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► **To cite this version:**

Guilherme Calabro-Souza, Philippe Dubois, Pedro Azevedo Solino, Mohamed Saad, Arthur Guillot-Legoff, et al.. An integrated system for monitoring the water quality of urban lakes: a decision-making tool for Lake Créteil (France). Novatech 2023, Graie, Jul 2023, Lyon, France. hal-04186706

**HAL Id: hal-04186706**

**<https://hal.science/hal-04186706v1>**

Submitted on 8 Sep 2023

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## An integrated system for monitoring the water quality of urban lakes: a decision-making tool for Lake Créteil (France)

Un système intégré de surveillance de la qualité de l'eau des lacs urbains : un outil d'aide à la décision pour la base nautique du Lac de Créteil (France)

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### RÉSUMÉ

Dans les lacs urbains, la qualité de l'eau et en particulier les proliférations phytoplanctoniques, ont un impact important sur les usages et limitent les activités récréatives et sportives. Les gestionnaires de plans d'eau sont confrontés à des difficultés de prise de décision lorsqu'il s'agit d'éviter les risques sanitaires des usagers. Le lac de Créteil (France), situé dans un bassin versant fortement urbanisé, est utilisé pour des loisirs aquatiques. Le lac a été équipé d'un système de suivi autonome, constitué d'une bouée instrumentée effectuant des mesures *in situ* de température, oxygène, conductivité, chlorophylle-a et phycocyanine (pigment spécifique des cyanobactéries), toutes les 15 minutes. La bouée embarque également une station météorologique. Les mesures sont télétransmises vers un serveur à terre. Un défi majeur pour l'utilisation opérationnelle d'un tel système est d'en assurer la généralité et l'interopérabilité. Cet article présente la conception d'un système de surveillance autonome et l'utilisation d'un logiciel open source pour la standardisation du format des données, leur archivage sur un serveur local et la procédure d'affichage sur une interface web. Les données sont transférées du serveur local vers l'outil graphique à l'aide de l'interface de programmation applicative (API) SensorThings de l'Open Geospatial Consortium (OGC SensorThings API). La visualisation s'appuie sur le logiciel FROST, un logiciel de serveur web comprenant sa propre base de données. L'implémentation de l'API SensorThings (OGC) permet d'interagir avec l'outil de visualisation (FROST). La visualisation sur un site Web de l'évolution temporelle des variables mesurées, permet aux gestionnaires du lac une prise de décision en temps réel.

### ABSTRACT

In urban lakes, water quality and, in particular phytoplankton blooms, have a significant impact on use and limit aquatic activities. Managers of water bodies are faced with difficulties in decision-making to avoid sanitary risks of users. Lake Créteil (France), located in a highly urbanised catchment, is used for water recreational activities. The lake has been equipped with an autonomous monitoring system, consisting of an instrumented buoy that takes in situ measurements of temperature, oxygen, conductivity, chlorophyll-a and phycocyanin (a specific cyanobacteria pigment) every 15 minutes. A weather station is installed on the buoy. The measurements are transmitted to a server on land. A major challenge for the operational use of such a monitoring system is to enable its generality and interoperability. This paper presents the design of an autonomous monitoring system and the use of an open source software to standardise the data format, archive the data on a local server and display them on a web interface. The data transfer from the local server to the graphical visualisation tool is done using the standard SensorThings application programming interface (API) of Open Geospatial Consortium (OGC). The visualisation is based on the FROST software, a web server with its own database. The implementation of the SensorThings API (OGC) allows interaction with the visualisation tool (FROST). The time evolution of the measured variables, plotted on a website allows the lake managers to make decisions in near real time.

### KEYWORDS / MOTS CLÉS

Data model; Data visualization; High-frequency monitoring; Urban lakes; Decision making.  
Format de données ; visualisation des données ; suivi à haute fréquence ; lacs urbains ; prise de décision.

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## 1 INTRODUCTION

Many waterbodies in urban areas are the result of the conversion of former quarries into small sand and gravel-pit lakes integrated into public parks and frequently used for recreational water activities (Mollema and Antonellini, 2016). In the Ile-de-France region, these lakes are managed by different administrative units (city, county and region) and often used for water activities (e.g. canoeing, sailing, swimming...). In addition, these water bodies provide oasis of freshness and allow for the maintenance of green spaces and public heritage. The heavy urbanisation during the last decades in the Ile-de-France region has altered the water quality of these lakes (Mitroi et al., 2022) and algal blooms have recurrently been observed. Some phytoplankton species, such as cyanobacteria, can be toxic to humans. This problem is intensified by climate change (Piccioni et al., 2021).

In order to survey the water quality and to regulate the water use, monitoring protocols have been established. They are primarily based on the visual observation of the physical characteristics of the lake water, if necessary for subsequent sampling and lab analysis of the samples and finally, for the determination of the associated risks. However, algal bloom dynamics is fast (few days) and not necessarily harmful to human health. These conventional procedures can lead to high analysis costs, and the time lag between the field observations and the lab analysis results can delay decision making or even make it incorrect or unnecessary.

Autonomous *in situ* water quality monitoring systems have been implemented in coastal areas or in large lakes. More recently, high-frequency monitoring devices have been deployed in small lakes to track water quality dynamics on an hourly scale (Tran Khac et al., 2018). Since 2014, an instrumented buoy measuring physico-chemical and meteorological variables has been installed in Lake Créteil (France). The *in situ* data have multiple applications including modelling studies of the lake thermal regime (Soulignac et al., 2017) or the dispersion of microbiological contaminants (Hong et al., 2021). In particular, they can provide key local information to lake managers to improve decisions limiting swimming and water use or to target water sampling and analysis.

However, the large diversity of the manufactured sensors, the multiple transfer protocols and data formats bring a major issue for supplying operational data. To overcome this challenge, a unified data model and an interoperable web interface are necessary.

This work focuses on the standard of data format and the open source software, defined for Lake Creteil monitoring system, the design of the developed user interface for displaying the lake measurements in near real-time and presents the display of the web interface.

## 2 MATERIALS AND METHODS

### 2.1 Study site

Lake Creteil (Fig. 1) is located in park, in a highly urbanized area in the Greater Paris region, France. The surface area of the lake is 0.4 km<sup>2</sup> and its width varies between 250 m and 400 m. The average depth is 4 m, with a maximum depth of 6 m. The lake water is used for the park watering on the west bank and for street cleaning. The lake is fed by groundwater flowing from the Marne to the Seine and by the stormwater network from an urban catchment of 1 km<sup>2</sup>.

### 2.2 Monitoring system

The instrumented buoy handles probes to measure water physical-chemical parameters and a weather station. Underwater measurements are performed every 15 minutes and meteorological measurements every 10 minutes. Temperature probes (CS225 Campbell) are placed at five different depths: 0.5 m, 1.5 m, 2.5 m, 3.5 m and 4.5 m. At 1.5 m depth, a multiparameter probe (YSI Exo3) measures oxygen, conductivity, chlorophyll-a and phycocyanin. The weather station measures the wind speed and direction, air temperature, relative humidity, atmospheric pressure, rainfall height, short and long wavelength radiations. A monthly data validation is performed by comparing field measurements using a FluoroProbe (BBE - Moldaenke) and a WiMo multiparameter probe (NKE instruments) to the buoy time series.

The buoy is self-sufficient in energy with a battery connected to a photovoltaic panel. A data acquisition module (CR1000X - Campbell) recovers the data from the different probes and sends them via a GSM protocol to a local server at Ecole des Ponts ParisTech.

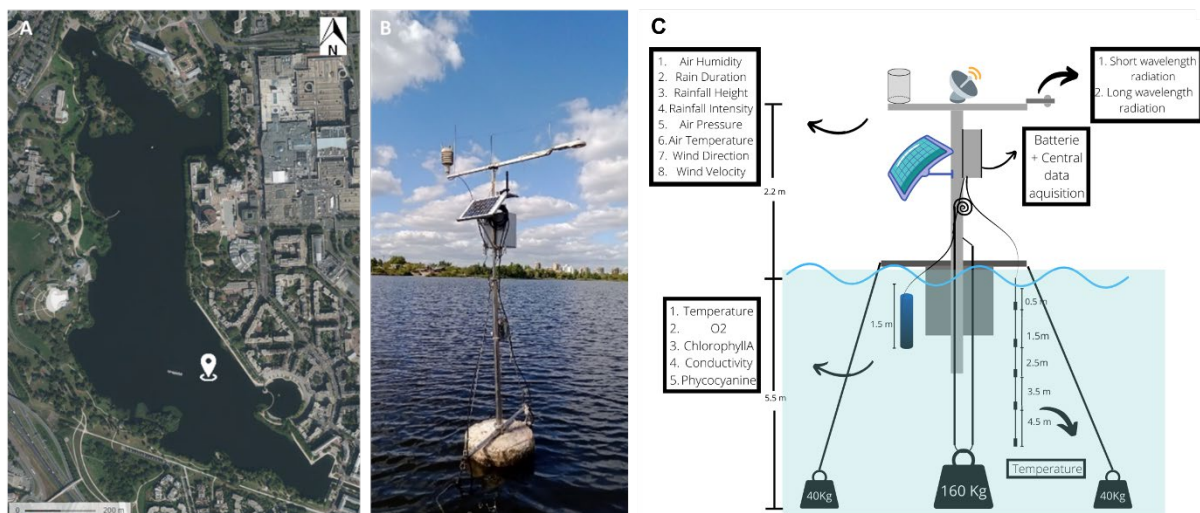


Figure 1 – (A) Satellite view of Lake Créteil (source: Géoportail); (B) the instrumented buoy installed in the lake; (C) schematic representation of the probes: below the water surface the multiparameter probe (1.5m depth) and the temperature chain; above the water surface the weather station, the energy source, the data storage module and the transmission antenna.

### 3 RESULTS

#### 3.1 User interface development

The data collected on the study site are exported to a local database (Fig. 2 - LEESU Server). Python scripts import these data and rewrite them to match a standard format and export them in a temporary JSON file (Fig. 2 – PC Lake). The data are then uploaded in a buffer database (Fig. 2 - FROST Database/Server). This new server is based on the standard format of the OGC SensorThings API, which provides a unified protocol to interconnect sensors, data, and applications on web pages (Liang et al., 2016). The FROST software (Fraunhofer-Opensource-SensorThings-Server) performs the implementation of this standard (Hertweck et al., 2019), used for Lake Créteil data. The data stored in the new database (Fig. 2 – FROST Database/Server) can be visualized on a web page (Fig. 2 – FROST user page), also implemented using FROST.

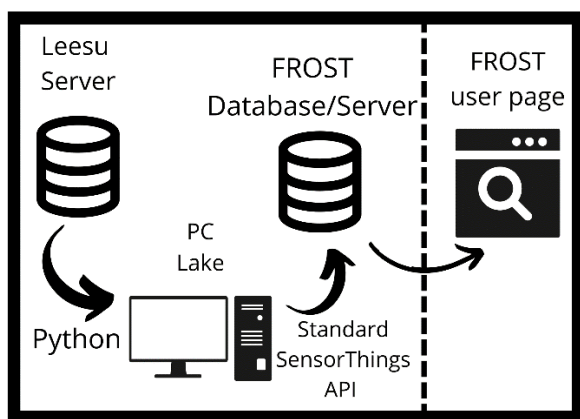


Figure 2 – Schematic representation of the path of the data from the Leesu server to the user interface/page.

#### 3.2 Visualisation of the data

The measurements of the buoy installed in Lake Créteil, are transmitted daily to the FROST database/server and updated automatically on the web page. The time evolution of the data can be seen in near real-time (Fig. 3) and used for decision-making.

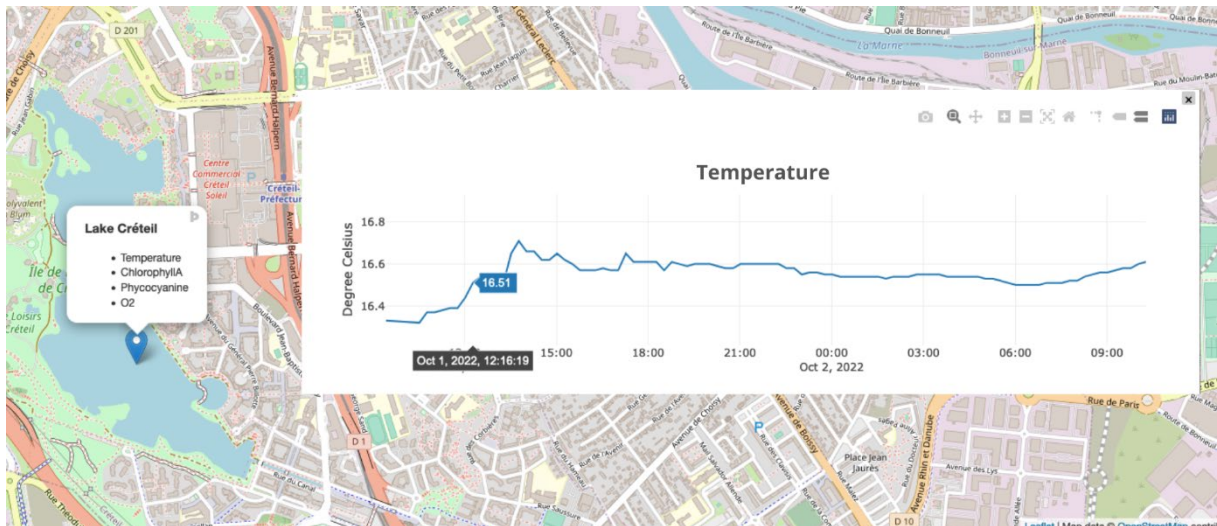


Figure 3 – Screenshot of Lake Créteil website: visualization of the measured temperature at 1.5 m depth over 24 hours (1<sup>st</sup> October 2022)

#### 4 CONCLUSION AND PERSPECTIVES

Linking continuous field data acquisition to their visualization on a website provides a helpful tool for decision-making. In this paper, the design of an autonomous buoy for the water quality monitoring of urban lakes is presented. The unified, interoperable data transfer and visualisation is described. At a regional scale, this unified type of monitoring system could be deployed to create a network of autonomous stations for water quality survey. At a short-time scale, this system can be used as an early-warning system coupling it with a forecast modelling to provide short-term predictive indicators of water quality.

#### 5 ACKNOWLEDGEMENTS

Lake Créteil monitoring system was first developed in the framework of research projects funded by the French National Research Agency (ANR). It is an observation site associated with the OLA facilities (INRAE) and a long-term observation site of the OSU EFLUVE and SNO OBSERVIL, attached to the INSU (CNRS). The authors thank them for the support in maintaining the station.

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