INNOVATIVE GROUND WATER AND SOIL REMEDIATION: IN SITU AIR STRIPPING USING HORIZONTAL WELLS

Dawn S. Kaback, Brian B. Looney,
Carol A. Eddy, and Terry C. Hazen

Westinghouse Savannah River Company
Savannah River Site
Aiken South Carolina 29808

ABSTRACT

An innovative environmental restoration technology, in situ air stripping, has been demonstrated at the U. S. Department of Energy's (DOE) Savannah River Site (SRS) in South Carolina. This process, using horizontal wells, is designed to concurrently remediate unsaturated-zone soils and ground water containing volatile organic compounds (VOCs). In situ technologies have the potential to substantially reduce costs and time required for remediation as well as improve effectiveness of remediation. Horizontal wells were selected to deliver and extract fluids from the subsurface because their geometry can maximize the efficiency of a remediation system and they have great potential for remediating contaminant sources under existing facilities.

The in situ air stripping concept utilizes two parallel horizontal wells: one below the water table and one in the unsaturated zone. The deeper well is used as a delivery system for the air injection. VOCs are stripped from the ground water into the injected vapor phase and are removed from the subsurface by drawing a vacuum on the shallower well in the vadose zone.

The first demonstration of this new technology was conducted for a period of twenty weeks. A vacuum was first drawn on the vadose zone well until a steady-state removal of VOCs was obtained. Air was then injected at three different rates and at two different temperatures. An extensive characterization program was conducted at the site and an extensive monitoring network was installed prior to initiation of the test. Significant quantities of VOCs have been removed from the subsurface (equivalent to an eleven-well 500 gpm pump-and-treat system at the same site). Concentrations of VOCs in the ground water have been significantly reduced in a number of the monitoring wells. In addition, the activity of indigenous microorganisms was increased as much as two orders of magnitude during the air injection.

OBJECTIVE

The objective of this project was to demonstrate a new in situ remediation technology that utilized horizontal wells as delivery and extraction systems. In situ air stripping, involving both air injection below the water table and vapor extraction above the water table, was to be demonstrated as a new technology for concurrently remediating both ground water and soils contaminated with volatile organic compounds. New characterization and monitoring technologies were to be demonstrated as part of DOE's first integrated demonstration project, which involves scientists from many DOE laboratories, other government agencies, universities, and the industrial sector.

BACKGROUND

The Savannah River Site is a 300-square mile facility owned by the U.S. Department of Energy near Aiken South Carolina (Figure 1). The environmental restoration research program at SRS involves investigation of new technologies for in situ remediation of ground water and soils. Technologies such as vapor extraction, vitrification, deep soil mixing, air stripping, and biotechnology, are currently being developed to remediate contaminated soils and ground water in place. Traditional methods involve pumping and above-ground treatment of ground water and excavation and removal or treatment of soils. In situ methods offer the potential to substantially reduce costs, as wells as to improve the effectiveness and efficiency of remediations.

Subsurface contamination with VOCs is a common problem across the United States. These solvent materials have been used as metal degreasers at numerous industrial facilities for a number of years. Contamination of ground water with these solvents has created large plumes that migrate both vertically and laterally fairly rapidly. The most common treatment technology for these ground waters is pumping to the surface and treatment with an air stripper. According to Henry's Law, these compounds will partition into the vapor phase from the aqueous phase. The in situ air stripping process contacts the two phases in the ground rather than in an above-ground unit.

At SRS trichlorethylene (TCE) and tetrachloroethylene (PCE) were used as metal degreasing solvents for a number of years. A ground water plume containing elevated levels of these compounds exists over an area greater than one square mile. A traditional ground water extraction and treatment system has been in operation since 1984 and has removed approximately 230,000 pounds of solvents from the ground water. However, additional solvents have continued to leach into the ground water from the vadose zone.

The demonstration site was selected along an abandoned process sewer line that carried wastes to a seepage basin operated between 1958 and 1985. The sewer line acted as a source of VOCs as it is known to have leaked at numerous locations along its length. Because the source of contamination was linear at this particular location within the overall plume, horizontal wells were selected as the injection/extraction system.

GENERAL SITE GEOLOGY AND HYDROLOGY

The SRS is located on the upper Atlantic Coastal Plain. The site is underlain by a thick wedge (approximately 1000 feet thick) of unconsolidated Tertiary and Cretaceous sediments that overlay the basement, which consists of preCambrian and Paleozoic metamorphic rocks and consolidated Triassic sediments (siltstones and sandstones). The Cretaceous and younger sedimentary section consists predominantly of sands, clayey sands, and sandy clays.

Groundwater flow at the site is controlled by hydrologic boundaries: flow at and immediately below the water table is to local tributaries, whereas flow in the lower Tertiary aquifer is to the Savannah River or one of its major tributaries and flow in the Cretaceous aquifers is towards the Savannah River. Flow in the shallow aquifers in the immediate vicinity of the test site is highly influenced by the eleven-well recovery network (pump-and-treat).

TEST SITE DESCRIPTION

The test site is located within the large VOC plume in the M-Area of the SRS. Two horizontal wells were successfully installed, borrowing technology from the petroleum industry (Kaback and others, 1989), along the process sewer line which carried wastes from the M-Area facilities to the M-Area Settling Basin (Figure 2). One horizontal well was installed below the water table at a depth of 150 to 175 feet along 300 feet of horizontal. This well was designed to be the air injection system (Figure 3). The second horizontal well was installed in the vadose zone in a permeable sand at approximately 75 feet for a length of 200 feet. This well was designed to be used for vapor extraction (Figure 3).

The water table is located at a depth of approximately 135 feet. Groundwater in the vicinity of the process sewer line contains elevated concentrations of TCE and PCE to depths greater than 180 feet, within the local Tertiary aquifer. A detailed geologic and hydrologic model of the test location has been developed using the voluminous site characterization and monitoring data collected as part of this project.

SITE CHARACTERIZATION AND MONITORING

Extensive characterization data were collected to increase our understanding of the site geology, hydrology, character of the contaminant plume, and distribution of indigenous microbial population. Characterization and monitoring points were concentrated along the length of the injection well (Figure 4). Fifteen boreholes were continuously cored. Ten were cored to 190 feet depth and geophysically logged. Five were cored to approximately 130 feet. Geologic cross sections showing the continuity of lithologic units have been prepared.

Samples for chemical and microbiological analyses were collected from the core at five to ten foot intervals or at depths where the lithology changed. Volatile organic compounds in the sediments are generally concentrated within the clay-rich intervals, at depths of approximately 35 to 40 and 85 to 110 feet.

Vertical depth sampling of groundwater was also performed in a number of boreholes. Problems with advancing the sampling tool at depths greater than 140 feet prevented collection of a complete sample grid. However, these samples did provide insight into the vertical distribution of contaminants in the plume. Generally, the highest concentrations of TCE and PCE in the groundwater were found at depths greater than 180 feet, below the zone of injection.

The predominant direction of groundwater flow in the upper part of the Tertiary section, immediately below the water table, is downward. A potentiometric map for the lower Tertiary aquifer demonstrated that the groundwater flow gradient is very flat. Flow is toward the west and is likely influenced by the M-Area groundwater recovery well system.

Monitoring wells were installed as clusters (10), one screened at the water table and one in the upper sand in the local Tertiary aquifer where the injection well is located for approximately the first 150 linear feet. The horizontal well then drops to the lower sand in the local Tertiary aquifer at a depth of approximately 175 feet. No monitoring wells were screened at this depth. Ground water samples were collected from the monitoring wells weekly for VOC analyses and biweekly for microbial analyses during the in situ air stripping test. Ground water monitoring on a biweekly basis has continued after the conclusion of the test.

Clusters of vadose-zone piezometers were installed to monitor the effects of the vacuum in different lithologies within the vadose zone. Scientists from DOE national labs tested new geophysical technologies to monitor the effects of the air injection.

IN SITU AIR STRIPPING TEST DESIGN

The in situ air stripping concept involved installation of two parallel horizontal wells to maximize the efficiency of the process. Horizontal wells were selected because they provide more surface area for injection of reactants and extraction of contaminants. Injection into and extraction of fluids from the subsurface have been used to enhance recovery of petroleum hydrocarbons from oil fields for a number of years. Because many water-bearing formations are deposited as relatively thin but areally extensive units and contaminant plumes often mimic the geology, the use of horizontal wells may improve the efficiency of the injection/extraction system. In addition, horizontal wells can be used along linear sources of contamination and under existing facilities, such as buildings, waste sites, or landfills.

The deep well was used for injection of air, whereas the shallow well was used for extraction of air by drawing a vacuum at the wellhead (Figure 4). Both wells were operated concurrently to remove VOCs from both the ground water and vadose-zone soils. Tubes of varying lengths were installed in both horizontal wells to monitor pressure and concentrations along their entire length. First, a vacuum was drawn on the shallow well for a period of two weeks. Concentration and temperature of the extracted vapors were measured at least three times a day.

Air injection was then added at three different rates and at two different temperatures. Each of the operating regimes was operated for a minimum of two weeks. Helium tracer tests were conducted to learn more about vapor flow paths and the heterogeneity of the system between the two wells. At the end of the injection period, the vacuum alone was continued for a period of three weeks. The entire test ran for a period of 20 weeks, five of which were extraction only.

Two-dimensional modeling of the air injection process is underway by scientists at the Lawrence Livermore National Laboratory. These models will be utilized to design future demonstrations of this process.

RESULTS

Almost 16,000 pounds of solvents were removed during the test (Figure 5). Extraction rates during the vapor extraction only phase averaged 110 pounds of VOCs per day (Figure 6). The extraction flow rate was constant at approximately 580 scfm during the entire length of the test. During the air injection periods with medium (170 scfm) and high (270 scfm) rates, approximately 130 pounds of VOCs were removed daily (Figure 6). The bundle tubes demonstrated that air was entering the screen along the entire length of the horizontal sections in both horizontal wells. However, because of the natural heterogeneity of the sediments, some sections were more productive than others.

Concentrations of chlorinated solvents removed during the vapor extraction only regime decreased rapidly during the first two days of operation. Initial concentrations were as high as 5000 ppm but stablized at 200 to 300 ppm. When the medium air injection rate was initiated, the ratio of TCE to PCE changed significantly (Figure 7). Several explanations for this behavior have been proposed. Post-test characterization data will provide additional information to assist in explaining this phenomenon.

Concentrations of VOCs in the groundwater were significantly reduced in several of the monitoring wells. For example, ground water from two wells showed changes from 1600 and 1800 ug/l TCE at the beginning of the test to 10 to 30 ug/l TCE at the end of the twenty-week test. However, ground water in several of the wells showed no significant change and ground water in three wells actually had TCE concentrations increase. One explanation for increases in concentrations of VOCs in groundwater is that more contaminated water at depth (as characterized with depth sampling of ground water) was being forced upward due to the air injection. Two of the wells that had TCE concentrations in the groundwater increase were screened approximately twenty feet above the air injection.

A helium tracer test demonstrated connectivity between the two wells. However, recovery rates for the helium were slow, indicating significant dispersion. The test was run for a period of 46 days, after which approximately 45% of the injected helium had been recovered by the extraction well. The activity of indigenous microorganisms was found to increase at least an order of magnitude during the air injection period (medium and high rates). This activity then decreased when the air injection was terminated. It is possible that simple injection of air has stimulated indigenous microorganisms that have the potential to degrade TCE. A mass balance calculation will be performed after post-test coring and chemical analyses have been completed. Injection of heated air (155 degrees F) appeared to have no effect on the amount of contaminant or temperature of the gas extracted from the shallow well. However, slight increases in activity of the indigenous microorganisms were detected.

Vadose-zone piezometers demonstrated the effect of the vacuum both horizontally and vertically over the test area. The zone of capture in the vadose zone extends across the entire demonstration site (approximately 200 by 300 feet). The effect of the vacuum remained stable during the entire demonstration.

CONCLUSIONS

Extraction rates of VOCs during the vapor extraction only regimes averaged 110 pounds of solvents per day as compared to approximately 25 pounds per day in one vertical well during a vapor extraction test completed in 1986. The extraction rate was increased by approximately 20 percent by addition of air injection below the water table. In addition, a significant mass of VOCs was removed from the ground water during the air injection phase, as demonstrated by mapping the TCE concentrations in the groundwater over time.

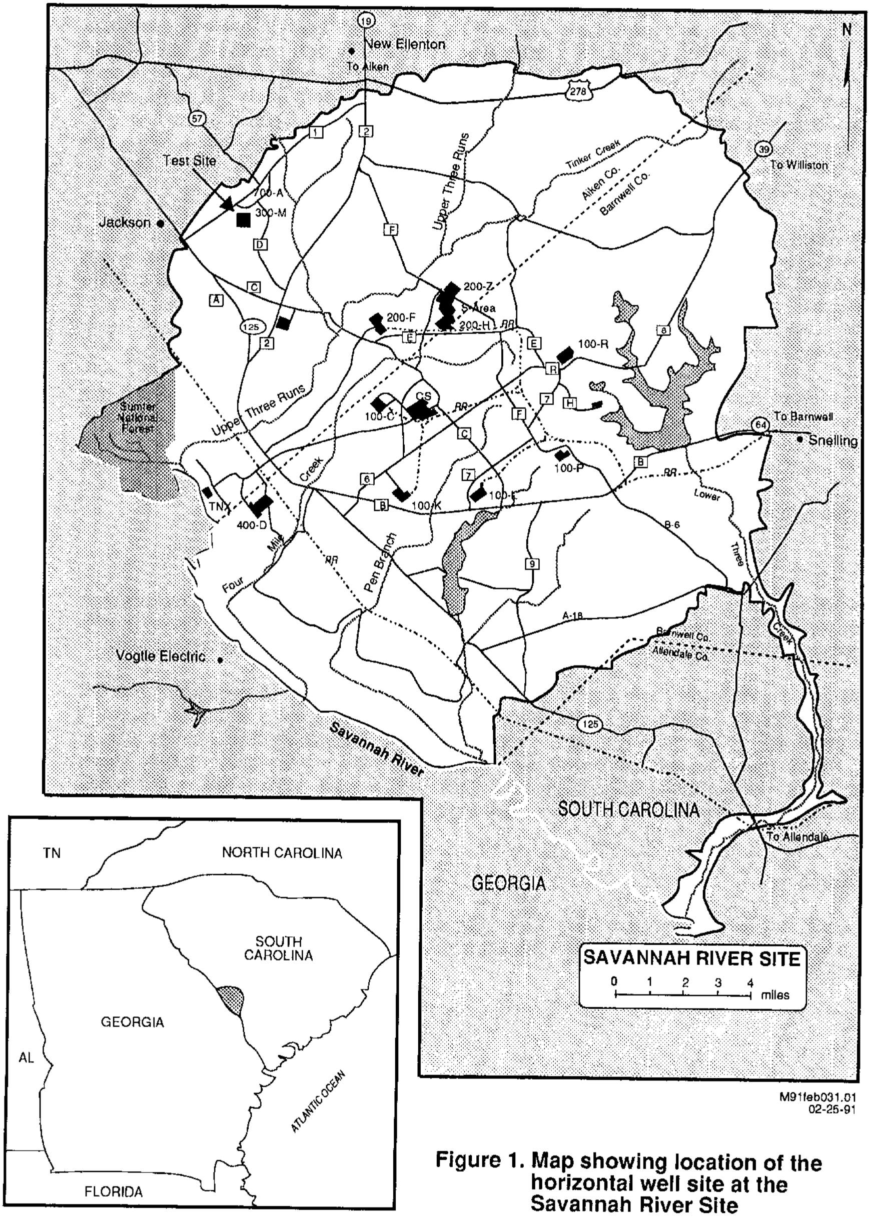
PLANS

Plans involve installation of additional horizontal wells, demonstrating several different technologies for application to environmental problems. The ultimate goal is to demonstrate that horizontal wells can be installed cost effectively to maximize the efficiency of environmental restoration activities.

The existing horizontal well system will be used to demonstrate an in situ bioremediation that will consist of injection of a methane/air mixture to stimulate methanotrophic microorganisms known to have the capability to degrade TCE to carbon dioxide, water and hydrogen chloride in an aerobic system. Future plans include demonstration of other remediation technologies, such as steam stripping, in the new horizontal wells. Other aspects of the program include testing of new air abatement technologies to be used in conjunction with vapor extraction systems and testing of new chemical sensors.

REFERENCES

Kaback, Dawn S., Brian B. Looney, John C. Corey, Leonard M. Wright III, and John L. Steele, 1989, Horizontal Wells for In Situ Remediation of Groundwater and Soils: NWWA Third Outdoor Action Conference Proceedings, p. 121-135.



M91feb031.01
02-25-91

Figure 1. Map showing location of the horizontal well site at the Savannah River Site

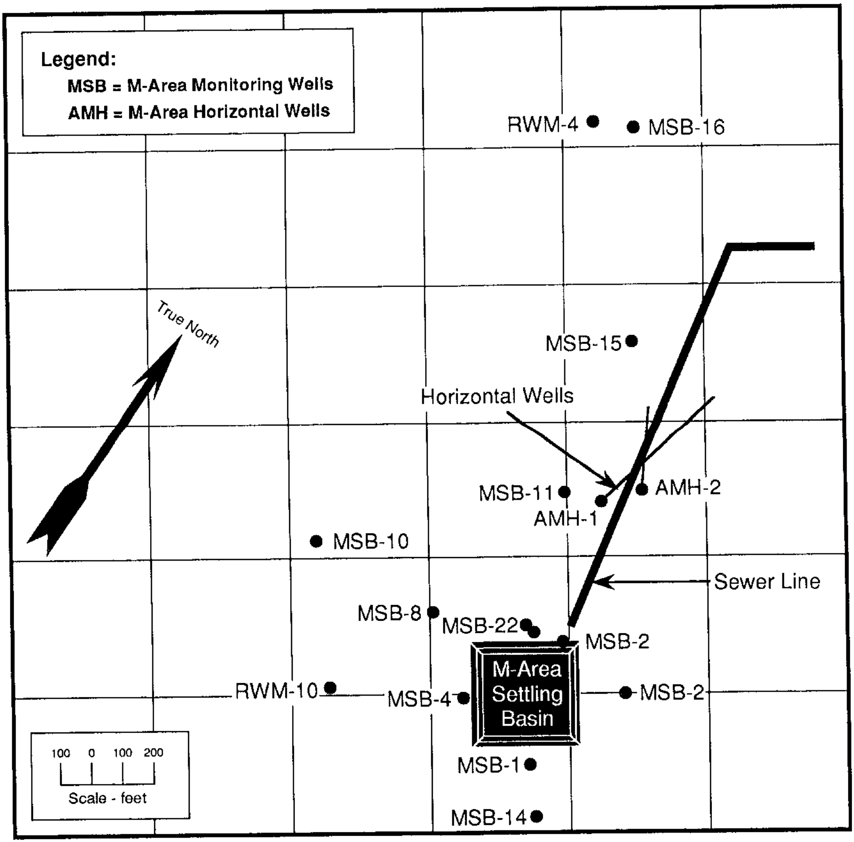
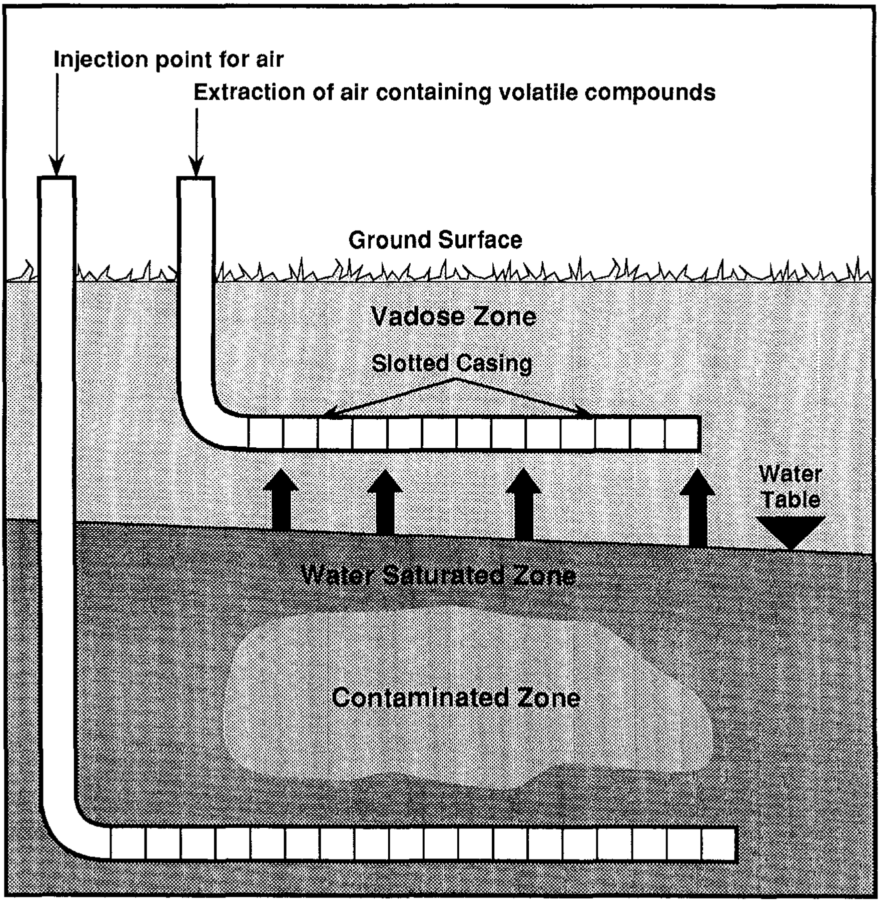
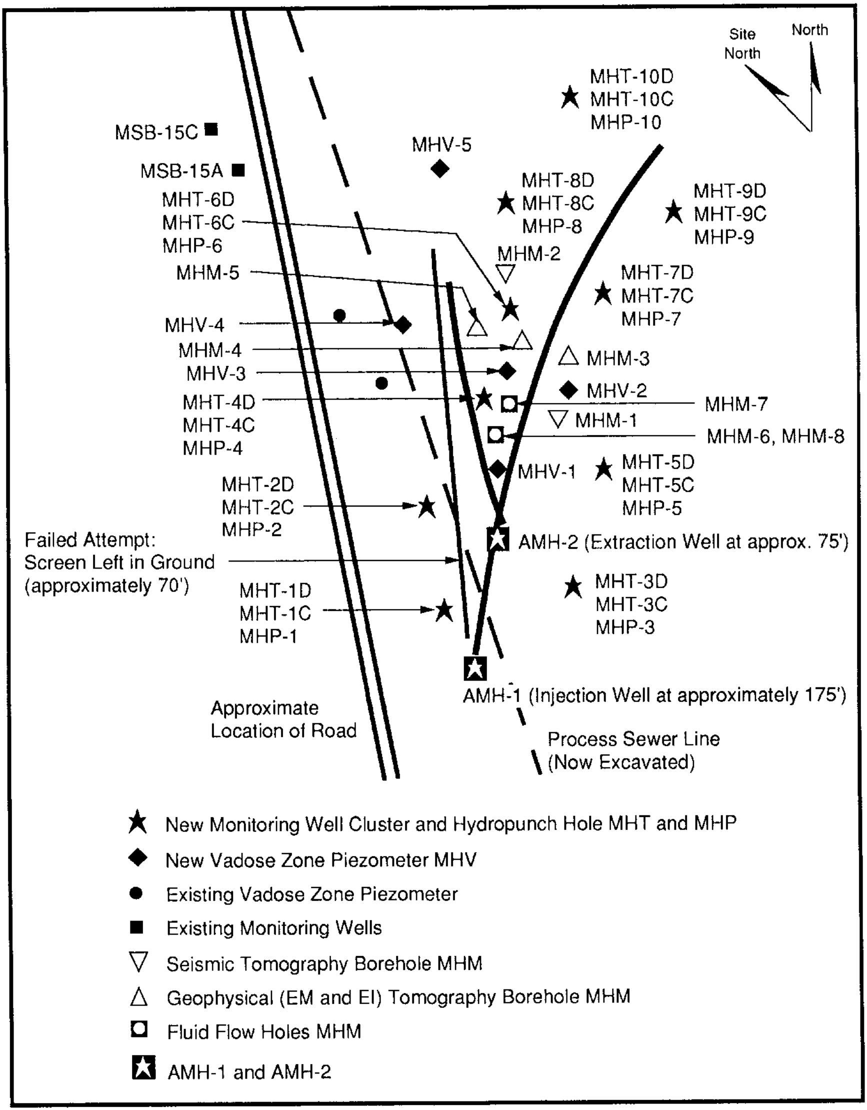


Figure 2. Map showing location of the horizontal well test site outside of the M-Area, Savannah River Site



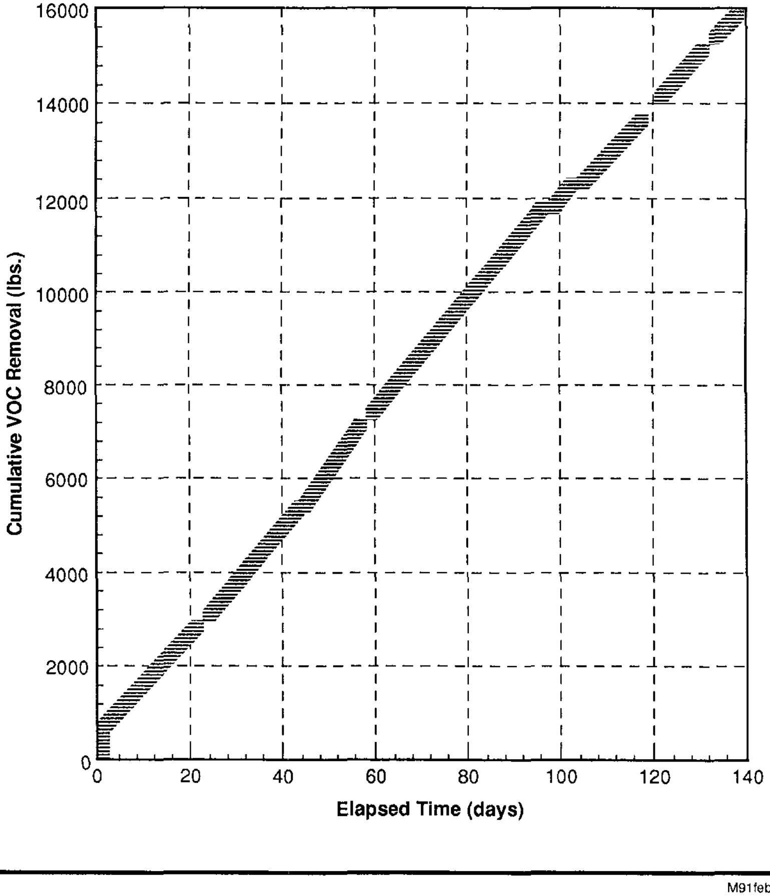
M91feb031.03
02-26-91

Figure 3. Cartoon of in-situ air stripping system



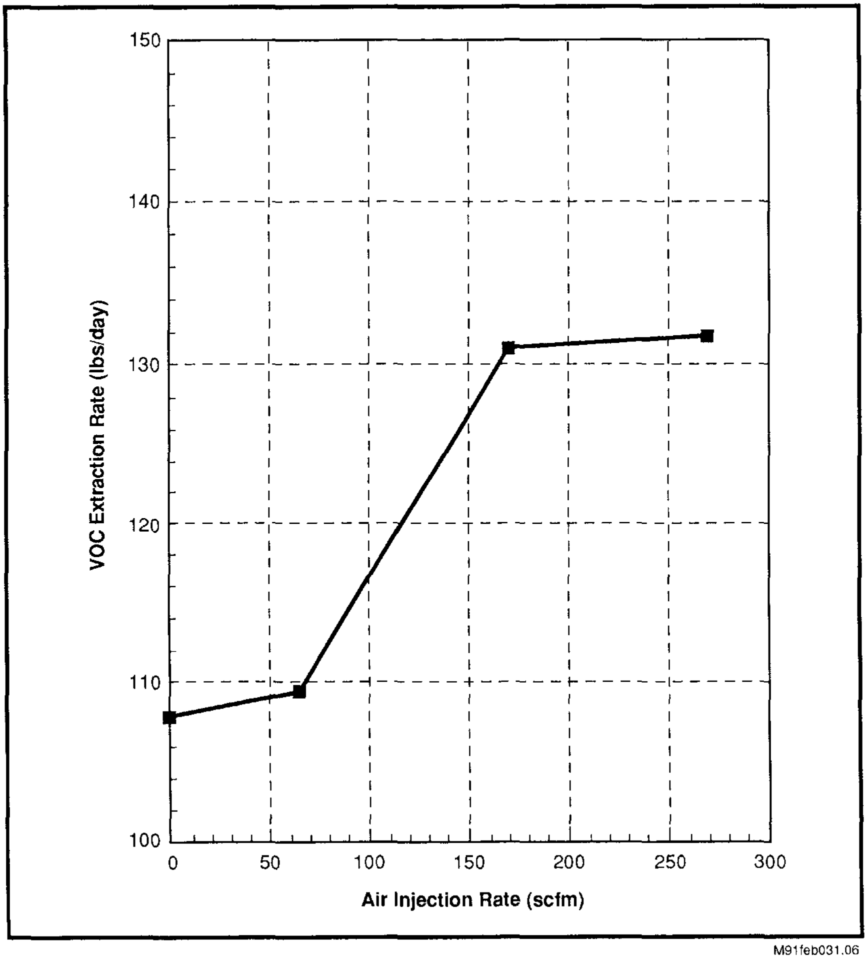
M91feb031.04
02-27-91

Figure 4. Detailed map of the horizontal well site showing all monitoring wells



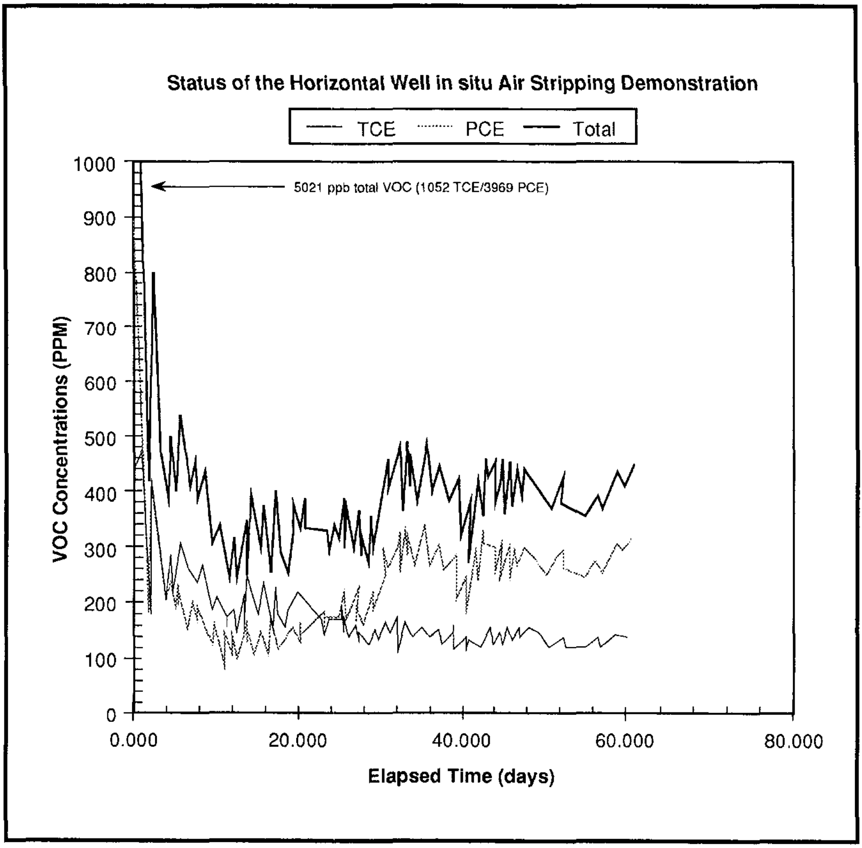
M91feb031.05
02-27-91

Figure 5. Cumulative Removal of Chlorinated Solvents During the Test



M91feb031.06
02-27-91

Figure 6. Effect of Air Injection on Removal Rate of Chlorinated Solvents During the Test - Average Removal Rate for Each Condition vs. Flow Rate



M91feb031.07
02-27-91

Figure 7. VOC concentrations in the horizontal extraction well as a function of time during the in-situ air stripping test