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IN SITU AIR STRIPPING USING HORIZONTAL WELLS (U)**

by

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IN SITU AIR STRIPPING USING HORIZONTAL WELLS**

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**ABSTRACT**

An innovative environmental restoration technology, in situ air stripping, has been demonstrated at the U.S. Department of Energy (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 (VOC). 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 micro-organisms 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 the DOE 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 near Aiken, South Carolina, owned by DOE (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 well 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 technology for these ground waters is to pump them to the surface and treat 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 the 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 we knew it had 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 Savannah River Site is located on the upper Atlantic Coastal Plain. It 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 red Triassic sediments (siltstones and sandstones). The 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. 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 SRS. Two horizontal wells were successfully installed, borrowing technology from the petroleum industry<sup>1</sup>, along the process sewer line that 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. It 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 was 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 a 190-foot 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 (ten), 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 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 wells weekly for VOC analyses and biweekly for microbial analyses during the in situ air stripping test. Ground water monitoring on a biweekly basis continued after the conclusion of the test.

## **IN SITU AIR STRIPPING TEST DESIGN**

The in situ air stripping concept involved installation of two parallel horizontal wells to maximize the process efficiency. 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 has 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. Also, 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 for extraction only.

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

## RESULTS

Almost 16,000 pounds of solvents were removed during the test (Figure 5). Rates during vapor extraction averaged only 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 stabilized 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, two wells showed changes from 1600 and 1800 ug/l to 10 to 30 ug/l. However, several of the wells showed no significant change, and three wells actually had concentrations increases. 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 as a result of the air injection. Two of the wells that had increases 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 percent of the injection helium was recovered by the extraction well.

The activity of indigenous micro-organisms was found to increase at least on 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 stimulated indigenous micro-organisms that have the potential to degrade TCE. A mass balance calculation will be performed after post-test coring and chemical analyses have been completed.

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 extended across the entire demonstration site (approximately 200 by 300 feet). The effect of the vacuum remained stable during the demonstrations.

Injection of air heated to 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 micro-organisms were detected.

## CONCLUSIONS

Vapor extraction rates of VOCs in only one horizontal well 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 ground water during the air injection phase, as demonstrated by mapping the TCE concentrations in the groundwater over time.

## PLANS

Installation of additional horizontal wells are planned to demonstrate several different technologies for application in environmental problems. The ultimate goal is to demonstrate that horizontal wells can cost effectively 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 micro-organisms known to be capable of degrading TCE to carbon dioxide, water, and hydrogen chloride in an aerobic system. Plans include demonstration of other remediation technologies such as steam stripping in the new horizontal wells. Other aspects of the program include new air abatement technologies tests to be used in conjunction with vapor extraction systems and new chemical sensors tests.

## ACKNOWLEDGEMENT

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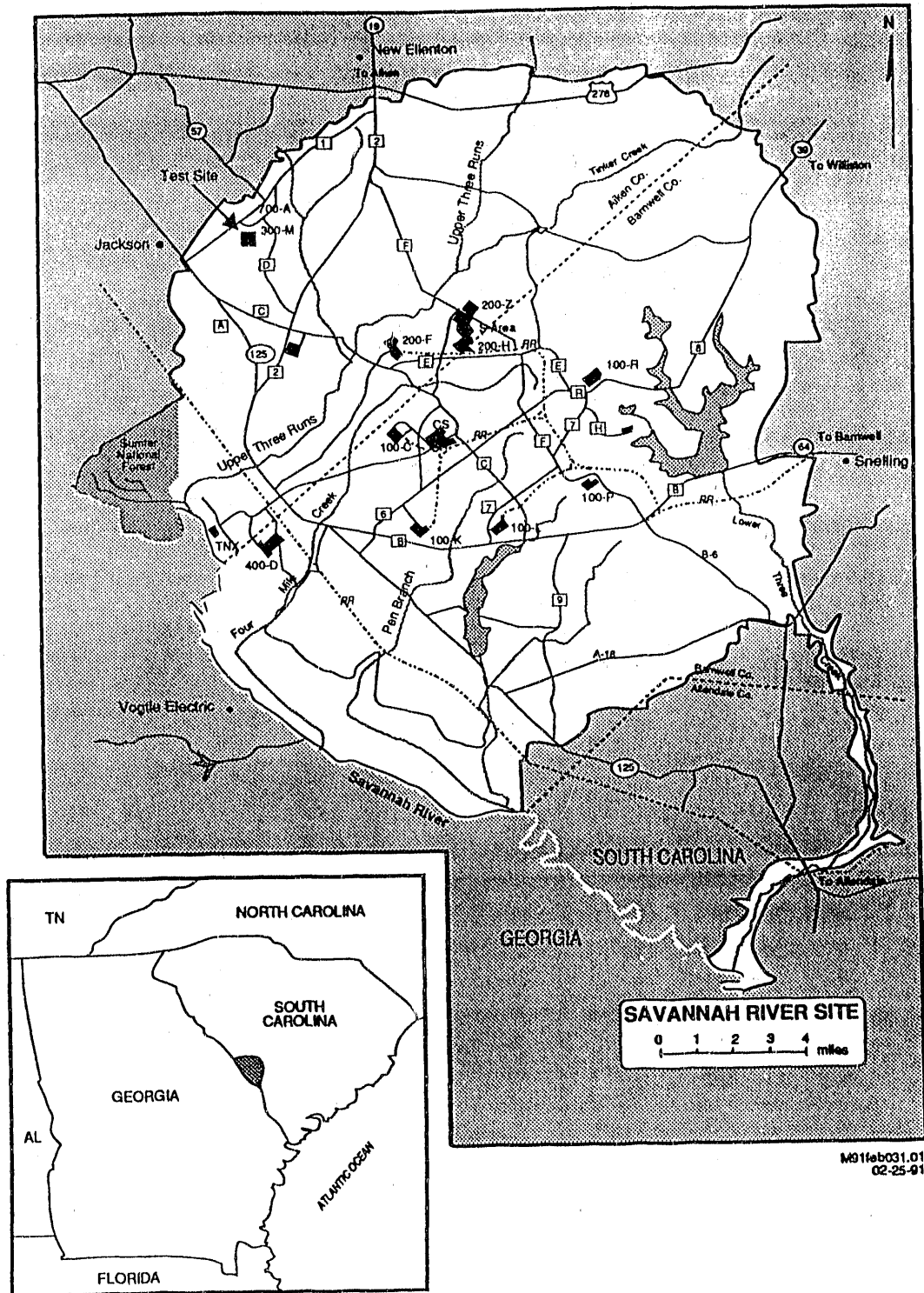
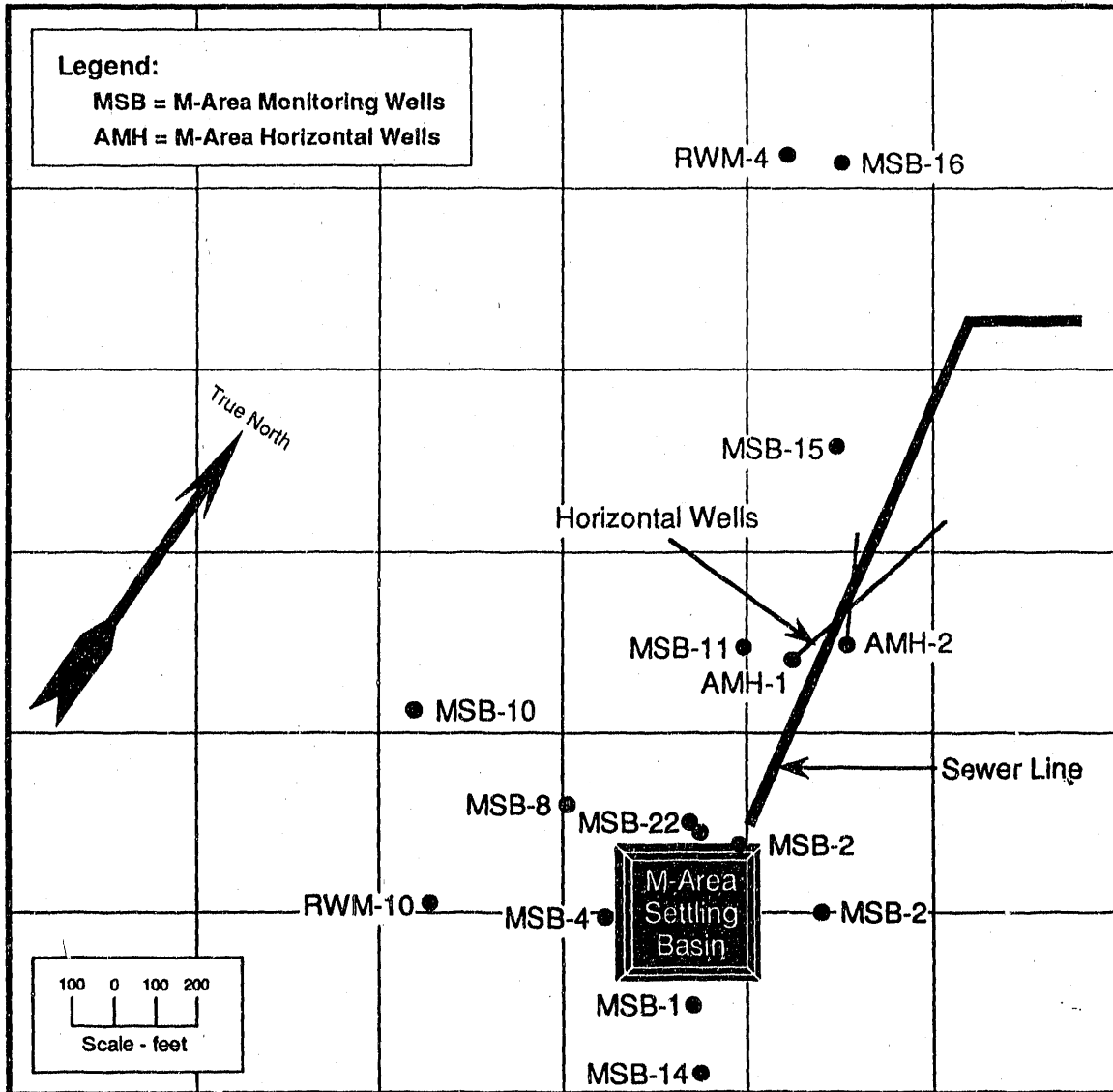


Figure 1. Location of Horizontal Well Site at the Savannah River Site



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**Figure 2. Location of Horizontal Well Test Site Outside of M-Area, SRS**



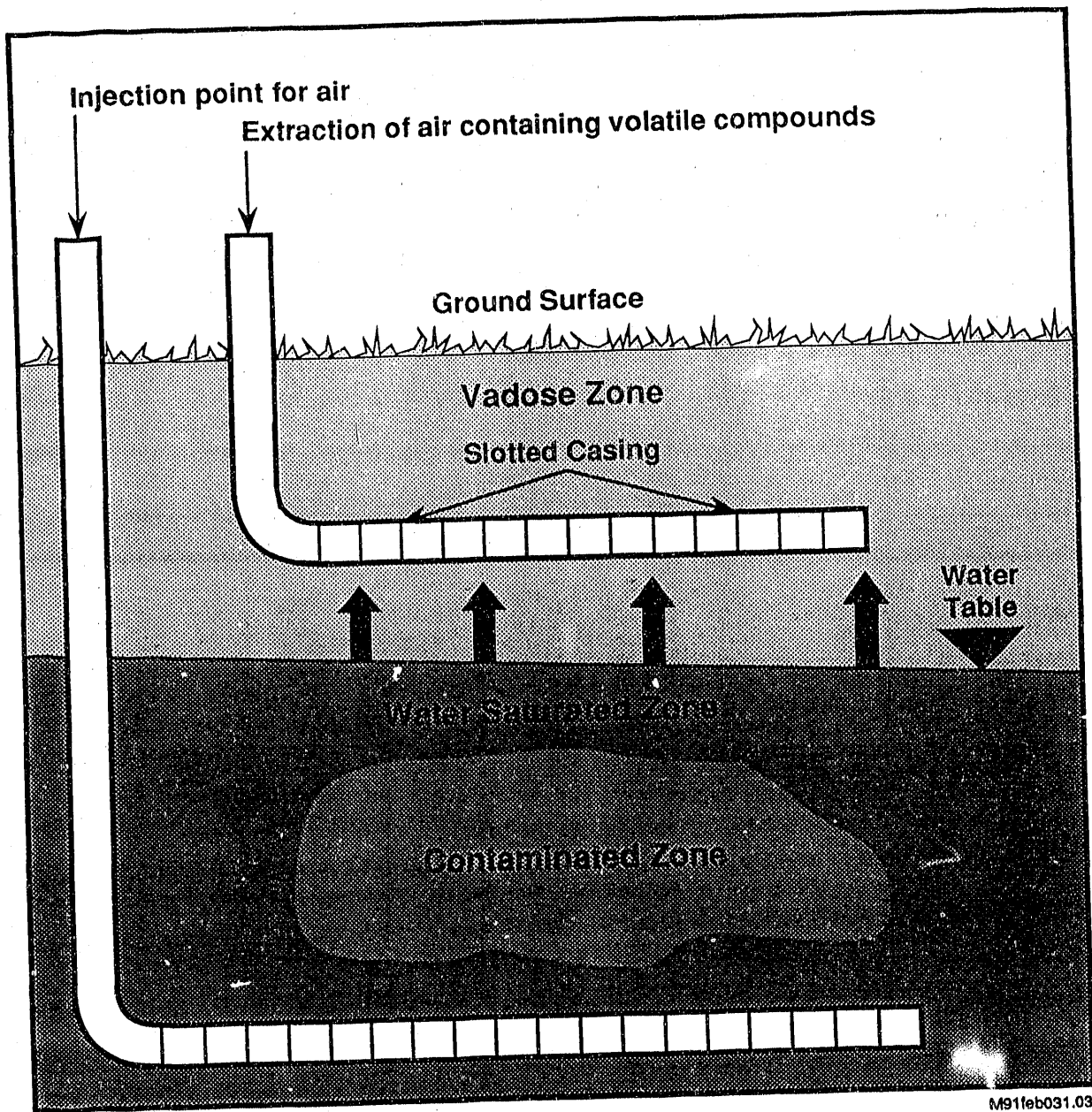


Figure 3. In-Situ Air Stripping System

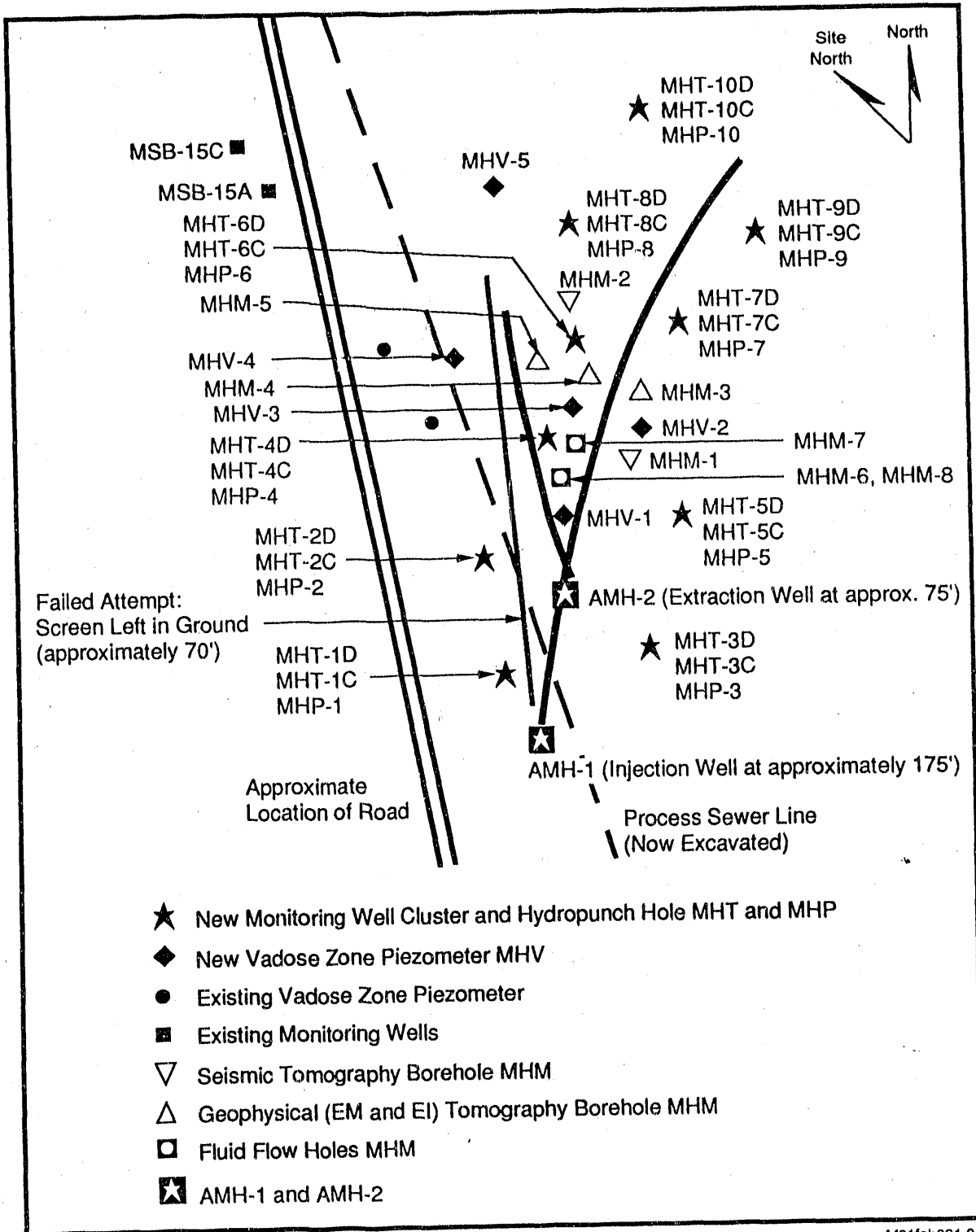
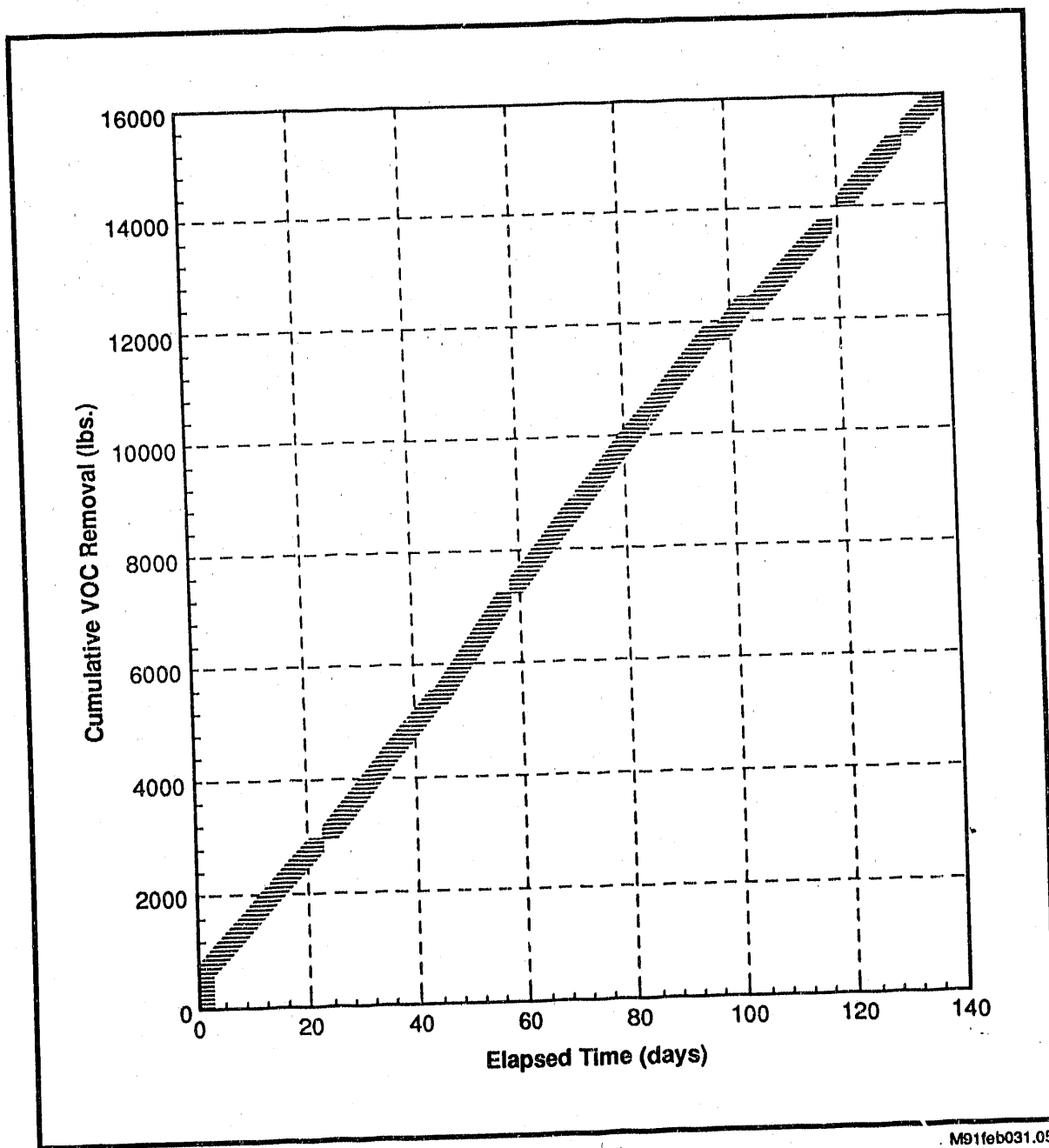
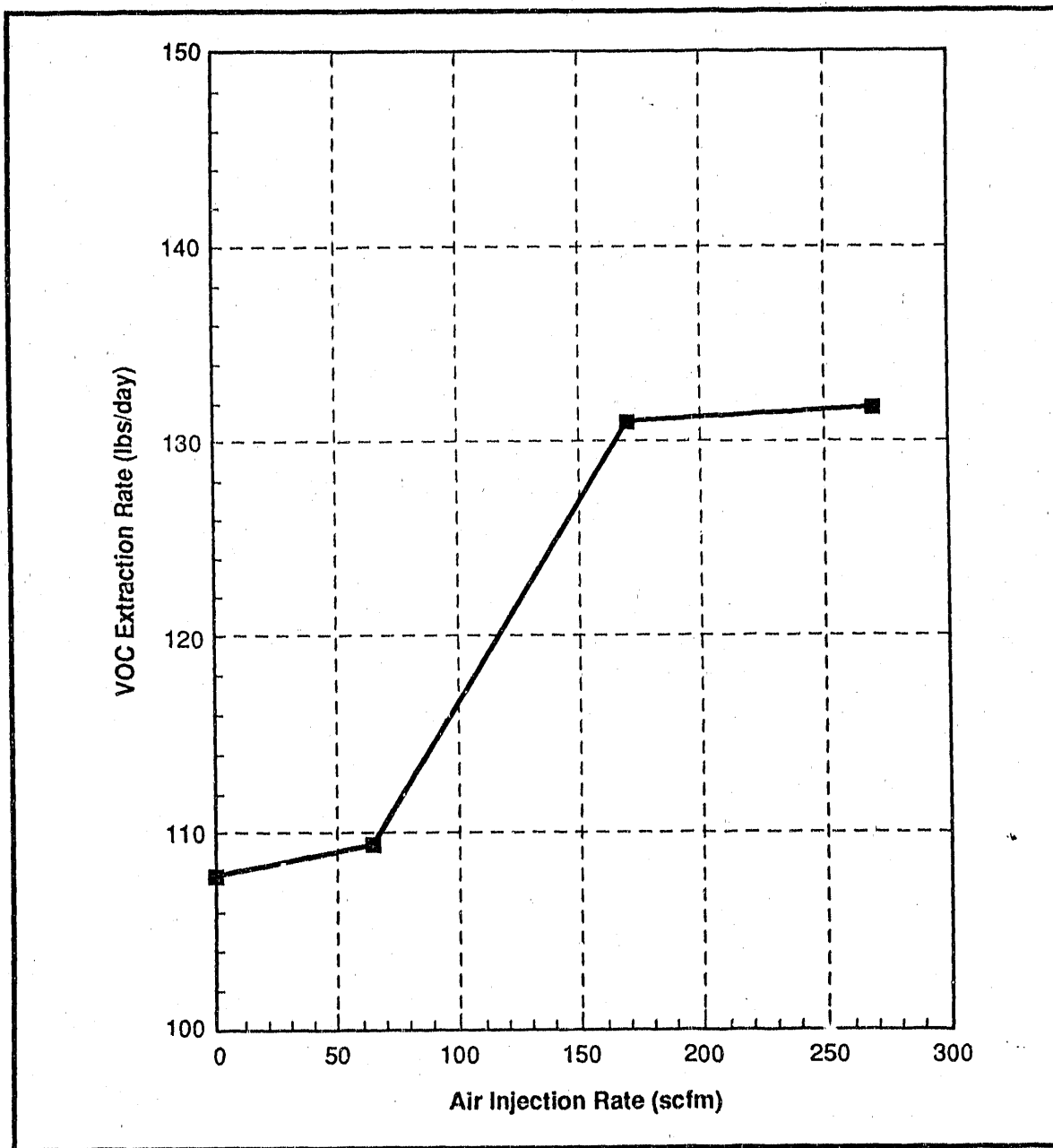


Figure 4. All Monitoring Wells at Horizontal Well Site



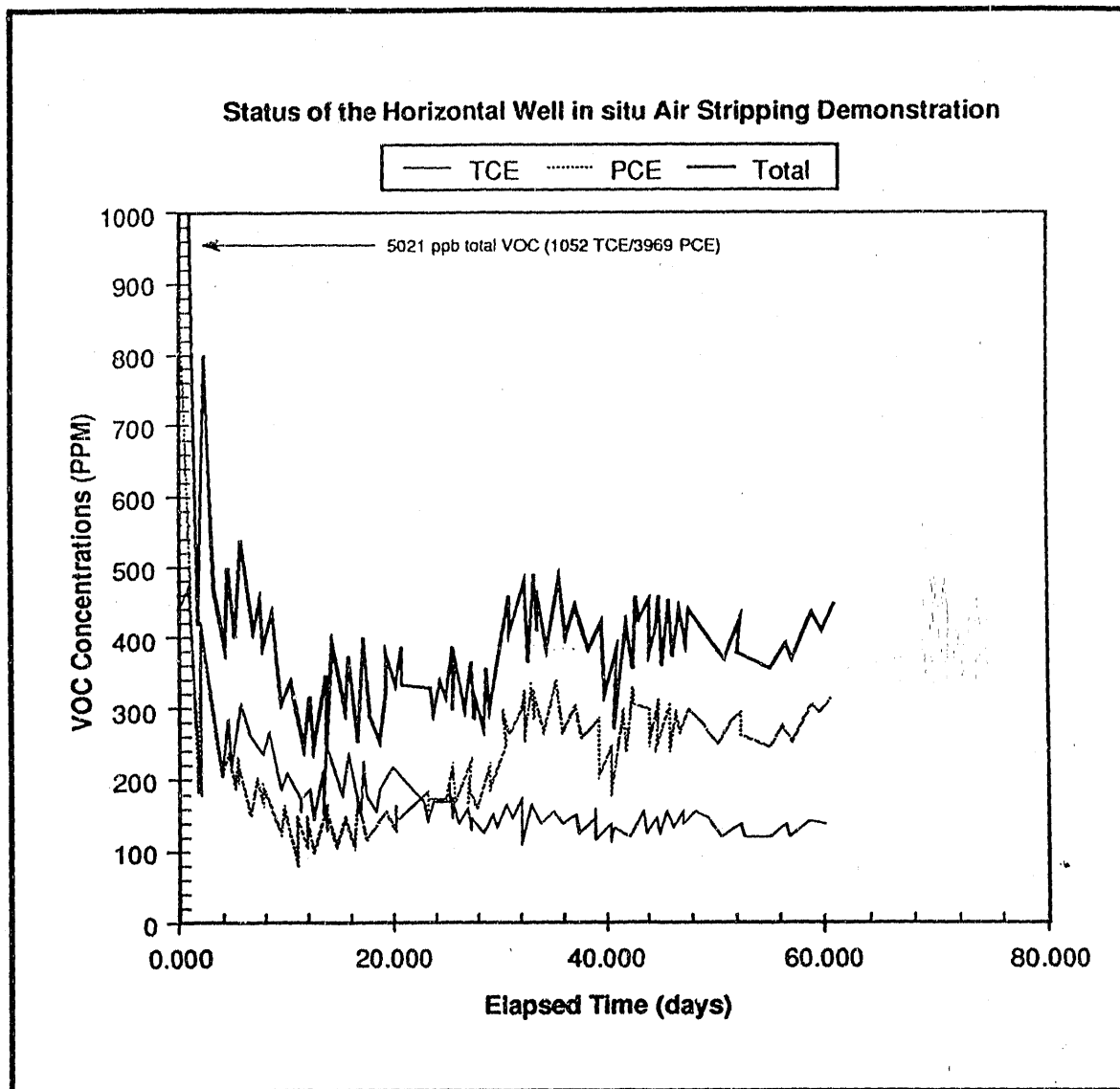
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Figure 5. Cumulative Removal of Chlorinated Solvents during the Test



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**Figure 6. Effect of Air Injection on Removal Rate of Chlorinated Solvents during the Test — Average Removal Rate for Each Condition versus Flow Rate**



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**Figure 7. VOC Concentrations in the Horizontal Extraction Well as a Function of Time during In Situ Air Stripping Test**

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