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The Impact of Coal Combustion Product Leachate on Groundwater Geochemistry and Microbial Communities

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Coal has been a globally dominant source of energy over the past century. Despite the decline of US coal production and consumption in the past two decades, the waste generated by coal combustion remains an environmental concern, particularly leaching of coal combustion products (CCPs) into groundwater. In this study, we focus on the geochemistry and microbial diversity within a CCP leachate plume, providing new insights into highly relevant but understudied constituents of interest. The groundwater in the leachate plume is enriched in Mo but not other common CCP constituents As, Cd, Cr, or Pb. Mo is an essential element for enzymatic function but is limited in most environmental systems, and so its enrichment creates a unique habitat to control microbial dynamics. Our goal was to apply a holistic approach to understand how CCP leachate, and particularly Mo, affects subsurface geochemistry and microbial dynamics. Diffusive microbial samplers were designed and deployed at the study site for 9 weeks. Afterwards, geochemical and metagenomic analyses were used as the basis to understand how microbial communities respond to CCP leachate. Our results show that the leachate does not impact the diversity of the community (similar alpha diversity metrics between control sites and those in the plume), counter to trends observed at other highly contaminated sites. Genes encoding sulfate reduction and sulfur/sulfide oxidation predominated the functional potential at all sites, and accumulation of sulfate in groundwater suggests that sulfate reduction is limiting the sulfur cycle. These observations are reasonable considering that molybdate, MoO_4^{2-} (the dominant Mo-species in this regime), is a structural analog of sulfate and can inhibit sulfate reduction. Interestingly, sulfate-reducing bacteria were not present in wells with the highest Mo concentrations (3 ppm) but were abundant (up to 10% relative abundance) in in wells where Mo < 0.8 ppm. The results point to important considerations for bioremediation potential in groundwater settings impacted by Mo.