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Beyond the Mass Balance: Watershed phosphorus legacies and the evolution of the current water quality policy challenge

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Increased use of phosphorus (P) fertilizers and detergents, as well as the growth of animal feeding operations, have more than doubled P inputs to human-impacted watersheds over pre-industrial levels. While P fertilizer use and manure application help to maximize crop yields, excess P is lost to runoff, leading to eutrophication of downstream waters—a phenomenon of great concern in the North American Great Lakes region. Excess P also accumulates across the landscape, leading to legacies that serve as long-term sources of P to surface waters, even after inputs to the watershed are reduced. We developed, for the first time, a process-based model, ELEMeNT-P, designed to capture legacy P accumulation and depletion trajectories along the land-aquatic continuum. To drive the model, we reconstructed a more than 100-year trajectory of P inputs to the Grand River Watershed (GRW), Canada's largest river basin draining directly to Lake Erie. Our results show that since 1900 the GRW has served as a net P sink, with an estimated accumulation of more than 480 ktons P, of which 89% resides in soils and 6% in reservoirs and riparian areas. Future simulations suggest that while a 40% reduction in P discharge to Lake Erie is possible under aggressive management scenarios, legacy P will continue to elevate P loads to Lake Erie for centuries.