The Design of Praia dos Ingleses Submarine outfall, Florianópolis, Santa Catarina, Brazil.

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Abstract

An outfall 1,800 meters long was initially proposed by Water and Sanitation Company of Santa Catarina (CASAN) to dispose the treated effluent from Praia dos Ingleses. The final plan average flow, estimated for the summer season is 0.1543 m^3/s, corresponding to a peak population of 83,340 people attended. The characteristics of the diffuser's near field were calculated using the NRFIELD model supplied by series of current profiles (ADCP) and density gathered at the diffuser location between March, 22nd and April, 22nd, 2007. Reliable information of raw sewage fecal coliform concentration has been supplied by CASAN, as a result of continuous monitoring of sewage on its treatment plants. This information was grouped into histograms and a Weibull probability density function was fitted. Series of artificial random numbers following Weibull distribution were generated and incorporated as a source into the transport model. The current velocity spectrum shows that semidiurnal astronomical tide is markedly dominant and there is no significant contribution of sub inertial components. Thus, for basic design purposes, it was assumed that 30 days of oceanographic observation in late summer and early autumn, when there are periods of high stratification followed by periods with homogeneous water column, would be sufficient to determine operation of the outfall. The results of far field modeling showed the need to increase the outfall length. A new location 3,300 meters far from the beach has been proposed.

Keywords
Ocean outfall; Ingleses Beach; Brazil; bacterial decay; near field; far field.

INTRODUCTION

The disposal of domestic sewage through ocean outfalls is a viable alternative for many coastal cities with high population density. Particularly in balneary cities that, for many reasons, had the process of urban settlement favoring the agglomeration of floating population around its main attraction, the beach, this solution becomes very attractive. Assuring the quality of the water to bathers without compromising aesthetic areas of the beaches, many coastal municipalities have found ocean outfalls the best way to dispose their sewage, treated or not.

The benefits of treatment and the use of emissaries are not restricted to human beings. As the diffusers are generally located hundreds to thousands of meters off-shore, in an environment where the density of organisms and biodiversity are significantly lower than other ecologically sensitive coastal environments such as coves, beaches, promontories and mangroves, there is a gain on the environmental quality for the entire ecosystem. It should be noticed that inside these coastal environments, many marine organisms, some of commercial interest, look for shelter and food to develop into larvae, juvenile and adult phases.

The districty of Praia dos Ingleses is located north of Santa Catarina island, where is located the Santa Catarina State Capital, Florianopolis. The beach borders the Cove of Ingleses, the most northern areas within the North Bay. The North and South bays separate the island from the mainland. They are characterized by having clean and calm waters. Within their domain there are several coves, sandy beaches, islands, promontories and mangroves. In these sheltered areas, an intense and important activity of mariculture (primarily oysters and mussels) has been developed over the past 20 years.

Florianópolis is the most important tourist destination in the southern coast of Brazil. The city grows fast since three decades trying to preserve the beautiful coastal landscapes, so attractive to Brazilian and foreign tourists. Sanitation problems are already limiting factors for development of tourism and begin to be solved by the Water and Sanitation Company of Santa Catarina (CASAN).

A 1,800 meters long outfall was initially proposed by CASAN to dispose the treated effluent from Praia dos Ingleses. The treatment would consist of screenning, gravity desanding and grease retention. The final plan average flow, estimated for the high season, is 0.1543 m^3/s corresponding to 83,340 people attended. After preliminary analysis by the environmental agency, the project design has changed. The project must be adequated to the State Environmental Code BOD_5 release standards. The designed treatment plant had its capacity increased to remove organic load. A secondary treatment plant shall be constructed, consisting of UASB reactor after biological filter treatment followed by a disinfection unit.

This paper presents a proposal for ocean disposal of effluents after it passes through the Sewage Treatment System of Ingleses, Florianopolis, Santa Catarina, Brazil, through ocean outfalls. The design of the proposed outfall must ensure quality of bathing on Ingleses beach, at the promontories and at Mata-Fome island, helping to improve the quality of water resources, in particular to Capivari river, currently quite impacted, thus meeting at least the legal compliance.

Legal requirements

In Brazil, CONAMA 357/2005 (CONAMA, 2005) defines the classifications and guidelines for the of water bodies as well as establishes the conditions and standards for effluent discharge. Table 1 summarizes the resolution information.

Table 1: Water Classification and quality standards on the marine environment.

Classe	**Especial**	**1**	**2**	**3**
Designed uses	a) conservation of aquatic environments in conservation units of integral protection; b) preserving the natural balance of aquatic communities.	a) primary contact recreation. b) protection of aquatic communities; c) aquaculture and fishing activity.	a) recreational fishing; b) secondary contact recreation.	a) navigation; b) landscape harmony.
		Bathing: satisfactory limits		
Fecal Coliforms	0.0 NPM/100 ml	a) 1,000 NPM/100ml by 80% of the samples. b) less than 2,500 NPM/100 ml at the last sampling. For bivalve molluscs crop: c) 88 NPM/100 ml in 90% or more of the samples. d) Geometric mean less than 43 NPM/100ml.	a) 2,500 NPM/100 ml in 80% or more of the samples.	a) 4,000 NPM/100 ml in 80% or more of the samples.
Escherichia coli	0.0 NPM/100 ml	a) 800 NPM/100ml by 80% or more of the samples. b) less than 2,000 NPM/100ml at the last sampling.	Can replaced with the fecal coliform limits specified by the competent environmental authority.	Can replaced with the fecal coliform limits specified by the competent environmental authority.
Enterococci	0.0 NPM/100 ml	a)100 NPM/100 ml at 80% or more of the samples. b) less than 400 NPM/100ml at the last sampling.	NA	NA
		Inorganic parameters		
Nitrate	0.0 mg/l	0.4 mg/l	0.7 mg/l	NA
Nitrite	0.0 mg/l	0.07 mg/l	0.2 mg/l	NA
Total ammonia nitrogen	0.0 mg/l	0.4 mg/l	0.7 mg/l	NA
Total Phosphorus	0.0 mg/l	0.062 mg/l	0.093 mg/l	NA

Fonte: CONAMA (2005).

REGIONAL OCEANOGRAPHY

By investigating of the thermohaline structure of the North-Central Coast of Santa Catarina, Carvalho et al. (1998) observed two distinct seasonal patterns influenced by the wind, first one during spring-summer, in which the water column is divided into two layers with the presence of a very sharp thermocline. The northern winds cause the coastal upwelling of South Atlantic Central Waters (SACW), while the southern winds cause the elevation of waters close to the coast resulting on the thermocline sink. In another situation, during autumn and winter, the water column is homogeneous, both caused by coastal subsidence due to increased magnitude and persistence of the southern winds, and by advection of subantarctic waters influenced by continental input of the La Plata River and Patos Lagoon.

The patterns of coastal water bodies observed in this region have very similar characteristics to those found on the Brazilian South Continental Shelf, where the most important oceanographic feature is the western limit of the Subtropical Convergence formed by the confluence of the Malvinas and Brazil currents. Subtropical Convergence migrates seasonally, strongly influencing the distribution of water masses and circulation on the Continental Shelf. During winter, the region is dominated by Coastal Water Subantarctic influenced, with temperatures varing between 4 and 15 °C and salinity ranging between 33.7 and 34.15. It moves to the north due to the action of coastal currents. During summer, it is dominated by the Coastal Water influenced by the Tropical Water which is transported to the south by the Brazil Current (Castro & Miranda Filho, 1998). The penetration of a cold and less saline water through the southern coast of Brazil often occurs on the Southeastern Brazilian Continental Shelf during winter. Campos et al. (1996) found an incursion of water up to 24° S during winter of 1993.

Figure 1 shows the map of the study area and locations of sampling hydrodynamic and meteorological parameters.

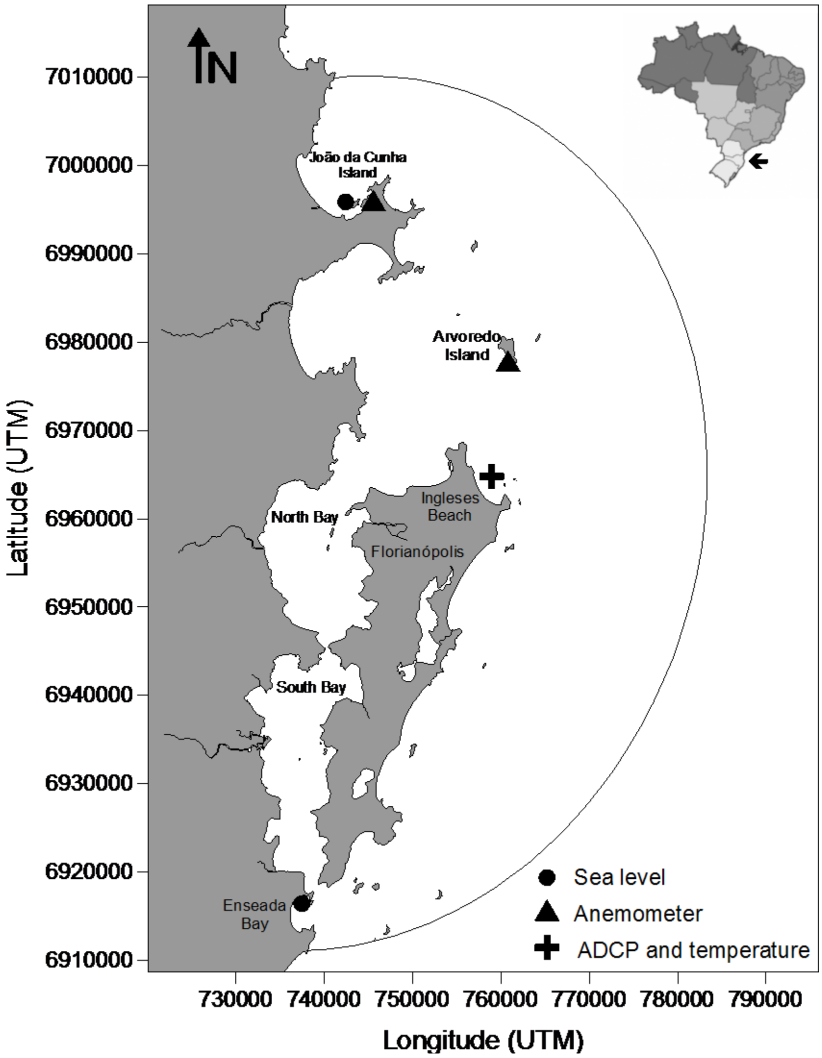

Figure 1: Study area and location of the meteorological and oceanographic stations. The full line delimits the boundary of the hydrodynamic model.

Meteo-oceanographic information

In order to support studies for the best location of diffusers, time series of wind speed and direction, acoustic current profiles, water levels and temperature profiles were acquired during 31 consecutive days. Time series of speed and wind direction were obtained from a Davis meteorological station, installed 10 meters high on João da Cunha (Figure 1), simultaneouusly to the hydrodynamic parameters, from 03/22 to 04/22/2007. It was also used information of wind speed and direction from the meteorological station of Arvoredo Island operated by the Company for Agricultural Research and Rural Extension of Santa Catarina (EPAGRI).

In order to gather current velocity and direction along the water column it was used an acoustic doppler profiler (ADP SONTEK 250MHz). The equipment was installed about 1,700m far from the beach, 15 meters deep (Figure 1). The along water column data were collected every meter and stored at 20 minutes. At the same place, 2 meters spaced along the water column, there were installed Onset Stowaway Tidbit temperature sensors.

Water level information was obtained in two different places: in the south at the Pinheira cove using a pressure tide gauge XL-205, and in the north at the pier of João da Cunha Island with a tide gauge Orphimedes from OTT Hidrometrie. The tide gauges were positioned strategically at these locations because they represent the southern and northern boundaries of the finite element grid of the numerical model.

The total spectrum of current signals measured showed a markedly predominant semidiurnal tide. A second peak, worse defined, characterized the subinercial frequency associated with the passage of cold fronts over the region. Thus, it is assumed that the period of 31 days is enough to hydrodynamically characterize the region of influence of mixing zone.

NEAR FIELD MODELLING

The theoretical reference of this work consists on the set of equations used in the NRFIELD model (ROBERTS, 1999). The model incorporates as input features of the environment, such as time series of current speed and direction on available depths and profiles of water density, the characteristics of the diffuser (Table 2) and effluent (effluent density: 998 kg/m^3) . From this information, it calculates, among others, the following parameters of the plume: initial dilution (*S*), height in relation to the diffuser of the top of the plume (*Ze*) and thickness of the plume (*He*). The Froude number Densimetric (*F*) is also provided by the model.

Table 2: Characteristics of the Ingleses outfall diffuser used to model the near field.

Diffuser depth	15 m
Number of ports	10
Port spacing	10 m
Port diameter	3”
Diffuser orientation	90°

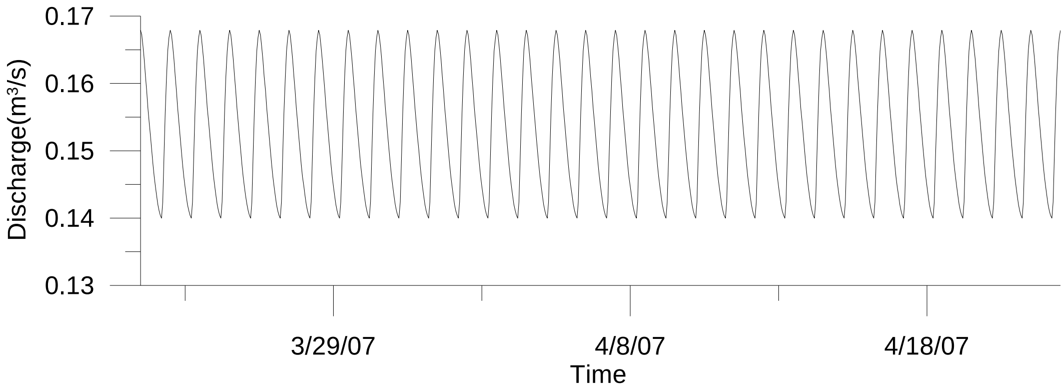

Figure 2: Hourly discharge estimated for the SOS-Ingleses during the simulation period. The average discharge is 0.154 m^3/s with a 20% increase during high demand compared to the low demand peak time.

The time series of current profiles and density of seawater (inferred from temperature profiles) obtained at the Submarine Outfall System of Ingleses (SOS-Ingleses) diffusers location, from March, 22nd to April, 22nd, 2007, were introduced into the model to reproduce the oceanographic environment characteristics. Levels above and below the limits of sampling, have been assumed no vertical variation of the properties, repeating the current and density values of these limits to the surface or to the seabed.

The NRFIELD model results were series of the parameters mentioned above. The information is presented in Cartesian graphical form and reduced statistically to allow descriptive analysis relating the plume dilution, when necessary, with oceanographic episodes, or even significant variation in discharge.

The diffuser was designed to maximize initial dilution and thus achieve sufficient dilution in order to fulfill legal requirements for inorganic parameters in the near field most of time. The diffuser is located 15 meters deep, 40 meters long, five pairs of ports, each port three-inch diameter, 10 meters distant from each other. This information is summarized in Table 2.

It was produced time series of synthetic discharge from SOS-Ingleses, 0.154 m^3/s average (Figure 2). Peak times happens around 11:00 am, when the average discharges are supposed to be 20% higher than the times of lower demand, which occurs at about 5:00 am.

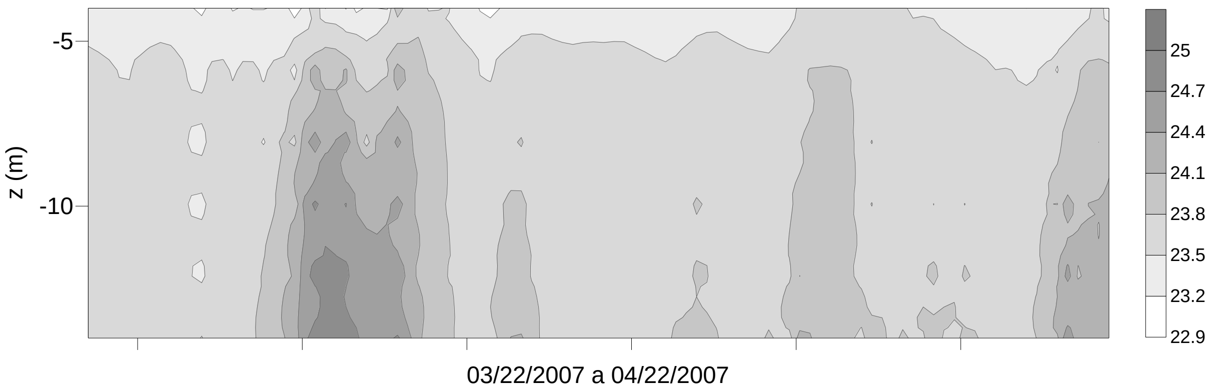

Figure 3: Evolution of water column density stratification at the SOS-Ingleses diffuser location in the period between 03/22/2007 and 04/22/2007. Notice periods in which a denser water rises pushing the thermocline close to the surface.

The hourly time series of vertical profiles of sea water density were infered from the temperature information obtained with thermistors placed along the water column. It was assumed a constant salinity of 35.00 PSU.

Figure 3 shows the temporal evolution of the density structure along the water column. Notice that the water column remains homogeneous most of the time, however, in some periods, the thermocline is pushed upward stratifying the water column. This pattern is common during summer when the winds from the north and northeast are more constant and persistent (CARVALHO et al., 1998) promoting the advection of surface waters off the coast. To ensure continuity, the bottom waters arise along the coast. If the water colum was deeper, possibly events stratified water column would be more constant.

Table 3: Summary of modeling plume parameters of SOS-Ingleses near field.

SOS-Ingleses	
Submerged wastefield	
Frequency of time (%)	16.9
Average elevation (m)	9.6
Minimum diluition	75.4
Mean dilution	125.7
Maximum dilution	242.9
Surfacing wastefield	
Frequency of time (%)	83.1
Minimum diluition	106.8
Mean dilution	158.0
Maximum dilution	319.3
Mean near field length (m)	35.2
Maximum near Field length (m)	126.7

The Figure 4a), 4c), 4e) and 4g) show the time series of the SOS-Ingleses near field modeled plume parameters from March to April 2007. Table 3 summarizes the estimated information. The maximum initial dilution (319) during the period occurred when the water column was homogeneous, but with strong currents reaching nearly 0.3 m/s, which produced a densimetric Froude number of 23.06. This is a very common situation during flood or ebb tides, close to the peak velocity. Notice that the frequencies of astronomical tide flow are quite stable at the proposed site for the diffuser, because it is a bay entrance, where the astronomical tide predominantly runs the flow.

In the situation of low or high tide, when the flow is very slow, with homogeneous water column, the minimum initial dilution rate was 107. In this case, the densimetric Froude number was around 0.01, indicating the dominance of buoyancy forces. In a situation of stratified water column, it has just reached the level 76. However, the average initial dilution of submerged plumes was 126.

Histograms of the modeled plume parameters for the summer are shown in Figures 4b), 4d), 4f) and 4h). The minimum dilution presented two main modes, one between 100 and 120 and another between 180 and 200. This reflects the patterns of homogeneous and stratified water column with and without currents. The plume thickness at the end of the near field, had two modes, the higer one centered between 13 and 14 meters and the second, less important, between 8 and 9 meters. Similarly, the top of the plume was located mostly between 14 and 15 meters from the bottom and between 9 and 10 meters when submerged. These modes are also reflecting the stratification pattern found. When the water is homogeneous, the plume extends throughout the water column. Stratification tends to keep plumes confined below the thermocline. The densimetric Froude number was below 0.1 in about 18% of the time. This reflects the situation of homogeneous water column during the moments of low or high tide when the dilution is dominated by the buoyancy forces. The sharp tail of this distribution shows that Froude numbers are more common due to the strong ebb and flood currents. The length of the mixing zone varied between zero and 127 meters, 35 meters average.

On the concentration of inorganic contaminants inside near field

The domestic sewage treatment followed by ocean disposal may not satisfactorily fit the effluent to the legal standards for coliform bacteria within the mixing zone. It is desired to promote in this region the maximum possible efficiency in the dilution of organic contaminants, but still need the dilution what happens on the far field. The environmental quality standards are achieved often miles away from the diffusers. It is a public health issue to avoid the proliferation of waterborne diseases.

There is another worry, however, on the eutrophication of receiving environments. For these cases, CONAMA Resolution 357/2005 established discharge standards that must be, as better as possible, satisfactorily met inside the mixing zone area.

Table 4 presents the geometric mean concentrations of inorganic contaminants quantified before to enter treatment plants operated by CASAN in Florianopolis, so in raw sewage. Are also presented, the concentration values expected by the end of the mixing zone, i.e., 35 meters away from the diffuser, considering an average dilution of 158, calculated for the period of modeling the near field as shown in Table 3.

Table 4: Geometric mean concentrations of inorganic contaminants in the raw sewage at treatment plants operated by CASAN in Florianopolis and the concentration values expected by the end of the mixing zone.

	Geometric Mean	Concentration expected at the end of the mixing zone
Nitrate (mg/l)	16.20	0.1035
Nitrite (mg/l)	0.20	0.0013
Total ammonia nitrogen (mg/l)	30.72	0.1944
Total phosphorus (mg/l)	14.75	0.0934

Notice that the emissions of nitrate, nitrite and total ammonia nitrogen were, on average, already adequated to the Resolution 357/2005 to Class 1. The total phosphorus, on average, would be fitted only to Class 2 of marine waters. Other diffuser configurations could easily provide dilution of total phosphorus for Class 1 if necessary. Whereas the location of the diffuser is sufficiently distant from the places most probably to have the primary contact, the emission standards in the desirable location must meet at least the marine waters of Class 2, since only activities of recreational fishing and water sports can possibly happen close to the mixing zone. The concentrations presented here refer to the release of raw sewage into the marine environment. It was not considered, therefore, the decrease in concentration the treatment plant could be producing. Therefore, the outfall and its diffusers is able to produce the necessary dilution to satisfactorily meet the quality standards established by CONAMA Resolution 357/2005 already inside the mixing zone.

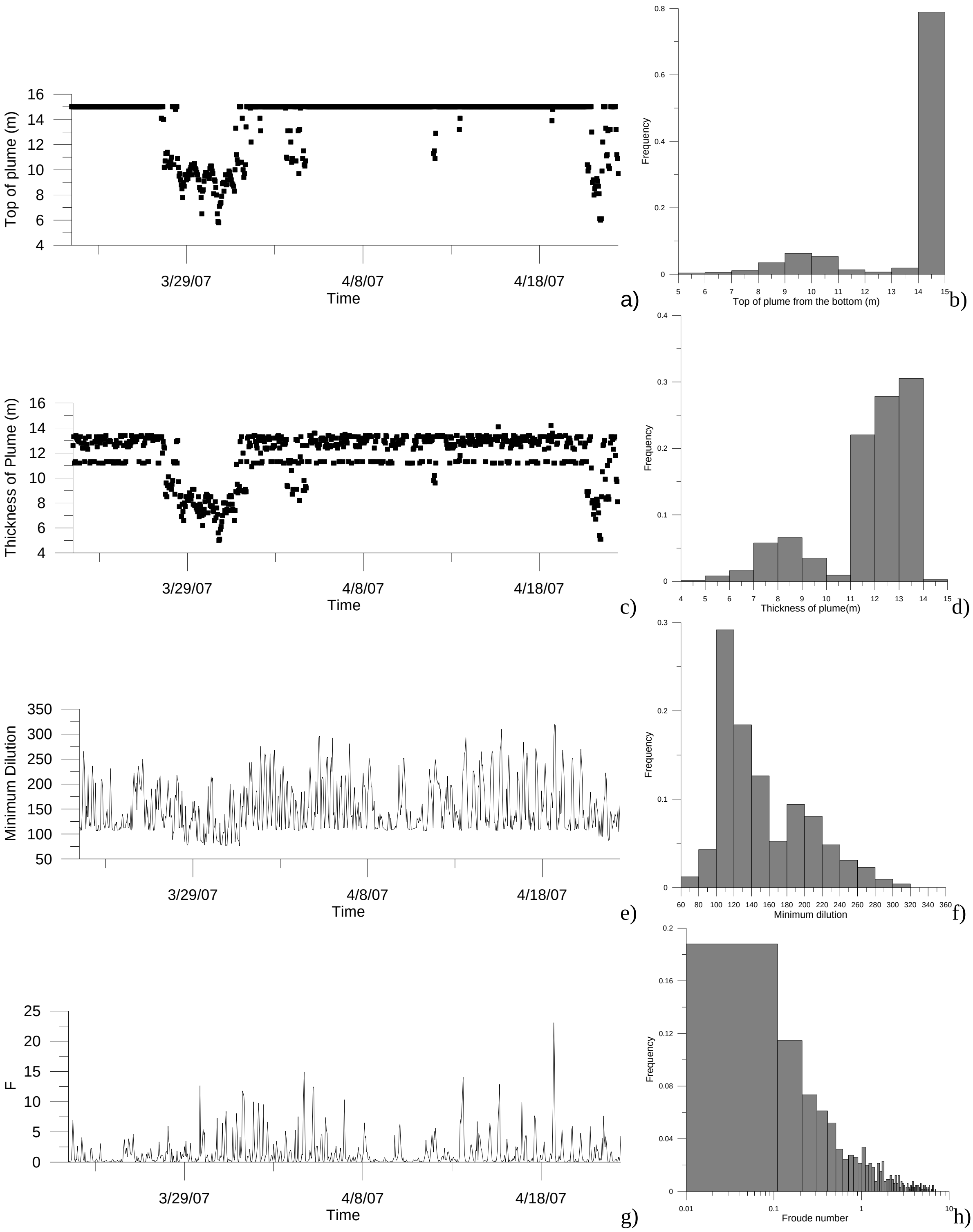

Figure 4: a) and b) Distance from the top of the plume against the background (time series and histogram); c) and d) thickness of the plume; e) and f) minimum dilution; g) and h) Densimetric Froud Number estimated for the SOS-Ingleses by NRFIELD for the period simulated. The initial maximum dilution occurs during the period when the water column is homogeneous and the plume emerges. The minimum value occurs when the water column is well stratified, causing entrapment of the plume at half depth.

FAR FIELD MODELLING

The protection to the primary contact is the main purpose when designing an ocean disposal system of domestic sewage. It should, in theory, meet the standards required by legislation to ensure the desired security. It is necessary to predict, based on physical characteristics of the diffuser, discharge and receiving water body, the dimensions of the plume. This plume whose minimum concentration in the bathing area can be defined as the maximum permissible by law considered safe for primary contact.

The initial dilution phase completed, the environmental turbulence causes the stabilished sewage field to suffer diffusion as it is advected by ocean currents. This makes the concentration of bacteria in the field lower. The velocity field, that will promote the advection and dispersion of the plume, can be estimated over a spatial domain and throughout time, if the initial and boundary conditions needed to solve the differential equations system governing the movement are known. For each point of the domain, at any time step, the hydrodynamic model estimates the components of vector velocity and elevation of the sea surface. These information estimated by the hydrodynamic model must then be validated. To do so, they are compared with field measurements made within the area. The boundary conditions must also be known from field information.

The way the plume is advected and the dispersion caused by turbulence is estimated by the model lagrangian advective-diffusive transport which uses the current field estimated by the hydrodynamic model. The decrease in the concentration on the bacteria plume is also due to mortality the population suffers when it reaches the aggressive marine environment. The estimative of that mortality is accomplished by the implementation of a "peripheral model" of bacterial decay which is coupled to the Lagrangian transport model. The bacterial decay model makes use of other peripheral models that estimate, for example, the amount of light that penetrates the water column or how the bacteria respond, as population mortality, to physical and chemical agents.

Therefore, the modeling of plumes is a complex and laborious task as it requires the interaction of various models and *in situ* measurements. All models are, in theory, very consistent in terms of physical and biological. However, there are several levels of uncertainty due to the little knowledge available for one or another process. Field studies for the validation of transport models could significantly decrease the uncertainty level of these models.

The hydrodynamic model

To perform the hydrodinamic simulations and scalar transport the SisBaHiA® software was utilized. It is the result of a joint development between the Coastal & Oceanographic Engineering Area of the Oceanic Engineering Program and the Database Area of the Systems Engineering & Computer Science Program, both from the Department of Graduate Programs in Engineering (COPPE), Federal University of Rio de Janeiro (UFRJ), under the auspices of the Coppetec Foundation.

The model generates current fields in free surface shallow waters bodies, whose density gradients are not relevant. It enables working with vertically averaged current velocity (2DH module) and/or know the vertical tridimensional current profile (3D module) influenced by the tension of friction on the surface and bottom.

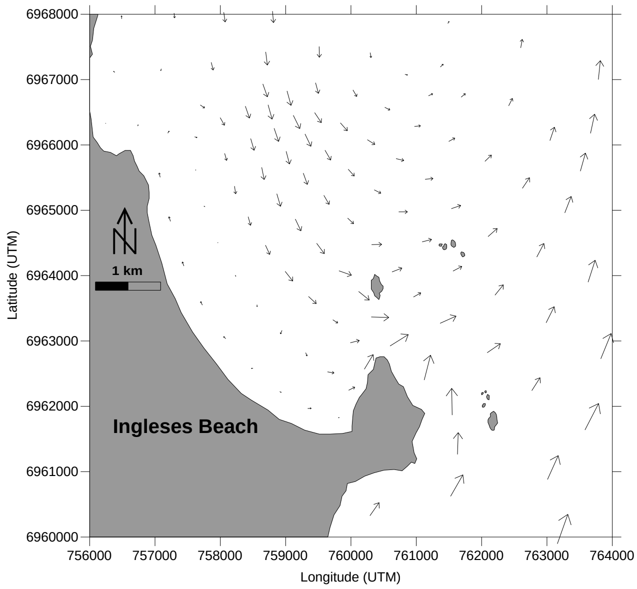

Figure 5: Details of the hydrodynamic residual flow obtained after 30 consecutive days of simulation in the region of the Ingleses Cove.

Information on variation of water level, velocity and direction of winds and currents gathered in the field were used in the implementation of hydrodynamic model. After verifying the consistency of these informations, the values of velocity and direction of currents were absorbed into the hydrodynamic model, aiming to influence the simulated currents in the region surrounding the area of the outfall diffuser.

The typical condition for the land’s contours is the prescription of the flow component normal to the boundary at all it’s points, representing the edges of the water body studied and possible points of influx or outflux, such as rivers or estuaries. Specifically for this study, it was imposed flow or a null nodal velocity on this border, in order to consider the coastline impermeable.

The opened boundaries, however, are not a physical barrier, representing the modeled water dominium. The conditions of influx along this border were determined in order to provide guidelines for the hydrodynamic flow parallel to isobaths and, in this case, the coast line, aiming to represent actual conditions of streams in this area.

The initial conditions, provided for the modeling of hydrodynamic circulation of the study area, were velocities vector in X and Y and zero free surface elevation corresponding to the initial instant of sea level, equal to 0.48 m.

Estimation of the bacteria concentration in raw sewage.

One of the most important information in plume modeling for submarine outfalls is the concentration of fecal coliforms, *Escherichia coli* and enterococci enterococci in treated wastewater effluent. Such information varies by several orders of magnitude and can significantly influence the size of the plume in the far field. Usually, one uses a concentration of *Escherichia coli* by the order of 10^8NPM/100 ml. Figure 6 shows the distribution of concentration of *Escherichia coli* in the treatment plants operated by CASAN in Florianopolis. In fact, the geometric mean concentrations of this bacteria is about the order of magnitude usually adopted as the standard. However, notice that it varied from 10^4 to 10^{11} NPM/100ml. This variability may be due to physical, physical-chemical and biological dynamics inherent to the bacteria population in raw sewage, but can also be attributed to the variability of the quantification method.

Adopting extreme scenarios using the maximum concentration greather than 10^{11} NPM/100ml as input information to the transport model and evaluate the plume extent under maximum organisms survival conditions in the marine environment could be a good approach to evaluate the plume impact magnitude. However, this would be a minor event with low probability of occurrence. It would be more significant, somehow, to use the information of input concentration on the model, but giving to each event a respective probability of occurrence. That is, using a probability density function to equalize this information in the model. Thus, extreme events would be considered in the model but with less importance than the central events of the distribution. Aiming to actualize the procedure, a statistical analysis of the concentration of *Escherichia coli* in raw sewage (Figure 6) from information provided by CASAN was proceded. A Weibull probability density function was fitted to the logarithm of concentrations to allow later reconstruction of random numbers that follow this distribution. The random numbers would generate series of artificial *Escherichia coli* in the raw sewage that meet the parameters and best fit the probability distribution in order to best fit of the measured data. Although this procedure, does not reproduces the real concentration, allows to incorporate the statistical variability of this random variable in the probabilistic model of the plume.

Since no information is available, the distributions of fecal coliform and enterococci concentration were assumed to be similar to *Escherichia coli* multiplied by a scaling factor defined as the ratio between the limits of bathing for each group of organisms required by CONAMA 357/2005.

Modeling Bacterial Decay on Ingleses Submarine Outfall plumes

The distribution and quantity of intestinal origined bacteria, wich is used as an indicator of potential fecal contamination in the marine environment, depends on advection and dispersion, caused by the action of ocean currents, physic-chemical and biological processes that result in the decrease or increase of their populations.

In numerical modeling studies of bacteria transport, the parameter wich usually represents population decay is T_{90}, the period of time during which the bacteria population is reduced by 90% of the original amount. This is a parameter usually measured *in situ* in studies of dispersion of outfall plumes. These studies, however, are generally made during sunlight, at times with intense solar radiation, and water samples collected close to the surface (BRAVO & VINCENT, 1992). Due to the mechanism of photo-decay, the values of T_{90} adopted, often in a conservative way, to the models of transport are very small resulting on a very strong decay throughout the day.

At coastal tourist cities, the practice of bathing, underwater fishing and contemplative diving at night are very common, especially during the summer. Therefore, studies of disposal of domestic sewage through outfalls must ensure balneability to the beaches and diving points also during such periods. To do so, it is necessary to understand the kinetics of pathogenic microorganisms decay in order to make the transport model more realistic.

The bacterial decay model

Carvalho et al. (2004) Introduced the bacterial decay model which was an adaptation of CHAMBERLIM and MITCHELL (1978) and MANCINI (1978) models to include the geometric characteristic of ocean outfall plumes, wich are estimated from the near-field model.

$$\bar{k}_{Ze,He,S,T,I} = \left[0{,}8 + 0{,}006(\%seawater)\right] \times 1{,}07^{T-20} + \frac{k_t I_{Ze}}{He\alpha_p} e^{Ze(\alpha-\alpha_p)}\left(1 - e^{-\alpha_p He}\right) \quad 1$$

$\bar{k}$ = average rate of bacterial decay within the plume (m^{-1}).

Ze = depth of the plume (m);

He = thickness of the plume (m);

α = vertical attenuation coefficient of light in sea water (m^{-1});

α_p = Coefficient of vertical attenuation of light within the plume (m^{-1});

k_t = proportionality coefficient which measures the sensitivity of a specific body (cm^2/cal);

T = temperature of seawater;

$I_{Ze} = I_0 e^{-\alpha Ze}$ = light intensity at the top of the plume (cal/(cm^2.hora)).

I_0 = descending light intensity on the surface of water (cal/(cm^2.hora));

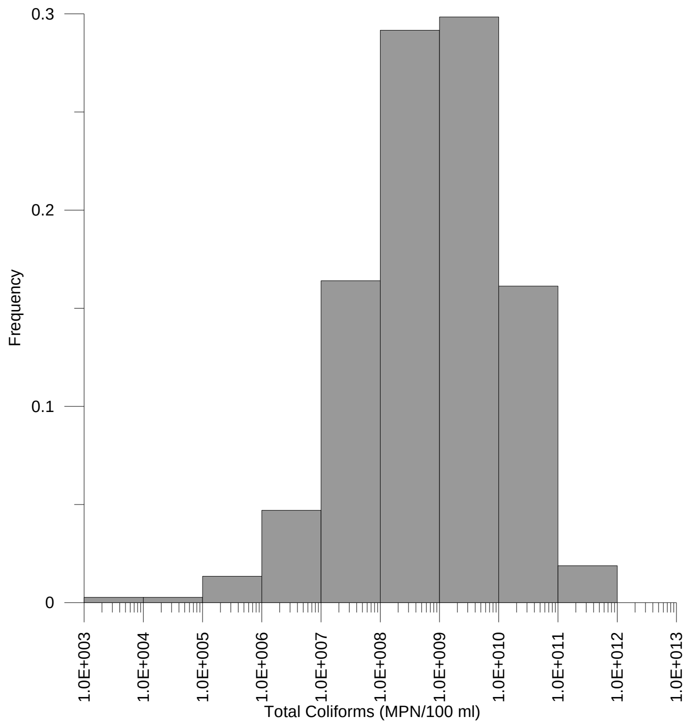

Figure 6: Histogram of the concentration of *Escherichia coli* obtained at treatment plants of CASAN in Florianopolis (n = 160). The geometric mean is around 10^8 NPM/100ml although there is a variation up to 10 orders of magnitude.

In this equation, effects of temperature, salinity and light are coupled to infer the bacterial dieoff. The salinity and water temperature can also be averaged over the vertical plume dimension or, knowing the nature of the Gaussian concentration within the plume, interpolated to the depths of maximum concentration provided by the near-field model.

The following equation relates the T_{90} to bacterial decay coefficient, $\bar{k}$.

$$T_{90} = \frac{2.3}{\bar{k}} \qquad (2)$$

The main objective of the advective-diffusive transport models is to evaluate the possibility of direct or indirect contact of humans with the sewage plume. Therefore, to calculate the bacterial decay, as proposed by Equation (1), it was opted to consider homogeneous water column, allowing the plume to reach the surface with an average thickness of 14 meters.

It was adopted constant values of temperature and salinity, typical for the north central coast of Santa Catarina during summer and winter as well as presented by Carvalho et al. (1998).

Because of the impossibility to know the vertical light extinction coefficient for all daylight hours of the modeled months, a statistical histogram of Secchi depth at the Ingleses Cove was attempted. A probability density function was fitted to the Secchi depths histogram (Figure 7) to allow later reconstruction of random numbers series that follow this distribution. In this case, although featuring a few local measurements, the Weibull distribution is best fit to the Secchi depth data. This procedure, although not reproducing the actual Secchi depth, allows to incorporate the statistical variability of this random variable in the T_{90} series.

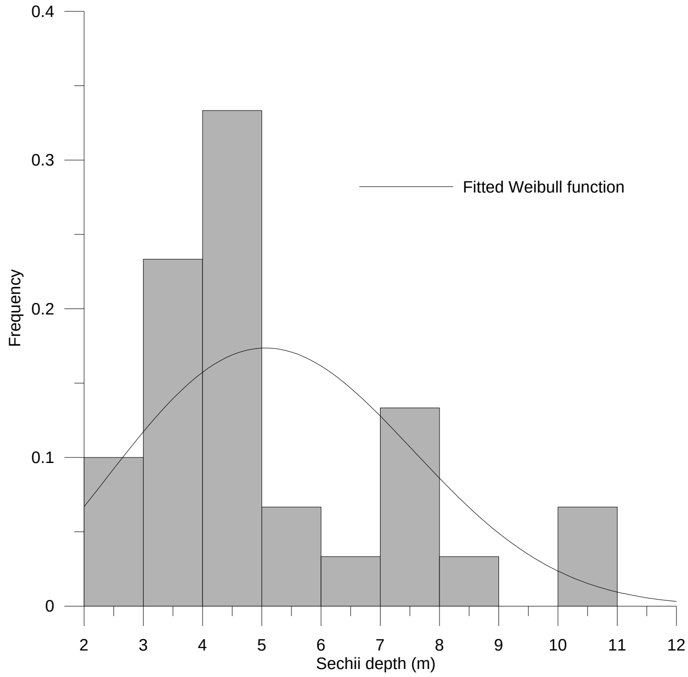

Figure 7: Histogram of Secchi depths in the Ingleses cove obtained during the environmental studies. It varied from 2 to 11 meters in the period with a peak between 4 and 5 meters. A Weibul type probability density function was fitted to the histogram for generating random numbers that follow this distribution.

The coefficient of light extinction is calculated by:

$$\alpha = \frac{1.9}{Z_s} \tag{3}$$

where Z_s is the Secchi depth. The extinction of light in seawater varied significantly in the region of the Ingleses cove, as shown in Figure 7. It was found Secchi depth values ranging from 2 to 11 meters, 4 to 5 meters mode and 5 meters average. It was assumed that the coefficient of vertical light attenuation within the plume is equal to the environment ($\alpha_p = \alpha$).

The information of hoursly solar radiation incident on the water surface was kindly supplied by the National Institute of Meteorology (INMET) at Florianópolis, which maintains a wheather station on the island. Figures 8a) and 8b) show that information for the period January and July, 2007. Notice the incident radiation during summer is about two times higher than during winter. It is also possible to observe the effect of variation of the radiation from one day to another, because, presumably, cloud covering.

Figures 9a) and 9b) show the decay of coliform groups calculated from Equation 1 for the summer and winter of 2007. It was used the sensitivity coefficient, representative of each group (= 0.150 for fecal coliform cm^2/cal, 0.355 cm^2/cal for *Escherichia coli* (not shown) and 0.091 cm^2/cal for enterococci (not shown). The information is presented as time series of T_{90}.

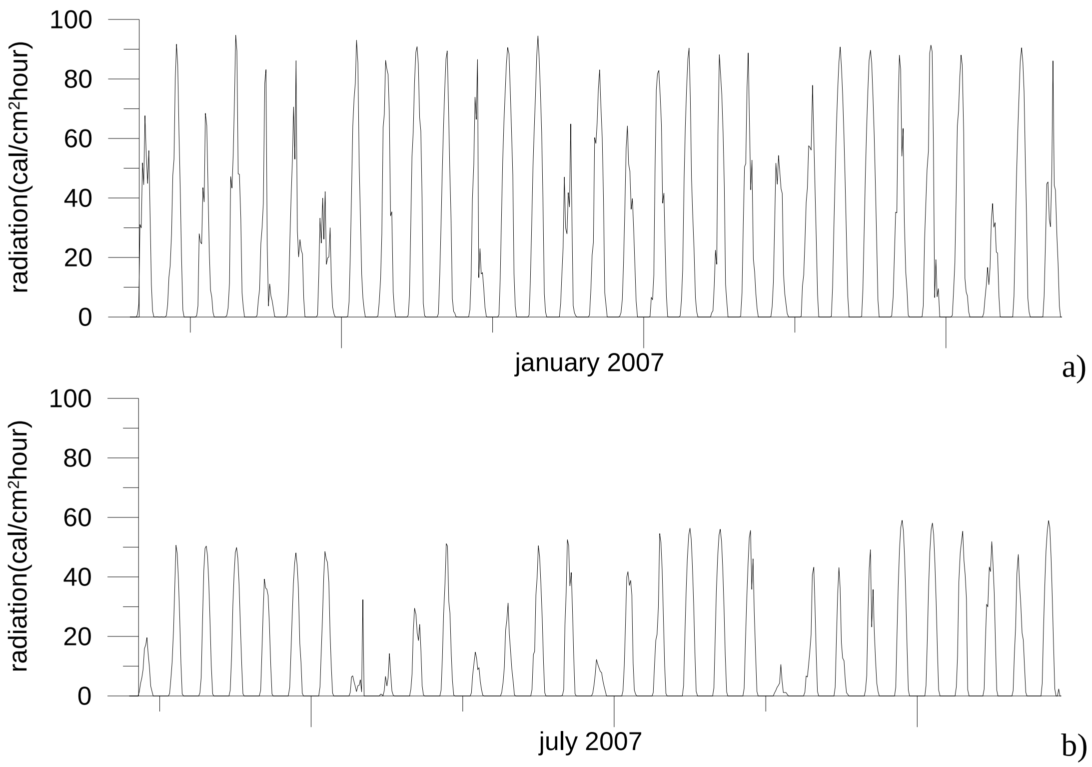

Figure 8: Solar radiation in Florianopolis during the months of a) January and b) July, 2007. Notice that the radiation during summer is approximately two times higher than during the winter. Data kindly provided by EPAGRI.

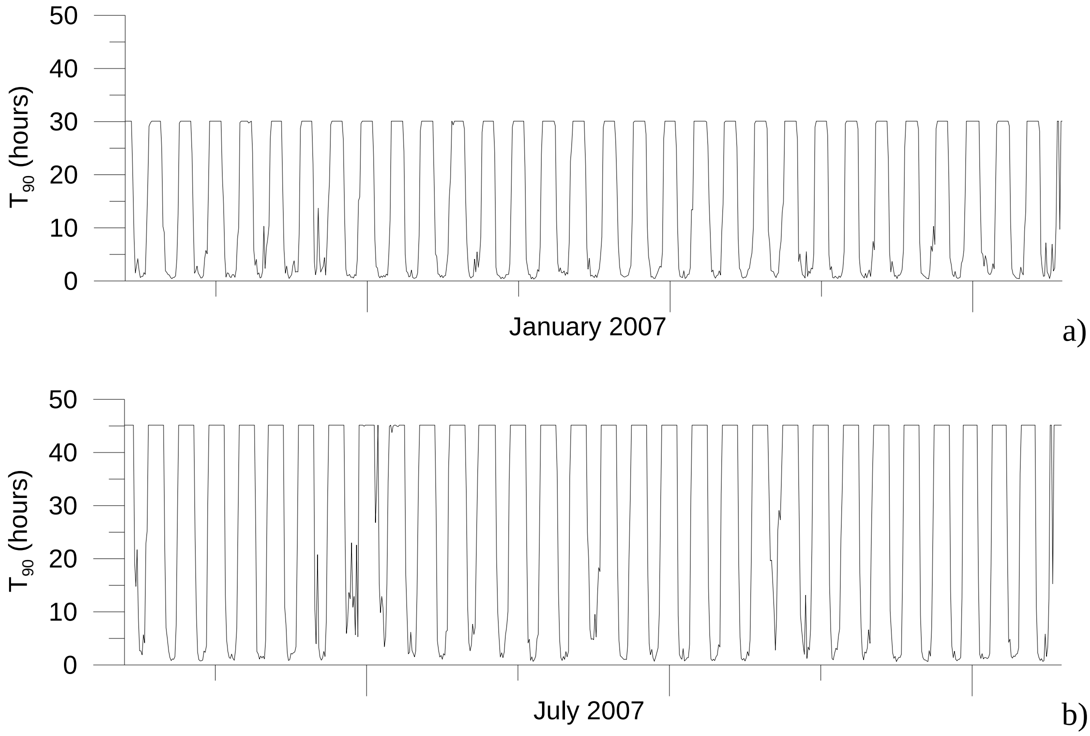

Figure 9: T_{90} for the faecal coliforms group within the SOS-Ingleses during a) summer and b) winter, 2007. It was estimated from information of salinity (S = 35 PSU); the average temperature of the water column (24^{o}C) and (18^{o}C), respectively; solar radiation measured at the weather station of INMET in Florianopolis; top of the plume close to the surface and plume 14 meters thick.

In winter (Figure 9b), the T_{90} during night reached 45 hours due to lower water temperatures encountered in this season. In diurnal periods, the T_{90} were significantly higher than in summer leading to a lower bacterial decay. In summer (Figure 9a), the T90 during the nighttime is lower compared to the winter due to higher average water temperature. The significant value for this period was 31 hours. During the day, the situation is reversed. In the summer found the lowest values of T_{90} for all organisms due to the effect of luminosity.

Plume Modeling of Bacteria

The process of modeling the bacteria plume was done considering typical situations of winter and summer. Spatial distribution of faecal coliforms plume, *Escherichia coli* and enterococci are presented, with their respective concentration limits in accordance to CONAMA 357/2005. Although the three organism groups have been modeled, results showed that the more conservative, better for safety, was the feacal coliforms. Thus, it will present here only the results of this group of organisms.

The first scenario considered in this study was the first option proposed by CASAN for the location of the diffuser, 1800 meters from the beach, within the Ingleses cove. At figures 10a) and 10b), the contour curves represent the exceedande frequencygreather than 20%, according to the limits established by CONAMA Resolution 357/2005, for fecal coliform in the saline water class 1 during summer and winter conditions, respectively. Additionally, these figures show the limit of exceedance of 1% (black line) for a concentration of 2,500 NPM/100ml for instantaneous touch. Notice that this limit reaches the beach during winter and remains very close to the beach during summer.

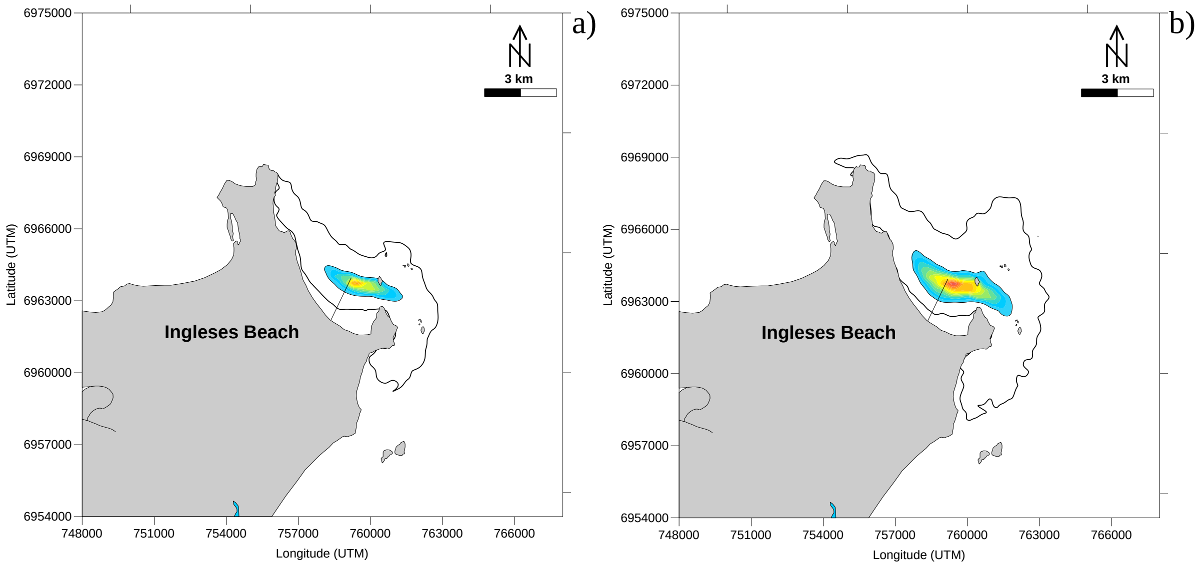

Figure 10: Scene 1 in the typical situation of a) summer and b) winter. Exceedande frequencyover 20% of the limits established by CONAMA Resolution 357/2005 for Fecal Coliforms. The color contour shows the probanilistic plume for Saline Waters Class 1 (1000 NPM/100ml).

Additionally, the Mata-Fome island would remains inside the probabilistic plume domain for a 20% exceedance of 1,000 NPM/100ml, difficulting the primary and secondary contact. As the island receives fishermen and divers, especially during the summer, it was desirable to find a new place for diffusers maintaining the balneability characteristics of oceanic islands.

Given the need to find an alternative position for the diffusers, it was elaborated the second scenario. A new position was proposed for the diffusers, following the same alignment of the previous one, but 3,300 meters long. The choice of this alternative launching point followed the assumptions: 1) It should be located in a place where the currents were relatively intense to allow the increase of initial dilution, 2) These currents should ensure residual advection out of the North Bay in order to avoid accumulation of contaminants inside. 3) It should ensure balneability facilities for the surrounding oceanic islands to allow the activity of scuba diving.

Figure 5 shows the residual current within the Ingleses cove. Notice that close to the Mata-Fome island, the currents turn from SSE to NE in a counterclockwise direction. Being the diffuser inside the current, there was a residual tendency to move the plume far from the coast.

Moving the diffuser far away from the beach, the Moleques do Norte islands could be inside the probabilistic plume. Several arrangements of the diffuser position were then tested to ensure that these islands remain classified as Class 1.

At Figures 11a) and 11b it is noticed that the probability plumes flows between Mata-Fome Moleques do Norte islands ensuring classification at least as good as class 1. The black lines show that the beaches are never touched by the plume of SOS-Ingleses. During summer, when the risk of primary contact during the night could be higher, the limit of the maximum excursion of the plumes is still far away from the beach.

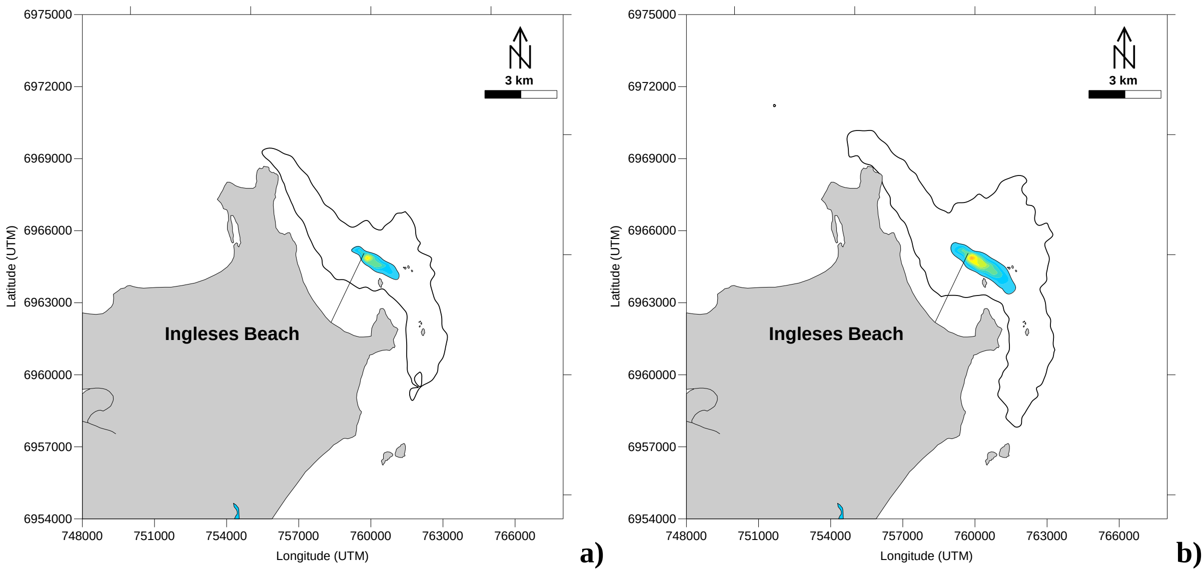

Figure 11: Scene 2 in the typical situation of a) summer and b) winter. Exceedande frequencyover 20% of the limits established by CONAMA Resolution 357/2005 for Fecal Coliforms. The colored contour shows the probabilistic plume for Saline Waters Class 1 (1000 NPM/100ml).

CONCLUSIONS

A proposal to construct an outfall in Praia dos Ingleses was presented. Based on extensive *in situ* measurements of oceanographic parameters, on consistent information about the concentration of fecal coliforms and nutrients in raw sewage, and adopting a bacterial decay model coupled to the transport and hydrodynamic model, it was possible to make a robust evaluation of the mixing zone domain and advection of the plume. Thus, it was possible to determine the best location for diffusers to meet the standards of environmental quality that Brazilian law requires.

The model results showed on maps the locations where the exceedance frequency was 20% higher than the limits established in Resolution 357/2005 for faecal coliform, enterococci and *Escherichia coli*. The line of maximum excursion of the plume with concentrations greater than or equal to the maximum limit established in the same resolution for fecal coliforms were also presented.

All simulations were performed for non-treated sewage concentrations of bacteria in order to show the plume for the cases in which control systems were not in operation. Therefore, the outfall would be designed with higher safety.

Two scenarios were modeled, one with the diffuser at 1,800 and the other at 3,300 meters from the beach. In order to ensure the greatest possible safety for users of the beaches, ocean and surrounding islands and promontories, the SOS-Ingleses diffusers, in the position located according to the second scenario modeled, fully satisfies the objectives, eliminating the risks of contamination by microorganisms that produce waterborne diseases.

The project has now entered a new phase. The environmental agency has requested further hydrodynamic studies. One year oceanographic measurement campaign of current profiles, temperature and salinity could be done. A three-dimensional hydrodynamic model and a mesh with more comprehensive will be elaborated to better represent the flow.

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