

Hydrodynamic and microbiological modelling of urban aquatic environments for the prevention of health risks associated with open water swimming

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Since the early 2000s, open water swimming has been growing in many regions of France. In Paris, the organisation of the Olympic and Paralympic Games in 2024 included plans to establish permanent public bathing facilities throughout the Parisian region. However, swimming in urban waterways presents a health risk. In a densely urbanised region, the cause of peaks in contamination is well known. During heavy rainstorms, combined sewerage systems reach saturation point, discharging a mixture of rainwater and wastewater into rivers. In the case of separate systems, the sources are often the result of incorrect domestic connections to the rainwater network. To limit the health risks for swimmers, European regulations (Bathing Water Directive 2006/7/EC) provide for monitoring based on faecal indicator bacteria (FIB). Currently, bathing water quality is monitored daily during the summer season. However, as it takes around 24 hours to obtain the results of regulatory laboratory analyses, it is not possible to detect contamination in time for the bathing area to be closed.

To overcome this limitation, water quality measurements can be taken upstream of the bathing area, at a sufficient distance depending on the flow speed of the water to take account of the analysis time. Combined with digital simulation of the spread of any contaminated water, the measurements taken upstream can then be used to predict contamination in the bathing area. A warning system of this kind therefore relies on two things: reliable and sufficiently frequent measurements, and an accurate and fast digital model.

The objective of the thesis is to test the deployment of this warning system (measurements and modelling) on instrumented study sites.

High-frequency in situ detection of FIB is currently impossible. To address this problem, we can look at the use of a substitute or proxy value. The fluorescence of dissolved organic matter (FDOM) can provide information on the composition of a water matrix. More specifically, Tryptophan-type FDOM (TLF) has been identified as a proxy for BIF. TLF sensors were deployed at two study sites (La Villette Basin in Paris and in the Marne at Joinville-le-Pont and Champigny-sur-Marne) to monitor the microbiological quality of watercourses in situ at high frequency. The measurements were compared with regulatory punctual measurements and other types of continuous measurement.

The use of hydrodynamic models for freshwater bathing sites is still rare. However, the time and space scales in an urban environment and the characteristics of bathing areas, which are artificial and have a complex hydraulic system, require specific hydrodynamic modelling. A model of the La Villette basin has been developed using the openTELEMAC code. It is used to represent the flow of the canal in order to determine the transfer time of bacteria and their spatial distribution as a function of the physical characteristics of the watercourse (thermal stratification, recirculation zones, etc.). The final objective is to be able to use this model, along with continuous measurements upstream, to estimate when the bathing threshold has been exceeded and how long this will last.

Finally, additional high-frequency bacteriological dataset was obtained from measurements taken in the Seine in Paris. This new data enabled contamination episodes to be described with fine temporal resolution. By cross-referencing this bacteriological information with rainfall data, it was possible to study the cause-effect continuum between rainfall and the microbiological quality of rivers. Using statistical dimension reduction methods (PCA and ISOMAP Manifold), a predictive model was developed. Using rainfall data as input, this model estimates the maximum concentration of BIF likely to be observed, and thus categorises rainfall events according to their potential impact on water quality.