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Relevance of a decades-old TCE DNAPL source zone architecture to its effective remediation

Rachel Dearden (1), Michael Rivett (2), and Gary Wealthall (1)

(1) British Geological Survey, Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG, UK (rach1@bgs.ac.uk), (2) School of Geography, Earth & Environmental Sciences, University of Birmingham, Birmingham, B15 2TT, UK (M.O.Rivett@bham.ac.uk)

Industrial site closures and improvements in managing hazardous DNAPL (dense non-aqueous phase liquid) chemicals such as TCE (trichloroethene) mean that many contaminated sites now contain old DNAPL source zones where releases to the subsurface may have discontinued decades previous. The age of a source has important implications for its remediation. Sources that have undergone several decades of natural groundwater flushing may exhibit a markedly different architecture to that present during active chemical release. Preferential DNAPL dissolution will have occurred from the more permeable geological units, up-gradient source areas and where saturations are sufficiently low to allow reasonable water flow. More inaccessible DNAPL in lower permeability zones or within pools may be largely bypassed. Consequently remediation programmes are faced with the prospect of not only attempting to remove the more inaccessible DNAPL, but also preventing remediation applications (treatment fluids) bypassing remaining DNAPL as they preferentially migrate through more permeable, but DNAPL-depleted, horizons. We present detailed field data from the UK SABRE (Source Area BioREmediation) research – industrial site that permit consideration of the above issues. Inadvertent industrial releases of TCE occurred over 20 – 45 years prior to our field study. The DNAPL source area present in the underlying 6 m thickness of an alluvium and river terrace gravels aquifer and upper few metres of an underlying mudstone had hence been naturally flushed for several decades. Our study has focused upon a streamtube of the DNAPL source enclosed by the 30 m long, 4 m wide, 6 m deep, 3-sided SABRE sheetpile cell keyed into the underlying mudstone. Data are presented pre and post implementation of a bioremediation programme zone involving injection of SRS, an emulsified soybean oil that provided a slow release of partitioning electron donor enhanced by bioaugmentation with the KB-1® culture. Principal data include high resolution (centimetre to decimetre vertical delineation) coring to establish the DNAPL source zone architecture pre- and post-remediation, dissolved-phase plume evolution pre- and during remediation via a network of multilevel samplers and a conservative bromide tracer test conducted across the DNAPL source zone.

Our results demonstrate the importance of both high and low permeability extremes on the architecture that had historically evolved over decades previous, the natural dissolution of the source prior to remediation and effectiveness of bioremediation implemented. Much of the source pre-remediation had low percent DNAPL saturations present with maximum saturations associated with low permeability geologic layers and some values indicative of pooling. Both linear and exponential declines in DNAPL saturation were evident vertically from these maxima. The tracer test was particularly instructive in demonstrating the presence of very rapid flow paths (several m/d velocities) through the source associated with gravel layers that provided potential for bypassing of the remaining DNAPL. Despite high sampling density, DNAPL mass estimate medians (25th - 75th percentile) pre-remediation of 940 (490 – 1760) kg and post-remediation of 450 (240 – 850) kg exhibited significant uncertainty. Cell effluent indicated around 1000 kg was removed, around the difference in the 75th percentile values. Post remediation data suggested persistent DNAPL was associated with the less accessible low permeability layers, (pooled) high saturations and underlying mudstone. Reflecting back over the study, it is clear that a more thorough initial understanding of the influence of the geologic permeability field on source architecture, dissolution and bypassing flow, would have facilitated a more targeted application of the remediation undertaken. This understanding is particularly important for older DNAPL sources where localised, more inaccessible DNAPL may remain amongst more permeable, contaminant-free zones to which remediation activity may be inadvertently focused.