

TAMING A LARGE SOLVENT PLUME: PROGRESS AT THE SAVANNAH RIVER SITE IN REMEDIATING GROUNDWATER

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ABSTRACT

From characterizing the A/M-Area at the Savannah River Site in 1983 to having cleaned 3,200,000,000 gallons of groundwater in that area today, this paper will share lessons learned for today's environmental professional. Its focus will be how to manage a large solvent-contaminated plume. A/M-Area's plume, contaminated primarily by volatile organic compounds (VOCs), is such an entity.

Savannah River Site started remediating the A/M-Area plume using traditional air stripping technology, but has since added powerful, efficient soil-vapor extraction units. Tackling VOCs and the significantly more persistent version of such solvents, Dense Non-Aqueous Phase Liquids (DNAPLs), the site's Environmental Restoration and Technology Center engineers and scientists have teamed up to continually improve the performance of existing remediation equipment, while aggressively demonstrating and deploying new technologies at A/M-Area. Air-lift recirculation wells, in situ chemical oxidation, and the patented BaroBallTM are just a few of the cutting-edge technologies demonstrated or deployed at A/M. This paper will not only share ideas about the effectiveness of these technologies, but also cost information, which is important to environmental project managers.

In addition, this paper will explain Savannah River Site's holistic approach to remediation as demonstrated through A/M-Area's cleanup, including management's approach to working with regulators. Using video, animation, charts, and valuable handouts, this paper and presentation will guide the audience through the evolution of remediating the A/M-Area plume. Anyone who must address remediating a large, solvent-contaminated plume will value the information learned from SRS's 15 years of progress with this plume. Taming it is a challenging and dynamic process with new lessons learned each year.

HISTORY

In 1983, the Savannah River Site (SRS), near Aiken South Carolina, initiated one of the largest and most successful remediation programs aimed at cleaning up organic solvents from the soils and groundwater. Located in the northern portion of SRS, the 350-acre A/M Area housed facilities for the manufacture of reactor fuel and target assemblies, attendant support facilities, laboratories, and administration buildings. At several stages in the fabrication process, fuel assemblies were degreased using industrial solvents, primarily trichloroethylene (TCE) and tetrachloroethylene (PCE).

Through waste management practices of the time and incidental spills, approximately **3.5 million pounds** of solvents were released to the environment. This has led to a groundwater contaminant plume of approximately 1500 acres in size. The timing of the releases, location, quantity, and chemical differences among the solvents determined the partitioning and dispersion in the soil column and the groundwater aquifer systems.

Groundwater contamination was discovered near the M-Area Settling Basin, an end point in a waste processing system, in 1981. In February 1983, groundwater cleanup voluntarily began with the operation of a prototype, air-stripping system of 70 gpm capacity. A 600 gpm system was placed into operation in 1985, and a Resource Conservation and Recovery Act (RCRA) Part B Corrective Action Permit was approved two years later. The large air stripper system consists of 11 recovery wells treating the most heavily contaminated portion of the plume. In 1992 the prototype system was relocated and placed back into operation in the northern sector of A/M Area. In 1996, a more robust 300 gpm unit replaced the prototype stripper. To date, two air strippers removing over 350,000 pounds of solvents have treated more than 3.2 billion gallons of contaminated groundwater. Soil vapor extraction units have removed an additional 350,000 pounds of solvents from the vadose zone since their installation in 1995. These are impressive results and have shown a substantial commitment of attention and resources by the Department of Energy; however, they still represent only a 20% achievement of the total clean up.

During the course of the design and implementation, it was recognized that the then-current individual technologies, such as pump-and-treat, would have limitations. Realizing this, the RCRA permit was written with provisions to have periodic system performance evaluations for installed technologies, and to allow for the evaluation and implementation of appropriate new technologies. This strategy provided a systematic way to select and implement new and complementary remediation methods. Technologies are evaluated and brought on-line in phases to address various target areas and forms of solvent contamination. Even though groundwater in the A/M Area was the result of different point source releases, the permit called for basing remediation on a single groundwater unit, eliminating the need for multiple permits. The structure of the Part B permit also provides mechanisms for rapid demonstration and implementation of new remediation technologies.

Once the initial groundwater remediation cleanup was initiated, the focus broadened to include remediating the different sources feeding contamination to the groundwater. In 1985 SRS began RCRA closure activities for the M-Area Settling Basin. Certified closed by the state of

South Carolina in 1991, this was one of the first approved basin closures within the DOE complex.

GROUNDWATER STRATEGY

Early recognition of the vast nature of this contaminant problem and the complexity of the release points and effected media brought about a need to phase the overall assessment and remedial effort. As early action was taken in stepwise increments to achieve efficiencies in clean up, it was seen that the management of the remedial effort must also be taken in a phased approach. As a consequence, an A/M Area groundwater strategy was developed consistent with the RCRA Permit to optimize the balance between assessment and remediation.

The strategy recognizes the dynamics of a source-to-groundwater system. It focused the initial phases of action toward learning as much detail as practicable about the contaminants, the release points, and the optimal locations for early deployment of clean up technologies. The A/M Area plume was extensive, and early action did not have to be detailed or comprehensive, only efficient. Since no one technology type or deployment was going to remedy the whole plume, the intent was to aggressively go after the highest concentrations of contaminants accomplishing the highest possible mass removal. Characteristic of the treatment technology was high capital and operational costs, but with high return on contaminates removed. Also in this initial phase, work was performed to close off all original release points.

“Cutting off the head of the snake” combined with achieving substantial, early mass removal enabled the focus to shift toward the more arduous search for secondary sources in the effected media, that is, searching for VOCs and DNAPLs bound up in the vadose zone and groundwater systems. Coincident with this characterization, additional information was also gained on the geology and hydrogeology of the effected media.

This “worst first” approach demonstrated a commitment to clean up and would be continued as the subsequent phased efforts were undertaken. In the second phase of attacking the plume, focus was shifted to locating and containing of the leading facets of the plume. In this approach, using the information gained about contaminant fate and transport, plume fronts were targeted for retarding movement or for interception with treatment curtains. The A/M Area plume was found to have moved into several different aquifer systems, and the determination of retarding or interception depended upon the flow gradients, potential receptors, available technologies, and other plume features. The goal of this phase was to cease or significantly retard the further growth of the plume by capture in extraction wells or by treatment in situ to effect substantial mass removal. In the case of interception and treatment, the 500 parts per billion (ppb) isopleth plume feature was established as the target. The technology characteristics to be employed needed to be of moderate capital and operating cost, have high efficiency for contaminant mass removal in that more dilute plume condition, and ideally would have no effluent stream requiring a permitted and monitored outfall.

Final phase actions will consider the dilute fringe of the plume or will be polishing actions employed after significant mass removal has taken place at the source and secondary source locations. The target is to address very low concentrated plume and vadose zone conditions where minimal opportunity for mass removal exists, with the objective of achieving maximum

contaminant limit goals. Attributes of the treatment technologies would be very low capital and operating cost with easy installation and minimal maintenance.

The common denominator in the strategy of technology selection for each phase is to match the cost and effectiveness for mass removal with the relative concentration, that is, the opportunity for mass to be removed. A measure of successful technology selection would be that the cost per unit of contaminant removed is low in all phases, and relatively equal. The following figures summarize this strategy:

In Figure 1, the relationship is shown between the cost for installation and operation of a technology relative to the plume contaminant concentration as effected by distance from the source.

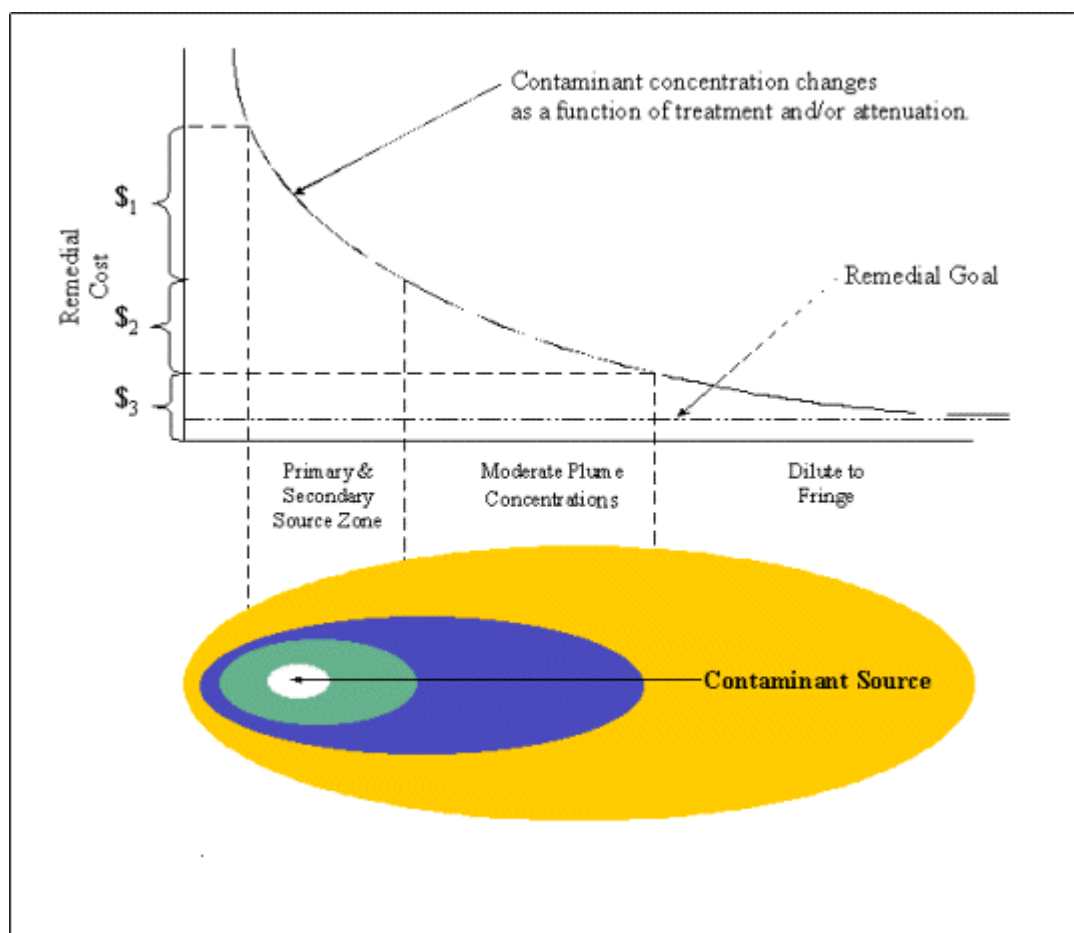


FIGURE 1

S_1 Very high contaminant concentrations associated with the initial release points and secondary sources yields attendant high opportunity for mass removal or destruction. This supports very aggressive treatment technologies with significant capital and operational cost.

- \$₂ Moderate contaminant concentrations in a large spatial dispersion yielding a moderate opportunity to remediate contaminant mass. This will require technologies with more efficient operating parameters with moderate initial capital and operating cost.
- \$₃ Very dilute contaminant concentrations require technologies with very small capital and operating cost. This aspect of the plume is ideal for the deployment of passive and natural remedial systems.

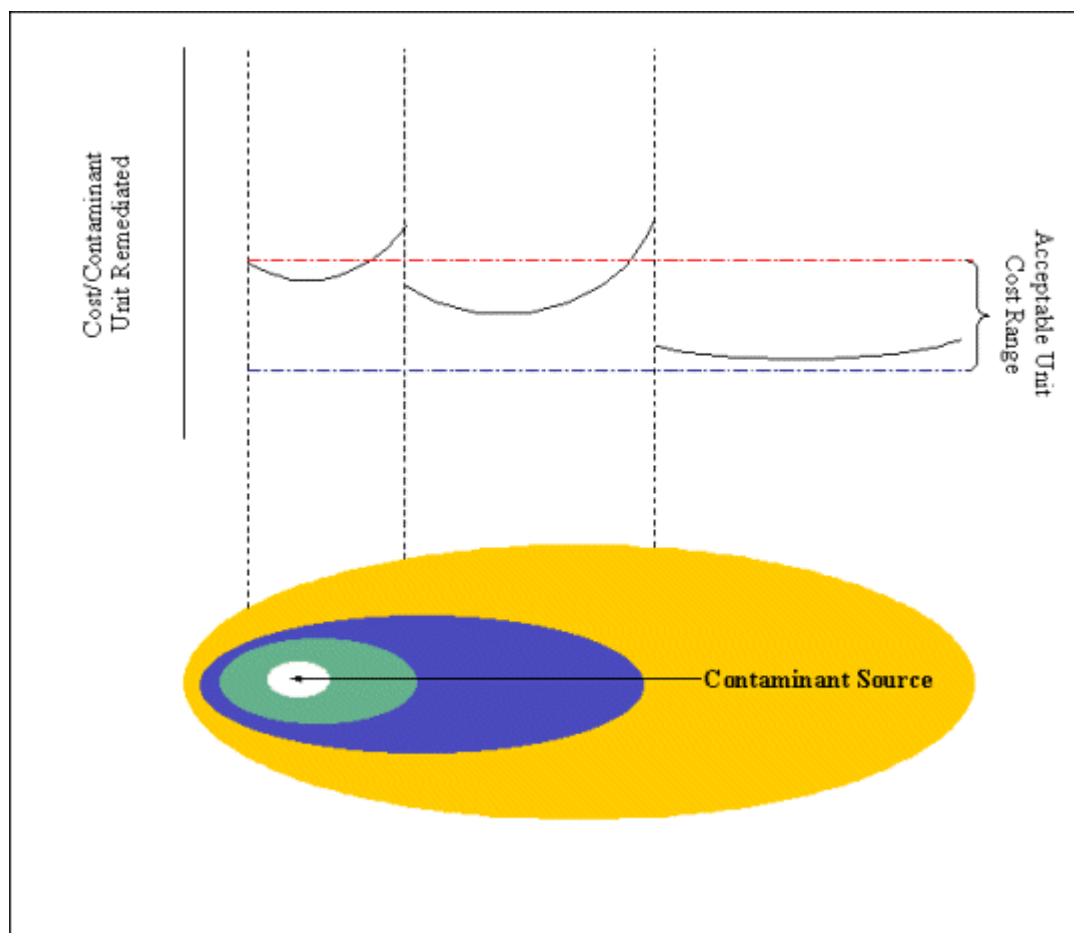


FIGURE 2

Technology selection for the initial installation, or the later replacement of a system, should be made in order to achieve overall remediation at some relatively constant and low cost per unit of contaminant mass treated. The curves reflect some initial operational period where the capital and start up cost strongly influence the unit cost rate. This is followed by a period where steady state operational cost is stable, but unit cost begins to rise as the mass availability declines. Finally, the unit cost will begin to steadily rise as mass is continued to be depleted. At this point, if remedial goals are not yet achieved then the technology needs to be considered for replacement with a more efficient alternative.

REMEDATION SELECTION

The unsaturated or vadose zone above the water table at SRS contains nearly one-half of the estimated solvent content released to the environment. Consequently six soil vapor extraction units were placed into operation to achieve solvent recovery before contamination reaches the groundwater. A combination of vertical and horizontal wells were employed to maximize the extraction process. In addition, automated control systems have been installed to allow remote/autonomous operations intended to increase efficiency and reduce operating costs.

As concentrations from the vadose zone recovery wells decline, the mechanical units will be shut down and the recovery wells will be affixed with a passive remediation device called a BaroBallTM. A BaroBallTM takes advantage of natural barometric pumping phenomenon to remove VOCs from the vadose zone as a result of changes in barometric pressure above and below the ground surface. When the subsurface pressure is higher, contaminants naturally move upward where they can be treated or released. The BaroBallTM significantly increases the effectiveness of barometric pumping by preventing the back flow of air into a venting well when atmospheric pressures reverse, a condition that can reduce contaminant removal by diluting and disbursing the contaminant. Its design consists of a simple plastic sphere that seals the well from incoming surface air. The cost of the device is approximately \$50.00 and can be installed on wells installed by direct push methods.

Several innovative technology demonstrations at the site have been performed since 1988. These demonstrations include: the installation of horizontal wells; air sparging; co-metabolic in situ bioremediation; radio frequency and joule heating; and solvent collection and recycling. This has led to the remediation of more than 30,000 pounds of solvents.

Two of the largest demonstration tests involved air injection and extraction using horizontal wells. Seven horizontal wells were installed, some below the water table (for air sparging) and some above the water table (for soil-vapor extraction). The first test used only air, with remediation resulting primarily from physical removal as the contaminant plume partitioned into the sparged air. In the second test, methane was added to the air to stimulate existing organisms to break down the solvents through co-metabolism.

One current deployment in operation involves in-well air stripping. Unlike conventional groundwater sparging, the vertical recirculation well is an improved variation of a pump and treat system

that uses a combination of existing technologies (air stripping, air lift pumping, and groundwater extraction wells) in one complete in situ assembly. The system consists of two concentric wells, each with upper and lower screen zones. Compressed air is injected inside the inner well bore at the lower screen zone. The air/water mixture within the lower screen zone induces an upward flow of groundwater while the contaminant is being stripped from the water phase into the air phase. The groundwater is discharged through the upper screen into the annular ring and eventually back into the aquifer. The stripped volatile moves with the air continuing upward through the well to the release stack. Groundwater flow outside the well between the upper and lower screens establishes a recirculation pattern. Under normal conditions, water will cycle through the system several times before escaping the recirculation pattern, ensuring effective treatment. In addition to the stripping, oxygen and other nutrients (if elected to be added) are transferred from the air bubbles into the recirculating water, improving the conditions for natural bioremediation of residual contaminants in the aquifer.

This technology has been selected for targeting the 500 ppb plume isopleth in two major sectors of the A/M plume. Installing a curtain of wells across the advancing plume, the intent will be to reduce the concentrations out of the down gradient side of the system by as much as 90%. In a third planned application of this technology, three successive curtains of recirculation wells will be deployed to address a high concentration plume slug (>500 ppb), a lower concentration isopleth (150 ppb), and finally at the distal edge of the plume to achieve zero plume growth. This system will have higher initial cost for deployment, but is expected to operate for a shorter time to achieve a reasonable life cycle cost objective.

As the performance data is gained on the operation of the recirculation well systems, the cost savings will be confirmed with actual data; however, this technology is projected to save several million dollars when compared to a conventional air stripper system over its operational period.

PCE is also found in the A/M Area groundwater as a Dense Non-Aqueous Phase Liquid (DNAPL) and will dissolve slowly with time unless it is removed or destroyed in situ. Every gallon of DNAPL removed or destroyed is equivalent to millions of gallons of groundwater treated through future pump-and-treat operations. Since DNAPL is the primary driver for the long cleanup period, carefully targeted and detailed characterization methods are being deployed and aggressive treatment is planned. Recent test deployments of an in situ oxidation process using Fenton's chemistry were demonstrated on site. The results were very impressive as a 94% destruction rate was achieved. Although used previously for floating products in shallow groundwater systems, this first-of-a-type deployment involved DNAPL in groundwater at depths over 150 feet below ground surface. This initial testing of the technology showed that for a similar deployment, a pool of approximately 1100 pounds or more would be required for the technology to be more cost efficient than conventional pump and treat. Since the time of the demonstration, other successful deployments and market conditions have adjusted to advances in the application of the process that would effect a lowering of costs.

The Fenton's chemistry approach is very effective, but is sensitive to the characteristics of the formation and how the DNAPL may be dispersed in the vadose zone and aquifer system. To account for these problems, a more aggressive technology using steam injection is being

planned for the A/M plume. This dynamic underground steam injection process will focus on in situ destruction of DNAPL, as well as, effecting substantial VOC mass removal in the dissolved and vapor phases. It is expected to be less sensitive to how the DNAPL may be dispersed since the steam treatment effects the entire local geology and hydrogeology. A test deployment will determine the site-specific effectiveness and enable planning for future applications.

As the site is looking at this very aggressive technology, a plan is working to develop a passive approach for dealing with the distal plume portion. Many regulators and facility owners alike are realizing that monitored natural attenuation (MNA) is a technology that can be deployed alone or in conjunction with other remediation systems. Expected to play a significant part in the final remedial effort at Savannah River Site, the Environmental Restoration Division is working in conjunction with the United States Geological Survey and the site's regulatory agencies to define remedial investigation, design, implementation, and monitoring protocols to assure its acceptable and successful implementation.

SUMMARY

Based on data from more than a decade of operation, no single technology is appropriate to clean-up industrial solvents at this site. Robust cleanup requires a combination of pump-and-treat, soil vapor extraction for solvent vapor and DNAPL in the vadose zone, and innovative technologies for DNAPL below the water table and for dilute plume edges. The selection of the mix of technologies is guided by the contaminant conditions, and needs to strive for mass removal at a consistently low unit rate. When source term is present in significant concentrations, then very aggressive technologies can be rapidly deployed and begin the remediation of the "worst first". As contaminant levels decrease due to successful initial treatment or through the attenuation from plume movement, then less aggressive technologies need to be substituted for achieving the mass remediation at lower cost per unit of treatment.

Finally, the regulatory process has to recognize the significance of this strategy and have the appropriate decision documents in support of its deployment. As is the case at the Savannah River Site, this phased approach allows remediation to start quickly, and with subsequent operational and characterization data to continually improve the basis for system modification and optimization.