SUMMARY OF EXAMPLE E-REDOX® CASE STUDIES

CASE STUDY 1: E-REDOX® ENHANCEMENT OF *IN SITU* GROUNDWATER BENZENE BIODEGRADATION AT A FORMER PETROLEUM BULK PLANT

Location: Former petroleum bulk plant in Lafayette, Colorado, USA

Contaminated Matrix: Groundwater

Primary Contaminants of Concern: Benzene

Project Objective: Enhancement of in situ contaminant degradation by full-scale implementation of E-Redox® technology

Case Study Description & Results: Groundwater at a former petroleum bulk plant site was impacted by petroleum hydrocarbon contamination. Despite past remediation efforts, benzene contamination persisted at the site, primarily within a residential area. Twelve E-Redox® units were installed in groundwater wells within a residential area that had a contaminated area of 6000 ft^2. The units were installed in an array throughout the contaminant plume, and operated with zero energy input. Figure 1 shows the installation of the E-Redox® technology at the site.

Figure 1. (Clockwise from top right) Museum yard within the benzene plume; uncovering one of the existing wells to be used as an E-Redox® unit well; E-Redox® unit well; installation of E-Redox® unit.

After 18 months of operation, approximately 99% benzene mass removal was observed at the site (see Figure 2 below). Voltage was generated by all E-Redox® units, which ranged from 30 to 293 mV. The voltage profiles serve as a convenient tool for monitoring the E-Redox® units performance and groundwater quality in general, without groundwater sampling. Overall, the full-scale implementation of the E-Redox® technology at this site has resulted in a substantial reduction of overall benzene concentrations in the groundwater. The site is currently under post-remediation phase monitoring for closure.

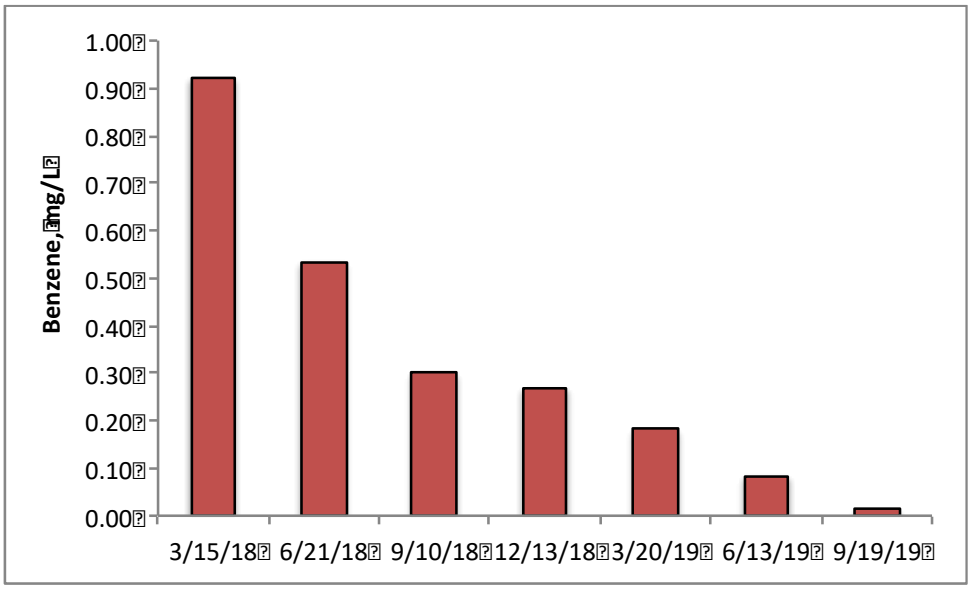

Figure 2. Overall benzene concentrations.

CASE STUDY 2: E-REDOX® ENHANCEMENT OF IN SITU REDUCTION AND MASS REMOVAL OF CHLORINATED SOLVENTS IN GROUNDWATER

Location: Former adhesives production site at a confidential location in South Carolina, USA

Contaminated Matrix: Groundwater and saturated soil

Primary Contaminants of Concern: Chlorinated ethenes

Project Objective: Full-scale enhancement of *in situ* contaminant reduction and mass removal using the E-Redox® technology coupled with dual-phase extraction (DPE)

Case Study Description & Results: A full-scale implementation of E-Redox® systems was conducted at a former adhesives production plant site in South Carolina, United States, where subsurface soil and groundwater were contaminated with chlorinated volatile organic compounds (CVOCs). The CVOCs were mostly composed of 1,2-cis-dichloroethene and vinyl chloride. The full scale implementation of E-Redox® systems consisted of initially 11 electrode wells using pre-

existing monitoring and injection wells. Figure 1 shows the installation of the E-Redox® technology at the site.

Figure 1: (Clockwise from top right) Site preparation and laying out conduit for wire protection; installation of an electrode in hill-side wells; installation of electrode in primary site area; warehouse sheltering low-intensity power source.

After two weeks of operation, substantial desorption and back-diffusion were observed in locations with historically low CVOC concentrations (yet persistent). In one example well, the CVOC concentration was 12 mg/L before E-Redox® operation (Figure 2, *left*). CVOCs concentrations increased to 50,000 mg/L after 26 weeks of operation. At the peak CVOC level, the E-Redox® system polarities were switched to initiate and sustain reductive degradation, decreasing concentration of CVOCs sharply to near non-detect level within three weeks. This demonstrated that one electrode polarity works on CVOC back-diffusion and desorption, while the opposite polarity achieves contaminant destruction through a combination of abiotic and biological reductive dechlorination. A DPE system was installed onsite for CVOC mass removal that was enhanced by the E-Redox® technology. Overall, the total CVOC concentrations are decreasing with the combined enhancement of contaminant reduction and mass removal (see Figure 2, *right*).

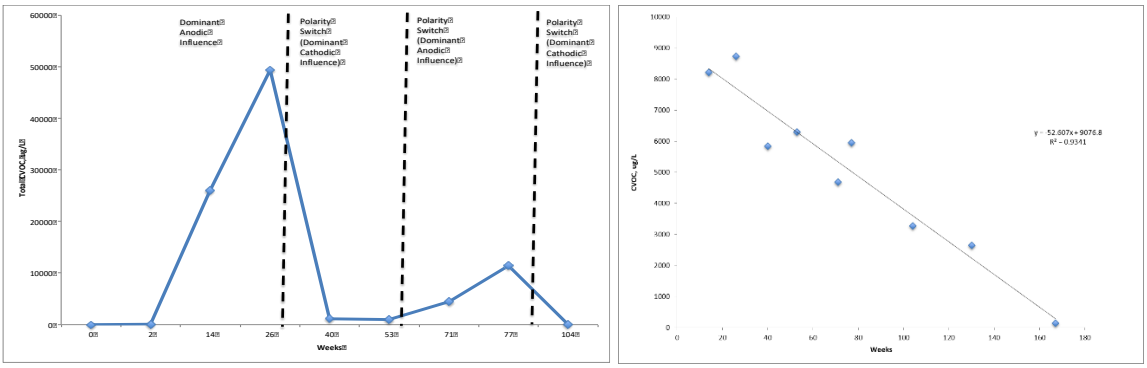

Figure 2. Chlorinated VOCs concentration change in a representative well (*left*), and the overall site chlorinated VOCs concentrations (*right*).

CASE STUDY 3: E-REDOX® ENHANCEMENT OF *IN SITU* GROUNDWATER BENZENE BIODEGRADATION AT A FUEL STATION AND RESIDENTIAL AREA

Location: Fuel station and residential area in Denver, Colorado, USA

Contaminated Matrix: Groundwater

Primary Contaminants of Concern: Benzene

Project Objective: Enhancement of in situ contaminant degradation by full-scale implementation of E-Redox® technology

Case Study Description & Results: A leaking underground storage tank released petroleum hydrocarbons into the groundwater at an operating fuel station, where the contaminant plume eventually migrated into residential areas near the fuel station. Despite past remediation efforts, benzene contamination persisted at the site. Fourteen E-Redox® units were installed in groundwater wells within the contaminant source area and in the down-gradient areas. The units were installed in an array with 20-ft spacing, and operated with zero energy input. Figure 1 shows the installation of the E-Redox® technology.

Figure 1. (Clockwise from top right) Installation of an E-Redox® unit near the fuel station; installation of an E-Redox® unit within a residential area; installation of an E-Redox® unit across a street from the fuel station; the fuel station (source of contamination).

After 2 years of operation, total benzene concentrations in the source area dropped 90% from the pre-installation levels (see Figure 2). Voltage was generated in all E-Redox® units, ranging from 20 to 150 mV, depending on contaminant and background organic carbon levels. The voltage profiles serve as a convenient tool for monitoring the E-Redox® units performance and groundwater quality in general, without groundwater sampling. Overall, the full-scale implementation of the E-Redox® technology at this site has resulted in a substantial reduction of overall benzene concentrations in the groundwater.

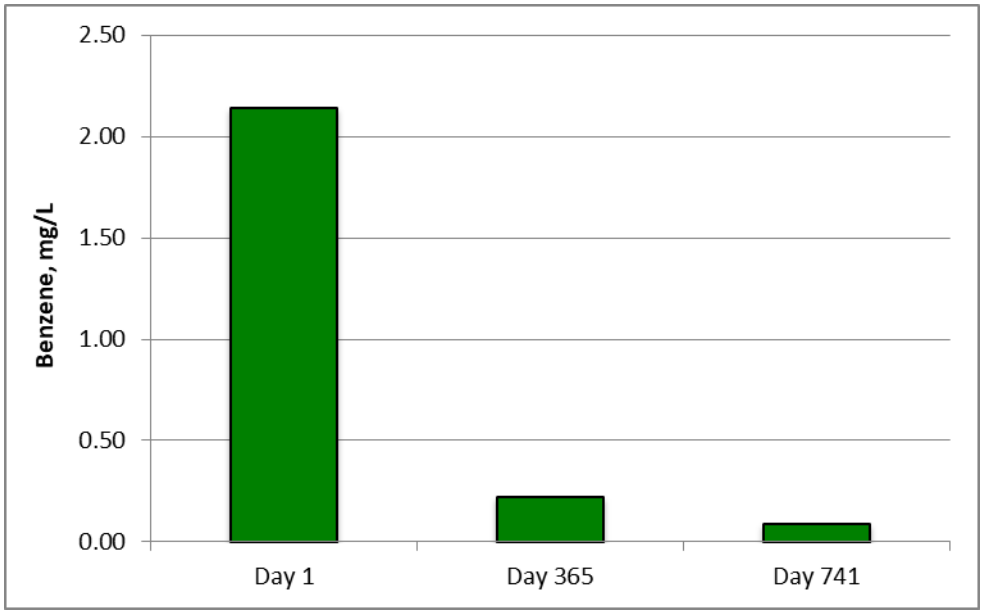

Figure 2. Overall benzene concentrations in the source area.

CASE STUDY 4: E-REDOX® ENHANCEMENT OF IN SITU REDUCTION OF TETRACHLOROETHENE (PCE) IN GROUNDWATER

Location: Former dry cleaner in Denver, Colorado, USA

Contaminated Matrix: Groundwater

Primary Contaminants of Concern: Tetrachloroethene (PCE)

Project Objective: Full-scale *in situ* reductive treatment of PCE in groundwater using the E-Redox® technology

Case Study Description & Results: The E-Redox® technology was implemented at a site in Denver, CO that was originally a dry cleaner facility. The primary persistent groundwater contaminant is tetrachloroethene (PCE), and the subsurface matrix formation is clayey with highly limited permeability. Due to the tight groundwater formation, the effectiveness of past remediation efforts was limited. Six E-Redox® systems were installed in existing monitoring wells, and were powered by low-intensity residential power source. Figure 1 shows the implementation of the E-Redox® technology at the site.

Figure 1. (Clockwise from top right) Installation of electrodes in wells within the basement of the building; installation of electrodes outside of the building; shelter with low-intensity power supplies.

Figure 2 shows PCE concentration changes in one of the primary monitoring wells after 33 days of operation. Approximately 73% of the PCE at saturation concentration was degraded without production of any hazardous daughter products, suggesting an abiotic beta elimination degradation pathway. The PCE degradation rate was 3053 μg/L/day within the induced electric field generated by the E-Redox® system.

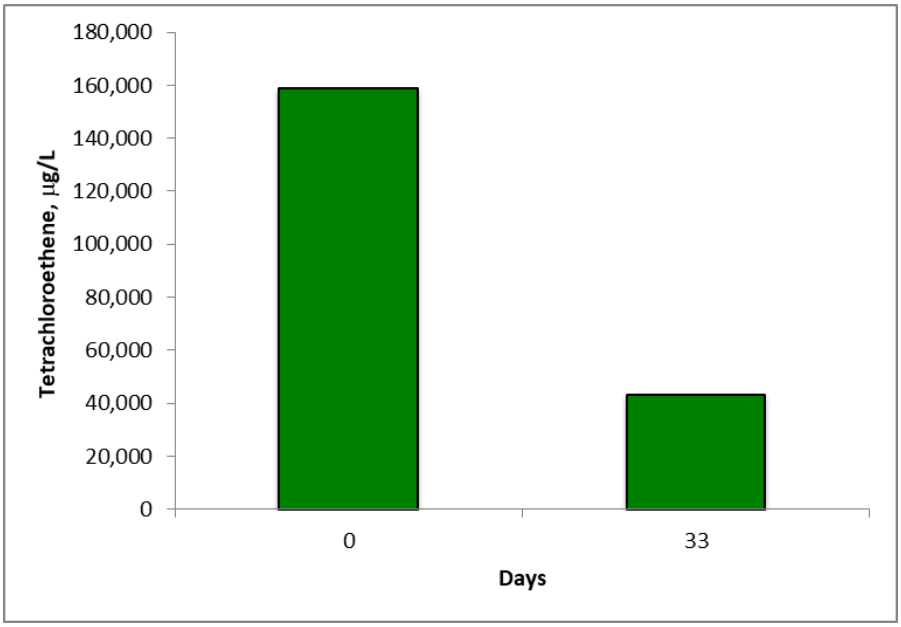

Figure 2. PCE concentrations from a monitoring well.

CASE STUDY 5: E-REDOX® ENHANCEMENT OF IN SITU REDUCTION OF CHLORINATED ETHENES IN GROUNDWATER

Location: HVAC manufacturing site in Denver, Colorado

Contaminated Matrix: Saturated matrix

Primary Contaminants of Concern: Chlorinated ethenes (e.g., trichloroethene)

Project Objective: *In situ* reductive treatment of chlorinated solvents using the E-Redox® technology

Case Study Description & Results: The E-Redox® technology was implemented at a site in Denver, CO that currently operates as a HVAC manufacturing facility. The primary persistent groundwater contaminants are mostly trichloroethene (TCE) with tetrachloroethene (PCE), dichloroethenes (DCEs) and vinyl chloride (VC). Also, the subsurface formation is clayey with highly limited permeability. An E-Redox® system was installed at the site and was powered by a municipal power source. Figure 1 shows the implementation of the E-Redox® technology at the site.

Figure 1. (Clockwise from top left) Trenching from electrode well to the building; installation of the electrode in well with the connecting wire running to the building; sealing of the trench with the connecting wire within the trench; electrode well inside the building; trenching from electrode to power source inside the building.

Figure 2 shows chlorinated ethenes concentrations changes in the primary monitoring wells after 56 days of operation. Significant decreases in concentrations of all chlorinated ethenes were observed (decreases of 86-97%), where 73% TCE decreased from 443,000 μg/L to 60,500 μg/L. Results to date indicate that the E-Redox® is successfully enhancing the reduction of chlorinated ethenes in groundwater.

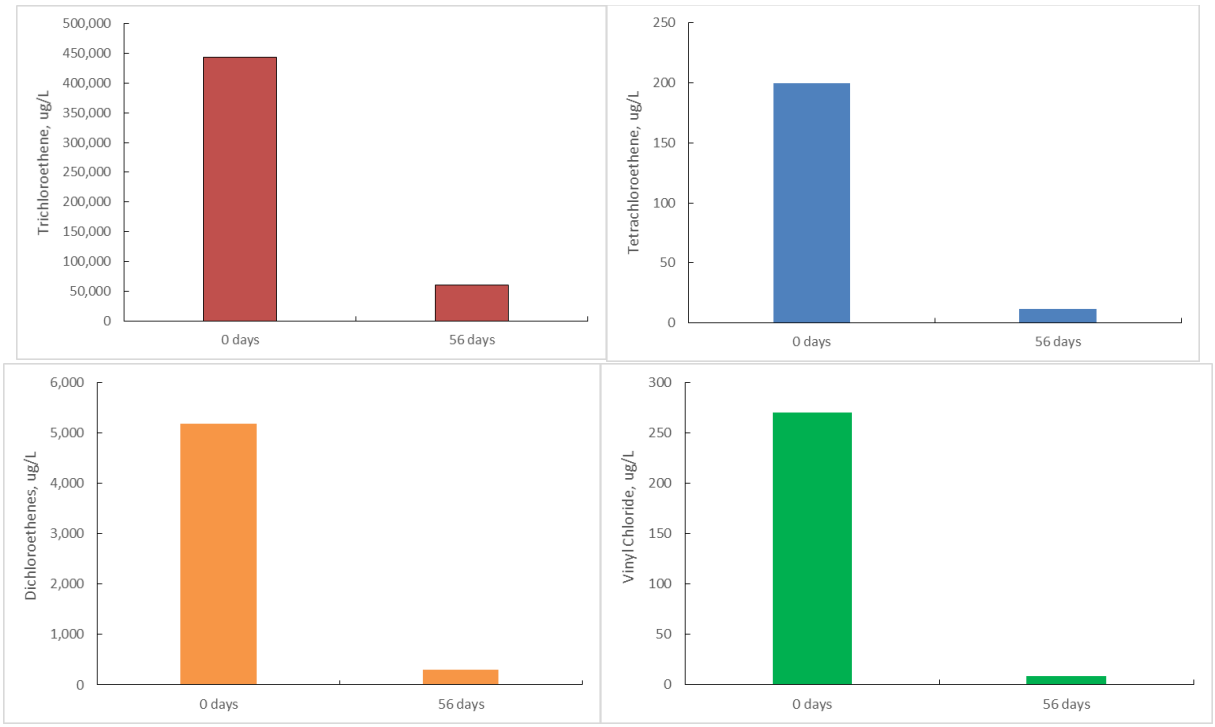

Figure 2. Chlorinated ethenes concentrations from the primary monitoring well.

CASE STUDY 6: E-REDOX® ENHANCEMNET OF IN SITU REDUCTION OF TETRACHLOROETHENE (PCE) IN GROUNDWATER

Location: Former dry cleaner in Wheat Ridge, Colorado, USA

Contaminated Matrix: Groundwater

Primary Contaminants of Concern: Tetrachloroethene (PCE)

Project Objective: Full-scale *in situ* reductive treatment of PCE in groundwater using the E-Redox® technology

Case Study Description & Results: The E-Redox® technology was implemented at a site in Wheat Ridge, CO that was originally a dry cleaner facility. The primary persistent groundwater contaminant is tetrachloroethene (PCE), and the subsurface matrix formation is clayey with highly limited permeability. Five E-Redox® systems were installed at the site and were powered by residential power source. Figure 1 shows the installation of the E-Redox® at the site.

Figure 1. (Clockwise from top left) Trenching for protecting connecting wires; conduit inside a trench; electrode installation in a well; power source preparation inside shelter.

Figure 2 shows PCE concentration changes in one of the primary monitoring wells. Approximately 62% of the PCE was degraded without rebound. Substantial reduction in PCE concentration has been observed for the overall site during the five months of operation without any rebound. Ethane is the final product of complete PCE reduction, where increases in ethane concentrations were coinciding with the decrease in PCE concentrations. The increases in ethane production indicated actually more PCE was being degraded than the direct groundwater water PCE measurements indicated, where the average total site-wide PCE reduction rates were determined to be 31 μg/L/day (maximum 50 μg/L/day) based on the measured ethane concentrations. This indicates that undissolved PCE and PCE adsorbed to the groundwater sediments were being reduced within the radius of influence of the E-Redox® system. Site closure is pending.

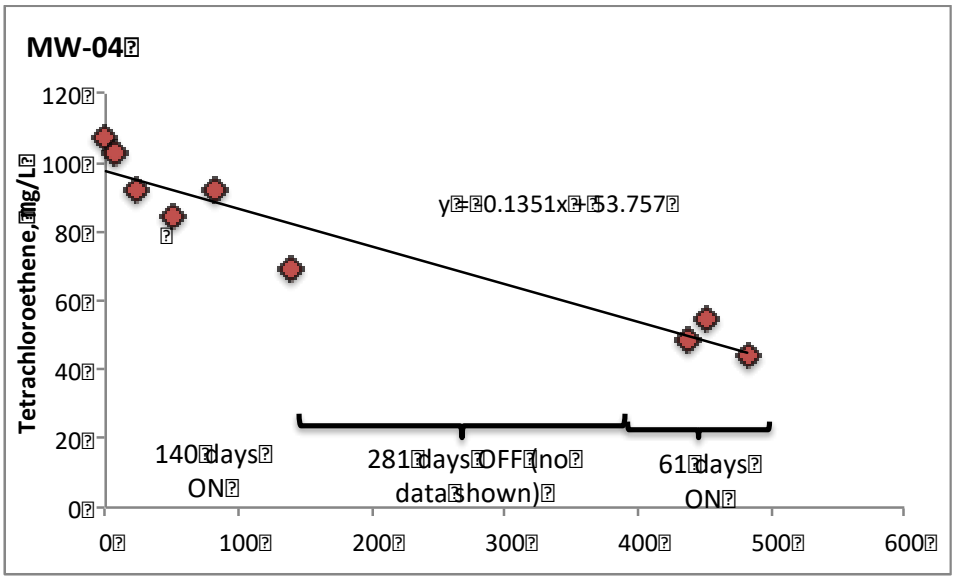

Figure 2. PCE concentration in groundwater.