Towards Implementation of the new EU Bathing Water Directive – Case studies: Copenhagen & Århus, Denmark

Vers une mise en œuvre de la nouvelle directive Européenne sur la qualité des eaux de baignade – Exemples de Copenhague et Århus, Danemark

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RESUME

La nouvelle directive européenne relative à la qualité des eaux de baignade requiert une information rapide et appropriée du public. Les systèmes temps réel de prévision de la qualité des eaux couplés à un système d'alerte constituent un moyen efficace mais encore peu répandu pour répondre à cette demande. Dans la présente étude, différents modèles numériques (écoulements de surface, dans les égouts et éventuels débordements) sont mis en œuvre et les résultats utilisés dans un modèle hydrodynamique et écologique 3D de la baie d'Arhus afin de déterminer la qualité des eaux de baignade du site.

Le présent papier illustre les performances de ces différentes approches numériques pour prédire la qualité des eaux de baignade en termes de précision et de nombre de jours de baignade perdus. Les avantages et inconvénients de chaque système sont également présentés et discutés.

ABSTRACT

EU has updated "The Bathing Water Directive" which dated back to 1976. The new version calls for "Adequate management measures, incl. surveillance, early warning systems and monitoring" in case beaches are exposed to short term pollution. Few real time bathing water systems are in operation today. Examples are: Copenhagen, Denmark and Sydney, Australia.

In the present study, three different models are applied for the Bay of Århus to compute overflow from the sewers to the sea. These models range from conceptual lumped models to a fully hydrodynamic model with simulation of the water quality in the sewers. The resulting water quality in the bathing water area is simulated with a 3D hydrodynamic and water quality model.

The present paper discusses the performance of these different modelling approaches for prediction of the bathing water quality in terms of accuracy and the number of lost bathing days. Further, the paper discusses the benefit/disadvantages of each modelling approach.

KEYWORDS

Bathing water, combined sewer overflows, drainage system, EU Bathing Water Directive, integrated modelling.

1 BACKGROUND

The intentions of the new Bathing Water Directive are clear: *'... The purpose of this Directive is to preserve, protect and improve the quality of the environment and to protect human health ...(article 1, section 2)'* and as a tool to secure the health of the bathers in connection with e.g. sewage outfall the directive introduces early warning systems (fractured cited): *'... Bathing waters are to be classified as 'sufficient/good/excellent': if the bathing water is subject to short-term pollution, on condition that: (i) adequate management measures are being taken, including surveillance, early warning systems and monitoring, with a view to preventing bathers' exposure, by means of a warning or, where necessary, a bathing prohibition (Annex II, sections 2, 3 and 4)* (EU 2006).

Traditionally, bathing water quality assessments are based on microbiological analyses for indicators of pathogen bacteria. A major problem of these analyses is the time lag until results are available and their limited representation in time and space. Introduction of a Bathing Water Forecast System (BWF), which is an innovative on-line predictive tool, will significantly improve the assessment of human health risks.

The core of the BWF system is hydrodynamic models (1D, 2D or 3D) simulation and forecasting the physical conditions and the water quality at the bathing water sites. On one hand the BWF system ensures that managers and bathers are warned when the water is unsafe to swim in and on the other hand that the beaches are closed for as short periods as possible. Furthermore, the tool provides quantitative assessments of the impact of pollution sources and provides a basis for reviewing the monitoring programs and identifying mitigation measures. This provides a strong tool for identification of the most cost-effective measures to reduce contamination – an important element of the new Bathing Water Directive in accordance with the 6th Environmental Action Programme.

2 EXISTING REAL TIME BATHING WATER INFORMATION SYSTEMS

Today three different types of real time bathing water systems are in operation around the world. The complicity of these systems varies from empirical models based on simple computations to advanced real time hydrodynamic and water quality models, which in real time both simulate the past and forecast the bating water quality. The three systems are briefly described below.

2.1 Empirical bathing water forecasts based on accumulated rain

An example of such a system is "Beachwatch" in New South Wales, Australia. Beachwatch was started in 1989 because of community concern about the impact of sewage overflows on people and the environment at Sydney's ocean beaches. At that time gross visual indicators of sewage pollution such as: sewage grease, condom rings, cotton tips and sanitary napkin backings were frequently washed on to beaches. Since then the situation has been greatly improved by the construction of deep ocean outfalls to service Sydney's main coastal sewage treatment plants at North Head, Bondi and Malabar. As stormwater is now the major pollution issue affecting Sydney's ocean and harbour beaches, daily bulletins are derived from rainfall information for the previous 24 to 72 hours (NSW EPA 2006). A similar system is operation in California. Here the public is warned against swimming, windsurfing etc. for 3 days after more than 2.5 mm rainfall within 24 hours. (Ackerman, D. and Weisberg, A.B. 2003). This system doesn't take into account the rainfall intensity, which according to (Ackerman, D. and Weisberg, A.B. 2003) is an important factor.

2.2 Statistically based bathing water forecasts

A number of different statistical approaches have been developed and tested including simple rainfall or river flow thresholds (McPhail and Stidson 2004), multivariate regression approaches using meteorological and tidal predictors (Crowther *et al*. 2001) and (Crowther *et al*. 2002), neural and network analysis (Kashefipour *et al.* 2002). The Scottish Environment Protection Agency (SEPA) provides daily forecasts of water quality at 10 beaches (McPhail and Stidson 2004). The information is displayed on electronic message boards and on the SEPA website, see Figure 1.

Figure 1. Bathing water information board at Ayr, Scotland. Picture from http://www.sepa.org.uk/

This system provides a forecast of the water quality related to the EU Bathing Water Directive. The system is based on dominant environmental processes (mainly rainfall) from the past two days. On a daily basis a “sign message management decision” is made and the signs are updated remotely accordingly. The system was tested and validated for 2 years by SEPA before it was put into operation.

2.3 Deterministic bathing water forecasts

The city of Copenhagen, Denmark, has an early warning system for bathing water. The foundation of the system is deterministic modelling as described in (Erichsen and Rasch 2001). The system provides a 4-day forecast for bathing water quality at different locations in Copenhagen Harbour. The objective of the service is to bring early warnings to beach guests. In addition, information is supplied about air and water temperatures, wind and current.

From the early start it was obvious to Copenhagen Environmental Protection Agency (EPA) that combined sewer overflows (CSOs) were bound to occur during the bathing season and therefore an early warning system was designed. Today, it is difficult, to make reliable forecasts of the individual CSOs on a day-to-day basis. Therefore, the early warning system does not yet include any prediction as to when and where the CSOs will occur. Hence, the CSOs are measured and the water quality in the harbour is subsequently modelled. On the background of the simulated water quality the affected beaches and the closure periods are identified, and if necessary the bath is closed and the public warned through the Internet and at the beach. This procedure makes the water quality forecast modelling a central part of the early warning system.

The Copenhagen EPA has decided to include a relatively large safety margin in the predictions (conservative estimates of outfall concentrations). After the termination of the 5th bathing season, the status is that 100% of measured increased *E.coli* levels have been described by the BWF system. Furthermore, a specific campaign was carried out to monitor the fate of bacteria after one incidence, see Figure 2.

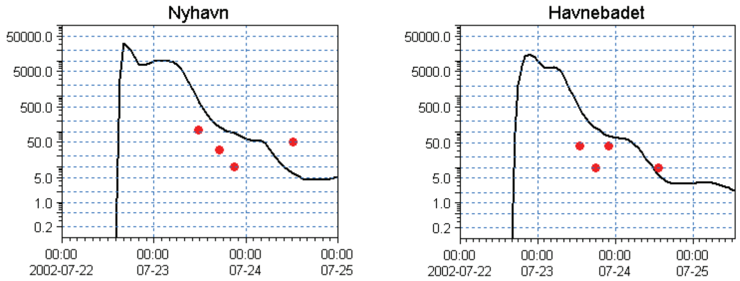

Figure 2: Measurements (circles) and model results (line) from one CSO incidence. (Left) is a station in the northern part of the harbour, (right) is at the main beach.

3 CASE STUDY ÅRHUS BUGT

The bathing water forecast for the municipality of Århus is very similar to the system in Copenhagen. The backbone of the system is a deterministic model for the receiving waters, and furthermore a fully operational hydrodynamic and water quality model (MOUSE TRAP) has been introduced to describe CSOs volumes and the concentrations of *E.coli*.

The coastal model includes the entire bay area but with focus on the beaches just South of the City. Thus, the model system has been applied to investigate (theoretical) effects of different levels of knowledge. The hypothesis behind the scenarios below is that the less knowledge the authorities have got about the extent of the pollution – the longer time the beach must be closed in order to compensate for the lack of knowledge.

The modelling scenarios have been selected to represent a real life modelling case – and are meant to illustrate the difference between levels of model complexities. The characteristics of the model and the meteorological situation are listed in Table 1. In the following examples we have combined three different approaches for the sewer system and four different approaches for the receiving waters:

Forcing	**Characteristics**	**Comments**
Precipitation	5 year event	Commence at 14.00 CSOs start after 1 hour CSOs stop after 5 hours
Solar radiation	Modelled data (http://www.vejr2.dk)	Data covering a rainfall event from the 20-23. July 2002 (in Figure 2)
Wind	Modelled data (http://www.vejr2.dk)	Do.
Air temperature	Modelled data (http://www.vejr2.dk)	Do.

Table 1: Meteorological conditions applied for this paper.

Sewer system: In “the geometric” approach the water exceeding the overflow design rain (in this case: 10 mm) is discharged as CSO. The total amount of bacteria is discharged instantaneously after the CSO has ended, which in this example is after 6 hours. For the hydrodynamic model, simulated time series of overflow are applied whereas modelled concentrations are applied in the hydrodynamic and water quality modelling. In the first two examples a fixed concentration of $9{,}0 \cdot 10^6$ *E.coli* per 100 ml has been applied. The results of the different approaches are listed in Table 2.

Sewer system	Receiving water
Geometric approach ($1.76 \cdot 10^{14}$ cfu)	Dilution
Dynamic HD modelling ($9.77 \cdot 10^{13}$ cfu)	Decay
Dynamic HD and AD modelling ($4.47 \cdot 10^{12}$ cfu)	Dilution, decay and dynamic modelling

Table 2: The different scenarios from the sewer system and from the receiving water. The figures in brackets indicate the bacterial loading resulting from a 5 years rain event.

Receiving water: The approaches reach from theoretical solutions of simple dilution, simple decay, a combination of the two and finally a full 3D hydrodynamic and decay model. Furthermore, some additional assumptions need to be applied in some of the following examples, see Table 3.

Average depth (where bathymetric data are not available)	1.0 m
Water temperature (where not modelled)	20 °C
Salinity (where not modelled)	15 psu
Secchi disc depth	5 m

Table 3: Additional assumptions applied in the following examples

In the Methods 1 to 3 only the results from the geometric approach has been applied, whereas all three sewer system approaches have been applied in Method 4.

3.1 Method 1 – Warning based purely on dilution

In this method processes of decay and transport are ignored, and hence, it is the most conservative estimate. The analytical solution for the concentrations at the beach can be written as:

$$C = \frac{P}{4 \cdot \pi \cdot H \sqrt{D_x \cdot D_y}} \cdot \frac{1}{t}$$

Where P is the total discharged amount of bacteria (cfu), H (m) is the average water depth in the area, and D_x (m^2/s) and D_y (m^2/s) are dispersion coefficients in the two directions (parallel to the beach and perpendicular to the beach). D_x and D_y are assumed to be 1 m^2/s.

3.2 Method 2 – Warning based purely on decay of E.coli

In this method only decay is included ignoring processes of dilution and transport. When computing *E. coli* decay it is recommended to include both a contribution from day (light) and night (dark) situations. The theoretical solution is taken from (Jensen 1990) and the concentrations at the beach can be described as:

Decay	$C = C_0 \cdot e^{-k \cdot t}$ where $k = k_m + K_l \cdot I_l$	C = actual concentration [ml^{-1}] C_0 = initial concentration [ml^{-1}] I_l = actual light availability in the water [$W \cdot m^{-2}$]; t = time [h]
Dark	$k_m = a_T \cdot T - k_{m0}$ $4°C \leq T \leq 24°C$	T = actual water temperature [°C] a_T = 0.002425 [$h^{-1} \cdot °C^{-1}$] k_{m0} = 0.00826 [h^{-1}]

Light	$K_I = S_m \cdot (b_T \cdot T + K_{I0})/(a \cdot S_m - (a^{-1}) \cdot S)$ $12°C \le T \le 34° C$	T = actual water temperature [°C] S = actual salinity [psu] S_m = 34,5 [psu] a = 1.54 [-] $b_T = 0.133 \cdot 10\text{-}3\ [m^2 \cdot W^{-1} \cdot h^{-1} \cdot °C^{-1}]$ $K_{I0} = 2.124 \cdot 10\text{-}3\ [m^2 \cdot W^{-1} \cdot h^{-1}]$

3.3 Method 3 – Warning based on dilution and decay

The two methods can easily be extended to include both dilution and decay by multiplying the two single contributions:

$$C = \frac{P}{4 \cdot \pi \cdot H \sqrt{D_x \cdot D_y}} \cdot \frac{1}{t} \cdot e^{-kt}$$

3.4 Method 4 – Warning based on dynamic modelling

The 3D hydrodynamic model established for Århus Bugt describes all the dominant processes such as: pressure, flow, advection, dispersion, salinity and water temperature. In addition to the physical processes the model for the bacterial decay, described above, was included. In this case all bacterial loads in Table 2 are applied.

4 RESULTS

The results from Method 1 to 3 are presented in Figure 3. If Only dilution is taken into account the time where the bathing water criteria (< 500 *cfu/*100 ml) is exceeded are several days. If decay is included the time before bathing water quality is obtained is reduced to approx. 44 hours from the time beginning of the first CSO. By introducing both dilution and decay the time is reduced to 24 hours.

As can be seen from Figure 3 decay alone will fulfil the bathing water criteria after approx. 2 days (with a Secchi Disc depth of 5 m). This is in accordance with the observations from California where rain exceeding 2.5 mm results in increased levels of bacteria for up to 5 days, but typically fulfilling the bathing water criteria (400 cfu/100 ml) after 3 days (Ackerman and Weisberg 2003). Similar evaluations are applied with the dynamic model approach. The computations are carried out for the full area of Århus By, and time series are extracted at two bathing localities, i.e. at the outlet from Giber Å, – a coastal beach and at the beach inside the fjord Knebel, in the North of the Bay, where the water exchange is significantly smaller than on the coast. For each model two time series of *E.coli* concentrations have been extracted, i.e. the concentration at the outlet and the maximum concentration in the model area during the entire event. The results are shown in Figure 4.

The results clearly illustrate the dynamic behaviour of the pollution transport. In all cases the pollution has been moved away from the outfall after 8 hours, but the concentration exceeds 500 cfu/100 ml during 15 to 27 hours depending on the selected method. Furthermore, it is noted that a part of the pollution returns to the outfall at Knebel Vig, but when it return is does not exceed the critical threshold value.

In the present case there is not much difference between the concentrations computed in the sea when the loads origin from the geometric approach or the hydrodynamic sewer model. However, when applying a water quality model for the sewers as well, the results are obvious. In this example the time of excedence is reduced from 19 to 16 hours at Giber Å and from more than 24 hours to 8 hours at Knebel Vig.

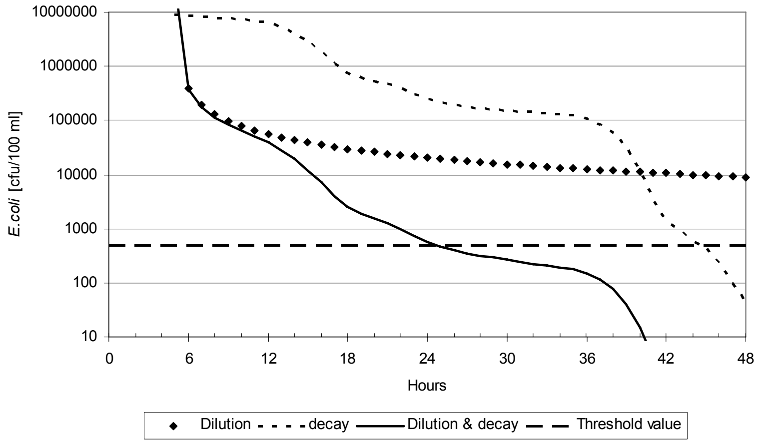

Figure 3: Computed E.coli concentrations in the sea. The computations are based on the following three Methods: 1) Only dilution is included (the dotted line), 2) Only decay is included (the dashed line) and 3) Decay and dilution are included (the solid line). The threshold value is 500 E.coli per 100 ml

5 CONCLUSION

The aim of the new Bathing Water Directive is to secure human health, and the authorities face great responsibilities when pathogenic bacteria are potentially present. An important element of the new directive is therefore early warning systems as a management tool to secure both that the aim is fulfilled and at the same time beaches are not closed unnecessarily; the latter having direct economic implications. Furthermore, unnecessarily closing might in general influence the public opinion on the bathing water quality and environmental status in general.

There are no guidelines about the complexity of early warnings systems but with less knowledge of today's bacterial pollution some conservatism needs to be included to account for the lack of knowledge compared to more precise management tools. Hence, increases in on-line data and on-line models have a direct impact on the time of expected exceedance of the bathing water criteria.

The present study illustrates that the choice of model complexity controls the period a beach will be closed for swimming due to too high concentration of bacteria. If dynamic modelling of the sea is combined with different approaches for CSO modelling, the time the beach is closed varies from approx. two days for the simple decay computation to 8 hours, when the CSO is computed by use of a hydrodynamic and water quality model. Finally, in the present study there is not much difference between a hydrodynamic model (without pollution transport) and the case when the overflow volumes are computed based on the geometry of the sewer system.

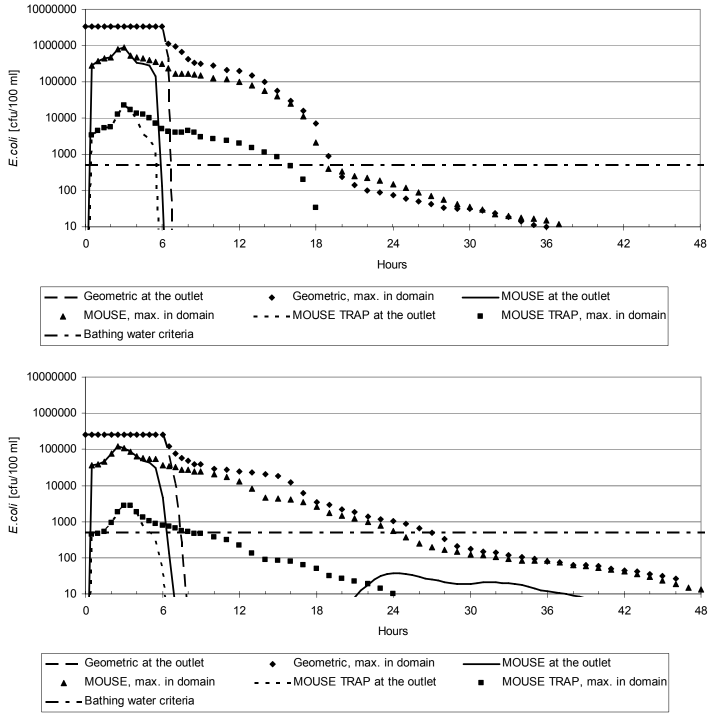

Figure 4: 3D dynamic modelling of E.coli concentrations at (top) the outlet at Giber å and (bottom) in Knebel Vig. The loads refer to the computations carried out for the sewer system (see Table 2). The time series shown are from the outlet or the maximum concentration in the area.

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