

# Modelling of a relationship between phosphorus, pH, calcium and chlorophyll-a concentration

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## Abstract

The influence of algal growth on phosphate concentration in water was qualitatively simulated by means of a mathematical model. Phytoplankton, by carbon uptake through photosynthesis, decreases the carbonate concentration which results in equilibrium shifts through several connected chemical reactions that increase the supply of phosphorus to the phytoplankton. This internal cycling mechanism probably serves as a substantial source of P during the development of an algal bloom.

Based on these shifts, the developed mathematical model shows that, depending on the phytoplankton biomass, the phosphate (PO<sub>4</sub>-P) concentration in the water could increase, remain more or less the same, and/or decrease during an algal bloom. The proposed mathematical model suggests that calcium concentration, pH and chlorophyll-a concentration may play an important role in the solubility of phosphate in aquatic ecosystems.

## Introduction

The three major environmental variables that control photosynthesis in water bodies are light, temperature and nutrient availability (Peterson et al., 1987), and there is a general correlation between the nutrient status of a body of water and its primary productivity (Riley and Prepas, 1985). Almost all studies on eutrophication emphasise the importance of nitrogen (N) and phosphorus (P) as major causes of excessive algal growth (e.g. OECD, 1982).

Several studies show a limiting effect of P for phytoplankton growth in temperate lakes and reservoirs (Bostrom et al, 1982), but in certain tropical regions, N seems to be a critical nutrient (Henry et al., 1984). The conventional wisdom is that inorganic N is generally limiting in the oceans while inorganic P limits phytoplankton growth in freshwater environments (Harris, 1986). The major conclusion of the Co-operative Programme on Eutrophication (OECD, 1982) is that phosphorus availability controls algal biomass (chlorophyll-a) concentration in most of the lakes studied.

A significant positive correlation between average chlorophyll-a concentration and average total phosphorus (TP) has been documented by numerous investigators (e.g. OECD, 1982; White, 1989; Roos, 1992). Several authors have shown that the summer chlorophyll-a concentration in lakes is closely correlated to the concentration of winter TP or TP at spring overturn (e.g. Edmondson, 1969; Riley and Prepas, 1985; Golterman, 1988).

TP occurs in aquatic systems in three different components, namely:

- \* soluble reactive phosphorus (SRP) or phosphate, the form thought most likely to represent the phosphorus directly available to algal growth;
- \* soluble non-reactive phosphorus, which is largely organic and at least partially available to algal growth through enzymatic hydrolysis; and

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paniculate phosphorus, which is stored in living cells, present in organic detritus, and adsorbed on abiotic paniculate surfaces (Aueretal., 1986).

In water, phosphorus usually occurs in the oxidised state, either as inorganic orthophosphate ions or in organic, largely biogenic, compounds (Reynolds, 1984).

The relationship between chlorophyll-a concentration and phosphate phosphorus is, however, not clear. It has often been stated that phosphorus limits phytoplankton growth in lakes because the concentration of phosphate (SRP) is very low (Harris, 1986). Phosphate phosphorus limitation of algal growth or production has been reported in several streams (Newbold, 1992). In all cases the supposedly limiting concentrations of phosphate were equal or less than 15 ug-l<sup>-1</sup> and frequently less than 5 ug-l<sup>-1</sup>, but a direct measurement of phosphate in water rarely gives an accurate measure of the phosphorus available to algae (Fogg, 1980; Reynolds, 1984; Harris, 1986). Determining the concentration of a nutrient (i.e. a state variable) is not necessarily an indication of whether or not it is limiting. What one needs to know is the pool size and the rate of turnover, i.e. the rate variable (Harris, 1986). For example, Bostrom et al. (1982) showed that lake sediments (as a nutrient pool) play an important role in the overall phosphorus metabolism in lakes. Caraco et al. (1992) indicated that the P supply to Mirror Lake (USA) by surface runoff and precipitation accounted for less than 19% of calculated algal demand. They suggested that a possible explanation for this phenomenon is that recycling of nutrients in surface water provides almost the entire requirement for phytoplankton growth. Additional interacting factors are the mechanisms that algae have developed to overcome phosphorus deficiency. These include luxury consumption, the ability to use phosphate at low levels and alkaline phosphatase production (Goldman and Home, 1983).

However, it has been generally observed that blooms of planktonic algae appear in freshwater when concentrations of phosphate and nitrate are at their lowest (Fogg, 1980; Eriksson and Forsberg, 1992; Istvanovics et al., 1992). This happens because assimilable forms of N and P decrease simultaneously with the increase of biomass. For example, Edmondson (1969) demonstrated