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SUCCESSFUL IN SITU BIOREMEDIATION OF PERCHLORATE IN GROUNDWATER

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ABSTRACT: Remediation of groundwater impacted historically by the production, handling, and use of rocket propellants such as ammonium perchlorate is an ongoing interest at United States Department of Defense (DOD), Department of Energy (DOE) and defense contractor facilities. Few cost-effective technologies currently exist for the treatment of perchlorate-contaminated groundwater. Of the technologies being developed, bioremediation is among the most promising because it has the potential to destroy perchlorate rather than transferring it to another waste stream (e.g., impacted resin or brine) requiring costly treatment or disposal. Accordingly, significant effort has been directed in recent years to the development of in situ bioremediation treatment systems that afford a less costly and less O&M-intensive approach for both plume containment and source remediation. In a successful field demonstration completed at the former Nevada Field Laboratory near Reno, Nevada (a former rocket engine testing facility), perchlorate concentrations in groundwater were rapidly (within weeks) reduced from 530 µg/L to less than the practical quantitation limit (PQL) of 4 µg/L in a closed-loop recirculation system following amendment with citric acid as electron donor. The results of this pilot test indicate that in situ bioremediation is a suitable technology for the remediation of perchlorate-impacted groundwater at this site.

INTRODUCTION

It is estimated that perchlorate has been manufactured and/or used in 44 states, resulting in groundwater contamination in at least 14 of these states (Damian, 1999). In California, Arizona and Nevada alone, it is estimated that perchlorate impacts the drinking water supplies of more than 15 million people (US EPA, 1999). The concern surrounding perchlorate in groundwater and drinking water supplies relates to its potential ability to impact thyroid function (Urbansky, 1997). While a national regulatory standard has yet to be set, the California Department of Health Services (CDHS) established a provisional action level (PAL) of 4 µg/L for perchlorate in drinking water, and this PAL has been adopted as an interim regulatory guideline for groundwater by various regulatory agencies. Health and Safety Code §116275 [Chapter 425, Statutes of 2002, SB 1822 (Sher)] requires DHS to adopt an MCL for perchlorate by January 1, 2004 (CA DHS, 2003).

This paper describes the results of a pilot test of the application of in situ bioremediation technology to the remediation of perchlorate-impacted groundwater. The primary objective of the pilot test was to confirm the ability of the indigenous (naturally-occurring) bacteria to biodegrade perchlorate in the site groundwater through the addition of a food-grade, carbon-based, electron donor such as citric acid. The pilot test utilized a

recirculation design, consisting of a single groundwater extraction well and a single groundwater recharge/electron donor delivery well. Groundwater was extracted, amended with electron donor (citric acid) and reinjected into the aquifer to promote perchlorate biodegradation in situ.

OVERVIEW OF PERCHLORATE BIODEGRADATION

Perchlorate biodegradation results from microbially-mediated redox reactions, whereby perchlorate serves as the electron acceptor, and is reduced via chlorate to chlorite. Chlorite then undergoes a biologically-mediated dismutation or disproportionation reaction, producing chloride and oxygen. The oxygen is subsequently reduced, provided sufficient electron donors are available. Figure 1 shows the pathway for perchlorate reduction.

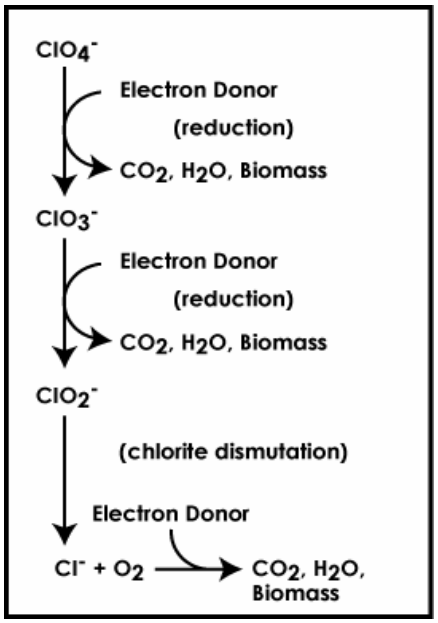

FIGURE 1. Pathway for the reduction of perchlorate.

FIELD DEMONSTRATION RESULTS

The pilot test was initiated in May 2003 within the interior of a trichloroethene (TCE) and perchlorate plume, containing trichloroethene in concentrations ranging from 26 to 100 µg/L and perchlorate concentrations up to 530 µg/L. The pilot test infrastructure consisted of a closed loop continuous recirculation system, whereby groundwater was continuously extracted from the aquifer, combined with water extracted from site extraction wells outside the pilot test area, passed through a volatile organic contaminant (VOC) treatment system, amended with electron donor (once daily), and re-injected to the aquifer to promote perchlorate reduction in situ (Figures 2 and 3). Citric acid was selected as the electron donor because it is a cost-effective food-grade product that would not adversely impact groundwater quality. In addition, the low pH of the citric acid helps prevent mineral and biological fouling of the injection well. The electron donor was injected in a daily one-hour pulse, at a time-weighted average concentration of 21 mg/L (calculated based on a stoichiometric safety factor of two). Baseline groundwater redox

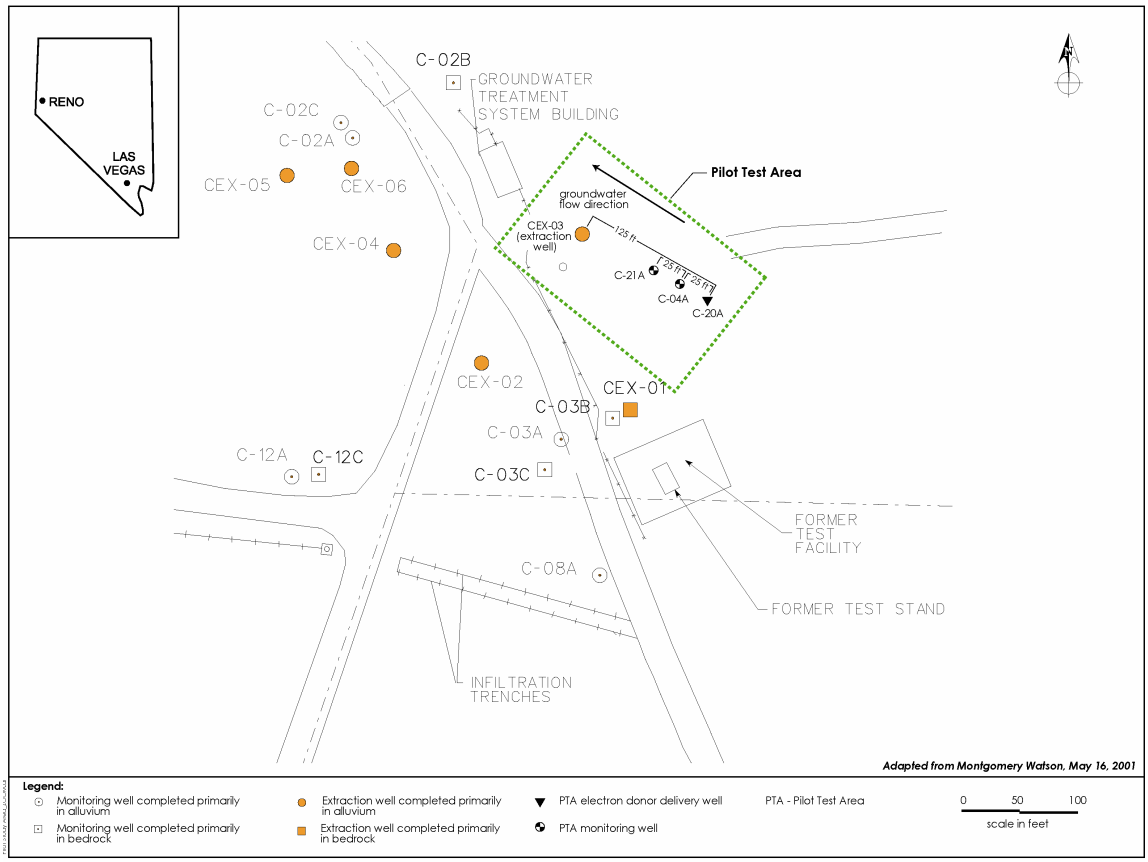

FIGURE 2. Site layout with inset site location.

conditions in the pilot test area were aerobic and oxidizing, with dissolved oxygen (DO) concentrations ranging between 6.27 and 7.27 mg/L and oxidation-reduction potential (ORP) ranging from 152 to 192 mV. Consistent with the prevailing aerobic redox conditions, nitrate and sulfate were present in the groundwater at concentrations ranging up to 2.5 and 120 mg/L, respectively. Methane, which is produced in anaerobic environments and consumed in aerobic environments, was not detected.

Performance monitoring was accomplished using several monitoring wells, two of which were part of the recirculation system and were located at distances of 8 meters (m) (well G-04A) and 16 m (well G-21A) downgradient from the electron donor delivery well. The hydraulics of the pilot test area (e.g., pore volume, residence time, travel times to monitoring wells) were estimated through conservative tracer (bromide) testing. Based on the tracer test results, the average travel time to reach well G-04A was estimated at 7 days.

Figure 4 presents perchlorate and other electron acceptor concentration trends at performance monitoring well G-04A (the nearest monitoring well downgradient of the injection well), the well with historically the highest concentrations of perchlorate. Perchlorate biodegradation was readily initiated, without apparent lag time. Perchlorate concentrations at the target well G-04A rapidly declined from 530 µg/L to non-detect (< 4 µg/L) 40 days after the initiation of citric acid addition. As a benefit, perchlorate

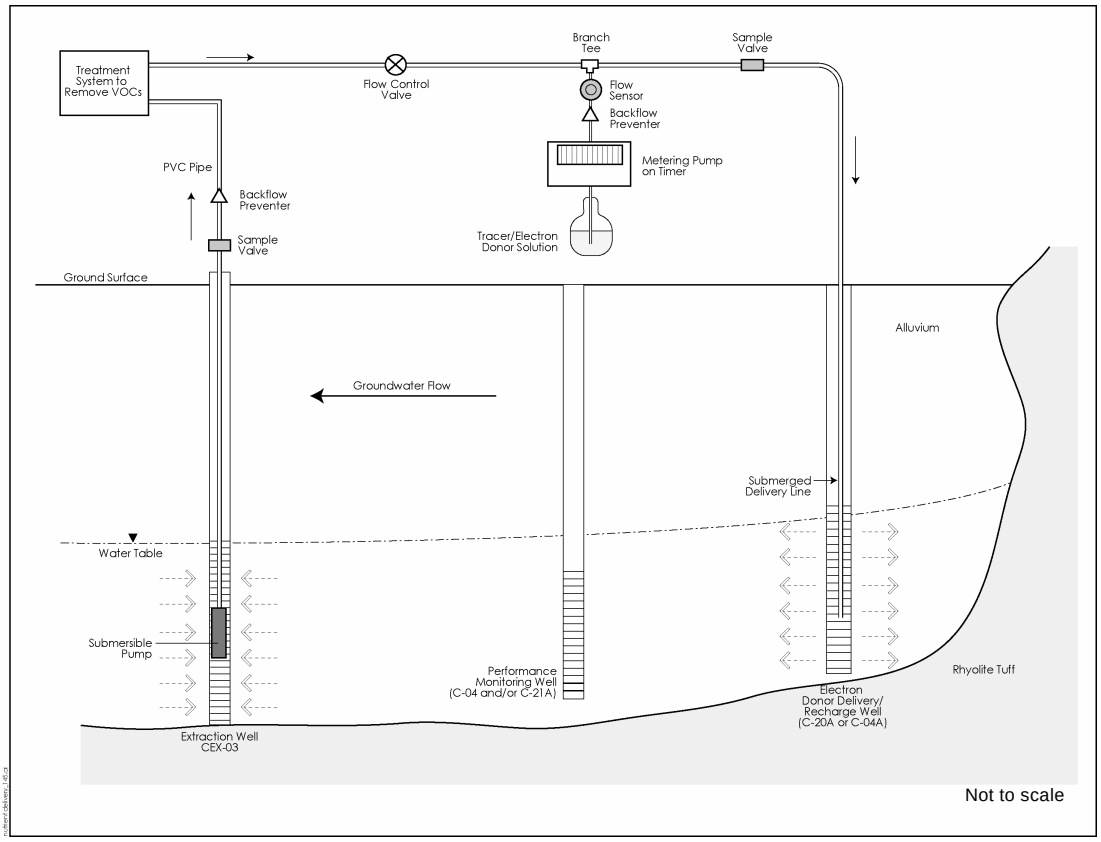

FIGURE 3. Conceptual schematic showing the closed loop recirculation system used at the site.

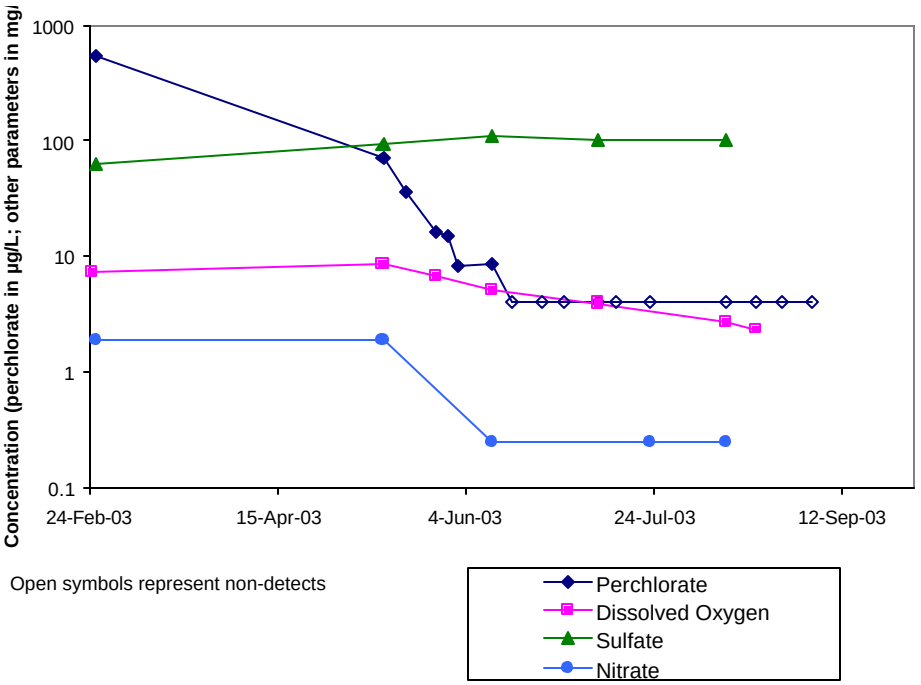

FIGURE 4. Results of in situ bioremediation of perchlorate – monitoring well C-04A.

biodegradation did not require highly reducing conditions. These data have important implications for site remediation in that it may be possible to biodegrade perchlorate while not significantly impacting secondary water quality parameters (i.e., creating anaerobic groundwater with high dissolved metals, sulfide and methane). Of note, the reduction of sulfate was avoided by balancing electron donor addition versus demand (i.e., only enough electron donor was added to reduce oxygen, nitrate and perchlorate, leaving no excess electron donor to instigate the reduction of sulfate as well).

CONCLUSIONS

The results of this pilot test suggest that bacteria capable of in situ perchlorate reduction are present at the site. The addition of citric acid stimulated rapid biodegradetion of perchlorate at a starting concentration of 530 µg/L to less than 4 µg/L within 40 days of the initiation of electron donor additions and within 8 m of the injection well without adverse affects on secondary groundwater quality and without lag time.

This study also adds to the growing number of in situ bioremediation success stories for remediation of perchlorate-impacted sites. GeoSyntec Consultants has completed several equally successful perchlorate bioremediation pilot tests at sites elsewhere in Nevada and California using the recirculation loop approach as in this site as well as an active biobarrier design.

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