Methodology to elaborate the bathing water profile in urban beaches, according to the requirements of the European Directive 2006/7/EC: the case of Santander beaches (Spain).

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Abstract.

The approval of the current Bathing Water Directive (Directive 2006/7/EC) involves a set of changes regarding to its predecessor. One of the most important is the necessity to elaborate the bathing water profile. The final goals of the profile are to know all the processes that determine bacteriological concentrations in the aquatic environment, to obtain relationships between the cause of pollution and its effects, to evaluate the fulfilment of the Directive, both in terms of quality and pollution risk and, finally, to set the Quality Monitoring and Assessment Program, according to the bacteriological characteristics of the bathing water. In urban beaches, bacteriological pollution problems depend, in most of cases, on the sanitation systems behaviour. Due to the novelty in the bathing water profile concept, the methodologies found in the bibliography that try to solve this issue are scarce. This paper introduces a methodology to elaborate the bathing water profile, and their application in several bathing waters located in Santander municipality (North Spain). The methodology involves the characterisation of effluents under different hydrometeorological conditions, the characterisation of advection, diffusion and reaction processes of bacteriological organisms in bathing water and the selection of a criteria to evaluate: i) the risk to exceed the bacteriological concentrations established in the Directive 2006/7/EC and ii) the risk to impair the classification criteria under the requirements of such directive. In the elaboration of the bathing water profile has been considered the normal behaviour of the sanitation system, which involves discharges through the submarine outfall and through the combined sewer overflows (CSO's), and those produced under the failure of the sanitation system, among others. Furthermore, the elaboration of the profile allows to design the most appropriate Quality Monitoring and Assessment Program, according to the bacteriological characteristics of the bathing water considering, on the one hand, the new quality requirements established in the assessment method of the Directive 2006/7/EC and, on the other, the limitations and uncertainties detected in such method.

Keywords.

Directive 2006/7/EC; bathing water profile; risk assessment; pollution processes; monitoring programs.

INTRODUCTION

The Directive 76/160/EEC was the first legislative approach establishing quality criteria to be fulfilled by European bathing waters. It has improved bathing water quality, through the implementation of different Quality Monitoring and Assessment Programs. However, the technical and social advances that have taken place during the last decades have forced authorities to review this approach in order to improve bathing water quality and public health protection in member states.

These goals are set in the new Bathing Water Directive (Directive 2006/7/EC) and should be achieved through the elaboration of a "bathing water profile", a task that should be carried out by the authorities responsible of the bathing waters management. The definition of the bathing water profile must respond to: i) "the identification and assessment of causes of pollution that might affect bathing waters and impair bathers' health", and ii) "if such assessment shows that there is a risk of short-term pollution, the following information: the anticipated nature, frequency and duration of expected short-term pollution, the details of any remaining causes of pollution and the management measures taken during short-term pollution events" (EEC, 2006).

In urban beaches, bacteriological pollution is highly related to the wastewater discharges produced through the sanitation system. Although the implementation of these systems has resulted in an improvement in bacteriological quality (García-Barcina *et al.*, 2006), there are cases in which it has not been enough to comply with the quality standards established in the legislation (Obiri-Danso & Jones, 1999; Orozco-Borbón *et al.*, 2006). In fact, most of methodologies are unable to identify the way in which discharges are disposed into the aquatic environment and their influence on the bacteriological quality of aquatic environment.

Waste water is poured into the aquatic environment via several routes: discharges produced under normal operation of the sanitation system (Comino *et al.*, 2008), which include storm overflows (Ackerman & Weisberg, 2003; Lipp *et al.*, 2001), uncontrolled discharges or failures in the system. The effect of these discharges has been, in general, overlooked in bathing water management policies, and this has hampered the adequate elaboration of the bathing water profile. As a matter of fact, the analyses of these discharges can be a key factor for the final result of the profile.

The elaboration of the profile establishes that the assessment of pollution causes should be done in terms of risk. In this sense, Risk Assessment Programs are a tool to evaluate the pollution degree in aquatic environments, their main goal being to organize and analyse data in order to assess the probability of any negative impact resulting from exposure to one or more substances (Suter II *et al.*, 2000; USEPA, 1998).

For risk assessment in bathing waters a criteria that can be commonly used throughout Europe, should be considered. Furthermore, such criteria should be representative of the usual bacteriological status of bathing waters. In addition, this bathing water profile should take into account the temporal and, especially, the spatial variability of pollution sources that can be found in bathing water areas. Therefore, for the analysis of spatial variability, the generation and mechanisms of transport of pollutants in the aquatic environment should be considered (Strobl *et al.*, 2006).

The analysis of the mechanisms involved in the fate of a specific effluent makes it necessary to provide an integral approach, in which the use of simulation models can give an appropriate answer to the different circumstances that can be found in a bathing water area.

With the considerations mentioned above, the main objective of the paper is to show the methodology that has been developed to elaborate bathing water profiles. The methodology is useful to know the causes of bacteriological pollution in bathing waters and to analyze the influence of each discharge process in global pollution levels. Consequently, it is a tool to help authorities in the process of decision making while trying to conduct an appropriate management of these areas.

METHODOLOGY

Assessment of the effluent characteristics.

The first step of the methodology is to characterise the wastewater flow in the sewers of the sanitation system. Under dry weather conditions, the flow and bacteriological concentrations can be calculated according to the local characteristics of the system and the population.

Under wet weather conditions, it is necessary to calculate the runoff generated by rainfall in the urban basins, using the following continuity (Equation 1) and momentum (Equation 2) equations, used in the Storm Water Management Model (in advance, SWMM) (Rossman, 2004):

$$\frac{dV}{dt} = A \cdot \frac{dp}{dt} = A \cdot i^* - Q \qquad \text{(Eq 1)}$$

$$Q = \frac{W}{n}\left(p - p_p\right)^{5/3} \cdot S^{1/2} \qquad \text{(Eq 2)}$$

where Q is the flow out of the basin (in m^3/s), W the basin width (in m), n the Manning coefficient, p the water depth (in m), p_p the surface retention depth (in m), S the slope (dimensionless), V the water volume of the basin (in m^3), t the time (in s), A the basin area (in m^2) and i^* the net rain intensity (in mm/h).

Assessment of the flow and concentrations of the discharged effluent.

To obtain the flow discharged through each point of the sewer system, it is necessary to integrate the Saint Venant equations for continuity (Equation 3) and momentum (Equation 4):

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \qquad \text{(Eq 3)}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial \left(Q^2 / A \right)}{\partial x} + g \cdot A \cdot \frac{\partial H}{\partial x} + g \cdot A \cdot S_f = 0 \qquad \text{(Eq 4)}$$

where A is the cross section (in m^2), Q the flow (in m^3/s), x the distance along the collector (in m), t the time (in s), g the acceleration due to gravity (in m^2/s), H the water depth (in m), z the elevation (in m) and S_f the friction slope (dimensionless).

The calculation of bacteriological concentrations in the effluent is more difficult to achieve, because accumulation, transport and discharge are processes which are difficult to characterise. Some models, however, can simplify and calculate such processes, the simplest one being the complete mixed model (Harremoes, 1990; Johansen, 1985), whose formulation is given by the Equation 5:

$$P = Q_S \cdot C_S + Q_T \cdot C_T \qquad \text{(Eq 5)}$$

where P is the pollutant flux (in mg/s), Q_S the dry weather flow (in m^3/s), C_S the dry weather pollutant concentration (in mg/l), Q_T the runoff flow (in m^3/s) and C_T the runoff pollutant concentration (in mg/l).

Hydrodynamic and transport assessment.

Tidal velocities can be calculated using of a two-dimensional hydrodynamic coastal and estuarine model since vertical velocity profiles can be assumed to be almost uniform (Dean & Dalrymple, 1991). The governing equations of continuity (Equation 6) and momentum (Equations 7, 8 and 9) are described as follows:

$$\frac{\partial \overline{U}}{\partial x}+\frac{\partial \overline{V}}{\partial y}+\frac{\partial \overline{W}}{\partial z}=0 \qquad \text{(Eq 6)}$$

$$\frac{\partial \overline{U}}{\partial t}+\overline{U}\frac{\partial \overline{U}}{\partial x}+\overline{V}\frac{\partial \overline{U}}{\partial y}+\overline{W}\frac{\partial \overline{U}}{\partial z}=-\frac{1}{\rho_o}\frac{\partial p}{\partial x}+\nu_e\left(\frac{\partial^2 \overline{U}}{\partial x^2}+\frac{\partial^2 \overline{U}}{\partial y^2}+\frac{\partial^2 \overline{U}}{\partial z^2}\right) \qquad \text{(Eq 7)}$$

$$\frac{\partial \overline{V}}{\partial t}+\overline{U}\frac{\partial \overline{V}}{\partial x}+\overline{V}\frac{\partial \overline{V}}{\partial y}+\overline{W}\frac{\partial \overline{V}}{\partial z}=-\frac{1}{\rho_o}\frac{\partial p}{\partial y}+\nu_e\left(\frac{\partial^2 \overline{V}}{\partial x^2}+\frac{\partial^2 \overline{V}}{\partial y^2}+\frac{\partial^2 \overline{V}}{\partial z^2}\right) \qquad \text{(Eq 8)}$$

$$\frac{\partial \overline{W}}{\partial t}+\overline{U}\frac{\partial \overline{W}}{\partial x}+\overline{V}\frac{\partial \overline{W}}{\partial y}+\overline{W}\frac{\partial \overline{W}}{\partial z}=-\frac{1}{\rho_o}\frac{\partial p}{\partial z}-g\frac{\rho}{\rho_o}+\nu_e\left(\frac{\partial^2 \overline{W}}{\partial x^2}+\frac{\partial^2 \overline{W}}{\partial y^2}+\frac{\partial^2 \overline{W}}{\partial z^2}\right) \qquad \text{(Eq 9)}$$

where $\overline{U}, \overline{V}$ y $\overline{W}$ are, respectively, the average velocities in x, y and z axes, p the pressure, g the acceleration due to gravity, ρ the fluid density, ρ_0 the average fluid density and ν_e the fluid viscosity.

Wind currents have a different vertical pattern than tidal velocities. The wind moves the water mainly on the surface, while near the bottom its effect is generally negligible. A quasi three-dimensional model that takes into account the different structure over the depth of horizontal velocities along the depth due to wind action was used (Koutitas, 1988).

Next, it is necessary to characterise the evolution of substance concentration in the aquatic environment, which depends on the simultaneous action of advection and dispersion processes. Furthermore, in the case of bacteriological substances, also the transformation process should be characterised.

The differential equation describing the advective-diffusion in three dimensions (Equation 10), which describes the variation of a substance concentration, in a specific point, can be written as follows (Fischer *et al.*, 1979):

$$\frac{\partial c}{\partial t}+\frac{\partial}{\partial x}(uc)+\frac{\partial}{\partial y}(vc)=\frac{\partial}{\partial x}\left(D_{tx}\cdot\frac{\partial c}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_{ty}\cdot\frac{\partial c}{\partial y}\right)+\frac{\partial}{\partial z}\left(D_{tz}\cdot\frac{\partial c}{\partial z}\right)+R(c) \qquad \text{(Eq 10)}$$

where c is the concentration of the substance, D_{tx}, D_{ty}, D_{tz} the turbulent diffusion components in x, y and z directions, and $R(c)$ the transformation (inactivation) processes.

For the inactivation and decay rates of bacteriological substances, Thomann & Mueller, (1987) and Chapra, (1997), proposed a first order decay kinetic, according to the next general equation (Equation 11).

$$\frac{dC}{dt}=-K\cdot C \qquad \text{(Eq 11)}$$

The K value, which is closely related with the T_{90} value, defined as the time during which the organisms population would reduce by 90%, should be assessed specifically for each bathing area, according to the characteristics of the different factors (salinity, temperature, light intensity, etc) that are involved in the inactivation process.

Bacteriological pollution probability in bathing waters under Directive 2006/7/EC criteria.

Once the evolution and spatial distribution of bacteriological concentrations in the marine environment are obtained, it is possible to calculate the pollution risk involved at each discharge point.

To calculate the pollution risk in a given bathing water area, we have followed a probabilistic approach. The proposed criteria consist to calculate the probability of exceeding a specific bacteriological concentration (of the classification guidelines established in the Directive 2006/7/EC), according to the next general equation (Equation 12).

$$Probability\ to\ exceed\ "x"\ concentration = \frac{Time\ to\ exceed\ "x"\ concentration}{Total\ time\ of\ modelling} \cdot 100$$

(Eq 12)

Next, it is necessary to set a criterion to evaluate the bacteriological pollution risk, according to the probability value obtained. A study conducted by Nikolov *et al.*, (1994) yielded a relationship between the probability to exceed a concentration and the probability to impair the quality criteria given by such concentration, according to Directive 76/160/EEC, which allow to propose the criterion described in Table 1 for the assessment of the bacteriological pollution risk.

Table 1. Bacteriological pollution risk according to the probability of exceeding a specific concentration value.

Probability to exceed the limit concentration	Bacteriological pollution risk
$P < 0.5\%$	Very low
$0.5\% < P < 1\%$	Low
$1\% < P < 2\%$	Medium
$P > 2\%$	High

Design of the Quality Monitoring and Assessment Program.

From the result provided by the profile, regard to the bacteriological status of the bathing water, it is necessary to design the most appropriate Quality Monitoring and Assessment Program.

In this sense, in Europe, data on the 95^{th} and 90^{th} percentiles of bacteriological quality indicators are used to classify bathing waters, according to the requirements of Directive 2006/7/EC. However, percentile values and consequently, classification of bathing waters depends on the type of sample under consideration. This may undermine an appropriate assessment of the bacteriological status of the bathing water under study. To analyse the influence of the number of samples on water quality classification, a bootstrap approach was applied (Efron & Tibshirani, 1993), by resampling 1000 times.

The bootstrap distribution of the 95^{th} and 90^{th} percentiles ($P95^B$ and $P90^B$) is used to estimate how the percentile of the actual sample ($P95^S$ or $P90^S$) would vary due to random sampling. For example, the probability to impair Directive 2006/7/EC (the "Sufficient" quality criteria) for each sample size, is calculated as follows (Equation 13):

$$\textit{Probability to impair Directive 2006/7/EC} = \frac{\textit{number of bootstrapped samples with } P90^B > 500}{\textit{total number of bootstrapped samples } (B)}$$

(Eq 13).

Results obtained by bootstrap application will be compared with those obtained from the application of the Quality Monitoring of Assessment Programs carried out.

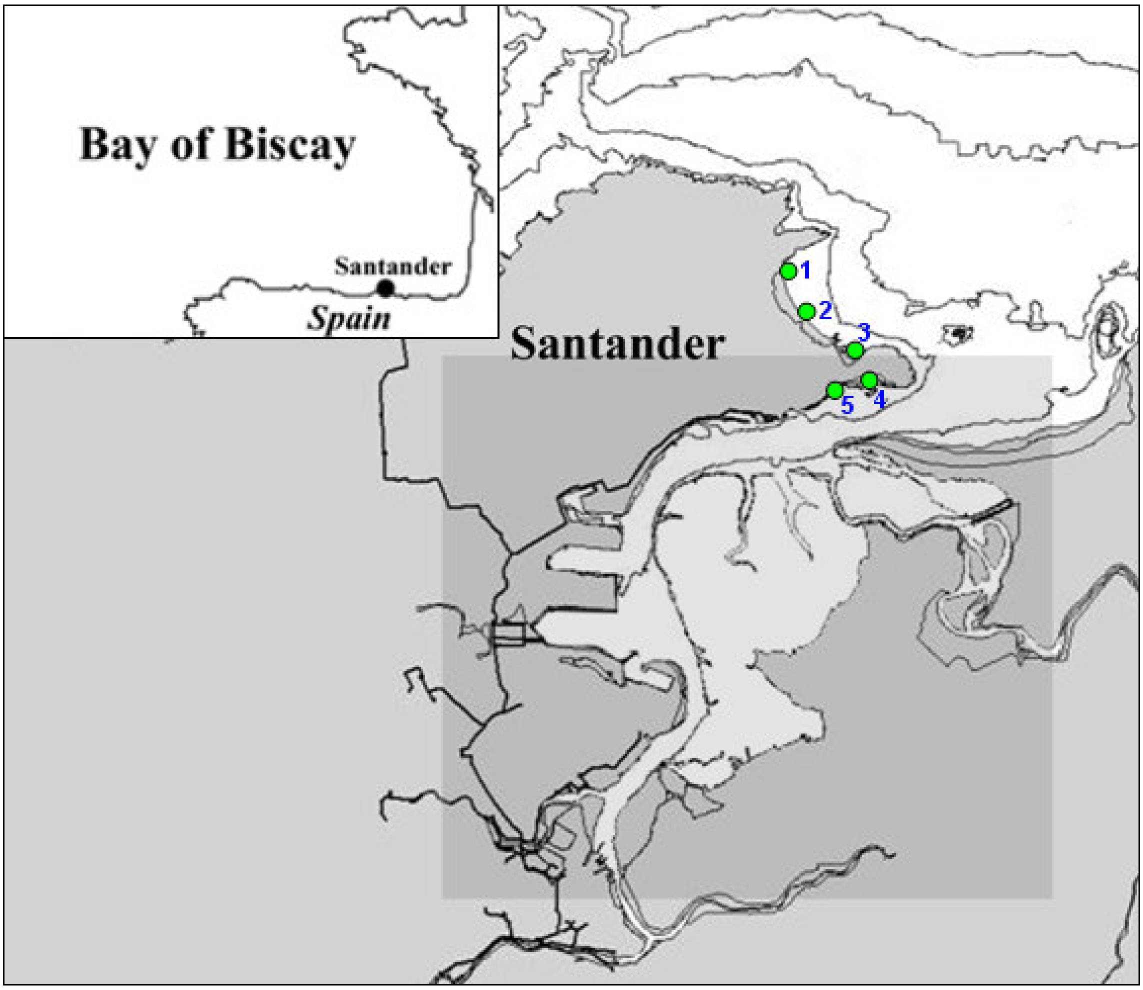
APPLICATION

Study area.

The Bay of Santander is an important economic, recreational and natural area in the northern coast of Spain (Gulf of Biscay), with a total extension of 22.5 km^2. The estuarine ecosystem was significantly stressed by urban and industrial continuous untreated discharges of more than 250.000 inhabitants until June 2001, when the new sewer system came into operation.

There are two bathing waters located inside the bay (Los Peligros and Magdalena), which form the study area. The climatic condition in this area are typical of Atlantic areas, with high levels of rainfall throughout the year (1200 mm) and an average of 12 rainy days per month, during a bathing season (from June to September, both included). The study area and the bathing water areas located in the Bay of Santander are shown in Figure 1.

Figure 1. Bay of Santander (Spain) and location of bathing water areas. 1) 2ª Sardinero beach, 2) 1ª Sardinero beach, 3) Camello beach, 4) Magdalena beach, and 5) Los Peligros beach.



Sewer system characteristics.

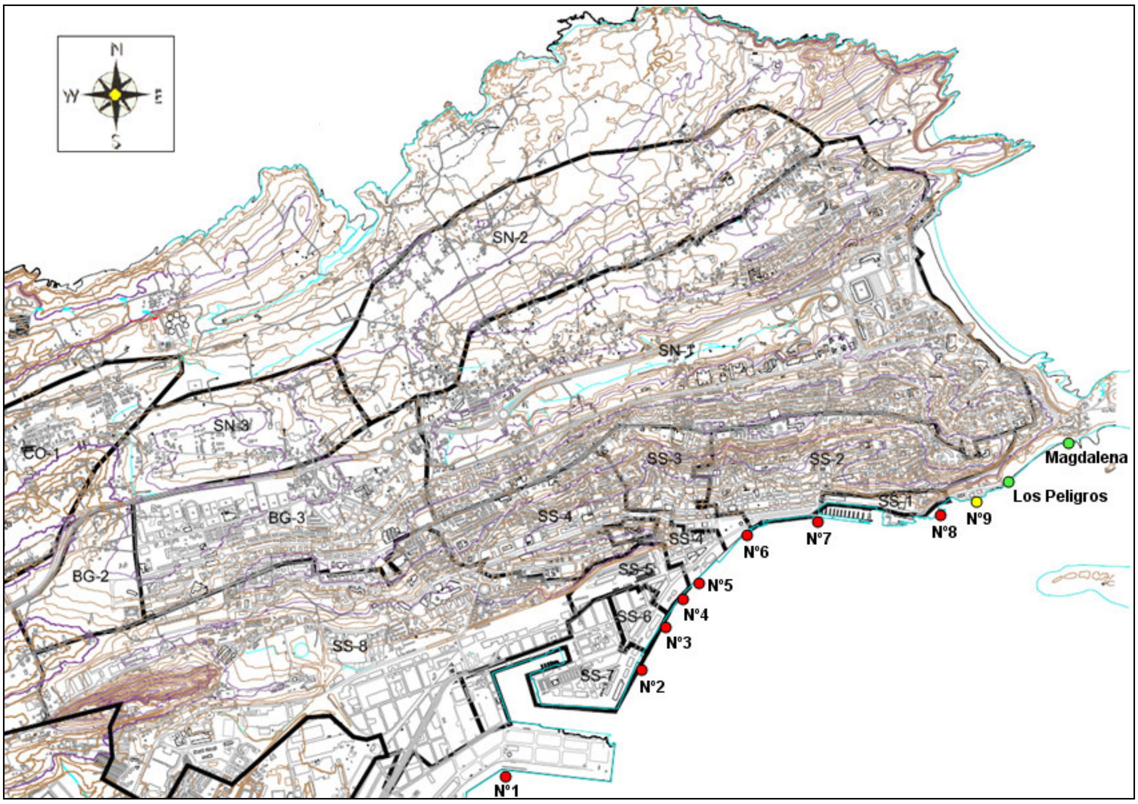
The current combined sewer system was designed to prevent the pollution of bathing water caused by the discharges of more than 30 CSOs, 8 of which are located near the main beaches in this area.

Moreover, there are some effluents that do not enter the sewer system, that cause the continuous discharge of sewage, given rise to even worse pollution problems in these beaches. The most important uncontrolled discharge is produced near Los Peligros beach, and it is caused by a recreational facility.

Furthermore, the failure in the pumping system of the sanitation could be produced. In this case, the wastewater is discharge through the CSO Nº6. Managers of the system have reported that the mean duration of a failure in the pumping system is 24 hours.

In Figure 2, basins of the sanitation system (SS-1 to SS-8), the CSOs of the system (Nº1 to Nº8), the uncontrolled discharge Nº9 and the bathing water quality control points (Los Peligros and Magdalena) are shown.

Figure 2. Basins of the sanitation system (SS-1 to SS-8), CSOs of the system (red dots), uncontrolled discharge point (yellow dot) and bathing water quality control points (green dots).

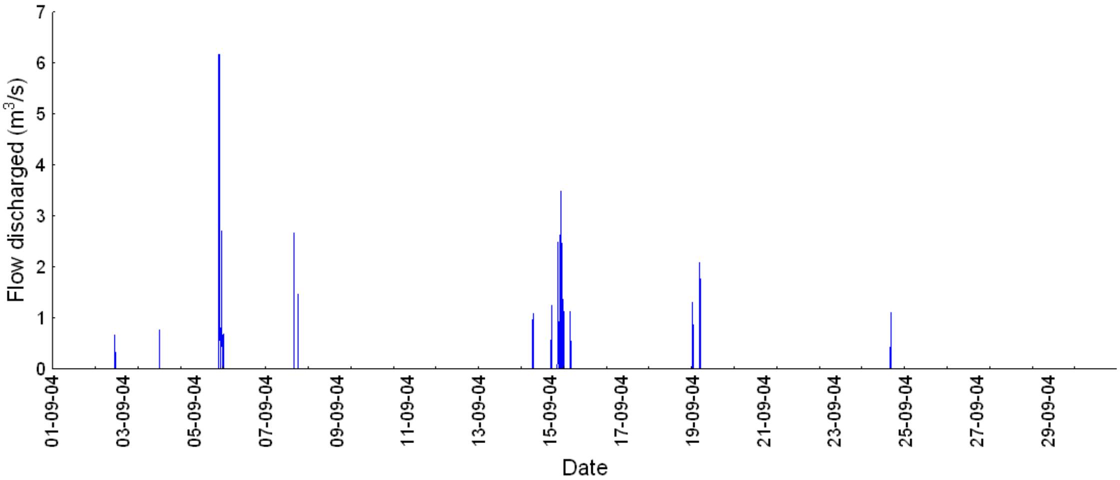


Assessment of the flow and concentrations of the discharged effluents.

The evolution of the overflows characteristics were obtained specifically for each discharge point, for the bathing seasons from 2004 to 2007, using SWMM software (Rossman, 2004).

Once calculated the inflow in the sewer system, applying the SWMM hydrological module, it has been calculated the outflow of the sewer system through every discharge point, by application of the SWMM hydraulic module, which solves the momentum and continuity Saint Venant equations, defined above. An example of the evolution of flow discharged (in m^3/s) though CSO Nº4 in September of 2004 is shown in Figure 3.

Figure 3. Evolution of discharged flow through CSO Nº4 in September 2004.



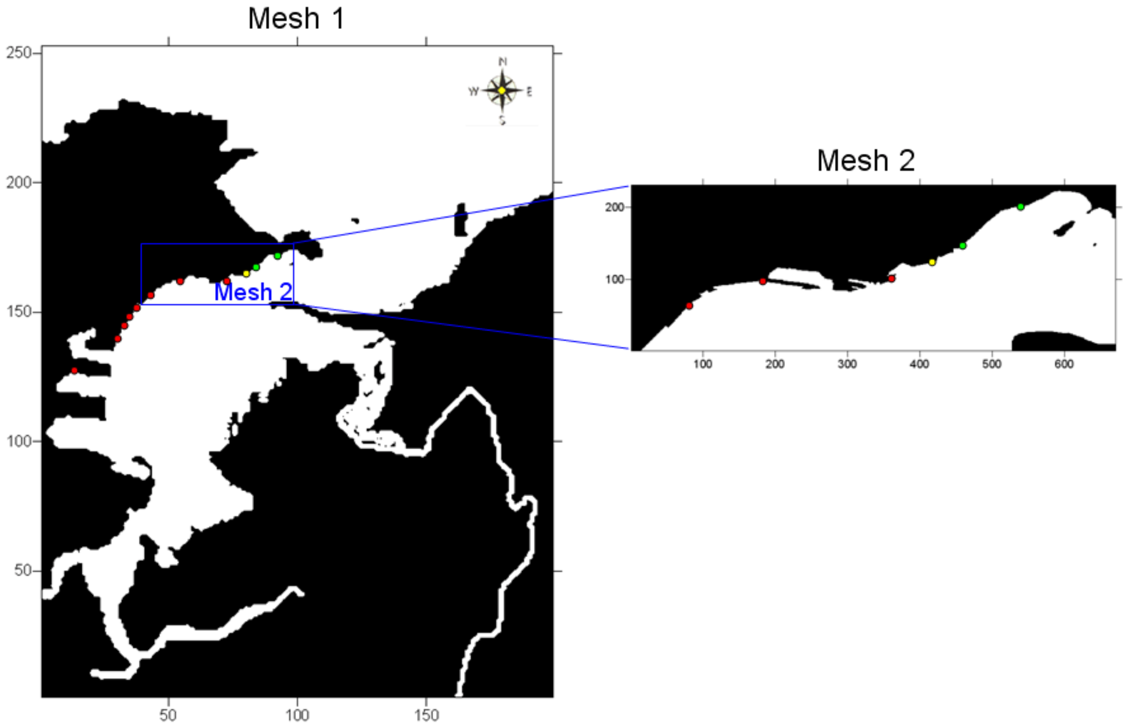
To calculate the evolution of the bacteriological concentration of each of these discharges, it has been solved the complete mixed model (Harremoes, 1990; Johansen, 1985), giving a mean *E. coli* concentration equal to $1 \cdot 10^5$ cfu/100 ml.

The discharge of the point Nº9 corresponds to a volume of 2.4 m^3 in 2 minutes, giving an average flow of 0.02 m^3/s. This discharge regime is repeated twice a day, irrespective of the weather conditions. The sampling and laboratory analysis of the effluent provided a mean concentration of $1.4 \cdot 10^7$ cfu/100 ml for the *E. coli* indicator.

Hydrodynamic and transport characterisation in the Bay of Santander.

To analyse both the hydrodynamic and transport conditions in the aquatic environment it has been considered the use two different meshes, which are shown in Figure 4.

Figure 4. Meshes of study area, for the Bay of Santander (Mesh 1) and the specific bathing water area (Mesh 2).



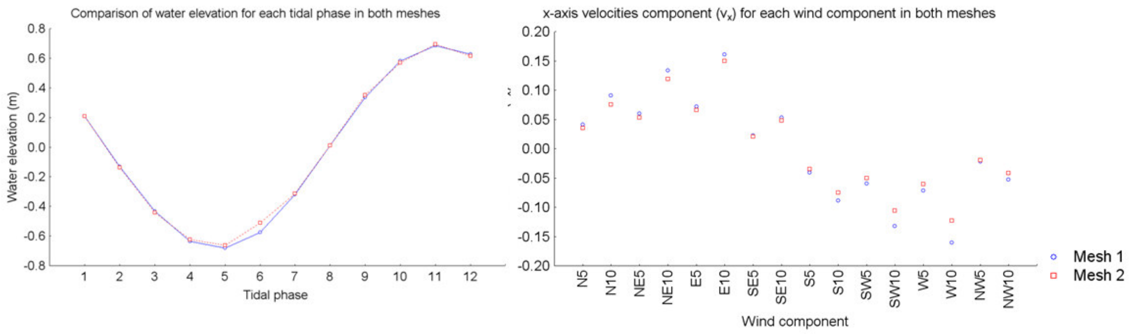
In Mesh 1, an area of 131.1 km^2 was represented using 199 x 253 grid cells with a constant grid space of 51 m. In Mesh 2, an area of 4.73 km^2 was represented using 671 x 231 grid cells with a constant grid space of 5.1 m. Hydrodynamic and transport conditions in Mesh 2 were obtained from those in Mesh 1 using the mesh nesting method. Bathymetry of Mesh 2 required a more detailed smoothing and interpolation process than that for Mesh 1.

Hydrodynamic conditions were calculated continuously for bathing seasons from 2004 to 2007. For that, water elevation and velocity currents were calculated in both meshes, for each of the main processes causing water motion. For the evolution of tidal currents, we used a real tidal wave of 15 days, which covers spring and neap tide periods. Next, such a tidal sequence was employed along the assessment period to obtain tidal currents, using a 2D model.

To calculate wind-generated currents, wind was divided into its 8 principal components (N, NE, E, SE, S, SW, W, NW) and 2 intensities (5 and 10 m/s). Currents produced by each of these components were calculated using a 3D model, which follows a parabolic profile approach to calculate the vertical component of the velocity. Next, to obtain the wind currents in the period assessment, MonteCarlo method has been applied, considering constant wind conditions in periods of 8 hours, and the probability of occurrence of each wind component in the Bay of Santander.

Water elevation for each tidal phase and velocity for each wind component were compared in a specific control point in both meshes, as shown in Figure 5.

Figure 5. Comparison of water elevation for each tidal phase, (left plot) and velocity currents for each wind component (right plot), in both meshes.



Finally, advection and dispersion of *E. coli* indicator was calculated using the model described in Equation 10. The inactivation model considered in this process is the one described by the Equation 14, which was developed specifically for the Gulf of Biscay (Canteras *et al.*, 1995):

$$K\left[day^{-1}\right] = 2{,}533 \cdot 1{,}040^{(\mathrm{T}-20)} \cdot 1{,}012^{S} + 0{,}113 \cdot I_0 \left(c \middle/ H \right) \qquad \text{(Eq 14)}$$

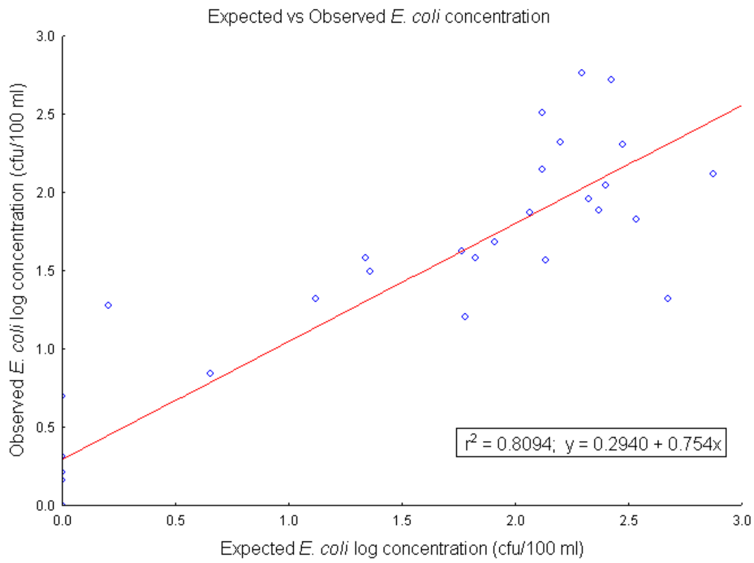
where T is the temperature, S the salinity, c the light extinction coefficient (= 0.80 m^{-1}), H the depth and I_0 the light intensity in the water surface. T_{90} values can be obtained according to the light intensity for different depths (H), in meters, considering the specific conditions of salinity (= 33‰) and temperature (= 17ºC) of the Gulf of Biscay.

Calibration of the quality model.

Bacteriological quality data were obtained from the implementation of the QMAP, carried out in Los Peligros and Magdalena control points during bathing seasons 2006 and 2007. During this period a total of 30 samples were taken, weekly, and *E. coli* concentration of each sample was assessed.

Figure 6 shows the comparison of the *E. coli* observed concentration (from the QMAP) and those obtained by the modelling of usual processes occurring in bathing water, which are responsible for its typical bacteriological status.

Figure 6. Comparison of *E. coli* concentrations obtained by modelling (expected data) and through the Quality Monitoring and Assessment Program (observed data).



The linear regression shows a value of $r^2 = 0.81$, which involves a good fit of the quality model. With the calibration of the model, it is possible to characterise the advection, transport and reaction processes for each of the waste water discharge processes, which will provide a definition of the bathing water profile.

RESULTS

Bacteriological pollution probability produced by each discharge process.

Table 2 shows the results of modelling the discharges during 4 bathing seasons (2004 to 2007) regarding the probability of exceeding the 500 cfu/100 ml of *E. coli* concentration considered in Directive 2006/7/EC, for Los Peligros and Magdalena control points.

Table 2. Probability of exceeding the limit concentration of 500 cfu/100 ml of *E. coli*, under normal conditions of the bathing water area.

Control point	Probability to exceed (%)
Los Peligros	1.47
Magdalena	0.48

In order to identify relationships between the cause and effect of bacteriological pollution, as established in the definition of the profile, the use of mathematical models allows obtaining the relative effect of every discharge on the quality of aquatic environment. Next, it is shown the separate effect produced by the discharge of CSOs (Figure 7) and by the discharge produced through point Nº9 (Figure 8), in Los Peligros and Magdalena control points.

Figure 7. Evolution of *E. coli* concentrations caused by the CSOs (points Nº1 to Nº8), for Los Peligros and Magdalena control points, in the assessment period.

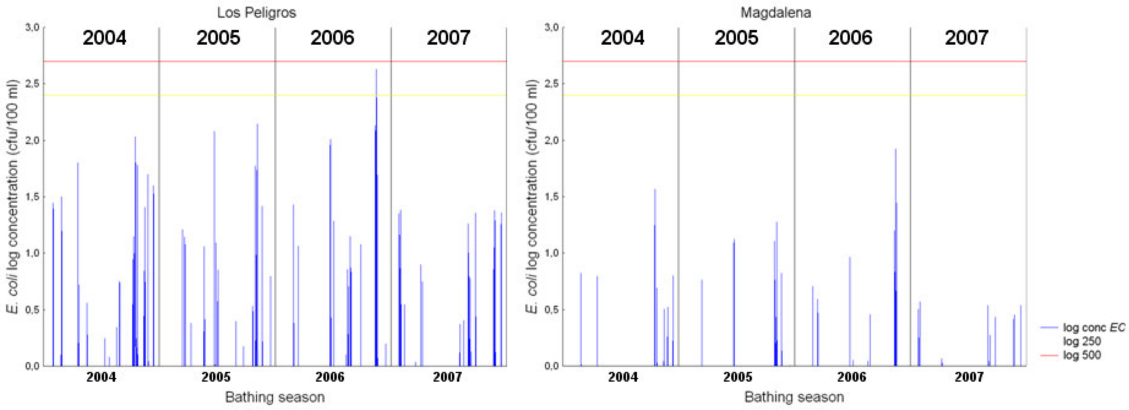
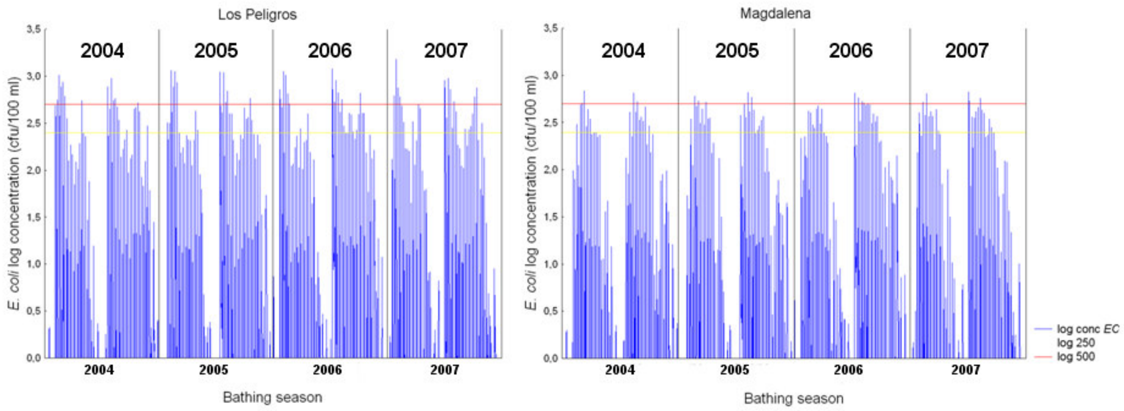


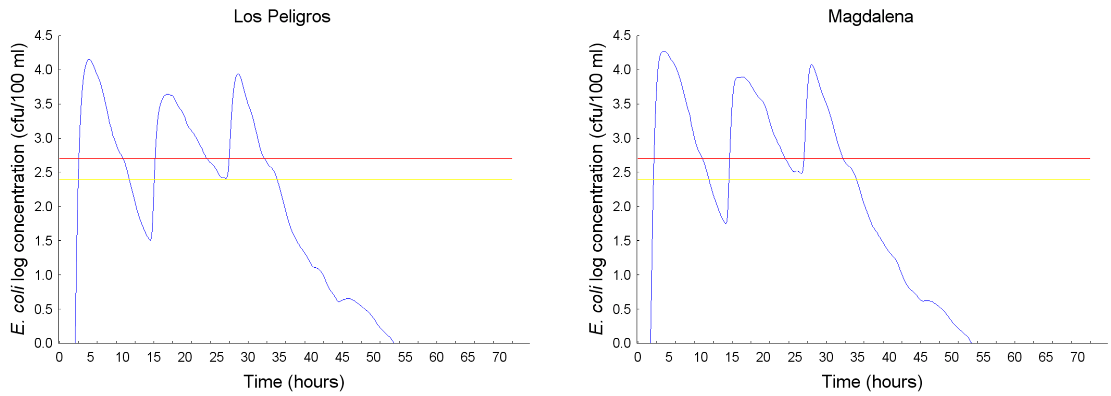
Figure 8. Evolution of *E. coli* concentrations caused by the discharge through point Nº9, for Los Peligros and Magdalena control points, in the assessment period.



These figures show that the overflows of the system are not the main origin of the bacteriological pollution produced in the bathing water area. In this case, the concentration of 500 cfu/100 ml of *E. coli*, established as a limit concentration, is not exceeded during the 4 bathing seasons considered as study period (Figure 7). Consequently, the discharge produced through point Nº9 together with the hydrodynamic and transport conditions of the aquatic environment lead to pollution probability values of 1.47% and 0.48% in Los Peligros and Magdalena, respectively, during the study period (Figure 8). This fact suggests that this discharge process is the origin of the bacteriological pollution in bathing water area.

Next, it is shown the effect produced by one event of 24 hours failure in the pumping system (Figure 9).

Figure 9. Evolution of *E. coli* concentrations caused by the discharge through point Nº6 due to a failure in the system, for Los Peligros and Magdalena control points, in the assessment period.

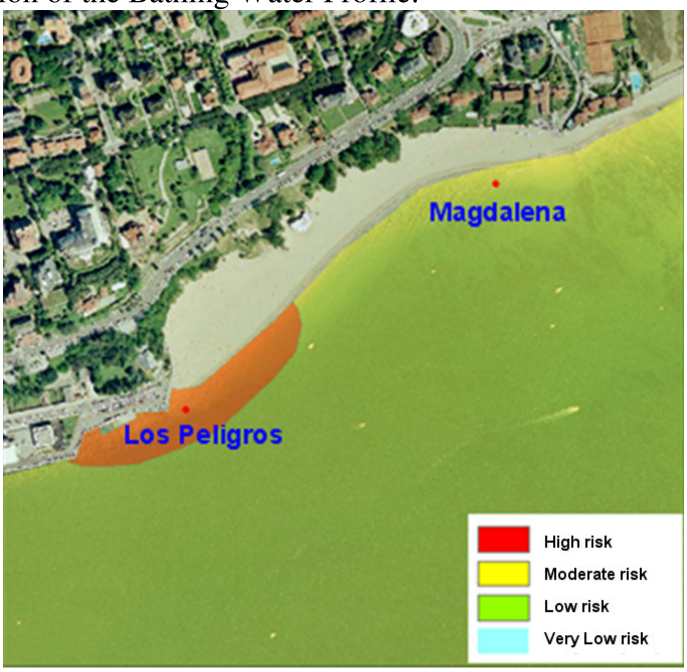


In this case, the probability of exceedence of 500 cfu/100 ml of *E. coli* concentration is 0.82% in Los Peligros and 0.79% in Magdalena control point. Furthermore, the bacteriological concentrations in the aquatic environment due to this discharge process can reach values higher to 10^4 cfu/100 ml of *E. coli*.

Definition of the bathing water profile.

For the definition of the bathing water profile it is necessary to consider the spatial variability produced by the discharging processes in the bathing water area. To analyse the spatial variability produced by these discharges, it has been characterised the probability to exceed the limit concentration in 220 control points in the bathing water area, providing a pollution probability map (Figure 9).

Figure 9. Definition of the Bathing Water Profile.



As it is observed, there are two areas with different pollution degree. The higher pollution risk values are located near Los Peligros area, and the lower, in Magdalena area. This fact is due to Los Peligros control point is located closely to both CSOs and uncontrolled discharge Nº9 and, consequently, the effects of the usual wastewater discharges have greater impact on bacteriological pollution in such control point.

Discharge point that is independent of the normal operation of the sanitation system (*i.e.*, uncontrolled point Nº9) and failure in the sanitation system cause higher probabilities of impairing the bacteriological quality criteria. While, the overflows produced by the CSOs of the sanitation system are not responsible of the bacteriological pollution in the water area. Furthermore, the methodology shown here allows to analyzing, separately, the contribution of each discharge point of the sewer system.

The definition of the profile should be useful, therefore, to manage the aquatic environment, but also the pollution emitting sources, according to the established in the Directive 2006/7/EC.

Design of the Quality Monitoring Assessment Program.

In the same way, this methodology is a useful tool to determine the optimum control point. According to the established in the Directive 2006/7/EC, the control point should be located within the bathing water where i) most bathers are expected or ii) the greater risk of pollution is expected, according to the bathing water profile.

Taken into account this point of view, it could be enough to select the control point located in Los Peligros, where the risk of bacteriological pollution is higher. This would reduce the sampling effort in the bathing water area, avoiding the taken of samples in Magdalena control point.

However, this approach could lead to consider the whole bathing water area as a high risk of pollution area, and that is not the reality. Hence, it seems more appropriate to consider two different areas that should be managed according to their bacteriological quality status.

Bacteriological quality data were obtained from the implementation of the Quality Monitoring and Assessment Program (in advance, QMAP) carried out in Los Peligros and Magdalena control points during bathing seasons from 2006 to 2009. During this period a total of 80 samples were taken, weekly. According to the quality criteria and evaluation system established in the Directive 2006/7/EC, percentile values for *E. coli* indicator and classification obtained in each control point is shown in Table 3.

Table 3. Percentile values (in cfu/100 ml) and classification for both bathing water quality control points, Los Peligros and Magdalena.

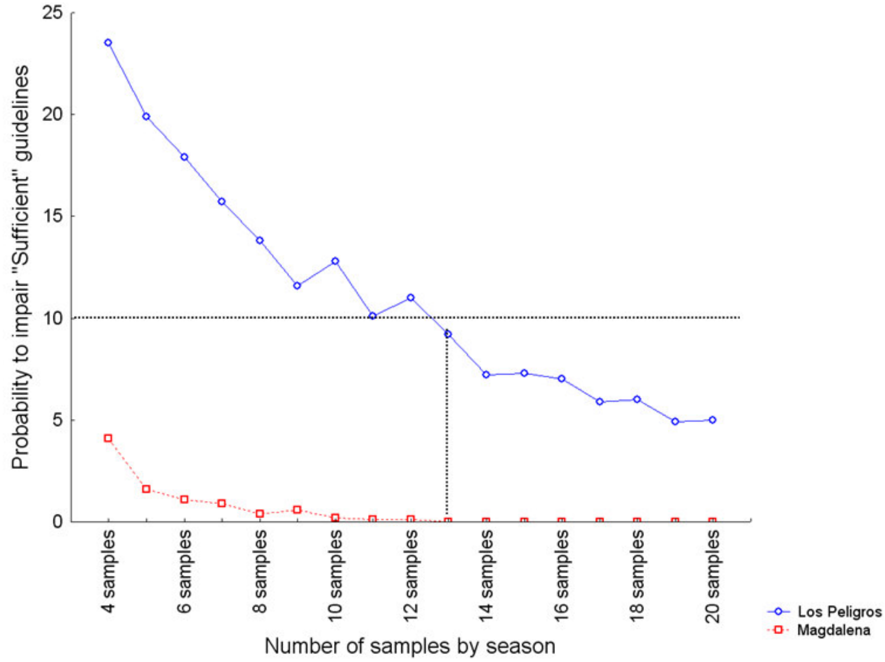
	P95 *E. coli*	P90 *E. coli*	Classification
Los Peligros	605	334	Sufficient
Magdalena	327	---	Good

Optimum number of samples

By using the inferred parameter values, and once applied the bootstrap method to simulate 1000 varying-size samples of FIB concentration, 1000 $P95^B$ and $P90^B$ values were obtained for each group varying-size samples.

Despite the fact that probability to impair all classification guidelines shown in Table 1 were analysed, here we only show the impairment probability of the Directive; in other words, the probability that a random sample impairs the “Sufficient” classification guideline (*i.e.*, has a $P90^B$ value higher than 500 cfu/100 ml of *E. coli*), according to Equation 13, both for Los Peligros and Magdalena sampling points (Figure 10).

Figure 10. Probability to impair the "Sufficient" quality standards established in Directive 2006/7/EC, for Los Peligros and Magdalena, according to the number of samples taken by season.



As it is possible to observe, classification of bathing waters depends on the sampling effort and on the number of samples. In order to ensure a low probability to impair (for example, < 10%; Figure 10) the Directive guidelines, it would be enough to consider 13 samples by season in Los Peligros and 4 in Magdalena, instead the 20 samples by season that are taken in each sampling point. This approach allows managers to allocate resources in those waters where the investment is necessary.

CONCLUSIONS

In this paper, a methodology based on the mathematical modelling of the discharges of the sewer systems for the definition of the bathing water profile, in line with Directive 2006/7/EC, is described. The application of this methodology to several urban bathing waters in the north of Spain shows the importance of considering storm overflows, uncontrolled discharges and failures in the system pumping, as variables to take into account when defining the bathing water profile.

Modelling of the evolution of pollutants during long assessment periods (4 bathing seasons) and several control points (in this case, 220 control points) allows the definition of spatial and temporal variability in the concentration of the bacteriological indicators, which is fundamental for the adequate definition of the bathing water profile. The use of mathematical models, which are adequately calibrated and validated, constitutes a very powerful and useful tool to identify the origin of the pollution and assess the risk produced by each pollution source, which is ultimately the aim of developing such a profile.

In such definition, and according to what is established in the Directive, it is necessary to select the most appropriate control point, which should be located where the greater risk of pollution is expected. The methodology shown here allows to distinguishing different pollution areas, depending on the bacteriological pollution risk value, which allows to selecting the most appropriate control point. Furthermore, the definition of the profile allows to obtain the bacteriological characteristics of the bathing water area, which is necessary to design the most appropriate Quality Monitoring Program of the area.

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