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A tool for better management of water quality during periods of algal blooms: the case of the River Oise

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Like other rivers in the Paris area, the Oise is subject to important seasonal algal blooms. This eutrophication generates notable problems for the production of drinking-water from a treatment plant on the river at Méry. A mathematical model has been developed to simulate variation in water quality in a pre-treatment storage basin, and another model is currently being adapted to model the River Oise. Integration of the two models should provide a comprehensive tool for predicting variations of phytoplankton and water-quality parameters associated with algal blooms. This will be a decision-aid for optimizing control of the treatment process for providing potable water.

Introduction

Seventy-five percent of water distributed in the Ile-de France region around Paris comes from surface water. The Compagnie Générale des Eaux supplies almost 2 million cubic metres of drinking water per day from three large treatment plants installed on the Seine, Marne and Oise rivers. The treatment plant located on the River Oise at Méry has a capacity of 270,000 m^3 d^{-1}. The treatment plant is fed by water from the river after retention for about 3 days in a 400,000 m^3 storage reservoir.

Like the other rivers in the Paris area, the Oise is subject to important seasonal algal blooms which appear in early April and last until the end of May. Figure 1 shows the evolution of chlorophyll-*a* concentrations at the sampling station of Méry sur Oise. Diatoms dominate at the

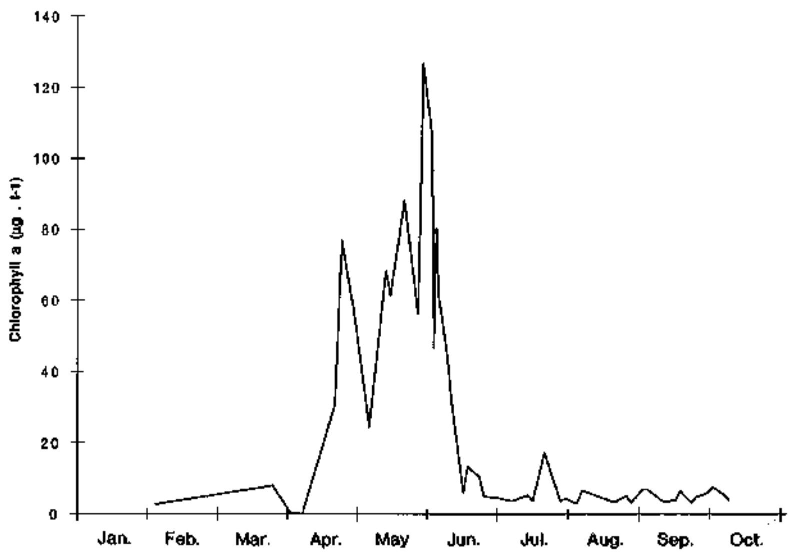

Figure 1. Seasonal evolution of chlorophyll-*a* concentrations in the River Oise at Méry sur Oise.

beginning of the bloom and Chlorophyceae are more important later. A very good and significant correlation between chlorophyll-*a* and phytoplankton cell numbers is found. At other sampling stations on the River Oise we have observed higher concentrations, but these were below 200 μg l^{-1} chlorophyll-*a* in 1991.

This eutrophication of the river generates notable problems for drinking-water production. Variations in pH, ammonia and oxygen concentration are associated with algal activity and this can appreciably modify the necessary water-treatment parameters. In order to obtain a better understanding of these phenomena, we began to develop a mathematical model to simulate water-quality variation. This work is done in cooperation with Professor Billen and his team at the University of Brussels. The first step of the study, now completed, was to simulate water quality in the storage reservoir at Méry. The second step, currently being developed, is focused on adapting a new model to simulate conditions in the river. Integration of the two models should then give us a comprehensive tool for predicting the variation of phytoplankton and water-quality parameters during the period of algal blooms, providing us with an aid to decision-making for controlling the optimal production of potable water.

The reservoir model

The main objective of the reservoir model was to produce a dynamic description of the most important processes of transformation in the reservoir. The model takes into account sedimentation and phytoplankton dynamics, and also organotrophic bacterial activity and mineralisation of organic matter in the sediment.

The model is composed of four sub-models, enumerated below.

(1). *Sedimentation.* This sub-model relates suspended matter in the reservoir to suspend matter in the river and evaluates net sedimentation.

(2). *Phytoplankton.* This sub-model calculates phytoplankton primary production and chlorophyll content in the reservoir from the chlorophyll concentration in the river, given incident light intensity and temperature. It is linked to sub-model (1), because suspended matter determines the coefficient of light penetration and because phytoplankton also undergoes a process of sedimentation which must be taken into account.

(3). *Organotrophic bacterial activity.* This sub-model evaluates dissolved and particulate organic carbon content, based on concentrations in the river, together with primary phytoplankton production and bacterial decay. It is related to sub-model (2) as phytoplankton production is a source of organic matter.

(4). *Mineralization of organic matter in the accumulating sediments.* This sub-model evaluates the fluxes of nutrients and oxygen through the water–sediment interface, as well as seasonal and long-term variations.

Simulations with the model

The model of the natural processes occurring within the reservoir can be coupled with a simplified hydrodynamical model accounting for the different ways in which the storage reservoir can be operated. Two examples are given below.

In the first example we simulate events where water is drawn out of the reservoir at a constant rate, but is not replaced from the river, so water depth gradually decreases in the reservoir (Fig. 2). In this case, ammonia-nitrogen and phytoplankton increase rapidly. The chlorophyll-*a* concentration reaches approximately 200 μg l^{-1} after 4 days and there is then a real risk of severe eutrophication.

In the second example we simulate events where the reservoir is shut-off for periods of 5 to 10 days. i.e. there is no inflow or draw-down of water. A strong vertical stratification appears in the reservoir (Fig. 3). The main risk is excessive development of phytoplankton,

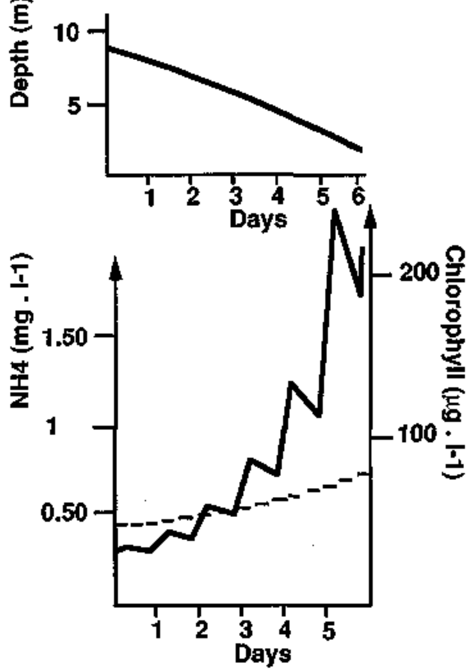

Figure 2. Model simulation of the evolution of water depth (m), ammonia-nitrogen (mg l^{-1}) and chlorophyll-*a* concentrations (µg l^{-1}) in the storage reservoir during a theoretical withdrawal of water at a constant flow rate (50,000 m^3 d^{-1}) in summer-time.

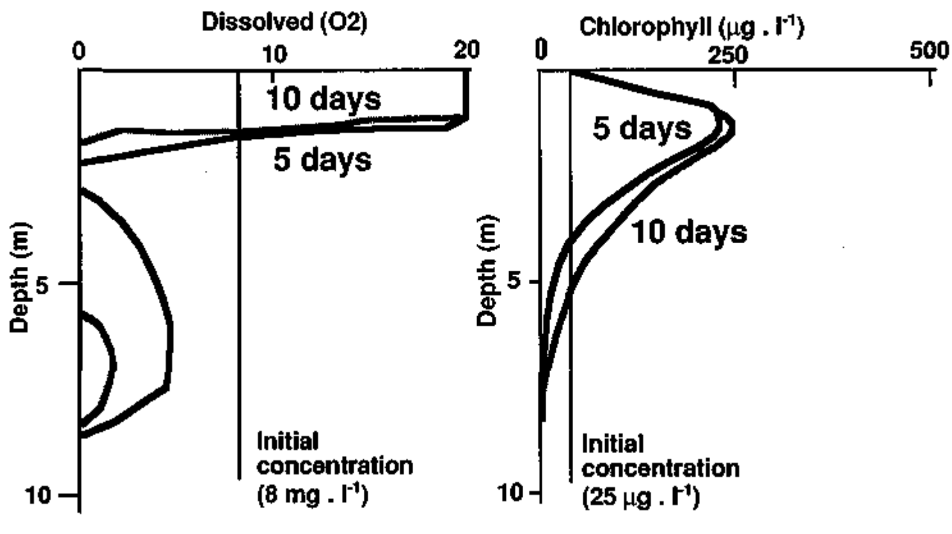

Figure 3. Model simulation of oxygen concentration profiles (mg l^{-1}) and chlorophyll-*a* concentrations (µg l^{-1}) established 5 and 10 days after shutting off the reservoir (zero input and output of water) in summer-time.

accompanied by oversaturation of oxygen in the photic zone (0–4metres depth) and undersaturation in the subphotic zone which may lead to anoxia.

We now turn our attention to the development of a model for the river.

Phytoplankton development in the river

The development of phytoplankton biomass is a result of the competition between biological growth and physical dispersion of cells (Vandevelde *et al* 1987). According to Kierstead & Slobodkin (1953), accumulation of biomass occurs when the net growth rate (including grazing by zooplankton) is higher than the dispersion rate by physical factors.

Light, temperature and nutrients are the factors that control the growth. They are proximal agents controlling cell physiology. Figure 4 gives an example of photosynthetic production at different light intensities in the River Seine during summer. Experiments, based on carbon-14 assimilation, showed the importance of light and allowed us to precisely define the characteristics of production versus photosynthetically active radiation. The variations of production observed between the four sampling dates are mainly explained by a temperature effect. This is confirmed by the good correlation observed between temperature and phytoplankton production in the rivers of the Seine basin, with a marked increase of production when temperature increases (Fig. 5) (for more detail, cf. Hanset *et al.* 1991).

Figure 6 shows an example of the seasonal evolution of zooplankton, with a large increase in numbers of zooplankters at the end of May. This was accompanied by a substantial decrease in phytoplankton, indicating the importance of grazing by zooplankters in determining variation in phytoplankton biomass.

Phytoplankton production is also dependent on the concentrations of nutrients such as phosphorus. In the River Oise, phosphorus is not limiting, but in some of its tributaries the concentrations of phosphorus are very low and could be a limiting factor for phytoplankton growth.

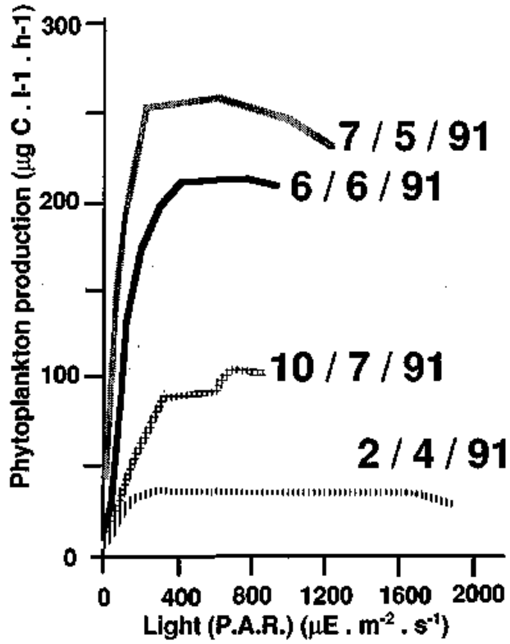

Figure 4. The observed effect of light (photosynthetic active radiation, PAR; µE m^{-2} s^{-1}) on phytoplankton biomass (µg carbon l^{-1} h^{-1}) measured (by ^{14}C assimilation) in the River Seine on four occasions during April to July 1991.

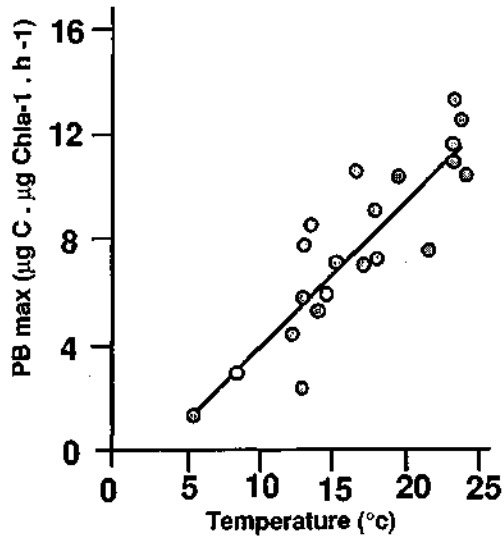

Figure 5. The effect of temperature on phytoplankton production (PB_{max}; µg carbon per µg chlorophyll-*a* h^{-1}) measured in rivers of the Seine basin during 1991.

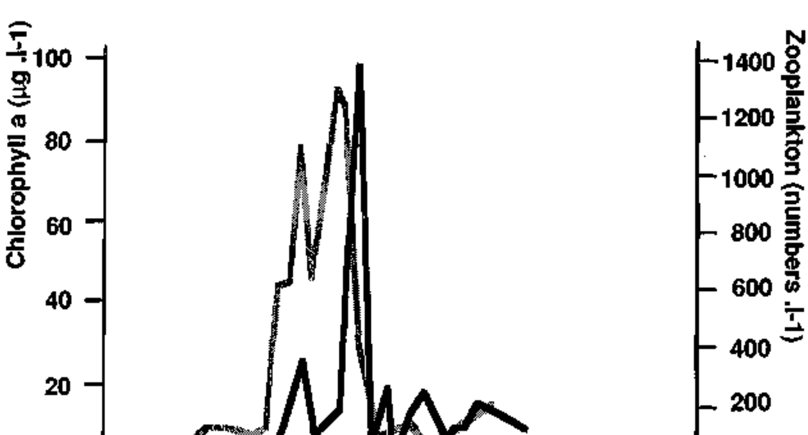

Figure 6. Seasonal evolution of chlorophyll-*a* concentrations (µg l^{-1}) and the impact of grazing by zooplankton (numbers l^{-1}) in the River Seine during 1991.

A biological model for the River Oise

The analysis of the effects of light, temperature and other parameters that influence the production of phytoplankton have been used to produce basic equations for a biological model of the river, shown in Figure 7, where major variables are depicted within circles and major processes are represented in square boxes.

The biological model works in conjunction with a simple hydrological description, based on Strahler's conceptual model (Strahler 1957, 1958) representing a drainage basin by a regular confluence scheme of increasing rank-order tributaries (Fig. 8).

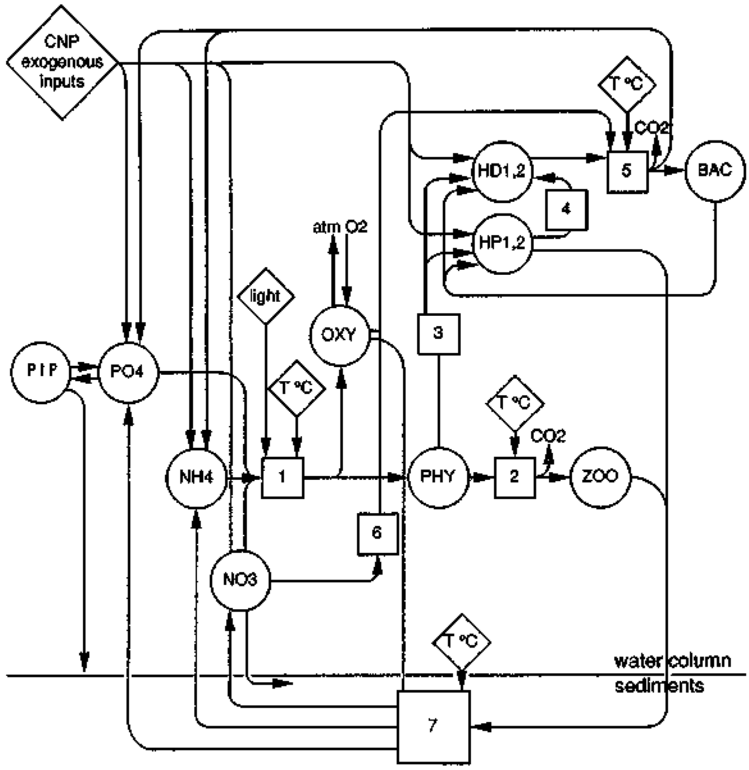

Figure 7. A summary of the biological model for the River Oise.

Circles denote major variables: phytoplankton (PHY), zooplankton (ZOO), heterotrophic bacteria (BAC), dissolved organic matter (HD, 1, 2) and particulate organic matter (HP 1, 2), oxygen (OXY), ammonium (NH_4), nitrate (NO_3), phosphate (PO_4) and inorganic adsorbed phosphorus (PIP).

Numbered squares denote major processes: 1, photosynthesis, prevalence of nutrients, phytoplankton growth; 2, zooplankton grazing, growth, respiration and excretion; 3, algal excretion and lysis; 4, bacterial hydrolysis of particulate organic matter; 5, bacterial hydrolysis and utilisation of dissolved organic matter, bacterial respiration, excretion and growth; 6, denitrification; 7, processes in the sediments which affect the water column (cf. Billen & Servais 1989, 1991).

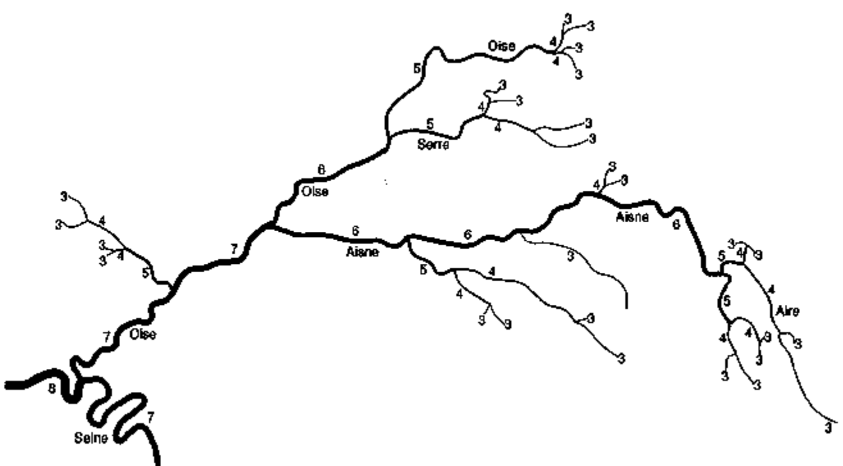

Figure 8. Schematic representation of the Oise basin (16,900 km^2) with hydrological ranking of tributaries (stream orders 1 and 2 not shown).

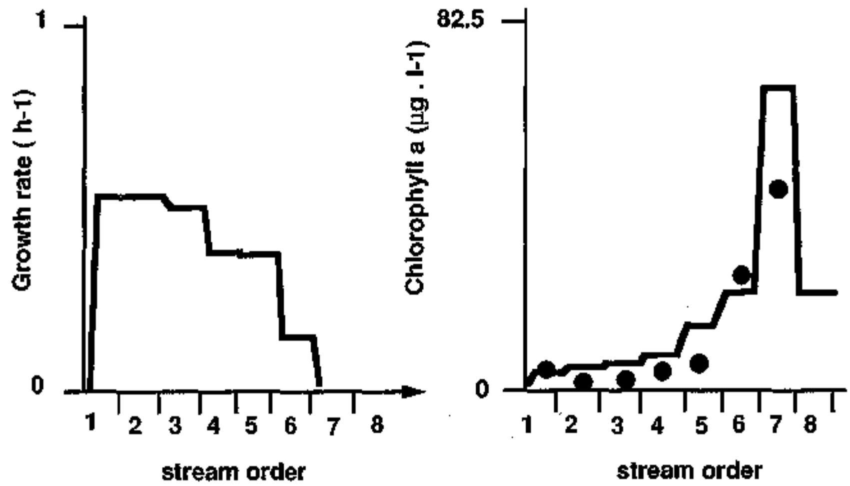

Figure 9. On the right, phytoplankton biomass (µg chlorophyll-*a* l^{-1}) is shown for seven classes of tributaries of the River Seine in April 1991. Measured biomass (points) is plotted against a preliminary simulation (solid line) of biomass using the biological river model shown in Fig. 7. On the left, simulated phytoplankton growth rates are shown against stream rankings.

There is a clear relationship between the rank-order of tributaries and some parameters that control the accumulation of biomass, such as dilution rate, light or hydrodynamics. Field sampling showed that the phytoplankton biomass is low in tributaries with a low hydrological ranking. In fact, biomass development is greatest in rivers where there is a favourable balance between phytoplankton growth and dilution rate. An initial trial simulation with the model gave reasonable agreement with measured phytoplankton biomass (chlorophyll-*a*) in the River Seine; the largest biomass occurred in the river ranked seventh (Fig. 9).

The next step of our work will be to complete the model for the River Oise and link it with the model for the storage reservoir.

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