SITE NAME: DRY CLEAN USA #11502, ORLANDO, FLORIDA

Highlight included in Section 3.1: **Text Box 3-1. Dry Clean USA, Well-Defined Objectives** At Dry Clean USA the primary project goal was to see whether treatment could reduce PCE concentrations to the Florida MCL of 3 µg/L throughout the aquifer and to 30 µg/kg for soil (based on leaching potential) so that closure (i.e., no further action) could be obtained from the state regulatory agency. Additional soil objectives (set by the state's drycleaner program) included 30 µg/kg TCE, 400 µg/kg cDCE, 700 µg/kg *trans*-DCE, and 7 µg/kg VC. Having such well-defined objectives allowed the appropriate technologies to be applied and a Site Rehabilitation Completion Order was issued within 8 years of the initial treatment.

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Site Description

Dry Clean USA is a former PCE dry-cleaning facility that operated 1988–1998. The site is located in a shopping center in a mixed retail commercial/residential setting. Three public water supply wells are located within a 1-mile radius of the site. The shopping center was served by a septic system until the early 1970s. Soil sampling shows that the contaminant source areas appear to be the soil beneath the building floor slab where the dry-cleaning machine was formerly located and the sanitary sewer lateral line. The site was part of the Florida Department of Environmental Protection's Drycleaning Solvent Cleanup Program. Investigation and cleanup occurred 1999–2005.

Contaminant Nature and Extent: PCE in groundwater was found to extend vertically to about 68 feet bgs. The dissolved-phase plume was found to extend 800 feet long and 300 feet wide. Contaminant concentrations before treatment included 27,300 µg/L PCE in groundwater and 3.9 mg/kg detected in soil. The presence of DNAPL was suspected. The vapor intrusion pathway was not a concern at this site.

Hydrogeology: The site is underlain by a slightly silty, fine- to medium-grained sand to a depth of 47 feet bgs. This unit is in turn underlain by a 6-foot-thick, slightly sandy clay followed by a 20-foot-thick, fine- to medium-grained sand that is interbedded with clayey sand. A 4-foot-thick fine to coarse sand with shell fragments overlays a hard, phosphatic, limestone bedrock that occurs 93–94 feet bgs. The depth to groundwater is 8–10 feet bgs.

Lithology

- Slightly silty, fine to medium-grained quartz sands: surface to 47 feet bgs
- Slightly sandy clay: 47–53 feet bgs
- Fine to medium-grained sand interbedded with clayey sand: 53–83 feet bgs
- Sandy, clayey, silt: 83–89 feet bgs
- Fine to coarse-grained sand with shell fragments: 89–93 feet bgs
- Hard phosphatic limestone: 93–94 feet bgs

Conductivity

- Surficial (8–47 feet bgs): 1.4–2.4 feet/day

- Intermediate (47–93 feet bgs): 0.4 feet/day

Gradient

- Surficial: 0.002 feet/foot

Objectives

The primary project goal was to see whether treatment could reduce PCE concentrations to the Florida MCL of 3 µg/L throughout the aquifer and to 30 µg/kg for soil (based on leaching potential) so that closure (i.e., no further action) could be obtained from the state regulatory agency. Additional soil objectives (set by the state's dry-cleaning program) included 30 µg/kg TCE, 400 µg/kg cDCE, 700 µg/kg *trans*-DCE, and 7 µg/kg VC.

Remedial Approach

Technologies: ISCO (hydrogen peroxide), P&T, SVE

- SVE and P&T started in April 1999; chemical oxidation injection occurred October 4–5, 2005.
- SVE was chosen to remediate the soils at the site because it is a proven technology for recovering VOCs from permeable unsaturated sediments. Groundwater recovery was chosen to contain the contaminant plume and remediate contaminated
- Low-level PCE concentrations in the source area well (installed beneath the facility floor slab and screened across the water table and the capillary zone) continued to persist, and the decision was made to polish contaminated groundwater using chemical
- On October 4–5, 2005, an additional monitoring well was installed in the source area, and 1057 gal of a 1% hydrogen peroxide was injected into the former source area monitoring well.

Project Time Line

- 4/99—SVE and P&T systems start
- 12/01/00—SVE turned off
- 1/17/01—P&T system shut down
- 2/26/01—P&T system restarted because of rebound
- 11/02—P&T system turned off
- 10/04–05/05—Peroxide injections
- 2/07—Site Rehabilitation Completion Order signed

- SVE and P&T systems were run April 1999 to November 2002. The SVE system recovered at total of 9.8 pounds of VOCs; the P&T system recovered a negligible amount of
- SVE for soil contamination and P&T for groundwater were successful in reducing groundwater contamination levels to <10 µg/L. Rebound did occur near the source area, so a 1% hydrogen peroxide solution was used as a polishing
- One year of post-oxidation groundwater monitoring (10/2005–10/2006) showed

concentrations of PCE ranging from nondetect to 3 µg/L.

Remedy Evaluation

PCE concentrations in groundwater met cleanup target levels for four consecutive quarterly monitoring events 10/2005–10/2006.

Costs

- Assessment: $97,700
- SVE/P&T systems: $221,400
- Chemical oxidation: $28,400

- Remedy O&M: $147,800 (includes monitoring)
- Total: $503,300

Outcomes and Challenges

The Site Rehabilitation Completion Order (no further action) was signed February 16, 2007, and all wells were abandoned.

Lessons Learned

- Numerical groundwater modeling was very valuable in siting the recovery well on
- The injection of a low concentration of a chemical oxidant in the upper portion of the surficial aquifer and the capillary fringe was successful in polishing already low concentrations of

References and Links

U.S. Environmental Protection Agency. 2009. *DNAPL Remediation: Selected Projects Where Regulatory Closure Goals Have Been Achieved*. EPA/542/R-09/008. www.clu- in.org/download/remed/542r09008.pdf.

SITE NAME: WELL 12A SUPERFUND SITE, TACOMA, WASHINGTON

Contacts

Highlight included in Section 3.2: **Text Box 3-2. Well 12A, Tiered Remedial Action Objectives Tier 1:** Address residual sources, including principal threat wastes, minimize the risk to receptors due to contaminated surface soils, and achieve at least a 90% reduction in contaminant discharge from the high-concentration source area to the dissolved-phase contaminant plume. **Tier 2:** Achieve the cleanup levels at interim performance monitoring points. **Tier 3:** Determine whether cleanup levels can be achieved in a reasonable time frame throughout the entire contaminant plume by discontinuing the groundwater extraction and treatment system operation and implementing MNA of remaining contamination. If the Tier 3 compliance is deemed infeasible, additional remedial alternatives will be evaluated, and/or a technical impracticability waiver may be sought for the noncompliant portions of the aquifer.

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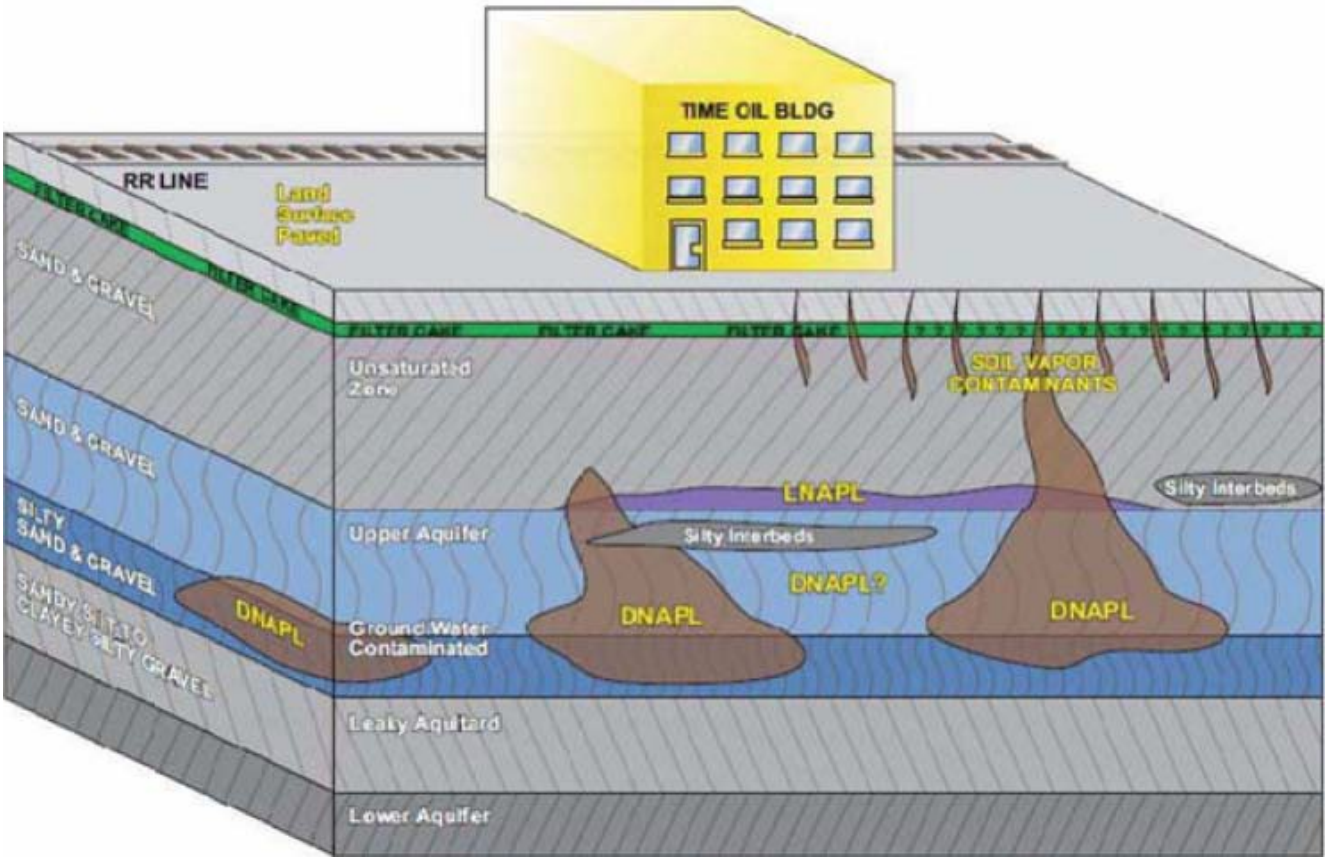
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Site Description

Well 12A is one of 13 wells used by the city of Tacoma to meet peak summer and emergency water demands. The well was taken out of operation by the city when it was found to be contaminated but has been operating since July 1983 with five air-stripping towers. Investigations by USEPA found the source of contamination to be centered on properties owned by the Burlington Northern Railroad and the Time Oil Company (see figure). A waste oil and solvent recycler had previously operated on the properties from approximately the 1920s until the 1960s. A groundwater extraction and treatment system (GETS) was installed in November 1988. Five additional GETS wells were installed in August 1993. During construction of an SVE system in August 1993, approximately 5,000 cubic yards of waste sludge was removed and 37,000 pounds of solvent was recovered by the vapor extraction system at the time of shutdown in May 1997. As of September 1998, the GETS had removed 13,428 pounds of VOCs from treated groundwater. The GETS was not meeting the cleanup criteria set forth in the 1985 ROD. A remedial enhancement and optimization project was conducted to determine whether the groundwater extraction and SVE systems could be enhanced to address NAPL at the site or a different treatment technology would be more appropriate. Field work for the optimization project was completed in 2002 and resulted in recommendations to

analyze the capture zone. Capture zone analysis was completed in 2005, and those data are being evaluated to improve the system (http://yosemite.epa.gov/r10/nplpad.nsf/88d393e4946e3c478825631200672c95/0c76d9e47c6c21bf85256594006df0e7?OpenDocument).



Source: USEPA 2009.

Objectives

The remedy considered a final remedy for soils and an interim remedy for groundwater that will be protective, achieve RAOs, and assist in achieving the long-term objective for the Well 12A Site of restoring the aquifer to its beneficial use as a drinking water source for the City of Tacoma. Compliance with RAOs was divided into three tiers to allow for implementation of the multicomponent remedy and decision making, such as when to transition from one treatment technology to another and to O&M of the remedy. A brief description of each tier follows:

- **Tier 1.** The primary goals for the first tier of compliance are to address residual sources, including principal threat wastes; minimize the risk to receptors due to contaminated surface soils; and achieve at least a 90% reduction in contaminant discharge from the high- concentration source area near the Time Oil Building to the dissolved-phase contaminant plume. The soil excavation and disposal, in situ thermal remediation, and enhanced anaerobic bioremediation components of the remedy will be considered complete and the remedy considered operational and functional when the Tier 1 criteria have been met. This also will determine when operations transition to O&M.
- **Tier 2.** The primary goal of the second tier of compliance is to achieve the cleanup levels at interim performance monitoring points CW-1, CW-2, and Well 12A to ensure that groundwater concentrations are below ARAR (applicable or relevant and appropriate requirements)-specified levels
- **Tier 3.** The primary goal of the third tier of compliance is to determine whether cleanup levels can be achieved in a reasonable time frame throughout the entire contaminant plume, including the Time Oil Building source area, by discontinuing GETS operation and implementing MNA of remaining contamination. If the third tier compliance is deemed not feasible, additional remedial alternatives will be evaluated and/or a technical impracticability waiver may be sought for the noncompliant portions of the

Remedial Approach

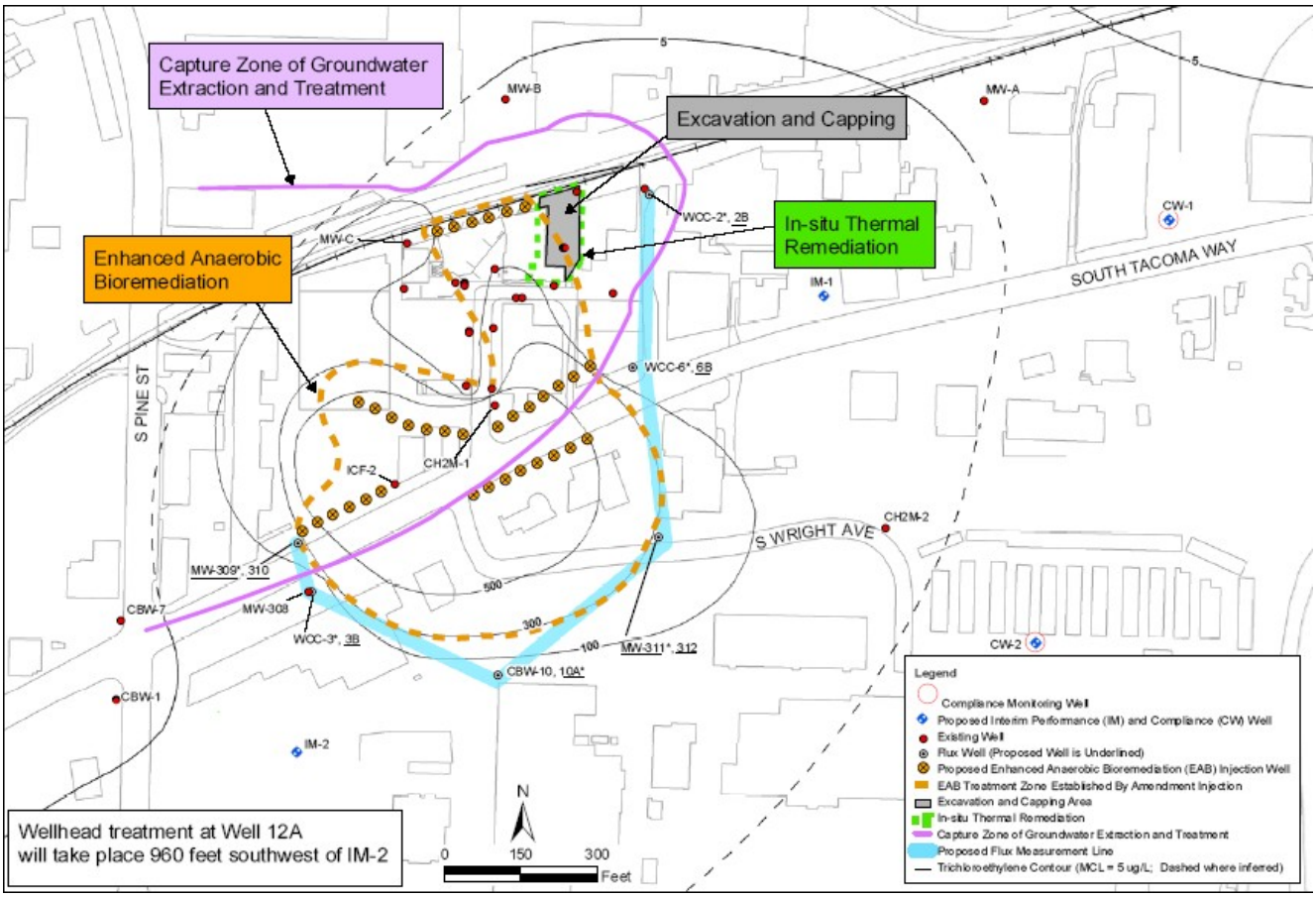
A comprehensive remedial action strategy was developed that includes aggressive treatment of persistent soil and groundwater contamination at the site, including primarily chlorinated-solvent DNAPL, LNAPL, and coal tars. Multiple treatment technologies will address different contaminated areas based on the nature and extent of contamination and risks to receptors within those areas. These areas include high-concentration soil and groundwater contamination within the source area near the former Time Oil Building and a large groundwater chlorinated solvent contaminant plume that extends from the source area approximately 2000 feet to the east and approximately 2000 feet to the southwest to a municipal supply Well 12A of the city of Tacoma.

This multicomponent remedy (EPA 2009) includes in situ thermal treatment and excavation within the source area, enhanced anaerobic bioremediation in the high-concentration contaminant plume, operation of an existing groundwater extraction and treatment system, and well head treatment at the municipal supply well (see figure).

Performance

Pending—Implementation began in 2010. **Remedy Evaluation** Pending—Implementation began in 2010.

Outcomes and Challenges



Pending—Implementation began in 2010.

References and Links

USEPA (U.S. Environmental Protection Agency). 2009. *Amendment #2 to the Record of Decision for the Commencement Bay–South Tacoma Channel Superfund Site, Operable Unit 1, Well 12A, Tacoma, Washington*. Region 10, Seattle. https://semspub.epa.gov/work/10/500010097.pdf

USEPA. n.d. "Commencement Bay–South Tacoma Channel," Region 10 Web page. http://yosemite.epa.gov/r10/cleanup.nsf/4c5259381f6b967d88256b5800611592/d3c814fe6394c2ba882565220048abb2!OpenDocument#Site%20History.

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Site Description

Highlight included in Section 4.1: **Text Box 4-1. Kings Bay, Coupling Technologies** The Kings Bay site was naturally anaerobic. A P&T system intended to contain the groundwater plume at the site boundary was not fully capturing the plume, and modeling indicated that, if plume concentrations were lowered to 100 µg/L total chlorinated VOCs, MNA would address the remaining contaminants before crossing the base boundary. Four injections of Fenton's reagent were conducted 1998–2001. ISCO reduced VOC levels to the target but made the aquifer aerobic in injection areas and some distance downgradient. Injections of emulsified vegetable oil returned the aquifer to anaerobic conditions. By 2004, VOC concentrations were reduced to <14 µg/L, and MCLs were met at the property boundary.

Kings Bay is a 16,000-acre facility in Camden County, Georgia that serves as the home port for the next generation of ballistic submarines support facilities for the U.S. Atlantic Fleet. Site 11 is the location of a former 25-acre landfill, known as the Old Camden County Landfill, which was operated by the county during the mid-1970s to 1980. A variety of wastes from the local community and the Navy were disposed in the landfill. Site investigations found the groundwater in the area to be contaminated with PCE, as well as TCE, DCE, and VC. In 1994, Navy Submarine Base Kings Bay entered into a Corrective Action Consent Order with the

Georgia Environmental Protection Division to address prior releases of hazardous constituents from Site 11, and a GETS was constructed. In 1998, the extraction system was found to not completely capture the plume, and the Navy selected ISCO using Fenton's reagent to expedite and improve the remedy rather than expand the existing treatment system. The Navy's approach was to use ISCO to reduce groundwater contaminant concentrations in the source area, followed by anaerobic biodegradation to address residual contamination, and thereby be allowed to terminate the ongoing GETS.

Objectives

A treatment objective of 100 µg/L total chlorinated aliphatic compounds in the treatment area was selected as the functional objective for source remediation, based on the natural attenuation capacity of the aquifer (Chapelle and Bradley 1998). A

reduction to this concentration was anticipated to result in degradation of all COCs to regulatory levels at the base boundary adjacent to the site.

Remedial Approach

The ISCO treatment was conducted in four phases. Each phase consisted of installation of injection wells, injection of Fenton's reagent solution, and post-treatment monitoring. Phase 1 focused on the primary source area. Phases 2 and 3 expanded the treatment area to both downgradient and upgradient areas. Comprehensive groundwater sampling after each phase was conducted to optimize the next phase. One portion of the site exhibited consistent rebound of PCE concentrations. A focused soil removal was conducted, during which crushed PCE containers and contaminated soil were removed. A fourth and final phase of Fenton's reagent injection was conducted to complete the ISCO program. Following the ISCO program, an engineered anaerobic bioremediation remedy was implemented using vegetable oil as the organic carbon substrate.

Performance

The Phase 1 injection demonstrated that Fenton's reagent ISCO could achieve the remediation goals, and Phases 2 and 3 expanded the treatment area. The comprehensive sampling program and dense network of monitoring and injection wells were critical in identifying a rebounding area at the site and ultimately for identifying the shallow DNAPL source zone that was removed by excavation. The remedial objective of 100 µg/L total chlorinated aliphatic compounds was achieved throughout the site following the soil removal and Phase 4 of the ISCO injection. The long-term degradation of the source area following implementation of the anaerobic bioremediation treatment has been closely monitored since 2002. VOC concentrations throughout the site have remained below the 100 µg/L goal and have continued to degrade nearly to MCLs.

Remedy Evaluation

See "Performance."

Outcomes and Challenges

The Kings Bay site has been carefully monitored by the U.S. Geological Survey for the impact on the natural attenuation capacity of the site, recovery of the microbial population, and success of an anaerobic bioremediation system at the site following the Fenton's reagent ISCO program. The most significant outcome regarding Fenton's reagent ISCO in general is that treatment does not result in sterilization of the aquifer and anaerobic microbial activity returned relatively quickly at the site. The results also demonstrated the value of very dense sampling to identify DNAPL sources; the final identification and removal of the source was probably critical in ensuring the ultimate success of the project and achievement of remedial goals. The GETS was terminated, thereby eliminating a significant expansion of the system and at least 30 years of continuing O&M.

References and Links

Chapelle, F. H., and P. M. Bradley. 1998. "Selecting Remediation Goals by Assessing the Natural Attenuation Capacity of Ground-Water Systems," *Bioremediation Journal* **2**(3–4): 227–38.

Chapelle, F. H., P. M. Bradley, and C. C. Casey. 2005. "Behavior of a Chlorinated Ethene Plume Following Source-Area Treatment with Fenton's Reagent," *Ground Water Monitoring and Remediation* **25**(2): 131–41.

Chapelle, F. H., M. A. Widdowson, J. S. Brauner, E. Mendez, and C. C. Casey. 2003. *Methodology for Estimating Times of Remediation Associated with Monitored Natural Attenuation*. U.S. Geological Survey Water-Resources Investigations Report 03-4067.

USEPA (U.S. Environmental Protection Agency). 2004. *DNAPL Remediation: Selected Projects Approaching Regulatory Closure.* EPA/542/R-04/016.

SITE NAME: GOLD COAST

Contact

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Site Description

Gold Coast is a 2-acre property used to operate a mineral spirits and lacquer thinner distillation factory. Companies disposed of all spent oil and solvent waste on site, either by direct discharge to the soil or improper tank storage. The soil was heavily contaminated with heavy metals and organics, and groundwater contained VOCs at levels that exceeded drinking water standards. Twenty-five hundred corroded drums full of distillation/paint sludge and contaminated soils were found leaking into the subsurface, in addition to large hazardous waste storage tanks and a tank truck.

The groundwater at Gold Coast lies 5 feet bgs and is part of the Biscayne Aquifer that supplies drinking water to Dade County. The extensive groundwater contamination posed a significant risk to humans and the environment, and USEPA placed the site on the National Priorities List (NPL) in September 1983 (www.epa.gov/region4/waste/npl/nplfls/gldcstfl.htm#back).

The COCs at Gold Coast were VOCs, including the chlorinated solvents TCE and PCE. The following table provides a full list of COCs found at the site, initial concentrations, MCLs, ROD remediation goals, and post-treatment reductions. DNAPL was present in the groundwater, as indicated by the presence of TCE and PCE at greater than 1% and 60% of their aqueous solubilities, respectively, as well as by visual observations on site. A 0.87-acre (areally) TCE/PCE plume developed in the DNAPL source area with an estimated volume of 2,834,700 gal.

Contaminants of concern at Gold Coast Oil Superfund site: Goals, maximums, and reductions (µg/L) (*Sources*: USEPA 1998, USACE 2001.)

COC	2001 federal MCL value	1997 ROD standard[a]	Maximum initial concentration	1991 concentration (after 1 year of P&T)	October 1996 concentration (1 year after P&T shut down)
1,1-dichloroethane	None[b]	5	2,000	Below MCL	BDL[c]
trans-1,2-DCE	100	70	3,000	Below MCL	BDL
Methylene chloride	5	5	100	Below MCL	BDL
Toluene	1,000	340	545	Below MCL	BDL
PCE	5	0.7	100,000 (avg. 176)	8	BDL
TCE	5	3	48,000 (avg. 88)	9	BDL

[a] The ROD standards are at or below federal MCLs.
[b] MCL for 1,1-dichloroethane is 5 µg/L.
[c] BDL = below detection limit (PCE detection limit = 0.5; for all other compounds, detection limit = 1.0)

See table above.

Remedial Approach

The remedy included P&T followed by air sparging. After the ROD was issued in 1987, drum and tank removal and disposal occurred immediately. Removal of 683 tons of contaminated soils and hardened waste sludges occurred 1989–1990. The contaminant plume had not reached any private or municipal wells.

A P&T system operated from July 1990 to March 1994, treating extracted groundwater with an air stripper before discharging it into the Biscayne Aquifer. The groundwater recovery, treatment, and discharge system operated 21 wells and 2 air strippers. The porous limestone facilitated groundwater extraction (USEPA 1998). Within 1 year of operation, the groundwater extraction system treated over 25 million gal of water and reduced all COC concentration levels to below ROD goals with the exception of TCE and PCE. The remaining contamination was confined to two monitoring wells in the suspected DNAPL zone.

Subsequent remedial action focused on the chlorinated-solvent groundwater plume, the source of which was most likely residual DNAPL trapped in the aquifer matrix (USEPA 1998). Two unsuccessful attempts were made to address the PCE/TCE plume surrounding these wells. First, hydrogen peroxide was applied to the contaminated groundwater from March through July 1993. Second, the P&T system was shut down from August to November 1993 to encourage TCE/PCE desorption from the aquifer matrix into the groundwater. However, no significant desorption increase occurred, and dissolved TCE/PCE lingered in groundwater in this area due to low hydraulic gradient that essentially prevented groundwater movement without pumping (USEPA 1998).

Neither of these actions achieved significant reductions in contaminant concentration levels; maximum concentrations

remained at 6 µg/L for TCE and 24 µg/L for PCE (USEPA 1998). The area of recalcitrant PCE/TCE was confined to a 200-square-foot area and extended to 30 feet bgs. Monitoring data during a temporary system shutdown indicated that P&T was no longer reducing concentrations, and USEPA officially shut the system down in May 1994.

In November 1994, additional soil suspected to contain DNAPL was excavated. Surprisingly, no PCE or TCE was detected in the excavated soil. Finally, the groundwater in the excavated area was sparged using a portable air sparger. Because TCE/PCE concentrations dropped below ROD goals after sparging, it appears that DNAPL was in the groundwater (saturated zone) (USEPA 1998).

Performance

Soil remediation sufficiently reduced exposure. The P&T system adequately contained the groundwater plume and even reduced its size. P&T reduced contaminant concentrations to below ROD standards except for PCE and TCE. The concentrations of PCE and TCE were significantly reduced but stabilized, indicating the system had reached it capacity. Air sparging was used to reduce concentration of PCE and TCE to below ROD standards (USEPA 1998).

Outcomes and Challenges

Following two 5-year reviews in 1996 and 2001, the project was considered protective of human health and the environment. The Gold Coast site has been removed from the NPL.

References and Links

USACE (U.S. Army Corps of Engineers). 2001. *Superfund Five-Year Review Report, Gold Coast Oil Company, Inc., Miami, Dade County Florida.* http://semspub.epa.gov/src/document/04/10498229

USEPA (U.S. Environmental Protection Agency). 1998. *Cost and Performance Summary Report—Gold Coast Soil Superfund Site, Miami, Florida.* www.frtr.gov

SITE NAME: FORMER REESE AIR FORCE BASE

Contact

None currently available.

Site Description

The former Reese Air Force Base (near Lubbock, Texas) is the site of an 18,000-foot-long dissolved-phase TCE plume covering more than 250 acres, lying in the Ogallala Aquifer, a regional alluvial fan formation that spans approximately 100–150 bgs. The Ogallala is highly heterogeneous and anisotropic, with zones of extreme high and low hydraulic conductivity interspersed throughout the affected interval. Groundwater transport velocities in the formation have been measured at greater than 5 feet/day in some areas.

Objectives

MCL for TCE, cDCE, and VC by 2014.

Remedial Approach

P&T containment.

Performance

As of 2004, the plume was contained by a 900 gpm groundwater extraction, treatment, and reinjection system that had established capture but was projected to operate for at least an additional 25 years. In 2004, the site was contracted under a guaranteed, fixed-price instrument, with the objective of restoring groundwater to MCLs or better across the entire plume

footprint in 10 years.

Remedy Evaluation

The project team made several key observations that served as a basis for reworking the CSM, including the following:

- The aquifer is highly anisotropic and heterogeneous, so transport velocities will greatly exceed average groundwater
- The centerline of groundwater transport does not align directly with the groundwater elevation gradients; in the vicinity of Reese Air Force Base, there is a 40° offset between groundwater transport and the elevation
- Conventional groundwater modeling and pumping strategies derived from those models will not provide optimal
- In some areas, extraction well placements may have spread contaminants

Through an iterative reconstruction of the CSM, initially using existing data from more than 700 monitoring, extraction and reinjection wells, then through additional monitoring and treatment well construction, a much different picture of the site emerged. The following are among the key findings:

- Contaminant concentration patterns are much more complex than were depicted previously with “plume limits”
- Peak TCE concentrations are notably higher than earlier
- Flow is highly organized in well-formed channel complexes that meander along the general flow
- Many extraction wells were placed in locations that spread TCE

The updated site characterization data and the resulting CSM provided the basis for a substantial revision of the groundwater extraction and reinjection efforts. The CSM is continually adjusted as new data become available, and remedial system operations are adjusted quarterly, including placement of new pumping wells, as needed. With the placement of extraction points in more optimal locations and adjustment of flow allocations in response to plume behavior, the pace of plume shrinkage accelerated dramatically, and the plume area (as of March 2011) has fallen to less than 25 acres. The site is on target to reach MCLs for chlorinated VOCs, plume-wide, by 2014. The location of the extraction wells was chosen based on a fairly low-resolution mapping of contaminants. Further, the locations were often “optimized” for convenient access. In 2006 the CSM was updated to include a greater resolution regarding hydraulic flow paths, resulting in the realization that the large plume actually flowed through relatively narrow high-permeability channels conveying the majority of contaminant mass discharge. The P&T system was redesigned to focus operations on these high-flow channels, and the CSM was iteratively adjusted as new information about the site was obtained. In addition, anaerobic biostimulation was applied to the source. As a result of these improvements TCE, cDCE, and VC were all at concentrations below detection in the source area, and by 2010 the TCE plume mass had been reduced by an order of magnitude.

Outcomes and Challenges

The updated site characterization data and the resulting CSM provided the basis for a substantial revision of the groundwater extraction and reinjection efforts. The CSM is continually adjusted as new data become available and remedial system operations are adjusted quarterly, including placement of new pumping wells as needed. With the placement of extraction points in more optimal locations and adjustment of flow allocations in response to plume behavior, the pace of plume shrinkage accelerated dramatically, and the plume area (as of March 2011) has fallen to less than 25 acres. The site is on target to reach MCLs for chlorinated VOCs, plume-wide, by 2014.

SITE NAME: TEST AREA NORTH, IDAHO NATIONAL LABORATORY

Highlight included in Section 6.3.1: **Text Box 6-3. Test Area North, Reevaluation of the CSM** The Test Area North CSM was developed through an iterative process of identifying data gaps, conducting activities to fill those data gaps, reporting on the results of those activities, and identifying new data gaps. This process resulted in a series of four reports. Following are examples of characterization activities that have been conducted in the source area since the sludge removal activity was completed and before the ISB field test was implemented: · Several wells have been installed within or adjacent to the source area. · Pumping tests, slug tests, and tracer tests have been conducted to determine aquifer properties, from which residual source distribution has been inferred. · Standard geophysical, gamma spectroscopy and acoustic televiewer logging were performed in several source area wells. · Cross-well seismic tomography was conducted. · Extensive groundwater sampling has been conducted throughout the source area, both in support (see Section 2.3) and prior to initiation of ISB operations. · Furthermore, results of abiotic column studies confirmed that the dissolution of TCE DNAPL was enhanced during amendment with high concentrations of some electron donors. Of these, a whey powder solution enhanced TCE DNAPL dissolution by a factor of 6 while sodium lactate had a much smaller impact (Macbeth et al. 2006). ISB remedy was initially implemented using sodium lactate injections and then optimized with whey injections. These activities greatly improved the understanding of aquifer hydraulic conductivity, porosity, and preferential flow paths; dissolved contaminant composition and distribution; and residual contaminant source distribution.

Contacts

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Site Description

The Test Area North (TAN) site is part of the Idaho National Engineering and Environmental Laboratory (INEEL). Contamination at TAN included a TCE residual source area and a nearly 2-mile-long dissolved-phase plume. The plume, located within the deep, fractured basalt of the Snake River Plain aquifer, was the result of historical disposal practices at the site, including an underground injection well that was operated from the 1950s to 1972 to dispose of liquid waste streams 200–300 deep. Waste streams included low-level radioactive wastewater, industrial wastewater (including organic liquids), and sanitary sewage.

Groundwater contamination was first discovered in 1989. A thorough discussion of the complete CSM is presented in Sorenson (2000). Contaminants present in the Snake

River Plain Aquifer at the TAN site include primarily TCE, PCE, and tritium. Both cDCE and *trans*-DCE are present in the plume at low concentrations. Other contaminants of importance that appear to be associated with the sludge and are limited to the immediate vicinity of TSF-05 are cobalt (^{60}Co) and cesium (^{137}Cs).

The depth to water at TAN is approximately 200 feet. The aquifer and most of the unsaturated zone are composed primarily of layered basalt flows, intercalated with sedimentary interbeds deposited during periods of volcanic quiescence. Groundwater flow in the aquifer is controlled by the highly transmissive zones that occur during contact between individual basalt flows and, to a lesser extent, the fractured zones within flow interiors. Groundwater velocity at the site is approximately 0.4 feet/day, and porosity of the uncontaminated aquifer is 1%. Transmissivity ranges 12,000–20,000 square feet/day, with the source area being an order of magnitude less than this. The scale of the basalt geology dictates that preferential flow can be very important at spatial scales less than approximately 330 feet.

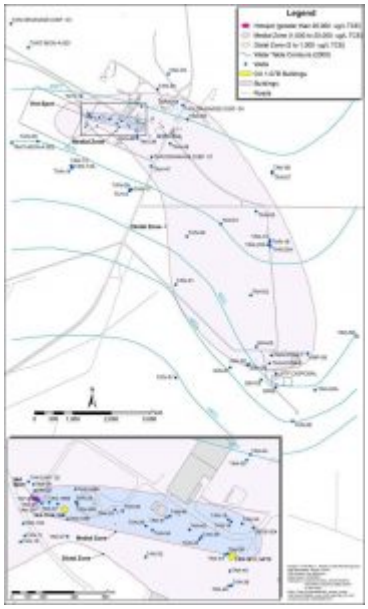
The most significant interbed is termed the “QR interbed,” an apparently continuous stratigraphic unit located approximately 400 feet bgs and dipping gradually. All available data indicate this unit provides an effective bottom boundary for the contaminated aquifer.

The residual source of contamination in the aquifer is the sludge that was injected into the well more than 15–20 years ago. The pore water of the sludge probably contains large amounts of TCE, with PCE and tritium also present in significant amounts. Given the organic content of the sludge, sorbed PCE and TCE are also likely to be present. Some of the sludge has been shown to have TCE concentrations as high as 3% (by weight). The sludge, therefore, represents a long- term source of contamination to the aquifer. It has also significantly affected the properties of the aquifer in the area. The effective porosity has been estimated to be about 0.05%, which indicates that the sludge occupies much of the pore space in the source area, and the transmissivity is about an order of magnitude lower than that of nearby wells. Both gamma logs measuring radionuclides associated with the sludge and tracer tests measuring effective porosity yield an estimated radius for the sludge distribution of about 100 feet, with most of the sludge being present in the upper 100 feet of aquifer. The sludge is also very important because of the organic material available in the residual source area that creates a very different

geomicrobiological environment than is present in the fringe and even in most of the core. Prior to bioremediation activities, redox conditions were mildly reducing near the injection well but were aerobic throughout most of the plume.

The distribution of TCE at TAN exemplifies the fringe-and-core hypothesis for the anatomy of chlorinated-solvent plumes (Cherry 1997). A very large, low-concentration fringe surrounds and emanates from a much smaller, high-concentration core (see figure). Within the core is a very small residual source area that continues to contaminate fresh groundwater flowing through from upgradient. A transition occurs from the scale of the residual source, where preferential flow is significant, to the scale of the fringe, where sufficient vertical communication has been present along the flow path to create a relatively well-mixed, predictable groundwater plume.

Objectives



The overall objective of the enhanced ISB field evaluation was to determine whether intrinsic biodegradation of TCE in the plume's residual source area could be enh

anced through addition of an electron donor to achieve RAOs specified in the ROD amendment (DOE-ID 2001) as follows:

- Restore the contaminated aquifer groundwater by 2095 (100 years from the signature of the ROD [DOE-ID 1995]) by reducing all COCs to below MCLs and a 1×10^{-4} total cumulative carcinogenic risk– based level for future residential groundwater use and, for non-carcinogens, until the cumulative hazard index is <1.
- For aboveground treatment processes in which treated effluent will be reinjected into the aquifer, reduce the concentrations of VOCs to below MCLs and a 1×10^{-5} total risk-based level.
- Implement institutional controls to protect current and future users from health risks associated with (a) ingestion or inhalation of or dermal contact with contaminants in concentrations greater than the MCLs, (b) contaminants with a $>1 \times 10^{-4}$ cumulative carcinogenic risk–based concentration, or (c) a cumulative hazard index of >1, whichever is more restrictive. The institutional controls shall be maintained until concentrations of all COCs are below MCLs and until the cumulative carcinogenic risk–based level is $<1 \times 10^{-4}$ and, for noncarcinogens, until the cumulative hazard index is <1. Institutional controls shall include access restrictions and warning signs.

Remedial Approach

A sludge removal action was performed in 1990, during which 55 feet of sludge was removed from the 12-inch-diameter casing of well TSF-05. An interim P&T system was installed and operated from about November 1996 to November 1998, at which time it was placed in standby mode for the ISB field evaluation. A 9-month full-scale field evaluation of ISB was

performed at TAN beginning in January 1999.

A ROD amendment signed in September 2001 (DOE-ID 2001) documents regulatory approval of enhanced ISB as the final remedy for the plume hot spot and MNA as the final remedy for the distal portion of the plume. The implementation of ISB in the hot spot to achieve RAOs has been divided into individual phases with specific objectives for each phase. The *In Situ Bioremediation Remedial Action Work Plan for Test Area North Final Groundwater Remediation, Operable Unit 1-07B* (DOE-ID 2002a) and supporting documents, specifically the *In Situ Bioremediation Remedial Action Groundwater Monitoring Plan for Test Area North, Operable Unit 1-07B* (INEEL 2003) and the *ISB Operations and Maintenance Plan for Test Area North, Operable Unit 1-07B* (DOE-ID 2002b), are the governing documents. The phases are described below:

- Interim Operations Phase (11/2002–10/2003): This ISB remedy officially began in November 2002 with the Interim Operations Phase. This phase included activities designed to support a better understanding of alternative electron donors, development of injection strategies to support the Initial Operations Phase, ISB model refinement, continued ISB sodium lactate addition, and construction of the ISB facility. The results and details of activities conducted during the Interim Operations Phase are reported in the *Annual Performance Report for In Situ Bioremediation Operations November 2002 to October 2003, Test Area North Operable Unit 1-07B* (Armstrong et al. 2004).
- Initial Operations Phase (10/2003–current): The completion of the ISB facility marked the start of the Initial Operations Phase. The goal of this phase is to reduce VOC concentrations in downgradient wells TAN-28 and TAN-30A to below MCLs. The Initial Operations Phase will be complete when it is determined that downgradient flux from the hot spot has been reduced such that VOC concentrations remain less than MCLs at TAN-28 and TAN 30A for a period of 1 year. Activities conducted during this phase include injections into newly installed injection well TAN-1859 and initiation of a pilot test to evaluate the effectiveness of whey powder in March
- Optimization Operations Phase (future)—This phase will focus on reducing the flux of VOCs from the hot spot in the crossgradient direction, as measured at TAN-1860 and TAN- 1861 while maintaining VOC flux reduction in the downgradient direction. During this phase, data will continue to be gathered and analyzed relating to achievement of long-term performance objectives.
- Long-Term Operations Phase (future)—This phase will focus on achievement of hot spot source degradation, while maintaining the reduction of VOC flux from the hot spot in the crossgradient and downgradient

The TAN monitoring well network included 17 sampling locations from 14 monitoring wells. Well TSF-05 has been used as the electron donor injection well since the beginning of the project and is sampled at two discrete depths. Well TAN-37 is sampled at three discrete depths. Sampling was performed biweekly during the field evaluation and monthly since then. The program includes parameters to monitor electron donor and nutrient distribution, redox-sensitive parameters, VOC contaminants and degradation products, biological activity indicators, and water quality parameters.

Periodic injection of high-concentration sodium lactate solution approximately from the water table (210 feet) to 300 feet bgs into TSF-05 was conducted during an enhanced ISB field pilot study at TAN in 1999. Groundwater samples were collected to assess redox conditions, bioactivity, and reductive dechlorination. Data collected within the residual source area during the field pilot study demonstrated that sodium lactate injections stimulated complete biological conversion of all aqueous-phase TCE to ethene within 1 year (Song et al. 2002). The stable carbon isotope data collected by Song et al. (2002) also showed that the isotope ratio of the TCE changed over time, suggesting that the nature of the source term was impacted. Since then, data collected over the course of ISB operations show significant production of ethene, indicating complete dechlorination of aqueous-phase TCE.

During the field evaluation, increases in total molar concentrations of VOCs at well locations impacted by the electron donor injections suggested that enhanced mass transfer of TCE from the residual source was occurring as a direct result of the injections. For instance, total chloroethenes in TAN-26, a deep well sampled at 389 feet bgs and approximately 50 feet downgradient from the injection well TSF-05, increased over an order of magnitude in molar concentration during injection of 30% and 60% sodium lactate. At least three potential mechanisms could have contributed to this observation:

- physical displacement of the TCE from the residual source
- desorption of TCE from the residual source
- the electron donor solution itself interacting with the residual source to enhance the dissolution and/or increase effective solubility

The first mechanism was ruled out because, while TCE concentrations increased dramatically in TAN-26, the aqueous inorganic components of the sludge, most notably tritium, did not. At the time this work was performed, the potential importance of the second and third mechanisms was not suspected. It was proposed that the mass transfer of TCE within the residual source to the aqueous phase was somehow being preferentially enhanced by the injected sodium lactate.

Subsequent interfacial tension (IFT) measurements between TCE DNAPL and different concentrations of sodium lactate suggested that the sodium lactate might be acting as a mild surfactant or cosolvent by lowering IFT between the residual TCE and the surrounding groundwater (Sorenson 2002). In addition, this newly mobilized TCE was efficiently biodegraded.

The use of high-concentration electron donor solutions to enhance mass transfer of contaminants into the aqueous phase to facilitate rapid reductive dechlorination and residual source depletion is referred to as Bioavailability Enhancement Technology (B.E.T.™, U.S. Patent 6,783,678). At TAN, the use of B.E.T. was critical for demonstration that enhanced ISB was a viable option for remediation of the chlorinated-solvent residual source area because accelerated mass transfer of contaminants from the residual phase to the aqueous phase makes the contaminants available for biological degradation and significantly shortens the overall remedial time frame.

Since the field evaluation, enhanced ISB operations over the last 6 years have resulted in the continued degradation of contaminants within the residual source area impacted by electron donor injections, as evidenced by ethene accumulation. The kinetics of the degradation reactions are such that liberated contaminants are generally observed as elevated concentrations of ethene, as opposed to TCE, cDCE, and VC concentrations, following injection events. Therefore, residual source degradation at TAN appears to be limited not by the kinetics of the degradation reactions but by the dissolution of TCE from the residual phase into the aqueous phase. Thus, optimization activities at TAN have been focused on enhancing mass transfer of VOCs to the aqueous phase to maximize degradation of the residual source, as well as reducing operation and monitoring costs and accomplishing site remediation goals. These activities have included laboratory and field tests to evaluate alternative electron donors that might be more effective than sodium lactate for ISB within a residual source area.

Highlight included in Section 6.2.1: **Text Box 6-2. Test Area North, Optimizing In Situ Treatment** The results of abiotic column studies confirmed that the dissolution of TCE DNAPL was enhanced during amendment with high concentrations of some electron donors. Of these, a whey powder solution enhanced TCE DNAPL dissolution by a factor of 6 while sodium lactate had a much smaller impact (Macbeth et al. 2006).

Laboratory studies were performed to assess several important properties of electron donors used for ISB, including effectiveness in stimulating degradation reactions, longevity or utilization rate of the electron donor, the ability to distribute electron donor over a large area through a single injection location, and ability to enhance the mass transfer of TCE DNAPL (Macbeth et al. 2006). The laboratory studies included IFT analyses of

different concentrations of the electron donor solutions, microcosm studies using a TCE-dechlorinating culture enriched from TAN groundwater, molecular characterization of the microbial communities stimulated by the various electron donors, and column studies to evaluate the abiotic enhanced dissolution effect of high and low concentrations of the electron donors on TCE DNAPL. The results of the abiotic column studies confirmed that the dissolution of TCE DNAPL was enhanced during amendment with high concentrations of some electron donors. Of these, a whey powder solution enhanced TCE DNAPL dissolution by a factor of 6 over that observed during potable water amendment, while sodium lactate had a much smaller impact (Macbeth et al. 2006).

Based on the collective results of the laboratory studies, a field-scale pilot test was conducted to examine the extent of enhanced mass transfer and subsequent dechlorination of TCE from the residual source area at TAN in response to injections of whey powder as compared to sodium lactate. The pilot test was implemented in two phases, the first of which involved high-resolution monitoring following two injections of sodium lactate conducted in March and May of 2004.

Following these injections, spikes in TCE and cDCE concentrations from a baseline near 0 µg/L up to 300–400 µg/L at the injection well and up to 25–75 µg/L 25 feet downgradient were observed. In addition, there were dramatic increases in ethene concentrations within 48 hours, indicating rapid dechlorination of the newly bioavailable TCE.

Phase 2 of the pilot test involved three cycles of whey powder injections conducted in August and October 2004 and January 2005. These injections resulted in spikes in TCE and cDCE concentrations from near 0 µg/L up to 400–600 µg/L within the injection well and up to 250– 400 µg/L 25 feet downgradient. In addition, the total chloroethene and ethene molar areas

were evaluated during these injection cycles to compare the total mass of contaminants liberated and subsequently degraded to ethene. The total molar areas were approximately three times greater during a whey injection cycle compared to sodium lactate. The rate at which the molar area increased (indicator for mass removal rate) was calculated to be 50%–250% higher during a whey powder injection cycle than for sodium lactate. These data indicate that whey powder enhanced mass transfer and degradation of TCE to a greater degree than sodium lactate. The use of whey powder for long-term ISB operations is expected to increase the rate of contaminant source depletion, ultimately resulting in a reduction of the remediation time frame at TAN.

Outcomes and Challenges

The CSM for TAN was developed through an iterative process of identifying data gaps, conducting activities to fill those data gaps, reporting on the results of those activities, and identifying new data gaps. This process has resulted in a series of four reports, the last of which was Wymore, Bukowski, and Sorenson (2000). Examples of characterization activities that have been conducted in the source area since the sludge removal activity was completed and before the ISB field test was implemented are as follows:

- Several wells have been installed within or adjacent to the source
- Pumping tests, slug tests, and tracer tests have been conducted to determine aquifer properties, from which residual source distribution has been
- Standard geophysical, gamma spectroscopy, and acoustic televiewer logging were performed in several source area
- Cross-well seismic tomography was
- Extensive groundwater sampling has been conducted throughout the source area, both in support of ISB operations (see Section 2.3) and prior to initiation of ISB

These activities greatly improved the understanding of aquifer hydraulic conductivity, porosity, and preferential flow paths; dissolved contaminant composition and distribution; and residual contaminant source distribution. A thorough discussion of the complete SCM is presented in Sorenson (2000).

The TAN ISB monitoring program maximizes cost-effectiveness by using a combination of fixed laboratory and field analyses. The source area bioremediation at TAN remains one of the largest-scale projects in a source area of its kind in the world, certainly in deep, fractured rock. An area approximately 60 m (200 feet) in diameter is being treated, initially across an aquifer thickness of 60 m (200 feet). As contaminants have been removed in the deepest part of the contaminated aquifer, which presumably was limited to aqueous- (and possibly some sorbed-)phase contamination, the focus is now on the upper 30 m (100 feet) of the aquifer. Both field and laboratory data have demonstrated that bioremediation through injection of high-concentration electron donor solutions has enhanced depletion of the residual source by enhancing mass transfer into the aqueous phase. The biodegradation kinetics have largely remained faster than the mass transfer kinetics, leading to an optimization strategy largely devoted to accelerating mass transfer rates even further. This requires continued injections of high-concentration electron donors throughout the area impacted by residual source material. As the volume of this area is large and the transmissivity of the aquifer is very high, injection volumes are larger than at many other chlorinated-solvent sites.

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SITE NAME: AIR FORCE PLANT 44, TUCSON, ARIZONA

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Air Force Plant 44 (AEP-44) Raytheon Project Area. Source: www.azdeq.gov/environ/waste/sps/download/tucson/raytheon.pdf.

Site Description

Air Force Plant 44 is part of the Tucson International Airport Area (TIAA) located 8 miles south of downtown Tucson. It is bounded to the north and east by the Tucson International Airport, to the South by Hughes Access Road, and to the West by the Nogales Highway Route 89. The facility is part of the TIAA CERCLA site.

> ***Highlight included in Section 5.5.2:*** **Text Box 5-2. Air Force Plant 44, Stable Trend Resulting in a Change in the Remedy** TCE values immediately below the former disposal areas indicated that mass discharge equaled mass removed using the P&T system. This finding resulted in the decision to remove the source areas while still operating the P&T system.

The regional aquifer is composed of unconsolidated to semiconsolidated basin-fill alluvium divided into upper and lower zones. The upper zone is 90–140 feet bgs, more permeable than the lower zone, and the focus on most of the remediation efforts. Groundwater flows northwesterly in the southern part of the well field and almost due north in the northern part of the well field. The change in flow direction is controlled by variation in the stratigraphy of the subsurface and controls the areal shape of the plume. The treatment site covers of the southern half of a 6-mile-long TIAA TCE plume.

Objectives

Drinking water quality in the regional aquifer.

Remedial Approach

In 1987 P&T was installed to treat the southern half of the 6-mile-long TIAA Superfund site using a 2-square-mile well field including 15 extraction wells located in the middle and at the downgradient end of the plume and 16 discharge wells located along the plume margins to enhance flushing and containment (Allen, Katz, and Warner 2005). The treatment plant design capacity was 4500 gpm using air stripping. In the early 1990s the P&T system successfully contained the TCE plume and eliminated almost all chromium in the downgradient potion of the plume but was ineffective near the former solvent-disposal locations. These proved to be ongoing sources of TCE. Fine-grained sediments in the uppermost part of the regional aquifer and immediately downgradient of the source areas continued to have the highest TCE concentrations. Soil gas samples identified high VOC in the unsaturated zone above the former disposal areas. TCE values immediately below the former

disposal areas indicated that mass discharge equaled mass removed using the P&T system. This resulted in the decision to remove the source areas while still operating the P&T system.

SVE and dual-phase extraction were installed at all former solvent disposal areas in the early 1990s, and by 1999 the first disposal area was remediated and closed. The second was near performance standards, and two others were making significant progress. Regardless, TCE concentrations in groundwater beneath these former disposal areas displayed little improvement. Full-scale application of potassium permanganate began in 2003 on a 15-acre site using 15,000 pounds of potassium permanganate in 0.5% solution injected into the upper part of the aquifer using former monitoring and extraction wells. Six thousand pounds of potassium permanganate at 0.3% solution was injected through former SVE wells into the lower aquifer. Pumping was started in 2004 to improve potassium permanganate distribution.

Concentrations declined from an average of 297 µg/L in 2001 to 28 µg/L in February 2005 (90% reduction). Rebound has occurred, requiring additional injections.

Performance

This remedial approach has prevented ongoing migration of the plume further into sole source drinking water aquifer, quickly reducing risk/exposures for local residents; DNAPL source removals have shrunk plume dimensions such that the pumping rate achieves adequate capture with 50% of the original flow rate; SVE in DNAPL source zones has resulted in site closure and significant reduction in groundwater concentrations; ISCO in saturated DNAPL source zones has reduced mass flux, helping the U.S. Air Force argue for a revised containment strategy that will further reduce flow rates and associated costs. Initial P&T, enhanced by DNAPL source zone remediation, has reduced mass flux overall by 97.8%.

Highlight included in Section 2.3: **Text Box 2-1. Air Force Plant 44, Diffusive Storage** A new CSM indicated that even though SVE had effectively removed TCE from the vadose zone, chlorinated-solvent contamination was still discharging to the downgradient aquifer due to diffuse storage in fine-grained materials in the capillary fringe and in the upper part of the aquifer material. SVE did not effectively remove this material.

Remedy Evaluation

A new CSM indicated that even though the SVE had effectively removed TCE from the vadose zone, chlorinated-solvent contamination was still discharging to the downgradient aquifer due to diffuse storage in fine-grained materials in the capillary fringe and in the upper part of the aquifer material. SVE could not effectively remove this material. To remove this diffuse storage contamination ISCO using potassium permanganate was tested and applied.

Outcomes and Challenges

Agencies are recommending further DNAPL source area actions, which the U.S. Air Force does not agree are necessary.

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SITE NAME: CALDWELL TRUCKING, FAIRFIELD TOWNSHIP, NEW JERSEY

Highlight included in Section 6.2.1: **Text Box 6-1. Caldwell Trucking, Optimizing In Situ Treatment** A full-scale field test using enhanced biological treatment from January 2001 to July 2002 was designed to determine whether enhanced bioremediation was viable to treat residual DNAPL in the basalt bedrock. The test goals were to accelerate the dissolution and treatment of source material and reduce the overall lifetime and impact of the source, rather than to achieve specific concentration reductions (NRC 2005).

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Site Description

The Caldwell Trucking site is an 11.25-acre facility that hauled and stored sewage from the early 1950s through 1988. Disposed of industrial waste and residential/commercial septic waste in unlined lagoons caused contamination on site. In 1973 underground storage tanks were used to hold waste before off-site disposal. Waste storage was abandoned in the early 1980s. In 1988, all operations ended.

The source of soil, sludge, and groundwater contamination is industrial waste that was discharged into unlined lagoons from the 1950s through the early 1970s. A CVOC groundwater plume extends 4000 feet downgradient of the lagoons in the direction of the Passaic River (USEPA 2007).

The primary COCs in groundwater at the site and nearby surface waters (e.g., the Passaic River) are CVOCs (e.g., PCE, TCE, and daughter products). Residual DNAPL is suspected in a fractured basalt bedrock aquifer beneath a glacial sand and gravel aquifer. TCE was detected in this source zone at levels up to 700 mg/L in 2005. The soil contains metals, VOCs, SVOCs (polycyclic aromatic hydrocarbons [PAHs]), and polychlorinated biphenyls, largely from underground storage tanks (NRC 2005).

Since 1981 over 300 private drinking wells have been closed due to VOC groundwater contamination off site. The 1986 Operable Unit (OU)-1 ROD required excavation of contaminated soil, air stripping a municipal water supply well, and an alternative water supply for off-site residents. Air-stripping was subsequently removed since a decision was made not to use the well. The soil remedy was adjusted to address disposal of certain waste materials and stabilization of lead-contaminated soils. In 1995 excavation and off-site disposal of soils with VOC concentrations >100 mg/kg and in situ S/S of remaining soil contamination was added. An SVE system was also installed to minimize odors and soil gas emissions during S/S.

In 1989 P&T was required to intercept the groundwater plume, plus a technical impracticability waiver for groundwater was prepared. USEPA was unable to install groundwater recovery wells in 15 locations due to access conflicts with local property owners, so wells were installed in the most highly contaminated areas of the lower water table aquifer and the upper bedrock aquifer (USEPA 2007).

Objectives

The principal responsible parties amended the P&T remedy to be replaced with enhanced ISB (EISB). The EISB system continues to perform voluntary bioaugmentation of the source zone. The 2007 5-year review indicated that groundwater contamination concentration levels are steadily decreasing but remain above MCLs.

Remedial Approach

Remedial action included removal of underground storage tanks, excavation of soil and waste material, S/S of metal-contaminated soils, SVE of VOCs in the unsaturated zone, installation of an iron reactive barrier wall with a supplemental seep remediation system, EISB, and hydraulic containment using P&T.

The SVE system operated from June 1996 to March 1997, when it was shut down due to odor complaints (NRC 2005). Next, 40,000 cubic yards of contaminated soils was stabilized from March through September of 1997. Additionally, an iron reactive wall was installed to intercept contaminated groundwater as it flows towards a surface water seep. The anticipated abiotic degradation as groundwater passed through the reactive wall did not sufficiently reduce contaminant concentrations to target levels, so an air stripper was installed to replace the reactive wall treatment.

A full-scale field test was conducted using enhanced biological treatment from January 2001 to July 2002. The test was designed to determine whether enhanced bioremediation was viable to treat residual DNAPL in the basalt bedrock, which is the source of the VOC plume. The test goals were to accelerate the dissolution and treatment of source material and reduce the overall lifetime and impact of the source rather than to achieve specific concentration reductions (NRC 2005).

Ambient groundwater conditions at the site appear to support natural degradation of TCE at low levels. A substrate feed of lactate, methanol, and ethanol and a microbial supplement of *Dehalococcoides ethenogenes* were injected into six nutrient injection wells screened in glacial deposits and bedrock. Seven monitoring wells were also installed.

A vapor intrusion study included approximately 120 additional properties. Sampling began at residential and commercial properties downgradient of the site in April 2007. Mitigation systems have been installed and up to 25 systems may be

required (Ryan 2010).

Performance

The SVE system recovered over 25,000 pounds of VOCs from the soil in 1 year (USEPA 2005). The EISB field test induced bacterial reductive dechlorination of contaminants in the residual DNAPL source zone during its 18-month test through July 2002. During a 30-month monitoring period, net reductions in PCE and TCE concentrations averaged 95% and 93%, respectively (see table) across the treatment zone (NRC 2005).

EISB field test, Caldwell Trucking: Results from a 30-month monitoring period

Location	Compound	Initial concentration (µg/L)	Concentration reduction (µg/L)	Average net reduction in concentration (%)	Degradation product production (µg/L)
Entire treatment zone	TCE	700,000	790	93	Average observed ethene concentration was 723.
	PCE	No results	131	94	
Well C-22 (highest initial concentrations)	TCE	680,000	1,700	99.8	cDCE went from nondetect to 36,000 (then declined to 27,000); VC sustained at 2,000; ethene sustained at 30–40.
	PCE	27,000	260	99.0	

Sources: Finn et al. 2003, NRC 2005, USEPA 2010.

Two of seven monitoring wells in the EISB treatment area contained no PCE after the 30 months, and one well had no detectable TCE. Breakdown products such as DCE and VC remained at elevated concentrations in several wells (NRC 2005), including the following:

- MW-B23: This overburden monitoring well exhibited disappearance of PCE and TCE coupled with ethene Concentrations of cDCE remained elevated, and VC increased from December 2000 to December 2002. From December 2002 to September 2003, concentrations of both cDCE and VC decreased to less than 20 µmoles/L.
- MW-C22: This bedrock monitoring well had the highest TCE and PCE concentrations prior to EISB treatment. Post-treatment samples detected mixture of cDCE, VC, and Significant solvent reductions occurred in both injection wells and monitoring wells, accompanied by large increases in ethene concentrations, indicating that a continuous treatment zone was present across the test area (NRC 2005).

Remedy Evaluation

The principal responsible parties have amended the EISB system and continue to perform voluntary bioaugmentation of the source zone. The 2007 5-year review indicated that groundwater contamination concentration levels are steadily decreasing but remain above MCLs. Remedial activities continue and optimization studies are under way (USEPA 2007).

With the excavation and off-site disposal of contaminated material and stabilization of the remaining contaminated soil and waste materials at the site, all on-site soil contamination has now been removed or rendered harmless. The restored wetlands monitoring is complete after 5 years. The use of an alternative drinking water supply by affected homes and businesses in the area of the Caldwell Trucking site has significantly reduced the potential for exposure to contaminated groundwater. However, high levels of groundwater contamination still remain, and the principal responsible parties have completed the construction of a P&T containment facility to remediate the contaminated groundwater near the source area using extraction wells in the vicinity of O'Connor Drive. The upgrade of the seep area treatment system has been completed, and additional investigations are being conducted. A vapor intrusion study is also nearing completion (USEPA 2010).

Outcomes and Challenges

The principal responsible parties wanted to amend the P&T remedy and replace it with EISB. USEPA has not approved the amendment since EISB does appear to be reducing VOC levels in the source zone and daughter products remain at elevated concentrations, indicating that P&T is necessary to hydraulically contain the groundwater plume (USEPA 2007). A P&T system was installed in December 2008. Monitoring data to date indicate that it is functioning as intended and that the most highly contaminated portion of the plume is contained (Ryan 2010).

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SITE NAME: FORT LEWIS—EAST GATE DISPOSAL YARD

***Highlight included in Section 5.1:* Text Box 5-1. Fort Lewis East Gate Disposal Yard, Strategic Monitoring** The Fort Lewis East Gate Disposal Yard remedial action is a prime example case study showing how strategic monitoring resulted in more effective and efficient cleanup of chlorinated solvents. In 1998 an Explanation of Significant Difference was issued to allow further investigation into the nature and extent of the COCs as well as to enhance the selected remedy. This understanding allowed innovative treatment strategies to be considered, such as the Triad approach for characterizing migration of COCs, as well as the use of ERH to remove the NAPL. Having this flexibility in place was instrumental in the practitioners' ability to make modifications during all phases of remedial action, from initial installation to relocating to the additional areas needing treatment, to ensure remedial process performance.

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Site Description

The East Gate Disposal Yard (EGDY) at is the source of a large TCE plume at the Logistics Center Site in Fort Lewis, Washington. The EGDY was used between 1946 and the 1970s as a disposal site for waste generated at the Logistics Center. While petroleum, oils, lubricants, PCE, TCE and its degradation products cDCE and VC were all detected at EGDY, TCE is the primary COC. TCE is present in multiple locations over the 23-acre source area, often as a NAPL. The most highly contaminated areas have been designated as NAPL Areas 1, 2, and 3.

The TCE plume extends down the Vashon Aquifer from the source area for approximately 2 miles. About halfway down this plume, TCE also enters the Sea-Level Aquifer (SLA) via a hydrogeologic preferential pathway, from which it extends in the SLA for approximately

2.5 miles. The level of TCE in both aquifers exceeds the ROD goal of 5 µg/L, which is the drinking water standard for TCE. TCE has been historically detected in the groundwater beneath the Logistics Center at a maximum concentration of 100,000 µg/L (USEPA 2007).

Objectives

Restore groundwater to MCLs and prevent contamination above MCLs from spreading beyond the site boundaries (Ryan 2010, USEPA 2010).

Remedial Approach

In 1985 groundwater contaminated with TCE was confirmed. P&T was selected as the preferred remedy for the upper aquifer and also for the lower aquifer as necessary. The P&T system for the upper aquifer began operations in 1995. The source area investigation began in 1999 and was completed in 2002 with an engineering evaluation/cost analysis and drum removal remedial activity occurring between two investigation phases (USEPA 2005).

Performance

ERH has effectively targeted NAPL source zones at EGDY. Performance results indicate that 12,787 pounds of VOCs has been extracted, groundwater TCE concentrations have reduced from 100 ppm to <100 ppb, soil TCE concentrations have been reduced by 96%, and contaminant mass flux has reduced by 60%–90% (Ryan 2010). According to a 2009 assessment of ERH at EGDY, "ERH treatment appeared to be robust in removing mass from the targeted zone with a minimal rebound of contamination observed" (Truex et al. 2009). The thermal remediation project at the Logistics Center was successful and can be used a model for future thermal operations.

Remedy Evaluation

The EGDY remedial action is a prime example case study showing how strategic monitoring resulted in more effective and efficient cleanup of chlorinated solvents. In 1998 an Explanation of Significant Difference was issued to allow further investigation into the nature and extent of the COCs as well as to enhance the selected remedy. This understanding allowed innovative treatment strategies to be considered, such as the Triad approach for characterizing migration of COCs as well as the use of ERH to remove the NAPL. Having this flexibility in place was instrumental in the practitioner's ability to make modifications during all phases of remedial action, from initial installation to relocating to the additional areas needing treatment, to ensure remedial process performance. One instance of the success of this flexibility occurred during the initial remedial action at Area 1, when operational data indicated that the original contracted temperature requirements for NAPL removal would not be achieved throughout each of the areas being treated. Using accumulated data gathered during subsequent drilling activities associated with implementation of the ERH installation, the practitioner was able to modify the temperature specification at areas of known NAPL concentrations or areas indicating a high probability of having NAPL. As the ERH operations progressed, real-time data collection (vapor and groundwater) was used to continually modify the ERH application to address possible or potential areas where NAPL may be present. The lessons learned in the adaptation of the ERH application in Area 1 were incorporated into Areas 2 and resulted in shorter operational time frames to achieve successful removal of NAPL.

The innovated use of treatment technologies and strategies for this chlorinated-solvent site resulted in the average concentrations of TCE dropping from a historical maximum of 100 ppm to below 100 ppb, with future land uses identified as commercial or industrial and future land uses downgradient of the source zone primarily industrial with some residential and open space. Because of this successful outcome implementing an innovated thermal treatment technology, the Fort Lewis site received the 2005 Secretary of Defense Environmental Award for Environmental Restoration.

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Highlight included in Section 4.2: **Text Box 4-4. Launch Complex 34, Sequential Treatment Compared to Individual Technologies** A cost analysis at full scale was prepared by comparing the life-cycle costs of sequential ISCO/ISB compared to P&T, ISCO only, and ISB only, based on a theoretical site with a 100-foot- long, 100-foot-wide source area with 12,500 pounds of TCE (sum of TCE as DNAPL, on soil and at approximately 175 mg/L in groundwater) present 10–80 feet bgs. The geology was assumed to be composed of a sand unit 10–40 feet bgs and a silty sand unit 40–80 feet bgs. The cost analysis suggests that all in situ alternatives have lower lifetime costs than P&T, providing that they have short operating durations. While the sequential ISCO/ISB option has a higher life-cycle cost than ISB alone, the shorter lifetime of a sequential approach may make it more advantageous than ISB alone. Over 75% of the ISB costs in the sequential approach were driven by the donor demand associated with the aggressive permanganate dose.

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Site Description

Hydrogeological conditions at Launch Complex (LC)-34 are highly favorable to the implementation of a recirculation- based remediation technology. The aquifer consists of relatively homogeneous sand and silty sands and is easily instrumented using low-cost, direct-push drilling technologies (e.g., GeoProbe). A surficial aquifer and a semiconfined aquifer beneath a clay unit compose the major water- bearing units at LC-34. The surficial aquifer extends from the water table to approximately 45 feet bgs. The clay confining unit ranges in thickness 1–3 feet. The surficial aquifer is subdivided into the upper sand unit (USU), the middle fine-grained unit (MFGU), and the lower sand unit (LSU) (Eddy-Dilek et al. 1998). The USU is composed of medium- to coarse-grained sand and crushed shells and extends from ground surface to approximately 18–25 feet bgs. The MFGU, which varies in thickness about 4–14 feet, is composed of gray, fine- grained silty/clayey sand and generally contains finer-grained sediment than the remainder of the aquifer unit. The MFGU is thicker to the north of the Engineering Support Building (ESB) and appears to thin towards the south and west of the ESB. The LSU, the deepest subunit of the surficial aquifer, consists of gray fine to medium-sized sand and shell fragments. In addition, the LSU contains some isolated fine-grained lenses of silt and/or clay. The thickness of the underlying confining unit is unknown since boreholes are typically completed at the top of the clay unit to prevent drilling-induced migration from the LSU into the confined aquifer. The confining unit may act as a barrier to DNAPL migration into the confined aquifer.

The Atlantic Ocean is located immediately to the east of LC-34. To determine the effects of tidal influences on the groundwater system, water levels were monitored in 12 piezometers over a 50-hour period during RCRA facility investigation activities (G&E Engineering, Inc. 1996). All the piezometers used in the study were screened in the surficial aquifer. No detectable effects from the tidal cycles were identified in the subject area. However, the Atlantic Ocean and the Banana River (west of LC-34) are sufficiently close to the site and appear to act as hydraulic barriers or sinks, as groundwater likely flows toward these surface water bodies and discharges into them. Other hydrologic influences at LC-34 include features such as paving, constructed drainage ditches, and topographical relief. Permeable soils exist from the ground surface to the water table, and drainage is excellent. Water infiltrates directly to the water table. Only limited data were available to characterize background geochemistry at LC-34 (Battelle 1999) prior to the sequential technology demonstration. As may be expected, the salinity of groundwater in the surficial units increases with depth with concentrations of total dissolved solids as high as 1200 mg/L in the LSU (predominantly Na, K, Mg, Ca, Al, Cl, and total SO_4/S). Groundwater pH is near neutral (7.3–8.0) with an alkalinity of up to 360 mg/L (as $CaCO_3$). Although no direct measurements of redox potential are available, the high concentrations of dissolved iron and manganese indicate that the groundwater redox potential is generally reducing.

A preliminary site investigation was conducted by Geosyntec in December 2002 to facilitate selection of locations for the ISCO pilot demonstration. Five boreholes were drilled within the ISCO pilot test area adjacent to the ESB to characterize the geology and the soil and groundwater chemistry. Soil samples from five boreholes were submitted for laboratory analysis of VOCs. The presence of DNAPL was inferred based on photoionization detector readings exceeding 9,999 ppm by volume and concentrations of TCE in soil exceeding 10,800 mg/kg. Appendix A of the Project ER-0116 final report provides a detailed

summary of the preliminary site investigation.

Objectives

The main objectives of this project were to assess the technical feasibility of sequential application of these technologies and to identify the optimal timing of the transition from ISCO to ISB. The principal benefit of ISCO using permanganate (MnO_4^-) is that it aggressively enhances dissolution and destruction of the target contaminants within a relatively short period of time (i.e., months to years); however, the cost-benefit of this technology diminishes as the mass of target chemicals decreases. The most effective application of ISCO consists of rapid destruction of the readily accessible target chemical mass within the source area although it can also be coupled with a less costly in situ remediation mass removal technology such as ISB.

Remedial Approach

Sequential application of ISCO and ISB is potentially widely applicable at chlorinated-solvent sites throughout North America. However, several issues may potentially limit the widespread application of this technology. In the long term, ISCO application using permanganate is likely to increase the concentration of manganese in soil and groundwater, a potentially adverse geochemical impact with respect to subsequent treatment by ISB. The cost and performance of ISB, both using biostimulation and bioaugmentation, were evaluated at the LC-34 technology demonstration site. A number of remediation technology demonstrations for treatment of DNAPL dominated by TCE have been conducted at LC-34, including ISCO using permanganate (completed 2000), six-phase heating (completed 2001), and steam flushing (completed 2002). In addition, smaller-scale demonstrations of ISB using bioaugmentation and emulsified ZVI were also conducted.

Implementing two source-control technologies (ISCO and ISB) may add cost and performance barriers to implementation. However, implementing these technologies sequentially may provide substantial schedule and performance advantages when implemented in a compatible manner, off-setting the increased capital costs with reduced O&M costs. The uncertainty surrounding the performance of these coupled technologies is another barrier, particularly at full scale.

Prior to this project, little had been documented regarding the field-scale impact of ISCO on groundwater geochemistry and microbiology of TCE DNAPL treatment by ISB. Specifically, the application of an aggressive dose of permanganate may have adverse impacts on the indigenous microbial community and the cost of post-ISCO ISB. A field trial evaluating biostimulation and/or bioaugmentation after aggressive permanganate treatment at LC-34 was conducted. Specifically, ISB was evaluated with respect to the completeness of dechlorination and the effect on mass flux emanating from a source zone.

During the demonstration, groundwater was recirculated through the ISCO-treated area at a constant groundwater velocity. A number of treatment phases were used to evaluate the rate of DNAPL removal and the extent of VOC treatment. Each phase was operated under each of the different operating conditions (i.e., baseline groundwater recirculation only, electron donor addition, electron donor addition, plus bioaugmentation).

A cost analysis at full scale was prepared by comparing the life-cycle costs of sequential ISCO/ ISB compared to P&T, ISCO-only, and ISB-only based on a theoretical site with dimensions of 100 feet long by 100 feet wide source area with 12,500 pounds of TCE (sum of TCE as DNAPL, on soil and at approximately175 mg/L in groundwater) present from 10 to 80 feet. The geology was assumed to be composed of a sand unit from 10 to 40 feet and a silty sand unit from 40 to 80 feet. The cost analysis suggests that all in situ alternatives have lower lifetime costs than P&T providing that they have short operating durations. While the sequential ISCO/ISB option has a higher life-cycle cost than ISB alone, the shorter lifetime of a sequential approach may make it more advantageous than ISB alone. Over 75% of the ISB costs in the sequential approach were driven by the donor demand associated with the aggressive permanganate dose.

Sequential application of ISCO and ISB is potentially widely applicable at chlorinated-solvent sites throughout North America. However, several issues may potentially limit the widespread application of this technology. In the long term, ISCO application is likely to increase the concentration of manganese in groundwater, a potentially adverse geochemical impact. The capital cost associated with implementing two source-control technologies (ISCO and ISB) may be a barrier to implementation. However, implementing these technologies sequentially may provide substantial schedule advantages over the implementation of either technology alone, off- setting the increased capital costs with reduced O&M costs.

Performance

The principal results of the project include the following:

- Electron donor addition (ISB) after ISCO resulted in partial biodegradation of TCE, with complete biodegradation

observed after
- At the field-scale, ISB did not increase the mass flux of chloroethenes after
- The precipitated manganese dioxide produced by MnO_4 reduction, which can oxidize some organic compounds, did not abiotically degrade any of the chloroethenes or

- Manganese dioxide (MnO_2) greatly increases the electron donor demand above that typically required to reduced the dissolved constituents (e.g., oxygen, nitrate, sulfate, and the target chloroethenes) during
- MnO_2 can be dissolved by the activity of Mn(IV)-reducing bacteria, which appear to preferentially use hydrogen and inhibit the activity of dechlorinating microorganisms (i.e., *Dehalococcoides*, which use hydrogen as their sole electron donor).
- The limited cost assessment indicated that there was a significant cost and schedule advantage for the sequential treatment strategy over using P&T or ISCO

Remedy Evaluation

Following the ISCO demonstration at LC-34, the residual permanganate remaining in the test plot likely continued to slowly react with soil and/or residual TCE present in the subsurface while slowly migrating downgradient of the test plot. Permanganate was not observed during a groundwater monitoring event (October 2002) conducted using monitoring wells located in and adjacent to the test plot, suggesting that the residual permanganate was depleted, which was an essential step prior to initiating treatment via bioremediation.

Pre- and post-treatment soil sampling was performed by Battelle during the previous technology demonstrations (Battelle 2001). The results of post-treatment monitoring in the ISCO test plot indicate that 844 kg of total TCE mass, including 637 kg of TCE DNAPL, remained in the LSU.

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SITE NAME: PALL AEROPOWER

Highlight included in Section 4.1.3.1: **Text Box 4-2. Pall Aeropower, Rebound from Desorption** ISCO was able to destroy DNAPL and reduce dissolved contaminant concentrations to a greater degree than reductive dechlorination in the short term. However, desorption of soil- adsorbed CVOCs caused contaminant concentrations to rebound after the oxidants were consumed.

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Site Description

Six chlorinated-solvent source areas beneath the former Pall Aeropower facility in Tampa, Florida support five plumes up to

600 feet long. Chloroethene solvents were used at the site 1972–1998. Pretreatment sampling detected TCE concentrations as high as 470,000 µg/L and PCE concentrations as high as 110,000 µg/L, confirming a DNAPL phase was present. Based on compound solubilities, DNAPL was suspected at two locations. cDCE and VC, which are daughter compounds of PCE and TCE, and eight other VOCs also are present.

Site soils are fine sand to a depth of ~15 feet. Silty fine sand extends 15–28 feet bgs; the majority of CVOCs were found in the deeper interval. Two to three feet of clayey sand or sandy clay begin at ~28 feet bgs. Silts and clays containing decomposed limestone and shell fragments are present ~30–90 feet bgs soils. CVOCs are rarely found at or below 70 feet bgs.

The water table aquifer is encountered at 3–4 feet bgs, depending on the season. Groundwater moves slowly to very slowly, approximately 8 feet/year 3–15 feet bgs, 1 foot/year 15–28 feet bgs, and <1–10 feet/year 30–90 feet bgs per year. Natural groundwater pH ranges 5.0–6.0. Natural dissolved levels of oxygen, Eh, nitrate, phosphorus, total alkalinity, and dissolved organic matter are low. Groundwater temperatures average 75°F.

Objectives

Source removal to remediate CVOCs and VOCs in groundwater in the surficial aquifer system and the intermediate confining unit (Pall Aeropower 2009a, 2009b).

Remedial Approach

A two-phase CVOC destruction plan, ISCO followed by augmented reductive dechlorination, was approved by the Florida Department of Environmental Protection and began in 2004. Remediation has focused on in situ destruction of DNAPL and high dissolved concentrations portions of the CVOC plumes. This was the most cost-effective method to destroy contaminant mass and decrease dissolved-phase loading to the plumes, which should then weaken and shorten through natural attenuation.

The low hydraulic conductivity of the site limits the groundwater recovery rate and reagent solution injection rates. As a result, up to 303 permanent treatment wells and 97 direct injection locations have been used during individual injection events to maximize contact between contaminants and remedial solutions.

- Chemical oxidation using Fenton's reagent was the first step because of its ability to destroy large masses of CVOCs in a short period of time. During three events, approximately 115,000 pounds of 50% hydrogen peroxide (a total of 82,000 gal of hydrogen peroxide and iron solutions) was injected at a rate of 0.75–1.5 gpm. Dissolved TCE destruction typically exceeded 90%.
- Potassium and sodium permanganate are longer-lived chemical oxidants. Twenty-eight thousand pounds of both (98,000 gal of solution) was injected during three events after the majority of the DNAPL and high dissolved concentrations of CVOCs were destroyed and desorption of parent CVOCs from the soil, a relatively slow process, had begun. Residual permanganate ions destroyed CVOCs desorbing from the soil for 6–9 months after
- One hundred fifty-three thousand pounds of emulsified soybean oil (electron donor) and 270 L of proprietary bacteria were injected during four events to enhance and augment reductive dechlorination after chemical
- Other solutions were injected to raise the groundwater pH or increase nutrient concentrations to enhance reductive dechlorination.
- Different source areas received different treatments depending on previous contaminant destruction rates and other aquifer parameters. For example, Source Areas 1, 5, and 6 were injected with chemical oxidants once and have received only soybean oil, nutrients, and bacteria since. In contrast, Source Areas 2, 3, and 4 were injected with Fenton's reagent, then soybean oil and bacteria, Fenton's reagent, potassium permanganate, and, finally, soybean oil and bacteria again.

Performance

June 2010 sampling of 92 monitoring wells verified the highest pretreatment TCE concentration (470,000 µg/L in MW-31D) has been reduced >99.95%. PCE in the same well was reduced 99%. A simultaneous 62% increase in cDCE and a 3770% increase in VC provided evidence that reductive dechlorination is continuing. Overall, though concentrations of daughter compounds, which are more soluble than their parents, have risen in several monitoring wells, total moles of PCE, TCE, cDCE, and VC in the nearly all wells continue to decrease.

Recently, the chlorinated solvent stabilizer 1,4-dioxane was found beneath Source Area 4 at concentrations as high as

63,000 µg/L. 1,4-dioxane is also found beneath three of the other five source areas though concentrations do not exceed 320 µg/L, the natural attenuation default concentration set by Florida Department of Environmental Protection. Pump and ex situ treatment using ultraviolet irradiation and hydrogen peroxide to chemically oxidize the dissolved 1,4-dioxane was chosen as the remedial method because the stabilizer does not adsorb to the soil and recovery and treatment of a pore volume of water should destroy most of the 1,4-dioxane in Source Area 4 in approximately 1 year.

Remedy Evaluation

ISCO was able to destroy DNAPL and reduce dissolved-contaminant concentrations to a greater degree than reductive dechlorination in the short term. However, desorption of soil-adsorbed CVOCs caused contaminant concentrations to rebound after the oxidants were consumed. After establishment of suitable conditions, reductive dechlorination, the second remedial method, destroyed contaminants efficiently and for 1–2 years after each Emulsified Oil Substrate® injection. Reductive dechlorination is better suited than additional ISCO treatment to reach final cleanup goals for the site. Overall, results to date indicate that the remedial methods and order of application selected in 2004 were appropriate (USEPA 2009).

Outcomes and Challenges

In 2004, the principal responsible party decided to begin remediation immediately rather than await completion of the site assessment. While this decision delayed discovery of the fifth and sixth sources and the fifth plume, it ensured that treatment of the two likely DNAPL source areas began 2–3 years sooner than if a conventional schedule had been followed. The fifth plume was discovered in 2007. Treatment began in 2008. Prior to that time, only four sources and plumes were treated. Initial treatment of each source and plume with Fenton's reagent greatly reduced the mass in the most contaminated plume and to a lesser degree in three others. Adjustment of groundwater pH and injection of emulsified soybean oil and bacteria in four plumes was within 3 months. Source and Plume 1 has been maintained as enhanced reductive dechlorination since that time with one exception. Sodium permanganate was injected into Plume 1 at a point where PCE and TCE were no longer present and cDCE and VC were the dominant contaminants in October 2009. Sources and Plumes 2–4 and eventually 5 have alternated among Fenton's reagent or potassium permanganate chemical oxidation and augmented reductive dechlorination since. Overall, the treatments appear to have quickly destroyed source mass, converted parent compounds to daughters or ethane/ethene, and greatly reduced plume concentrations.

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SITE NAME: PEMACO, MAYWOOD, CALIFORNIA

***Highlight included in Section 4.2.1:* Text Box 4-5. Pemaco, Treatment Transitions** To meet RAOs within 5 years, thermal treatment was used on the highly contaminated soil and groundwater in the source zone. The 2005 ROD divides the Pemaco site into the following: · The "surface and near-surface soil remediation zone"—Remedy for this zone is soil cover and revegetation. · The "upper vadose zone soil and perched groundwater"—Remedy for this zone is high- vacuum dual-phase extraction. · The "lower vadose zone soil and Exposition zone groundwater"—This is considered the source area of the site; the most highly contaminated soil is found here, as well as the dissolved-phase groundwater plume. The remedy for the lower zone is ERH with vapor extraction, vacuum-enhanced groundwater extraction, and groundwater pump and treat, followed by MNA. The ROD stated that ERH would be applied within the 10,000 µg/L TCE groundwater contour, with electrodes installed as deep as 100 feet bgs.

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Site Description

Chlorinated and aromatic solvents, oils, flammable liquids, and specialty chemicals were used at the 1.4-acre Pemaco site from the 1940s until June 1991. They were stored in drums and above- and underground storage tanks. USEPA conducted an emergency assessment and stabilization of the area after a 1993 fire.

Both the soil and groundwater at Pemaco are contaminated, and groundwater contamination has migrated off site beneath nearby industrial and residential properties. Plumes in the perched groundwater and the Exposition Aquifer are discussed below, and the table below shows maximum concentrations of COCs.

Maximum concentrations and remedial action objectives for COCs at the Pemaco site

Matrix/zone	Compound	Maximum concentration (ppb)	RAO (ppb)
Soil/upper vadose	TCE	3,300	60
	PCE	2,000	-
Soil/lower vadose	TCE	2,100	-
Groundwater/perched	TCE	680	5
	PCE	1,100	5
	1,1-DCE	2,000	6
	VC	240	0.5
Groundwater/Exposition	TCE	22,000	5
	cDCE	14,000	6
	VC	780	0.5

Source: USEPA 2005.

- In the surface and near-surface soil, COCs include SVOCs (PAHs) and In the perched groundwater, VOC plumes contain primarily TCE, PCE, and VC. The presence of VC is most likely due to TCE/PCE degradation. Multiple “hot spots” exist within the plumes where VOC concentrations exceed 10,000 µg/L. Contaminated groundwater extends 250 feet south and 200 feet southwest of the site boundaries. In the perched groundwater, halogenated and nonhalogenated contaminant plumes originating from other former industrial properties adjacent to Pemaco are mixing with the plumes originating at Pemaco (TN&A 2004).
- In the upper zones of the Exposition Aquifer (“A” and “B” zones), a source is creating a contaminant plume of TCE and its degradation products. DNAPL presence is suspected (TCE at greater than 1% of its aqueous solubility); however, the relatively small amount of mass recovered from the source area during ERH treatment indicated that DNAPL was not present at the time of At its historic maximum, the plume extended laterally over an area measuring 1,300 × 750 feet, and its thickness ranged 1.5–10 feet. TCE was present at a maximum concentration of 22,000 µg/L (TN&A 2004). Within the >10,000 µg/L contour of the plume, the average TCE concentration was approximately 16,700 µg/L (USEPA 2005).

Objectives

The ROD called for groundwater restoration to potential beneficial use as a drinking water source within a remedial action period of 5 years.

Remedial Timeline at Pemaco · 1991–1999: Emergency removal activities by USEPA, including excavation and removal of drums and above- and underground storage tanks, as well as building demolition. · 1998–1999: SVE system removed 90,000 pounds of hydrocarbons and solvents from vadose zone soils. The system was shut off due to concerns about dioxin by-product generation. · 2005: Construction of final remedy begins after ROD is issued in January 2005. City of Maywood begins construction of Maywood Riverfront Park. · April 2007: Groundwater treatment system begins to operate. · May 2007: Vapor recovery and treatment system begins to operate. Maywood Riverfront Park completed. · September 2007–April 2008: ERH applied to source area. · June 2008: Vapor treatment system permanently switches from flameless thermal oxidation to granular activated carbon due to substantial VOC concentration reductions. *Source*: USEPA 2005, n.d.

Remedial Approach

To meet RAOs within 5 years, thermal treatment was used on the highly contaminated soil and groundwater in the source zone. The 2005 ROD divides the Pemaco site into three subsurface zones. Each zone is described below.

- The “surface and near surface soil remediation zone” extends 0–3 feet bgs, and the selected remedy for this zone is soil cover and
- The “upper vadose zone soil and perched groundwater” extends 3–35 feet bgs, and the selected remedy for this zone is high-vacuum dual-phase extraction. This system removes liquid- and gas-phase contamination to address contaminated soil and the perched groundwater plume. Extracted soil vapor was treated with flameless thermal oxidation until VOC concentrations decreased sufficiently to allow vapor treatment via granular activated carbon (GAC). Extracted groundwater is treated on site using a GAC/ultraviolet oxidation unit.
- The “lower vadose zone soil and Exposition zone groundwater” extends 35–100 feet bgs. This is considered the source area of the site; the most highly contaminated soil is found here, as well as the dissolved phase Exposition zone groundwater plume. The selected remedy for this zone is ERH with vapor extraction, vacuum-enhanced groundwater extraction, and groundwater P&T, followed by MNA. The ROD stated that ERH would be applied within the 10,000 µg/L TCE groundwater contour, with electrodes installed as deep as 100 feet bgs. The design report amended the contour, expanding the heating area to include a 4,000 µg/L contour. The ERH treatment area was approximately 14,000 square feet. Thirty thousand cubic yards of material was treated in the Exposition A and B zones, 30–95 feet bgs. A flameless thermal oxidation unit was used to treat vapor, while groundwater was treated with GAC/ultraviolet oxidation (USEPA d.).

Construction was completed in September 2007. The ERH system was applied to the source area for approximately 6 months in conjunction with the vapor and groundwater extraction and treatment system.

Performance

The initial TCE mass estimate in the ERH target zone ranged 96–106 pounds. Pre-ERH groundwater pumping removed 70% of the dissolved TCE mass in this area. The remaining 30% was extracted during ERH, amounting to approximately 31.5 pounds of TCE in the vapor phase and 9 pounds of TCE in groundwater (TN&A 2009).

The small amount of mass removal indicates that no DNAPL was present in the source area at the time of treatment. Despite a relatively small amount of recovered contaminant mass, groundwater and soil TCE concentrations in the ERH area decreased by over 99% (TN&A 2009).

Since USEPA turned off the ERH system in April 2008, contaminant concentrations in the source area, dissolved-phase plumes, and vapor have declined steadily (USEPA n.d.). COC concentrations are now below remedial goals in several monitoring locations. The ERH treatment is considered to be a success. For example, in Exposition Zone B and the area immediately surrounding the treatment zone, July 2010 monitoring data shows TCE groundwater concentrations are below MCLs in 11 out of 18 monitoring wells (USEPA 2010).

- Of the 11 wells that meet MCLs, the range of current TCE concentrations is 0.5–5 µg/L. Pre- ERH concentrations in these wells ranged 100–4600 µg/L.
- Of the seven wells that do not meet MCLs, the range of current TCE concentrations is 5.2– 190 µg/L. Only three wells are above 25 µg/L. Pre-ERH concentrations in these wells ranged 170–2900 µg/L.

Almost all post-ERH soil samples taken from the treatment area in November 2008 exhibited TCE concentrations significantly below 60 µg/kg (TN&A 2008). Almost all concentrations are below 10 µg/kg. Pre-ERH concentrations in these wells were typically on the scale of hundreds or thousands of µg/kg.

Significant reductions in VOC levels have been achieved in other contaminated areas of the site due to groundwater pumping and dual-phase extraction. A total of 14,584 pounds of VOCs has been removed site-wide, including a substantial amount of hexane and other light-end hydrocarbons. Groundwater pumping and monitoring are ongoing at Pemaco.

At the Pemaco Superfund site, ERH technology was used to address a CVOC source zone. Initial concentrations of TCE in the source zone were as high as 22,000 µg/L. After 6 months of thermal treatment, TCE concentrations fell below MCLs in several monitoring wells, and other wells exhibit significant concentration reductions.

References and Links

TN&A (T N & Associates, Inc.). 2004. *Final Feasibility Study Report, Pemaco Superfund Site, 5050 E. Slauson Blvd., Maywood, CA.* http://yosemite.epa.gov/r9/sfund/r9sfdocw.nsf/3dc283e6c5d6056f88257426007417a2/93f5ba4e2205be958825727b006e6276/$FILE/Pemaco%20Feasibility%20Study.pdf

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TN&A. 2009. *Electrical Resistance Heating Summary Report, Pemaco Superfund Site, Maywood, California.://yosemite.epa.gov/r9/sfund/r9sfdocw.nsf/3dc283e6c5d6056f88257426007417a2/7e5c873676b1315c882576ce0003839d/$FILE/Pemaco%20ROD%2001_2005.pdf*

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SITE NAME: WESTERN PROCESSING, KING COUNTY, WASHINGTON

Highlight included in Section 6.3.3.1: **Text Box 6-4. Western Processing, Changing Direction after No Recognizable Benefit** After 8 years of aggressive efforts to restore the groundwater to acceptable levels via P&T and surface water infiltration, USEPA changed the remedy to containment in December 1995 for the following reasons: · The chlorinated-solvent plume had a continual DNAPL source. · O&M costs for the P&T system were prohibitively high. · Monitoring showed that the plume was naturally attenuating outside the slurry wall.

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Due to improper waste storage/disposal and spills at the Western Processing Site, site soils, shallow groundwater, and Mill Creek became contaminated with more than 90 of USEPA's priority pollutants. The primary categories of contaminants at this site are VOCs, SVOCs, and heavy metals. Organic COCs at this site include TCE, cDCE, *trans*-DCE, dichloromethane, toluene, and chloroethene. DCE concentrations detected in groundwater are greater than 6% of the compound's aqueous solubility, indicating that DNAPL is likely present in the subsurface (USEPA 1998). The water table begins 5–20 feet bgs, and over 95% of all contamination at the site is located in the uppermost 15 feet of soil. The table below shows historical VOC concentrations.

"Trans" plume concentration reductions at the Western Processing Site (µg/L)[a]

	1988	1995	1992	2002	2003	2005	2006	2007	2008	MCL
TCE			ND[b]	ND	ND	ND	ND	ND	ND	5
cDCE	>2000	<100			ND	ND	ND	ND	ND	70
Chloroethene				150[c]		<16[d]	<16[d]	ND	ND	2

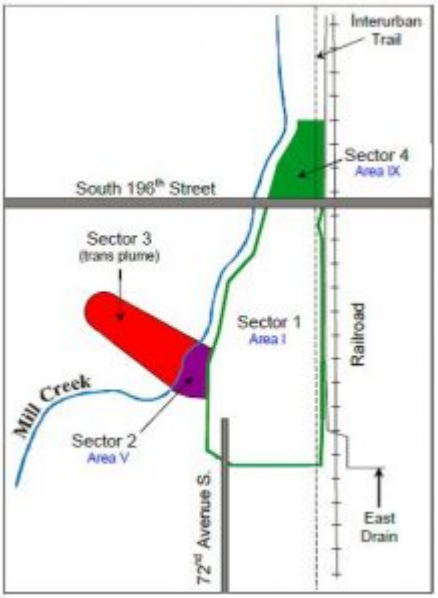
[a] A blank cell indicates that information was not readily available. The plume primarily contained cDCE when it was initially discovered in 1988.
[b] ND = nondetect.
[c] Detected in six wells.
[d] Detected in one well.
Sources: USEPA 1998, 2008.

Groundwater contamination on site primarily affected the shallow groundwater (top of water table to 30–40 feet bgs) in the uppermost hydrogeologic zone (Zone A). The volume of the shallow, on-site plume, consisting of a wide variety of contaminants, was estimated at 500 million gallons in 1987 (USEPA 1998). However, contamination also reached the second hydrogeologic zone (Zone B), which extends to 80 feet bgs. In 1986 an off-site plume, consisting of what was thought to be *trans*-1,2-DCE, was discovered. This plume, referred to as the "trans" plume, had migrated underneath Mill Creek and extended just west of it. The primary compound in the plume was later determined to be cDCE; however, it is still referred to in site documents as the "trans" plume. No drinking water sources have been affected by this site.

See table above

Remedial Approach

The site has been divided into four sectors (see figure). Sector 3 refers to the "trans" plume. Surface cleanup was completed in 1984 as part of the Phase I removal action. In 1988, two P&T systems began to operate, and a 40-foot-deep slurry wall was constructed around the site. On- and off-site P&T systems were installed to contain groundwater contamination within site boundaries and produce an upward flow within the slurry wall/source area. A shallow groundwater extraction/infiltration system and a "trans" plume extraction system were also constructed in 1988.



After 8 years of aggressive efforts to restore the groundwater to acceptable levels via P&T and surface water infiltration, USEPA changed

the remedy to contain ment in December 1995 for the following reasons:

Western Processing Site map. *Source*: EPA 2008.

- The chlorinated-solvent plume had a continual DNAPL
- Prohibitively high operations and maintenance costs for the P&T
- Monitoring showed that the plume was naturally attenuating outside the slurry.

Since then, the following remedial activities have occurred:

- 1996: New, more automated extraction system was installed to contain on-site and off-site plumes.
- 1997: Hot spots were excavated, treated, and
- 1997: An isolation wall was constructed around Sector 4 because it has relatively low contamination; this reduced the amount of groundwater
- 1999: A RCRA cap was placed over the containment area (Sector 1) to reduce infiltration to subsequently the amount of
- 1999: Evaluation of geochemical indicators shows that proper conditions for natural degradation of “trans” plume
- 2000: Extraction wells in Sector 3 were turned off and MNA was used for the “trans”

Indications of “Trans” Plume Breakdown · TCE has not been detected since 1992. · 1,2-DCE has not been detected since 2002. · Chloroethene (VC) has not been detected since 2006. *Source*: EPA 2008.

Performance

Since 1990 the surface water in Mill Creek has met Federal Ambient Water Quality Criteria, indicating that the shallow groundwater is sufficiently clean. Maintaining an inward groundwater flow from Zone B to Zone A within the slurry wall has also been met.

Significant improvements have been made in the “trans” plume area since the MNA program began in 2000. The off-site VOC plume currently extends in a northwest direction from the southwest portion of the site. Both the size of this plume and its VOC concentrations continue to steadily decrease. The plume is biodegrading to well below MCLs (USEPA 2008).

Geochemical indicators such as redox potential, dissolved iron, VOCs, methane, ethane, and ethene continue to be monitored to ensure that proper geochemical reducing conditions exist in Sector 3. USEPA (2008) stated, “Geochemical sampling continues to support that conditions in the trans plume area are conducive to the natural breakdown of vinyl chloride (chloroethene); sampling results appear to verify that this breakdown is occurring as expected.”

The Western Processing Site is currently in the long-term O&M phase. The slurry wall has cut off the chlorinated-solvent

plumes and has isolated the contaminant mass. The P&T and MNA program has reduced the groundwater concentration outside the slurry wall to nondetectable levels. The new containment strategy has made it possible for the P&T system to operate at a much lower rate while still containing onsite contamination. As a result, annual operating costs have fallen from $5 million to approximately $600,000. USEPA has determined that current human exposure pathways and groundwater migration for the site are under control (USEPA 2008).

Remedy Evaluation

A cDCE plume is currently biodegrading to well below MCLs at the Western Processing Site under an MNA program coupled with a slurry wall that cut off the source of the plume. As cDCE (a daughter product of TCE) degrades to ethene, it produces an intermediate, carcinogenic compound—VC. For this reason MNA remedies backfire if the natural groundwater conditions are unable to completely dechlorinate intermediate compounds to the end compound, ethene. Now that the contaminant source has been isolated at the Western Processing Site, MNA appears to be completely degrading contaminants in the groundwater plume with no detections of intermediate compounds in the plume area since 2006.

References and Links

USEPA (U.S. Environmental Protection Agency). 1998. *Pump and Treat of Contaminated Groundwater at the Western Processing Superfund Site, Kent, Washington.* http://costperformance.org/pdf/Western_Processing.pdf.

USEPA. 2008. *Fourth Five-Year Review Report for Western Processing Superfund Site.* https://semspub.epa.gov/work/10/1280288.pdf