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SUBMARINE OUTFALLS
GENERAL OVERVIEW, BASIC DESIGN CONCEPTS AND DATA REQUIREMENTS FOR LATIN AMERICA AND THE CARIBBEAN

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1. ABSTRACT

A description of long submarine outfall performance is presented including initial dilution, horizontal dilution and coliform mortality and comparisons are made to secondary treatment with near shore discharge. Field data requirements and/or procedures are described for currents, T_{90}, water quality, meteorology, bathymetric and geology. Design and construction considerations are mentioned and costs are presented.

Microbiological water quality standards are discussed as well as mixing zone aspects.

2. MODEL DESCRIPTION

Sufficient dilution of discharged sewage to reduce contaminant concentrations well below established water quality standards under most circumstances can be achieved with a properly designed ocean outfall system. A minimum initial dilution of 100:1 is common, making the ocean outfall superior to conventional waste treatment plants.

There are several mechanisms which govern the dilution characteristics of an ocean outfall. These are usually considered separately in three phases: initial dilution which occurs in the first few minutes as the waste stream leaves the outfall diffuser and rises in the water column; horizontal transport and dispersion of the sewage field; and kinetic reactions which take place in the sea. For domestic sewage disposal the principal reaction for design is the die-off or disappearance of indicator bacteria (coliforms).

Initial dilution occurs due to three effects: jet mixing due to the momentum of the sewage stream as it leaves the diffuser port; the buoyancy effect resulting from density differences between the sewage and the ambient ocean water (temperature and salinity differences) which causes the sewage field to rise upward in the water column as an expanding plume, thus mixing with the sea water; and finally the current effect causing the lateral entrainment of fresh sea water into the sewage plume.

The sewage plume may rise to the water surface, or may be trapped below the surface depending on the degree of stratification of the water column. Brooks (1983) developed a model that can predict initial dilution, based on the parameters of depth, port, diameter and exit velocity and the density differences between the effluent and ambient fluid. Later, Roberts (1977, 1987) developed a model which predicts initial dilution for different current structures, with or without stratification. Critical to achieving the desired degree of dilution is the proper design of the outfall diffuser. The diffuser length, depth and orientation, as well as the area and spacing of discharge ports, are the key design considerations. Rawn, *et al.* (1961) has presented diffuser design methods, and these have been incorporated into a simple computer program by Salas (1983).

The horizontal transport and dispersion are governed by the local current regime and eddy diffusion (lateral mixing due to eddy currents). Brooks (1960) has developed a model which adequately characterizes these processes to predict the horizontal dilution.

A simple log die-off model of bacterial disappearance gives an adequate prediction for outfall design purposes. The model has the form:

$$S_b = 10^{\frac{T}{T_{90}}}$$

where:

S_b = "dilution" of coliforms
T = travel time of sewage field to protected areas, for example, beaches, in hours
T_{90} = time required for 90% disappearance of coliforms, in hours.

Ludwig (1988) has compiled typical T_{90} values, and these are presented in Table 1.

The total dilution obtained as a result of the three processes described in simply the product of the individual dilutions. That is, for bacteria:

$$S_T = S_i \; X \; S_h \; X \; S_b = \frac{C_o}{C_T}$$

where:

S_t = Total dilution
S_i = Initial dilution
S_h = Horizontal dilution
S_b = Coliform disappearance
C_o = Initial coliform concentration in sewage
C_T = Coliform concentration after T hours (on beaches)

Table 1

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

Initial dilution and bacterial die-off are usually much more significant than horizontal mixing. For example typical values are:

S_i : 50-200
S_h : 2-3
S_b : 500-10,000
S_T : $5 \times 10^4 - 6 \times 10^6$

For conservative substances (non-degradable) initial dilution is the most important factor.

The most important environmental parameters in ocean outfall design are usually ambient density and current regimes and T_{90}. Therefore, data collection programs should concentrate on obtaining good measurements of these phenomena.

3. CURRENT MEASUREMENT

Submarine outfall design requires an adequate definition of dominant currents of the study area. Installation of current meters is recommended to continuously measure current velocity and direction at 3 m from the surface and 2 m from the bottom, located at the most probable submarine discharge area and other locations; the latter depending on current circulation patterns in the area and the location of the beach areas to be protected. Generally, these current meters should be installed during two or three months during the rainy season and two or three months during the dry season. Figure 1 presents a possible anchoring system. The above should be combined with surface float surveys. Tidal variations should also be measured during the same period.

The Acoustic Doppler Current Profiler (ADCP) represents a new generation of current meters. The ADCP can be fixed at the bottom, at any depth, or at the surface. The ADCP can also be attached to boats. The ADCP uses sonar technology measuring particle movement in the water. One of the manufacturers, RD Instruments of California, reports that one ADCP can measure the velocity in the water column at as many as 128 depths. As such, an ADCP can replace a large number of the older type of current meters.

If continuous recording current meters are not available, the use of instantaneous recording current meters is recommended as a minimum, taking measurements every 15 minutes during extended periods. Daily boat-side measurements would be required over several weeks during each season. These should be combined with drogue and float bottle studies conducted periodically at the current metering stations. The float positions should be recorded hourly, for a period of 1 up to 5 days depending on study area characteristics, through visual sightings from a boat or by transits located on shore and/or radar sightings.

The current data should be analyzed using harmonic or filtering techniques. Visual presentation of means and 80% or 90% probability values, depending on the water quality standard, in rosette diagrams (polar coordinate histogram) would be useful. Float survey and current meter data are best presented as a progressive vector plots (sequential "tail to head" plot).

4. DIE-OFF (T_{90}) MEASUREMENT

There are several techniques for measuring T_{90} values and three of them are presented below:

4.1 *On-site measurement in artificial plume*

A large volume of waste is transported to the proposed discharge site. A suitable conservative tracer such as Rodamine WT or a radioactive substance is then mixed with the waste. The mixture is discharged into the ocean environment as a slug release. Several samples are taken in the center of the discharge and measured for the initial concentration of both dye and indicator organisms (i.e. total and/or fecal coliforms). An on-board fluorometer which will provide rapid dye measurements can be used to define peak dye concentration; that is, the location where samples for subsequent

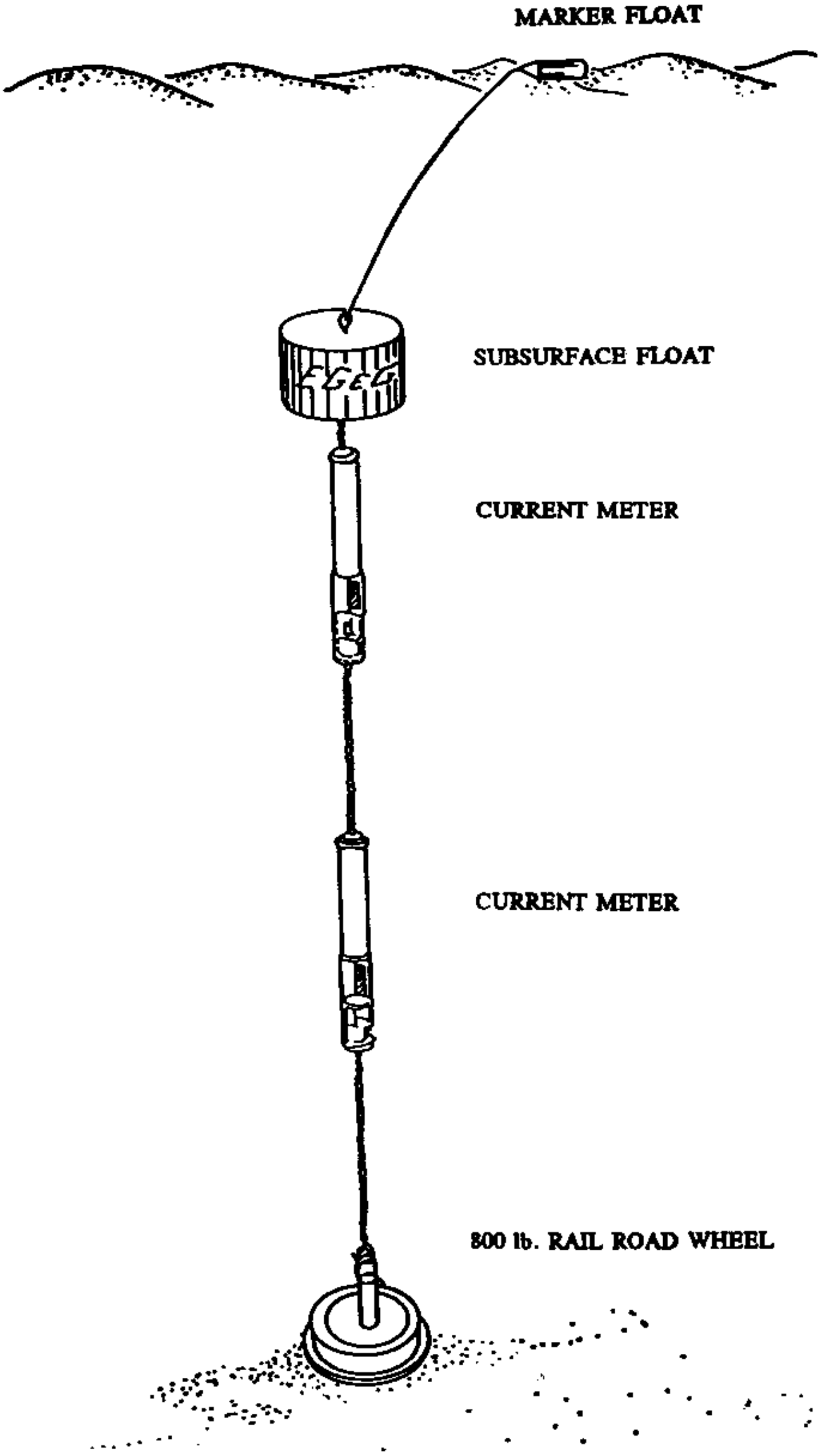

Figure 1. Mooring for two recording current meters (Hydroscience,1974)

laboratory analysis of indicator organisms should be collected. Pearson (1971) suggests that samples be drawn at 0.6-0.9 m and at approximately 3 m below the surface at the initial drop point and at subsequent positions at suggested times of 10, 20, 30, 45, 90, 120, 180 and 240 minutes. However, field judgment is required and the key criterion is that samples be collected at the location of the peak dye concentrations.

The resulting coliform data is modified for physical dilution by multiplying the observed coliform concentration by the ratio of the initial dye concentration to the observed dye concentration at any time. A line of best fit is then drawn on a semi-log plot of modified coliform data versus time from which the T_{90} value can be read. It is noted that this procedure incurs high cost due to the large volume of waste and dye required which is dependent on ambient conditions.

4.2 *On-site measurement in existing waste discharge*

An alternative in-situ procedure is the discharge of floats and/or dye in the area of an existing waste discharge, with the collection of samples as above in the vicinity of the tracers. These samples would be analyzed for the indicator organism (i.e. total and/or fecal coliforms) and another parameter of the discharge that can be considered as conservative in the ocean environment without sedimentation. The selection of this latter parameter would depend on the characteristics of the waste discharge. Although not considered as a conservative parameter, dissolved orthophosphate has been utilized for the purpose by ENCIBRA (1969) with the justification that its decay is relatively much slower than that of the coliform indicator organisms. The resulting data are analyzed as described above but modified with the data of the parameter considered as conservative.

4.3 *Bottle Method*

This method utilizes transparent bags or large bottles, which are filled with raw sewage discharge mixed with ambient ocean water in the dilutions expected at the outfall discharge site after initial dilution, i.e. 1:100. These receptacles are placed at fixed locations near shore just below the surface to maintain ambient conditions of temperature and light. Samples are drawn every 15 minutes for total and/or fecal coliforms. This procedure substantially reduces costs and equipment by eliminating the use of a conservative tracer and reducing required waste volumes. These data are directly plotted versus time on semi-log paper as described previously. The simultaneous use of opaque receptacles, (e.g. painted black) to simulate nocturnal conditions can provide information on nocturnal mortality rates.

The use of dialysis bags can complicate issues in that exchange rates with the ambient waters have to be determined, and predator relationships are not incorporated.

Although the use of the confined receptacle procedure has received criticism from some investigators, i.e. Ludwig (1976), satisfactory results were obtained in the study of Guanabara Bay in Rio de Janeiro (Hydroscience, 1977) and the coastal areas of Mar the Plata (INCYTH, 1984).

It is noted that Acra *et al.* (1990) reports that ordinary glass transmits 90% of incident ultraviolet radiation considered the most important germicidal component of sun light. Plastic transparent materials, such as lucite and plexiglass as well as translucent materials such as polyethylene, can also transmit the germicidal components of sunlight.

Because of its simplicity and low costs, the Bottle Method is recommended in general.

Britto (1979) presents various additional techniques for T_{90} measurement.

5. WATER QUALITY SURVEY PROGRAM

If resources are available, it would be extremely valuable to carry out comprehensive background water quality monitoring surveys. Samples should be taken at stations strategically located in the disposal area to 300 meters from the nearest beaches with significant recreational use. Such background surveys would permit pre- and post-construction comparisons of water quality.

In an open ocean situation, the primary parameters to be measured are as follows:

- Temperature (vertical profile)
- Salinity (vertical profile)
- Total and Fecal coliforms
- Dissolved oxygen*
- pH*
- Secchi disk
- Suspended solids
- Grease and oil

Although survey frequency depends on local conditions, in general, two or three times during different seasons (for example, rainy and dry season) would be adequate.

For systems without treatment or limited to pretreatment, it is recommended that studies be conducted to identify and quantify bottom organisms in order to evaluate the possible impact of sedimentation of sewage particulates.

This program should be combined with wastewater quality and quantity surveys. Also, study area runoff quality and quantity measurements would be useful. This will allow an evaluation of the possible impact of non-point sources of contamination that would continue uncontrolled after the construction of the submarine outfall. This would also allow a relative comparison of non-point source and sewage mass discharges.

In addition to the above, routine water quality surveillance programs for total and fecal coliforms or other indicator upon which the standard is based should be conducted in the principal beaches. According to the water quality standards for primary contact recreation in countries such as Brazil, Mexico, USA, among others, it is recommended that the measurement frequency be five times a month. In view of the Cabelli (1984) studies, enterococci (U.S. EPA 1985) should also be included in the surveillance program, if possible.

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* Preferably at the surface, mid depth and just above the bottom.

When there is a potential eutrophication problem, as could be the case for a discharge into a bay of limited exchange with the sea, additional secondary parameters would be as follows:

- Nitrogene series (Organic N, NH_4, NO_2, NO_3)[**]
- Total phosphorus and ortho-phosphate[**]
- Chlorophyll 'a' (euphotic zone)
- Biochemical Oxygen Demand[**]

Also, biological studies by surface and bottom trawls could be conducted to identify sensitive organisms.

It is noted, nevertheless, that in open ocean discharge situations measurements of these parameters are usually not necessary.

6. METEROLOGICAL SURVEYS

Concurrent with the hydrodynamic surveys, hourly wind speed and direction should be recorded to correlate these phenomena.

7. BATHYMETRIC AND GEOLOGIC SURVEY

Bottom geology should be studied by "boomer" sonar soundings and divers to determine the best outfall route, avoiding rock outcroppings and corral formations, if possible. Bathymetric information should be collected along the proposed outfall line.

8. DESIGN AND CONSTRUCTION

The preliminary design of an ocean outfall looks at the dimensioning of the outfall: length, diameter, location and discharge depth. Also, at this stage the hydraulic design of the diffuser section is completed.

The final structural design will specify the pipe materials and construction techniques and requirements for bottom support, outfall burial or ballasting. Design procedures have been summarized by the World Bank (1983) and Grace (1978).

Detailed information on wave heights will be necessary in this phase of the project.

Figure 2 shows the cost of submarine outfalls developed by Wallis (1979) and updated by Ludwig (1988) and the author. This figure also includes costs developed by Reiff (1990) of small diameter submarine outfalls of high density polyethylene applicable to small communities.

[**] Preferably at the surface, mid depth and just above the bottom.

WATER QUALITY STANDARDS

9.1 *Microbiological standards*

Salas (2002) presents the history and application of microbiological water quality standards in the marine environment. This paper indicates that the scientific base utilized to establish existing world-wide microbiological water quality standards for primary contact recreation in the marine environment is limited and that each Latin American country would better develop its own standards on the context of its own social economic conditions in lieu of simply adapting standards of other countries.

Also, it is noted that according to epidemiological evidence, Cabelli (1984) has concluded that enterococci is the superior indicator organism and has developed a quantitative relation between health risk due to gastrointestinal illness associated to swimming in contaminated water. As reported by Saliba and Helmer (1990), prospective epidemiological studies similar to that conducted by Cabelli (generally referred to as "Cabelli style studies") were carried out in a number of countries between 1982 and 1989, and reported that correlation between specific illness symptoms and indicator concentrations, as well as the indicators determined as the best, considerably varied among studies. Special attention should be paid in the application of relationships developed in other areas to factors as general health and total population immunity.

9.2 *Mixing Zone*

In the design of ocean outfalls for final sewage disposal, consideration should be given to defining a separate set of standards within a limited region surrounding the outfalls' diffuser section. The purpose of this mixing zone is to allocate a limited region for complete effluent mixing with ocean water. As such, the mixing zone is a region of non-compliance and limited water use. It normally encompasses a volume extending 50-600 meters on all sides of the initial dilution zone. Mixing zone standards are generally limited to water quality variables for acute toxicity protection (usually determined by bioassays) and to minimize visual impacts. Mixing zone standards for coliform organisms are normally not imposed unless the diffuser is located in close proximity to shellfish harvesting areas or water contact recreational use areas. Such standards are not usually applied to BOD, dissolved oxygen, and nutrients.

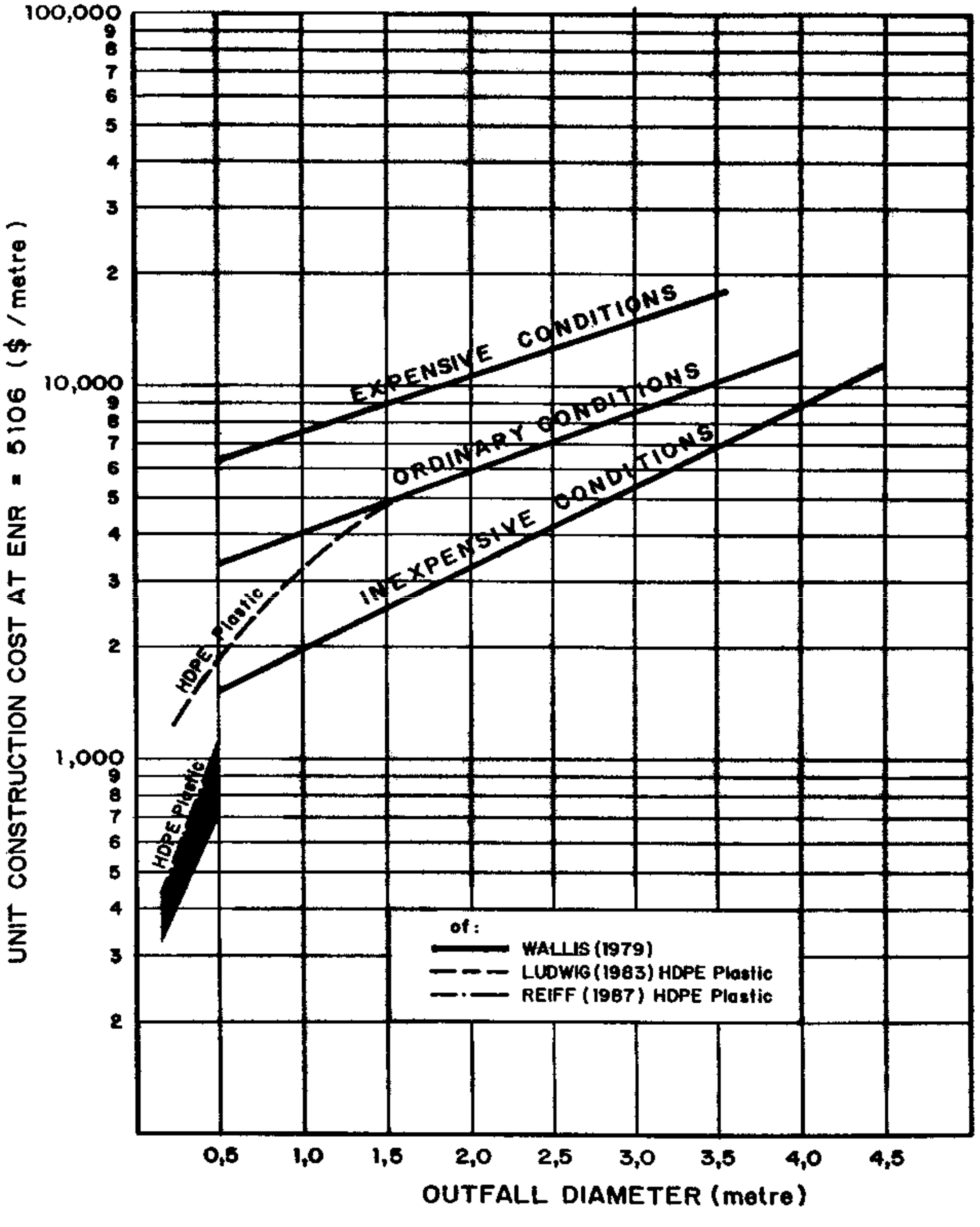

Figure 2. Submarine Outfall Cost

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