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# Real-time nutrient monitoring in rivers: adaptive sampling strategies, technological challenges and future directions

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Excessive nutrient concentrations in river waters threaten aquatic ecosystem functioning and can pose substantial risks to human health. Robust monitoring strategies are therefore required to generate reliable estimates of river nutrient loads and to improve understanding of the catchment processes that drive spatiotemporal patterns in nutrient fluxes. Furthermore, these data are vital for prediction of future trends under changing environmental conditions and thus the development of appropriate mitigation measures. In recent years, technological developments have led to an increase in the use of continuous in-situ nutrient analysers, which enable measurements at far higher temporal resolutions than can be achieved with discrete sampling and subsequent laboratory analysis. However, such instruments can be costly to run and difficult to maintain (e.g. due to high power consumption and memory requirements), leading to trade-offs between temporal and spatial monitoring resolutions. Here, we highlight how adaptive monitoring strategies, comprising a mixture of temporal sample frequencies controlled by one or more 'trigger variables' (e.g. river stage, turbidity, or nutrient concentration), can advance our understanding of catchment nutrient dynamics while simultaneously overcoming many of the practical and economic challenges encountered in typical in-situ river nutrient monitoring applications. We present examples of short-term variability in river nutrient dynamics, driven by complex catchment behaviour, which support our case for the development of monitoring systems that can adapt in real-time to rapid environmental changes. In addition, we discuss the advantages and disadvantages of current nutrient monitoring techniques, and suggest new research directions based on emerging technologies and highlight how these might improve: 1) monitoring strategies, and 2) understanding of linkages between catchment processes and river nutrient fluxes.