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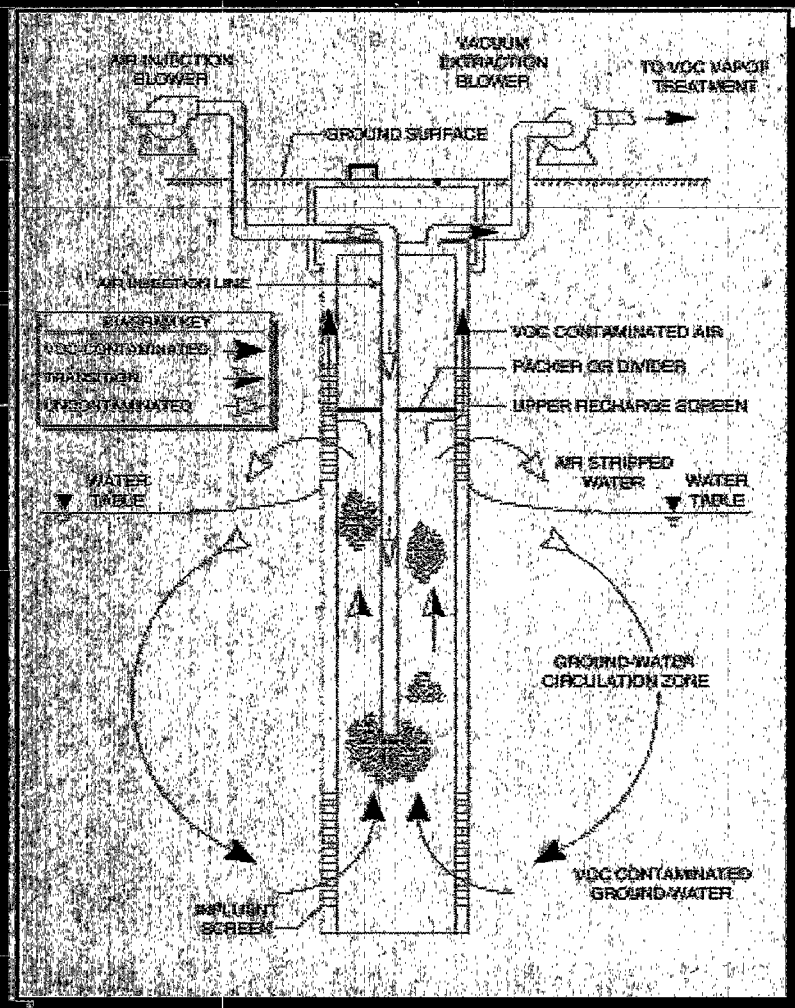
Field Applications of *In Situ* Remediation Technologies:

Ground-Water Circulation Wells



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Ground-Water Circulation Wells

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office
Washington, DC 20460

Notice

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Foreword

Approximately 85% of the hazardous waste sites in the United States have contaminated ground water. The conventional approach for remediating contaminated ground water has been to extract the contaminated water, treat it above ground, and reinject or discharge the clean water ("pump-and-treat"). The recovered contaminants must be disposed of separately. It is becoming increasingly apparent that pump-and-treat technologies require considerable investment over extended period of time, and often times do not actually clean up the source of the contamination. Current policies and law stress "permanent" remedies over containment. Consequently, there is considerable interest and effort being expended on alternative, innovative treatment technologies for contaminated ground water.

This report is one in a series that document recent pilot demonstrations and full-scale applications that either treat soil and ground water in place or increase the solubility and mobilit of contaminants to improve their removal by other remediation technologies. It is hoped that this information will allow more regular consideration of new, less costly, and more effective technologies to address the problems associated with hazardous waste sites and petroleum contamination. This and the other reports listed below are available to the public from the Technology Innovation Office website: http://clu-in.org/pubitech.htm.

Surfactant Enhancements
Treatment Walls
Hydrofracturing/Pneumatic Fracturing
Cosolvents
Electrokinetics
Thermal Enhancements
In Situ Chemical Oxidation
Ground-Water Circulation Wells

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Introduction

Purpose and Process

The purpose of this document is to describe completed and ongoing pilot demonstrations and full-scale applications of ground-water circulation well systems for the remediation of saturated soils and ground water at hazardous waste sites.

Information for this report came from computerized databases such as the Dialog Information Services and the Environmental Protection Agency's (EPA) Vendor Information System for Innovative Treatment Technologies (VISITT). Additional materials were obtained from EPA Regional Offices, the Ground Water Research Technology Analysis Center (GWRTAC), Department of Energy staff at the Oak Ridge National Laboratory and Westinghouse Savannah River, Department of Defense site staff, and Battelle. Personal interviews and discussions with representatives of EPA and other federal agencies, state environmental quality offices, academic research centers, hazardous waste remediation consulting firms, and technology vendors provided supplementary information.

The sites selected for this report represent a mix of government and private demonstrations of various applications of ground-water circulation well systems. The level of detail may vary by demonstration depending upon the availability of information and the willingness or ability of the site representative to share proprietary data.

Technology Needs

Although ground-water contamination reportedly has been found at up to 85% of hazardous waste sites, few efficient and cost-effective cleanup solutions have been identified. The number of solutions available has been limited by the complexity of existing ground-water technologies, the diversity of site characteristics, and the high cost of operation and maintenance for remediation. Two classes of contaminants commonly present at many of these sites are chlorinated volatile organic compounds (VOCs) and petroleum products and their constituents.

Ground-water circulation wells (GCWs) are a developing technology designed to remove contaminants from ground water and saturated soils. They are applied to chlorinated solvents, hydrocarbons, and any strippable contaminant. The technology is simpler than other often-used technologies such as air sparging or pump and treat. It is designed to run continuously with only routine maintenance, and usually has no moving parts below ground and no complicated components. Most of the field applications of this technology have involved treating halogenated VOCs, such as trichloroethene (TCE), and petroleum products and their constituents such as benzene, toluene, ethylbenzene, and xylene (BTEX). Applications of GCWs to non-halogenated VOCs, semi-VOCs (SVOCs), pesticides, and inorganics have been proposed based on modifications of the basic remedial process. The technology also has been applied to ground water contaminated with both radionuclides and VOCs. It has been applied to a wide range of soil types from silty clay to sandy gravel.

The process can remove VOCs continuously from ground water without pumping water to the surface, avoiding the need to handle contaminated water above ground or to dispose of or store partially treated water. The technology does not require injection wells, discharge lines, discharge fees, permits, or water rights to recirculate and discharge ground water. The contaminated vapors generated in the process are more easily removed and treated above ground than contaminated water.

Ground-water circulation wells can be used in conjunction with other technologies such as bioremediation, bioventing, soil vapor extraction, surfactant, zero-valent dehalogenation, and oxidation.

Engineering decisions regarding the application of GCWs must take into account that this technology is site specific. If the system is not properly designed or constructed, the contaminant plume may spread beyond the radius of influence or the wells may become clogged. GCWs may have limited effectiveness in shallow aquifers because of the limited space for circulation. Addition of air can cause sealing in wells.

Technology Description

GCW systems create a circulation pattern in the aquifer by drawing water into and pumping it through the well, and then reintroducing the water into the aquifer without bringing it above ground. Depending upon the configuration of the system, the technology is also known as in-well vapor stripping, in-well air stripping, *in situ* vapor stripping, *in situ* air stripping, and vacuum vapor extraction.

The well is double-cased with hydraulically separated upper and lower screened intervals within the aquifer. The application may be enhanced by the addition of ozone, activated carbon adsorption, or biological treatments. The radius of influence of the well can also be modified through the additions of chemicals to allow *in situ* stabilization of dissolved metals in ground water. In general, the selection of a configuration is dependent upon site conditions, contaminants, and the vendor.

The system can be configured with an upward in-well flow or a downward in-well flow. The most common configurations involve the injection of air into the inner casing, decreasing the density of the ground water and allowing it to rise. This constitutes a type of air-lift pumping system. Through this system, volatile contaminants in the ground water are transferred from the dissolved phase to the vapor phase by the rising air bubbles. Contaminated vapors can be drawn off and treated above ground or discharged into the vadose zone, through the upper screened interval, to be degraded via *in situ* bioremediation.

The ground water, which has been partially stripped of volatile contaminants, moves upward within the inner casing and is eventually discharged into the outer casing, moving through the upper screened interval into the vadose zone. Once returned to the subsurface, the ground water flows down reaching the lower portion of the aquifer where it is cycled back into the lower screened interval, replacing the water that rose due to the density gradient. This cycling of water in the area around the well creates a hydraulic circulation pattern that allows continuous cycling

of ground water *in situ* through the air stripping process. Ground water is repeatedly circulated through the system until sufficient contaminant removal has taken place.

Examples of the systems developed based on this technology are NoVOCs™, *Unterddruck-Verdampfer-Brunnen* (UVB™) or "vacuum vaporized well," Density Driven Convection (DDC), and C-Sparge™.

NoVOCs™ is similar to the generic system described above. It uses a compressor to deliver the air to the contaminated water column. The bubble-water mixture rises in the well until it encounters a deflection plate. At this point the air bubbles combine. The water flows out of the well through the upper screen and the coalesced bubbles are drawn off by vacuum for above ground treatments of VOCs.

The UVB™ system supplements air-lift pumping with a submersible pump to maintain flow at a standard rate. It also employs a stripper reactor to facilitate transfer of volatile compounds from aqueous to gas phase before the water is returned to the aquifer.

The DDC system emphasizes the enhancement of bioremediation and involves the discharge of extracted vapors into the vadose zone for degradation by naturally occurring microorganisms. Oxygen is supplied to both the saturated zone and the vadose zone to promote natural aerobic processes.

The C-Sparge™ system combines *in situ* air-stripping, where the dissolved chlorinated solvents are extracted from the aqueous solution into small bubbles, and the introduction of encapsulated ozone to oxidize the contaminants.

Department of Defense Sites

Edwards Air Force Base, CA

Installation Date:
1995

Contaminants:
TCE

Enhancement:
Not applicable

Soil Type:
Sand, gravel

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A field demonstration of in-well vapor stripping (NoVOCs™) for remediation of trichloroethene (TCE) in ground water was conducted at Edwards Air Force Base, California, from 1995-1996. This was the first demonstration of a system of this kind in the U.S. It was conducted as an interim cleanup action as part of the Comprehensive Environmental Response, Compensation, and Liability Act (Superfund) process.

Site Background

The primary use of Edwards AFB is for aircraft research, development, and testing programs. The ground water beneath the site is contaminated with dissolved volatile organics, primarily TCE. The site consists of unconsolidated sediments overlying granite bedrock. The sediments are alluvial and lacustrine deposits of sand with some gravel and smaller fractions of caliche, silt, and clay. Ground water occurs at 25 ft below ground surface (bgs). The vertical hydraulic conductivity of the aquifer is 1ft/d with a vertical gradient of 0.1. The horizontal conductivity is 10ft/d with a gradient of 0.005. Previous investigations identified the maximum concentration of TCE in the area to be 502 µg/L; the average concentration was 300 µg/L. Maximum concentrations upgradient of the demonstration site were as high as 3,400 µg/L.

Technology Application

Measurements specifically important to the in-well vapor stripping system, such as hydraulic conductivity and soil chemistry, were obtained prior to application. The monitoring network consisted of a treatment well with associated access tubes, five monitoring wells, three piezometers, three flow sensors, two characterization wells, and two older monitoring wells drilled during the remedial investigation. The treatment well was completed to 50 ft bgs with the lower screen from 40 to 50 ft, and the upper screen from 3 to 18 ft bgs. A treatment trailer equipped with an air compressor, blowers, generator, instrumentation to control the system, diesel fuel tank, and high-efficiency particulate-air filter was placed on site. Air was injected into the base of the well by the compressor. This created a bubble column that lifted the water and stripped the contaminants, which were vacuumed off and sucked through a carbon granular activated cannister. The compressor was eventually replaced with blowers. The demonstration was

operated nearly continuously for 191 days. Pumping rates of water pushed through the well via lifting (7-10 gpm) and air-injection rates (34-62 standard cubic feet per minute) were reconfigured during the process.

Results

Geological heterogeneity at the site resulted in an asymmetrical cleanup zone. The zone of influence defined by the TCE reduction had at least a 50-ft radius in the upper zone of the aquifer and at least a 10-ft radius and possibly greater that a 30-ft radius in the lower zone. The concentration in the upper zone decreased from highs of 34-160 μg/L to below the regulatory limit of 5 μg/L. In the lower zone of the aquifer (between 45-50 ft below ground), the concentrations in the well nearest the treatment well fell from 270 to 173 μg/L. A low permeability layer at about 44 ft below ground appeared to limit the recirculation of the water. The stripping ratio of the system averaged 90%; that is, 90% of the contaminant was removed per pass through the system.

This system was moved to an area of higher concentration at the site and has been operational since December 1997. The facility is in the process of adding another stripping well to the system.

The funding for this field demonstration was provided by the Air Force and the Department of Energy (DOE). The Air Force's total expenditures for installing the wells, assembling the equipment, and operations and maintenance, were approximately $600K. DOE provided additional personnel, equipment, a trailer, and software for a total of approximately $217K.

Site-specific References

Gilmore, T.J.; White, M.D.; and Spane, F.A. *Performance Assessment of the In-Well Vapor-Stripping System*, Pacific Northwest National Laboratory, Richland, Washington, October 1996

Gilmore, T.J.; Spane, F.A.; White, M.D.; Lewis, R.E.; and Gee, G.W. "The Effect of Geologic Heterogeneities on the Installation and Operation of the Pilot In-Well Vapor Stripping System at an Air Force Base in California," 28th Annual Meeting of the Geological Society of America, Denver, Colorado, October 28-31, 1996

White, M.D., and Gilmore, T.J. *Numerical Analysis of the In-Well Vapor-Stripping System Demonstration at Edwards Air Force Base*, Pacific Northwest National Laboratory, Richland, Washington, 1996

Keesler Air Force Base, MS

Installation Date:
1995

Contaminants:
TPH, BTEX

Enhancement:
Not applicable

Soil Type:
Silty sand, sand, clay

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A field demonstration of a Density Driven Convection (DDC) system coupled with soil vapor extraction (SVE) was conducted at Keesler Air Force Base (AFB) in Biloxi, Mississippi from 1995-1997. The primary contaminants of concern at the site included total petroleum hydrocarbons (TPH) and benzene, toluene, ethylbenzene, and xylene (BTEX) in ground water.

Site Background

Kessler AFB is located approximately 80 miles east of New Orleans, Louisiana. The upper 3-4 ft of soil is silty sand with fine- to medium-grained sand to 22 ft below ground surface (bgs) and clay beneath. The demonstration was conducted in a shallow, unconfined aquifer with ground water at approximately 7-8 ft bgs. The horizontal and vertical conductivities were measured at 32 and 9.5 ft/d, respectively. The source of contamination was gasoline and diesel fuel leaks from underground storage tanks (USTs) and dispensers. TPH concentrations up to 21,000 mg/kg in soil were detected at 7 ft bgs, and 9,900 mg/kg at 9 ft bgs. Concentrations tapered off below 9 ft. The ground-water plume extended approximately 400 ft down gradient of the site. The maximum concentrations of TPH and BTEX within the treatment area were 96 and 7.46 mg/L, respectively. The maximum TPH and BTEX ground-water concentrations detected downgradient, outside the treatment area were 32 and 14 mg/L, respectively.

Technology Application

This project began with a pilot application followed by a full-scale installation. The pilot system included one DDC well and one SVE well. The large-scale system consisted of 32 DDC wells and 6 SVE wells. The DDC wells had screened intervals from 4-14 ft and 16.5-21.5 ft bgs. The SVE wells were installed to 7 ft and screened 2-7 ft bgs. The SVE wells were installed to prevent vapor migration and to draw oxygen from the DDC wells into the vadose zone. The system is designed to strip volatile compounds from ground water flowing through the well. As the stripped hydrocarbons and oxygen are introduced via the upper screen into the surrounding soils they

are subject to removal by the SVE system. The oxygenated ground water and air flowing out of and away from the DDC well also enhance bioremediation in soils and ground water.

Results

The system operated for approximately 18 months. The estimated mass of TPH removed from the SVE effluent was approximately 3,449 lbs, primarily by direct volatilization. Average TPH concentrations in the monitoring wells decreased by 87% from 51.4 mg/L to 6.5 mg/L, while the average BTEX concentrations decreased by 91% from 4.8 mg/L to 0.42 mg/L. However, over the same period, concentrations in down-gradient wells outside the treatment area increased to levels more than double the original amount and finally levelled off to concentrations slightly higher than in samples collected before system startup. This could have been the result of incomplete ground water capture by the large-scale system following desorption of soil contaminants by the DDC well effluent.

TPH and BTEX soil concentrations dropped throughout the site during the demonstration, averaging a 98% decrease in the capillary fringe. Concentrations for both contaminant groups dropped anywhere from 35 to 87% at various depths below the water table.

Since new influent and effluent monitoring points were not installed between the pilot and large-scale system, various assumptions were required to estimate mass removal rates. Therefore, it is unclear as to what proportion of the total mass removed is attributable to the SVE rather than the DDC system, as well as how much of the contaminants actually migrated off-site.

The total cost of this field demonstration was approximately $360K, $100K of which was for the pilot study.

Site-specific References

Wasatch Environmental, Inc. *DDC In-Well Aeration Technology Demonstration, Keesler Air Force Base, AOC A (ST-06), BX Service Station, U.S.EPA I.D. #MS2 570 024 164, Biloxi Mississippi,* prepared for the Air Force Center for Environmental Excellence, Brooks Air Force Base, Texas, July 1998

March Air Force Base, Riverside, CA

Installation Date:
1993

Contaminants:
TCE

Enhancement:
Not applicable

Soil Type:
Fine-grained sand & silt

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A field demonstration of a UVB™ ground-water recirculating well for remediation of trichloroethene (TCE) was conducted at March Air Force Base, California between 1993-1994.

Site Background

The site is a solvent disposal site. The underlying formation is a fine-grained sand and silt sediment. The depth to ground water is approximately 40 ft below ground surface (bgs) and the thickness of the aquifer is approximately 80 ft. The hydraulic conductivity of the aquifer was 10^{-4} cm/s, and the gradient was 0.007. Initial sampling indicated TCE concentrations ranging from 3.4 to 1,000 µg/L with an average of 500 µg/L.

Technology Application

Prior to installing the UVB™ well, a pilot boring was installed to a depth of 118.5 ft bgs to characterize stratigraphy. The UVB™ treatment well was drilled to a depth of 87.5 ft. Three monitoring wells were installed within the UVB™ borehole, one screened across the influent section and two at 90° screened across the effluent section. The distance between the effluent and influent screens was 40 ft. Two clusters of monitoring wells were located 40 and 80 ft downgradient of the UVB™ well. The clusters consisted of discretely-screened shallow, intermediate, and deep wells. A vadose zone well was installed 60 ft from the UVB™ well. The blower was located adjacent to the well-head and connected to two vapor phase carbon canisters. The 18-month operational monitoring consisted of effluent air monitoring and sampling, ground-water sampling, and analysis.

Results

EPA' Superfund Innovative Technology Evaluation Program reports that, over the 18 months of operation, TCE concentrations averaged 250 µg/L, varying from 47 to 270 µg/L. Influent TCE concentrations in the lower screen varied between non-detectable and 320 µg/L throughout the study, averaging 30 µg/L. Occasional influent values that were greater than 30 µg/L indicated mechanical problems with the system. Effluent concentrations varied between non-detectable and 15 µg/L. The stripper unit indicated that TCE removal was greater than 90% for 95% of the samples, and 95% removal was achieved for 77% of the samples.

The capital cost for one UVB™ well was approximately $180K. First year operations and maintenance (O&M) costs

were approximately $75K, and second year O&M costs were approximately $42K. The cost for ground-water treatment was about $260 per 1,000 gallons of treated water. The UVB™ well was designed to treat about 1M gallons per year. Approximately 60-90% of the ground water treated was recirculated.

Site-specific References

Bannon, Jeffrey L.; Sontag, J.G.; Sabol, J.R.; and Dominick, M.T. *In-Situ Groundwater Remediation: Pilot Study of the UVB-Vacuum Vaporizer Well, March Air Force Base, California*, presented at the 88th Annual Meeting and Conference of the Air and Waste Management Association, San Antonio, Texas, June 18-23, 1995

EPA SITE Technology Capsule, "Unterdruck-Verdampfer-Brunnen Technology (UVB) Vacuum Vaporizing Well," EPA/540/R-95/500a, July 1995

Massachusetts Military Reservation, Cape Cod, MA

Installation Date:
1996

Contaminants:
TCE, other solvents

Enhancement:
Carbon

Soil Type:
Fine- to coarse-grained sand

Points of Contact:
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A field demonstration of two ground-water recirculating well configurations (NoVOCs™ and UVB™) was conducted at the CS-10 plume at Massachusetts Military Reservation (MMR), Cape Cod, Massachusetts, in 1996. The primary contaminant addressed in this demonstration was trichloroethene (TCE).

Site Background

MMR is located in the upper western portion of Cape Cod. The subsurface soils are primarily sand and silt. Lakes, ponds, and rivers formed during the last glacial retreat and active and abandoned cranberry bogs are the major surface water features of the area. The depth to ground water at the test site ranges from 15 to 45 feet below ground surface (bgs), depending on surface topography. The aquifer is approximately 230 ft thick. The estimated horizontal conductivity was 144 to 230 ft/d, and the hydraulic gradient was 0.002. The primary contaminant is TCE, which probably originates from maintenance of ground-to-air missiles and armored and wheeled vehicles. Pre-pilot test data indicated maximum TCE concentrations of 2,800 µg/L in ground water, with lower concentrations of other chlorinated solvents, hydrocarbons, and metals.

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Technology Application

The UVB™ system installed at CS-10 North consisted of two triple-screen treatment wells installed to a depth of 275 ft. Each well is designed to induce two vertically adjacent circulation cells intended to capture the full 120-ft thickness of the plume. At each well, reinjection screens are located in the upper and lower sections of the plume, and an extraction screen is located in the middle portion of the plume. Ground-water extraction and reinjection for the UVB™ system is accomplished using submersible pumps. Air stripping of volatile organic chemicals (VOCs) occurs under negative pressure using a patented stripper in a below-ground vault. Offgas is filtered with granular activated carbon (GAC) prior to release. Thirty-three monitoring wells located at upgradient, cross-gradient, downgradient, and near-field locations and three piezometers were used to monitor circulation cell development at the UVB™ test area.

The NoVOCs™ system installed at CS-10 South included two dual-screen/dual-casing wells that each induced a single circulation cell. The wells were installed to a depth of 245 ft. The extraction screens were located at the base of the plume and the reinjection screens were located in the upper portion of the 100-ft thick plume. The wells utilized air-lift to facilitate pumping. VOCs were stripped via in-well sparging using closed-loop positive-pressure regenerative blowers. VOC-laden air was circulated through GAC and then redirected to the wells. Thirty-two monitoring wells located at upgradient, cross-gradient, downgradient, and near-field locations and three piezometers were used to monitor circulation cell development at the NoVOCs™ test area. Ground-water monitoring was conducted on a monthly basis during the 5-month pilot test. Subsequently, quarterly monitoring of a smaller number of wells at each site has been performed. The project began with a third location (UVB™), which was closed after the 5-month pilot since concentrations were determined to be too low to evaluate the effectiveness of the technology.

Results

The systems were originally run as part of a 5-month pilot-scale evaluation. Results from the UVB™ system indicated effluent concentrations did not reach the target of 1 µg/L. TCE concentrations in ground water near the upper effluent screen remained relatively constant at approximately 100 µg/L. Middle zone or influent TCE concentrations dropped from approximately 600 to 180 µg/L. However, upgradient concentrations, outside the zone of influence of the wells, also

dropped from approximately 400 to 150 µg/L during the same period. Lower zone TCE concentrations corresponding to the lower effluent screen remained nearly constant throughout the period at 200 µg/L. Results from the NoVOCs™ system also indicated effluent concentrations did not reach the target of 1 µg/L. TCE in the reinjection zone was reduced from 2,700 µg/L to approximately 100 µg/L, while concentrations in the extraction zone remained stable at approximately 1,300 µg/L. TCE in the monitoring wells was reduced by 42-97%, whereas concentrations in the lower zone increased by 241%. Other solvents' concentrations were reduced below detection levels.

Subsequent to the pilot phase of operation, the Air Force Center for Environmental Excellence (AFCEE) has continued operation of both systems as an interim action for mass removal. Over an 18-month period, based on calculations from offgas samples, approximately 40 kg of VOCs have been removed by the 120-gpm UVB™ system, and 84 kg of VOCs have been removed by the 300 -gpm NoVOCs™ system. Effluent concentrations for the UVB™ system have generally been below the maximum contaminant level (MCL) of 5 µg/L for TCE. Effluent concentrations for the NoVOCs™ system have generally been in excess of the MCL since initiation of the pilot test. However, background levels for TCE are higher at the NoVOCs™ site (approximately 1,000 µg/L) than at the UVB™ site (about 550 µg/L). Average stripping efficiency was 95.5% for the UVB™ system and 91% for the NoVOCs™ system.

The cost of the CS-10 demonstration was approximately $3.6M. This included approximately $2.1M for drilling and construction, $616K for sampling and analysis, $442K for project management, $331K for design and pre-construction planning, and $96K for system evaluation reports. The total cost for the project, including the terminated third location, was approximately $5.3M.

Site-specific References

Parsons Engineering Science, Inc., *Evaluation of Groundwater Circulation Well Technology at the Massachusetts Military Reservation (MMR) on Cape Cod, Massachusetts*, prepared for the Air Force Center for Environmental Excellence, Brooks Air Force Base, Texas, June 1997

Conde, P. and Wasp, R.G. "*In Situ* Remediation of Plume Using Vertical Recirculation Technology," Battelle, First

International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, California, May 1998

Dwight, D. M.; Mantovani, P.F.; and English, J. "Pilot Recirculating Well System (NoVOCs™) for Remediation of a Deep TCE Plume," Battelle, First International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, California, May 1998

Lakhwala, F.; Desrosiers, R.; and Wasp, R.G. "A Unique Groundwater Circulation Well Technology: Case Study MMR CS-10 Plume," Battelle, First International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, California, May 1998

Ward, D.; Bostick, K.; and Carman, J. "Effects of Anisotropy and Low Conductivity on Recirculating-Well Performance," Battelle, First International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, California, May 1998

Port Hueneme Naval Exchange Site, CA

Installation Date:
1995

Contaminants:
BTEX

Enhancement:
Not applicable

Soil Type:
Silty sand, sand

A field demonstration of ground-water circulating wells (GCW) for remediation of benzene, toluene, ethylbenzene and xylene (BTEX) in ground water was conducted at Port Hueneme Naval Exchange site, California in 1995. These wells are variations of the UVB™ technology.

Site Background

The site is a former gasoline station which was contaminated with approximately 11,000 gallons of gasoline that leaked from two delivery lines. The shallow soils consist of three layers: fine-grained silty sand to 5.6 ft below ground surface (bgs), fine- to coarse-grained sand to 20.3 ft bgs, and sandy-to-silty clay between 20.3-26.2 ft bgs. The contamination is confined to the upper perched aquifer. The depth to ground water is between 3.3-12.1 ft bgs. The horizontal hydraulic conductivity was measured at 3.84×10^{-2} cm/s, and the vertical hydraulic conductivity at 3.84×10^{-3} cm/s. Pre-treatment concentrations of BTEX ranged from 4.66 mg/L at the well near the source to 118 mg/L at the deep monitoring wells. The concentrations were lower near the source because well placement was based upon incorrect characterizations provided in a previous project.

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Technology Application

The system consisted of four circulating wells. One (GCW-400) was installed near the source and three (GCW-200) were installed downgradient of the main spill to provide plume containment. The upper and lower screens of the GCW-400 extended from 7.9-15.7 ft bgs and 21.8-26.3 ft bgs, respectively. The well was equipped with a single blower and submersible pump. Four clusters of three monitoring wells were installed at various depths around the well. The three GCW-200 wells were installed with overlapping radii of influence to form a "biocurtain" to prevent off-site migration of contaminants. This biocurtain was possible since bioremediation was added secondarily to the site. The upper and lower screens of these wells were placed between 7.2-16.4 ft bgs and 23-28.5 ft bgs, respectively. A total of eight monitoring wells were placed around the "biocurtain." An intensive monitoring schedule was followed including eight quarterly sampling events.

Results

The demonstration began in January 1995 and lasted for 18 months. After six months of operation, data from the wells in the biocurtain indicate BTEX concentrations dropped from 77 mg/L to 2 μg/L. BTEX concentrations in the ground water from the deep wells were reduced from 118 mg/L to under 1 μg/L. Within 8 months of operation, BTEX in the shallow monitoring wells closest to the GCW-400 were reduced by 52% from 4.66 to 2.88 mg/L.

The cost of this field demonstration, including capital and operations and maintenance costs, was approximately $184K. This does not include the research and development costs of the project.

Site-specific References

Spargo, B.J. (ed.) *In Situ Bioremediation and Efficacy Monitoring*, Naval Research Laboratory, Washington, DC Report No. NRL/PU/6115-96-317, 1996

Tyndall Air Force Base, FL

Installation Date:
1994

A field demonstration of a modified coaxial ground-water circulating (mKGB) system coupled with a modified bio-venting well (MBW) system for remediation of hydrocarbons in both the saturated and unsaturated zones was performed in a

Contaminants:
TPH

Enhancement:
Bioventing

Soil Type:
Sand

Point of Contact:
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portion of a large plume at Tyndall Air Force Base, Florida, from 1994-95.

Site Background

The site, once a tank farm, was contaminated primarily with jet fuel as a result of leaking underground storage tanks. The soil is sandy with ground water at 5 ft below ground surface (bgs). Attempts were made to determine the water flow rate but results were highly variable.The maximum concentration of total petroleum hydrocarbons (TPH) in ground-water samples collected prior to the demonstration was approximately 16 mg/L.

Technology Application

The MBW system consisted of a simple air lift pump installed in a 4-in diameter bioventing well modified to extend into the ground water with one screened section from 11 to 15 ft bgs and the other from 2 to 6 ft bgs. The mKGB system was installed in an 8-in diameter well casing and screened the same as the MBW. The monitoring system included five piezometers with screens placed at the middle of the upper screen of each ground-water circulating well (GCW), one piezometer with the screen placed at the middle of the lower screen of each GCW, and eight tri-level ground-water monitoring points placed at varying distances from the wells with probes at 9, 12, and 15 ft bgs. The MBW system was operated for 3 months and the mKGB system for 9 months. Each system was operated at an airflow rate of 1 standard cubic foot per minute, the maximum rate that did not result in the excessive discharge of contaminant vapor from the ground surface. Hydrocarbon concentrations were measured in influent, effluent, and offgas samples.

Results

The demonstration lasted for 12 months, from July 1994 to July 1995. After one year of operation the concentration of TPH ranged from non-detectable to a high of approximately 15 mg/L.The conclusion from this demonstration was that these two technologies could be effectively coupled to treat hydrocarbon contamination. However, questions remain about the efficiency of this type of application.

The total cost for this small-scale demonstration was approximately $80K.

Site-specific References

Alleman, Bruce C. *Final Report on In-Well Air Stripping/Bioventing Study at Tyndall Air Force Base, Florida*, Report No. AL/EQ-TR-1995-0039, Battelle, Columbus Ohio, 1995

Portsmouth Gaseous Diffusion Plant, Piketon, OH

Installation Date:
1996

Contaminants:
TCE, TC^{99}

Enhancements:
Fe^0, Activated Carbon

Soil Type:
Sand, gravel

Point of Contact:
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A field-scale demonstration of horizontal recirculation wells coupled with treatment modules for remediation of trichloroethene (TCE) and technetium-99 (Tc^{99}) was conducted at the X-701B site of the Portsmouth Gaseous Diffusion Plant in Piketon, Ohio, in 1996. This demonstration followed an earlier pilot test of a horizontal well system at an uncontaminated site at Portsmouth.

Site Background

The site is contaminated with metal-bearing acidic wastewater and solvents, mostly originating from a chemical cleaning facility. The site has four distinct underlying strata. The field test was targeted at treating contamination in a relatively permeable sand and gravel layer, approximately 30 ft below ground surface (bgs). Testing revealed lateral heterogeneities in the area between the two wells. Pre-demonstration testing indicated concentrations of TCE up to 1,800 mg/L. Tc^{99} activities were measured up to 926 picocuries per liter (pCi/L).

Technology Application

Two horizontal wells 234 ft long were installed at a depth of 32 ft using directional drilling methods. The wells were placed along the bedrock surface in a 3- to 7-ft-thick zone of a moderately permeable, unconsolidated fluvial deposit. The horizontal sections of the wells were constructed with ductile, porous polyethylene. A network of 14 monitoring wells was used to assess the influence of the horizontal flow field both on the subsurface hydraulics and the ground-water contaminants. The first well extracted water to a treatment unit consisting of a carbon and an iron filter on the ground surface. The filtered water was then reinjected into the second well.

Field testing was performed for 74 days, during which more than 580,000 gal of water were recirculated. The water was pumped at a rate of 6 gpm, and hydraulic and tracer tests were performed. Hydraulic tests of well performance showed that a hydraulic gradient of 0.13, twice the magnitude in non-pumping conditions, could be induced between the wells. Treatment of the mixed contaminant stream was conducted with zero-valence iron (Fe^0) for removal of Tc^{99} and with activated carbon for removal of TCE and other hydrocarbons.

Results

The treatment concept, to treat an aqueous mixed waste without producing another mixed waste, was successfully demonstrated. All of the Tc^{99} in the more than 580,000 gal of water was removed by approximately 12 in of coarse iron particles. Because Fe^0 also slowly reduces TCE, the remaining solid waste was not mixed waste by project's end. After storage for a few days, the residual TCE was degraded leaving only the Tc^{99} on the Fe^0. During operation, TCE was removed by the carbon following passage through the Fe^0. Because the water no longer contained Tc^{99} after flowing through the Fe^0, the waste carbon could be handled as a hazardous waste with no concern for radioactivity.

The approximately $1.43M in design and construction funds for this field demonstration were provided by two offices in the Department of Energy. Other costs are more difficult to estimate since this project was part of a larger effort. Cost estimate details are provided in the reports cited below.

Site-specific References

Korte, N.; Muck, M.; Kearl, P.; Siegrist, R.; Houk, T.; Schlosser, R.; and Zutman, J. *Field Evaluation of a Horizontal Well Recirculation System for Groundwater: Field Demonstration at X-701B Portsmouth Gaseous Diffusion Plant*, ORNL/TM-13529, Oak Ridge National Laboratory, Grand Junction, Colorado, June 1997

Korte, N.E.; Liang, L.; Gu, B.; Muck, M.T.; Zutman, J.L.; Schlosser, R.M.; Siegrist, R.L.; Houk, T.C.; and Fernando, Q. *In Situ Treatment of Mixed Contaminants in Groundwater: Application of Zero-Valence Iron and Palladized Iron for Treatment of Groundwater Contaminated with Trichloroethene and Technetium-99*, ORNL/TM-13530, Oak Ridge National Laboratory, Grand Junction, Colorado, April 1997

Muck, M.T.; Kearl, P.M.; Siegrist, R.L.; Korte, N.E.; Schlosser, R.M.; Mumby, M.E.; Davenport, D.T.; Greene, D.W.; Pickering, D.A.; and Muhr, C.A. *Field Evaluation of a Horizontal Well Recirculation System for Groundwater Treatment: Pilot Test at the Clean Site, Portsmouth Gaseous Diffusion Plant*, ORNL/TM-13531, Oak Ridge National Laboratory, March 1997

Westinghouse Savannah River Site, Aiken, SC

Installation Date:
1996

Contaminants:
TCE, PCE

Enhancement:
Under consideration

Soil Type:
Sand

Point of Contact:
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A field demonstration of airlift recirculation wells (ARW) for remediation of trichloroethene (TCE) and tetrachloroethene (PCE) in ground water was installed at the Savannah River Site, in Aiken, South Carolina, in 1996.

Site Background

The site once held metal finishing operations, which used chlorinated solvents for cleaning and degreasing activities. Discharges created a contaminant plume. Depth to ground water is approximately 100 ft below ground surface (bgs). Pump-and-treat technology was initiated in 1983 to contain and remediate the central portion of the plume nearest the source of contamination. Outlying portions of the plume continue to migrate with the natural flow of the ground water. The southern edge of the plume is in a confined aquifer approximately 54-ft thick and consisting of fine- to medium-grained sand. The horizontal and vertical conductivities are 25.8 ft/d and 1.43 ft/d, respectively. Initial pre-treatment sampling at one well indicated TCE concentrations in excess of 10 mg/L. Since the plume exists in a stratified configuration, concentrations throughout the plume are uneven.

Technology Application

Two 8-in diameter recirculation wells were installed to a depth of approximately 175 ft. Each well has a 10-ft inlet screen at the bottom of the aquifer and a 10-ft discharge screen at the top of the aquifer. An airlift pump was installed in each well with an inflatable packer to isolate the wells' upper and lower screen zones. A duplex, oil-free air compressor package provides air for the pumps. A piezometer cluster was installed upgradient and downgradient of each well. Five additional clusters have subsequently been installed at the well that continues to operate.

Results

Initial data obtained from each of the wells after the first few months of operation indicated equipment and utility problems. Review of hydrologic data indicated that the upper screens were probably plugged after only a few weeks of operation. As a result, a decision was made to focus on only one of the wells. After carefully redeveloping that well, performance appears to be very good. Recent sampling data indicate that over the past 14 months, TCE concentrations have been reduced by approximately 30-80% within the roughly 300-ft zone of influence.

Exhaust stream measurements have confirmed that TCE is being stripped from the ground water at a rate of 1 to 2 lbs/day. Ten additional wells are currently being installed between the two existing wells with startup planned for December 1998. Supplemental technologies aimed at enhancing the stripping efficiency of the wells are under study.

The cost of the recirculation wells has been about $100K per well, including the design of the installation and the need to extend electrical power to the area.

Site-specific References

White, R.M. and Hiergesell, R.A. *Airlift Recirculation Well Test Results - Southern Sector (U)*, Westinghouse Savannah River Company, Aiken, South Carolina, 1997

EPA Superfund Sites

Cabot/Kopper's Superfund Site, Gainesville, FL

Installation Date:
1995

Contaminants:
PAHs

Enhancement:
Microorganisms, bioreactor

Soil Type:
Sand

Points of Contact:
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A vacuum vaporizer well (UVB™-400) and an *in situ* bioreactor for the remediation of polycyclic aromatic hydrocarbons (PAHs) in soil and ground water were installed at Cabot/Kopper's Superfund Site in Gainesville, Florida, in 1995.

Site Background

This Superfund site held both a pine tar and charcoal generation facility and a wood treatment facility. The source of the contamination was the creosote used in the wood treating operation. The plume is 110 ft wide x 500 ft long. The soil is 93% sand with some silt and clay. Remedial investigation results indicated that ground water in the shallow aquifer (10 to 23 ft below ground) had been impacted. Horizontal and vertical conductivities were 9×10^{-3} cm/s and 9×10^{-4} cm/s, respectively. The horizontal gradient was 0.00625. Initial total concentrations of PAHs in the soil exceeded 700 mg/kg. Average total concentrations of PAHs in ground water for all wells tested ranged from 5-50 mg/L.

Technology Application

A single UVB™ well and *in situ* bioreactor were installed at a depth of 25 ft, downgradient from a lagoon area that had been identified as a potential source of creosote constituents. Twelve new monitoring wells were installed to supplement three existing wells. A schedule of weekly monitoring, and quarterly sample analysis of soil, ground water, and gas were established over a two-year period.

Results

The system was started in February 1995 and continues to operate into 1998, having been taken over by the client. Samples taken after 18 months of operation indicated total PAH concentrations of 10-35 mg/L in upgradient wells. Concentrations in downgradient wells were measured at 0.04-2 mg/L. In 1997 phosphate and nitrogen were added directly into the UVB™ to stimulate microbial activity within the zone of influence. Particular nitrogen and phosphate species were determined to be limiting in this biological system. Results of this supplemental study have not been conclusive.

The cost of this remediation was approximately $255K. This included approximately $8K for mobilization, $85K for monitoring, sampling, testing and analysis, $3K for site work, $129K for equipment related costs, $4K for demobilization, and $26K for administration. According to vendor estimates, a similar system would run approximately $50K less in 1998.

Site-specific References

Spargo, B.J. (ed.) *In Situ Bioremediation and Efficacy Monitoring*, Naval Research Laboratory, Washington, DC Report No. NRL/PU/6115-96-317, 1996

Mueller, J.; Lakhwala, F.; Carter, J.; Spargo, B.; and Brourman, M. *Economics and Performance of UVB Technology at a Creosote Site*, Battelle, First International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, California, May 1998

Sweden-3 Chapman Superfund Site, Sweden, NY

Installation Date:
1994

Contaminants:
Acetone, DCE, TCE, PCE, MEK, and MIBK

Enhancement:
Bioreactor

Soil Type:
Silt/clay, sand, gravel

Points of Contact:
James Harrington, P.E.
New York State Dept. of Environmental Conservation
Room 268

A pilot-scale field demonstration of a microbiologically enhanced vacuum vaporizer well (UVB™-400 system) for the remediation of chlorinated and nonchlorinated hydrocarbons in soil was conducted at the Sweden-3 Chapman Superfund Site in Sweden, New York, from July 1994 to October 1995. An *in situ* bioventing system and *ex situ* biovault treatment process were also tested.

Site Background

The site is an inactive landfill that was used to dispose of construction and demolition debris and hazardous waste. The soil composition is heterogeneous with 19% gravel, 24% sand, and 57% silt/clay. The seasonal water table fluctuates between 8 and 10 ft below ground surface (bgs). The average horizontal hydraulic conductivity ranged from 3.3×10^{-6} to 2.3×10^{-7} ft/s, and the average gradient was 0.054. Preliminary site investigations indicated that the soil and ground water were contaminated with a host of compounds. This demonstration examined trichloroethene (TCE), dichlorethene (DCE), tetrachloroethene (PCE), acetone, methylethyl ketone (MEK), and 4-methyl 2-pentanone (MIBK). Pre-treatment data available from EPA and the state, indicate that average initial concentrations in soil were 6,967 µg/kg acetone, 14,554 µg/kg MEK, 2,471 µg/kg MIBK, 653 µg/kg PCE, 2,245 TCE, and 2,322 µg/kg total DCE.

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Technology Application

The system was installed in a 50 x 50 ft test plot. It consisted of a 1.4 ft inner-diameter steel treatment well set at a depth of 25.9 ft bgs. A fixed packer was installed at a depth of 22 ft to isolate the upper from the lower screen. Water was pumped from the lower screen and discharged to an *in situ* bioreactor. An aerator/stripper with an above-ground ambient air intake pipe was attached to the outlet of the bioreactor to volatilize contaminants. Offgases were extracted by a blower at the top of the well and treated using gas phase bioreactors inoculated with bacterium followed by granular activated carbon drums. Six shallow and seven deep monitoring wells were installed around the UVB™ well, and two wells were installed within the annulus of the UVB™ well. Shallow wells were installed to a depth of 12 ft and deep wells to 22 ft bgs. Ten ground-water sampling events, from all 15 monitoring wells, were conducted. Five soil sampling events, with 25 soil borings performed per event, were also conducted.

Results

Both decreases and increases in concentrations of target VOCs were observed in ground water. The UVB™ system generally was effective in treating ground-water contamination based on the VOC reductions observed. Ground-water VOC removals generally decreased with distance from the well and were higher in the shallow wells than in the deep wells. However, actual ground-water data are not available in the EPA or state reports since evaluation of ground-water treatment was beyond the scope of this demonstration which was intended to evaluate bioremediation treatments of vadose zone soils contaminated with volatile organic compounds. With regard to soil, this demonstration did not meet its goal which required that 90% of the samples collected be in compliance with the state's published acceptable concentrations. Only 70% of the soil samples met the criteria at the end of the demonstration. At the outset of the demonstration, the calculated compliance rate was 67%.

The cost of the initial 5-month demonstration was approximately $153K. Of this, $15K was allocated for mobilization, $61K for operational costs of the first half the treatment, $31K for the second half of treatment, $15K for decontamination and demobilization, and $31K for the final report. Approximately $82K was added to the project to extend it for an additional 7 months. This does not include sampling and analysis provided by EPA's Superfund Innovative Technology Evaluation (SITE) program.

Site-specific References

Kufel, Todd and Weber, A.S. "Analysis of the New York State Demonstration of Bioremediation Technology at the Sweden-3 Chapman Site," New York State Center for Hazardous Waste Management, State University of New York at Buffalo, August 1996

Lakhwala, Fayaz S.; Mueller, J.G.; and Desrosiers, R.J. "Demonstration of a Microbiologically Enhanced Vertical Ground Water Circulation Well Technology at a Superfund Site," *Ground Water Monitoring Review*, p 97-106, Spring 1998

Weber, A. Scott, "Multi-Vendor Bioremediation Technology Demonstration Project," 4th International Conference for Site Investigation for Hazardous Sites, London, England, October 3-4, 1995

Private Commercial Sites

Amcor Precast, Ogden, UT

Installation Date:
1992

Contaminants:
TPH, benzene, toluene, ethylbenzene, xylene, naphthalene

Enhancement:
Not applicable

Soil Type:
Silty sands, gravel, clay

Point of Contact:
Shelley Quick
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A Density Driven Convection (DDC) system for the remediation of fuel hydrocarbons was installed at Amcor Precast in Ogden Utah, in 1992. It was part of system that also contained a ground-water pumping and reinjection system and a soil vapor extraction system.

Site Background

Amcor Precast operated three underground storage tanks used for gasoline and diesel fuel. Release of contaminants was discovered when the tanks were removed for permanent closure. At that time, the spill had impacted an estimated 6,700 yd^3 of soil. The stratigraphy consisted of silty sands, fine gravel, and a silty clay aquitard at about 18 ft below ground. Hydraulic conductivity was measured at 190 ft/d. Contaminants were concentrated within a zone from about 5 to 11 ft below ground. Maximum pre-remediation concentrations of total petroleum hydrocarbons (TPH) were measured at 1,600 mg/kg in the soil and 190 mg/L in the ground water. Average concentrations in the plume were 555 mg/kg in the soil and 51 mg/L in the ground water. Total concentrations of benzene, toluene, ethylbenzene, xylene, and naphthalene were measured at maximums of 139 mg/kg in soil and 25 mg/L in ground water, with averages in the plume of 46 mg/kg and 7 mg/L, respectively.

Technology Application

The system consisted of three principal components—a DDC system, a ground-water pumping and reinjection system, and a soil vapor extraction system. The DDC system consisted of 12 wells installed to a depth of 18 ft each connected via underground lines to a pressurized air supply source and each having a separate air injection line. During operation, air injection rates were maintained at between 60-100 standard cubic feet per minute (scfm). The ground-water pumping and reinjection system consisted of three downgradient extraction wells installed to a depth of 20 ft and one upgradient injection gallery. Pressurized air supply lines for extraction and water lines for conducting pump discharge to the gallery were placed below ground. The total extraction rate for all three wells was maintained at 10 gpm. The soil vapor extraction system consisted of three vertical vapor extraction wells located adjacent to the downgradient ground-water extraction wells. They were connected via underground lines to a vacuum

blower motor. Total soil vapor extraction rates were maintained at 70-90 scfm. Soil concentrations were measured 11 months after startup. System operation and ground-water monitoring was continued for an additional 7 months.

Results

The system ran from March 1992 to September 1993. Final concentrations of TPH in the soil from the plume area averaged 1.6 mg/kg, with a maximum of 6.3 mg/kg. Final concentrations of TPH in ground water averaged 0.71 mg/L, with a maximum of 1.3 mg/L. Similar reductions were achieved for benzene, toluene, ethylbenzene, xylene, and naphthalene.

The cost of this remediation was approximately $157K for capital costs and project management and $63K annually for operations and maintenance.

Site-specific References

Wasatch Environmental, Inc. *Density-Driven Groundwater Sparging at Amcor Precast, Ogden, Utah*, final report prepared for the U.S. Army Corps of Engineers, Omaha District, July 1994

Former Service Station, Commerce City, CO

Installation Date:
1997

Contaminants:
TPH, BTEX

Enhancement:
Ozone

Soil Type:
Sand-gravel mix

A full-scale application using a system of air and ozone injection with vertical circulation of ground water (C-Sparge™) in combination with a vacuum extraction system was administered at a former service station site in Commerce City, Colorado, in 1997. It was designed to remediate soil and ground water contaminated with petroleum hydrocarbons and benzene, toluene, ethylbenzene, and xylene (BTEX) The addition of ozone to the circulation well serves to oxidize the contaminants in the subsurface.

Site Background

The site, which once served as a bulk storage and service station facility, currently is part of a metal recycling facility. Subsurface material consists of sand and gravel mixtures to a depth of approximately 43 ft below ground surface (bgs), grading to a blue clay. Ground water is approximately 28 ft bgs. Because of the composition of the soil hydraulic conductivity tests were deemed unnecessary. A soil and ground-water investigation indicated that total petroleum hydrocarbons (TPH) in the soil ranged from 90-2,380 mg/kg. Total BTEX in soil ranged from 7,800-36,550 µg/kg. TPH in

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the ground water ranged from free product to 490 mg/L and BTEX ranged from 22-2,260 µg/L. Concentrations of benzene, the contaminant by which the cleanup standard of 5 µg/L is measured, ranged from non-detectable to 16 µg/L.

Technology Application

Two C-Sparge™ panels, each operating three wells, were installed. Each well consisted an in-ground sparge point, which blows ozone and air into the ground water, an in-well sparge point which blows water in the well casing, a pump to generate circulation, and a packer. Each well boring was advanced to a depth of 50 ft bgs. The well was sealed from a depth of 10 ft to the ground surface. The panels were installed in an outside area, open to the weather. Sparge point pressures ranged from 14-20 pounds per square inch (psi) depending on the distance from the well to the panel. The system was augmented with a large blower pulling 160 ft ^{3}/min (cfm) at 48-in vacuum water column. The entire system ran through 12 complete cycles per day. Each cycle involved all six wells blowing ozone and air into the ground water, blowing the water into the casing, and pumping. Each cycle lasted approximately 25 minutes. The blower unit operating constantly.

Results

The system started in August 1997 with quarterly monitoring. The March 1998 results showed a concentration of 37 mg/L TPH in the well that previously contained free product. No TPH or BTEX was detected in any other of the monitoring wells, so the remediation system was turned off. Monitoring results in June and September 1998 indicated that levels remain below the state maximum contaminant levels for drinking water (MCLs). The state did not require confirmatory soil borings. Quarterly sampling is required for a year following the sytem's shutdown in March 1998.

The anticipated cost of the demonstration from site investigation through completion of final monitoring is approximately $160K. Of this, approximately $20K was allocated for site investigation, $55K for equipment, $35K for installation, and $15K for sparge wells.

Site-specific References

Not available

Top Stop Store, Park City, UT

Installation Date:
1995

Contaminants:
TPH, benzene, toluene, ethylbenzene, xylene, and naphthalene

Enhancement:
Not applicable

Soil Type:
Silty clay, gravel

Points of Contact:
Bruce Hagans / Dale Urban
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A Density Driven Convection (DDC) system for the remediation of fuel hydrocarbons was installed at the Top Stop Service Station in Park City, Utah, in 1995.

Site Background

Soil and ground water at the site were contaminated by a release of gasoline from an old underground storage tank fueling system. The contamination impacted the shallow unconfined aquifer, which is used as a back-up water supply to the city and discharges to a wetland and stream. Soils at the site consist of silty clay, gravel, and cobbles. Depth to the water table varies seasonally from 15 to 20 ft. Pre-treatment concentrations of total petroleum hydrocarbons (TPH) averaged approximately 30 mg/L, and total concentrations of benzene, toluene, ethylbenzene, xylene, and napthalene averaged 2 mg/L.

Technology Application

An 18-well DDC system was installed along with five soil vapor extraction (SVE) wells to treat vadose zone contamination. The wells were screened at 10-20 ft below ground surface (bgs) and at 25-30 ft bgs. They were spaced 30-35 ft apart. Five monitoring wells, interspersed around the site, were sampled to evaluate contaminant concentrations within and downgradient of the plume. Samples were taken quarterly.

Results

The average dissolved contaminant concentrations within the plume have been reduced more than 99% in just over 2 years of operation. Early 1998 samples indicate no detectable concentrations of either TPH or benzene, toluene, ethylbenzene, xylene, and napthalene. Furthermore, no contamination was detected in downgradient wells after the system became operational.

The cost of this remediation was approximately $99K for equipment installation (including the thermal catalytic oxidizer, only used in the first year to treat the vapors), $34K for first-year operations and maintenance (O&M), and $12K for second-year O&M.

Site-specific References

DeHart, T.; Pennington, L; and Urban, D. "Operation of In-Well Aeration and Soil Vapor Extraction Remediation Systems," U.S. EPA Region VIII Corrective Actions Conference, Salt Lake City, Utah, August 1997

Dry Cleaning Facilities, Hutchinson, KS

Installation Date:
1997

Contaminants:
PCE

Enhancement:
Ozone

Soil Type:
Sand, silt, clay

Points of Contact:

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A pilot test using two different in-well stripping processes for remediation of tetrachloroethene (PCE) in ground water was conducted in Hutchinson, Kansas, in 1997. This pilot was part of a test involving three similar locations within the city to evaluate three different technologies: air sparging with soil vapor extraction (AAS/SVE), ozone and air injection with vertical circulation of ground water (C-Sparge™), and in-well stripping (NoVOCs™)

Site Background

All three test sites were located near former or existing dry-cleaning facilities within the city limits. Underlying sediments consist of unconsolidated stream and terrace deposits (sand, silt, and clay). The water table is from 14-16 ft below ground surface (bgs). The hydraulic conductivity value calculated at one location was estimated at 500-770 ft/d with a general hydraulic gradient of 0.001. Dissolved-phase PCE appeared limited to the top 15 ft of the aquifer with maximum concentrations ranging from 30-600 µg/L.

Technology Application

Each test configuration consisted of an above-ground remediation system in a temporary enclosure or trailer, a single or combination remediation well configuration, above- and below-grade piping, and ground-water monitoring wells. The placement of monitoring wells varied for each site to accommodate the technology-specific data collection requirements.

The NoVOCs™ system included an 8-in diameter PVC remediation well installed to a depth of 38 ft with one stainless steel screen bracketing the water table and one fully in the saturated zone. The system was also equipped with an air diffuser and an infiltration gallery. Four monitoring wells were constructed to a total depth of 35 ft bgs at distances of 30-80 ft from the remediation well. Air was injected into the remediation well at a rate of approximately 70-95 standard

cubic feet per minute (scfm) and the flow rate through the well was approximately 40 gpm.

The C-Sparge™ system involved a 4-in diameter PVC remediation well installed to 35 ft bgs with a micro-porous sparge point placed in the lower part of the borehole. The well was screened in the vadose and saturated zones. A self-contained down-hole unit, including a second sparge point and fluid pump, was installed in the casing. Ground-water information was collected from a cluster of five monitoring wells. The average rate of injection was 3 scfm. This technology is enhanced by the addition of ozone (O_3) to oxidize the contaminants. It further differs from NoVOCs™ treatment in that the reaction takes place in the formation instead of in the well, thereby treating PCE in both the saturated soil and ground water as opposed to only treating the ground water.

Results

Pilot test activities for all sites were conducted over a 5-month period and included monitoring well and system installation, pre-test ground-water sampling, a 6-day system start-up period, on-going data collection and operation and maintenance, and post-test ground-water sampling.

Monitoring wells 30 ft from the remediation well using NoVOCs™ indicate an 87% reduction in concentration of PCE, from 39-5 µg/L. C-Sparge™ resulted in a 91% reduction from 34 to 3 μg/L, and AAS/SVE resulted in a 66% reduction from 489 to 168 μg/L.

This field demonstration cost approximately $195K, of which $95K was for the NoVOCs™ test and $52K was for the C-Sparge™ test. A cost comparison indicated that the AAS/SVE system was the least expensive to install and the C-Sparge™ most economical to operate. The NoVOCs™ was the most expensive to install and operate.

Site-specific References

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Wood Treatment Site, Denver, CO

Installation Date:
1996

Contaminants:
PCP

Enhancement:
Not applicable

Soil Type:
Silty sand, clay, gravel

Point of Contact:
Andrew Kopania
EMKO Environmental
2329 Shortlidge Ct.
El Dorado Hills, CA 95762
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A pilot study of Density Driven Convection (DDC) for the remediation of pentachlorophenol (PCP) was conducted at a wood treatment site in Denver, Colorado, in 1996.

Site Background
The contamination at this site impacts ground water across two distinct aquifer units with substantially different hydraulic conductivities. Conductivity in the upper zone was measured at $5x10^{-3}$ cm/s and at $5x10^{-5}$ cm/s in the lower zone. The upper unit is approximately 15 ft of interbedded silty sand, silty clay, and gravel, and the lower unit is an approximately 10-ft thick claystone layer. The water table is about 13 ft below ground. Pre-treatment sampling indicated PCP concentrations of 1,600 µg/L.

Technology Application
The pilot was conducted in an off-site portion of the plume. Two ground-water circulation wells (GCW) were installed to depths of approximately 25 ft. Each well had two piezometers within the borings. In addition, two piezometer pairs were placed 5-15 ft away from each of the GCWs in both the shallow and deep aquifer units. The wells pumped non-stop for the duration of the test. A dye tracer test was performed over the period of the demonstration to determine the radius of influence.

Results
The pilot ran from December 1996 through March 1997. After 84 days of operation, PCP concentrations were reduced by 43% to approximately 900 µg/L. The dye tracer was detected at least 15 ft from the wells after 7 days of operation. The tracer was found in all monitoring points in both aquifer units.

A containment wall currently is being installed to contain free product. In addition, a DDC system is being investigated to remediate the dissolved phase plume.

The cost of this pilot was approximately $80K.

Site-specific References
Not applicable

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