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An EIA Guidance Document

ENVIRONMENTAL IMPACT ASSESSMENT

SITING AND DESIGN OF SUBMARINE OUTFALLS

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MARC

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Environmental Impact Assessment

Siting and design of submarine outfalls

by Russell G. Ludwig*

An EIA Guidance Document (1988)

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* Consulting Engineer, Rio de Janeiro, Brazil

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Foreword

There is a growing awareness worldwide of the need to assess the implications for human health of many major development projects and policies. The belief that 'prevention is better than cure' was never more applicable than in the assessment of potential damage which can occur when implementing these projects, particularly in developing countries. Sound development planning and the application of acceptable guidelines are essential at the outset to avoid damaging health effects.

A series of major guidance documents has been developed at MARC in co-operation with the World Health Organization for the assessment of broad human health and welfare effects in the context of the Environmental Impact Assessment process. These documents highlight substantive issues relating to decision-making and the evaluation of impacts. The aim is to provide a compact source of references that gives a quick perspective of the important issues for different types of projects and information that helps to guide the evaluation of impacts and alternatives. Case studies will be outlined where possible to provide a practical perspective to the conceptual framework.

One set of guidance documents addresses the methodological issues and substantive problems of decision-making and provides background information. The second series of documents, also in the MARC series, will provide specific guidance relating to design proposals that focus on classes of projects that affect human health and welfare.

The documents are designed to assist health agency officials and decision-makers in developing countries in dealing with human health and welfare issues related to development projects. Graduate students gaining experience in effective impact management will also find the documents of use either in their training course or when they assume wider responsibilities for community development projects.

P. J. Peterson
Director

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Introduction

The disposal of waste-water effluents to the ocean by means of submarine outfall and diffuser systems represents a viable alternative for the many population centres of the world located on sea-coasts, particularly for developing countries where financial resources are limited. Such systems when designed, constructed and operated can make maximum utilization of the natural assimilating capacity of the ocean water environment which serves as a treatment and disposal facility, and when properly planned will not produce undesirable impact upon such ocean waters.

The purpose of this document is to provide a compact guide for technical personnel in developing countries who need a perspective and ready reference on the possible environmental impact resulting from marine disposal systems using submarine outfalls and the essential parameters governing such effects.

I Environmental Impact Considerations

The possible effects of waste-water discharges into marine waters can be classified as public health effects, aesthetic effects and effects on the marine ecology.

1 Public health effects

The public health concern regarding bacteriological requirements in bathing waters is based on the prevention of contact between persons utilizing the waters for recreational activities and pathogenic organisms which might be present in such waters if affected by significant amounts of sewage materials. Recent investigations indicate a close correlation between bacteriological levels and gastro-intestinal symptoms attributed to swimming in polluted waters, particularly for swimmers in the 0 to 4-year-old group.*

Public health considerations are of even greater importance in waters from which shellfish are harvested. There is conclusive evidence that diseases such as typhoid and hepatitis are transmitted from shellfish grown in polluted waters. Shellfish concentrate microbes by their natural filtering of large quantities of sea-water and in addition provide a favourable environment for continued growth. Thus, waters which contain

* (Salas 1987; Fattal *et al.* 1987).

relatively small numbers of harmful microbes can produce shellfish containing concentrations which will transmit disease.

Severe cases of poisoning resulting from the direct discharge of contaminants to marine waters have occurred, such as the Minamata Bay incident in Japan where large quantities of toxic methylmercury entered the bay. However, such incidents are not associated with systems which discharge normal municipal sewage effluents through proper marine disposal systems.

2 Aesthetic effects

Aesthetic concern relates to the possible presence of sewage associated materials such as floatable solids, grease and oil which result in visual or olfactory pollution and to discoloration of the marine waters when dilution is insufficient. Proper pretreatment and design of submarine outfall diffuser systems can provide effective control of aesthetic problems.

3 Ecological effects

Ecological effects include impact of sewage-related substances on all types of marine organisms including possible toxic substances such as chlorinated hydrocarbons (DDT, PCB) and metals, the effects of nutrient enrichment on plankton and its relationship to eutrophication, and the effects of particulate material on benthic organisms.

4 Very large waste-water discharges from highly industrialized areas

Studies have indicated that where large quantities of waste-water effluents containing substantial volumes of industrial waste pollutants are discharged, 'particles' or particulate matter can cause undesirable impact for the following reasons:

(1) Fine particles tend to flocculate in the ocean waters and combined with discharged suspended solids can result in organic enrichment of the bottom sediments in the vicinity of the diffuser, if the rate of sedimentation is greater than the rate of assimilation at the ocean floor.
(2) Trace metals and trace organics tend to attach to particles and thus could accumulate to undesirable levels.
(3) Particles can reduce light transmission and thus have an undesirable impact on the growth of kelp and other marine organisms.

Under such conditions pretreatment should give consideration to additional removal of suspended solids by incorporating primary sedimentation. For maximum particle removal, 'advanced primary' treatment processes have been developed. These include the utilization of polymers in sedimentation processes and the use of final milliscreening and have been shown to increase the removal of suspended solids by as much as 70 to 80 per cent.

However, such considerations are usually of no concern in typical municipal systems in developing countries where large sewage volumes are not concentrated at a single discharge zone.

In order to provide a complete understanding of the possible impacts of marine disposal systems it is necessary to examine the various parameters which serve as the basis for proper planning of such systems as well as the techniques used in system design.

II Design Parameters for Ocean Disposal

Where effluents are discharged to the open ocean, only a few parameters are important and applicable, including consideration of the protection of public health, aesthetic considerations, particularly as related to floatable material, and toxic substances such as DDT, PCB, etc. which will persist and may cause ecological damage. The latter are usually not a factor for typical municipal sewage effluents.

All other sewage constituents such as BOD, suspended solids, dissolved oxygen, salinity and nutrients are not of significance when effluents are discharged to open ocean waters through properly designed long outfalls equipped with adequate diffuser systems, wherein initial dilution values of a minimum of 100 to 1 are immediately achieved.

Persistent floatable material which can return to the ocean shores and cause aesthetic damage should be removed prior to discharge.

Toxic substances such as DDT, PCB, etc. cannot be economically removed from sewage to the levels necessary and must be eliminated through source control.

Although it remains prudent to limit the quantities of metals in waste discharges, the extensive research conducted by the Southern California Coastal Water Research Project has clearly shown that the concentrations of metals usually encountered in municipal wastes do not impose a hazard to sea animals nor to the persons who eat those animals (Bascom 1982; Bascom and Brown 1984).

III Pretreatment Considerations for Ocean Disposal

A fundamental observation in the application of treatment processes is that the selection of treatment cannot be sensibly separated from the method of final disposal of the pretreated effluent. This association is important because of the extreme differences in the capacities of receiving water bodies to accept residual pollutants—which range from the near zero capacity of a small stream to the maximum capacity of the open ocean.

In considering pretreatment options for ocean disposal of effluent, we can establish three significant types of treatment:

(a) Preliminary treatment such as the use of milliscreens wherein removal is limited to the gross solids including particulate grease of size greater than the chosen screen openings. The solids removed are of a relatively small volume and can be disposed of to a sanitary landfill.

(b) Primary treatment wherein the waste-water remains in a relatively quiescent state for approximately two hours wherein solids of a specific gravity higher than the liquid will settle and those with a lower specific gravity tend to rise. In this case the total removal of solids is increased over that of preliminary treatment. Inasmuch as the volume of solids removed is large, pretreatment of the solids must also be accomplished through the use of anaerobic digestion which provides stabilization and reduces the volume to permit economical disposal.

(c) Secondary treatment systems which first incorporate preliminary or primary treatment processes, but in addition provide biological treatment of the primary effluents to produce relatively stable final effluents, suitable for discharge into lower-capacity receiving water bodies. The volume of solids removed is considerably greater than that of primary treatment which further increases the cost of solids disposal.

When waste-water is discharged to the open ocean through a properly designed long outfall equipped with an adequate diffuser system, only gross solids including persistent floatables need to be removed prior to discharge. Normal processes of sedimentation, flotation and secondary chemical or biological processes result in the removal of excessive amounts of material including fine solids which will be rapidly assimilated in the ocean environment without significant impact. This conclusion is

confirmed by the experience at Durban, South Africa (McGlashan and Macleod 1987) where primary sedimentation facilities were constructed along with two long submarine outfalls (3,200 and 4,200 m) discharging to deep waters (50 to 60 m). Because of difficulties experienced in sludge treatment and disposal, permission was granted for a comprehensive two-year research programme during which the sludge from the primary tanks was returned to the submarine outfalls, with the tanks remaining in service only for removal of floatable materials. Inasmuch as the reintroduction of primary sludge caused no pollution of the beaches, no deleterious effects on the quality of the sea-water nor the quality and well-being of the marine fauna and no bacteriological and chemical pollution at any of the monitoring stations, permission was granted for continued sludge discharge.

The non-necessity for removing sewage constituents such as BOD is emphasized in the following example: when a sewage effluent with a BOD of 200 mg/ℓ is continuously subjected to dilution with sea-water at the 100 to 1 ratio, the resulting BOD concentration in the mixed plume will be about 2 mg/ℓ, which is equivalent to a treatment efficiency of 99 per cent. No treatment process can consistently match this performance standard.

In fact, the ocean serves as a treatment facility similar to the use of an area of land utilizing stabilizing ponds or mechanical processes. The essential difference is that relatively unlimited resources of dissolved oxygen and vast amounts of energy are available naturally to provide the treatment required.

The optimum method of treatment is the utilization of rotary screens, or milliscreens. Extensive studies conducted at New Zealand (Bannatyne and Speir 1987) have shown that the performance of milliscreens is comparable to primary treatment when ocean disposal is utilized. Table 1 presents the removal of significant constituents by milliscreens and by primary sedimentation. It is noted that the main differences in effluent characteristics relate to the removal of settleable solids and suspended solids and, to a lesser extent, to removal of grease. However, milliscreens remove floatables and particulate fat which is the material of significance regarding aesthetic impact on the ocean environment. The only adverse impact of the discharge of grease relates to slick formation, and when initial dilution is sufficient, the concentration of such material in the mixed effluent/sea-water plume is very low and this problem is eliminated.

Table 1 Removal of waste-water constituents: milliscreens and primary treatment

Constituent	Percentage removals		
	Milliscreens		Primary treatment
	0.5 mm Apertures	1.0 mm Apertures	
Settleable solids	43	23	95–100
Suspended solids	15	10	50
Grease	43	30	50–55
Floatable solids	99	96	95–100

Although the available data are limited, the optimum screen opening has been indicated by the studies conducted in New Zealand (Bannantyne and Speir 1987) as well as those conducted at Santos, Brazil to be 1.0 mm. The removal of floatables is closely the same for screens of 0.5 and 1.0 mm openings (99 per cent and 96 per cent). Although the removal of grease is somewhat greater for the 0.5 mm opening screens (43 per cent as compared with 30 per cent), the 1.0 mm screens remove that portion of particulate fats which is of concern.

The 0.5 mm screens remove 2.5 times as much total volume of solids because of the inclusion of fine suspended material which does not require removal, thus greatly increasing the solids disposal problem, resulting in significant environmental impact on land or air resources depending on the method of disposal.

In addition, the experience data show that the smaller openings require extensive maintenance for cleaning whereas the 1.0 mm screens do not.

IV Influence of Design Considerations on Environmental Impact

1 Submarine outfall location

Perhaps the most important factor in considering the environmental impact of marine disposal systems incorporating submarine outfalls is the very location of the outfall.

Wherever feasible, an outfall should be located in an area of minimum environmental sensitivity, i.e., in the open ocean as compared with an

estuary or bay. The discharge point or points should be selected to avoid unnecessary impact on recreational or shellfish resources. For large systems, where economically feasible, the total discharge should be divided into two or more systems to avoid concentrating wastewater constituents at a single discharge point.

2 Depth of discharge

Where the natural ocean topography permits, discharge should be at a depth of 20 m or more. This is important for two basic reasons.

First, where depths of 20 m or more are attainable, significant stratification exists in the sea-water column especially during the summer months. Where sufficient density stratification exists, the mixed sewage

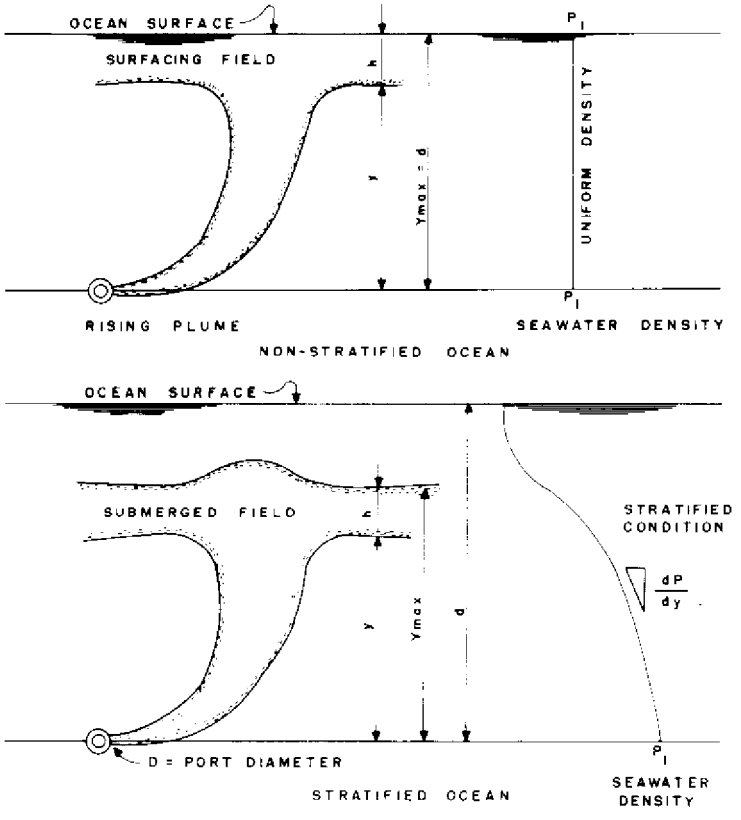


Figure 1 Rising sewage/sea-water plumes under stratified and non-stratified conditions

effluent/sea-water plume will not rise to the ocean surface, but will remain submerged at an intermediate location. This is illustrated in Figure 1. Sewage density (average value 0.9995) is less than the density of normal sea-water (average value 1.0258) and if discharged into an unstratified ocean environment, would rise to the surface to form a surface field. Where stratification exists, if the less dense sewage effluent is rapidly mixed with the colder/denser bottom ocean water, the resulting mixture will be denser than the surface layer. Under such conditions, at some point in the sea-water column the sewage/sea-water mixture will encounter water of the same density and will have no further tendency to rise. This latter condition is extremely desirable as, when achieved, there is no resulting surface field and materials which would otherwise tend to rise to the surface over the diffuser section will remain submerged, either indefinitely or for a sufficient period of time to result in further diffusion from ocean currents and thus result in much lesser surface concentrations.

In addition, studies have shown (Garcia Agudo *et al.* 1987; Josa 1974) that when sewage materials including floatable substances such as particles of fruit, faeces, etc. are discharged at a depth of 20 m or more, the resulting pressure modifies the material so that it no longer floats, but instead settles to the ocean floor. Thus residual floatable materials which may not be removed in a pretreatment system will no longer be of concern regarding aesthetic impact.

3 Diffusers and initial dilution

The planning and design of a sewage effluent diffuser system warrants especial attention because of its profound effect on environmental impact. It makes little sense to construct a long outfall with a poor diffuser system as it is this small portion of the pipeline system that accomplishes the greatest protection of the environment, through the attainment of maximum initial dilution.

First let us define initial dilution. Submarine outfall diffusers consist of conduits with circular ports located along each side of the conduit, usually just above the pipe centreline. The sewage effluent is discharged as round turbulent jets from these ports and, being less dense than the receiving ocean water, rises toward the surface. In the receiving water body, the column of effluent becomes diluted due to entrainment and grows in size as it rises. Depending upon port spacing, exit velocity and

water depth, jets may merge together before reaching the surface or some maximum height of rise. The resulting dilution at this maximum height of rise is called initial dilution.

With proper diffuser design, initial dilution values of 100 to 1 can be readily obtained, and with reasonably deep waters even much higher values can be reached. As an example, if a sewage effluent with a BOD of 200 mg/ℓ is continuously subjected to dilution with sea-water at the 100 to 1 ratio, the resulting BOD concentration in the mixed plume will be about 2 mg/ℓ, which is equivalent to a treatment efficiency of 99 per cent. There is no treatment process that can consistently match this performance standard.

On the other hand, subsequent dilution ratios, resulting from ambulant turbulence as the initially diluted sewage field travels with ocean currents, are estimated to be in vicinity of 2 to 1 when long diffusers are utilized.

Finally, and this is of maximum importance, of all of the factors named which affect the outfall design, the one which is most under the control of the engineer is initial dilution. If the diffuser is properly designed and constructed, high values of initial dilution can be obtained, and sewage field submergence produced.

4 Ocean currents

Of extreme importance in the planning and design of submarine outfalls is complete knowledge of ocean current regimes. Currents must be measured at all seasons of the year and at various depths to develop the information required for analysis of general coastal circulation and hydrodynamics, for determining initial dilution including consideration of submergence, for prediction of far field dilution and transport and, in summary, for prediction of wastefield impact probability.

Currents should be determined at various depths and locations in order to be able to make proper estimates of dilution, submergence and field transport. For example, when discharged from an outfall diffuser placed on the ocean floor, sewage effluent rises due to buoyancy and mixes with sea-water to form a mixed effluent/sea-water plume which will reach equilibrium at some vertical rise point. To predict dilution and submergence, we must have knowledge of current speeds in the vertical intercept from ocean floor to maximum height of rise. Following this initial dilution, the mixed plume will be transported by currents existing at the point of maximum rise.

Of particular importance are current vectors toward the shoreline where impact could be imposed on beneficial uses such as recreational activities, shellfish harvesting, etc. The outfall length must be sufficient to provide adequate time for the elimination of possible disease vectors which might be present in the waste-water effluents.

Ocean currents must be measured in the ocean at all significant periods of the year to obtain a proper value for design shoreward current velocity.

Currents can be measured or estimated using fixed current meters or drift type instruments such as drogues and drift cards. In an open ocean coastline, where it is reasonable to expect that there is spatial coherence in the water current regime, fixed point current observations can provide the maximum amount of information, not only for estimating field travel

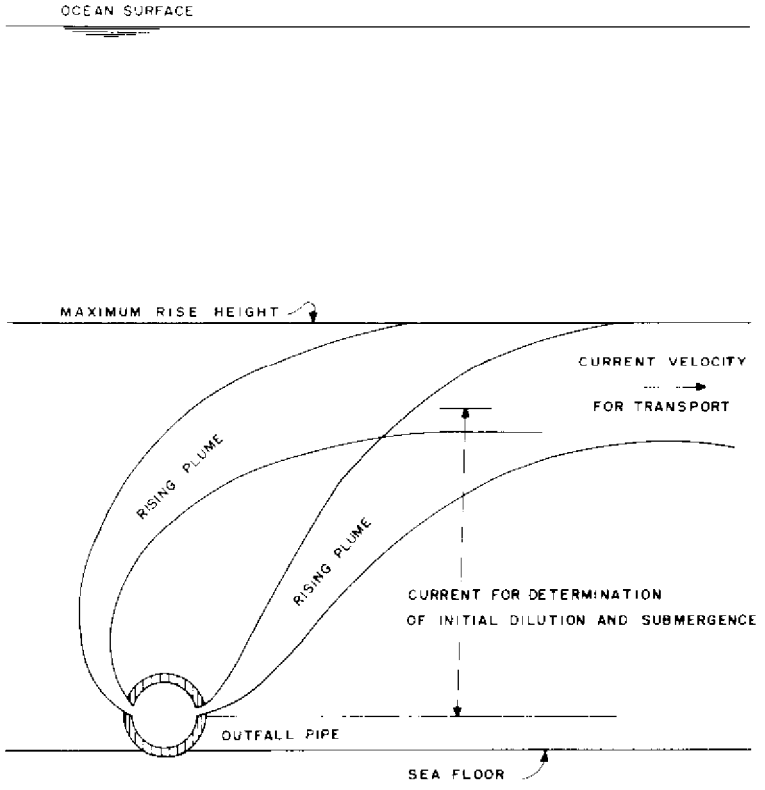


Figure 2 Current velocity affects sewage plume function

time but for providing the type of data needed for estimating initial dilution. Magnetic meters are preferred over Savonius rotor types because of the influence of waves on the latter type.

The current velocity figure for determining outfall length is that value in the direction of the zone to be protected which is not exceeded more than 20 per cent of the time. The reason for this is that the usual standard for allowed coliform concentration is expressed in the same terms, e.g. 1,000 MPN/100 mℓ not exceeding 20 per cent of the time.

Currents for estimating initial dilution are those occurring in the zone of plume formation which will vary depending upon stratification.

These data are illustrated in Figure 2.

5 Typical outfall design parameters for developing countries

The following section will provide general guidance for the review of marine disposal systems in developing countries for providing proper protection of bathing areas. Although the several parameters need to be specifically verified for a particular location, the values listed are typical:

Initial coliform concentration in discharged effluent with milliscreening pretreatment = 3×10^8 MPN/100 mℓ
T_{90} value for tropical waters = 1.5 hours

In the usual case, a diffuser can be designed to provide a minimum value of initial dilution of between 100 to 150 when functioning under the most unfavourable ocean and stratification conditions. Horizontal dispersion can be taken as 2.0 for a general overview.

It can be readily noted that the required total reduction, R is:

$$R = \frac{3.0 \times 10^8}{1.0 \times 10^3} = 3 \times 10^5$$

Total reduction R is a product of Initial Dilution (ID), Horizontal Dispersion (HD) and Bacterial Disappearance (BD), i.e.

$$R = (ID)(HD)(BD)$$

Using an average for initial dilution of 125, and a value of 2.0 for horizontal dispersion, the required value of bacterial disappearance, BD is:

$$BD = \frac{3 \times 10^5}{125 \times 2} = 1{,}200$$

Inasmuch as BD can be expressed as:

$$BD = 10^{T/T_{90}} \quad \text{where } T \text{ is time of travel}$$

For a T_{90} value of 1.5 hours, the required travel time, T can be determined as follows:

$$10^{T/T_{90}} = 1{,}200 \qquad \therefore \quad \frac{T}{1.5} = \log 1{,}200 = 3.08 \qquad \therefore \quad T = 4.6 \text{ hours}$$

In other words, an outfall length is required that will result in a travel time of 4.6 hours in the direction of the nearest zone of protection.

A typical coliform standard for the zone of protection for ocean waters utilized for recreation is that of the State of California, U.S.A. wherein it is required that final total coliform values shall remain below 1,000 MPN/100 mℓ at least 80 per cent of the time.

To correlate the resulting coliform concentrations of submarine outfall system with the required standard, a value of shoreward current velocity vector is selected to meet the identical probability value, i.e. a shoreward current velocity vector which is not exceeded more than 20 per cent of the time.

Although this parameter will vary for each location, based on observations in many systems in developing countries it can be concluded that the suitable shoreward velocity vector will lie in the range of 0.12 to 0.20 metres per second, or from 432 to 720 metres per hour.

For the above estimated travel time of 4.6 hours, an effective outfall length range of from about 2,000 to 3,300 metres is indicated. Allowing for a 300 m wide beach zone, total outfall length would be from 2,300 to 3,600 metres plus diffuser length as shown in Figure 3.

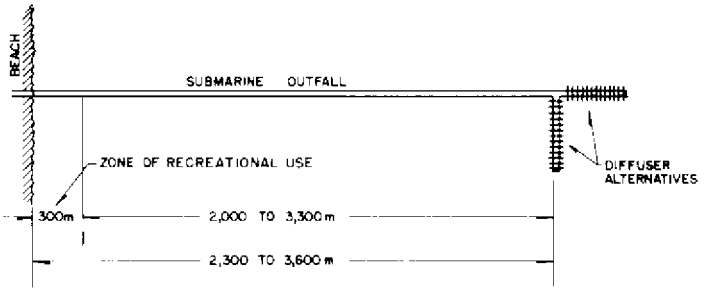


Figure 3 Typical submarine outfall parameters

V Influence of Submarine Outfall Functional Design on Environmental Impact

The total functional design of a submarine disposal system includes determination of the length of the outfall, the corresponding depth of discharge, the length and orientation of the diffuser section and the specific hydraulic design of the pipeline and diffuser including shape, number, size and spacing of orifices. A proper design will include a combination of initial dilution, subsequent horizontal dispersion of the initially formed sewage plume due to ocean current, and bacterial disappearance sufficient to reduce the total coliform concentration from its initial value to a final value satisfying the standard for protection of all beneficial uses.

1 Outfall length

The required length of a submarine outfall from the shoreline to the start of the diffuser section is largely a function of the design shoreward current vector combined with the applicable T_{90} value for coliform disappearance. The volume of effluent discharge does not enter into this calculation. Diffuser length is directly a function of effluent volume and controls the value of initial dilution. Inasmuch as diffuser length is greater for a larger effluent flow, initial field width will be increased and therefore will result in a lesser value for horizontal dispersion.

For marine disposal systems using submarine outfalls for typical shoreline cities in developing countries, outfall length and diffuser design can be suitably determined using the following methodology.

(1) Determine density profiles for the various seasons of the year. Usually, maximum stratification will occur in the summer season and minimum stratification during the winter. However, where significant flows of fresh water enter the ocean, stratification will be maximum during the periods of maximum runoff. Typical stratification curves are shown in Figure 4 for the ocean in the Barra da Tijuca region of Rio de Janeiro, Brazil.

(2) Determine the average value of current speed in the zone of plume formation for the same seasons of the years.

(3) Determine the probability of shoreward current vectors at several depths in the sea-water column during the same seasons of the years. Currents are usually measured using *in situ* recording meters which register current velocity and direction at set intervals of time.

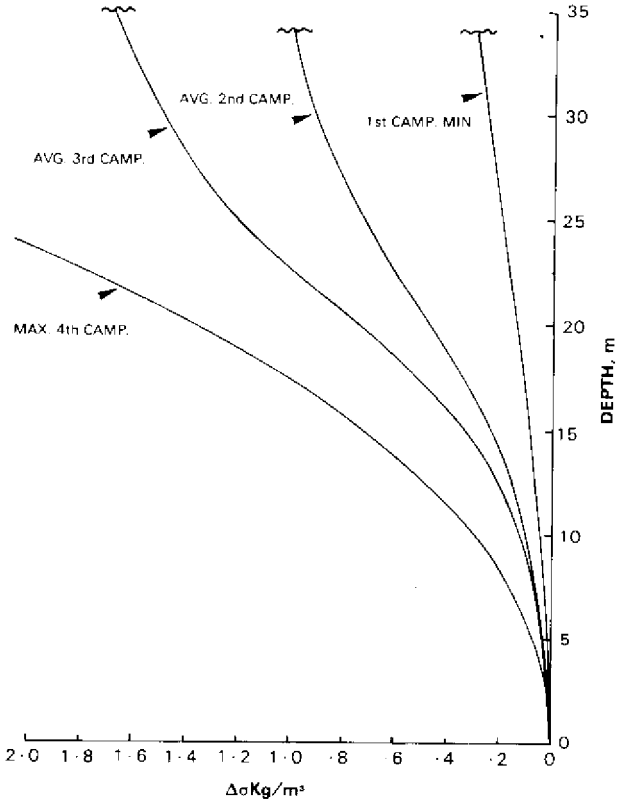


Figure 4 Density stratification of marine waters Barra Da Tijuca

Measurements at ±15-minute intervals will usually provide adequate information. At this measuring frequency, the meters will provide for about 30 days recording. Typical curves of the probability of shoreward current vectors are shown in Figure 5 for the ocean 3 km offshore of Barra da Tijuca, Rio de Janeiro, Brazil. These curves were prepared by calculating and analysing the shoreward vectors of all current recordings, i.e. by multiplying current velocity by the cosine of the angle of current direction, 0° representing a current directly toward shore and 90° representing a current parallel to shore. The vectors for all currents between 90° and 270° are rated as zero.

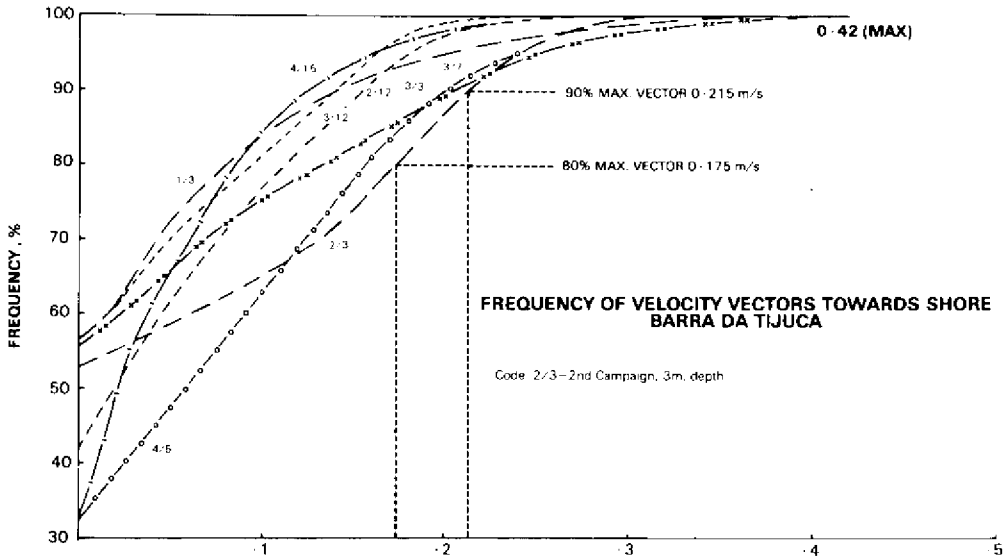


Figure 5 Velocity vector towards shore, m/s

Although many models exist for the determination of initial dilution of an effluent discharge into sea-water, the only model which simultaneously includes the effects of sea-water stratification and ocean current is that of Philip Roberts (Roberts 1977, 1979, 1980). The model permits the determination of maximum rise height and initial dilution including the effects of ocean currents and field submergence resulting from stratification.

A simple graphical solution of the Robert model is shown in Annex 1, which is an example of the functional design of a submarine outfall.

Roberts and Snyder (1987) have recently described the preliminary results of an extensive series of experiments to study the characteristics of merging horizontally discharged buoyant jets in a linearly density-stratified current. Whereas the model referred to above (Roberts 1979) simulated stratification, the more recent experiments were actually conducted in a stratified environment. The available results indicate that although initial dilution is underestimated in the previous model, the trend of the predicted dilutions is correct. The authors intend to report in future separate papers on other experimental results such as the effect on rise height. In addition, Chin (1985) has shown that for tidally influenced coastal environments, effluent dilutions predicted by near-field models overestimate the average dilution since they neglect the advection of the pollutant cloud over the source.

The two effects are approximately equal, one neutralizing the other. It is therefore recommended that the original model of Roberts continues to be utilized at the present time.

2 Diffusers and initial dilution

Diffuser length may be determined using a simple graphical solution of the model presented by Roberts (1979) which permits the determination of maximum rise height and initial dilution, including the effects of stratification and submergence.

Roberts' model can be expressed as follows:

$$Y_{max} = \frac{(1{,}000)\rho^{1/3}\Delta\rho^{2/3}c^2q^{2/3}}{g^{1/3}\Delta\sigma}$$

where

Y_{max} = maximum rise height in meters

ρ = density of sea-water: normal value 1.0258

$\Delta\rho$ = density of sea-water − density of effluent

Normal value $1.0258 - 0.9995 = 0.0263$

q = unit effluent discharge from the diffuser in m^3/s per meter of diffuser

g = acceleration due to gravity $= 9.806\ m \cdot s^2$

$\Delta\sigma$ = density variation in the sea-water column expressed in oceanographic units, i.e.

$\Delta\sigma = 1{,}000\ (1-\rho)$ or when $\rho = 1.0258$ $\Delta\sigma = 25.80$

For the normal values of ρ and $\Delta\sigma$ above, the model becomes:

$$Y_{max} = \frac{C_1 q^{2/3}}{\Delta\sigma} \quad \text{where } C_1 = 41.67 C^2$$

Values of C_1 are plotted for various values of the Froude number, F on Figure 6 for several diffuser orientations, $\theta = 0°$, 45° and 90°.

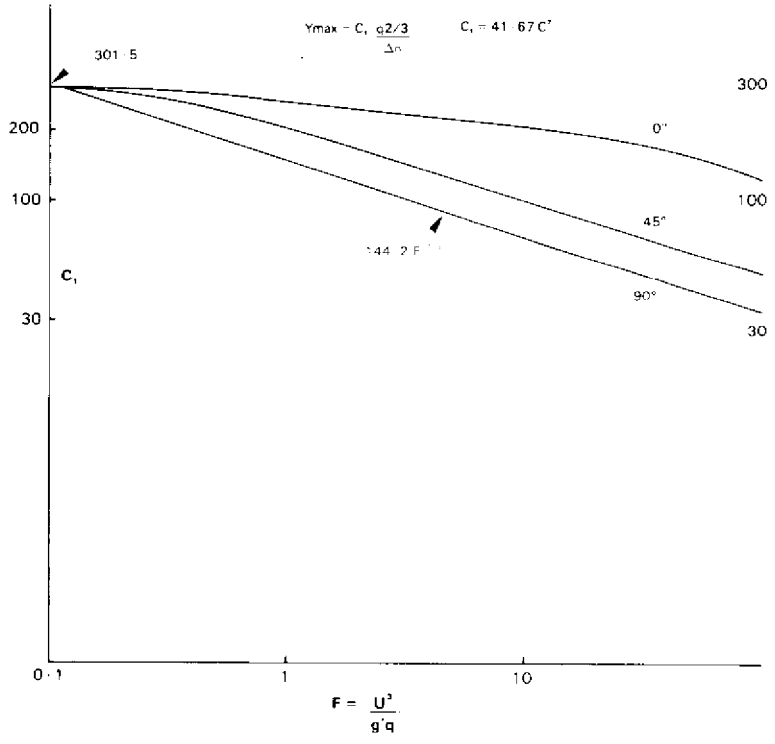


Figure 6 Terminal Y_{max}—Line plume into linearly density stratified current

The Foude number, $F = U^3/g'q$ where

g' = apparent acceleration due to buoyancy

$$g' = \frac{\Delta\rho}{\rho} g = \frac{0.0263}{1.0258}(9.806) = 0.251 \text{ m s}^2$$

U = ocean current velocity, m/s in the zone of plume formation

θ = orientation of diffuser in relation to ocean current direction

$\theta = 90°$ when current is perpendicular to the diffuser.

Roberts has shown that for values of F less than 0.1, $C = 2.69$ and $C_1 = 301.5$. For such values, initial dilution is independent of current velocity and diffuser orientation which provides a base for minimum initial dilution calculations. In such cases the model reduces to

$$Y_{max} = \frac{301.5q^{2/3}}{\Delta\sigma}$$

Initial dilution which occurs at the centre-line of the mixed sea-water/effluent plume at the maximum height of rise, Y_{max} is expressed as Sm and can be determined for all cases as:

$$Sm = \frac{1980}{\Delta\sigma}\Delta\rho \quad \text{or} \quad \frac{52}{\Delta\sigma}$$

Average initial dilution of a line source plume is expressed as Sa:

$$Sa = \sqrt{2}\, Sm \quad \text{or} \quad \frac{73.5}{\Delta\sigma}$$

3 Horizontal dispersion

Although there are many theories and formulas for estimating horizontal dispersion, the method of Brooks (1970) is usually utilized in outfall calculations, and is shown in Figure 7 wherein:

Co = Initial coliform concentration

C_T = Coliform concentration in time T

a = Coefficient of horizontal diffusivity, $m^{2/3}$ hour

T = Travel time of sewage field, hours

b = Initial width of field, metres

$$\frac{C_o}{C_T} = \frac{1}{\operatorname{erf}\sqrt{\dfrac{1,5}{\left[1+\dfrac{8aT}{b^{2/3}}\right]^3 - 1}}}$$

$a = .01\ cm^{2/3}/sec. = 1,67\ m^{2/3}/hr.$

T in hours

b in meters

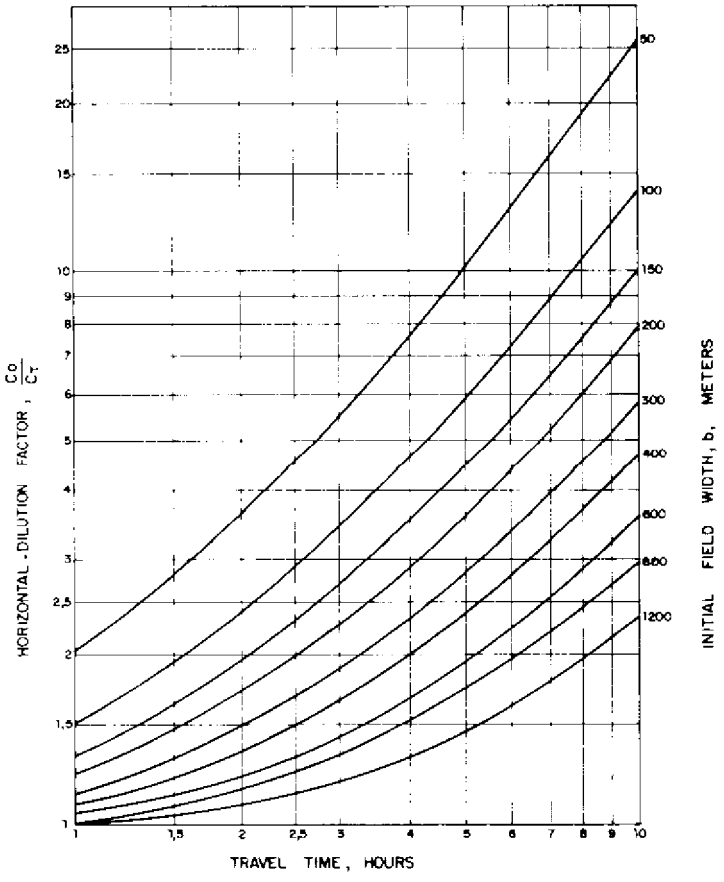


Figure 7 Dilution resulting from horizontal dispersion (after Brooks 1970)

As can be seen, the formula is quite complex and its derivation is beyond the scope of this discussion. However, its use is simplified by the utilization of Figure 7, wherein all that is required is an estimation of the initial effluent/sea-water field width which is normally the length of the diffuser and the travel time to the point under consideration.

As can be seen, for a given value of travel time, T, horizontal dispersion decreases as initial field width increases. However, because horizontal dilution values are relatively small, the resulting effect on the total design is minimal. For sewage effluent flows in the range of 2.0 to 3.0 m^3/s, the resulting value for horizontal dispersion will be in the range of 2.5 to 2.0.

4 Bacterial disappearance

4.1 *Public health/Pathogenic organisms/Bacteriological standards*

The public health concern regarding bacteriological requirements in bathing waters was extensively debated at the 1974 London Conference (Gameson 1974). This concern is based on the prevention of contact between persons utilizing the waters for recreational activities and pathogenic organisms which might be present in such waters if affected by significant amounts of sewage materials. Recent investigations indicate a close correlation between bacteriological levels and gastro-intestinal symptoms attributed to swimming in contaminated waters, particularly for swimmers in the 0 to 4-year-old group (Salas 1987; Fattal *et al.* 1987).

The well-known California standard for bathing beaches which was developed during the nineteen forties was predicated on aesthetic considerations. Investigators found that when total coliform numbers remained consistently (more than 80 per cent of the time) below 1,000 MPN per 100 mℓ, the beaches remained aesthetically satisfactory with no visual evidence of sewage pollution. Obviously, an indirect health significance is evident in such a standard, in that when aesthetic conditions are satisfactory, materials of sewage origin have been reduced to satisfactory levels.

In 1974 a Working Group convened by the WHO Regional Office for Europe issued a report entitled "Guides and Criteria for Recreational Quality of Beaches and Coastal Waters" (WHO 1975) which states, "recommended upper limits for indicator organisms should be expressed in broad terms of orders of magnitude rather than as rigidly stated specific numbers. Highly satisfactory bathing areas should, however, show

E. coli counts of consistently less than 100 per 100 mℓ, and to be considered acceptable, bathing waters should not give counts consistently greater than 1,000 *E. coli* per 100 mℓ". Using a total coliform to *E. coli* ratio of 5 to 1, this is equivalent to 5,000 total coliforms per 100 mℓ. During discussions at Rio de Janeiro in December 1975, Dr. B. Moore of England who served as rapporteur for the WHO Working Group defined "consistently" as more than 50 per cent of the time.

It should be emphasized here that public health considerations are of even greater importance in waters from which shellfish are harvested. There is conclusive evidence that diseases such as typhoid and hepatitis are transmitted from shellfish grown in sewage polluted waters. Shellfish concentrate microbes by their natural filtering of large quantities of sea-water and in addition provide a favourable environment for the continued growth of such microbes. Thus, waters which contain relatively small numbers of harmful microbes can produce shellfish containing concentrations which will transmit disease. For example, a usual standard for coliforms in shellfish harvesting waters requires a median concentration of total coliforms not to exceed 70/100 mℓ.

4.2 *Recent developments regarding microbiological standards*

An excellent historical review of the application of bacteriological water quality standards in the marine environment was presented by H. Salas at the Marine Disposal Seminar held at Rio de Janeiro in August 1986 (Salas 1987) wherein it was reported that, based on epidemiological studies conducted by Cabelli *et al.*, the U.S. Environmental Protection Agency (EPA) has adopted a new criterion for marine recreational waters, namely, 33 enterococci organisms per 100 mℓ. At the same seminar, Fattal (1987) of Israel presented conclusions regarding morbidity among bathers which differ from those of Cabelli, but which also correlate bacteriological levels and gastro-intestinal symptoms in swimmers in polluted waters. Concern was expressed that the swift rejection of the total coliform index for which over 40 years of successful experience is available was not prudent and that a simple adaptation of a particular bacteriological standard is inappropriate without a thorough review of local circumstances. It is therefore suggested that total coliforms continue to serve as an indicator organism for developing countries, along with the use of the newly adopted enterococci standard, at least until substantially more data are available to ensure that such a new index is appropriate.

4.3 *Coliform disappearance*: T_{90} *values*

Of the three mechanisms which produce reductions in coliform organisms, i.e., initial dilution, horizontal diffusion, and actual coliform disappearance, the latter usually has by far the greatest effect upon the calculations for long outfalls.

Therefore it is very important that proper attention be given to the determination of the disappearance rate which is applicable to the area of discharge. The rate of disappearance of coliforms is usually expressed as a T_{90} value which is defined as the time interval required for the disappearance of 90 per cent of the remaining coliform organisms, over and above the reduction due to dilution and/or diffusion. Thus, with a T_{90} value of 1.0 hour, after 3 hours of residence time, a reduction of $10^{T}/T_{90}$ or $10^{3/1}$ or 1,000 will occur.

The survival of bacteria in the ocean has been studied by many research workers who have concluded that their disappearance may be the result of any or a combination of various interrelated physicochemical and biological factors including: (a) the presence in sea-water of toxic substances; (b) the adsorption of bacteria and their flocculation and/or sedimentation; (c) the destructive action of sunlight; (d) the lack of required nutrients; (e) the presence of bacteriophages; (f) the utilization of bacteria as food by protozoa and other predators; and (g) the competitive and antagonistic effects of other micro-organisms. Investigators have noted that all of the above factors can be of significance, but that the individual effect of each is highly variable so that no single factor can be consistently figured to be of the greatest importance.

The interrelation and resulting complexity of the factors producing total bacterial disappearance explains the necessity for empirical observations of the rate. Laboratory studies may be conducted to check or evaluate methods or factors contributing to bacterial disappearance but should not be used in the development of T_{90} values to be used in outfall design. Rather, such rates must be determined by *in situ* studies conducted in the general location of the proposed discharge and preferably using existing waste discharges.

Attempts have been made to determine T_{90} values in the ocean through the use of dialysis tubes or plastic bags and by other similar means. Coliform T_{90} values determined as a result of such measurements are generally found to be of a magnitude greater than realistic values. Most authorities have concluded that the values obtained from such experiments have little or no significance when applied to outfall design.

The value of T_{90} is considerably affected by ocean water temperature. Values determined for relatively warm waters have consistently been found to be less than for cooler waters. For warm, tropical water such as exists in many developing countries, T_{90} values of from 1 to 1.5 hours are common.

Some typical T_{90} values determined from *in situ* measurements of actual sewage effluent/sea-water fields in tropical or semi-tropical waters are as follows:

Location	T_{90} values, hours
Honolulu, Hawaii	0.75 or less
Mayaguez Bay, Puerto Rico	0.7
Rio de Janeiro, Brazil	1.0
Nice, France	1.1
Accra, Ghana	1.3
Montevideo, Uruguay	1.5
Santos, Brazil	0.8 – 1.7
Fortaleza, Brazil	1.3 ± 0.2
Maceió, Brazil	1.35 ± 0.15

4.4 *Night-Time* T_{90}

Concern has been recently expressed that T_{90} values used in design must include determinations made at night because it is believed that sunlight is one of the many factors affecting disappearance rates, and based on laboratory studies, T_{90} values determined in the absence of sunlight are much larger than daytime values. Actual field investigations, although few in number, have not confirmed this premise. However, even if T_{90} values are longer at night, one should not forget that the coliform standards in use around the world (all adapted from the original California standard) are based totally on observations made during daylight hours. It could be hypothesized that if, during the original California studies, coliforms had been determined at night, and if disappearance rates at night were actually lower, higher coliform values would have been found—but still with the beaches remaining aesthetically acceptable.

5 Recent models for predicting far-field transport

For very large marine disposal systems where resources are available for more extensive oceanographic investigations, the model developed by Chin and Roberts (1985) and Roberts (1987) can be utilized. This model has the advantage that no diffusion coefficients need to be specified.

The effect of currents is to advect the initially mixed effluent/sea-water plume in a continuously changing pattern. Because of the variability and random nature of the currents, the location of the wastefield at any time should be considered as a stochastic variable. It is of particular importance to be able to estimate the probability of the wastefield reaching a particular location, or the shoreline, or the fraction of time a particular region will be impacted.

To provide the input data required for this type of model a number of spatially distributed recording current meters must be utilized, such as illustrated below (Figure 8).

Roberts (1987) applied the far field transport model during studies of the modification of an outfall for the City of Seattle, Washington discharging into Puget Sound at Alki Point. Four sites were investigated and

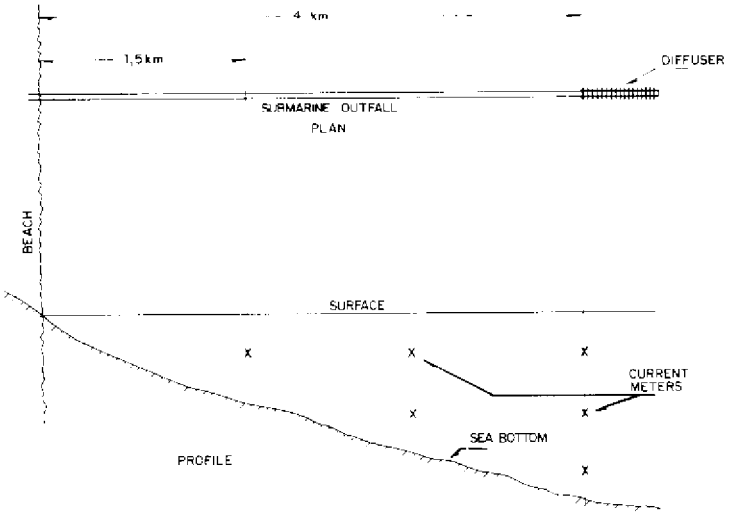


Figure 8 Location of current meters for transport prediction

compared regarding waste field transport within six hours after discharge. The results are shown in Figure 9.

These simulations have played a considerable role in the siting decision for the Alki Point outfall.

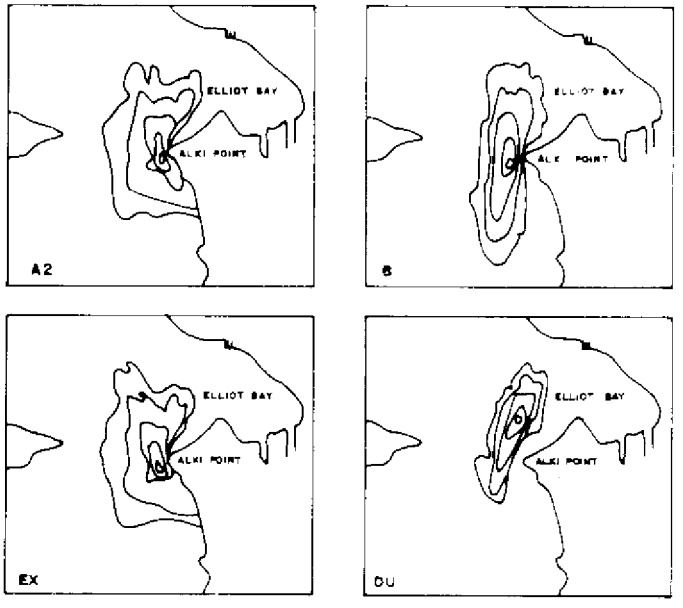


Figure 9 Contours of per cent probability that wastefield centreline lies in a grid square 250 m by 250 m within six hours after release from four alternative discharge sites

VI Influence of Outfall Construction on Environmental Impact

Outfalls can be classified into three general types, namely, placed, pulled, and floated. The placed outfall is constructed by laying and joining short pipe sections on the ocean floor. The pulled outfall is constructed by joining pipe sections on shore and pulling the outfall along the sea bottom to its ultimate postion. The floated outfall is also constructed on shore but is floated into position and then submerged.

As in all submarine outfall construction, there are two principal zones of construction activity, each requiring a different technique, namely, the in-shore or surf zone and the off-shore zone.

1 Inshore or surf zone

Construction within the surf zone requires that the pipe be placed in a trench excavated to a depth sufficient to provide protection of the completed pipeline during periods of heavy seas. In sandy surf conditions the pipe must be buried to a depth below the minimum profile level which can be expected, and/or provided with other means to maintain stability. Where the sea bottom is rock, the pipe may be placed in an excavated trench, backfilled and provided with a tremie concrete protective cover.

2 Offshore zone

At a certain depth in the ocean, depending upon the particular marine environment, it is no longer necessary to bury the pipeline. This depth can be as shallow as 10 m in certain areas and, in the case of the Honolulu outfall, was considered to be 27 m due to the possibility of tsunami waves.

Beyond this point it is only required that the sea bottom be able to support the limited pipe load and that the bottom be sufficiently even, without ledges or ridges.

3 Pipeline materials

Submarine outfalls have been constructed utilizing cast iron, ductile iron, reinforced concrete, lined and coated steel and plastic materials. The latter three materials are generally in use today.

Reinforced concrete is an excellent material for submarine construction, being highly resistant to sea-water. The original concrete outfall of the Los Angeles County Sanitation Districts constructed 50 years ago is still in good condition. Present construction methods permit the use of double rubber gasketed joints which can be pressure tested during pipe placement to ensure a leak-proof installation.

Where applicable, lined and coated steel pipelines can be pulled into place, sometimes resulting in lower costs. However, protection against sea-water corrosion is required utilizing cathodic protection systems.

High density polyethylene and polypropylene pipelines are increasingly being used for submarine outfall construction. Such plastic materials are not only highly sea-water resistant, but being less dense than water, may be floated into position filled with air and equipped with anchoring weights, towed to the site and sunk directly onto the sea-bed by controlled venting.

4 Environmental effects

4.1 *General*

The construction of submarine pipelines in excavation through the surf zone will cause temporary disturbance of the ocean floor in the immediate area of pipe placement; however this is not a significant problem. Actually, the exposed portions of large pipelines become a new habitat for marine animals.

4.2 *Ship anchors*

Outfalls can be seriously damaged by ship anchors when constructed in areas of shipping activity. During planning, steps should be taken to ensure that the outfall location is added to the nautical charts used by mariners. In relatively shallow waters where intensive shipping is involved the outfall pipeline must be buried and diffusers constructed on risers.

4.3 *Commercial fishing*

Another problem can occur where commercial fishing exists in the area of the diffuser section when diffusers are constructed on riser pipes. An example is the outfall at Santos, Brazil, where most of the diffuser risers have been seriously damaged, resulting in much reduced initial dilution. Such risers should be constructed with fail-safe joints and/or of rubber materials to minimize problems and to permit easy repair.

4.4 *Metal accessories*

There have been cases of failure of bolts and other metal accessories utilized at pipeline joints and manhole installations. Such failures have occurred at the Ipanema Submarine Outfall of Rio de Janeiro, causing the temporary discharge of sewage effluent close to shore. Metals such as monel should be used for such accessories to eliminate or minimize such problems.

4.5 *Steel pipelines*

Steel pipelines must be equipped with cathodic protection systems to prevent sea-water corrosion. Such devices require continual maintenance to ensure proper protection.

4.6 *Plastic pipelines*

Where plastic pipelines have been placed by floating and sinking with air venting it is of extreme importance that devices be installed to prevent air from re-entering the pipeline after installation. Of equal importance is the maintenance of such facilities to ensure that the pipeline does not refloat.

VII Baseline Information Required for Assessing Environmental Impacts

1 General project information

The Environmental Impact Assessment document should provide the following basic data regarding the proposed system:

(a) A map (scale 1:20,000 or appropriate) of the area to be served by the system including a schematic layout showing the location of principal sewage facilities (major interceptors, pumping stations, pre-treatment units and submarine outfall). This map shall also show significant topographic features such as lakes, rivers, lagoons, all beaches of the area, zones of shellfish harvesting where applicable, as well as general contours of ocean water depth (10 m intervals).
(b) Basic project parameters including population and sewage flow, both present and for design conditions.
(c) Data regarding significant industrial waste contributions.
(d) Pretreatment considerations and functional planning of facilities for the selected pretreatment option.
(e) A summary of the alternative locations considered for the submarine outfall and the environmental and economic bases for selection of the project alternative.
(f) A summary of the beneficial uses of the marine waters which require protection which may include water contact sports, commercial and sport fishing, shellfish harvesting, marine resources, aesthetic considerations, and others.

(g) Microbiological standards to be utilized in the assessment of impact and for monitoring of the system to ensure protection of beneficial uses.

Information should also be included regarding sources of pollution which will not be eliminated by the sewage collection and disposal system, such as slum areas. Experience has shown that even when the major population centres of a coastal area have been provided with adequate sewage collection, pretreatment and submarine outfall disposal systems, the discharges from unsewered slum areas can continue to cause pollution of adjacent beaches, with such pollution inevitably attributed to the outfall system. The inclusion of such data in the document can serve to eliminate future confusion in this regard.

Finally the Environmental Impact Assessment document should present conclusions which clearly describe both the positive and negative (temporary and continuing) impacts of the proposed system.

2 Public health impact

Field assessment of possible public health impact from marine disposal systems is performed through monitoring of the marine waters utilizing an indicator organism or organisms. Traditionally, the coliform group of bacteria has served to measure such impact inasmuch as sewage contains a great number of such organisms. It is important to stress the distinct difference between impact assessment of the effects of a submarine outfall effluent discharge upon recreational waters and the actual bacteriological quality of such waters because such waters can be affected by many other sources. Monitoring systems should be designed to make proper assessment of the impact of the marine discharge in a manner such as illustrated in Figure 10.

In essence the outfall monitoring programme seeks to assess the presence of sewage effluent at the monitoring stations. For this purpose total coliforms represent the most logical assessment tool inasmuch as this indicator is used as the basis for design of the outfall and diffuser system.

Coliform standards for recreational waters vary widely throughout the world, the majority of which are based on the well-known California Standard developed during the nineteen forties and predicated essentially on aesthetic considerations. Investigators found that when total coliform numbers remained more than 80 per cent of the time below 1,000 MPN per 100 mℓ, the beaches remained aesthetically satisfactory with no visual evidence of sewage pollution. An indirect health significance is evident

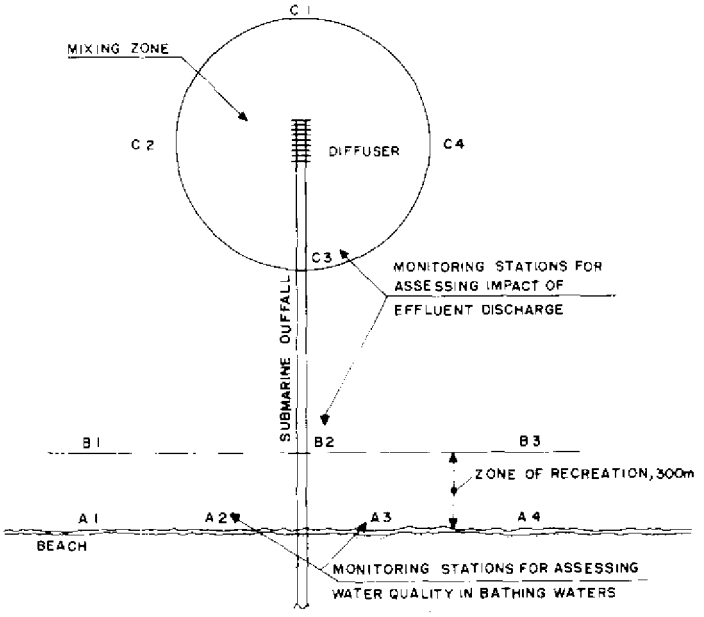


Figure 10 Monitoring station location

in such a requirement in that when aesthetic conditions are satisfactory materials of sewage origin have been reduced to satisfactory levels.

It has been emphasized by several researchers that the choice of a suitable bacteriological standard for a developing country must include consideration of social, cultural, economic and political factors as well as medical factors. Aesthetic consideration is dependent on the subjective perception of the community and must also be viewed in the context of social/economic aspirations.

An example of bacteriological standards for developing countries is that of Brazil wherein a beach is classified as satisfactory when total coliform numbers remain below 5,000 MPN per 100 mℓ more than 80 per cent of the time.

Coliform standards for areas where shellfish may be harvested for human consumption have been adopted from the California requirement in most developing countries, i.e., the median total coliform concentration shall not exceed 70 per 100 mℓ and not more than 10 per cent of the samples shall exceed 230 per 100 mℓ.

To establish baseline conditions upon which impact assessment can be based, measurements of bacteriological indicator organisms should be made at the system monitoring stations during one year prior to the operation of the marine disposal/submarine outfall system.

3 Aesthetic impact

Assessment of possible aesthetic impairment of marine waters is performed by monitoring such waters for materials known to result in such impairment, particularly grease and floatable materials of sewage origin. In addition, measurement of water clarity will assess the possible impact of the mixed effluent/sea-water plume. Monitoring guidelines for assessment are as follows:

—Floating particulates and grease and oil shall not be visible;
—There shall be no aesthetically undesirable discoloration of the ocean waters;
—The transmission of natural light shall not be significantly reduced at any point outside the initial dilution zone;
—There shall be no undesirable odour of sewage origin.

Prior to operation of the outfall system, baseline data on the various aesthetic parameters should be obtained at all stations of the monitoring programme. Water clarity can best be measured utilizing the Secci disc.

4 Ecological impact—biological and chemical information

Assessment of possible ecological effects of waste-water discharges to marine waters requires careful analysis of the beneficial uses which must be protected. Thoughtfulness in planning a programme of study that will produce useful answers is favoured over the collection of vast quantities of chemical and biological data which serve no practical purpose.

Bascom (1987) has summarized the ecological effects and the needs for biological and chemical information as follows:

"The first priority of biological studies is to describe the undersea situation well enough to protect any valuable resources in the region, especially sea foods. If the material discharged is mostly fine particles of sewage with only minor amounts of organic chemicals attached, it is likely to become a valuable source of food for sea animals at the lower end of the trophic scale. Small benthic animals will proliferate, becoming larger in size and numbers; a few species that do not like a specialized

food supply may be absent from a small area near the diffuser. One result of the increase in invertebrates will be more and larger fish around the outfall; these fish are not likely to be adversely affected by the material discharged. The same will be true of lobsters and crabs that feed on smaller animals; they too, will be edible. The problem, if any, will be with clams, oysters and mussels that make a living by filtering particles out of the water. Probably they will grow larger than average but their gut cavities may contain pathogenic bacteria, indicated by a high coliform count that could make them unacceptable as food.

"Data should also be assembled about local fishing methods and preferred fishing areas, so that unnecessary conflicts can be avoided.

"Data should be obtained on the sea animals in the region by using trawls (nets dragged along the bottom) or grabs (that retrieve a sample of soft bottom). A modest number of samples will reveal the main species of animals and hint at the number and biomass of creatures in the region. Only a very ambitious programme can produce a statistically reliable estimate of the number of any of the hundreds of species that may live in the area. It is unlikely this will be needed. Samples of the animals collected in these predischarge surveys can be preserved in formalin indefinitely to answer future questions about changes in sea life.

"Natural changes in ocean conditions (caused by current shifts, large storms, sunspots, etc.) cause changes in sea life that can be confused with changes caused by the outfall. One defence against criticisms is to make a set of equivalent biological measurements at another location where depths, bottom conditions, currents, etc. are as similar as possible to the outfall region. This will permit the outfall effects to be distinguished from natural effects.

"A dozen sampling locations arranged in three lines of four stations, paralleling the bottom contours, about 200 m apart, should be laid out in the outfall area. At each station samples of the bottom sediments and the animals can be collected by means of grabs and trawls. Single samples will be sufficient to meet the objectives stated here; an attempt to obtain statistically acceptable data will greatly increase the cost.

"Developing countries that do not manufacture or use synthetic organic chemicals in substantial quantities need not make any elaborate chemical measurements of the bottom or the animals. The only chemicals likely to cause a problem are those which are soluble in body fats such as the DDTs or PCBs. The former is more likely to reach the sea through runoff than via a pipeline; the latter is more characteristic of industrial societies,

where its use is now decreasing. Metals in waste-water discharges do not damage sea animals and measurements of them in the sea are not needed".

Eutrophication can be a factor if discharge is made to marine waters where a restricted water circulation pattern limits dilution, such as in estuaries, bays and lagoons. However, where discharge is to open ocean waters where initial dilution values of 100 to 1 and more are easily attained, eutrophication is not a factor.

5 Monitoring programmes for assessment needs

Monitoring of waste-water effluents and of waters receiving discharges is an essential part of a well-managed marine treatment and disposal system. Monitoring will not only supply valuable information to verify that a marine disposal system is providing proper protection of public health and beneficial marine water uses but will also develop data useful in the planning of system expansion or modification.

A complete monitoring programme for a waste-water discharge to ocean waters would include comprehensive analyses of the waste-water as well as receiving waters and ocean sediments in the vicinity of the discharge. Such monitoring would include baseline studies conducted during the year prior to waste discharge to establish background conditions as well as post-discharge analyses to determine significant changes in the marine environment. Analyses could include physical parameters (such as waste-water flow and solids content, ocean water transparency and temperatures), chemical parameters (such as BOD, dissolved oxygen, nutrients, heavy metals, and organic carbon) and biological parameters (such as coliform organisms, plankton, benthic organisms and toxicity).

In California, for example, self-monitoring programmes are a requirement for large sewage agencies. The extensiveness of such monitoring programmes is pointed out by the following summary of analyses of receiving waters which are conducted by Los Angeles County Sanitation Districts, wherein almost 15,000 individual analyses must be accomplished annually. These analyses are in addition to a comprehensive analysis of waste-water effluent (Ludwig 1976).

5.1 *Monitoring programme: Los Angeles county sanitation districts*

Station	Frequency	Analyses
Water analyses		
7 on-shore/surface	Daily	Coliforms

5 near-shore/surface	Weekly	Temperature, transparency, D.O., coliforms
24 off-shore/surface	Weekly	Temperature, D.O., turbidity, transparency, grease and oil
24 off-shore/three depths	Monthly	Temperature, D.O., turbidity, transparency, grease and oil
Benthic analyses		
40 stations, four samples	Twice yearly	Species: abundance, biomass, diversity Sediments: H_2S, organic N, trace metals
Fish trawling		
7 transects, three depths	Twice yearly	Species: abundance, diversity, anomalies
Blue light energy		
5 stations	Twice yearly	Light for kelp growth
SCUBA diving		
5 transects	Twice yearly at four depths	Species: fish invertebrates, algae, photographs.

Obviously, such an extensive programme would only be applicable to a very large agency which could afford the cost of the technical staff and resources required. In addition, as reported by Bascom (1987), such elaborate monitoring programmes are actually huge biological-chemical research projects which generate vast amounts of information which is unnecessary, not utilized, and sometimes generates unneeded controversy.

Monitoring programmes which might be recommended in developing countries must take into consideration the limits of resources which are available and are likely to be made available. The programmes must therefore be carefully thought out so as to include only investigations which relate to the protection of public health and to the protection of specific beneficial uses of a particular area.

For example, for a submarine outfall system proposed to be implemented at the island of Rarotonga, Cook Islands, the following programme was suggested (Ludwig 1980).

5.2 *Proposed monitoring programme: Rarotonga*

Waste-water effluent:
Quantity of waste-water—with recording flow meter
Waste-water effluent—24-hour composited samples, monthly
Biochemical Oxygen Demand, BOD, 5 day, 20°C
MPN of Total Coliform Organisms
Settleable and Suspended Solids
Temperature.

Receiving waters:
Total coliforms, MPN/100 mℓ at a network of 8 stations.

Sampling and analysis to commence prior to the completion of the system and discharge of effluent to provide background pollution data.

Sampling and analysis to be performed initially at monthly intervals, with frequency increased or decreased based on the experience obtained.

When samples are collected for coliform analyses, a general visual inspection is to be made to determine the overall appearance of the waters and to note any indications of pollution that would warrant the performance of additional monitoring analyses.

If and when any marine receiving water problems would seem to develop, special monitoring is to be conducted to identify the problem in order that corrective steps can be undertaken. Special sampling techniques, analytical procedures, laboratory equipment and associated skills are required for proper determination of many of the parameters involved in marine monitoring and this exercise would require technical co-operation from external sources.

5.3 *Monitoring stations/Mixing zones*

An example of monitoring stations has been shown in Figure 10, wherein three sets of stations are indicated, i.e., A, B & C.

Stations along the outer edge of the recreational zone, B_1, B_2 and B_3 represent those stations for verification that the marine treatment and disposal system is meeting the objectives prescribed to protect beneficial uses of the marine waters including public health, aesthetic and ecological parameters. Total coliform numbers (MPN/100 mℓ) at these stations must meet the standards for water contact recreational activities and for shellfish harvesting if applicable.

As previously stated, stations along the beach, A_1, A_2, A_3 and A_4 not only provide additional monitoring of the possible effects of the submarine outfall discharge but also of all additional sources of beach pollution including storm-water discharges and the use of the beaches by the population. Microbacteriological parameters for such monitoring can include not only coliforms (total and faecal) but also *E. coli*, enterococci and staphylococci.

The third set of monitoring stations, C_1, C_2, C_3 and C_4 define the limits of a prescribed mixing zone. The purpose of the mixing zone is to allocate a limited region for initial dilution of the effluent with sea-water, and as such it is a region of non-compliance and of limited water use.

VIII Marine Disposal Systems for Coastal Cities—Environmental Protection and Costs

The conceptual planning of a waste disposal system for discharges located along an open coastline involves the determination of the optimum combination of waste-water treatment and a disposal/dispersion system that will meet rational and realistic water quality objectives.

1 Hypothetical example

Figure 11 and Table 2 present an idealized set of waste disposal alternatives for a municipality located on the open coast. Three alternative systems are compared as follows: A. conventional secondary treatment,

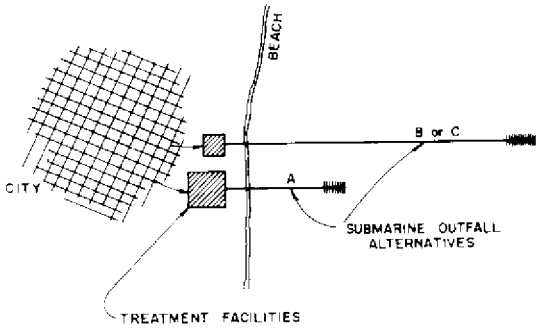


Figure 11 Idealized open coast disposal alternatives

90 per cent removal of pollutant, discharge through a short outfall, average dilution 10; B. primary treatment, 35 per cent removal of pollutant, discharge offshore with high average dilution 150; C. preliminary treatment, 10 per cent removal of pollutant, point of discharge and average dilution as in B.

The waste concentrations at the beach are compared for each alternative in terms of the untreated waste pollutant concentration, C_0, in Table 2. The residual waste concentrations consider removal by the various treatment processes, the initial dilution at the diffuser, and the combined effects of treatment, initial dilution, and dilution during transport. It is apparent that System B with primary treatment (35 per cent removal) and high initial dilution produces the minimum concentrations of conservative (non-decayable) pollutants which are affected only by treatment and dilution processes. It should be noted that the pollutant concentration at the beach for alternative B is $C_0/550$ which is 4.4 times lower than that of alternative A, $C_0/125$. Similarly, alternative C, which incorporates only preliminary treatment (10 per cent removal), will produce a pollutant concentration ($C_0/400$) 3.2 times lower than alternative A.

Table 2 Calculations for the example in Figure 11

Discharge location	A	B	C
Initial dilution at diffuser, S_0	5–20	100–200	100–200
(value assumed)	(10)	(150)	(150)
Treatment process	Secondary	Primary	Preliminary treatment
Percentage removal (assumed)	90	35	10
Equivalent dilution	10	1.54	1.11
Pollution concentrations at diffuser: conservative pollutants	$C_0/100$	$C_0/230$	$C_0/167$
Assumed transport time, T to beach zone, hrs	1.5	4.5	4.5
Assumed additional dilution factor during transport	1.25	2.4	2.4
T_{90} Value – decayable pollutants, hrs	1.5	1.5	1.5
Reduction in decayable pollutants during transport $10^{T/1.5}$	10	1,000	1,000
Pollutant concentrations at beach			
Conservative pollutants	$C_0/125$	$C_0/550$	$C_0/400$
Decayable pollutants	$C_0/1{,}250$	$C_0/550{,}000$	$C_0/400{,}000$

If one is concerned with decayable pollutants such as coliform organisms in the waste discharge (and this historically has been the focus of all marine disposal systems to date), the preference of alternatives B and C over alternative A is even more pronounced. Compare the pollutant concentrations in the beach zone for alternatives B and C of $C_0/550{,}000$ or $C_0/400{,}000$ with the corresponding value of $C_0/1{,}250$ for alternative A.

2 Unit costs for treatment units and submarine outfalls

Figure 12 presents estimated construction costs for treatment facilities as follows.

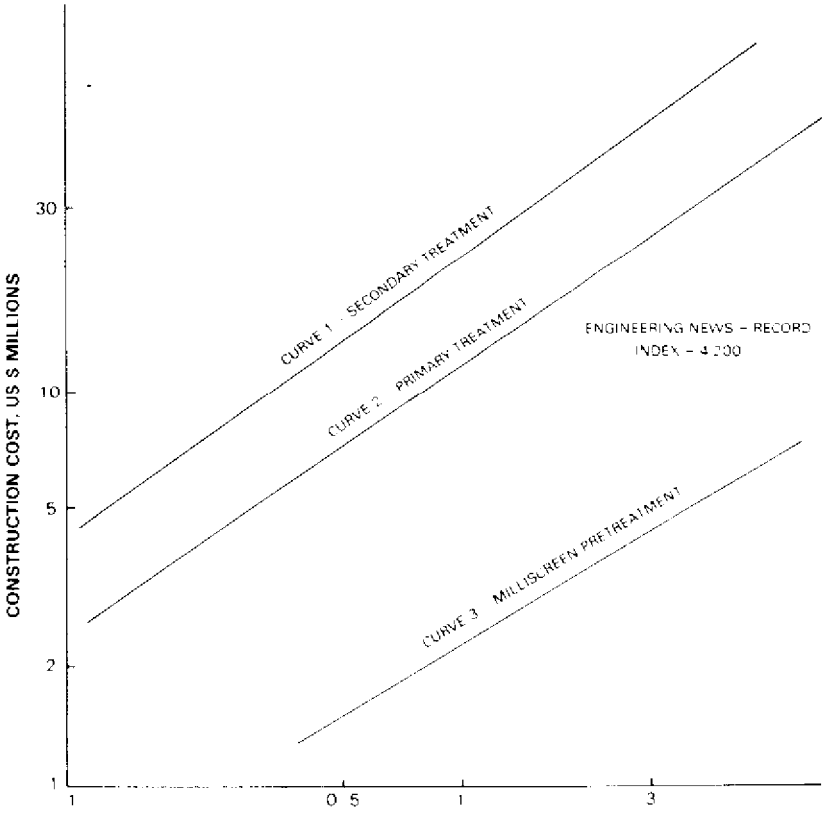


Figure 12 Average sewage flow, m^3/s

Curve 1: Secondary treatment including primary clarifiers, activated sludge biological treatment, secondary clarifiers, sludge digestion and disposal and chlorination.

Curve 2: Primary treatment including sedimentation tanks and sludge digestion and disposal.

Curve 3: Preliminary treatment incorporating milliscreens with 1.0 mm openings, screenings presses and facilities for screenings disposal.

All costs include associated operations buildings, electrical supply and equipment, mechanical equipment, piping, valves, access roads, fencing, landscaping and other required elements for a complete facility.

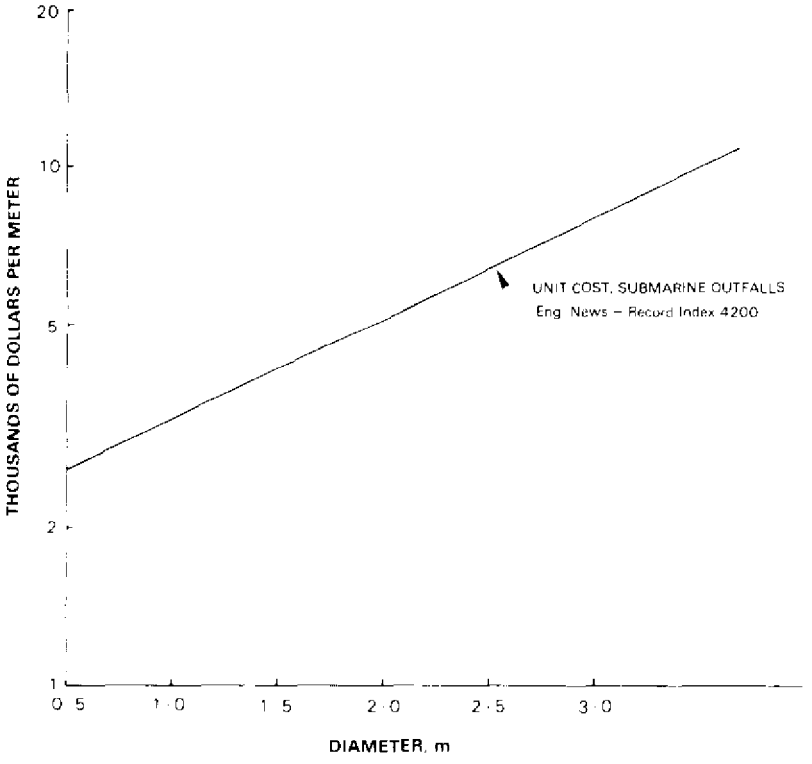


Figure 13 Submarine outfall costs

The curves are drawn for using average design sewage flow. However, the milliscreening alternative includes sufficient screens to handle peak flow and standby units.

Figure 13 presents estimated construction cost per metre for submarine outfalls of various diameters. The costs are based on an outfall length including diffuser of about 3,000 m.

3 Cost of alternative systems

The following estimated costs give a comparison of the relative costs for the three alternative systems described in the previous section, i.e., secondary treatment followed by a relatively short outfall to discharge effluent beyond the recreational zone (1,000 m), and primary or preliminary treatment utilizing a long outfall (3,000 m).

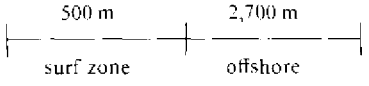
The example is based on the following input data:

Average design sewage flow	$Q_A = 1.3\ m^3/s$
Peak design sewage flow	$Q_p = 1.95\ m^3/s$
Design velocity in outfall at peak flow	$V = 2.5\ m/s$
Required area of outfall	$A = 0.78\ m^2$
Diameter of outfall	$D = 1.0\ m$
Required diffuser length	$L = 200\ m$

Table 3 Cost of alternative marine disposal systems

Treatment type	Cost of treatment facility U.S.$ millions	Length of submarine outfall including diffuser: metres	Cost of* submarine outfall U.S.$ millions	Total cost U.S.$ millions
A Secondary	27.0	1,200	6.1	33.1
B Primary	14.0	3,200	10.4	24.4
C Preliminary	2.7	3,200	10.4	13.1

* Submarine outfall cost breakdown



Mobilization cost	U.S.$ 2.0 M
500 m surf zone	2.65
2,700 m offshore zone	5.75
Outfall for primary/preliminary treatment	10.4
Outfall for secondary treatment	
$2.0 + 2.65 + \frac{700}{2{,}700}(5.75)$	6.1

The data of Table 3 clearly show the great economic advantage of alternative C using preliminary treatment in that the total system cost is 40 per cent of that of alternative A using secondary treatment.

In addition, operation and maintenance costs for alternative C are only a small fraction of the cost for alternative A. And, finally, the energy consumption is very low for alternative C.

Typical Submarine Outfall Design

The following example of the functional design of a submarine outfall is based on an actual design project for the Barra da Tijuca Jacarepaguá area of Rio de Janeiro, Brazil.

Design parameters

Population/Sewage Flow

		Sewage flow, m^3/s		
Year	Population	Minimum	Average	Maximum
1987	350,000	1.09	1.46	2.19
2009	800,000	2.65	3.52	5.30

Oceanographic data

Bottom topography

Investigation of the ocean floor revealed that mean ocean depths of 10, 20, and 30 m are reached at distances from shore of 300, 650 and 1,800 m respectively. Seaward from the 1,800 m mark the floor slopes at an almost uniform rate of 1 m in each 250 m, reaching a depth of 39 metres at a total distance from shore of about 4,000 m.

Current data

Current data are as shown in the previous Figure 5 wherein maximum shoreward vectors are as follows:

Probability/Frequency

- 80 per cent of the time—Less than 0.175 m/s
- 90 per cent of the time—Less than 0.215 m/s

Analysis of ocean current speeds measured at depths corresponding to the zone of plume formation indicate that a minimum current of 0.12 m/s can be safely considered for design.

Density stratification

Curves of density stratification for the four seasons of the year are shown in the previous Figure 4.

Total coliform bacteria and disappearance rate

The rate of disappearance of total coliform organisms, expressed as a T_{90} value, defined as that time interval required for the disappearance of 90 per cent of the remaining organisms (over and above reductions due to dilution and/or diffusion), was established as 1.5 hours. Many past studies of T_{90}, supplemented by additional experiments indicate a value between 1.0 and 1.3 hours. However, due to the fact that the T_{90} value has extreme influence on outfall length, a conservative value of 1.5 hours was adopted.

A raw sewage total coliform concentration of 3.5×10^8 MPN/100 mℓ was adopted based on analyses of sewage samples obtained in several areas of the city.

A recreational zone of 300 m was established. The desired coliform standard is to be met at this location.

Coliform standard for recreational waters

The coliform standard utilized in the design is that of the Secretary of the Environment of Brazil. For waters used for bathing, in 80 per cent or more of the group of samples obtained at the same location in each of the five previous weeks, total coliform shall not exceed the following:

—For marine waters considered excellent 1,250 MPN/100 mℓ.
—For marine waters considered satisfactory—5,000 MPN/100 mℓ.

Inasmuch as the beaches of Barra da Tijuca are presently considered 'excellent', the standard of 1,250 MPN/100 mℓ is to be met, using the shoreward current velocity vector which is not exceeded more than 20 per cent of the time.

Submarine outfall design

The submarine outfall has been designed based on the models of Roberts to determine initial dilution and field submergence and on the model of Brooks for horizontal dispersion, as outlined in Section V of these guidelines.

Diffuser length was selected to provide an absolute minimum average dilution of the mixed effluent/sea-water plume of 100 to 1 under the

most adverse conditions which may occur in the ocean, including maximum density stratification existing during the summer and minimal current velocity (less than 0.06 m/s), and to provide for submergence of the plume throughout the year.

Preliminary study indicated that a total outfall length of approximately 3,500 m would be required. The ocean depth at this distance from shore was estimated as 36 m and utilized in the design analysis.

Calculation of diffuser length

The selection of diffuser length is shown in Figure A-1, using the Roberts

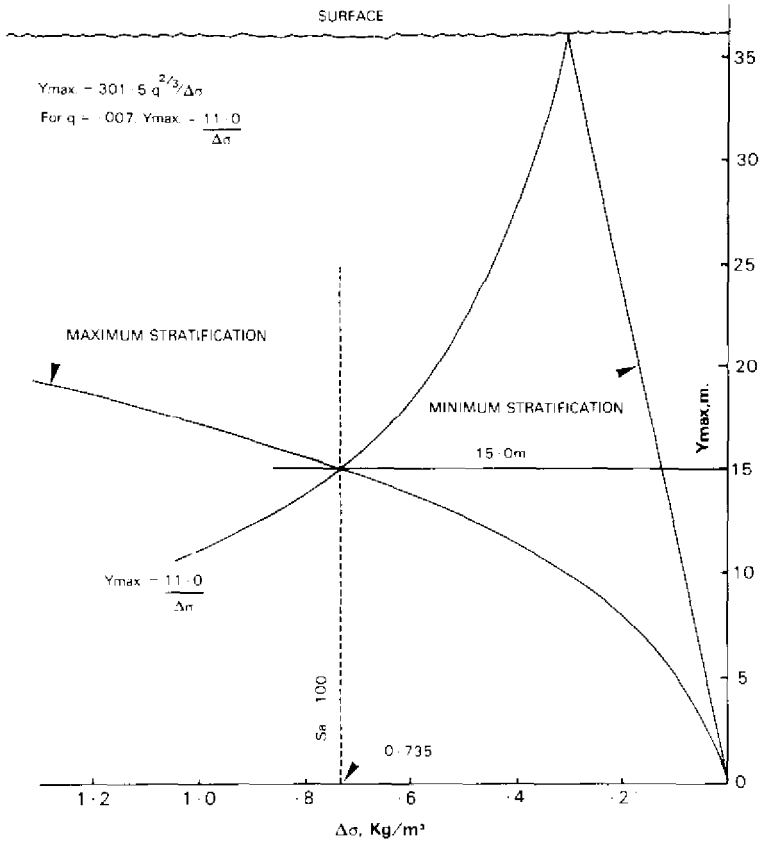


Figure A-1 Calculation of rise height minimum current velocity, $F_R < 0.1$

model for determination of maximum rise height for minimal current (<0.06 m/s), i.e.

$$Y_{max} = \frac{301.5q^{2/3}}{\Delta\sigma}$$

and the maximum stratification curve for summer conditions. For a value of $q = 0.007\ m^3/s$ per metre of diffuser, the condition of initial dilution, $Sa = 100$ is met, and the corresponding rise height, Y_{max} noted to be 15 m.

$$\text{Diffuser length, } L = \frac{Q}{q} = \frac{3.52}{0.007} = 503 \quad \text{or} \quad \underline{500\ \text{m}}$$

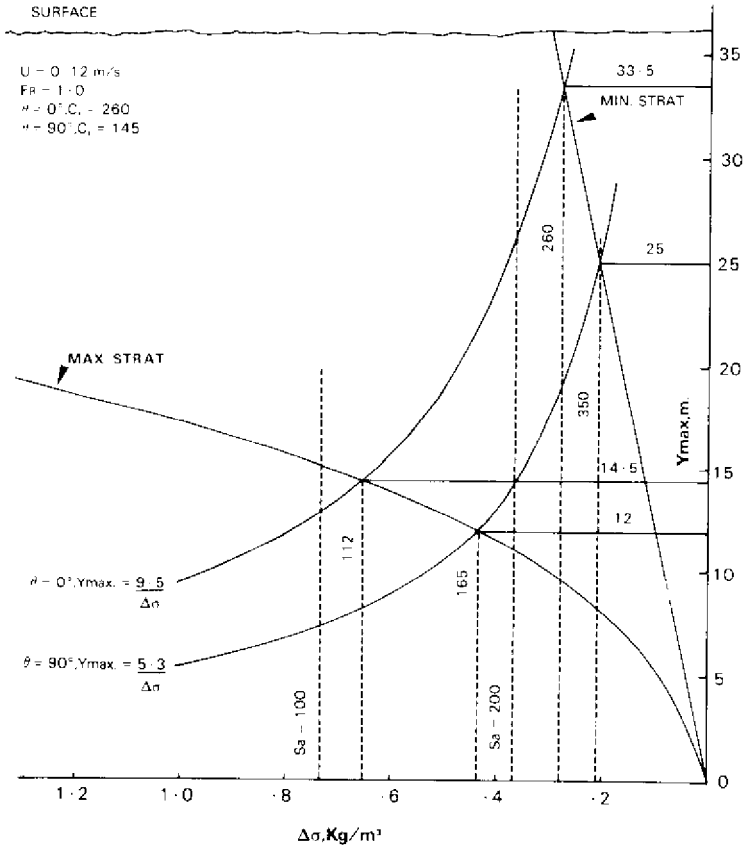


Figure A-2 Calculation of rise height current velocity 0.12 m/s, $F_R = 1.0$

Actual initial dilution values will be greater than 100 to 1 inasmuch as ocean current values greater than 0.06 m/s almost always exist. For the design current velocity in the zone of plume formation of 0.12 m/s, initial dilution and rise height values are determined in Figure A-2, and are summarized as follows.

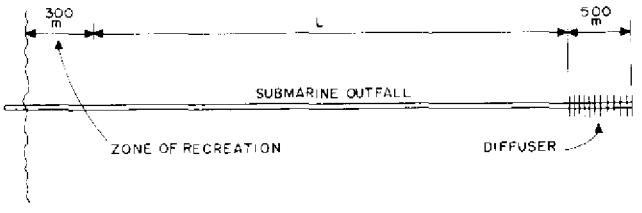
	Y_{max}, m		Initial dilution	
Condition	$\theta = 0°$	$\theta = 90°$	$\theta = 0°$	$\theta = 90°$
Maximum stratification	14.4	12.0	112	167
Minimum stratification	33.5	25	260	350

The combined data show that the plume will remain submerged throughout the year.

Calculation of submarine outfall length

The length of the outfall is selected (along with the chosen diffuser length) to produce a combination of initial dilution, horizontal dispersion, and bacterial disappearance sufficient to reduce total coliform concentration from the original value of 3.5×10^8 MPN per 100 mℓ to the coliform standard adopted for the zone of recreational activity.

In this case the diffuser has been orientated perpendicular to the coastline to take advantage of the much more frequent along-shore current vectors.



$$\text{Total Outfall length} = L + 300\text{ m} + 500\text{ m}$$
$$= L + 800\text{ m}$$

Calculations of coliform concentrations at the outer edge of the recreational zone are shown in the following Table.

Concentration of Coliform—Outfall Lengths 'L'

Current velocity, U m/s	m/hr	Initial dilution*	Travel time hours	Bacterial reduction $10^{T/1.5}$	Horizontal dispersion	Total reduction	Final coliform concentration MPN 100/mℓ
				$L = 3{,}000$ m			
0.175	630	112	4.76	1.49×10^3	2.06	3.45×10^5	1,010
0.215	774	112	3.88	3.84×10^2	1.79	7.69×10^4	4,550
				$L = 3{,}200$ m			
0.175	630	112	5.08	2.43×10^3	2.17	5.91×10^5	590
0.215	774	112	4.13	5.70×10^2	1.87	1.19×10^5	2,930

* Minimum value utilized.

The data indicate that an outfall length 'L' of 3,000 m will satisfy the adopted standard of 1,250 MNP/100 mℓ of total coliforms. In addition, for the 90 per cent current velocity vector, the same outfall length will result in coliform counts less than the 5,000 MPN/100 mℓ considered satisfactory. However a 3,200 m outfall is recommended to provide a factor of safety. Total outfall length is therefore 4,000 m including the 500 m diffuser section.

Diameter of outfall and diffuser system

The selection of outfall diameter is a normal hydraulic problem which must provide for adequate velocities for the minimal flows which will occur during the early years of operation as well as to limit head loss to a reasonable maximum when flows reach design values. Head losses must consider not only the usual friction and velocity head losses in the main pipeline and diffuser, but also the head resulting from discharge of essentially fresh water into salt water, the so-called salt water difference, which amounts to 2.6 per cent of water depth in normal sea-water.

The diameter of the diffuser section requires a consideration of the problems of construction and of the needs for cleaning as well as the question of minimum velocities.

For simplicity of construction and cleaning the pipe diameter is often kept constant. This means that velocity in the diffuser will vary from Q/A at the start to Q/NA at the end where N is the number of diffuser ports. This creates a subminimum velocity condition in the final portion of the diffuser, but experience has shown that this does not result in any significant problem.

Many of the major outfalls constructed in California and Hawaii have tapered diffuser sections in order to maintain higher velocities in the outer sections of the diffuser as flow decreases. In such cases, provisions for access at or near the reducing sections is necessary to provide for removal and insertion of cleaning equipment.

All diffusers must be equipped with end structures which contain gates which can be opened for periodic flushing if and when required. An end port is usually placed in the end structure to provide for a continuous flow at the outfall terminus.

Number and size of diffuser ports

Small diameter diffuser ports, closely spaced, will produce higher initial dilution values than larger ports spaced farther apart, for the same discharge per unit length of diffuser.

Liseth (1976) has determined that maximum dilution will result when the port spacing, l, is such that Y/l is between 5 and 10, where Y is the terminal rise height of the mixed effluent/sea-water plume.

There are some practical considerations regarding port diameter. When sewage which receives only bar-screening is to be discharged it is advisable to keep port diameter at 0.15 m to avoid plugging problems. For systems which receive primary or secondary effluents, port diameters as small as 0.05 m have been successfully used. However, when discharge is made to water of resonable depth, a proper design will usually result in the condition that dilution is not significantly affected by port diameter when diameter is 0.15 m or less. For this reason, for deep-water outfalls, diameters less than 0.08 m are not recommended because there is little or no advantage, and the possibility of clogging increases.

It is very important to ensure that the total port area is significantly less than the area of the pipeline downstream of any diffuser section. If diffuser diameter is reduced, this relationship must be maintained for the new diffuser diameter.

If total port area exceeds pipe area, the average velocity of port discharge would be less than pipe flow velocity, i.e., flow would have to be decelerated prior to discharge. This is not physically possible and consequently some ports would not flow full, or at all, thus defeating the purpose of the diffuser.

Also, under such conditions, where surface wave movement is a significant percentage of water depth, hydraulic perturbations can occur such as described by Grace (1978):

> "That wave action can perturb the continuous operation of a multiport diffuser has been confirmed by diver observations of two outfalls in Hawaiian waters. At one outfall a slug of dye released opposite a port as a crest passed moved directly into the port to reappear with a burst of effluent and sea-water on the next trough. There was some mixing within the diffuser since dye would appear at other ports in later cycles. At another outfall the port flow was slowed under wave crests but not actually reversed. Such situations as related above not only cause hydraulic perturbation but can lead to sand in suspension entering lines and settling inside them. Adequate flow must issue from all ports at all times".

Various authors have quoted port area/pipe area ratios of 50 per cent, 70 per cent, etc. but present no basis for a specific percentage. The early deep outfalls in California incorporated ratios of 0.94 and 0.85 and operated quite satisfactorily.

Brooks (1970) has stated that a reasonable criterion to ensure that ports will flow full is to keep $F > 1.0$; in practice this could mean a ratio of 90 per cent.

Ratios of 70–75 per cent are optimum for diffusers installed in deep waters in that they will provide the assurance of proper diffuser function, and also result in minimum pumping head.

A diffuser is usually designed with ports alternating on each side of the pipeline. The effective port spacing, l, considers all ports, regardless of location.

Hydraulic analysis

The hydraulic design of a multi-port diffuser is basically a problem in manifold flow.

The rate of discharge, Q, from a port is expressed as:

$$\Delta Q = C_D a \sqrt{2gE}$$

where

ΔQ = port discharge

C_D = discharge coefficient

a = area of port

E = total head in the flow of the main pipe at the port

$$E = \frac{V_n^2}{2g} + h_n$$

where

V_n = velocity in the main pipe

h_n = difference in pressure head between the inside and the outside of the pipe. This is only a factor when the diffuser is laid on a *slope*.

The discharge coefficient, C_D, varies as the ratio of velocity head to total energy changes and has been reported by Brooks (1970) as follows: For sharp-edged ports:

$$C_D = 0.63 - 0.58 \frac{V^2/2g}{E}$$

For smooth bell mouthed ports

$$C_D = 0.975 \left(1 - \frac{V^2/2g}{E}\right)^{3/8}$$

So, it is seen that the flow at any port varies with the changing pipe velocity, with changes in elevation (which introduce values of h_n) and with changing discharge coefficient.

The analysis is a step-by-step process, starting at the extreme outer end. It is apparent that one cannot decide on a particular total flow before starting the calculations. It is necessary first to estimate the flow from the terminal port, thence calculate flows from the remaining ports. The resulting summation of all port discharges is then compared with the desired total flow, and if it is significantly in error, a new initial estimate made and the process repeated.

During the process, the designer can modify the port diameter to keep discharge as uniform as possible.

The analysis for a diffuser laid on a zero slope is the simplest in that no pressure head differentials occur. Also, for such cases the relative distribution of flow from any given set of diffuser ports will be the same for all rates of discharge.

When a diffuser is laid on a sloping sea bottom it is extremely important to include the pressure head differentials in the calculations in order that approximately uniform flow will occur. Under such conditions, the initial diffuser ports will necessarily be smaller and gradually increase in size throughout the length of the diffuser.

Under a sloping diffuser condition, it will be impossible to achieve uniform distribution for all rates of flow. For such cases it is advisable to make the distribution fairly uniform at low or medium flow and let the deeper ports discharge more than average port discharge during high rates of flow.

The calculations are facilitated by using the Darcy–Weisbach formula, i.e.:

$$h_f = f \frac{l}{d} \frac{V^2}{2g}$$

A value for $f = 0.018$ is suggested which is equivalent to a Manning "n" value of 0.013 for a pipe diameter of 1.5 m.

For a diffuser laid without slope there is no need to modify port diameter as calculations show only a small variation in discharge from one end of the diffuser to the other.

For a sloping diffuser this variation would be much more pronounced, and port size would be adjusted accordingly.

The hydraulic calculations are ideally performed by computer analysis and programmes are readily available for such use.

Diffuser design—Barra da Tijuca

Based on a typical hydraulic-economic analysis the most cost-effective diameter was determined to be 1.5 m.

Outfall diameter, $D = 1.5$ m

Area of outfall pipe, $A = 1.767$ m^2

Total area of diffuser ports $= (70\text{–}75\%)\ A = \pm 1.25$ m^2

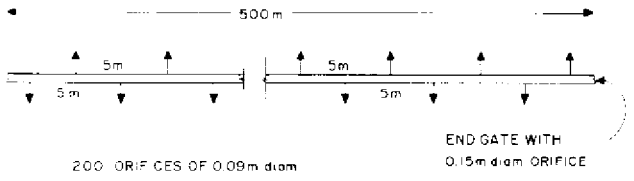
Orifice diameter d m	Orifice area a	Number of orifices N	Spacing l	Y/l	
				$Y = 15$ m	$Y = 25$ m
0.08	0.00503	248	2.02	7.4	12.4
0.09	0.00636	197	2.54	5.9	9.8
0.10	0.00785	159	3.14	4.8	8.0

To keep Y/l between 5 and 10, select orifice diameter of 0.09 m. Use 200 ports at a spacing of 2.5 m and one end port of 0.15 m diameter.

$$\text{Total port area} = (200)(0.00636) + 0.0177 = 1.29 \text{ m}$$

$$\text{Ratio of total port area to pipe area} = \frac{1.29}{1.767} = 73\%$$

$$Y/l \text{ will range from } \frac{15 \text{ to } 25}{2.5} \text{ or from 6 to 10.}$$



DIFFUSER DESIGN

Environmental Impact Assessment—A Case Study

The following section presents an environmental impact assessment of the proposed marine treatment and disposal system for a portion of the Barra da Tijuca-Jacarepaguá area of Rio de Janeiro, Brazil, an area of vital importance in the development of the city. Containing some 15,000

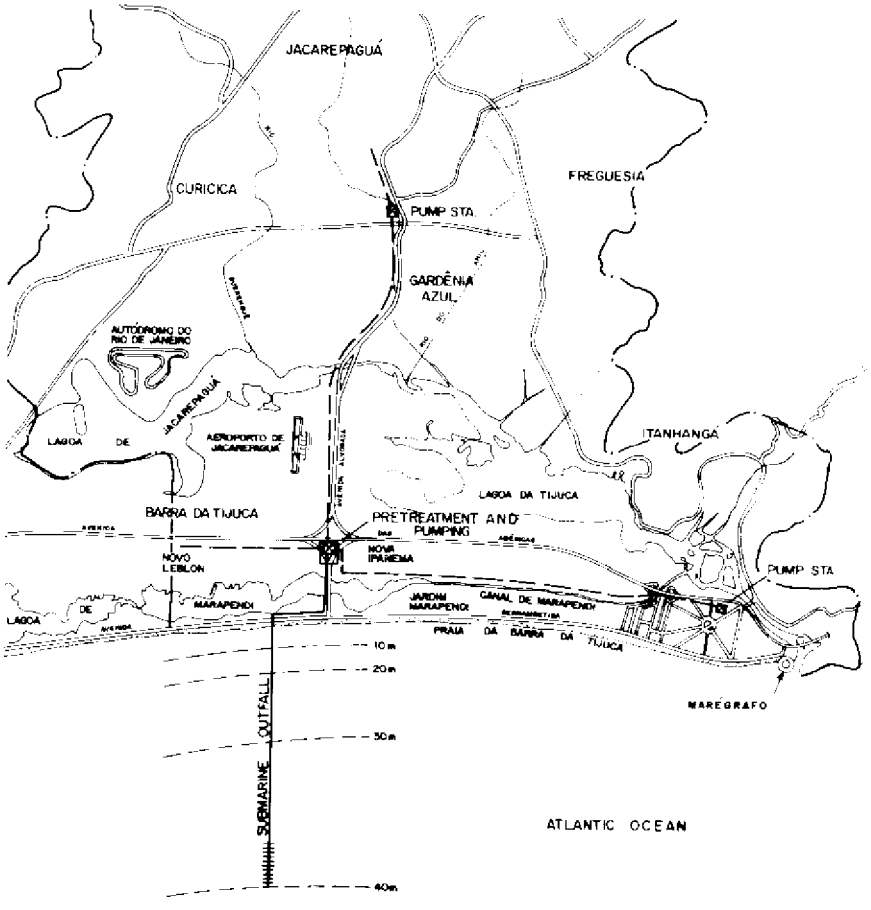


Figure B-1 Barra Da Tijuca--Jacarepaguá service area and sewage facility general plan

hectares, the area has 20 km of beach frontage along the Atlantic Ocean and a series of interconnected lagoons which provide inestimable beauty.

Recent rapid development of the area has created the need for a comprehensive plan for sewage of the area. The older population centre of Jardim Oceanico/Tijucamar does not have a sewage collection system. Septic tanks do not function well because of high ground-water levels and effluents flow to the adjacent canals, lagoons and to the nearby beaches. A number of new condominium units are served by small treatment units (of the rotating disc type) which operate with very low efficiency and discharge poorly treated effluents to the adjacent lagoons. Large commercial centres similarly discharge effluents to the lagoons.

The complete programme of the State Water and Sewage Agency (CEDAE) includes the construction of collection sewers, interceptors and pumping stations to deliver the waste-waters to a central pretreatment facility. Pretreated effluent subsequently will be discharged through a long submarine outfall and diffuser system.

Figure B-1 present the major features of the area including a schematic layout of the proposed sewage facilities.

Waste-water characteristics

The Barra da Tijuca–Jacarepaguá region is a typical residential area with normal accompanying commercial activities. No major industrial installations are contemplated for the area. A future administration centre of the City is also planned for the area.

Principal waste-water characteristics have been estimated based on analyses performed on actual waste-water flows from several small systems existing in the region, and are shown in Table B-1.

Table B-1 Waste-water characteristics

Constituent mg/ℓ	Raw waste-water	Percentage removal*	Effluent	Concentration after 100/1 initial dilution
Settleable solids	4	23	3	0.03
Suspended solids	250	10	225	2.25
Grease	50	30	35	0.35
Floatables	3	96	0.12	—
BOD_5	200	20**	180	1.8

* Using 1.0 mm aperture milliscreens.
** Estimated.

Submarine outfall and diffuser design

Details of the design of the proposed submarine outfall and diffusion system are presented in Section V and Annex 1 of these guidelines, and are summarized as follows:

The outfall is proposed to be a 1.5 m diameter pipeline extending 3,500 m seaward of the shoreline to connect to a 500 m long diffuser section equipped with 200 discharge ports of 0.09 m diameter. Discharge will be at a water depth of 36 m.

Consideration was given to the construction of two outfalls, one adjacent to the Jardim Oceanica area and the second at the location finally selected. The oceanographic studies clearly indicated the disadvantages of the Jardim Oceanica site. Ocean currents are not as favourable in this area and there is an unfavourable effect of the inlet to the lagoon system. In addition, studies of alternative costs clearly proved the economic advantage of the single outfall option.

Pretreatment facilities

The project includes the installation of an adequate number of 1.5 m diameter and 3.0 m long rotating milliscreens of the contra-shear type, using 1.0 mm aperture screens. Sewage enters in a trough inside the screen which distributes the flow over the length of the screen, and falls into the rising side of the screen drum in a 'contra' motion. The liquid portion passes between the wedgewire apertures while the screenings are retained on the internal surface of the drum and conveyed to the discharge end by the action of angled deflector plates.

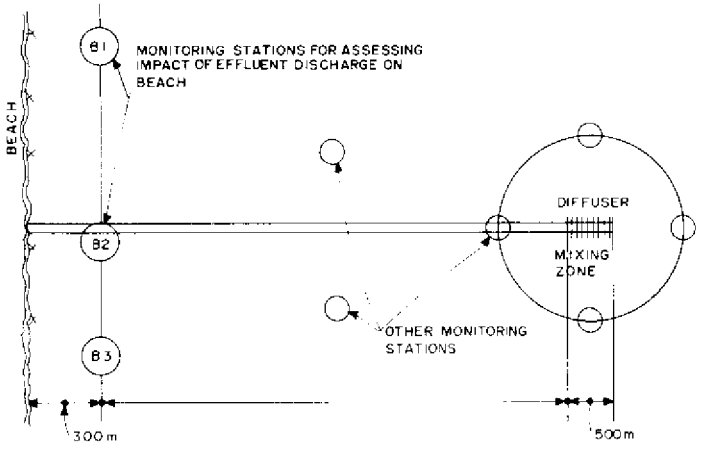
The performance of 1.0 mm aperture milliscreens has been reported by Fitzmaurice and Hedgeland (1981). Percentage removals of waste-water constituents from their studies are shown in Table B-1 along with estimated characteristics of raw waste-water, expected effluent, and concentrations of constituents after initial dilution of 100 to 1.

Post-project environmental impact assessment

(a) *Public health impact*

A monitoring programme is proposed for assessing the possible impact of the effluent discharge on the adjacent beaches of the Barra da Tijuca

area as follows:



The design provides that for the current velocity towards the shore that is not exceeded more than 20 per cent of the time (0.175 m/s), the MPN/100 mℓ of total coliform organisms at the monitoring stations along the outer edge of the recreational zone, i.e., at stations B_1, B_2 and B_3 will be reduced from the initial value of 3.5×10^8 to 550. This value is well below the Brazilian Government Standard for excellent bathing waters of 1,250 MPN/100 mℓ. The calculations also show that using the shoreward velocity vector which is not exceeded more than 10 per cent of the time, (0.215 m/s) coliform values will remain well below the standard for satisfactory waters.

In addition, there are a number of conservative factors provided in the design analysis including:

—No allowance has been made for coliform reduction in the milliscreens.
—The T_{90} value of 1.5 hours is conservative, probably being closer to 1.3 hours.
—Dilution calculations are for minimum conditions as represented by maximum submergence. Values will exceed those utilized at least 90 per cent of the time.
—Considerable additional dilution will occur as the mixed effluent/sea-water plume rises from its initially submerged depth.

—Current vectors toward shore are assumed to maintain their shoreward movement over the entire 4 to 5 hours of travel time. Ocean currents in this area rarely maintain movement in a fixed direction for more than an hour or so.
—Current values used to estimate coliform disappearance are those for depths of 3 to 5 m. Actual on-shore vectors at the equilibrium rise height for the majority of the year are much lower.

Inasmuch as shellfish are not harvested in the area, no impact assessment is necessary in this regard.

(b) *Aesthetic impact*

Aesthetic assessment of a waste-water discharge into marine waters relates to the possible presence of discoloration of the waters, odour problems, and the presence of floatable material including particulate grease.

Table B-1 shows the expected concentrations of significant waste-water characteristics when effluent has been subjected to the minimum initial dilution value of the project. The calculations show that the mixed effluent/sea-water plume will remain submerged throughout the year with submergence at more than half depth for the majority of the time.

The resulting values of ± 2 mg/ℓ of BOD and suspended solids, and less than 0.5 mg/ℓ of grease are insignificant.

The vast majority of floatable material will have been removed in the milliscreening pretreatment system. Further, with discharge at 36 m depth, the resulting minor concentration of such materials will most probably never reach the ocean surface.

It is concluded therefore that aesthetic impact will be virtually non-existent.

(c) *Ecological impact*

As outlined in Section I of these guidelines, ecological impact of sewage related substances include the possible effects of toxic substances such as chlorinated hydrocarbons and metals, the effects of nutrient enrichment and possible resulting eutrophication and the effects of particulate matter on benthic organisms.

Toxic substances

The only chemicals likely to cause a problem are those which are soluble in body fats such as DDT and PCB. In this area there is little or no likelihood that significant quantities of such materials would be encountered. And, as has been emphasized by Bascom (1982) and Bascom and Brown (1984), metals in normal municipal waste-water discharges do not cause harm to sea animals nor to people who consume such animals.

The analyses of diffuser behaviour indicate that initial dilution of any sewage constituent will range from a minimum value of 112 up to 350 to 1, with a median value of about 200 to 1. This dilution will generally reduce the concentration of any possible unknown toxic substances to values which are below the levels of possible harm to sea animals.

Extensive monitoring of the Ipanema submarine outfall of Rio de Janeiro has consistently shown no evidence of toxic effects.

Nutrients/plankton/eutrophication

Initial dilution of nutrients present in the waste-water discharge (nitrogen and phosphorus) will reduce concentrations to extremely low values and thus prevent any possibility of extensive plankton production and associated eutrophication.

The quantitative studies of marine hydrobiology conducted as a part of the monitoring programme of the Ipanema submarine outfall have shown that biological productivity is low and that there is no problem of eutrophication in the area of the outfall.

Particulate matter/benthic organisms

Total suspended and settleable solids concentration in the initially mixed effluent/sea-water plume are shown to be less than 3 mg/ℓ in Table B-1. All particulate material of size greater than 1.0 mm will be removed in the milliscreens of the pretreatment system with only fine solids remaining in the effluent flow. As Bascom (1987) has stated such fine organic solids will become a source of food for sea animals of the lower end of the trophic scale. Small benthic animals will proliferate resulting in the existence of more and larger fish around the discharge.

Inspections of the Ipanema submarine outfall have confirmed the above in that fishing nets have been consistently found attached to the pipe sections all along the outfall.

Summary of environmental impacts

Negative impacts

Some negative impacts are inherent in any system of treatment and disposal of waste-waters. Construction of treatment facilities will cause a temporary impact in the immediate area of the facilities. However, with the utilization of milliscreens, the required area for the pretreatment facilities is quite small and will be removed from residential areas. Also the project will contain provisions for minimizing odour problems. Construction of the submarine outfall will have an impact on the beach and lagoon in the vicinity of the outfall site during the period of construction, estimated to be not more than one year. Both impacts are temporary and not of significant consequence.

A permanent minor impact will exist in the mixing zone of the discharge area. However, the design provides for the mixed effluent/sea-water plume to remain submerged except for possible momentary periods in the winter season when ocean currents are minimal, and even if this should occur, initial dilution will be about 250 to 1 which will make such impact insignificant.

Positive impacts

The main purposes of providing a comprehensive sewage collection, treatment and disposal system for the area are the protection of the lagoon complex and the maintenance of adjacent beaches at their present excellent level.

At the present time, due to discharges of sewage and effluents to the various tributaries of the lagoon complex as well as directly to the lagoons, eutrophication is intensified and fish kills occur occasionally. Such fish kills would surely increase in number and severity as greater volumes of effluents enter the lagoon system. The proposed collection, pretreatment and submarine outfall disposal system will have a very positive impact on the lagoons by preserving their inherent beauty and eliminating the negative aspects of fish kills.

The adjacent beaches are presently meeting the coliform standards for excellent conditions, except in the immediate area of Jardim Oceanico-Tijucamar where the outflow of the lagoons enters the sea, and coliform counts are considerably higher. The proposed system will not only protect the presently unpolluted beaches, but will have a positive impact by

eliminating the problem at Jardim Oceanico, which would become more serious if nothing were done.

A positive impact will occur through the elimination of the many small treatment plants constructed at each of the new condominium units. These units receive minimum operation and maintenance, operate poorly and discharge poorly treated effluents to the lagoons. Also, sludge from such systems is not properly handled.

Conclusion

The analysis clearly shows that the balance of impacts greatly favours the positive side.

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