Modelling cyanobacteria blooms in urban lakes. Application to Lake of Enghien-les-Bains.

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Application to Lake of Enghien-les-Bains

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Context

The ecosystems in urban lakes are very vulnerable to human pressure because of their specific physical functioning, characterized by intermittent thermal stratification and low flow speeds. Furthermore, the high intake of nutrients in these environments encourages blooms of phytoplankton, including toxic cyanobacteria, disrupting their use and causing health problems (Catherine et al., 2008). This work focuses on the implementation of a predictive model of cyanobacteria blooms in urban lakes. It is part of a project whose objective is to develop a monitoring and warning system, in real-time, of phytoplankton blooms in freshwater ecosystems.

Lake of Enghien-les-Bains

Lake of Enghien-les-Bains is located in Val-d'Oise, France (48°58'N, 2°18'E) (Fig.1). It is an urban shallow lake (maximum depth: 2.5 m; mean depth: 1.3 m; area: 41 ha; volume: 534 000 m^3), it plays a significant role in the stormwater management of its watershed (54 km^2; over 200 000 inhabitants) by storing up to 100000m^3 of rainwater. The lake receives wastewater discharges from inappropriate connections in the stormwater network. This input results in a deterioration of the water quality and the lake is frequently affected by cyanobacteria blooms (Quiblier et al. 2008). In July 2009, the cyanobacterial biomass has reached 300 µgChlaL^{-1} (Silva, 2010). The prevailing species, *Planktothrix agardhii*, is potentially toxic and is usually found in the first meters of the water column in shallow turbid eutrophic lakes.

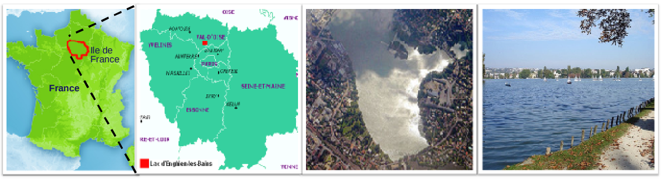

Fig. 1 : Lake Enghien: Location in France (**A**) Watershed (**B**) Air view (**C**) Landscape view (**D**)

DYRESM-CAEDYM

DYRESM is a one-dimensional numerical model for predicting the vertical distribution of temperature and density in lakes and reservoirs. It is based on a Lagrangian layer scheme (Imerito 2007). DYRESM was coupled to CAEDYM, the aquatic ecosystem model to simulate the cyanobacteria dynamics (Hamilton and Schladow, 1997). The input data are the lake morphometry, inflows, outflows, meteorological forcing (wind speed, air temperature, solar radiation, rainfall, cloud cover and vapor pressure), and the initial conditions for all variables to model (Fig. 2).

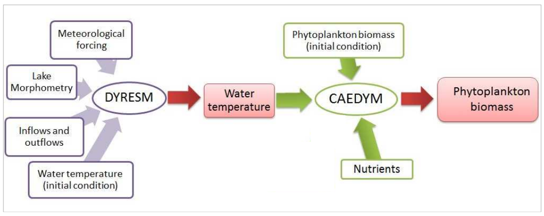

Fig. 2 : Coupled Dyresm – Caedym model

Measurement buoy

The data required for modelling (except the lake morphometry, flows and the nutrients) were obtained from a freshwater-adapted measurement buoy installed on the lake in November 2008. This buoy was located at the deepest region of the lake and it was equipped with meteorological sensors and immersed measuring probes of water quality parameters (Fig. 3). The measurements were performed in high frequency, every 30 min, at a depth varying from 0.50 to 1.0 m (for water parameters). Data were transmitted through GPRS protocol to a database as a daily email. If a shorter time step was necessary, the buoy could be remotely queried, which allows the continuous monitoring in a real-time of the physical-biological conditions of the lake.

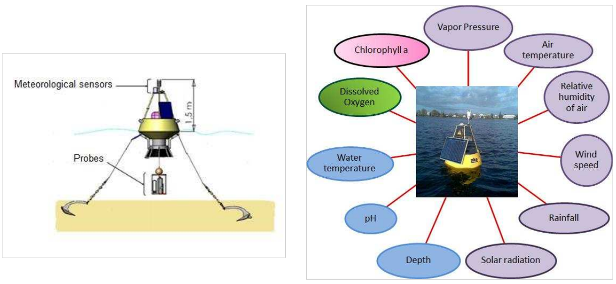

Fig. 3 : Mooring scheme of the buoy (**A**) measured parameters (**B**)

The lake morphometry was obtained from studies carried out for the lake management by the *Syndicat Intercommunal d'Assainissement de la Région d'Enghien-les-Bains* (SIARE). The 2009 flows were not available, however, during dry weather, the inflow is approximately 8 100 m^3day^{-1}(SIARE, 2004). Using a water balance, the outflow was set equal to 5 000 m^3day^{-1}. Subsequently, in order to verify the reliability of the results, the model sensitivity to flows was checked. Flow variation causes only insignificant changes in the model result. The nutrient concentrations (N and P) were obtained from a monthly monitoring of the lake physical-chemical parameters conducted from November 2007 to June 2008 (Marchandise 2008).

First results

The DYRESM model was run for the period from 1st April to 17th August 2009, the hottest period of the year and therefore, more favorable to cyanobacteria blooms (Fig. 4A). The maximum and minimum layer thickness was defined, respectively 0.16m and 0.70 m. The modelling of the cyanobacteria dynamics was conducted during a shorter period, from 1st to 20th June 2009 when cyanobacteria are the prevailing phytoplankton group (Fig.4B).

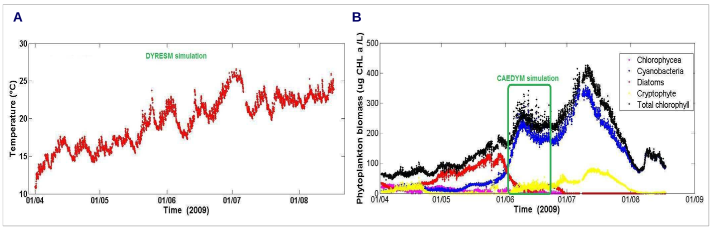

Fig. 4 : Buoy measurements: water temperature (**A**) and phytoplankton biomass (**B**)

The model performance was checked by using 4 indicators : the correlation coefficient, the arithmetic mean of the errors, the standard deviation of the errors and the root mean squared value of the errors (RMSε). The error arises from the difference between the model results for water temperature and phytoplankton biomass and the measures from the buoy, at the same time and at the same depth.

	Temperature	Phytoplankton
Correlation coefficient	0.91	0.84
Arithmetic mean	0.03°C	-14µgChl$_a$.l^{-1}
Standard deviation	1.01°C	23.9 µgChl$_a$.l^{-1}
RMSε	1.01°C	27.7 µgChl$_a$.l^{-1}

Discussion

The thermal model was able to adequately represent the daily cycles and the seasonal changes in water temperature (Fig 5A). Moreover, despite the shallowness of the lake, a thermal stratification at a depth of 2.0 m was noted during the summer (Fig 5B).

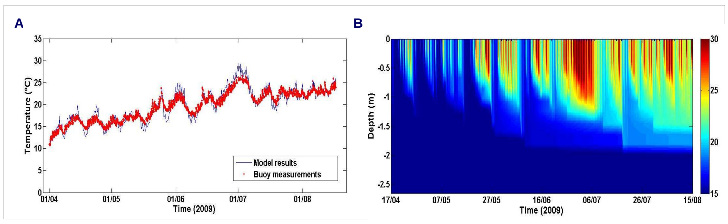

Fig. 5 : Model results versus buoy measurements for water temperature (**A**) and water temperature profile simulated (**B**).

Concerning the biological simulation, the negative value of the arithmetic mean indicates that the model underestimates the phytoplankton biomass (Fig 6A). It has been stated in several studies on cyanobacteria that nutrient concentration is very significant to phytoplankton growth (Quiblier et al. 2008). In an urban lake, the stormwater discharge may play a role in triggering the proliferation of phytoplankton because nutrient load can rapidly increase during rainfall events. Therefore, the underestimation of the model results for the phytoplankton biomass may be related to the rain occurred during the simulation period (Fig 6B).

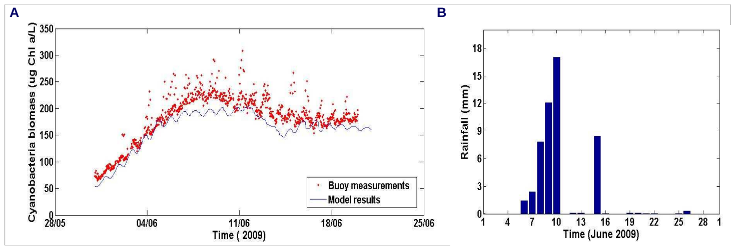

Fig. 6 : Model results versus buoy measurements for phytoplankton biomass (**A**) and rainfall during the simulation period (**B**).

Knowledge about nutrient inputs is necessary to improve the model results, specially during rain events. To broaden the simulation period, other groups of phytoplankton and zooplankton community should be taken into account because of the competitive relations to be imposed on cyanobacteria. Model validation on a data set different from that used for calibration will make it usable as a tool for predicting short and medium term cyanobacteria blooms in urban lakes such as Lake of Enghien-les-Bains.

Conclusion and perspectives

These results show the advantage of coupling this type of model with high frequency measurements, to simulate the phytoplankton biomass in a shallow urban lake. The model showed a good performance in simulating the cyanobacteria dynamics in an urban shallow lake. Moreover, DYRESM-CAEDYM can be employed as a predictive model of phytoplankton blooms based on the chlorophyll and nutrient concentrations and on the weather forecast.

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