Paper D-10, in: V.S. Magar and M.E. Kelley (Eds.), *In Situ and On-Site Bioremediation—2003.* Proceedings of the Seventh International In Situ and On-Site Bioremediation Symposium (Orlando, FL; June 2003). ISBN 1-57477-139-6, published by Battelle Press, Columbus, OH, www.battelle.org/bookstore.

INTEGRATED MASS RECOVERY AND MNA FOR RCRA CORRECTIVE ACTION

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ABSTRACT: Source recovery using modified groundwater recirculation well technology and monitored natural attenuation (MNA) initiatives were undertaken at an active creosote wood treating site in Arkansas where creosote DNAPL is present between 90 and 100 feet below ground. At many sites, DNAPL recovery is costly. Results are variable and substantial quantities of free phase DNAPL often remains in the subsurface. In the early 1990s, source control and recovery interim measures at the site included a single-phase pump and treat recovery system. Since 1998, more innovative source removal efforts were implemented utilizing groundwater circulation well technology to provide enhanced creosote DNAPL recovery. The enhanced recovery wells were designed for creosote DNAPL mass removal as well as in-situ soil flushing and source containment. At present, four enhanced creosote DNAPL recovery wells have been operating at the site with a cumulative mass recovery of over 550,000 pounds of creosote since 1998. The creosote DNAPL recovery wells have outperformed the previous pump and treat system at the site by many orders of magnitude in terms of mass recovery. Along with source area control, MNA data collected since 1998 have consistently shown a trend of plume reduction. These data substantiate the viability of DNAPL source management and MNA coupled with institutional controls as a remedial component to corrective action at the site.

INTRODUCTION

Remediation of DNAPL sites is a challenging endeavor in terms of technical practicability and cost. Creosote DNAPL is particularly challenging as it is predominantly comprised of low solubility polycyclic aromatic hydrocarbons (PAHs) that form a long-term continuing sources.

Recent regulatory initiatives to apply secondary oil field recovery technologies to creosote DNAPL sites have resulted in costly schemes that have yet to be proven more than marginally effective. Virtually all DNAPL guidance documents available, including the Technical Impracticability (TI) waiver (U.S.EPA, 1993), suggest free product removal to the extent practical as the most appropriate first remediation step. However, there has been minimal technical focus on the connection between the effectiveness of free product recovery techniques and the effectiveness of MNA for the resulting dissolved phase plume. This paper documents the synergistic success of free product removal using an engineered modification to groundwater circulation well technology in conjunction with MNA for creosote-impacted groundwater remediation.

The site is a 155-acre creosote wood treating facility that has been in operation since the early 1900s. Based on historical operational practices, a large DNAPL accumulation area is present between 90 and 100 feet below ground, on the surface of a confining clay layer (Figure 1). Creosote DNAPL exceeds eight feet within the thickest portion of the pool. The aquifer is composed of successive sequences of sand and gravel that coarsen with depth. Aquifer transmissivity is on the order of 100,000 gallons per day per foot with a corresponding groundwater seepage velocity of approximately 150 feet per day. A dissolved phase constituent plume, consisting primarily of low molecular weight PAHs, extends approximately 3,000-feet downgradient of the DNAPL source zone. In order to address the major groundwater remediation activities at the site, a DNAPL mass recovery and strategic groundwater monitoring and data evaluation program (including MNA) was initiated in the late 1990s.

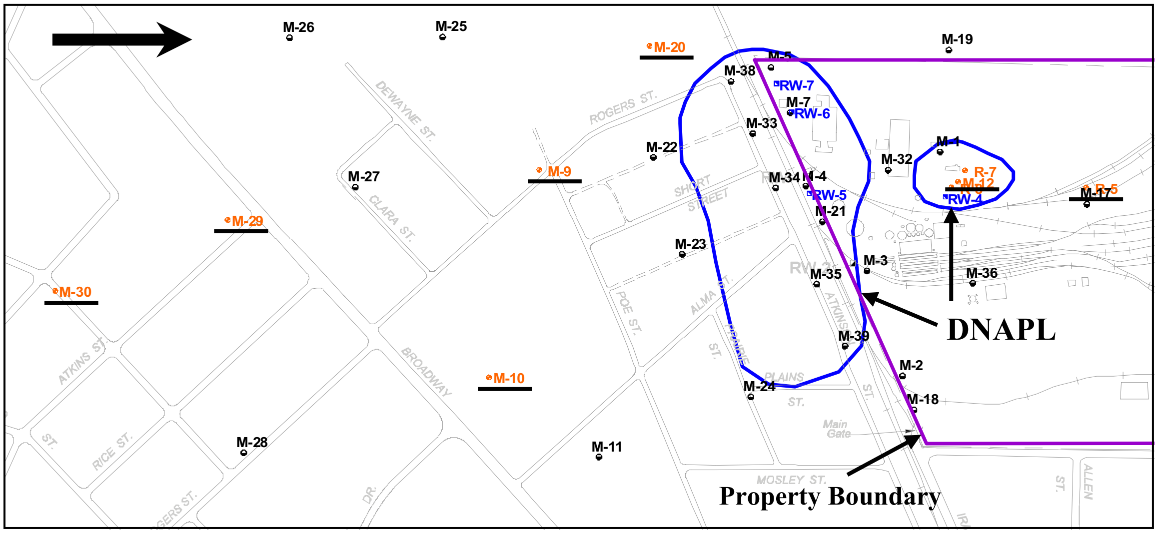

FIGURE 1. Site plan of DNAPL area, recovery wells (RW designation) and monitoring well network (underlined). Approximate scale 1 inch = 700 feet.

MASS RECOVERY

Conventional single-phase pump and treat was implemented at the site in the early 1990s with minimally effective creosote DNAPL mass removal in dissolved phase form. In order to provide for more effective creosote DNAPL mass removal and containment, a modified groundwater circulation well design was engineered and employed to achieve single-phase creosote DNAPL recovery. The recovery well design facilitates in-well creosote DNAPL separation and recovery.

The enhanced DNAPL recovery well design includes a single, large diameter borehole containing both a recovery well and a recirculation well (Figure 2). Groundwater and DNAPL are collected in the recovery well component. Recovered groundwater is directed into the circulation well component, while the DNAPL settles via gravity into the collection sump of the recovery well. The resulting groundwater circulation cells that are developed aid in the mobilization of DNAPL to the recovery well via flushing.

The enhanced DNAPL recovery well design was first developed in 1996 (Coll and others, 1997) and has been modified successively over the last few years. The recovery well design objectives are to maximize DNAPL recovery, minimize the potential formation of DNAPL emulsion, and maximize groundwater recirculation flow rates. The aggressive design includes an evaluation on the ability for DNAPL to be mobilized in response to groundwater extraction (Cohen and Mercer, 1993). Further, the design

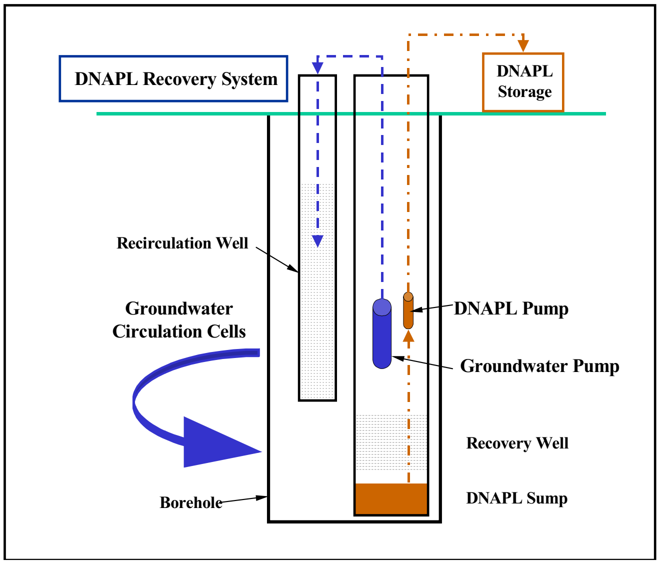

FIGURE 2. Conceptual recovery well via groundwater circulation schematic.

establishes acceptable ratios of entrance velocities and upwell velocities to well diameters and DNAPL settling velocities in order to achieve design objectives.

Each of the DNAPL recovery wells include a vault surface completion and associated control panel for automated system operation and performance monitoring via totalizing flow meters, sample ports and a DNAPL storage tank. A total of 18 monitoring wells and piezometers are also monitored for groundwater and DNAPL levels to evaluate the operational effectiveness of the four (4) DNAPL recovery wells currently in operation at the site.

The first enhanced DNAPL recovery well, RW-4, began operating in April 1998 (Figure 1). DNAPL recovery from recovery well RW-4 was substantially greater than the site's conventional single-phase pump and treat system, therefore, three additional DNAPL recovery wells, designated RW-5, RW-6, and RW-7, were installed. These additional recovery wells were located to target the main DNAPL pool at the site (Figure 1).

RW-5 began creosote DNAPL recovery operations in May 1999 and RW-6 & RW-7 began operating in January 2002. Creosote DNAPL recoveries are evaluated for each respective recovery well, though RW-6 & RW-7 recovery volumes are tallied together as these recovery wells are operated on a single control system and utilize a single DNAPL recovery tank.

Since inception, enhanced DNAPL recovery wells RW-4, RW-5, and RW-6 & RW-7 have realized average creosote DNAPL recovery rates of 3.9, 36.7, and 13.5 gallons per day, respectively. Figure 3 presents the monthly creosote DNAPL recovery volumes for the recovery wells since respective startups. Figure 4 presents the cumulative DNAPL recovery volumes for each individual recovery well as well as the totalized volumes for all recovery wells. As seen in Figure 4, recovery well RW-5 accounts for the majority of the recovered creosote DNAPL volumes, based on its proximity to the major DNAPL source area (Figure 1).

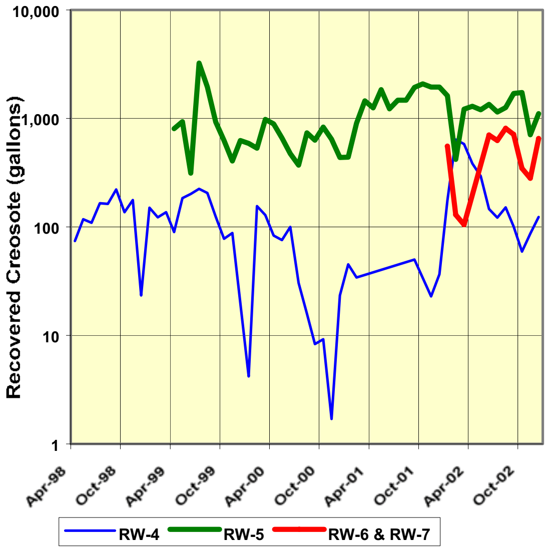

FIGURE 3. DNAPL recovery summaries.

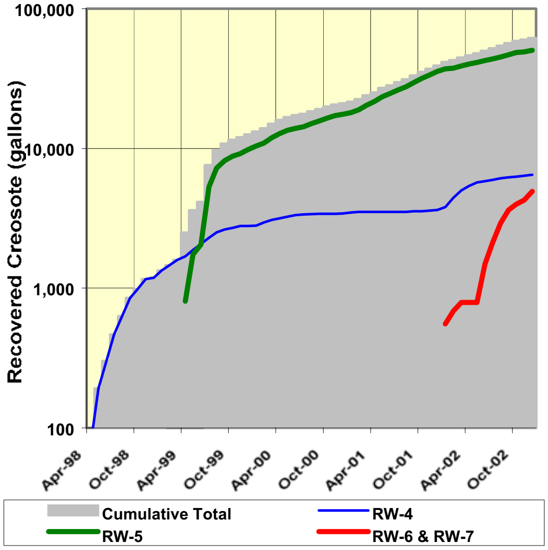

FIGURE 4. Cumulative recoveries.

The recovery wells collectively recovered a total of 61,704 gallons over the operational life of the recovery wells. During 2002, a total of 22,528 gallons of creosote DNAPL was recovered from the subsurface at the site, achieved by a full year of operation of the four (4) recovery wells. Specifically, RW-4, RW-5, and RW-6 & RW-7 accounted for approximately 13%, 65%, and 22% of the total recovered DNAPL volumes, respectively. Figure 5 presents the monthly recovered volumes for each recovery well and the cumulative recovery summary for 2002.

A comparative evaluation on the mass of creosote DNAPL recovered by the DNAPL recovery wells and the site's groundwater treatment plant (GWTP) was performed to demonstrate the effectiveness of free phase DNAPL removal versus the existing, single-phase pump and treat system. In order to normalize the data, the following conservative assumptions were utilized:

- Creosote DNAPL mass was assumed equivalent to the mass of total PAHs
- Site-specific creosote density of 1.1 grams per cubic centimeter
- GWTP influent total PAH concentrations were assumed at 10,000 micrograms per liter (site-specific and conservative)

In terms of mass recovery, on a cumulative basis since April 1998, the DNAPL recovery wells have recovered a total of 61,704 gallons of creosote, corresponding to a total mass of 566,153 pounds of DNAPL compared to an approximate total of 3,120 pounds of DNAPL recovered by the site's GWTP over the same time period (Figure 6).

Considering the mass of DNAPL recovered by the enhanced DNAPL recovery wells over their operational life, a total of approximately 180 years of operation of the existing site GWTP would be required to achieve the same mass removal.

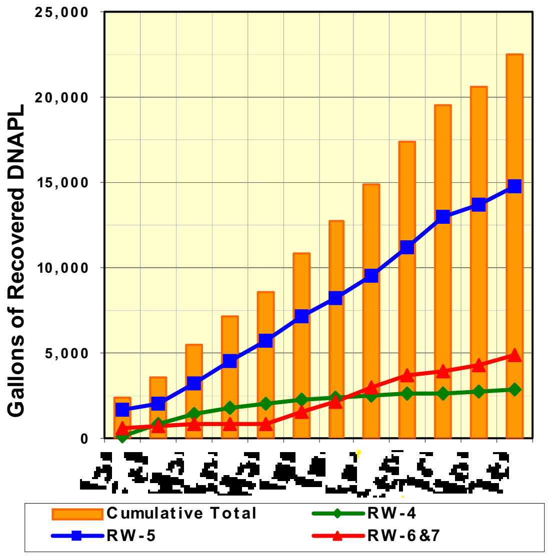

FIGURE 5. 2002 monthly recoveries.

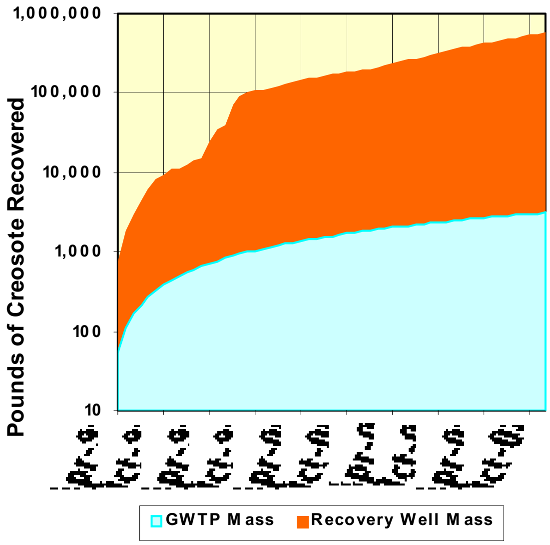

FIGURE 6. Cumulative mass recoveries.

DISSOLVED PHASE GROUNDWATER REMEDIATION

Along with the free phase creosote DNAPL recovery remediation at the site, a groundwater monitoring program is conducted on a quarterly basis. A total of 26 monitoring wells comprise the monitoring well network and monitor three depth specific intervals, referred to as the A, C, and D Zones. The primary depth interval zone of interest, based on the dissolved constituent results and free phase creosote, is the D Zone, present between approximately 70 and 90 feet below ground. Groundwater sampling is conducted for volatile, semi-volatile, and monitored natural attenuation parameters to evaluate the plume over time.

In order to evaluate the importance of natural attenuation processes, the data collected from the groundwater monitoring program was evaluated with respect to a generalized conceptual natural attenuation model for creosote sites (Figure 7).

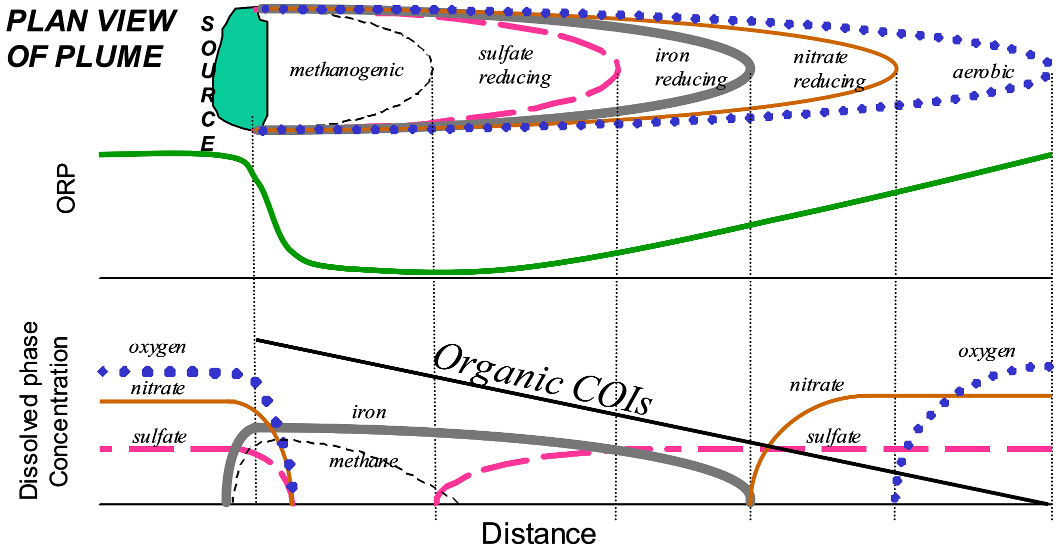

FIGURE 7. Conceptual MNA model for creosote sites (after King, 2003).

Site-specific data collected and evaluated on a quarterly basis from 1998 through 2002 indicates that natural attenuation processes are occurring at the site, based on organic constituent and MNA parameter results. Dissolved phase constituents in groundwater is presented for the D Zone, the principal zone of interest at the site. Figure 8 presents annualized averages of respective 10 part per billion isoconcentration contours for total PAHs and Figure 9 presents centerline and transverse total PAH distributions over the same time period.

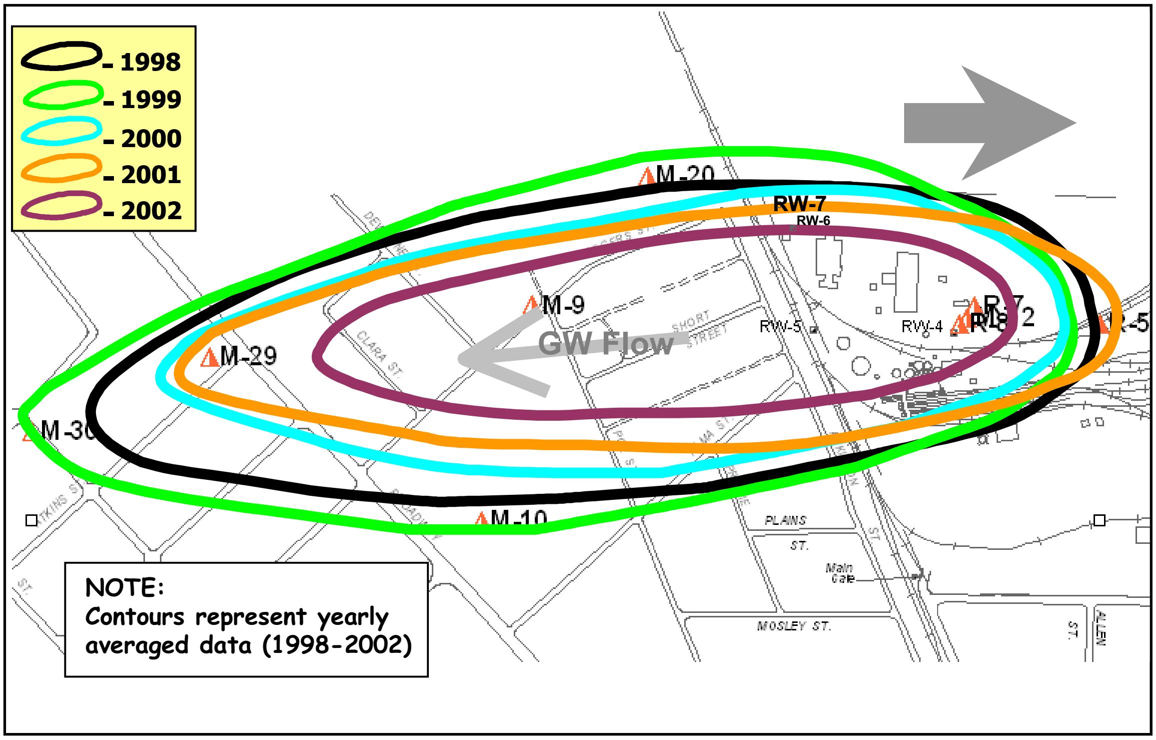

FIGURE 8. Annualized average 10 ppb isoconcentration contours for total PAHs (1998-2002). Approximate scale 1 inch = 300 ft.

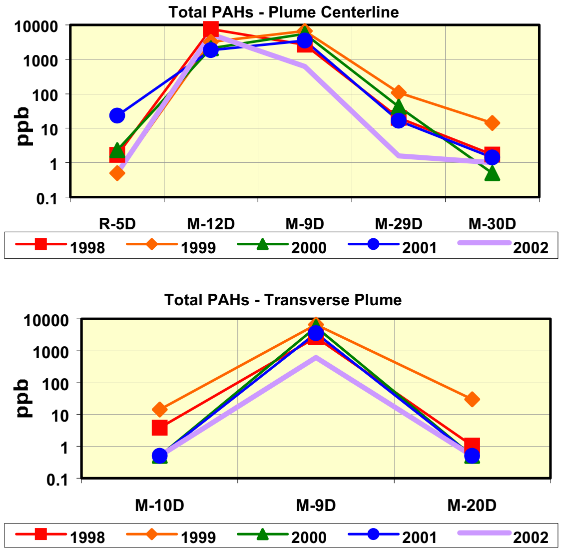

FIGURE 9. Total PAH plume concentrations.

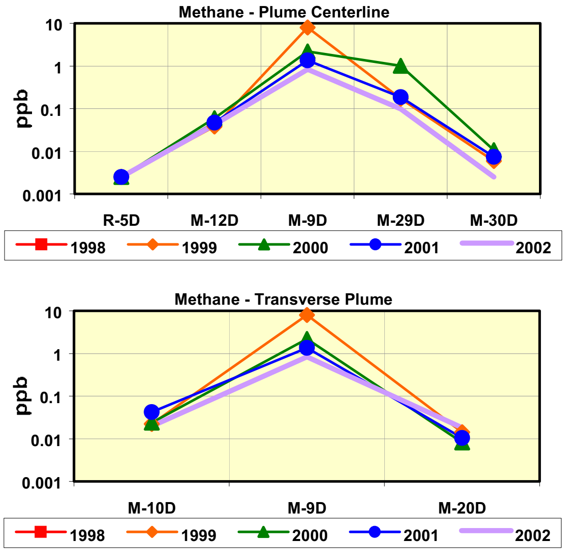

FIGURE 10. Methane plume concentrations.

Figures 10, 11, and 12 present additional support for MNA occurrence in terms of metabolic byproducts and redox conditions, respectively. Additional lines of evidence for MNA with respect to electron acceptors, indicates that sulfate and nitrate are important electron acceptors at the site and the distributions from 1998 through 2002 support the MNA conceptual model assumptions (Figures 13 and 14).

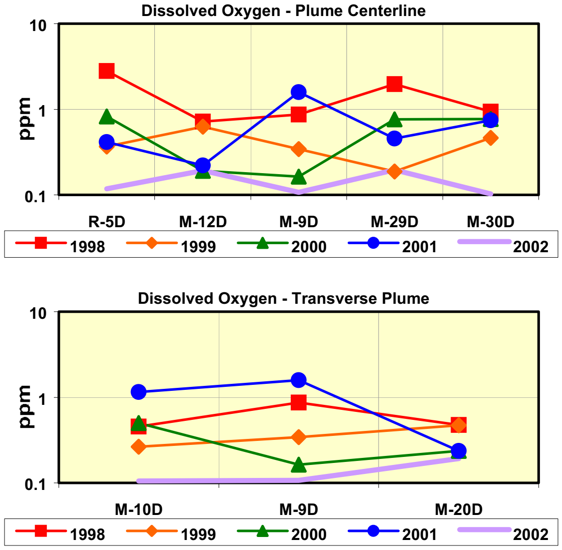

FIGURE 11. DO plume concentrations.

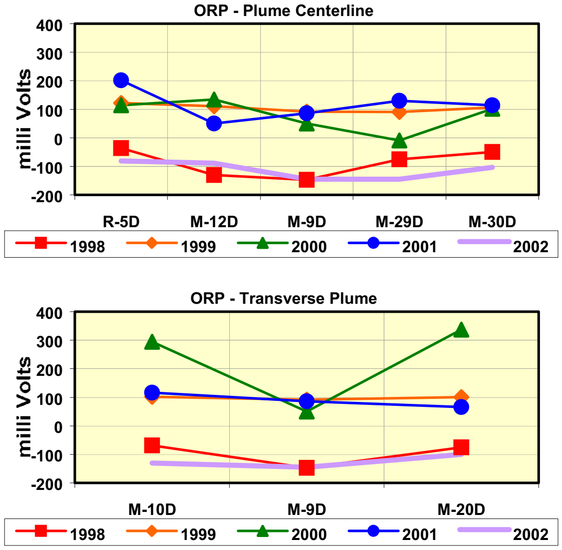

FIGURE 12. ORP plume concentrations.

Additionally, a mass balance evaluation was performed to evaluate the observed dissolved phase constituent plume reduction via employed source removal/containment and natural degradation processes. Figure 15 presents the estimated annualized total mass of total PAH compounds dissolved within groundwater (A, C, and D Zones) beneath the site. A total mass reduction, in terms of total PAHs, of approximately 60% has been realized for the dissolved phase constituent plume over the last five years.

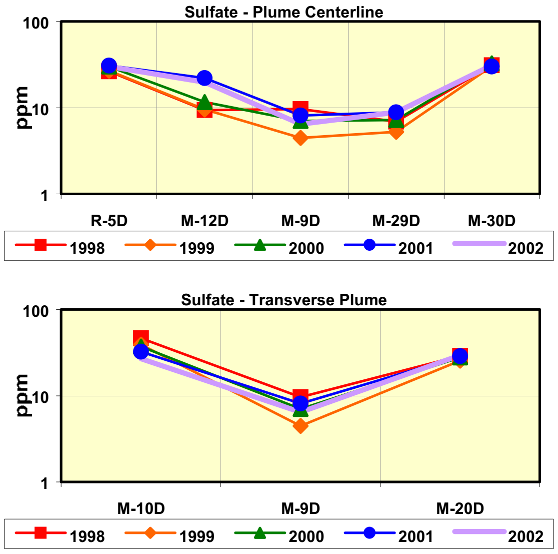

FIGURE 13. Sulfate plume concentrations.

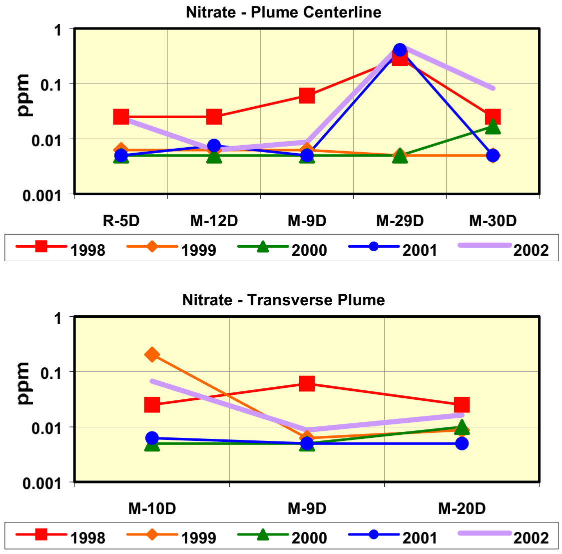

FIGURE 14. Nitrate plume concentrations.

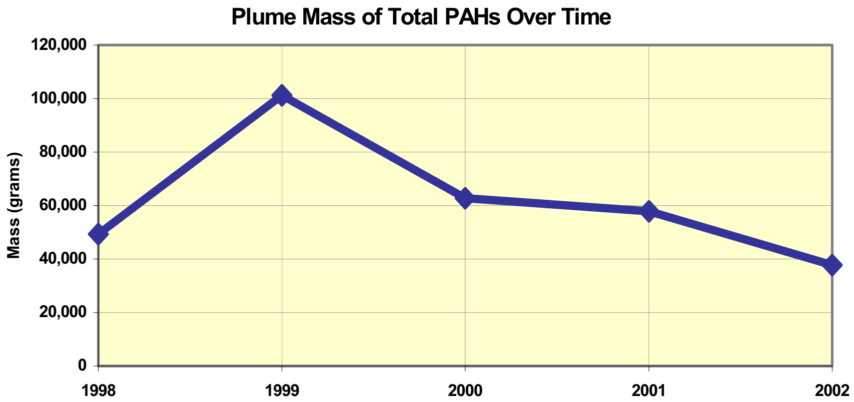

FIGURE 15. Mass reduction of Total PAHs in dissolved phase plume 1998-2002.

SUMMARY

Site-specific hydrogeological conditions and site setting were conducive to the application of enhanced DNAPL recovery techniques using a modified groundwater circulation well technology. The implementation of a strategic groundwater monitoring program including MNA evaluation have substantiated MNA as an important component to constituent fate at the site. The authors have worked proactively with the regulators and the site is a RCRA Corrective Action Showcase Pilot Project (U.S.EPA, 2000).

Integrated free phase recovery and strategic monitoring of the dissolved phase groundwater plume has lead to an effective corrective action approach for the site. Currently, institutional controls at the site include downgradient groundwater use restriction, therefore, site-specific risk assessments concur with the approach.

Application of a strategic groundwater monitoring program, in terms of network and parameters, and aggressive evaluations on free product recovery technologies should be considered for creosote sites.

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