In-Situ Chemical Oxidation with Sodium Permanganate in a Fractured Crystalline Bedrock Aquifer: A Case Study

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Abstract

Sodium permanganate ($NaMnO_4$) was applied and recirculated over a 5-month period to expedite remediation of a tetrachloroethene (PCE) groundwater contaminant plume in fractured crystalline gabbro-diorite bedrock at a site in eastern Maine. The contaminant source in soil was removed in 1999; however, elevated PCE (7,200 ug/L) at a bedrock well indicated the presence of an on-going source in January 2000. The dissolved PCE groundwater plume was approximately 180 ft. long, 200 ft. wide and 200 ft. thick. A groundwater extraction and treatment system, completed in 2001, included a groundwater extraction well at the PCE source (source well) and a line of extraction wells that cut-off downgradient migration of the dissolved-phase plume.

Pilot tests were conducted to evaluate the effectiveness of in-situ oxidation with $NaMnO_4$. In July 2000, 8 gallons of 20% $NaMnO_4$ was applied into four bedrock wells in the core of the PCE plume. PCE increased to 16,000 ug/L at the source well in September 2000. After a second dose (9 gallons of 20% $NaMnO_4$) to the 5 bedrock wells in the source zone, PCE increased to 22,000 ug/L at a nearby bedrock well in November 2000, then declined to 2,900 ug/L at the same well in December 2000. In April 2001, 35 gallons of 40% $NaMnO_4$ was applied into the same bedrock wells as the second dose, and PCE remained elevated (9,700 ug/L) at the source well in April 2001. In May 2001, 1,440 gallons of 5% to 1% $NaMnO_4$ (117 gallons of 40%) was injected into 72 (1-inch ID) overburden wells to infiltrate the oxidant to the bedrock surface. PCE declined to 2,100 ug/L at the source well in June 2001, then rebounded to 9,100 ug/L at the same well in November 2001. Iron, arsenic, and manganese remained elevated for 7 months after this application. Approximately 160 gallons of 40% $NaMnO_4$ was applied during the 4 applications. Based on the test results and a published report of oxidant recirculation at another site by others, it was concluded additional bedrock wells and recirculation of groundwater amended with the oxidant were necessary to improve oxidant delivery to the PCE source zone.

Five new bedrock wells were completed near the PCE source zone to support the installation of the in-situ recirculation system. Borehole geophysics located transmissive fractures, and discrete-interval groundwater results delineated the PCE source. The results of forced-gradient tracer tests indicated 3 new bedrock wells and 2 nested bedrock wells were hydraulically connected to the source well. Rock core samples, preserved in methanol, qualitatively confirmed limited PCE diffusion into the rock matrix near the source extraction well.

The recirculation system was established to deliver the oxidant to the PCE source zone in August 2002. Groundwater from the source well was discharged to a residence tank, filtered, treated with GAC, and amended with 100 mg/L to 250 mg/L $NaMnO_4$ before addition to the 5 bedrock wells. After 29 days of source zone recirculation, PCE decreased from 2,200 ug/L (pre-amendment) to 160 ug/L at the source well. Amendments were increased to 500 mg/L for 5 days and then stopped when the stock solution was depleted. PCE rebounded to 2,400 ug/L at the source well 14 days later. The source extraction well was converted to an addition well to enhance delivery to fractures connected to the source, and oxidant migration to the downgradient extraction wells required their activation for hydraulic containment. Bedrock wells along the upgradient plume boundary were also added to the recirculation system. After 85 days of recirculation with increased amendments (500 or 1,000 mg/L $NaMnO_4$), the source addition well was converted back to extraction and PCE decreased to 170 ug/L at this well 11 days later. An estimated 0.9 million gallons of treated water was amended with 385 gallons of 40% $NaMnO_4$ during 5 months of recirculation. Post-treatment monitoring, while the system was shutdown indicated PCE rebounded to 6,600 ug/L at the source well 8 months after shutdown. Manganese declined 75-99% from maximum values and ranged from 50 to 600 ug/L 8 months after shutdown. Iron and arsenic declined to baseline levels 3 months after shutdown.

In conclusion, complete oxidation of the PCE source was limited by delivery of insufficient oxidant mass to the source zone relative to the mass of the PCE source. Heterogeneities limited delivery. Options are being considered to enhance the connectivity of the bedrock fractures in the contaminant source zone.

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