Fluorescent Dyes Used for Characterization of the Interaction and Mixing between Groundwater Plumes and Surface Water

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Background/Objectives. Fluorescent tracer dyes have been used to aid understanding and characterization of contaminant fluxes and hydraulic properties at a site in Hagfors, Sweden. A dry cleaning facility, 'Hagforstvätten', was located at the site between 1970 and 1993. Throughout this period, large amounts of PCE (>50 tons) were leaked into the ground, likely through the sewers, contaminating soil and groundwater significantly. Traditional investigation tools (i.e., geological characterization, soil and water samples, MIP, and seismic exploration) conclude that the site comprises a highly complex geology and hydrogeological system. Hence, an extremely complex distribution of contaminants. Two source areas have been identified at the site; located approximately 150 m apart. Down gradient (ca. 120 m) estimates show that each year approximately 400 kg PCE is discharged into a small groundwater fed creek, 'Örbäcken' (average Q= 260 l/s). In order to plan remediation, detailed knowledge of the contaminated groundwater's flow path is needed. Hence, fluorescent tracers were successfully employed at the site with the objectives to determine the flow pathways of the groundwater plumes from each of the source areas; evaluate the interaction between the groundwater and surface water; estimate contaminant fluxes; and finally, update the conceptual site model (CSM) based on the results.

Approach/Activities. Four fluorescent dyes were selected for the study: fluorescein, eosine, sulforhodamine B, and rhodamine WT. These dyes are water soluble and considered conservative (i.e., not easily affected by geochemical changes nor adsorbed by formation materials). Moreover, they have no known toxicological impact on the environment nor humans. The dyes were individually injected to four monitoring wells: two wells at each of the source areas. At each source area, tracers were injected to the upper and lower part of the groundwater aquifer to be able to determine the origin of the contaminants once they reach the creek. The injection locations were chosen based on contamination source area as well as hydraulic properties of the aquifer. Dyes were injected in November 2016 following two rounds of baseline sampling. Subsequent monitoring has been carried out monthly, involving collection of grab and passive samples along the creek as well as from monitoring wells in the area. The investigation encompasses a total of 120 monitoring stations; 27 in surface water, 24 in the hyporheic zone of the creek, and 69 in monitoring wells spread across a 1 km^2 investigation area. In addition, detailed studies of the dye distribution across and along the creek have been carried out. More than 760 samples have been analysed.

Results/Lessons Learned. The dye tracer test illuminated flow pathways that were unexpected in terms of speed of groundwater migration as well as point of impact in the creek. The most rapid groundwater flux was observed from the secondary source area by dye injected in the uppermost part of the aquifer. Dye reached the creek within 25 days, resulting in a flux of 10 m/day; the average velocity of the dye was 1 m/day. Furthermore, the results reveal that contaminants are discharged into the creek along both banks; however, each bank is affected either by the upper or the lower part of the aquifer. Such knowledge is important when designing remediation. In conclusion, the use of tracer dyes is considered an under-utilized tool when investigating groundwater flow and interaction with surface waters. Using fluorescent tracer dyes is a technically valid and cost-effective method aiding the understanding of the spreading of contaminants in complex hydrogeological systems.