Elevated phosphorus inputs to Loch Leven during storm events – implications for load estimation and catchment management

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Introduction

Loch Leven is a eutrophic lowland lake in Scotland with an area of 13 square km and average depth of 3.9 m. After much remediation work during the last several decades, diffuse sources now dominate estimated nutrient loads. Phosphorus loads from the catchment of Loch Leven have, historically, been calculated on the basis of water samples collected from inflow streams on an 8-day sampling interval (Bailey Watts and Kirika 1987), but it was not known whether this was sufficient to provide accurate load estimates. It has been suggested that up to 80% of the total pollutant input to surface waters can occur during high-flow events, which occur over just 3% of the time (Smith et al. 1991; Littlewood 1993), and these might not be well represented in a traditional sampling regime. During this study, an autosampler/ autoanalyser (AutoLab, made by Envirotech) instrument was used to sample and measure soluble reactive phosphorus (SRP) in one stream, the Green's Burn (56°11' N, 3°13' W), every two hours. SRP, in comparison with total phosphorus, has been seen to be more relevant to eutrophication issues, as this fraction of the total phosphorus pool is more available to aquatic primary producers (Jarvie 2006). Streamflow was also measured every fifteen minutes by a Scottish Environment Protection Agency gauging station.

Relationships between soluble reactive phosphorus concentration and streamflow

Several high-flow events and periods of low flow were observed in 2006 and three representative periods of 12 days each are illustrated in Figure 1. It was observed that, while SRP concentrations were quite often elevated at the same time as streamflow, this was not always the case. Three different scenarios, relating to streamflow and SRP concentrations, have been generalised; (i) after periods of low flow, an increase in streamflow was associated with an increase in SRP concentration (Figure 1a, 1c), (ii) during periods of sustained low flow, there were occasional dramatic increases in SRP concentration (from 100 to 400 µgP.L^{-1} during one event in July), which then decreased back to baseline level within 12 hours, observed twice in 2006 (in July and October, Figure 1b), and (iii) during periods of sustained elevated streamflow, or elevated streamflow preceded by only a short interval of low flow, SRP concentrations did not appear to be related to flow (not illustrated).

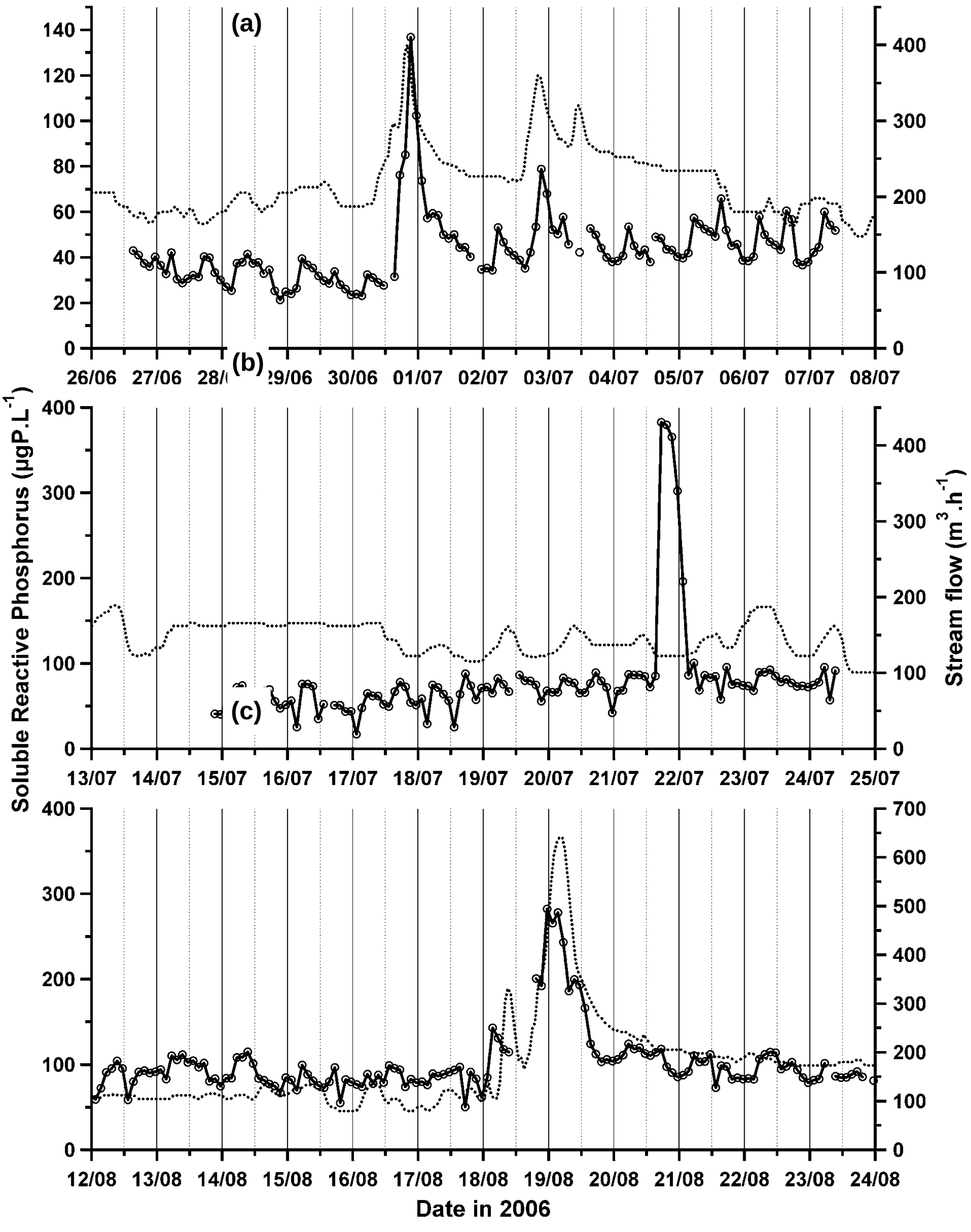

Figure 1. Streamflow (dotted line), measured every 15 minutes, and concentration of soluble reactive phosphorus (circles and solid line), measured every two hours, in Green's Burn, an inflow stream to Loch Leven, Scotland, during three different 12-day periods in 2006. Solid gridlines occur at midnight, dotted gridlines at midday. Note changes in scale between graphs in both y-axes.

The first of these scenarios could be explained by accumulation of SRP in soil and subsequent flushing during high-flow events, or by release of SRP from sediment associated with mobilisation of the sediment. The second scenario appears to be evidence of an intermittent point source of phosphorus. On one of these occasions, in November 2006, the stream water was observed to be distinctly green and had the odour of manure, suggesting a ruminant source. Both of these events occurred during the evening. It should be noted that, although total phosphorus was not measured in this study, a later similar study (unpublished) that did measure total phosphorus concentrations in parallel with SRP provided evidence of the same three scenarios presented here, and showed that, in this stream, the particulate fraction of phosphorus is generally larger than the soluble.

These results provide evidence that the traditional 8-day interval for sampling in this catchment will not be sufficient to estimate accurately loads of phosphorus to Loch Leven. In August, for example, the load of phosphorus as SRP in the stream between 18th and 20th August (2.8 kg) was nearly half of the total for the 12-day period (6 kg). The differences in total phosphorus loading later in the year were even more dramatic, with about 80% of total phosphorus in October delivered during short, elevated flow, periods, which would not have been sampled in the traditional regime. Estimates of the total phosphorus load for October 2006 were 47 kg when calculated on an 8-day sampling interval, and 249 kg when the two-hourly data was used.

Conclusions

The use of automated sampling and analysis equipment has allowed a more detailed examination of temporal patterns of phosphorus loading, which is not possible with standard, infrequent, sampling regimes. This has, in turn, provided evidence that previous studies have grossly under-estimated loads of both soluble and total phosphorus to Loch Leven, at least from this particular stream, but probably from others in the catchment as well. Relationships between flow and concentration data have provided evidence of soil and stream processes that need further study, if we are to effectively understand and manage nutrient loads to water bodies and fulfil our obligations under the EU Water Framework Directive.

References

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