NOT "JUST" PUMP AND TREAT

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ABSTRACT

The Lawrence Livermore National Laboratory (LLNL) has been consistently improving the site cleanup methods by adopting new philosophies, strategies and technologies to address constrained or declining budgets, lack of useable space due to a highly industrialized site, and significant technical challenges. As identified in the ROD, the preferred remedy at the LLNL Livermore Site is pump and treat, although LLNL has improved this strategy to bring the remediation of the ground water to closure as soon as possible. LLNL took the logical progression from a pump and treat system to the philosophy of "Smart Pump and Treat" coupled with the concepts of "Hydrostratigraphic Unit Analysis," "Engineered Plume Collapse," and "Phased Source Remediation," which led to the development of new, more cost-effective technologies which have accelerated the attainment of cleanup goals significantly. Modeling is also incorporated to constantly develop new, cost-effective methodologies to accelerate cleanup and communicate the progress of cleanup to stakeholders.

In addition, LLNL improved on the efficiency and flexibility of ground water treatment facilities. Ground water cleanup has traditionally relied on costly and obtrusive fixed treatment facilities. LLNL has designed and implemented various portable ground water treatment units to replace the fixed facilities; the application of each type of facility is determined by the amount of ground water flow and contaminant concentrations. These treatment units have allowed for aggressive ground water cleanup, increased cleanup flexibility, and reduced capital and electrical costs. After a treatment unit has completed ground water cleanup at one location, it can easily be moved to another location for additional ground water cleanup.

INTRODUCTION

For more than ten years at the Lawrence Livermore National Laboratory (LLNL) Livermore Site, the preferred remedy for ground water cleanup has been to pump and treat its nearly 40 identified co-mingled volatile organic compound (VOC) contaminated plumes. At the onset of its cleanup program, LLNL initially used traditional large permanent treatment facilities as agreed to with the community and the regulatory agencies and planned for in the 1992 Record of Decision (ROD). However, constrained or declining budgets in the past few years, loss of available space due to the encroachment of ongoing site construction, and the need to remediate contaminant plumes at an accelerated rate has required significant enhancements to the traditional "Pump and Treat" approach. These external factors required creating and implementing unique, aggressive, and cost-effective ideas on how to Not "Just" Pump and Treat. These actions, and the logical progression to each phase of implementation has allowed LLNL to achieve its primary goals of gaining complete hydraulic control of offsite plumes, and capturing all contaminated ground water moving offsite. The phases implemented include "Smart Pump and Treat," "Hydrostratigraphic Unit Analysis," the development and installation of innovative and portable treatment systems, "Engineered Plume Collapse," "Phased Source Remediation," and "3-Dimensional Modeling."

SMART PUMP AND TREAT

One of the first efficiency enhancements was implementation of the "Smart Pump and Treat" strategy (1992). This involved installing extraction wells in phases, with well spacing and locations based on observed performance of installed wells, to ultimately design the most efficient wellfield configuration. This included detailed sampling of the wells drilled, the establishment of a data management system to accurately store the data with real-time retrieval capabilities, and the development of a sound conceptual model.

"Smart Pump and Treat" consists of (1) detailed characterization of the geology, hydrology, and chemistry, (2) use of computer-aided data interpretation, data display, and decision support systems, (3) removal of source terms, if possible, (4) initial design for plume containment and source remediation, (5) phased installation of the wellfield, (6) detailed monitoring of the remediation, (7) active ongoing re-evaluation of the operating wellfield, including redesign as appropriate (dynamic management), (8) reinjection of treated ground water to speed the flushing of contaminants, and (9) establishing appropriate cleanup levels. Use of some or all of these techniques can dramatically reduce the time required to achieve cleanup goals and therefore the cost of ground water remediation.

In an active wellfield system, most of the ground water is withdrawn from the coarse-grained, high-permeability materials. While pumping ground water, flow velocities through these systems are usually relatively high and contaminant concentrations may be reduced relatively quickly. This condition causes the concentration gradient to reverse, and contaminants diffuse back into the more permeable materials from the bounding finer-grained materials. Contaminant concentrations from extraction wells typically show this relatively rapid reduction followed by a much slower rate of decline as this diffusion process takes place.

HYDROSTRATIGRAPHIC UNIT ANALYSIS (HSU)

An additional improvement to applying pump and treat at LLNL was the development of a Hydrostratigraphic Unit (HSU) Analysis approach to characterize the site for implementing the cleanup strategy detailed in the ROD. An HSU is defined as a body of sediment and/or rock characterized by ground water flow. This flow can be demonstrated as distinct under both stressed (pumping) and unstressed (natural) conditions, and is distinguishable from flow in other HSUs. Therefore, an HSU is defined by the ground water characteristics and flow within the HSU, rather than the overall geologic characteristics. The fundamental characteristics of the HSUs at LLNL are: a high degree of hydraulic interconnectivity within an HSU, a low degree of hydraulic interconnectivity with adjacent HSUs, and boundaries that significantly limit vertical hydraulic communication and contaminant migration.

The primary data sets used to define the HSUs include ground water elevation, pumping test, ground water chemistry, geologic, and geophysical data from about 500 wells that average 30- to 75-m depth and have about a 30- to 150-m lateral spacing. These multiple independent data sets were integrated using a densely-spaced, cross-section grid. The ability to make reliable ground water elevation and VOC isoconcentration maps under a variety of pumping conditions serves as one of the principal tools to verify that an HSU is correctly defined. Although the overall ground water flow direction in most LLNL HSUs are similar, distinct differences are observed especially in response to pumping. Similarly, the VOC plume geometry in each HSU is distinct. These distinct differences persist even in areas where extraction wells have been in continuous operation for months to years, suggesting limited leakage occurs across HSU boundaries over much of the site.

The HSU framework has allowed mapping of the complex network of co-mingled plumes, each of which can now be traced back to its respective source area. The ground water cleanup systems at the site have been designed to treat and capture individual contaminant plumes, and are optimized with respect to their location, geometry, and mobility.

CHANGING TIMES/PORTABLE TREATMENT UNITS

This new understanding of the subsurface led to the next significant modification to the "Smart Pump and Treat" strategy. As the wellfields were expanded, it became obvious that the construction of fixed, permanent treatment facilities with associated pipelines were too costly (over $1,000,000 per facility), not flexible enough to respond to ever improving wellfield analysis, and too large to be easily located at a highly industrialized site.

After relying on costly and obtrusive fixed treatment facilities, in 1996 LLNL began the construction and phased installation of various portable ground water treatment units. These treatment units have allowed aggressive ground water cleanup, increased cleanup flexibility, and reduced capital and electrical costs. After a treatment unit has completed ground water cleanup at one location, rather than being salvaged, it is moved to another location for additional ground water cleanup. These treatment units, in conjunction with four of the originally planned fixed treatment facilities serve as a network to target on and offsite VOC ground water plume configurations for effective remediation.

There are four types of portable ground water treatment units in use at LLNL. These include two air stripping type units — Portable Treatment Units (PTUs) and miniature treatment units (MTUs); granular activated-carbon treatment units (GTUs); and solar-powered treatment units (STUs) (Figure 1). Each of these facilities are easily relocated with a forklift. The installation and use of each type of facility in a particular area is determined by the amount of ground water flow and contaminant concentrations, as shown in Figure 2.

A PTU treats ground water flow up to about 50 gallons per minute (gpm) compared to a fixed facility that can treat over 500 gpm at LLNL. The technology utilized is an air stripper. The air stripper effluent vapor stream passes through granular activated-carbon to remove VOC contamination. The facility is housed in a 20-ft long by 8-ft wide by 9-ft high cargo-type shipping container. It is equipped with ports to attach ion exchange resin columns if the treatment of metals is required. The construction costs are approximately 10 per cent of a previously planned fixed facility (approximately $140,000).

A miniature treatment unit (MTU) treats ground water flow up to about 25 gpm using a smaller air stripper (half the capacity of a PTU). The air stripper effluent vapor stream passes through granular activated-carbon to remove any additional residual contamination. It is equipped with ports to attach ion exchange resin columns if treatment of metals is required. The facility is weather resistant and attached to a 9-ft by 4-ft skid. The construction costs are approximately 70 percent of a PTU (approximately $105,000).

A granular activated-carbon treatment unit (GTU) treats ground water flow up to about 45 gpm depending on carbon canister size. Ground water is pumped through granular activated-carbon to remove contamination. The facility is weather resistant and attached to a 9-ft by 4-ft skid. The construction costs are approximately 80 percent of a MTU (approximately $75,000).

A solar-powered treatment unit (STU) treats ground water flow up to about 5 gpm. Ground water is pumped through granular activated-carbon to remove contamination. At this low flow rate, residence time in the carbon is at least 11 minutes. An STU is powered with solar panels and has batteries to extend operation partially into the night. It is extremely adaptable for remote areas, or areas where electrical power is not available. The facility is enclosed in an 8-ft-long by 4-ft wide by 4 1/2-ft high housing that is attached to a skid. The construction costs are approximately 45 percent of a GTU (approximately $40,000).

Granular Activated Treatment Unit (GTU)

Miniature Treatment Unit (MTU)

Solar-powered Treatment Unit (STU)

Portable Treatment Unit (PTU)

Fig. 1. LLNL treatment units.

Use of these portable units have been incorporated into the implementation of LLNL's Engineered Plume Collapse (EPC) strategy (1996), and the subsequent implementation of Phased Source Remediation (PSR - 1999).

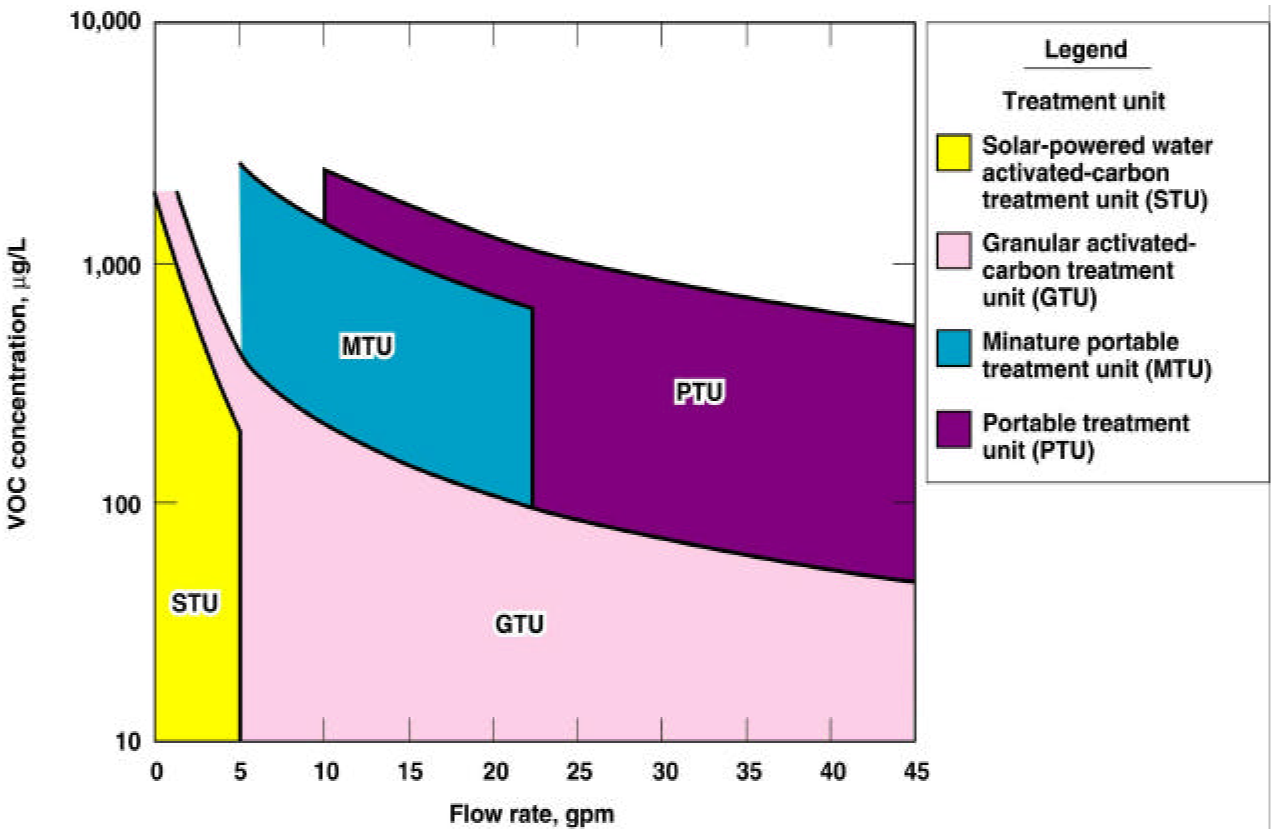

Fig. 2. Treatment unit options.

Engineered Plume Collapse (EPC)

By mid-1995 it became obvious that the constrained budgets were affecting LLNL's ability to meet scheduled milestones agreed to in the ROD with the regulatory agencies. A new strategy called Engineered Plume Collapse (EPC) was adopted which utilized the portable treatment unit concept, still in the development phase. Additional promising new technologies were also in the process of evaluation.

The philosophy behind EPC (1996) was to demonstrate a more time- and cost-effective remediation strategy through the use of assorted, mobile, efficient PTUs to aggressively pump and treat, combined with other existing and new source remediation technologies that were being considered and tested for implementation. EPC incorporates distal plume and source control prior to utilizing advanced technologies for source removal. Source control stops the movement of VOCs from source areas to the distal plume, starving the plume. Deprived of continued influx of VOCs, the distal plume collapses on itself. Distal plume and source control have been part of the overall cleanup process used at LLNL since the early 1990s. This strategy uses proven pump and treat technology to effectively remediate high-permeability zones, combined with new technologies that show great promise to effectively remediate low-permeability, fine-grained materials.

The combination of the portable ground water treatment units concept with several new technologies is used to reduce the contaminant mass in all portions of the plumes to levels that will be accepted by the regulatory agencies and stakeholders. The adaptive use of portable treatment units allows for the flexibility of treating the plumes containing the most VOC mass as remediation progresses and the plumes collapse. The technologies will target areas of the plumes containing the highest VOC mass until all sources of ground water contamination are removed. The combination of simultaneous cleanup of coarse-grained and fine-grained materials is what makes this strategy particularly effective. After the implementation of Engineered Plume Collapse (EPC), a dramatic increase in mass removed over what was predicted in the Record of Decision was realized (Figure 3).

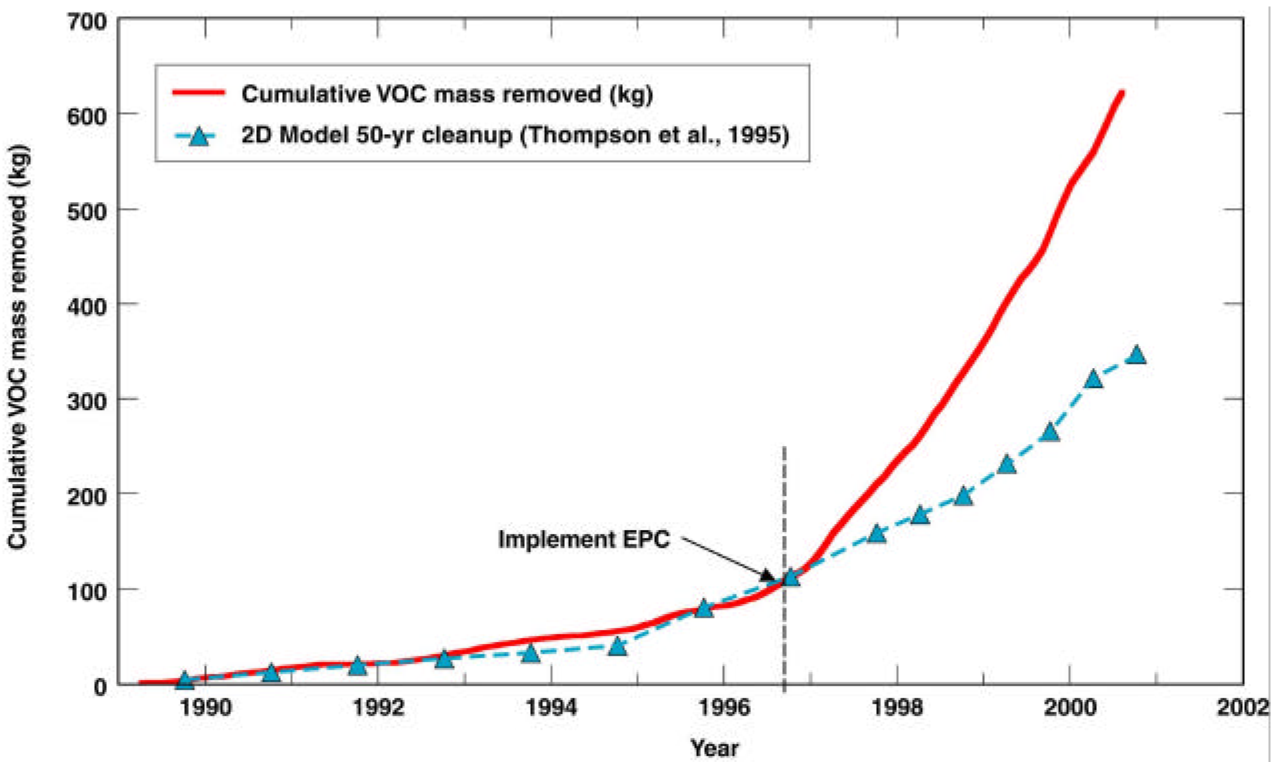

Fig. 3. Engineered Plume Collapse (EPC) is rapidly removing mass.

Phased Source Remediation (PSR)

Phased Source Remediation (PSR) is the logical extension of LLNL's successful Engineered Plume Collapse (EPC). The PSR strategy (1998) entails focusing the right technologies at the right place at the right time, utilizing increasingly energetic technologies as needed (Figure 4). PSR is being implemented to treat the fine-grained, low-permeability sediments in source areas. Technologies to be potentially utilized include Catalytic Reductive Dehalogenation (CRD), Electro-Osmosis (EO), and Dynamic Underground Stripping/Hydrous Pyrolysis Oxidation (DUS/HPO) (Figure 4).

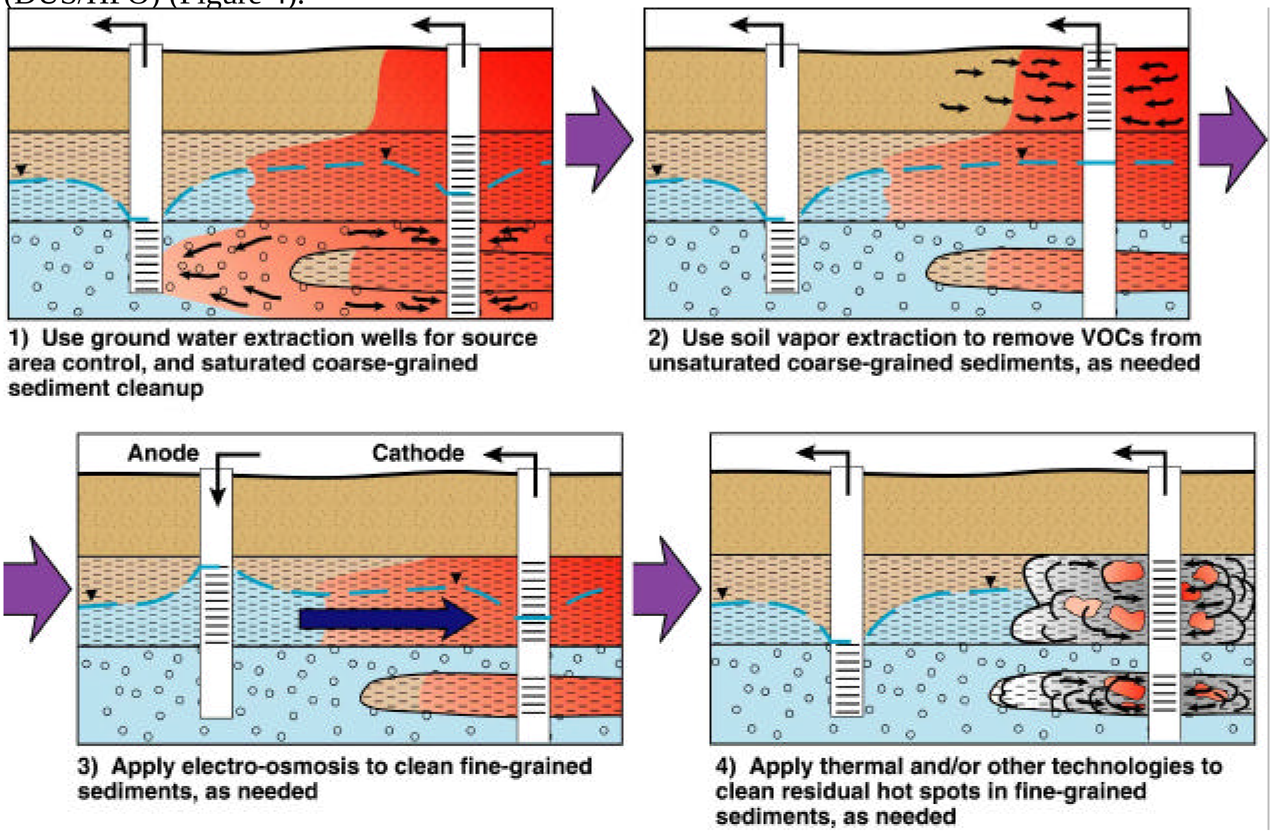

Fig. 4. Phased Source Remediation (PSR) strategy.

CRD technology was developed at LLNL in conjunction with Stanford University to be able to treat high concentrations of VOCs in the presence of tritium in ground water. Because the regulatory agencies and the community wanted the tritium to remain in the subsurface as much as possible, the CRD at LLNL operates as a closed-loop treatment system that utilizes dissolved hydrogen in the presence of a palladium catalyst to chemically reduce chlorinated VOCs into environmentally benign hydrocarbons (e.g., methane, ethane, ethene). The rapid reaction rates associated with this process allow the primary components of the treatment unit to be placed within the confines of a dual-screened well bore. This permits extraction, treatment, and discharge back into the formation to take place all within a single treatment well, leaving tritiated ground water to remain in the subsurface to naturally self-remediate via radioactive decay.

The first Catalytic Reductive Dehalogenation (CRD) unit was installed in 1998 in a downhole *in situ* configuration. This first unit served as a pilot system to test the viability of the process and gather operational experience and data while also achieving destruction of VOC mass (at a rate of approximately 1 gram/hour). Additional units are to be added in strategic locations to arrest the downgradient migration of the VOC plumes and to remediate the very high concentrations of VOCs in ground water in the immediate vicinity of the source area. These additional units may be placed in a dual-screen well bore similar to the first CRD unit, or used in combination with a pair of adjacent above- ground injection/extraction wells. A second CRD system was activated in September 2000 as an above ground treatment unit, with tritiated water contained within the closed-loop system until re-injected back into the same hydrostratigraphic unit (HSU). This latter configuration will be used in combination with Electro-Osmosis (EO) to facilitate the extraction of VOC and tritium contaminated ground water from fine-grained, low-permeability materials.

Electro-Osmosis (EO) is the phenomenon by which flow of aqueous fluids through a porous material is driven by an imposed electrical field. When two electrodes are introduced into water-saturated soil and a direct electrical current (DC) is passed between them, the ground water contained in the soil will flow from the anode (positive electrode) to the cathode (negative electrode). When the cathode is placed within an extraction well, ground water delivered to it by EO can be removed.

Though not commonly used as a remediation tool, EO has been used for decades by civil engineers to de-water clays. EO has been used at construction sites to de-water fine-grained soils for over 60 years. EO technology has been successfully applied to stabilize slopes of inorganic silt during the construction of bridges and dams worldwide.

The LLNL design uses Electro-Osmosis (EO) to mobilize contaminated ground water through clays and silts, with re-injection of treated water into the sediments to prevent de-watering. The first EO installation (August 2000) essentially superimposes an electro-osmosis array within an extraction wellfield to move contaminated ground water through fine-grained sediments. Both systems operate simultaneously. A monitoring program is being used to assess the advantage offered by using EO for remediation in mixed lithologies (both fine- and coarse-grained materials) at the site. In 2001, LLNL anticipates installing an EO system in conjunction with a Catalytic Reductive Dehalogenation (CRD) unit at one location to accelerate VOC mass removal of ground water contaminated with VOCs and tritium.

If warranted, a combination of Dynamic Underground Stripping (DUS) technology, which remediated gasoline contamination at an old gasoline station at this site, and Hydrous Pyrolysis/Oxidation (HPO) technology, which destroys dissolved contaminants in place by utilizing hydrothermal oxidation, will also be considered for deployment at suitable locations at the LLNL site. These two technologies are thermal remediation methods that are effective because of a variety of factors: increased contaminant volatility, rapid mass transfer, enhanced diffusion and evaporation, lower viscosity of water and contaminants, decreased sorption, boiling of the formation, and overall increase in the speed of chemical reactions.

DUS removes separate-phase and dissolved-phase organic contaminants from below the water table by introducing steam and heating the subsurface to temperatures above the boiling point of water. The contaminants are then removed from the subsurface by extracting ground water and vapor. Highly permeable layers (e.g., gravel) are amenable to heating by direct steam injection. Once a steam zone is created, a vacuum is applied to the center of the steam zone (from an extraction well adjacent to the injection well). This forces the residual fluids within the steam zone to boil, releasing trapped contaminant to a mobile vapor phase.

Hydrous Pyrolysis/Oxidation (HPO) technology can destroy contaminants in place by utilizing hydrothermal oxidation. The technique involves injection of steam into a contaminated subsurface HSU creating a heated oxygenated zone that oxidizes and degrades the contaminants to benign products (e.g., carbon dioxide, water, and chloride ion). With HPO, the ground water mixes with the condensate and oxygen, and any dissolved contaminants are destroyed by oxidation.

3-Dimensional Modeling

The ability to accurately predict clean-up times is essential for environmental project management. LLNL began using simple prediction tools from the very early days and progressively developed sophisticated three-dimensional subsurface flow and transport models as the need to predict behavior at individual plume levels became increasingly important for expedited cleanup. The development and continuous improvement of the site conceptual model (based on hydrostratigraphic units) has been an iterative process between (1) field observations, (2) HSU analysis, and (3) numerical model development. By testing the conceptual model using these three analyses, a calibrated three-dimensional flow and transport model for the LLNL site using an industry standard code (FEFLOW) was developed. LLNL used a deterministic approach in constructing the models and began incorporating stochastic heterogeneities and uncertainties as the need to evaluate the effects of such variables become important over time.

Currently, the three-dimensional flow and transport model for the LLNL site is calibrated to the past ten years of observed operational data. This model is constantly used to (1) predict cleanup times, analyze stagnation zones, place monitoring and extraction wells, and optimize extraction wellfields for the western boundary plumes, (2) assist operational decisions such as treatment facility capacity utilization, and to allocate resources (i.e., installation of new pumps) without expensive trial and errors in the field, (3) manage overall aquifer flow balance, and answer increasingly challenging questions such as dewatering of contaminated zones, (4) evaluate the effectiveness of Engineered Plume Collapse (EPC) plans, and to prioritize/schedule the use of portable treatment units, and (5) study the effects of Phased Source Remediation (PSR) on the overall plumes, and support PSR prioritization decisions.

In addition, the modeling efforts at LLNL have led to sophisticated visualization and data access tools that were initially developed for model construction. The Plume History Analysis (PLUHA) Tool, which allows visualization of all site plumes over time within the hydrostratigraphic unit (HSU) framework, has become a day-to-day tool for the site hydrogeologists. The three-dimensional visualizations are also essential to communicate the progress of cleanup to interested parties, and to support operational decisions.

CONCLUSIONS

Faced with constrained or declining budgets, lack of useable space due to the increased infrastructure at this highly industrialized site, and significant technical challenges; LLNL has been consistently improving the site cleanup methods by adopting new philosophies, strategies and technologies. The logical progression from a pump and treat system to the philosophy of "Smart Pump and Treat" coupled with the concepts of "Hydrostratigraphic Unit Analysis," "Engineered Plume Collapse," and "Phased Source Remediation," has led to the development of new, more cost-effective technologies which have significantly accelerated attainment of cleanup goals. This strategy is designed to bring the remediation of the ground water to closure as soon as possible.

By October 2000, approximately 28 treatment systems have been installed and are operating, including four large fixed facilities, about 19 various sized portable treatment units, two soil vapor extraction systems, two catalytic reductive dehalogenation (CRD) units, and an electro-osmosis (EO) system which have been important to increasing the Laboratory's ability to expeditiously remove contamination.

Modeling at the LLNL site is an integral part of the efforts to constantly develop new, cost-effective methodologies and technologies to accelerate cleanup. Performing model simulations is essential to test new ideas and evaluate potential effects of new technologies to support decision-making.

After slightly more than ten years of ground water remediation at the site, LLNL has proven that dramatic progress can be made in ground water cleanup by using the appropriate technologies at the right time and place. Ground water plumes that had migrated nearly one half mile offsite, have been pulled back, and their concentrations greatly reduced. This progress, much better than predicted in the ROD and noted at the 5-Year Review, has created a trust between LLNL, the regulatory agencies and the community alike.

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