries, the European Economic Community and International Organizations. Plans for the protection of other beneficial uses like fishing, aesthetics or wildlife have not generally resulted in the development of similar criteria.

It is evident that schemes for wastewater disposal into the marine environment should be designed primarily taking into account the beneficial uses to be protected in the area affected by the discharge. Therefore, water quality criteria derived from these uses are the principal parameters in the computations concerning the efficiency of a submarine outfall.

In order to be used in the design and calculation of a submarine outfall, water quality criteria need to fulfil the following basic characteristics:

- a) The criteria have to be expressed in terms of parameters and values which can be directly incorporated into the design procedure.
- b) Criteria and parameters should be relevant to the beneficial use that the submarine outfall has to protect. They have to be associated with sanitary and ecological consequences, either through a direct cause-effect relationship or through a clearly-stated statistical relationship
- c) Criteria should be attainable by normal technical procedures and should take into account the natural base-line concentrations in Mediterranean waters.
- d) Although, for purposes of the computation of submarine outfalls, only average values will be used, in order to take into account the natural variability and changes of environmental parameters, water quality criteria should be defined in a statistical form.

Table 1

Recommended Bathing Water Quality Criteria for Computation Purposes

Parameter	Unit	Percentiles		Remarks
		50%	90%	
A. Bacteriological				
1. Faecal Coliforms	n/100 ml	100	1,000	Bathing
2. Faecal Streptococci	n/100 ml	100	1,000	Bathing
B. Physical				
3. Colour	mg Pt-Col/l	10	30	*
4. Suspended Solids	mg/l	1.3NV	1.5NV	**
C. Chemical				
5. Dissolved Oxygen	mg/l	6	5	Surface
6. Nitrogen Ammonia	mg N/l	0.05	0.12	
7. Dissolved Ortho-phosphate	mg P/l	0.02	0.05	

- * To be observed at the plume surfacing point
 ** NV = Normal value in the area before the discharge

Recommended bathing water quality criteria which can be used as parameters for the design of submarine outfalls are listed in Table 1. In 1985, Mediterranean States adopted interim criteria based only on faecal coliforms, but faecal streptococci constitute an important additional parameter. In the case of shellfish waters, criteria and standards in current use are based on bacterial concentrations in the shellfish themselves, as opposed to the actual waters. Because of the concentration factor and uptake variations, no definite correlation has been established so far between concentrations in the actual shellfish and in the surrounding water. A recommendation made by WHO and UNEP in 1986 proposed a maximum concentration of 10 faecal coliforms per 100 ml in at least 80% of the samples, and a maximum concentration of 100 faecal coliforms per 100 ml in 100% of the samples. The quality criteria adopted on a joint basis by Mediterranean states in 1987 impose a maximum concentration of 300 faecal coliforms per 100 ml of shellfish (flesh + intervalvular fluid) in at least 75% of the samples for acceptability of the growing water.

For the computation and control of the outfall impact, faecal coliforms and faecal streptococci can be taken as non-conservative pollutants subjected to exponential bacterial decay. Dissolved oxygen should be evaluated taking into account the oxygen consumption due to bacterial degradation of organic matter. Nitrogen ammonia and dissolved ortho-phosphate should finally be considered as conservative pollutants, while colour, suspended solids and pH criteria are given to be applied in the upper point of the rising plume. All these criteria presented in Table 1 are technical recommendations; only the limit for faecal coliforms in bathing waters is an accepted standard on a joint Mediterranean basis.

The Consultation Meeting on Guidelines for Submarine Outfalls in the Mediterranean (EUR/ICP/CAH 085), convened in Madrid from 3 to 5 July 1989, proposed that the design and computation of submarine outfalls for the discharge of domestic wastewater into the sea should always take into account the openness of the affected area and the reservation of a 300 m wide band, parallel to the base line of the coast or the affected area, where no discharges should be made whatsoever the treatment applied to the effluent or the dilution obtained in the outfall. For computation purposes, water quality criteria should be applied in the outer border of this band.

Water quality criteria can also be set in order to be used as a tool for the control and evaluation of the efficiency of submarine outfalls. A complete set of criteria for this use is included in the "effluent standards" table of these Guidelines. They are included there only as references for the monitoring of domestic wastewater discharges into the sea and should not be taken as parameters of the design or as a substitute for national standards when they are available.

3.3 Effluent standards

The discharge of raw or pre-treated wastewaters through submarine outfalls should be restricted to domestic effluents which do not contain high loads of persistent, bio-accumulable or toxic substances. Industrial discharges should always be subjected to treatment before discharge into the marine environment.

In order to remain below the receiving capacity of coastal waters, for most Mediterranean situations and for medium to small submarine outfalls, it will be normally sufficient that the conditions mentioned earlier are maintained when considering all discharges in the affected area.

As a further guarantee that the discharge will not exceed the receiving capacity of the marine environment, some basic effluent standards can be applied on medium and large submarine outfalls of cities of more than 50,000 inhabitants. A set of these standards are proposed in Table 2. These effluent standards are expressed in a statistical form to allow their control by the corresponding Authority.

4. WASTEWATER AND ENVIRONMENTAL CHARACTERISTICS

4.1 Wastewater characteristics

Wastewater characteristics (flow and load) are normally obtained from charts or from the extrapolation of common unitary values found in the bibliography. As this is one of the main parameters for most of the calculations concerning the outfall, a short sampling campaign to check the order of magnitude of these values should be carried out, measuring at least the hourly flow distribution of the discharge for a day (the end of the working week is the best choice, together with the rainy season), and the wastewater's average color and ammonia and suspended solids concentrations. For faecal coliforms, faecal streptococci and dissolved ortho-phosphate average concentrations, it is normally sufficient to use the values given in the bibliography (see Table 3). In any case, field data should be checked against theoretical flow obtained from the number of people served by the sewerage system and the drained area and particular rainfall pattern of the zone.

4.2 Environmental characteristics

Although these Guidelines are intended to help in the design of medium to small submarine outfalls, where little resources are available for the study of the environmental parameters used for the siting and calculation, some preliminary work is nevertheless necessary for a correct design. The extent and detail of these studies will undoubtedly depend on the size of the outfall. Three size ranges can be considered when deciding on the extent and detail: "very small" or less than 1,000 inhabitants, "small" or between 1,000 and 10,000 inhabitants and "medium" or over 10,000 inhabitants.

The parameters or environmental characteristics to be considered or studied in the siting and calculation of a medium to small submarine outfall in Mediterranean situations are the following:

- a) Characteristics needed for outfall construction:
 - Topography and bathymetry (charts and maps of adequate scale)
 - Bottom materials and morphology.
- b) Characteristics needed for setting the water quality objectives:
 - Openness of the coast
 - Activities and sewage discharges in a 20 km sector around the selected outfall siting and sensitive areas in this sector.
- c) Parameters needed for the calculation of the efficiency of the outfall:
 - Predominant surface currents and winds pattern
 - Wastewater flow and contaminant load.

Table 2

Normal Effluent Standards

Contaminants	Units	Values for the limits					
		Open areas			Enclosed areas		
		Percentiles			Percentiles		
		50%	90%	Maxim.	50%	90%	Maxim.
1. Greases and Oil	mg/l	25	40	75	5	10	30
2. Settleable Solids	mg/l	1	1.5	3	2	3	6
3. Turbidity	FTU	75	100	250	50	75	150
4. pH		--	--	6-9	--	--	6-9
5. BOD ₅	mg/l	300	400	600	100	150	250
6. Organic Nitrogen*	mgN/l	--	--	--	5	7	20
7. Oxidized Nitrogen*	mgN/l	--	--	--	3	6	12
8. Total Phosphorus*	mgP/l	--	--	--	1	1.5	3
9. Colour	**			1:40			1:20

* These limits will be observed in areas where eutrophication is possible

** Should not be detected over 10 cm with the indicated dilution more than 10% of the reference value.

Table 3

Design Parameters for Domestic Wastewater (dry weather)

Design Flow	7 l/s.1000 people
Faecal Coliforms	10^7 FC/100 ml
Faecal Streptococci	$2 \cdot 10^6$ FS/100 ml
Ammonia Nitrogen	7.5 kg/d.1000 people
Dissolved Ortho-phosphate	3 kg/d.1000 people
Suspended Solids	80 kg/d.1000 people

d) Other parameters which should be measured in special situations only²:

- Continuous current measurements
- Dispersion coefficients
- T90 for faecal coliforms and faecal streptococci
- Temperature profile
- Benthic populations

The extension and detail of the studies to identify and measure these characteristics will depend on the size of the outfall. The methodology to use for each of them and the default values for most Mediterranean situations are summarized in the following paragraphs.

4.2.1 Topography and bathymetry

Good and detailed maps and charts of the coast and bottom areas where the outfall is planned are always necessary. Scales of 1:5,000 with 1 m bottom depth lines are normally sufficient for the study of the discharge area and the adequate siting of the outfall.

Most Mediterranean countries have issued good quality maps and sailing charts of the required scale which can be obtained locally without much problem. Nevertheless, it is always recommended to carry out a detailed bathymetric profile of the whole outfall length to identify possible sand bars, bottom material, rock outburst or any other factor which could interfere with the construction. Using manual depthmeters and a small vessel, these detailed profiles can be made in one single day, at a very low cost³.

4.2.2 Bottom materials and morphology

Bottom samples can be easily obtained simultaneously with the sounding of the profile as indicated above. Direct inspection using scuba divers in the surf area is also useful to decide on the possible protection

² **Although these parameters are not always used in the computation process proposed in the Guidelines, they should be considered when available resources or the fragility of the impacted areas allow and require a more detailed analysis.**

³ **The simultaneous measurement of the sea surface is always necessary to correct the soundings and refer them to the zero level.**

options. Also convenient and feasible at low cost is the carrying out of a superficial recognition of the most important benthic communities, such as **Poseidonia** beds⁴.

4.2.3 Openness of the coast

The openness and morphology of the coast is one of the main characteristics to be considered when siting, designing and calculating a submarine outfall, as it defines the renovation capacity. It is not uncommon to find submarine outfalls whose length appears to be sufficient for the efficient disposal of wastewaters into the sea, but because they start from the inner end of enclosed or semi-enclosed areas, the actual effective length is greatly reduced, when the discharge does not reach the open sea and is made inside the semi-enclosed area.

The degree of openness or enclosure of a certain zone clearly depends on the currents field. However, for the design of a submarine outfall, in most Mediterranean situations, the baseline defined in section 3.2 should be drawn linking all the clear outer coastal points in the zone of the outfall which are not separated more than five nautical miles (or approximately 9 km), nor less than three nautical miles (or approximately 5.5 km).

4.2.4 Activities, sensitive areas and discharges

In the sector comprising 20 km around the proposed siting of the submarine outfall, all zones which support activities with water quality objectives and all sensitive areas which could be affected by the discharge should be studied and plotted on appropriate maps. The distance between the discharge point and the line surrounding these zones and areas with a 300 m reserve band will be used for the computations concerning the dilution obtained by the outfall.

In order to evaluate the degree of saturation in the affected area due to other wastewater discharges, all such discharges should be identified in the 20 km sector around the proposed siting of the outfall. The combined load of the projected outfall plus that of the existing discharges in the dilution area should not exceed 10,000 person-equivalent per cubic hectometer of seawater⁵.

4.2.5 Predominant currents and winds

The study of predominant surface currents should always be included in the design of submarine outfalls. Although for very small outfalls the surface currents can be assumed to flow in a straight line between

⁴ **Discharges in the direct vicinity (less than 250-300 m) of Poseidonia beds should be avoided whenever possible. Pipe laying procedures should be designed taking into account the limitation of the damage and the possibility of the recovery of these communities.**

⁵ **In order to check this condition, the volume corresponding to the whole 20 km band with a width equal to twice the average length of the outfalls it contains can be considered. This is, of course, a very approximate approach that should be confirmed by other more precise methods whenever possible.**

the discharge point and the affected areas, with a speed of 30 cm/s, it is advisable to at least carry out a short survey using floating drogues released at the projected discharge point.

This type of survey is easy to make at little cost, as around 10 to 20 floats distributed in groups can be placed simultaneously and followed by a single boat. The trajectories can be traced without difficulty from the coast (marking the boat used to place and follow them) or from the boat itself (measuring the distance and direction to a buoy anchored at the discharge point), taking bearings at regular periods of time, for 2-3 hours, and later plotting them on the chart.

Surface current surveys for the design of submarine outfalls should preferably cover different climatic conditions, but must at least include the summer period, when seawater activities are at their highest. Three to four days of surveys are normally sufficient to obtain enough information for the design.

The study of wind patterns in the discharge area must complement the result of the field surveys on the surface currents. Whenever there is a meteorological station close to the proposed siting of the outfall, so that its measurements can be used for the prediction of the winds rose in the discharge area, surface currents can be estimated assuming that they have a velocity equal to 1% of the wind velocity, with the same direction

4.2.6 Other characteristics

Most manuals and guidelines for the design and computation of submarine outfalls recommend the measurement and study of other parameters and characteristics of the receiving waters. Among the more commonly recommended are the currents field using continuous measurements, the horizontal and vertical dispersion coefficients, the bacterial die-away rate or T90, the water temperature and density profiles and the benthic communities. Although it is evident that the information provided by these parameters increase the knowledge of the discharge area, for most Mediterranean situations and for medium to small submarine outfalls, they are not indispensable for a correct design and calculations, and the effort necessary to measure them with the required precision normally exceeds the available resources. Normal values are given in Table 4:

Table 4

Proposed Values for Computation Parameters

Surface currents	20-30 cm/s
Horizontal dispersion coefficient	300 cm ² /s
Vertical dispersion coefficient	100 cm ² /s
Faecal coliforms T90	1.5-2.5 hours
Faecal streptococci T90	2.5-3.5 hours

Continuous measurement of the currents field requires the deployment of a group of current meters, at various locations and at various depths, for long periods of time. Near-surface measurements have the extra difficulty of needing some wave attenuating device. Continuous deployment of current meters subjects very expensive equipment to vandalism, theft or bad weather damage and needs expertise for the processing and interpretation of the huge amount of data produced. This type of effort is justified in the case of big and long outfalls, while for medium to small outfalls the use of floating drogues is normally sufficient.

Horizontal and vertical dispersion coefficients are part of the calculation procedure for the subsequent dispersion of the sewage field, once the plume has reached the surface. The measurement of these parameters requires the carrying out of field campaigns at different climatological conditions, using either drogues or dyes, which have to be repeated a good number of times in order to obtain reliable results. Normal values in the Mediterranean for the horizontal dispersion coefficient lay around 200-300 cm²/s, while the vertical coefficient is about 70-100 cm²/s.

As the subsequent dispersion does not contribute much to the overall dilution in normal Mediterranean situations, it would not be fully justified to undertake the measurement of dispersion coefficients for the design of small to medium submarine outfalls. Normal values given above, the use of the Elder's formula or the "4/3 law", generally have enough precision.

The correct determination of the bacterial die-away constant is even more complicated than the determination of the dispersion coefficients. Furthermore, the T90 varies greatly between some organisms and others. If it is measured during the day or during the night the results can be one order of magnitude different and viruses have very little die-away when discharged into seawater. Normal safe values for Mediterranean conditions lie in the order of 2.5 hours for faecal coliforms and 3.5 hours for faecal streptococci and it is normally regarded as sufficient to adopt these values for the design of medium to small outfalls.

The temperature profiles in the discharge area are used to estimate the possibility of plume entrapping under the surface due to density stratification of the seawater. Plume entrapping reduces the impact on the surface and the transport of pollutants towards the coast, but can lead to excessive accumulation of contaminants in the bottom layers and clouds upwelling near the coast. The precise determination of density profiles is a difficult and time-consuming exercise, which also requires the use of continuous temperature and salinity recorders. Furthermore, stratification of seawater masses is an unstable phenomenon which can not be predicted with great accuracy. Therefore, for most small to medium outfalls it would not be justified to carry out such a study.

The mapping and characterization of benthic communities is also another environmental study generally recommended for the design of submarine outfalls. For most situations, however, a superficial survey is generally sufficient and, as is the case for the parameters described above, detailed studies would go beyond available resources with only marginal repercussion on the design.

5. DESIGN PROCEDURE AND COMPUTATIONS

Design procedure, simplifications and proposed models were adopted at the Consultation Meeting on Guidelines for Submarine Outfalls in the Mediterranean (EUR/ICP/CAH 085), convened in Madrid from 3 to 5 July

1989. It was also decided in this meeting that the method of design and the detail and extent of the environmental studies should be different if the outfall is very small (cities of less than 1,000 people), if it is small (roughly between 1,000 and 10,000 people) or medium sized (over 10,000 people but less than 100,000-200,000)

5.1 Pretreatment alternatives

Some pretreatment of wastewaters before discharge is considered essential for the correct functioning of a submarine outfall. Possible treatment alternatives include: (a) bar screening, (b) air control, (c) grease, scum and floatings removal, (d) grit removal (e) solids removal and (f) disinfection through natural processes. If disinfection is applied, the computation of the necessary length of the outfall should take it into account, adapting the initial values of the discharge accordingly.

Secondary biological treatment of wastewaters is considered unnecessary for most medium to small submarine outfalls given the receiving capacity of most Mediterranean situations and the difficulties and cost of the operation and maintenance of these processes, which are nevertheless technically sound. Only when the combined effect of multiple discharges in the same area can exceed this receiving capacity should secondary treatment be considered.

Chlorine disinfection is also not recommended because of operation and maintenance problems, unreliable efficiency and possible adverse environmental effects (see Appendix II). Although die-away and dilution on their own do not guarantee the disappearance of viruses in seawater, similarly, unless there is good expertise available in the area, ozone disinfection is also not recommended for small outfalls because of its higher costs and operation difficulties.

Ease of operation and maintenance, low energy consumption, small construction and labour costs and adequate treatment directed towards those contaminants which are relevant in a discharge into the marine environment, should be the main conditions to take in consideration when deciding on the treatment to apply. The principal characteristics of the recommended treatments for submarine outfalls are:

Screening. Coarse screening of wastewaters through bar racks is necessary in all outfalls (even in the very small ones) for the removal of large solids, which will otherwise have an important negative effect on the aesthetic quality of the receiving waters. Bar racks are also necessary to prevent the blocking of the diffusers.

Bar racks, which can be mechanically or hand cleaned, are a common and simple device, do not have an important head loss (about 10 cm) and are easy to construct and maintain. For submarine outfalls two or more units should be installed, preferably of the mechanically cleaned type, with bars separation of 1-2 cm

Air control. The control of air penetration into the pipeline is of paramount importance to prevent one of the main dangers for submarine outfalls: flotation. Air control devices must be included in the design of all submarine outfalls; it can be combined with floatings and scum removal, but best results are obtained when it consists of a simple equilibrium chimney. Minimum detention time for the tank under the chimney should be 1-5 min for maximum flow.

Floating, grease and scum removal. The separation of easily floating material transported by the wastewater can be done in tanks where these materials are allowed to rise to the surface, while the wastewater leaves under a skimming trap situated at the other extreme of the inlet. Typical detention times are in the range of 5 to 15 minutes.

Grease traps, as they are normally called, are simple devices, easy to construct and with a good impact on the most visible part of the discharge. Their use, however, is restricted to small and very small outfalls because of the operation problems associated to the necessary regular removal of the materials which accumulate in the surface of the tank. Odour production also complicates the use of grease traps.

Grit removal. The removal of the grit transported by the wastewater is normally deemed as necessary to prevent its accumulation in the pipeline. However, the provision of adequate transport velocities is sufficient, in most outfalls, to avoid this problem without incurring in the cost and operation problems of this treatment.

When grit removal is necessary because of lack of adequate velocities in the pipeline or excessive production, it is done using a grit chamber where it settles, while most organic particles remain in suspension. For medium to small outfalls the best choice is the constant velocity horizontal channel with parabolic section designed to maintain a velocity as close to 0.3 m/s as possible.

Solids removal. Suspended solids removal is a costly operation, which requires the construction and operation of a sewage treatment plant. In spite of the cost and operational problems of such a plant, the removal of solids should be included in all submarine outfalls serving cities with more than 50,000 inhabitants, and it is recommended in outfalls for more than 10,000 people, as solids sedimentation and turbidity are among the most important adverse ecological impacts of sewage discharges into the marine environment.

Solids removal can be done by micro-screening, sedimentation and flotation. For most situations micro-screening and especially sedimentation are the best choice because of their low cost and simplicity, although odour control should always be considered when the plant is situated close to the coast. Flotation provides the best degree of treatment, but it is a complex process, which requires more energy and maintenance than either sedimentation or micro-screening. Design criteria and normal values are in the bibliography.

Disinfection through Natural Processes. Chemical disinfection using chlorine or ozone present problems because of their cost, difficult operation and lack of reliable efficiency. When disinfection is necessary because of the existence of sensitive activities in the area affected by the discharge, the best practical solution is the use of shallow lagoons, which also provide good solids removal and some degree of treatment. Lagooning of the sewage before discharge is strongly recommended for those places where there is enough available land.

Lagooning should consist of two to three lagoons in series, one to one and a half meters deep and around thirty days retention time for the whole system (one to two hectares per 1,000 people are normally sufficient). Although lagooning normally requires the pumping of the effluent inland, in many small Mediterranean small cities there is enough cheap land available for this type of treatment, which has the added advantage of allowing the agricultural use of all or part of the effluent. Lagooning, either as a natural disinfection treatment or as a pretreatment for agricultural reuse, is a good alternative for small outfalls (up to 10,000 people) and its effect

on the effluent should be taken into account in the calculation of the required outfall length. Adequate sealing of the lagoon basin to avoid groundwater contamination is also an important precaution to take.

5.2 Design principles

The main principles which should guide the design, siting and computation of a submarine outfall in most Mediterranean situations are:

- a) Submarine outfalls should always end in open coastal waters, where multiple discharges in the same area do not affect the background levels. Discharges inside enclosed areas or within the 300 reserve band should be avoided whenever possible.
- b) As initial dilution is essential, every effort should be made to construct the outfalls with the discharge point situated at the longest distance from the areas to protect and to the greatest depth which can be economically reached. Modern pipe-laying techniques make the total length and depth of the outfall less important in the overall cost of the project⁶.

The use of diffusers increases the initial dilution at the discharge point. Diffusers ports must have a minimum diameter of 10-15 cm, a total combined surface not exceeding 75% of the pipeline cross section and a spacing equal to one fourth of the depth. For small outfalls it is advisable to adopt a single discharge outlet at the end of the pipeline to prevent the blocking of the diffusers.

The effective length (distance between the discharge point and the outer border of the 300 m reserve band) should be larger than 1,500 m and the depth of the discharge point should not be smaller than 15 m. Given these conditions, it can be accepted that the discharge of very small outfalls will have no negative effects in most Mediterranean situations, whatever be the results of the computation of dilution, dispersion and bacterial decay.

Dilution at the outer border of the 300 m reserve band should reach a minimum value of 10^5 when combining the effect of plume rising, bacterial decay and dispersion of the cloud by surface currents. The contribution of bacterial decay should be limited to a maximum of 10^2 . The Madrid expert meeting even recommended that the apparent dilution due to bacterial decay should not be considered when making the computations on the efficiency of the outfalls. This strong recommendation is based on the high nocturnal values of T90 for most indicator organisms and the very long persistence of pathogenic viruses in seawater.

Design should be geared to the worst possible situation. Therefore the possible advantages of trapping will not be considered, given the instability of this phenomenon.

Design velocity in the pipeline should be around 1 m/s. To prevent the blocking of the diffusers the velocity of the discharge should reach with sufficient frequency 1 m/s, but should not exceed 2 m/s to reduce head losses.

⁶ **The use of plastic pipes allows the laying of section of up to 1,000 m in one day, for diameters of up to 1 m. These materials are corrosion resistant, adapt to normal movements in the bottom and are leak free because do not present junctions.**

Pumping should be avoided if sufficient head is available because of the energy and maintenance costs.

In those places where drastic flow variations take place between summer and winter seasons, equalization and pumping should be considered. The use of lagooning is also very effective and should be considered whenever possible.

The setting of the outfall should whenever possible be decided taking into account the existence of sensitive benthic communities such as **Poseidonia** beds. In order to prevent any damage, the discharge point should be placed at a minimum distance of 250-300 m from these communities if it is economically feasible.

5.3 Computation procedure

This computation procedure is a simplification for the special characteristics of small to medium submarine outfalls in the Mediterranean, and does not conflict with other methods recommended in the bibliography.

For the computation concerning the efficiency of submarine outfalls, the quality criteria set accordingly to the activities supported by the affected area are checked against the concentration of the relevant pollutants after dilution, spreading and degradation, in the case of non-conservative parameters. The steps to follow are:

- a) On the appropriate maps and charts draw the coastal baseline and identify the affected activities in the area. For each of these activities set the water quality objectives and criteria and draw the 300 m reserve band around them in order to obtain the travel distance from the point of discharge. Using the surface current velocity (either measured or 30 cm/s) calculate the travel time.
- b) With the maximum dry weather wastewater flow and the rainy season discharge set the pipeline diameter, number of ports, their diameters and their spacing.

Figure 4. Dilution of wastewaters (a) on a vertical plane and (b) at the sea surface.

As shown in Figure 4(a), if P_o is the discharging port, where wastewater has initial concentration C_o , the computation problem is to estimate the concentrations C_s and C_c (Fig. 4(b)) at points P_s (surface) and P_c (coastal line).

The initial dilution due to dispersion of the plume and the apparent dilution due to bacterial decay for the travel distance and time calculated above are performed using the formulas given in Appendix III. Correct bacterial decay to the maximum of 10^2 and calculate overall dilution as the multiplication of these three dilutions.

Check that the initial dilution is higher than 150 and the overall dilution is over 10^5 . Compare water quality criteria with the contaminants concentrations obtained in the affected areas for maximum dry weather and rainy season discharge flows.

After comparing the quality criteria with the concentration of the relevant contaminants in the border of the reserve band, correct the siting, length and depth of the outfall accordingly and repeat the calculation until the design is adjusted to obtain the required water quality criteria in the areas where such criteria apply.

5.4 Example of application

The submarine outfall of a coastal Mediterranean city of 30,000 inhabitants is to be designed. An available outfall site, where the water depth is 20m, is located in a distance of 1800 m from a bathing beach.

Compute the sewage dilution and check if the water quality standards are fulfilled in the beach.

- (a) For dry weather flow, the design parameters given in Table 3 can be selected. The outfall flow rate of sewage is computed as follows:

$$Q = (30,000) \times 7 / (1,000) = 30 \times 7 = 210 \text{ l/s} = .21 \text{ m}^3/\text{s}$$

If a diffuser of length $L=300\text{m}$ is provided, the flow rate per unit length is given by the following expression:

$$q = Q/L = 0.21/300 = 7 \times 10^{-4} \text{ m}^3/\text{s/m}$$

- (b) Initial dilution (D_1), bacterial decay (D_2) and subsequent dispersion (D_3) are estimated by means of formulas given in Appendix III.

Initial dilution (D_1) (Appendix III, formula III.2(a))

$$D_1 = (0.38)g^{1/3} Hq^{-2/3} = (.38)(.267)^{1/3}(20)(7 \times 10^{-4})^{-2/3} = 620$$

Bacterial decay (D_2) (Appendix III, III.3)

Assuming a current velocity: $V=30 \text{ cm/s}$, the travel time t to the bathing beach is

$$t = \frac{1800}{(30 \cdot 10^{-2})3600} = 1.67 \text{ h}$$

With $T_{90} = 2.5\text{h}$, we have the following bacterial decay:

$$D_2 = 10^{(t/T_{90})} = 10^{(1.67/2.5)} = 4.66$$

Dilution due to the dispersion (D_3): it will be assumed equal to 10 (Appendix III, III.4).

- (c) The sewage concentration after the initial dilution, bacterial decay and dispersion will be given by the following expression:

$$C = \frac{C_0}{D_1 D_2 D_3}$$

where C_0 is the initial concentration. For the Faecal Coliforms $C_0 = 10^7 \text{ FC}/100 \text{ ml}$ (Table 3). Therefore, we obtain

$$C = \frac{10^7}{(620)(4.66)(10)} = 346 \text{ FC}/100 \text{ ml}$$

Comparing with the Bathing Water Quality Criteria (Table 1) this value lies between 90% (1000) and 50% (100) of the acceptable percentiles. It could be an acceptable concentration. Further dilution of sewage can be obtained by increasing the water depth (H) or the distance (L) of the outfall site.

6. MONITORING OF SUBMARINE OUTFALLS

Regular monitoring should be carried out on all medium and large submarine outfalls of cities with more than 50,000 inhabitants, and on industrial discharges. Effluent standards should be controlled on a monthly basis, water quality criteria every five years. Small urban outfalls performance can be controlled indirectly, through regular monitoring programs for bathing and shellfish growing waters.

In order to make the control of effluents possible, all outfalls, even the small ones, should be designed with adequate facilities for the sampling and gauging of the discharge.

Measuring devices that can be used for submarine outfalls include Parshall flumes, weirs and Palmer-Bowls flumes, if situated in the open channel, and Venturi tubes or nozzles if situated in the pipeline. Gravimetric and volumetric containers are used to calibrate these devices, whose description and design criteria is fully explained in the common bibliography (see Metcalf & Eddy for references). Easy access to manholes and draining pipes are usually the best solution for effluent sampling.

The water quality monitoring program should consist of intensive surveys. Repetitive measurements in the surface and vertical profile of a grid of around 12 points situated in and around the outfalls end, together with sediments sampling at distances of 100 and 500 m, should be done for the correct evaluation of the discharge. Two to four such surveys, covering each season for a week or so every five years will normally be sufficient for the evaluation of the outfall performance and effects.

Submarine outfall monitoring should not be restricted to water quality, effluent concentrations or sediment contamination studies. Also important is the regular control, preferably every year, of the physical state of the structure. It should include the identification of the possible damages suffered by waves and vessels action and the loss of the carrying capacity of the pipeline by sewage deposits or diffusers blocking.

Direct inspection of the pipeline is a difficult and expensive activity. Much better results are obtained with the addition of a small amount of a dye tracer which will mark the existence of any loose junction, leak or rupture of the outfall, as well as the situation of the discharge ports. This type of inspections can be done every year, during the spring time, after the winter storms, to identify damages in the outfall with enough time for their repair before the summer season starts (although better weather conditions would seem to favour that this controls should be made during the summer, the release of dyes during this time of the year should be restricted because of the negative impression it can cause on bathers and vacationers).

Excessive head losses in the pipeline can be checked measuring the available hydraulic head at the beginning of the outfall and the flow velocity. With simple hydraulic calculations of this measurements and the theoretical head losses obtained using design data, a possible blocking in the pipeline can be easily evaluated.

7. CONSTRUCTION PRECAUTIONS AND MAINTENANCE

Submarine outfalls are a good solution for the disposal of sewage from medium to small cities in the Mediterranean because they are easy to construct, do not have important maintenance and operation difficulties and costs and are effective in protecting the quality of coastal waters. Given the adequate discharge conditions described above, the design and construction of these structures should therefore be aimed primarily at reducing the operation and maintenance problems.

The necessary regular maintenance of outfalls is very little. It is mainly limited to the control activities and the operation and cleaning of the pretreatment system, together with the adequate disposal of the generated solid residues. Important maintenance is only needed when the outfall suffers damages and leaks that reduce the distance and depth of the discharge or when it is blocked by solids deposits or overgrown marine organisms.

The blocking of the outfall can be prevented by an adequate design of the discharge ports and by regular control inspections as described above. When it still occurs, it is easy and not expensive to re-open the pipeline, either manually or by pumping high flows for a short period. Ruptures in the outfall, or even small leaks, require much more resources, as repairing damages in underwater structures is generally a difficult and expensive task. Every effort should therefore be directed to provide adequate protection of the outfall in the construction phase; it is always cheaper and funds are more easily obtained for a little extra expenditure in preventive action than for corrective action.

The main causes of outfalls ruptures, leaks or even their whole destruction are wave action, the direct impact of anchors and fishing gear of pleasure and sailing vessels, and flotation. Natural seasonal changes in the bottom profile with failure of adaptation by the pipeline are also an important cause of outfall leaks.

To avoid flotation, it is important and generally sufficient to prevent air penetration in the pipeline by installing an air chamber before its landward end, and to adopt a vertical profile that does not present bendings and pockets where air can accumulate. Ballasting of the pipeline, or even its anchoring, will depend on the type of materials used. There are many examples in the literature that can be used to decide on the type and weight of the ballast needed and manufacturers will provide the designer with useful extra information more specific to each material.

Protection against the action of waves can be obtained by burying the pipeline or covering it with a jetty, and should include the whole surf band for the different seasons of the year⁷. A detailed design of this protection work requires the determination of the project wave height (as waves break down at a depth equal to 0.7 their height, this is the depth to which the protection should reach), but for most Mediterranean situations, and especially in the case of medium to small outfalls, the best solution will normally be to bury the pipeline to a depth equal to 4 m, measured from the water surface at the lowest tide level.

In order to protect the pipeline against the action of anchors and fishing gear, the only good solution is to bury it or to cover the outfall with ballast and rock-fill to a depth of 10-15 m. Although ballast thrown from the surface is expensive, it is the best alternative for small to medium outfalls, and usually pays for itself in the long term. To bury the outfall, there are different alternatives, which include the opening of a trench before laying the outfall or dredging it parallel to the pipe using manually operated equipment (see figure 3 for details of proposed protection measures).

The mobile nature of the sea bottom adds further requirements for a submarine outfall; it has to be able to adapt to small changes and movements without breaking up or leaking through the junctions. Although they are more expensive than concrete pipes, for medium to small outfalls the best option is the use of plastic materials or steel which can follow these changes without problem. Plastic material of the type of high density polyethylene or PVC has become a good alternative in recent years as it has no corrosion problems and can be set up on the coast in very long sections (up to 1,000 m) which are laid out in one day without junctions.

As a further precaution against damage by anchors or fishing gear, submarine outfalls should be marked with clear buoys at the end and at every bend of the unprotected part, fitted with clear signs prohibiting anchoring and fishing in a 200 m radius around it, and warning against swimming or wind-surfing in the vicinity⁸.

Outfalls should also be marked in commercial and sailing charts, clearly indicating that the area around these structures is forbidden for anchoring and trawl fishing.

⁷ **It is well known, but seldom applied by designing engineers that coast profiles change according to the season and that coast lines are a mobile and changing system.**

⁸ It is not uncommon to see boats anchored around the outfall's end for fishing or that the buoy is taken as a reference point for swimming or sailing.

There is an abundant bibliography on the construction methods and materials to be used with the submarine outfall structures for the disposal of sewage into the sea and some of the most important and readily accessible of these publications are listed in the attached table. For small and medium size outfalls it has been pointed out that the best option with available technology and materials is the use of ballasted high density polyethylene pipes which can be laid out in lengths of more than 1,000 m without junctions. These pipes can be easily towed out floating, keeping both ends closed. Once in the definite position the outfall is lowered by letting the water in, adding extra ballast to assure stability.

Other construction methods for small and medium size outfalls include the towing of the pipe from a pontoon anchored at a certain distance from the coast, either floating or through the bottom. In any case it is always advisable to make all the junctions and sealing of the outfall on land, out of the water, where the work and the inspection of its results can be carried out more easily.

It is also always advisable to avoid the simple method of laying the ballasted outfall directly on the bottom, without securing it with some anchoring mechanism. Although this anchoring or the even better burying the outfall is an expensive addition to the project, it prevents the pipe moving and the possible consequent rupture and its vibration under load, specially in the diffusers section.

APPENDIX I

CLASSIFICATION OF VARIOUS POLLUTANTS

From the point of view of marine pollution, one should analyze the various pollutant categories contained in the wastewater and the degree to which each one is harmful for the marine environment.

Pollutants, especially those contained in urban sewage, can be distinguished into four large categories on the basis of how they behave in the environment.

I.1. Suspended solids

It has been established that these are very harmful to the marine environment, especially if they are of very small size. They are the most harmful pollutants contained in urban sewage because:

- Suspended solids reduce the penetration of sunlight into the water. This is particularly harmful in areas where the limpidity of the environment allows certain plant species to form true "underwater meadows", as is the case of *Zostera* and *Poseidonia* beds in the Mediterranean. Turbidity caused by suspended solids raises the lower limit of such beds.
- Suspended solids can bring about the clogging of spawning grounds, thus compromising the reproduction of many species and can, in extreme cases, lead to the disappearance of fish and filtering animals sensitive to the blocking of branchiae (gills).
- Suspended solids serve as support to many pollutants adsorbed into them. This is particularly true of bacteria and viruses carried about by small particles; this hinders the normal self-cleaning action of the marine environment.
- The settleable fraction of suspended solids accumulates, through sedimentation, on the sea bed bringing about the asphyxiation of the benthic environment, especially in areas with low rate of water renewal. In addition, sedimented pollutants, if put back in suspension because of heavy swells, may affect water quality in a sensitive area.

I.2. Organic matter

Since almost all types of organic matter are biodegradable, which is also the case with urban sewage, they can be accommodated by the marine environment; they bring to it the nourishment needed by living organisms and thus help replenish, to a certain extent, the quantities caught in fishing.

The risk for adverse impact appears only when either of the following two specific conditions is present:

- content or renewal of dissolved oxygen is inadequate to ensure biodegradation;
- the water is stagnant or insufficiently renewed.

Both situations are found either in enclosed coastal bays, where currents do not penetrate and where it would be counter-indicated to install an outfall system, or under the layer of density discontinuity or "thermocline". The latter is a frequent occurrence in the Mediterranean in the summer season.

In both cases, biodegradation of organic matter is inhibited by inadequate oxygen renewal, resulting in a decrease of oxygenated compounds (sulphates, nitrates, phosphates). Thus all conditions for a dystrophic imbalance of the plant environment are assembled (eutrophication).

For this reason, if poor renewal of the waters at a certain depth from the surface is expected, a situation which is quite frequent in the summer in tideless seas, it is not advisable to discharge effluents at a certain depth because of the risk that the rising plume might be trapped under the thermocline.

I.3. Toxic substances

These may be of either inorganic or organic origin and frequently non-degradable, retaining their toxic properties for a relatively long time. Many heavy metals fall in this category. Urban sewage contains few such substances. When industrial effluents contain toxic substances in quantities large enough to create an unacceptable risk to the environment, then their elimination or the adequate abatement of their concentration before discharge cannot be expected to come from a treatment plant designed primarily for urban sewage. This operation should be carried out as a preliminary treatment of the effluent at the industrial plant, through the care and under the responsibility of the firm producing such toxic substances, and always by using the process recommended for the specific toxic substance to be eliminated.

I.4. Pathogenic micro-organisms

The enormous variety of pathogenic micro-organisms, and the extreme difficulty of the operation, make it impossible to systematically detect and count them in any type of effluent. Since they most frequently move through the digestive tract, the probability of their presence and, to a certain extent, their concentration in an effluent are considered to be linked with the presence and the quantity of organic discharge, more specifically of human origin. Of this group, the intestinal coliform bacteria have been chosen as indicators, because they can easily be detected and counted. However, it should be kept in mind that these intestinal bacteria are not pathogenic organisms and are used only as probability indicators for the presence of pathogens; moreover, that quantitative links between coliforms and pathogens, have not been firmly established on a general basis.

The only thing measured by the counting of test germs of faecal contamination is the number of people whose sewage is discharged into the sea. In regulations worldwide however, no better indicator for possibly dangerous microbial pollution has so far been found than these three families of test bacteria of faecal contamination.

APPENDIX II

DISINFECTION OF URBAN SEWAGE

The abatement of bacterial concentrations from those found in raw sewage to the standards covering "bathing waters" and "shellfish growing waters", is in the range of 10^5 - 10^6 . A factor of 10 - an order of magnitude possible for a treatment plant - is a negligible contribution to abatement and moreover one on which we cannot even count absolutely. Therefore, elimination of bacteria before entering the outfall is necessary in many cases by the disinfection process. Here the distinction is made between natural and chemical disinfection processes.

II.1. Chemical disinfection

This process is based on the bactericidal properties of oxidizing agents (chlorine, bromine, ozone). Its use is not, as a rule, desirable for a number of reasons.

As has been explained, a quantitative correlation between bacterial indicator organisms and pathogens has still not been established, and the same uncertainty holds good when the same indicators are used to assess the effectiveness of disinfection treatment. This is due to the fact that the destructive capacity of chemical oxidizing agents (mainly chlorine) is not the same for all micro-organisms, and many pathogens, particularly viruses, have a much greater resistance to the treatment than indicator bacteria. As, in practice, the effectiveness of disinfection is normally only measured by determining concentrations of indicator organisms before and after treatment, the results obtained cannot be said to afford any accurate indication of pathogen reduction.

There are additional reasons for which this process is counter-indicated, namely:

- Effluents contain nitrogen compounds, especially ammonia, binding a large portion of chlorine in compounds such as chloramines, which are less bactericidal than chlorine, but toxic for marine fauna even in concentrations as low as 0.02 mg/litre.
- Disinfection equipment is delicate in its operation, gets deregulated easily and, since its constant monitoring is not always assured, one cannot rely on the continuity of the operation and thus on the system's efficiency. Any interruption would result in non-compliance with the microbial standards in the areas to be protected.
- Finally, the installation and operational costs of a chemical disinfection system, which needs constant and very careful monitoring, are high and in many cases prohibitive.

Summing up, it can be said that the disadvantages of this type of treatment, whose effectiveness on pathogenic micro-organisms is neither guaranteed, nor controllable in practice, outweigh the advantages which only the assured continuity of operation would procure.

II.2. Disinfection through natural processes

Although the credibility of chemical disinfection may be considered as low, a natural process such as the use of solar radiation in a system of tanks is a lot more effective, because it has a relatively homogeneous impact of all the species of micro-organisms and its continuity is assured. Whether one considers either a complete system of tanks for the treatment of raw sewage which guarantees the sedimentation of suspended solids, the biodegradation of oxidizable matter and microbial disinfection; or about this last phase only in tertiary tank treatment, downstream from a classic treatment plant, this process is both low-cost and reliable and should be opted for in all cases where it is technically feasible. The main prerequisites are the following:

- a flat and rather waterproof area, 1 to 2 hectares per 1000 inhabitants, in order that the waste to remain in the tanks between 6 weeks and 3 months;
- a warm and sunny climate.

Since both of these conditions are easily found in many regions around the Mediterranean, the complete or partial treatment of wastes by using a tank system should be considered wherever the local situation permits.

The greatest advantage is that the waste thus treated is decontaminated and of a very low noxiousness; it can therefore be discharged at a small distance from the marine areas to be protected. Large savings are possible on the total outlay for a classic sea outfall system.

In effect, the effluent coming out of the system can easily meet the required standards for bathing waters of about 10^2 to 10^3 total coliforms per 100 millilitres.

However, it is not possible to resort to this method in all cases; it may be that for various reasons the site does not lend itself, or that the available area is not large enough, especially in the case of big cities. The solution then would be to obtain an abatement factor of the microbial load of between 10^4 and 10^5 , through a different process, for the effluent between the treatment plant outlet and the quality of the seawater in a bathing area. The abatement factor rises to 10^6 if the area under consideration is a shellfish growing one.

For the reasons indicated above, it is very rarely advisable to resort to chemical disinfection; it is always preferable to try and obtain the desired result through dilution, because in that case one is certain that it applies uniformly to all micro-organisms. The solution would then be to discharge the effluent at a certain distance from the sensitive areas; this would guarantee both an adequate hydraulic dilution and sufficient transit time; thus, concerning germs, their own decay would be added to the dilution, given the self-cleansing capacity of the marine environment.

Both effects are equivalent to a dilution and the final abatement factor is the sum of the two. The method that takes greatest advantage of both is therefore the discharge of wastewater into the sea through an outfall system of appropriate length.

APPENDIX III

CALCULATION METHODS FOR THE PREDICTION OF WASTEWATER DILUTION

III.1 Parameters

- L = Total outfall length (m)
Effective length should not be smaller than 1,500 m.
- D = Outfall diameter (m).
- X = Distance between the discharge point and the outer line of the reserve band (m).
- H = Depth of the discharge point (m)
It should not be less than 15 m.
- t = Travelling time (hours).
- C(t)= Concentration of a non-conservative pollutant.
- V = Wastewater velocity in the pipeline (m/s).
- l = Length of the diffusers sector (m)
It should not be less than 5% of L, except when $D < 0.25$ m, when a single outlet is preferred.
- d = Diameter of the diffusers pipe cross section (m).
- 2r = Diameter of the diffusers ports (m)
It should be larger than 0.10-0.15 m.
- n = Number of diffuser ports
Total diffuser port surface should not be bigger than 75% of the pipeline cross section.
- s = Diffuser spacing (m)
Must be about $H/4$.
- v = Velocity of wastewater outflow through diffusers (m/s)
Should reach 1 m/s on a consistent basis and not exceed 2 m/s.
- Q = Total discharge flow (m^3/s).
- q = Relative flow of the diffusers sector. $q=Q/l$ ($m^3/s.m$).
- Q_d = Discharge flow through a diffuser (m^3/s).
- h = Hydraulic head at a diffuser (m)
It must reach 0.5 m in the last outlet.
- m = Friction coefficient of the pipeline (Manning).
- g = Gravity ($9.81 m/s^2$).
- $\bar{\alpha}_a$ = Wastewater density (g/cm^3)
It will be assumed to be equal to 1,000.

\ddot{a}_m = Seawater density (g/cm^3)

It will be assumed to be equal to 1,028.

$\ddot{a}_m(z)$ = Seawater density at depth z (g/cm^3).

g' = Effective gravitational acceleration $g' = g \cdot (\ddot{a}_m - \ddot{a}_a) / \ddot{a}_a$ (m/s^2)

It will be assumed to be equal to 0.267.

u = Current velocity (m/s).

$D1$ = Dilution due to plume rise

Must be larger than 150:1.

$D2$ = Apparent dilution due to degradation or die-away of non-conservative pollutants.

Must not be higher than 100:1 for bacterial indicators.

$D3$ = Dilution caused by cloud dispersion and convection by surface currents.

K_y = Horizontal dispersion coefficient (m^2/s)

It can be assumed to be equal to $0.02 \text{ m}^2/\text{s}$.

K_z = Vertical dispersion coefficient (m^2/s)

It can be assumed to be equal to 0.007 .

Z_{max} = Maximum rising height of the plume in stratified waters.

$!$ = Stratification coefficient. $! = g \cdot (\ddot{a}_m(H) - \ddot{a}_m(z)) / z \cdot \ddot{a}_a$ (m/s).

$T90$ = Die-away rate for non-conservative pollutants (hours)

It will be assumed to be equal to 2.5 hours for faecal coliforms and 3.5 hours for faecal streptococci.

F = Froude number $F = v \cdot (g' \cdot 2r)^{-1/2}$

III.2 Calculation of dilution in the plume

Calculation of the dilution in the plume should be made using the formulas presented herein. Although for most situations no stratification is to be considered, formulas for the calculation of the plume rise height and the dilution at that point are also included. These formula assume that no current is acting on the plume. For the calculation of dilution in cases where ambient currents are considered, Robert's graph should be used.

a) Outfalls fitted with diffusers:

Homogeneous waters:

$$D1 = 0.38 \cdot g'^a \cdot H \cdot q^{-b}$$

Stratification:

$$D1 = 0.31 \cdot g'^{1/3} \cdot Z_{\text{max}} \cdot q^{-b}$$

$$Z_{\text{max}} = 2.84 \cdot (g' \cdot q)^a \cdot !^{-1/2}$$

b) Outfalls with a single outlet:

Homogeneous waters:

$$D1 = 0.089 \cdot g'^a \cdot H^{5/3} \cdot Q^{-b}$$

Stratification:

$$D1 = 0.071 \cdot g'^a \cdot Z_{\text{max}}^{5/3} \cdot Q^{-b}$$

$$Z_{\text{max}} = 3.98 \cdot (g' \cdot Q)^{1/4} \cdot !^d$$

III.3 Non-conservative parameters

For the calculation of the apparent dilution caused by bacterial die-away the following expression should be used:

$$D2 = C(0)/C(t) = 10^{t/T90}$$

where C(0) is the original concentration of the pollutant and C(t) is the concentration after a travel time t.

III.4 Cloud dispersion and convection

The dilution caused by cloud dispersion and convection has less importance and contribution on the overall process than the other two dilutions mentioned above. It can be assumed as 10^1 for small and very small outfalls.

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