Methods to Estimate Recharge to Determine Mass Discharge from Unsaturated Zone PFAS Source Areas

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Background/Objectives. To establish baseline risks and better understand the nature of per- and polyfluoroalkyl substances (PFAS) source zones to groundwater, there is a critical need to better understand the mass discharge (mass per time) of PFAS leaving the unsaturated zone and entering groundwater. If most of the PFAS source mass is in the saturated zone (e.g., a site with a very thin unsaturated zone and extensive matrix diffusion sources below the water table), then performing high-intensity, high-cost remediation of the unsaturated zone is likely counter-productive. However, for sites where the bulk of the PFAS are entering groundwater from the unsaturated zone, then remediation, containment, or enhanced attenuation measures can be employed if the risk from the PFAS unsaturated source zone needs to be managed.

There is extensive research on-going on how best to determine representative aqueous concentrations of PFAS in porewater, including using soil concentrations with partitioning calculations and direct approaches such as porewater sampling using field-deployed suction lysimeters (e.g., Anderson et al., 2022; Schaefer et al., 2022). However, there has been much less attention paid to the best method to obtain representative recharge rates that are required to estimate the mass discharge of PFAS leaving unsaturated source zones.

Approach/Activities. An extensive literature review of recharge estimation methodologies was conducted, finding 38 different methods comprised of Water Budgets, Computer Models, Darcy Methods, Unsaturated/Groundwater Methods, Surface Water Methods, and Tracer Methods. The spatial and temporal scale of a key type of PFAS source zone, aqueous film forming foam (AFFF) release sites, were then used to retain 14 recharge estimation methods that are particularly useful for estimating recharge at these particular unsaturated zone PFAS source areas. These 14 methods were then divided into three tiers: Tier 1 methods where recharge estimates could be derived in a few hours without detailed subsurface field data; Tier 2 methods where field data are obtained and processed to easily obtain recharge estimates; and Tier 3 methods comprised of more accurate but more complex and costly recharge estimation methods. The three recharge estimation tiers are designed to be applied to different types of unsaturated zone PFAS source areas: Tier 1 methods would be used as initial estimates for any site or at smaller, low risk sites; Tier 3 methods at the most important and complex PFAS sites; and Tier 2 methods for "sites in the middle," intermediate risk/complexity sites.

Results/Lessons Learned. Each of the retained 14 methods to estimate recharge were summarized with regards to favored site characteristics, relative accuracy, relative cost, key analysis tools/models to process site data, and what type of data are required to employ each method. Particular emphasis was placed on developing four easy-to-use Tier 1 methods for use at the numerous ongoing and upcoming PFAS site Remedial Investigations (RIs):

- *T1-A:* An empirical regression of recharge as a function of precipitation from ~100 different recharge studies compiled by Stephens et al. (1996).
- *T1-B:* A detailed map of baseflow for use as a proxy for recharge in humid environments.
- *T1-C:* Existing maps of recharge for selected states in the U.S., and access heuristic recharge estimates from the DRASTIC aquifer vulnerability system (Aller et al., 1985).

- *T1-D:* A simple water balance model based on site-specific SCS Curve Numbers which combine landcover and hydrologic soil type and other site-specific data to estimate recharge.