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Transport Behavior of Secondary Nanoplastics in Sand and Soil Media

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The extensive use of plastics since the mid-twentieth century has resulted in their widespread accumulation and progressive fragmentation in the environment, giving rise to secondary nanoplastics that dominate environmental nanoplastic pools. Despite their relevance, secondary nanoplastics remain poorly characterized due to analytical challenges associated with low concentrations, heterogeneous matrices, and polymer diversity. As a result, most existing transport studies rely on microplastics or primary nanoplastics that are idealized models that do not adequately reflect environmentally formed nanoplastics.

In this work, we introduce an analytical method capable of quantifying secondary nanoplastics in aqueous matrices and apply it to study the transport of polyethylene terephthalate (PET), low-density polyethylene (LDPE), high-density polyethylene (HDPE), and landfill-derived nanoplastics weathered naturally for more than two decades. Column experiments conducted in sand and soil media were evaluated using breakthrough curves and size-resolved particle distributions.

We show that the transport behavior is plastic-specific and strongly influenced by both the plastic polymer chemistry and porous medium characteristics. Aliphatic plastics exhibit greater retention than aromatic plastics, consistent with increased hydrophobic interactions. Size distribution analysis reveals that eluted nanoplastics are generally larger, indicating preferential retention or aggregation of smaller particles within the porous media. Despite similar chemical compositions, secondary LDPE and HDPE displayed distinct elution patterns, whereas secondary PET showed enhanced aggregation due to its extended π-electron system. Landfill-derived nanoplastics exhibited increased retention due to inorganic impurities that promoted aggregation. Additional experiments with secondary HDPE across sands of varying grain size and a sandy loam soil reveal broadly consistent retention, with enhanced trapping in fine sand likely driven by reduced pore throat dimensions. Collectively, these results provide mechanistic insight into secondary nanoplastic transport and advance realistic assessments of nanoplastic fate in subsurface environments.