Implications of 1,4-Dioxane Source Attenuation and Plume Biodegradation on Its Behavior at Groundwater Sites

David Adamson, Maile Smith, and Philip de Blanc (GSI Environmental, Houston, TX, USA)

Background/Objectives. 1,4-Dioxane is a contaminant of emerging concern that is present at many sites where releases to groundwater have occurred. The maximum concentrations of 1,4-dioxane observed at these sites are often relatively low, in part because the available monitoring record for this compound tends to be short. A growing body of research has shown that 1,4-dioxane is subject to aerobic biodegradation, and evidence for in situ biodegradation under natural attenuation conditions has been documented at multiple different sites. However, the apparent biodegradation rates at these sites are frequently slow, and the activity tends to be localized (i.e., observed at some but not all monitoring locations). As such, it is likely that additional fate and transport processes are contributing to the low concentrations currently observed at many sites. This includes recent evidence that source attenuation of 1,4-dioxane can be rapid, which is consistent with its physical-chemical characteristics, as well as the nature of releases, which can include contribution from diffuse sources. The goal of the study was to better document the relationship between these fate and transport processes for various types of 1,4-dioxane sources to provide a stronger technical basis for evaluating remedies, in particular the role that natural attenuation can play in managing 1,4-dioxane in the environment.

Approach/Activities. This study uses a combination of field and modeling data to examine the impact of different sources and attenuation processes on 1,4-dioxane concentrations observed in the environment. Several methods were used to estimate different types of rate coefficients, including: (1) a lab-scale ^{14}C assay that estimates well-specific biodegradation rates using groundwater samples; (2) kinetic models that calculate source attenuation rates from concentration versus time data; and (3) groundwater fate and transport models to predict biodegradation rates or source attenuation rates from concentration versus distance data.

Results/Lessons Learned. Empirical data compiled during this study confirm that 1,4-dioxane concentrations currently observed at contaminated groundwater sites are generally low (median = 130 µg/L) and significantly less than what would be expected if it was not attenuating over time and distance from the source. When 1,4-dioxane is detected in drinking water sourced from groundwater, the reported concentrations are significantly lower (median = 0.17 µg/L), reflecting the influence of pumping and long-term attenuation processes. At sites where source attenuation of 1,4-dioxane could be documented, the median source attenuation rate was 0.27 yr^{-1} based on site-wide data and 0.17 yr^{-1} based on well-specific data. At sites where plume biodegradation of 1,4-dioxane could be documented, the median rate was 0.0105 yr^{-1} based on well-specific data and 0.075 yr^{-1} based on site-wide data. These results were used to highlight several implications. First, source attenuation can result in rapid depletion of 1,4-dioxane from a point source, with the highest groundwater concentrations potentially located downgradient of the source, as has been observed at some 1,4-dioxane sites. Second, concentrations may change rapidly across a site due to breakthrough-type behavior and localized degradation activity. Third, due to slower biodegradation rates, 1,4-dioxane concentrations may change slowly with time at some sites where a persistent source is still present, but they would still be expected to decline. The only cases where 1,4-dioxane concentrations are not expected to decline are: 1) those where the 1,4-dioxane source is distant from the site/monitoring location (i.e., breakthrough has not yet occurred); or 2) those where diffuse, continuing sources of 1,4-dioxane are present. The latter include areas where 1,4-dioxane present in septic system discharges—a known issue—is entering groundwater at levels that result in detections.