Improving potentially toxic elements (PTEs) fate and transport modeling during stormwater management by incorporation of dynamic environmental factors

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Abstract

Low impact development (LID) is an efficient approach to tackling stormwater runoff challenges in urban areas by allocating drainage from large impervious surfaces to engineered landscapes, which typically increases infiltration, reduces peak flow, and improves water quality. Potentially toxic elements (PTEs), like metals, are concern-worthy in stormwater due to their abundance and non-biodegradability. Metals are likely to be effectively removed by engineered fill media. Solid-water distribution coefficient (K_d) for PTEs mainly governs removal, impacting the design and maintenance of LIDs. However, high metal removal is accompanied by high surficial fill media accumulation, particularly in fine particles, which may be a potential concern for metal redistribution as runoff flows over the LID bed. Additionally, the removal of metals by fill media is a reversible reaction and under certain environmental conditions (e.g., high salinity), the previously captured metals may be released due to a reduction in K_d. This study aimed to improve PTE transport modeling by incorporation of impacts of environmental factors like salinity on LID performance.

In this study, the mutual impacts of K_d and LID loading ratio (ratio of impervious to the pervious surface) were assessed by developing a 1-D transport model. PTE aqueous and solid-phase concentrations were compared with published screening values to provide recommendations about choosing fill media and loading ratio for designers as well as estimating the effective life span of the fill media. After simulation of 20 years of LID service under baseline salinity conditions, Cl^- was the only PTE that showed high mobility and quickly reached the groundwater table, while the other PTEs (e.g., metals) were effectively immobilized in the top ~60 cm of the fill media. However, it was observed that in higher salinity conditions, metal K_d values reduced significantly, resulting in metal leaching. Moreover, such reduction was alarming because it could readily lead to overestimation of fill media capability in metal removal. Higher loading ratio and K_d were generally associated with higher accumulation of PTEs in top layers, however, the simulation showed that a combination of high LR and low Kd (e.g., under higher salinity) may result in a faster breakthrough of PTEs through the fill media.

Particle behavior in the LID was considered, and potential resuspension of fine particles, as vectors for metals, and subsequent metal redistribution along a LID were monitored for storms with different intensities. Suspended solid samples collected from a LID confirmed that metals have a higher affinity for finer particles (i.e., $d < 10$ µm). These fine particles were resuspended for almost all monitored storms regardless of the intensity, while only storms with intensities higher than 0.18 in/hr resulted in resuspension of all size classes of suspended solids along the LID gradient. This resuspension could be followed by high salinity conditions downstream, leading to metal redistribution. Characterizing the dynamics of suspended solids and their associated metal surficial transport can be a key factor in enhanced design as well as recognition of the areas with higher priority for maintenance within LIDs. Also, increasing salinity to environmentally relevant levels resulted in higher stability of fine particles, yet another negative impact of high salinity on the mutual impacts of metals and particles. This study highlights the importance of considering holistic approaches that dynamically incorporate a range of environmental factors such as salinity, particle size, and storm intensity to more realistically model the fate and transport of PTEs during stormwater management.