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Groundwater-Borne Geogenic Phosphorus in a Drained Wetland: Mobilization, Transport, and Export

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The excessive input of nutrients into surface water is a global concern. Despite extensive efforts to mitigate phosphorus (P) from anthropogenic sources, water quality has not significantly improved in many catchments, likely due to an incomplete understanding of P sources and transport pathways, particularly groundwater P of geological origins. This study examines geogenic P dynamics in groundwater within a small (~1 ha) study site located in a drained riparian wetland in southeastern Germany, where an apatite-rich geological background and an extensive drainage network provide an optimal setting for investigating P mobilization and export processes.

A two-year monitoring program, integrating water sampling with vertical profiling of dissolved and solid phases, revealed substantial subsurface P enrichment. Approximately 70% of water samples exceeded the German Environment Agency's threshold for P of 0.1 mg/L. Soluble reactive phosphorus (SRP) concentrations in groundwater demonstrated remarkable temporal stability and spatial variability, averaging 0.34 and 0.43 mg/L in two of four wells, while the remaining wells exhibited 5- to 10-fold lower SRP levels.

The observed spatial heterogeneity and temporal stability appear to be driven by the site's specific geochemical setting. 1) Redox conditions strongly influence groundwater P levels, as evidenced by distinct redox characteristics among wells and strong correlations between P and iron (Fe). 2) Vertical sequential-extraction profiling identified Fe-P and apatite-P as the dominant soil P pools, with organic-P being more prominent in surface soils. 3) Electrical resistivity tomography revealed a paleo-channel acting as a preferential subsurface flow path, coinciding with high-P wells.

These findings support a conceptual model in which geogenic P mobilization is driven by the weathering of P-bearing minerals, reductive dissolution of Fe oxides, and organic matter mineralization. The transport of P-rich groundwater to surface water is accelerated by preferential flow pathways and drainage networks, reducing residence time and promoting direct groundwater-surface water connectivity. While riparian wetlands are typically considered P sinks, our study demonstrates that paleo flow paths can instead facilitate the transport of P-rich groundwater, feeding nearby streams with high loads of P. Effective catchment-scale water quality management should account for geological P sources, particularly in regions with similar geochemical settings worldwide.