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## **Conceptualization of residual contamination using depth discrete monitoring of dynamic PCE concentration changes during and after remedial pumping and pumping test.**

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**Background and objectives:** PCE contamination in a fractured limestone aquifer at a former central dry cleaning facility in Hedehusene, Denmark, has undergone pump and treat (P&T) remediation with re-infiltration for nearly 10 years after partial source removal in the overburden. A plume of PCE had migrated > 200 m down gradient prior to initiation of P&T remediation at the site. The pumping and re-infiltration has diverted the groundwater flow, and hence the transport of PCE, in the fractured limestone aquifer adding to the complexity. The distribution of PCE remaining in the limestone aquifer source and plume area was not well understood challenging evaluation of the remedial design.

The objective of the investigations was to generate a conceptual model for the residual contamination in the limestone aquifer at the site for optimization of the remediation. The conceptual model is based on the understanding of flow and transport processes in fractured limestone and high resolution data on the PCE distribution and dynamic concentration changes under different pumping schemes. The high resolution data was interpreted by support of a calibrated 3D site specific fracture model.

**Approach:** Due to instability of boreholes in the upper crushed and highly fractured zones of the limestone, limestone cores suffered significant core-loss, and most boreholes at the site were equipped with relatively long screens and sand-packs. Passive, semi-passive and active groundwater sampling methods were tested and applied in addition to core sub-sampling to obtain high resolution PCE data. Samples were collected from several wells at the site and in the plume during ongoing P&T with re-infiltration, during discontinuance of the remediation, and during a pumping test (with multiple tracer injections). The high resolution data is interpreted to determine the distribution of residual PCE contamination in the limestone and to create a conceptual model for the PCE source area and plume.

**Preliminary results/lessons learned:** The highest PCE concentrations were observed in the upper crushed Copenhagen limestone and the highly fractured Copenhagen limestone, with lower and decreasing concentration with depth in the underlying Bryozoa limestone. Significant concentration increases were observed when remedial pumping and re-infiltration was discontinued (in one case from < 1 to > 250 µg/L PCE). The concentration changes in the near source area were very dynamic in the fractured Copenhagen limestone. The dynamic changes observed are most likely due to fast fracture flow and back-diffusion from the limestone matrix in areas with higher residual contamination. The crushed limestone responded more slowly due to its lower hydraulic conductivity compared to the fractured zone. In addition to visualization and interpretation of the PCE distribution, the 3D model was used to deduce the likely zones of origin for the observed PCE contamination, showing that the P&T system has little effect on the contamination in parts of these zones. The new conceptual understanding can be used to optimize remediation.

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