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Water quality remediation faces unprecedented challenges from 'legacy phosphorus'

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The past three decades have witnessed a dramatic increase in recognition of the role of diffuse phosphorus (P) pollution in eutrophication of surface waters. Agricultural conservation and nutrient management programs have been very successful at reducing P losses in runoff at the edge-of-field, but there has often been disappointingly little improvement in downstream water quality and ecology[1]. Growing evidence indicates that a major reason for this is the chronic release of P from 'legacy P' stores, which have accumulated in watersheds and water bodies[2,3,4]. As a result, we face unprecedented challenges in meeting water quality targets, given that P legacies from past land management may continue to impair future water quality, over timescales of decades, and perhaps longer (Figure 1). Agricultural strategies across the U.S. and Europe are currently undergoing fundamental re-evaluation, with the drafting of the new Farm Bill and reform of the Common Agricultural Policy. This is focusing scrutiny on the cost-effectiveness of conservation measures and compliance standards, and raises the following questions concerning legacy P:

1. *How have we built up a legacy of P in our watersheds and what are the likely timescales of recovery?*

Agricultural systems have changed dramatically over the last 60 years, in order to satisfy growing populations and increasing reliance on protein-based diets. Mixed livestock and crop farming (where P was recycled locally) has given way to industrial-scale farming, reliant on large-scale transfers of P from mineral reserves to geographically distinct areas of grain and animal production and human consumption. This has led to a breakdown of the socio-geochemical P cycle, reduced efficiency of P reuse, and greater losses to the environment, as the large transfer distances preclude recycling of P in manure and human waste back to areas of grain production. Currently, only one fifth of P mined for fertilizer reaches the food consumed[5]. Annually, only around 20-30% of P applied to agricultural land is exported directly out of the watershed (in runoff or removal in grain and animal produce). The remaining 70-80% of applied P enters stores in soil, river sediments, groundwater, wetlands, riparian floodplains, lakes, and estuaries [2]. These stores can release legacy P as the storage capacity becomes saturated, under changing redox conditions, or after changes in land use, land management or wastewater treatment. Thus, when agricultural P inputs are reduced, legacy P release can compensate and mask downstream improvements in water quality[2]. The variable residence and recycling times of P within legacy stores indicate that they will continue to provide a long-term chronic source, for years or decades (Figure 1).

2. Have conservation and nutrient management interventions helped or hindered?

To mitigate the water-quality impacts of agricultural intensification, conservation and nutrient management programs by addressing P sources (e.g., rate, method and timing of applied P) and transport controls (e.g., conservation tillage, contour ploughing and riparian buffers). Transport controls have enhanced P storage, protecting downstream aquatic environments from the acute effects of high P loads, but have also accelerated storage of legacy P within the landscape. Perversely, transport controls, by building up legacy P, may now be counteracting water quality improvements from source controls. Greater emphasis is needed to exploit existing soil P reserves and draw-down legacy P through more efficient use of P already stored within agricultural systems.

3. How do we address the current paucity of quantifiable improvements in water quality?

The paucity of water quality improvements is leading many stakeholders to question the efficacy of investing tax dollars in conservation practices. Presenting a convincing case for legacy P and lags in water quality recovery is a vital challenge for scientists and water quality managers, so that arguments for longer timescales of recovery are not dismissed as simply lobbying for more time and funding. Lags in water quality response undermine adaptive management at the watershed scale, as it is often impossible to detect whether conservation measures simply do not work, or whether more time (perhaps on a scale of decades) is needed for improvements to be seen. To address this, we need to demonstrate how local water quality responds to conservation and nutrient management at varying spatial scales (including smaller sub-basin and headwater scales), and the timescales for these improvements to filter down to the larger watershed.

4. What are the prospects for legacy P recovery?

Soil legacy P reserves provide the greatest opportunity for recovery, by subsidising crop growth, and drawing-down soil P. Once lost from the soil to downstream ecosystems, the attenuated distribution of legacy P stores across the wider landscape limits the scope and cost-effectiveness of recovery. While technologies are available to immobilize and inhibit release of legacy P, these are currently only viable at demonstration scales[2]. However, as demand for P outstrips the easily exploited mineral phosphate reserves, rising prices of fertilizers will ultimately make P-recycling more profitable and essential. Locating, harnessing and recycling the more concentrated reserves of legacy P may then become a more attractive and cost-effective proposition. In the longer term, addressing the P legacy challenge could present a 'win-win' opportunity in helping to address P security shortfalls. However, this will entail profound shifts in the P cycle at local, regional and international food production scales, with a focus on closing the P cycling loop between grain and animal producers, and urban consumers

The water quality impacts of nutrient management and conservation programs, which inadvertently promoted the build-up of legacy P, have emerged too late to be resolved quickly. Nonetheless, the current review and re-writing of agricultural strategies, on both sides of the Atlantic, provides an historic opportunity to overhaul conservation and income support programs, securing environmental benefits and accountability of tax dollars, while ensuring continued financial support for farmers. To address legacy P, the priority is now to draw-down existing P legacies and prevent future legacy P build-up, through source controls, which balance P inputs and recycling more efficiently. The dynamics between market forces (mineral phosphate, food and energy prices) and government intervention will ultimately determine how quickly legacy P stores are tackled locally, nationally and globally.

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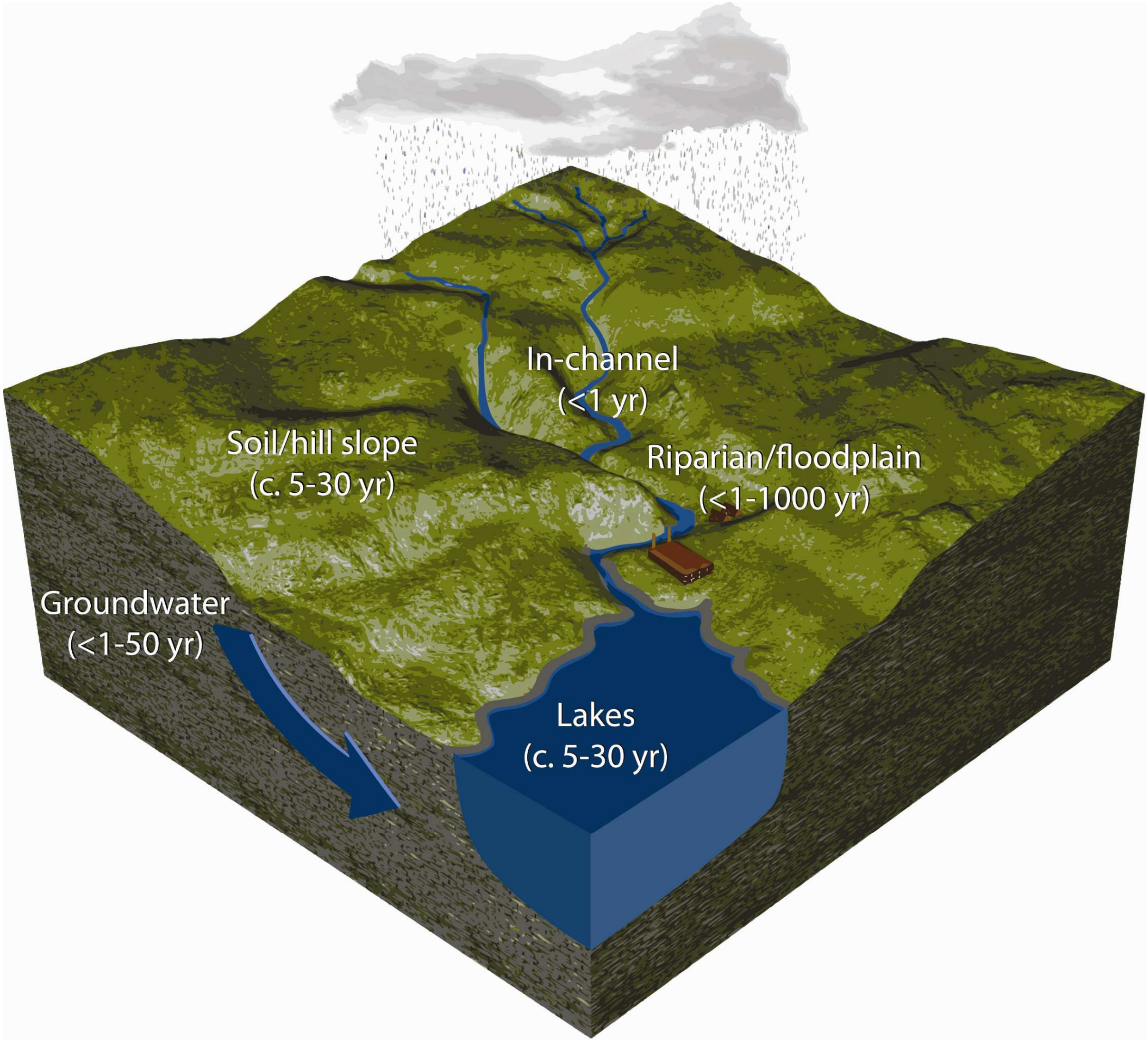

Figure 1: Typical timescales for phosphorus (P) retention and recycling in watershed and waterbody legacy P stores. These result in a continued chronic release of 'legacy P', impairing downstream water quality over timescales of years to decades, or even centuries (from data provided by Sharpley et al, 2013).