Open-water swimming in urban areas: How a three-dimensional hydrodynamic model can help in the microbiological contamination monitoring?

Nager en eau libre dans la ville : un modèle hydrodynamique peut-il contribuer à la surveillance de la qualité microbiologique de l'eau ?

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RÉSUMÉ

Les plans d'eau urbains sont de plus en plus utilisés pour des activités récréatives, dont la baignade. A Paris, la perspective des Jeux Olympiques et Paralympiques de 2024 amplifie l'intérêt pour la nage en eau libre et l'objectif de la pérenniser à long terme. Cependant, la baignade exige une bonne qualité sanitaire des milieux aquatiques, conforme aux réglementations basées sur la concentration de bactéries indicatrices fécales. Pour anticiper un éventuel risque sanitaire, une station de surveillance peut être placée en amont de la zone de baignade. Ensuite, le temps de transfert d'une éventuelle contamination microbiologique doit être calculé avec précision afin de déterminer le niveau de risque dans la zone de baignade. Un modèle hydrodynamique peut être un outil fiable pour atteindre cet objectif. Dans le bassin de la Villette (Paris, France), dans le cadre du programme Paris-Plage, une zone de baignade a été installée depuis l'été 2017. Nous présentons dans cet article les premiers résultats d'un modèle hydrodynamique 3D du bassin de La Villette, le transport d'*E. coli* vers le bassin et une évaluation de la faisabilité de cette approche de modélisation.

ABSTRACT

Urban water bodies are increasingly used for recreational activities, including swimming. In Paris, the perspective of the Olympic and Paralympic Games in 2024 brings to light the question of open water swim and the objective to make it sustainable on longer term. However, the practice of such activities requires a good water quality, complying with sanitary regulations based on the concentration of faecal indicator bacteria. To anticipate a possible sanitary risk, a monitoring station can be implemented upstream the bathing area. Then the transfer time of the microbiological contaminant must be accurately computed in order to derive the contamination level in the bathing area. A hydrodynamic model can be a useful tool for achieving this goal. In La Villette basin (Paris, France), as part of Paris-Plage programme, a bathing area has been implemented since summer 2017. We present in this paper first results about the implementation of a 3D hydrodynamic model of La Villette basin, the transport of *E.coli* towards the basin and the feasibility assessment of this modelling approach.

KEYWORDS

E. coli, hydrodynamic 3D modelling, open-water bathing, sanitary risk, warning system

1 Introduction

Urban water bodies are increasingly used for recreational activities, including swimming (*e.g.* Hintaran et al., 2018, Meyerhoff et al., 2010). In Paris, the perspective of the Olympic and Paralympic Games in 2024 brings to light the question of open water bathing and the objective to make it sustainable on longer term. However, the practice of such activities requires good water quality, complying with sanitary regulations. According to the European Union (EU) Bathing Water Directive (2006/7/CE), two microbiological parameters should be monitored: intestinal enterococci and *Escherichia coli*. The water quality is classified (Table 1) as sufficient, good and excellent, according to the concentration of the faecal indicator bacteria (FIB) measured in colony-forming units (CFU) per 100 mL over four consecutive bathing seasons.

Indicators (CFU/100mL)	Excellent	Good	Sufficient
Escherichia coli	95% < 500	95% < 1000	90% < 900
Intestinal enterococci	95% < 200	95% < 400	90% < 330

Table 1 Bathing water quality classes: guideline values expressed as FIB percentiles (90 or 95%)

Therefore *E. Coli* concentrations must be regularly monitored in order to detect the threshold of insufficient quality (900CFU/100mL). As laboratory analysis generally requires a delay of several hours, the quality threshold can be overpassed after the sampling in the bathing area, especially when a rainfall event occurs (Chen and Liu, 2017). To overcome this limit, in urban water bodies, the sampling can be taken upstream of the bathing area, at a distance that the contaminant flux would cross in a duration similar to the delay of the lab analysis. It is also necessary that no contaminant discharge is likely to occur between this sampling point and the bathing area. Then the transfer time of the contaminants must be accurately computed to be able to get reliable information about the contamination level at the bathing area. This can be achieved using a hydrodynamic model.

As part of Paris-Plage programme, a bathing area has been implemented since summer 2017 in La Villette basin (Paris, France). In this context, this paper presents a first attempt to implement a hydrodynamic modelling of La Villette basin, to simulate the transport of *E. coli* towards the basin and to assess the feasibility of this modelling approach.

2 MATERIALS AND METHODS

2.1 Study site : La Villette basin

Upstream La Villette canal, the Ourcq canal is divided in two branches. One forms the Saint Denis canal and the other flows into La Villette canal. Downstream, La Villette basin extends into Saint Martin canal. Additionally a water pumping station derives part of the flow to Paris non-drinkable water network (Figure 1). The upstream part of La Villette canal is 25m wide and 800m long. Then it widens and forms La Villette basin (width 75m; length 700m). La Villette canal and basin have a total extension of 1.5km and a depth of approximately 3m. The annual mean of the water flow is around 2.7m³/s.

In the study area, according to the Mairie de Paris (2017), potential microbiological pollution can come from (1) rainfall events: storm water from urban runoff and combined sewer overflows; (2) wastewater from poor connections and (3) boats not equipped with wastewater collection tanks or having poor management of these tanks.

2.1 Hydrodynamic model

The model used is Telemac3D (v7.2), the 3D hydrodynamic module of TELEMAC-MASCARET system (Desombre et al., 2016). It is a powerful integrated modelling tool for free-surface flows, used in many studies throughout the world (*e.g.* Kopmann and Markofsky, 2000). For input data processing and result visualization, Blue Kenue software (v3.3) was used.

The computational mesh grid is composed by horizontal triangles of 4m side and 10 layers of 0.30m height. At the junction between La Villette canal and basin, the mesh is finer, with triangles of 2m side. Regarding the boundary conditions, the upstream flow is defined according to measured data. At the outlet, the water level is defined according to the measurements at the water pumping station spillway.

We added to the model standard configuration, the process of heat exchange between the water body and the atmosphere according to (Desombre et al., 2016). The inflow rate and water level time series were provided by Mairie de Paris. The meteorological data (air temperature, pressure, humidity, precipitation, solar radiation, wind velocity and direction, nebulosity) were measured at the Météo France station of Orly airport. During 2017 summer, a bi-weekly monitoring of *E.coli* concentration was conducted at the upstream sampling station (Figure 1) by Mairie de Paris (Vanhalst, 2017).

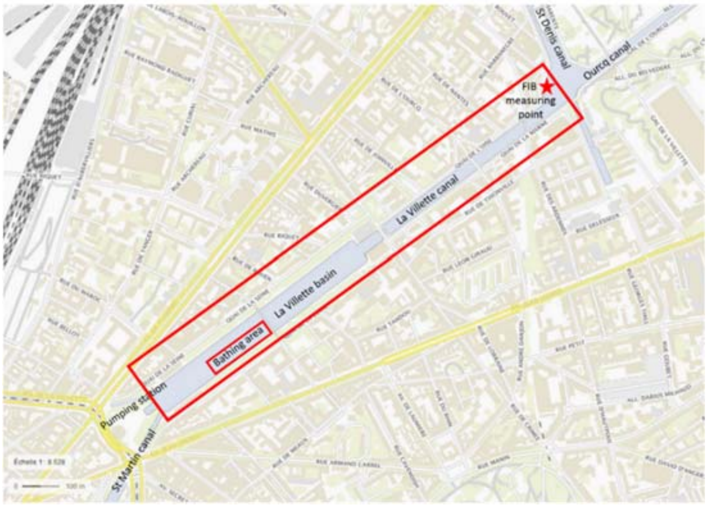

Figure 1 - Study area (map Geoportail). The red star indicates the location of water sampling for BIF measurements

3 RESULTS

For the hydrodynamic model parameters, we used all the default values, except the Strickler coefficient of bottom friction which was calibrated (K_s=50m$^{1/3}$/s). For defining the initial velocity conditions, we first ran the 2D version of Telemac over a two day period, previous to the intended simulation period. The results of the last step of the 2D simulation were used as initial conditions of the Telemac-3D simulation, which extended from 21st to 26th July 2017 for the results presented hereafter. The time evolution of surface water velocity in the bathing area, during the simulation period is presented on Figure 2-a. It fluctuates around 2 cm/s with a maximum value of 3.3 cm/s. The velocity distribution in La Villette system, canal and basin, at the end of the simulation is presented in Figure 2-b. As expected the velocities are higher in the canal and higher in the surface layer than in the bottom. The simulated velocities are within the range of the qualitatively estimated velocities in previous studies. An experimental assessment of surface velocities was performed in December 2018 by using GPS tracked floating devices. The model results of surface velocity range are consistent with the experimental data.

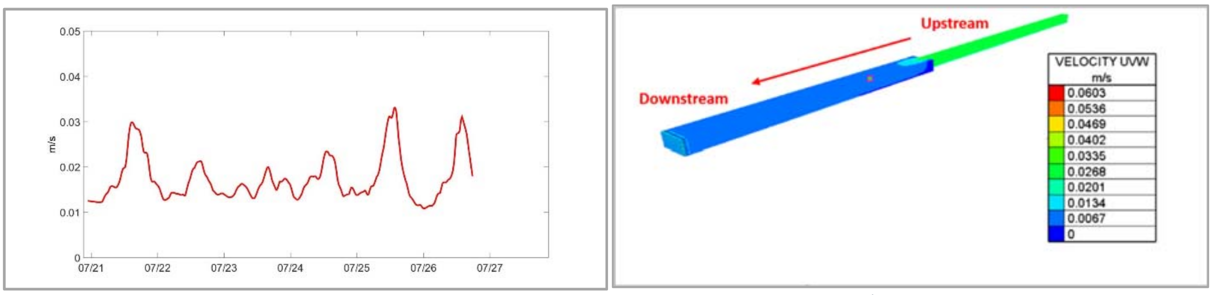

Figure 2 (a) Time evolution of surface water velocity in the bathing area from 21st to 26th July 2017 and (b) Distribution of water velocities in La Villette system at the end of the simulation

The water temperature was simulated using the heat exchange sub-routine. The initial temperature was estimated uniform at 24.8°C. As no measured data are available, temperature measured in a neighbouring water body was used. The simulated surface water temperature shows nycthemeral cycles and a decreasing trend along the simulated period, reaching 21.7°C on 26th July (Figure 3-a). During the simulated period, La Villette canal and basin presented a thermal stratification, with a difference of around 0.5°C between the surface and the bottom.

E. coli transport was simulated considering it as a passive tracer. No decay rate was used. *E. coli* initial concentration was assumed null. At the upstream sampling station, a concentration of 15 MPN/100mL was measured on 21st July and a concentration of 30 MPN/100mL on 25th July. These data were used as input to the model in order to calculate the lag time between the observations at the sampling site and at the bathing site. According to the results, the microbiological contamination takes, on 21st July, 5h50mn to flow from the sampling station to the bathing area and, on 25th July, 5h25mn (Figure 3-b).

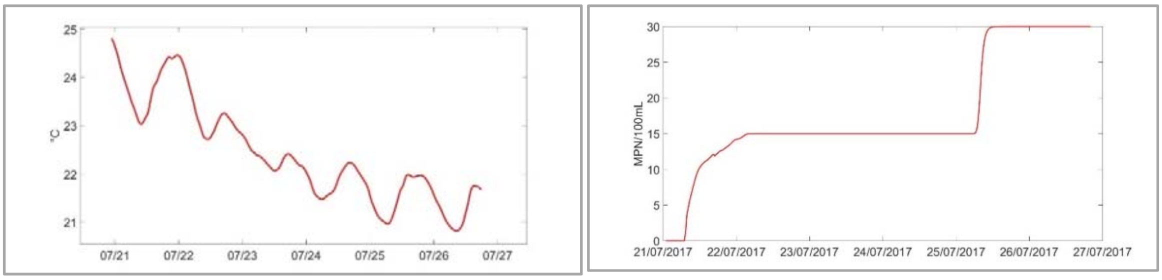

Figure 3 (a) Time evolution of surface water temperature and
(b) Time evolution of surface E. coli *concentration (MPN /100mL) in the bathing area*

4 CONCLUSION

According to the simulation results over a 6 day period (21st - 26th July 2017), the hydrodynamic model Telemac-3D was able to simulate the water velocities in La Villette system in a realistic range, consistent with previous estimations. The model simulated the expected summer thermal stratification, which reaches 0.5°C between surface and bottom layers. This temperature gradient is of the same magnitude as those observed in nearby shallow water bodies with slow water current. The water column cannot be considered well mixed during summer hot periods. This is an important outcome because thermal stratification can impact significantly the transfer time of an upstream contamination, depending on the depth where it was discharged. An accurate survey of water temperature in La Villette system will be performed in order to validate the heat exchange sub-model. Regarding *E. coli*, these preliminary modelling results provided an estimation of the transfer time from the upstream monitoring point to the bathing area. This outcome will allow to better forecast potential sanitary risks. In a further step, a decay rate of *E. coli* biomass, depending on the environmental conditions (water temperature, solar radiation…) will be implemented. *E. coli* initial conditions will be improved by introducing measured background concentrations. This new version of the model will be used to simulate other periods during 2017 and 2018 summers. The final objective is to embed the validated model in a real-time warning system of sanitary risks in the bathing area. The model could also support the measure planning aimed at protecting the bathing area from microorganism peaks, mainly following rain periods.

ACKNOWLEDGEMENTS

This research is part of the OPUR programme. We are very grateful to OPUR, especially for the support of F. Bezerra's scientific internship and to *Service des canaux* (Ville de Paris) for their valuable help.

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