Application of Natural Source Zone Depletion in Fractured Aquifer Remediation & Liability Management

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Advisian was retained to develop and implement a remedial strategy for a natural gas plant with hydrocarbon contamination. The plant is located within the foothills of Alberta, Canada. The hydrocarbon contamination is present within a fractured sandstone aquifer and is resulting in ongoing seepage of dissolved-phase hydrocarbons to surface. The seep is located approximately 100 m from the site boundary.

A previous modelling study suggested that it could take 1,200 years for the hydrocarbon contamination at the site to naturally attenuate and concentrations in groundwater to meet regulatory guidelines. As such, an active remediation strategy was seen as necessary in order to remediate the site within a reasonable timeframe. The mathematical model used to make this prediction assumes that natural hydrocarbon degradation can be fully accounted for by soluble electron acceptors entering and soluble by-products leaving an area containing residual hydrocarbon contamination. This is the case for most of the natural attenuation models that are used for predicting the fate and persistence of hydrocarbon contamination. While such models have been used effectively for over three decades for managing hydrocarbon plumes with low residual contamination, a growing body of evidence has emerged demonstrating that natural degradation is also occurring in more heavily contaminated source zones containing residual and/or mobile non-aqueous phase liquid (NAPL) hydrocarbons. This phenomenon, commonly referred to as "natural source-zone depletion" (NSZD), is driven mainly by methanogenesis of residual NAPL. Methane is generated in the pore space adjacent to the NAPL, and the produced gas migrates upward into the unsaturated zone where it is oxidized to produce carbon dioxide. The NSZD rate can then be determined by monitoring the resulting carbon dioxide generation rates.

In light of the recent changes in the understanding of how NAPL degrades in the environment, Advisian revised the conceptual model for the site by implementing a NSZD study to quantify the rate of natural attenuation. Additionally, characterization of the fracture network at the site was undertaken using coring, geophysics, structural mapping, statistical analysis, fracture porosity estimation, and modelling. Improved characterization and understanding of the fracture network was seen as a critical step for developing a strategy for minimizing seepage of hydrocarbons at the river and for estimating the mass of residual hydrocarbon remaining at the site in order to predict the amount of time it would take for the site to naturally attenuate. Revision of the conceptual site model and estimation of the NSZD rate for the site resulted in an order of magnitude decrease in the estimated timeframe for natural attenuation (i.e. from centuries to decades).

This paper presents a summary of key findings associated with the items above and highlights the potential of using NSZD as a less intrusive alternative to conventional remedial techniques, as well as its potential to quantify natural attenuation rates and significantly reduce site liabilities.

Vincent Stein

Vincent Stein is a Principal Environmental Engineer with Advisian, a division of Worley. He holds a bachelor's degree in civil engineering and a master's degree in environmental engineering from the University of Calgary. He has over twenty years of environmental engineering experience, including two years as a research associate at the University of Calgary and eighteen as a consultant. His consulting experience has focused mainly on conducting and managing environmental site assessments and remediation programs at upstream oil and gas sites in Alberta. Mr. Stein is currently using the models he developed while obtaining his master's degree (one of which received a "Best Theoretical Paper" award from the American Society of Civil Engineers), for modelling gas transport and methane oxidation in soils in order to estimate natural source zone depletion rates at sites contaminated with hydrocarbon non-aqueous phase liquids. While at Advisian, he has continued his involvement with the University of Calgary by guest lecturing for undergraduate and graduate environmental engineering classes and participating in research projects on methane biofiltration and natural source zone depletion.