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## Forecasting sanitary risks for open-water swimming in urban areas

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### Abstract:

Urban water bodies are increasingly used for recreational activities, including swimming. The practice of open water swim requires a good water quality, complying with sanitary regulations based on the concentration of faecal indicator bacteria. To forecast a possible sanitary risk, a monitoring station can be implemented upstream of the bathing area. Then the transfer time of the microbiological contaminant must be accurately modelled in order to derive the contamination level in the bathing area. A hydrodynamic model is 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 results of a 3D hydrodynamic model of La Villette basin, the transport of *E.coli* towards the swimming area and the advantages of this modelling approach.

**Keywords:** 3D hydrodynamic modelling, faecal contamination indicators, urban water, *E. coli*, open water swimming.

**Introduction.** Open water swimming is a recent practice in many large cities worldwide. With the next 2024 Olympic Games being held in Paris, France, it has been planned that the triathlon swimming event and the 10km open-water swim would take place in the Seine River. These new outdoor practices, combined with an increasing urban population and with climate change, increase the risk of waterborne epidemics. Moreover, the water quality already impacted by treated wastewater discharges is severely impaired during rainfall events or incidents on the sewerage system that lead to an increase in pathogens of faecal origin (enteric viruses, parasites and bacteria). In order to limit the infectious risks associated with open water swimming, the water quality must comply with health regulations. According to the European Union (EU) Bathing Water Directive (2006/7/CE), two faecal indicator bacteria (FIB) must be monitored: *Escherichia coli* (*E. coli*) and intestinal enterococci. As regulatory microbiological analyses require a delay of 24 to 48 hours, any contact with contaminated waters like swimming may be prohibited too late or too long. Therefore, an effective warning system must be based on reliable measuring stations located upstream of the bathing site with efficient and rapid modelling tools such as hydrodynamic models. These models, adapted to the time and space scales encountered in urban aquatic environments, are still very rare (e.g. Jovanovic et al., 2017; Eregno et al., 2018). In parallel, the emergence of new autonomous *in situ* monitoring systems makes it possible to consider the development of such warning

systems combining continuous measurements and predictive modelling. In this paper, we first aimed at illustrating how a 3D hydrodynamic model can enhance the assessment of microbiological contaminant transfer time from the measuring site to the area of interest. We also investigated how water thermal stratification, during warm summer periods, can modify the contaminant transfer time.

**Material and methods.** The study site is the basin La Villette (Paris, France) in which a swimming area has been open since the summer 2017, as part of *Paris Plage* program. La Villette system (canal and basin), with a length of 1200m, has a very complex hydraulics, as it is often the case in urban areas. Upstream it receives the Ourcq canal and downstream it discharges into the Saint Martin canal. The water level is regulated downstream by a lock and a pumping station (Figure 1). Since 2017 daily data of *E. coli* were transmitted, throughout each summer period, by an *in situ E. coli* measuring station located upstream of the bathing area. In addition, weekly measurements of microbiological quality at both the upstream measuring station and bathing area are available since 2017.

The hydrodynamic model is Telemac3D (v8.p0), the three-dimensional module of TELEMAC-MASCARET modelling suite (Desombre et al., 2016). The computational grid is composed by horizontal triangles of 4m side and 10 layers of 0.30m height. At the connection between La Villette canal and basin, the mesh is smaller, with triangles of 2m side. Regarding the boundary conditions, the upstream flow is defined based on measured discharges. At the outlet, the water level is defined according to the measurements at the water pumping station spillway. The inflow rate and water level time series were provided by *Mairie de Paris*. The initial velocity field of each simulation period was determined through a previous run of Telemac 2D version over a two-day period.

Heat exchange between the water body and the atmosphere was added in the model configuration according to (Desombre et al., 2016). The water temperature was simulated using the heat exchange sub-routine. The initial temperature in the canal-basin system was estimated uniform according to measurements in neighbouring water bodies. The meteorological data (air temperature, pressure, humidity, precipitation, solar radiation, wind velocity and direction, nebulosity) were measured from the *Météo France* weather station located at Orly airport.

The *E. coli* transfer time from the upstream measuring station to the bathing area was simulated considering *E. coli* as a passive tracer. No decay rate was used. *E. coli* initial concentration was assumed null. Discrete *E. coli* inputs of 500MPN/100mL, as an excellent water quality threshold, were launched upstream, every day at 0h.

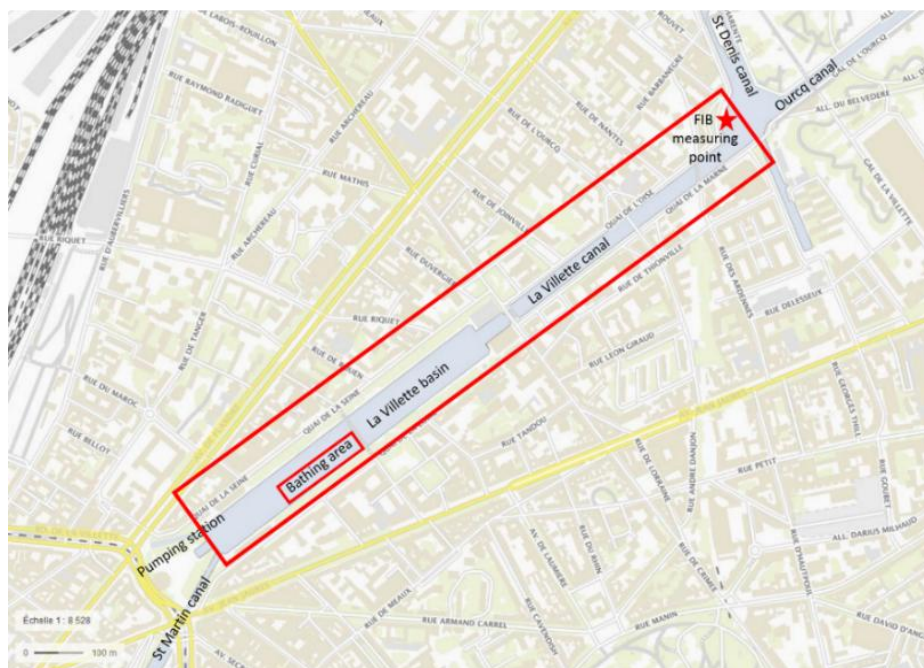
For input data processing and result visualization, Blue Kenue software (v3.3) was used.

**Results.** All the default values of the hydrodynamic model parameters were used, except for the Manning-Strickler coefficient of bottom friction which was calibrated ( $K_s=50\text{m}^{1/3}/\text{s}$ ). We present in this paper the results of velocities and water temperature in the bathing area for different simulation periods representative of typical hydro-meteorological conditions in Spring and Summer 2017. The simulated velocities were within the range of the qualitatively estimated velocities in previous studies. During the warmest simulated periods (for example air temperature of 35°C in June 2017), La Villette canal and basin presented a thermal stratification, with a maximum difference of nearly 1.5°C between the surface and the bottom.

The transfer time of *E. coli* from the upstream measuring station to the bathing area were computed for all simulation periods. We compared these values with the mean transfer time previously simply assessed by dividing the average discharge by the canal and basin sections.

**Discussion and conclusion.** According to the simulation results, the hydrodynamic model Telemac3D was able to simulate the water velocities in La Villette system within a realistic range, which is consistent with previous estimations. The model simulated the expected summer thermal stratification, which reaches 1.5°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 must be noticed when considering the representativeness of the measured data. This is also an important outcome because the thermal stratification can impact significantly the transfer time of an upstream contamination. Regarding *E. coli*, these preliminary modelling results provided good estimations of the transfer times from the upstream monitoring site to the bathing area. A few hour differences between computed lag times by the model and by a simple calculation are not negligible. This outcome shows that the model could be used to provide a more accurate forecast of potential sanitary risks. Moreover, during stratification periods, a difference of up to two hours of *E. coli* transfer time between the surface and the bottom of the bathing area occurred.

In a further step of the study, measured *E. coli* will be used as inputs at the upstream site and a decay rate of *E. coli* densities, depending on the environmental conditions (water temperature, solar radiation...), will be implemented. *E. coli* initial conditions will be based on measured background concentrations. 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 events.



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

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