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Nutrient Reduction or Nutrient Control?

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Rethinking wastewater treatment plant effluent standards: nutrient reduction or nutrient control?

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Many surface waters in the world suffer from eutrophication. Major investments in wastewater treatment plants (WWTPs) in developed countries have been made the last decades to meet the regulations enforcing reduction of nitrogen and phosphorus emissions. As a positive result, nutrient levels in receiving surface waters are decreasing. However, blue-green algae blooms appear to occur more often[1]. Nitrogen limitation, as well as increased temperatures, contribute to these blue-green algae blooms.[1,2] Blue-green algae blooms can produce metabolites, toxic to many organisms including humans, presenting risks regarding safe drinking water supply and possible health problems for e.g. swimmers.[1,3]

Controlling nutrient levels and ratios are possibly effective means to prevent blue-green algae blooms. Although wastewater treatment plants have always been assessed by their nutrient removal efficiencies, they could also act as points for controlled nutrient release to actively control the nutrient levels and nutrient ratio in receiving surface waters.

Wastewater treatment plant operators face strict effluent regulations. In Europe, they have to meet the European Urban Wastewater Treatment Directive and the Water Framework Directive (WFD), while in the United States effluent discharges to surface waters are regulated under the National Pollutant Discharge Elimination System (NPDES) and the Clean Water Act (CWA). These regulations have in common that they focus on effluent limits on a general minimal level and, where necessary, more stringent limits regarding nitrogen and phosphorus removal. This approach, however, can have a downside, which is illustrated in the following situation.

European Union countries have to meet the WFD requirements, with the objective to obtain a good status (clear water, without (blue-green) algae (blooms)) of groundwater and surface waters. To get clear water, eutrophication should be reduced. Therefore, in the last few decades efforts have been made to reduce the nitrogen and phosphorus discharges into freshwater systems, with on average quite good results (see Figure 1). However, despite large reductions in nitrogen and phosphorus discharge to freshwater systems, blue-green algae blooms occur more frequently.[1] Unfortunately, this is the result of the accepted notion among policy makers that eutrophication can be reduced or limited by nitrogen or phosphorus limitation, despite evidence in literature, that eutrophication of freshwater systems cannot be controlled solely by nitrogen limitation.[5,6] Instead, eutrophication could solely be controlled by phosphorus limitation.[4] In addition, the ratio of nitrogen to phosphorus (N:P ratio) in surface waters should not be neglected.[7] A low N:P ratio favours the growth of blue-green algae with nitrogen fixing capacities compared to other algae.[2] Moreover, low nitrate concentrations can also lead to an increase in release of phosphorus from the sediment[8], which in turn reinforces a low N:P ratio. If the relative abundance of blue-green algae in the algae community increases, the grazing pressure of zooplankton (such as Daphnia) on algae decreases because the blue-green algae negatively impact the zooplankton. These effects create situations in which blue-green algae dominate, despite overall relatively low nutrient concentrations.

To restore the water bodies to the required oligotrophic state, the phosphorus load (phosphorus emissions and release of phosphorus present in the surface water body (mainly present in the sediment bed)) should be reduced[9] and care should be taken that the N:P ratio in the freshwater system stays high enough to prevent a growth advantage for blue-green algae.

Surface water nutrient load originates from diffuse sources as well from point sources. E.g. in the Netherlands, WWTPs contribute to 34% of the annual phosphorous load and 14% of the annual nitrogen load, while agriculture contributes 62% for phosphorous and 41% for nitrogen. The diffuse sources are difficult to control actively, but the point source effluent of a WWTP can easily be controlled. This effluent could be used to increase the nitrogen concentration of surface waters by discharging higher nitrate concentrations in spring and summer. The nitrogen should be released during the spring and the summer when the water temperatures are rising, to counteract the warmer water conditions that are favorable for blue-green algae blooms. Higher nitrate concentrations lead to higher N:P ratios at which blue-green nitrogen fixing algae can be outcompeted by green-algae and plants. The take up of phosphorous by the green-algae and plants result in a situation where phosphorous is no longer available for the blue-green nitrogen fixing algae.[2] Research has demonstrated that additional discharge of nitrate does not lead to additional eutrophication of surface water.[10] As such, it is a safe option for controlling blue-green algae blooms during the next decades when the phosphorus load in the sediment bed and phosphorus release from agriculture will remain too high to control these blooms.

This approach requires flexibility in the effluent standards, allowing to discharge more nitrate when appropriate for improving surface water quality. This flexibility is lacking in current regulations, as these regulations perceive the WWTP as a means to protect the surface water rather than as an installation capable of creating effluent that could control and improve the surface water.

Controlling effluent quality is by no means the final and sole answer to blue-green algae blooms. Reduction of the phosphorus load, reduction of the fish population to relieve the grazing pressure on zooplankton[11] and, if possible, reducing hydraulic retention times may all be necessary. However, by focusing on current effluent limits aiming at surface water protection rather than surface water control, a big opportunity for improvement is missed. A holistic approach towards effluent limits could be beneficial to both surface water quality as well as to other recent objectives for WWTP performance, such as resource recovery.

Flexible discharge limits for WWTPs related to the desired status of the surface waters could transform WWTPs from a nutrient removal facility to a nutrient control facility. This challenges further research on flexible control of WWTPs, decision support for balancing conflicting objectives for freshwater and saltwater[12], and on the influence of nutrient concentration dynamics on algal bloom dynamics. The latter would also stimulate further development of water quality monitoring, as data to facilitate this research is scarce.

Author Contributions

The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript. ‡These authors contributed equally.

Notes

The authors declare no competing financial interest.

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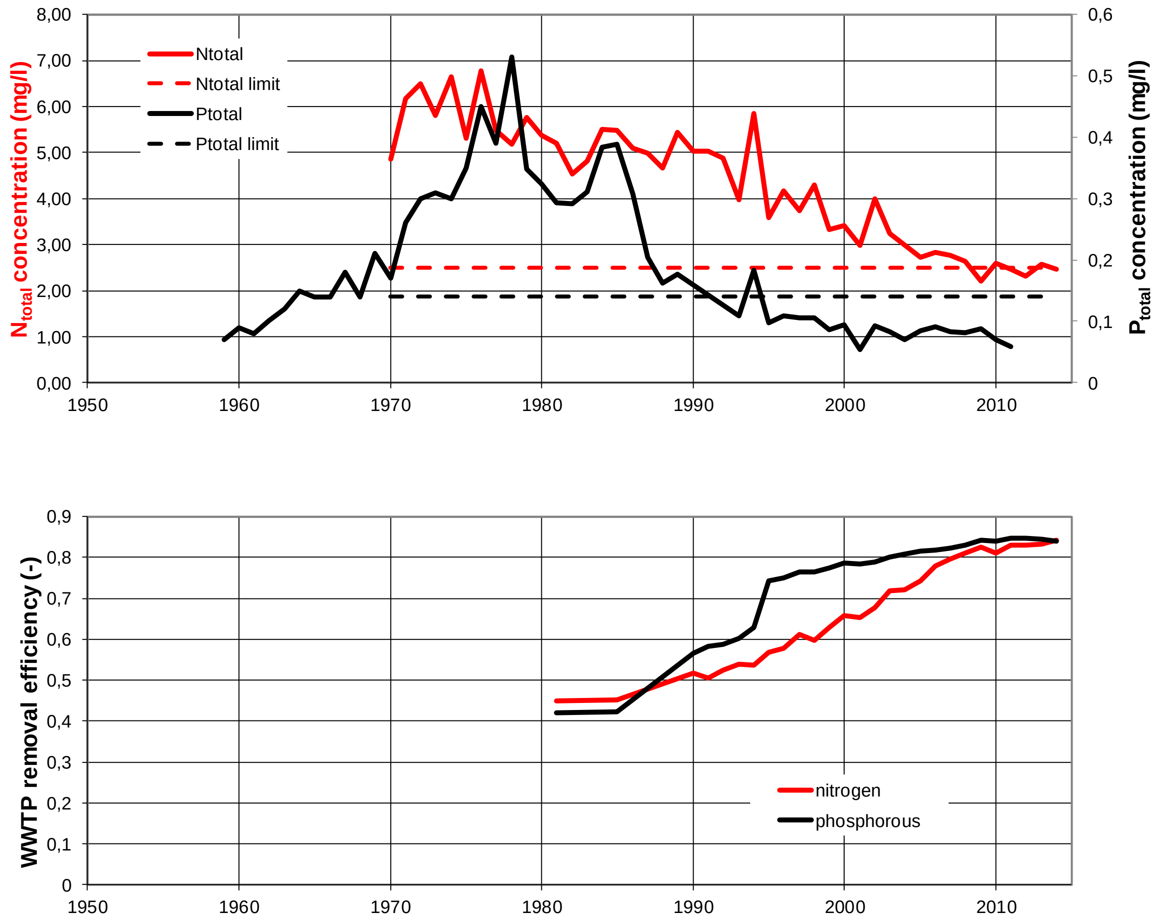

Figure 1. Nutrient concentrations in Dutch rivers (top) and nutrient removal efficiency at Dutch WWTPs (bottom). The minimal required average removal efficiency for nitrogen and phosphorous is 75%. (Source: statline.cbs.nl)