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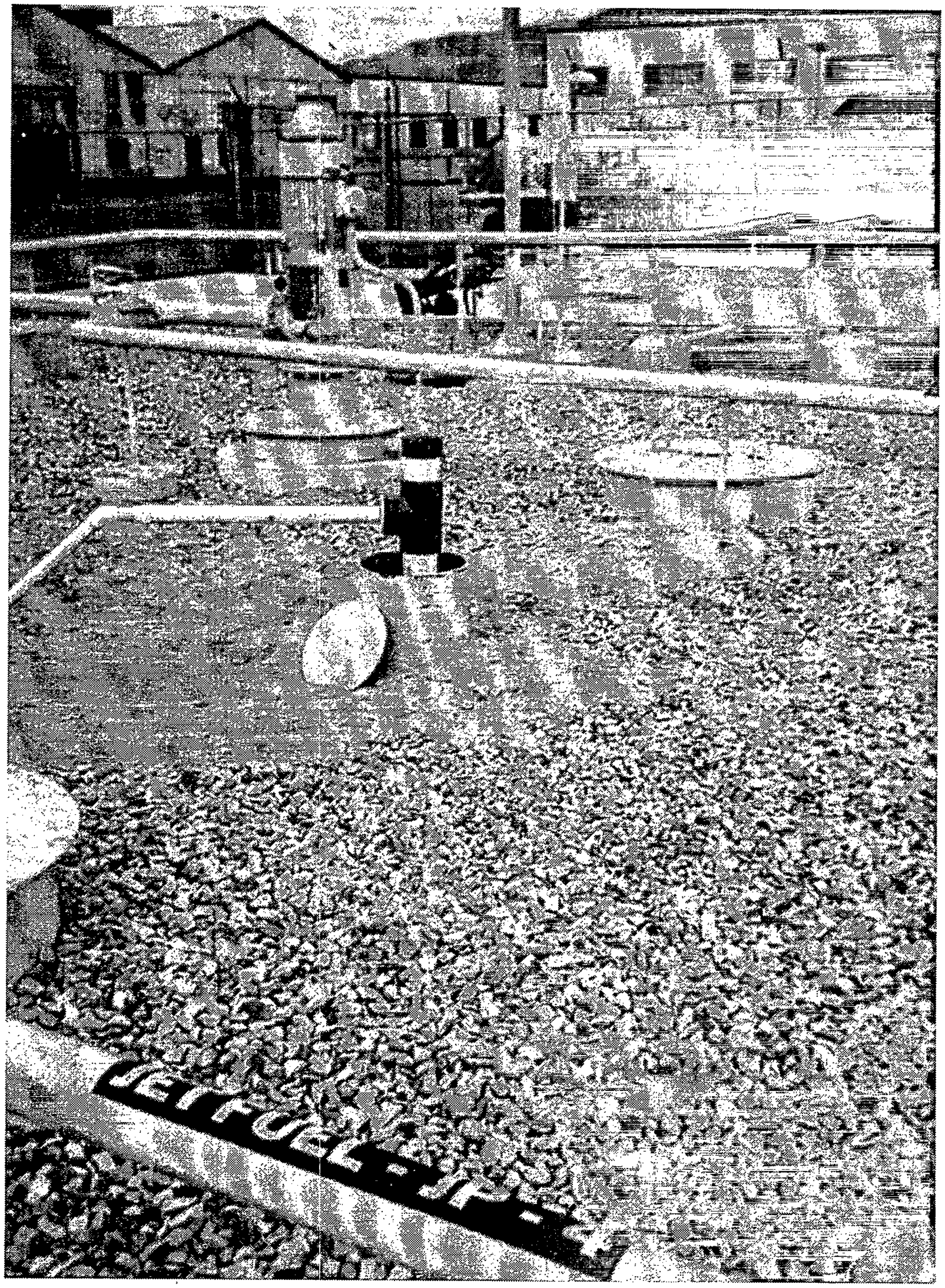
Bioremediation Field Evaluation

Hill Air Force Base, Utah



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Hill Air Force Base, Utah

U.S. Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks AFB, Texas

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Washington, D.C. 20460

U.S. Environmental Protection Agency
Office of Research and Development
National Risk Management Research Laboratory
Cincinnati, Ohio 45268

Notice

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The Bioremediation Field Initiative

In 1990, the U.S. Environmental Protection Agency (EPA) established the Bioremediation Field Initiative as part of its overall strategy to increase the use of bioremediation to treat hazardous wastes at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or Superfund) and other contaminated sites. The primary purpose of the Initiative is to collect and disseminate information on the capabilities of bioremediation technologies so that EPA and state project managers, consulting engineers, and industry representatives can make better-informed decisions about applying bioremediation in the field. Participants in the Initiative include EPA's Office of Research and Development, Office of Solid Waste and Emergency Response, and regional offices, as well as other federal agencies, state agencies, industry, and universities.

The Initiative conducts a variety of activities to facilitate the exchange of information about bioremediation, including sponsoring technology-transfer conferences on topics related to bioremediation, maintaining an electronic database of information on bioremediation sites nationwide, and publishing a bulletin of recent developments in field applications of bioremediation. In addition, the Initiative provides support to states and regions for intensive evaluation of bioremediation at selected sites across the country. The extent of the Initiative's involvement at these sites varies from providing support for laboratory feasibility studies, to assisting with field treatability studies, to overseeing and assessing full-scale site remediation.

Sites are nominated for field evaluations through the EPA regional offices or through the states with concurrence from the regional offices. To date, nine sites have been selected for performance evaluation of bioremediation: West KL Avenue Landfill Superfund site, Kalamazoo, Michigan; Libby Ground Water Superfund site, Libby, Montana; Park City Pipeline, Park City, Kansas; Bendix Corporation/Allied Automotive Superfund site, St. Joseph, Michigan; Eielson Air Force Base Superfund site, Fairbanks, Alaska; Hill Air Force Base Superfund site, Salt Lake City, Utah; Escambia Wood Preservation site—Brookhaven, Brookhaven, Mississippi; Public Service Company site, Denver, Colorado; and Reilly Tar and Chemical Corporation Superfund site, St. Louis Park, Minnesota.

Acknowledgments

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EPA also gratefully acknowledges the technical and financial contributions of those who collaborated with EPA to conduct this field evaluation. In particular, EPA wishes to acknowledge the additional funding provided by Hill Air Force Base.

Hill Air Force Base

ABSTRACT

This publication, one of a series presenting the findings of the Bioremediation Field Initiative's bioremediation field evaluations, provides a detailed summary of the evaluation conducted at the Hill Air Force Base (AFB) Superfund site in Salt Lake City, Utah. At this site, the Initiative provided support for an evaluation of bioventing at several airflow rates to stimulate in situ bioremediation of soil contamination resulting from a JP-4 jet fuel spill at the 280 Fuel Storage Yard Site. The main objective of the evaluation was to determine the effect of airflow injection rate on the effectiveness of bioventing in stimulating biodegradation while minimizing volatilization. The evaluation was conducted as a joint effort of the U.S. Air Force and the U.S. Environmental Protection Agency's (EPA's) National Risk Management Research Laboratory (NRMRL). The effort was initiated in November 1990 with the installation of an injection well and three soil-gas monitoring wells as well as collection and analysis of soil samples for JP-4 constituents. Air injection began in December 1990 at a flow rate of 67 cubic feet per minute (cfm). Over the next 4 years, seven additional soil-gas monitoring wells were installed and soil samples from these wells were analyzed. In situ respiration tests were conducted to evaluate four different injection rates (28, 40, 67, and 117 cfm). In addition, a soil-gas permeability test was conducted in June 1993, and final site characterization was completed in November 1994.

Bioventing was successful in the remediation of vadose zone soils at the site. Total petroleum hydrocarbons (TPH) and benzene, toluene, ethylbenzene, and xylenes (BTEX) concentrations were significantly reduced in the more contaminated soils within 25 ft of the injection well. In situ respiration tests indicated an average biodegradation rate of 0.53 mg/kg/day, compared to 0.75 mg/kg/day based on soil samples. Hydrocarbon concentrations did not increase in surrounding cleaner soils as the result of air injection, and surface emission testing found no measurable emission of hydrocarbons to the atmosphere as a result of air injection. The radius of influence ranged from 73 ft at an injection rate of 20 cfm to 278 ft at 117 cfm.

FIELD EVALUATION

Purpose of the Evaluation

Petroleum distillate fuel hydrocarbons such as JP-4 jet fuel are generally biodegradable if indigenous microorganisms receive an adequate supply of oxygen and nutrients. Typically, much of the hydrocarbon residue at fuel-contamination sites lies in unsaturated (vadose) zone soils immediately above the water table. To successfully bioremediate such sites, an adequate supply of oxygen must be provided to the unsaturated zone soils. To date, most efforts to bioremediate fuel spills have focused on soluble fuel components in ground water rather than hydrocarbon residues in unsaturated zone soils.

Conventional bioremediation systems use water to carry oxygen to the contamination. Water, however, does not deliver enough oxygen to the contaminated soil. This problem has led researchers to investigate the use of air as an alternative source of oxygen. Air has two major advantages over water. First, on a mass basis, less air than water is needed to deliver a sufficient amount of oxygen. Second, air is more diffusible than water, facilitating delivery of oxygen to soils such as clay that are relatively impermeable to water.

Researchers had reason to believe that moving air through soil could indeed supply enough oxygen to promote biodegradation of petroleum contaminants. As early as 1981, researchers had begun evaluating the use of soil vapor extraction (SVE) technology—the pulling of air through the ground—to remediate petroleum-contaminated soils. The technology involved moving air through contaminated soils at high rates to promote volatilization of the contaminants. Although SVE technology was designed to promote volatilization, researchers found that it stimulated aerobic biodegradation as well. This finding generated interest in developing a different soil aeration technology—called "bioventing"—that would maximize biodegradation rather than volatilization. Researchers found that by using airflow rates lower than those used during the SVE process (and by altering other design parameters) they could in fact maximize biodegradation rather than volatilization. Thus, bioventing is the process of moving air through subsurface soils to provide oxygen to microorganisms and stimulate aerobic biodegradation. As Figure 1 shows, the air movement required for bioventing can be achieved by blowing air into the soil (injection bioventing) or by creating a vacuum to pull air out of the soil (extraction bioventing).

In 1988, the Air Force initiated a study at Hill AFB to examine the potential of bioventing to remediate JP-4 jet fuel-contaminated soils. Promising results prompted the Air Force and NRMRL to con-

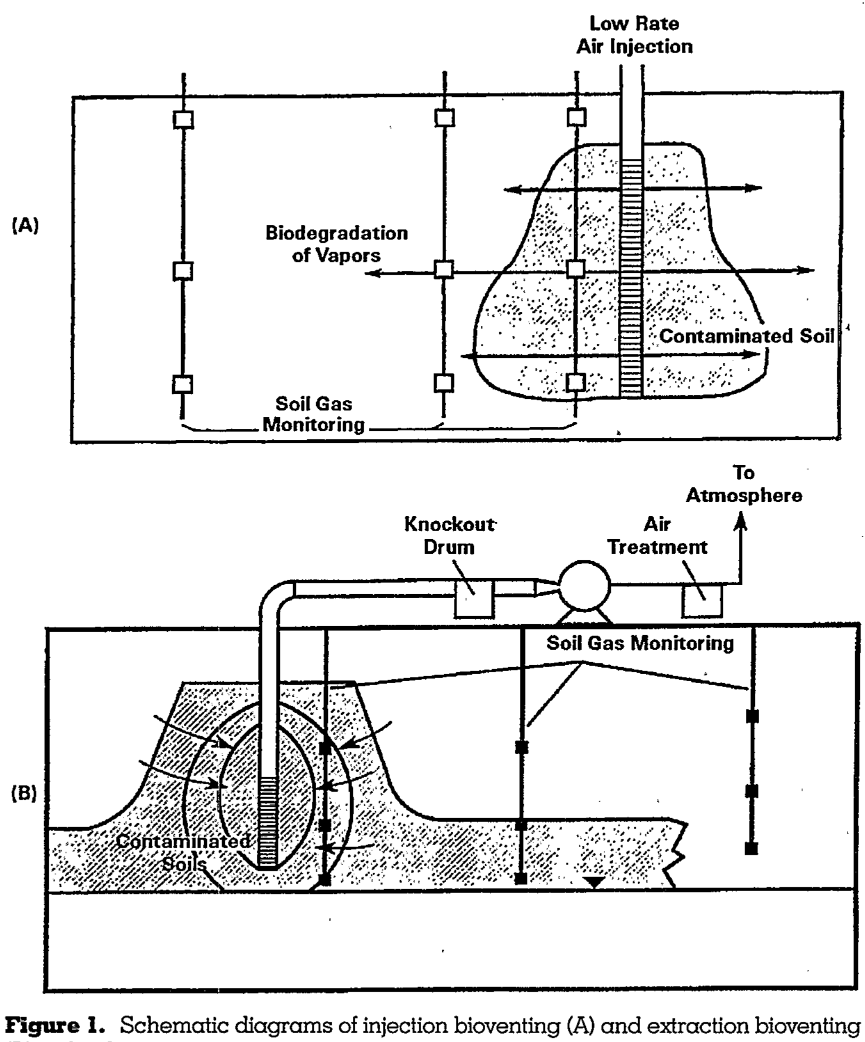


Figure 1. Schematic diagrams of injection bioventing (A) and extraction bioventing (B) technology.

duct a field evaluation at the site, consisting of two separate but integrated projects. The Air Force effort involved air injection at one flow rate along with surface-emission monitoring and in situ respiration testing to estimate biodegradation rates. A total of seven soil-gas monitoring wells (cluster wells), seven ground-water monitoring wells, and an injection well were installed for the Air Force effort. The NRMRL project involved injecting air at several different flow rates, along with follow-up in situ respiration tests, installation of three additional soil-gas wells, and additional soil sampling.

The objectives of the field evaluation were to:

- Determine site-specific conditions, including the extent of soil contamination.
- Estimate the effectiveness of injecting air to stimulate biodegradation, and to determine the kinetics of the biodegradation process.
- Determine if hydrocarbon releases occurred at the ground surface due to injection of air into the soil.
- Estimate the radius of influence that is caused by air injection into the specific soils at the site.
- Develop recommendations for routine bioventing applications.

Site History

The Hill AFB is an active base located 10 miles south of Ogden, Utah, and near the Great Salt Lake (see Figure 2). Approximately 15,000 people work on the base and approximately 4,000 live on the base. The area of the base studied is known as the 280 Fuel Storage Lot Site. It is located in the southeast corner of the base, next to the runway.

The 280 Site has been used since 1941 as a fuel storage area, first containing aviation-grade fuel and later JP-4 jet fuel. Four original 25,000-gallon underground storage tanks (Hill AFB designation

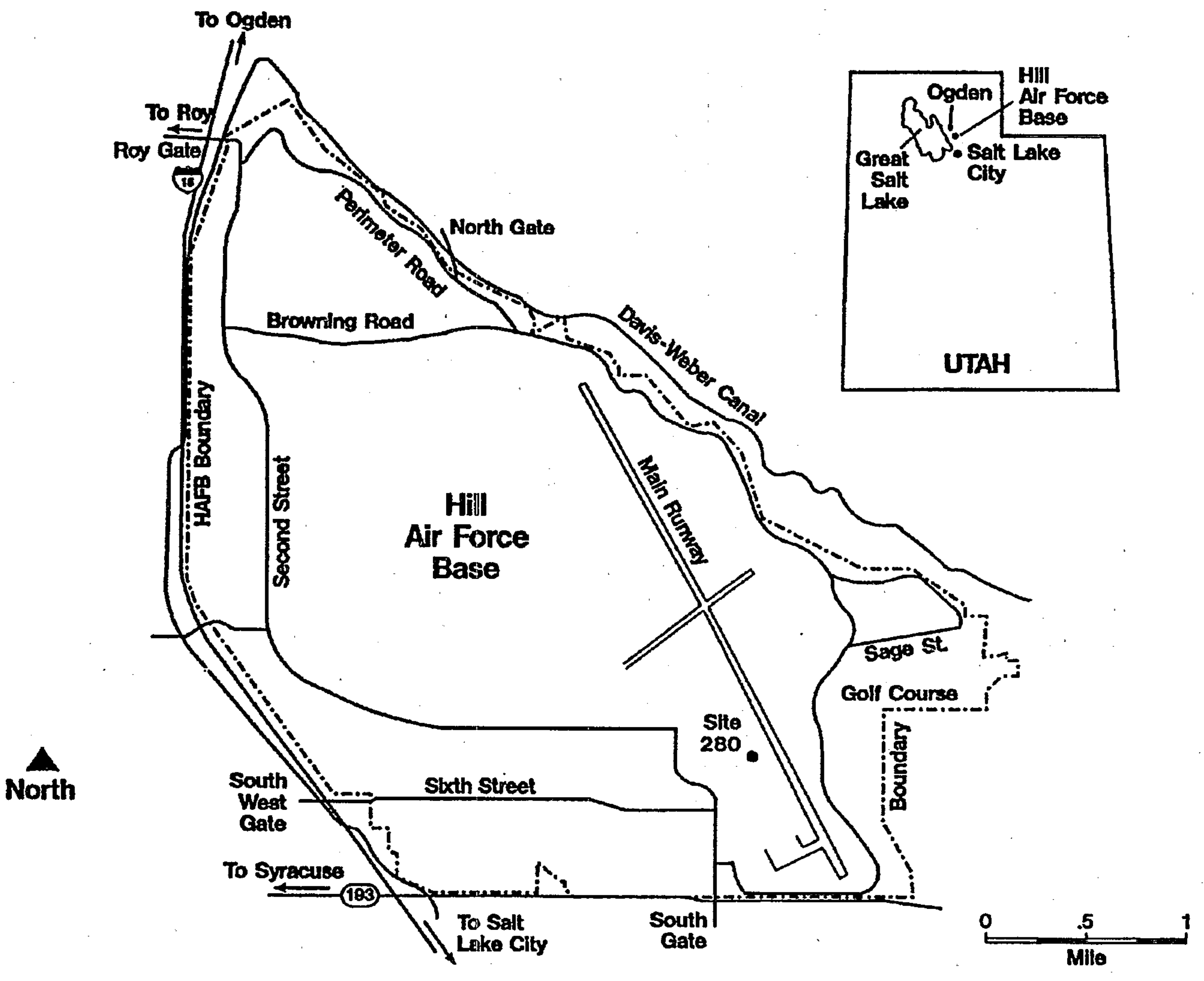


Figure 2. Hill AFB site map illustrating the 280 fuel storage lot site.

280.1, 280.2, 280.3, and 280.4) were removed in 1989 and replaced with two new 25,000 gallon tanks (Hill AFB designation 10268.1 and 10268.2). The 280 Site also contains tool maintenance and storage areas, jet engine storage and testing areas, pumping facilities, above- and below-ground piping, and other buried utilities. The land around the 280 Site is used for industrial purposes and contains warehouses, aircraft hangers, and aircraft service facilities.

There is no evidence that the fuel leaked from the storage tanks. Petroleum releases via surface spills during fuel transfer operations, maintenance of the system, and overfill into the pump and piping vaults appear to have occurred during the life of the system. The most recent recorded surface-spill event occurred around 1982, when the tanks were overfilled.

Prior to bioventing, the Hill AFB site was contaminated with JP-4 jet fuel from a depth of about 35 ft down to the ground water at 95 ft below the surface. Soil samples taken in September 1991 revealed an average TPH level of 890 mg/kg, with TPH levels at some depths reaching 5,000 mg/kg. At most depths, BTEX levels ranged from about 300 mg/kg to about 800 mg/kg. The area of contamination extended beneath the tool maintenance building, engine storage yard, and fuel storage yard (see Figure 3).

Because of the location of the potable ground water, the contaminated soil—consisting of sand and various clayey, silty, and gravelly sand zones—is not likely to pose a risk to human health. A shallow aquifer and two deeper aquifers (the Sunset Aquifer and the Delta Aquifer) lie below the 280 Site. The shallow aquifer is 95 ft below the surface water. The deeper aquifers are approximately 300 to 800 ft below the site. The ground water flows from east to west.

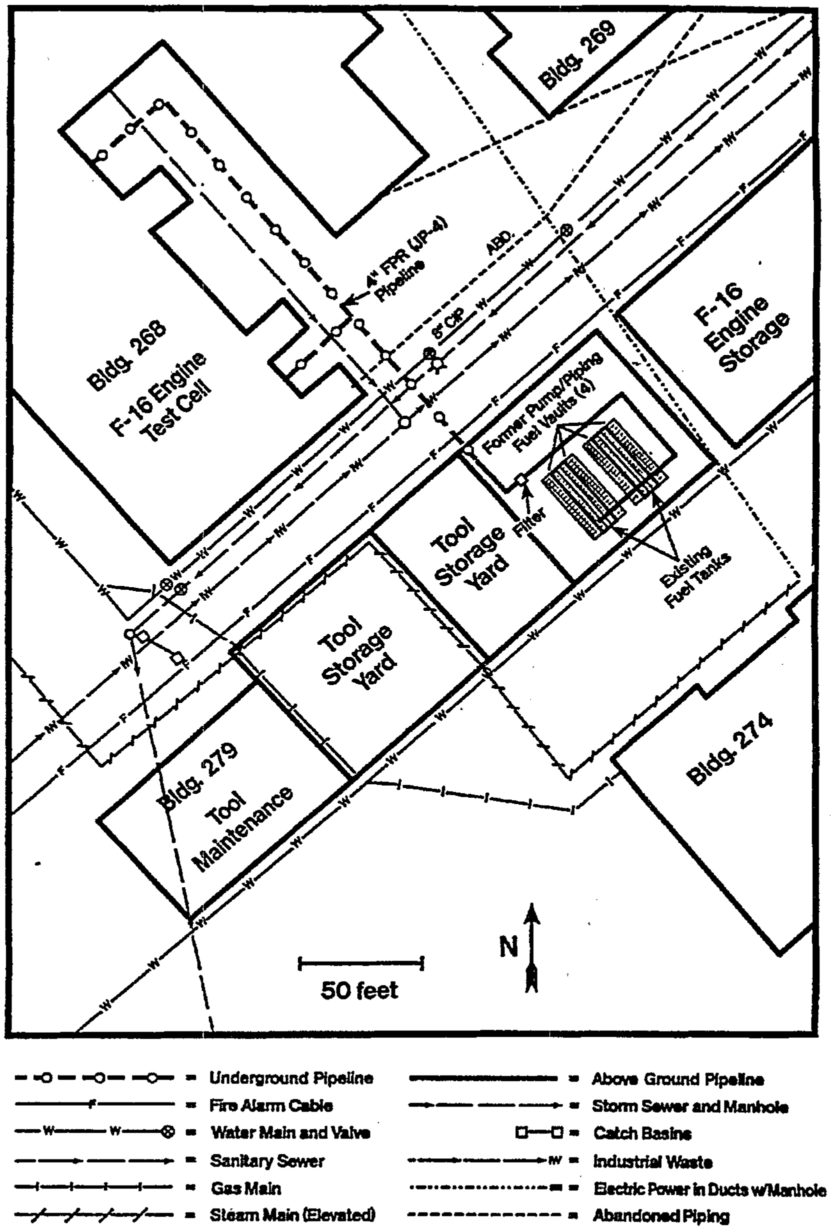


Figure 3. Hill AFB 280 site map showing the locations of the four removed underground storage tanks (USTs), two new USTs, existing utilities, and existing fuel system pipelines.

Conducting the Evaluation

From November 1990 through November 1994, the Air Force and NRMRL conducted their study of the effectiveness of air injection as a method of remediating the JP-4 jet fuel-contaminated 280 Site at Hill AFB. The study involved several steps:

- Initial site assessment.
- Installation of soil gas and ground-water monitoring wells to monitor soil gas and ground-water constituents over time.

- Testing to determine the locations of several of the ground-water monitoring wells.
- Varying the air injection flow rates in conjunction with in situ respiration and surface emissions testing to provide information for system optimization.
- Soil-gas permeability testing to quantify migration rates and dispersion/diffusion of vadose zone gases.
- Final site assessment to determine site-specific conditions after approximately 4 years of low-intensity bioreclamation efforts.

Site Assessment

A preliminary assessment of the 280 Site conducted in 1990 indicated that air injection technology appeared to be suitable for application but needed to be refined. The initial assessment, which utilized three multilevel soil-gas sampling wells and an air injection well, established a baseline of contamination levels.

To refine the study and determine the optimal parameters of an air injection bioremediation process, another injection well, 23 soil borings, 10 soil-gas monitoring wells, 7 ground-water monitoring wells, and 5 final soil borings were made over the course of the study. Cone Penetrometer Testing (CPT) was also conducted to determine the feasibility of this method for deep (approximately 125 ft) sampling and evaluation at the site, and to help locate several of the groundwater monitoring wells.

Soil and Ground-Water Samples

Soil samples were collected during drilling, and ground-water samples were collected after the ground-water monitoring wells were installed and completed. Soil and ground-water samples were submitted to the Utah State University Water Research Laboratory (USU-WRL) for testing for JP-4 constituents using modified EPA methods (EPA method 5030, a modified 8020 Method for volatile organic compounds, and a modified gas chromatographic method for non-volatile organic compounds).

A total of 82 separate soil, soil-gas, and ground-water sample collection events were conducted at Hill AFB 280 Site from November 1990 to November 1994. (An "event" is a discrete date on which individual tests, samples, or readings were performed.) A total of 558 individual tests, samples, or readings were performed at semi-regular intervals during that time. The busiest testing year was 1993. Table 1 summarizes the individual tests, samples, or readings performed in each year.

Over the course of these collection events, soil samples were drawn from bore holes and cluster wells; ground-water samples were taken from injection wells and ground-water monitoring wells; soil gases were collected from cluster wells and surface monitoring points; and ground-water depth gauging was conducted at injection wells and ground-water monitoring wells

Table 1.

Chronology of Soil and Ground-Water Testing Events at the 280 Site

YEAR (Number of events: Discrete dates on which individuals tests, samples or readings were performed)	INDIVIDUAL TESTS, SAMPLES, OR READINGS TAKEN DURING THE YEAR (#)
1990 (3)	Initial soil samples (5) Initial soil-gas O_2, CO_2, TPH (4) Initial ground-water sample (1) **YEAR TOTAL: 10**
1991 (9)	In situ respiration test for O_2, CO_2, TPH (3) Ground-water samples (5) Surface emission tests (2) Soil samples (6) Soil gas O_2, CO_2, TPH (12) ORS interface probe testing (4) **YEAR TOTAL: 32**
1992 (17)	CPTs (6) Soil gas O_2, CO_2, TPH (66) Ground-water depth gauging (28) In situ respiration test for O_2, CO_2, TPH (1) Soil samples (4) Surface emission tests (2) **YEAR TOTAL: 107**
1993 (36)	Soil samples (1) Soil gas O_2, CO_2, TPH (245) Ground-water depth gauging (95) Pressure reading (6) In situ respiration test for O_2, CO_2, TPH (2) Surface emission tests (3) **YEAR TOTAL: 352**
1994 (17)	Surface emission; soil gas O_2, CO_2, TPH (1) Ground-water depth gauging (50) In situ respiration test for O_2, CO_2, TPH (1) Soil samples (5) **YEAR TOTAL: 57**
1990-1994 (82)	**1990-1994 (558)**

(see Figure 4). An ORS interface probe was used to determine whether hydrocarbon product was present at the ground-water table for selected ground-water monitoring well locations. No hydrocarbon interface was detected at the ground-water table.

Air Injection Flow Rate Evaluation

A key objective of the Hill AFB study was to test different airflow rates to determine the maximum biodegradation rate while eliminating volatilization. A total of five flow rate evaluations were conducted at rates of 67, 40, 117, and 28 cfm. (The 67 cfm evaluation was repeated to include additional soil-gas monitoring wells completed at the site.) As the flow rate increased, so did the area of aeration.

Each evaluation was followed by in situ respiration testing (U.S. EPA and U.S. Air Force, 1995). Monthly soil-gas monitoring was initiated on August 13, 1992, to measure the oxygen, carbon dioxide, and TPH parts per million by volume (ppm) levels during each of the different airflow rates.

Each test consisted of injecting air into the injection well and performing:

- An in situ respiration test—measurement of the rate of oxygen uptake by microorganisms in the soil to estimate the rate of biodegradation occurring there.
- Surface emissions tests—both during air injection and while the air injection system was shut off so that emissions rates could be compared.
- Soil gas sampling—to monitor oxygen, carbon dioxide, TPH, and BTEX levels.

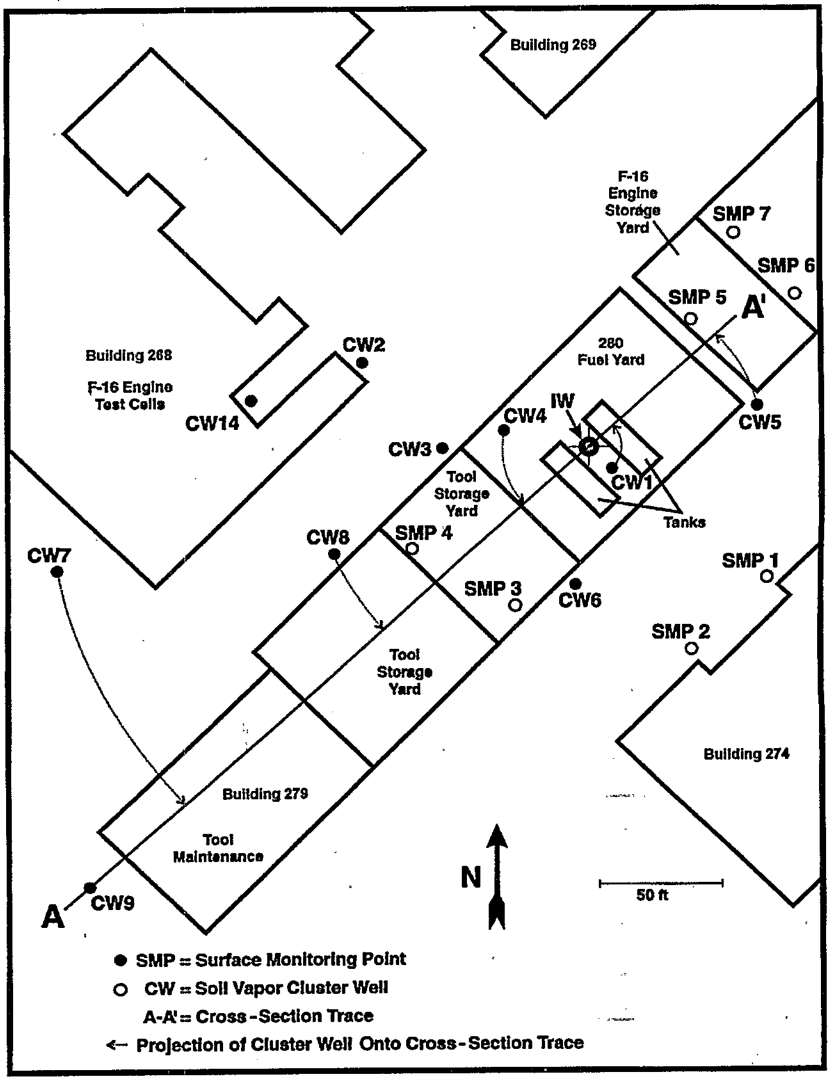


Figure 4. Plan view of Hill AFB site with soil gas cluster wells (CW), surface monitoring points (SMP), and injection well (IW).

Table 2 shows the in situ and biodegradation rates, by cfm, collected between April 1991 and November 1994 from a cluster well (280-CW1) situated 13.5 ft from the injection well and from a cluster well (280-CW3) situated 63 ft from the injection well. The greatest influence on changes in the respiration rate with time is the drop in contaminant concentrations with time. It is difficult to see any influence of airflow rate on respiration rate. However, the surface emission rate was negligible at all flow rates. Thus, the maximum flow rate that produces minimal surface emissions was not determined. Adequate oxygen levels were obtained at the lowest flow rate (28 cfm).

Soil-Gas Permeability and Radius of Influence

Estimates of the soil's permeability to gas flow and the radius of influence of venting wells are important elements of a full-scale bioventing design. Onsite testing also can be used to determine the radius of influence, flow rate, and air pressure that can be achieved for a given well configuration (U.S. EPA and U.S. Air Force, 1995). When full-scale systems are being designed, these data are used to

Table 2.

In Situ Respiration and Biodegradation Rates for Hill AFB 280 Site Data Collected April 1991 Through November 1994											
Well	Depth (ft)	In Situ Respiration Rate (% oxygen/hr)					Biodegradation Rate (mg/kg/day)				
		4/91 (67 cfm)	9/92 (67 cfm)	6/93 (40 cfm)	10/93 (117 cfm)	10/94 (28 cfm)	4/91 (67 cfm)	9/92 (67 cfm)	6/93 (40 cfm)	10/93 (117 cfm)	10/94 (28 cfm)
280-CW1: (13.5 ft from IW)	20	0.119	0.016	0.008	0.009	0.007	2.27	0.313	0.164	0.193	0.151
	30	0.126	0.020	0.011	0.011	0.008	2.41	0.379	0.219	0.219	0.157
	40	0.080	0.079	0.022	0.017	0.009	1.52	1.51	0.448	0.359	0.189
	50	0.048	0.077	0.086	0.038	0.026	0.921	1.47	1.79	0.794	0.535
	60	0.014	0.010	0.023	0.011	0.011	0.270	0.182	0.482	0.229	0.227
	70	0.009	0.008	0.011	0.011	0.011	0.168	0.140	0.238	0.225	0.231
	80	0	0.001	0.012	0.013	0.019	0	0.126	0.248	0.260	0.386
	90	0.012	0.062	0.018	0.077	0.004	0.236	1.20	0.359	1.59	0.089
280-CW1: (13.5 ft from IW)	10	0.010	0.006	0.004	0.002	0.002	0.189	0.118	0.088	0.036	0.052
	20	0.032	0.008	0.006	0.003	0.004	0.607	0.154	0.121	0.069	0.082
	30	0.035	0.007	0.014	0.004	0.004	0.663	0.134	0.299	0.075	0.081
	40	0.026	0.013	0.006	0.003	0.003	0.494	0.258	0.132	0.058	0.064
	50	0.096	0	0.004	0	<0.001	1.83	0	0.079	0	0.002
	60	0.014	0.021	0.004	0.007	0.004	0.262	0.394	0.076	0.146	0.083
	70	0.004	0.030	0.009	0.007	0.004	0.069	0.565	0.193	0.155	0.082
	80	0.009	0.025	0.051	0.022	0.014	0.169	0.482	1.07	0.456	0.283
	90	0.038	0.002	0.043	0.016	0.008	0.727	0.042	0.979	0.324	0.163

space venting wells, size blower equipment, and ensure that the entire site receives a supply of oxygen-rich air to sustain in situ respiration. Assuming steady-state conditions, the soil-gas permeability value calculated for only the air injection at 280-IW was 0.057 darcy. The radius of influence at the 280 Site was estimated to be approximately 200 ft (from 73 ft at an injection rate of 20 cfm to 278 ft at 117 cfm).

Results

The biodegradation rate for TPH and BTEX at the 280 Site was determined by testing samples taken from 10 equal depths down to 100 ft. The samples were taken from within two separate zones: a radius of 25 ft from the injection well and a radius of between 25 and 75 ft from the injection well.

Samples taken from the 25-ft zone indicate that at every level (0 to 10 ft, 10.1 to 20 ft, etc.) except the 90.1 to 100 ft level, a significant reduction in the TPH level occurred over the course of the study. The mean reduction was about 1000 mg/kg: from 1,384 mg/kg in 1990 to 330 mg/kg in 1994, which represents a hydrocarbon removal rate of 0.5 to 0.75 mg/kg/day. These rates are lower than those recorded at most bioventing sites, but are significant. The most likely reason for the low rates is moisture limitation, as there was considerable variation in the moisture levels at the site. Moisture addition was not used because of the extensive development on the site made moisture addition infeasible, and researchers desired to test the feasibility of bioventing at the site without water addition.

Samples taken from the 25-ft to 75-ft zone indicated that while an overall reduction of TPH levels occurred, reduction occurred at only 5 of the 10 levels. The mean reduction was about 100 mg/kg; 179 mg/kg in 1990 to 80 mg/kg in 1994, which represents a hydrocarbon removal rate of .07 to .28 mg/kg/day (see Table 3 and Figures 5 and 6).

Like TPH levels within the 25-ft zone, BTEX levels decreased except at the 90.1 ft to 100 ft level. Over the course of the study, the levels fell from 312 mg/kg to 50 mg/kg. The final average BTEX concentration was 52 mg/kg. Like the TPH levels within the 25- to 75-ft zone, BTEX levels did not drop at all levels. In fact, the mean level was virtually unchanged from 1990 to 1994: from 55 mg/kg to 64 mg/kg (see Table 4 and Figures 7 and 8).

Table 3.

Summary of Mean Extractable TPH Levels in Soil Samples

Injection Well Zone	TPH Concentration (mg/kg)				Significantly Different
	1990/1991		1994		
	Mean	SD	Mean	SD	
<25 ft	1,384	1264	330	606	Yes, p = 0.001
25-75 ft	179	434	80	272	No, p > 0.1

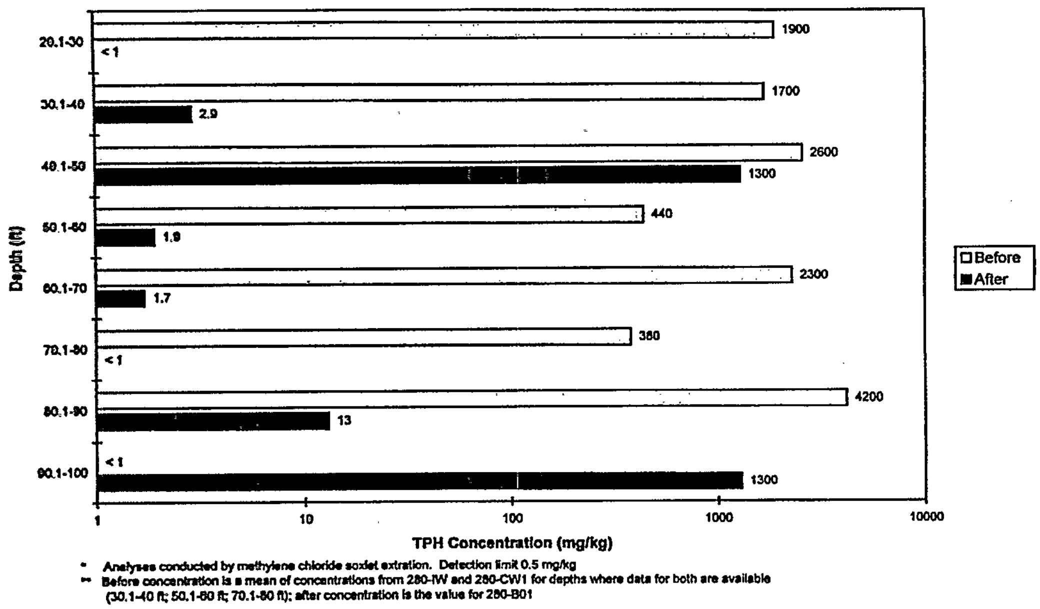


Figure 5. Comparison of extractable TPH concentrations within the IW 25-ft zone before (1990) and after (1994) air injection.

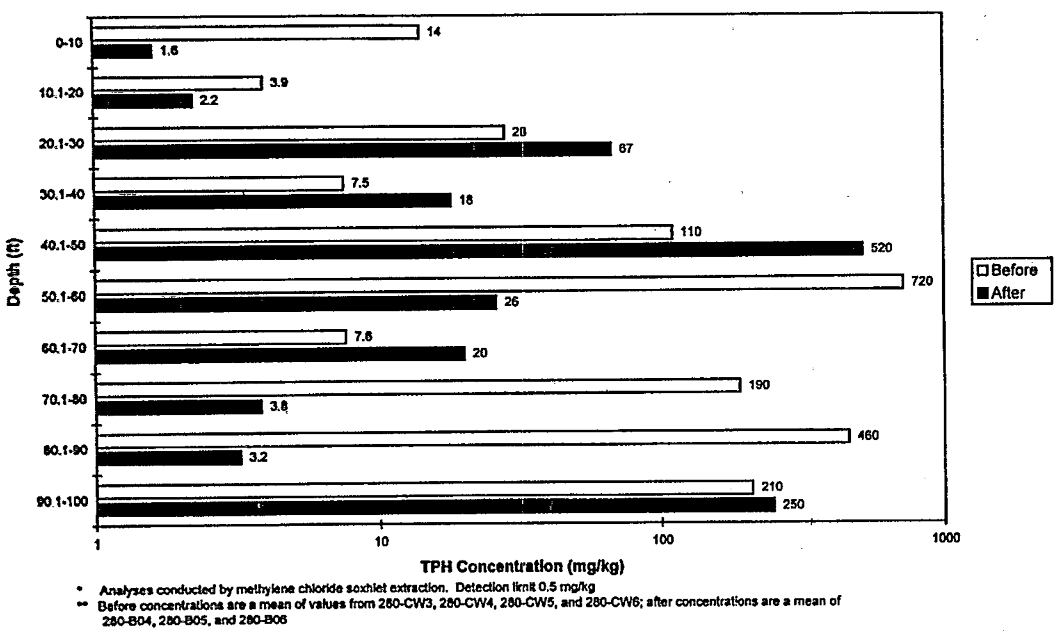


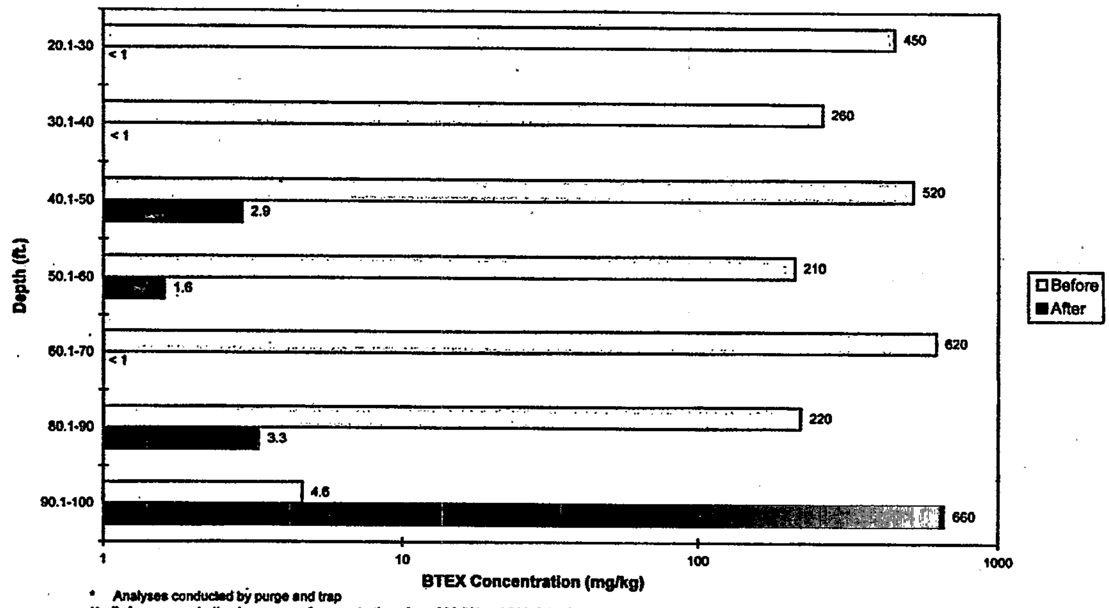
Figure 6. Comparison of extractable TPH concentrations within the IW 25- to 75-ft zone before (1990/1991) and after (1994) air injection.

Table 4.

Summary of Mean BTEX Concentrations in Soil Samples

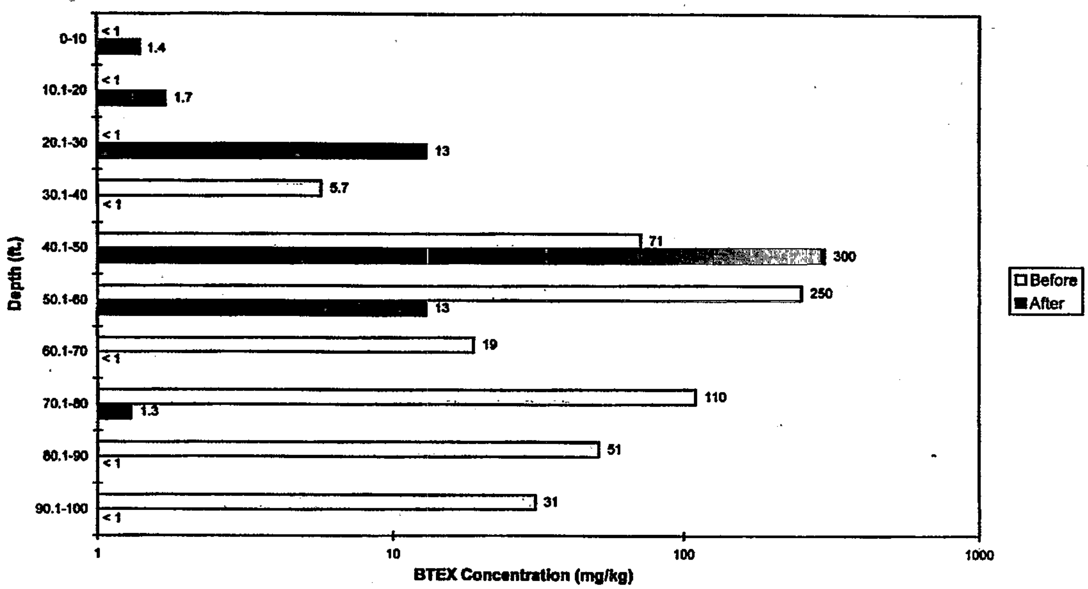
Injection Well Zone	TPH Concentration (mg/kg)				Significantly Different
	1990/1991		1994		
	Mean	SD	Mean	SD	
<25 ft	312	276	52	183	Yes, $p < 0.001$
25-75 ft	55	110	64	255	No, $p = 0.608$

One pattern observed for the 280 Site TPH and BTEX results was that the mid-range (40.1- to 50-ft) and deepest (90.1- to 100-ft) depth intervals generally showed an increase in TPH and BTEX levels after the air injection effort. One possible explanation for this may be the inability of the limited soil sampling conducted to accurately represent the heterogenous nature



* Analyses conducted by purge and trap
** Before concentration is a mean of concentrations from 280-IW and 280-CW1 for depths where data for both are available (30.1-40 ft; 50.1-60 ft; 70.1-80 ft); after concentration is the value for 280-B01

Figure 7. Comparison of BTEX concentrations within the 25-ft zone before (1990) and after (1994) air injection.



* Analyses conducted by purge and trap
** Before concentrations are a mean of values from 280-CW3, 280-CW4, 280-CW5, and 280-CW6; after concentrations are a mean of 280-B04, 280-B05, 280-B06

Figure 8. Comparison of BTEX concentrations within the IW 25- to 75-ft zone before (1990/1991) and after (1994) air injection.

represent the heterogenous nature of the hydrocarbon soil contamination. Thus, the high TPH and BTEX levels recorded for specific soil samples may represent a small pocket of contamination, and not the contamination for the entire 10-ft depth interval.

Surface emissions rates remained about the same with increasing airflow rates. More importantly, surface emissions rates during air injection were not significantly different from those during bioventing shutdowns (no injection). This was an important finding because it indicates that bioventing at the airflow rates evaluated does not increase emissions of volatilized contaminants.

Summary and Conclusions

Bioventing was successful in the remediation of vadose zone soils at the Hill AFB 280 Site. Final soil sampling conducted in December 1994 revealed that TPH and BTEX levels had declined at all but one soil depth within a 25-ft radius of the injection well. Only at a depth of 90 to 100 ft (at the capillary fringe) did TPH and BTEX levels fail to decline, suggesting that the capillary fringe was not adequately aerated. These results help demonstrate the feasibility and effectiveness of bioventing at the airflow rates evaluated.

Key findings of the study include the following:

- In the more contaminated soils (within 25 ft of the injection well) hydrocarbon concentrations were significantly reduced from initial average TPH concentrations of 1,384 mg/kg to final average concentrations of 330 mg/kg, and from initial average BTEX concentrations of 312 mg/kg to final average BTEX concentrations of 52 mg/kg.
- The in situ respiration test provided a reasonably good indication of the biodegradation rate in the most contaminated zone (within 25 ft of the injection well). In situ respiration testing estimated an average rate of 0.53 mg/kg/day, while soil sampling indicated an average rate of 0.75 mg/kg/day.
- Hydrocarbon concentrations did not increase in surrounding cleaner soils as the result of air injection
- Surface emission testing found no measurable emission of hydrocarbons to the atmosphere as a result of air injection.
- The radius of influence was measured to range from 73 ft at 20 cfm to 278 ft at 117 cfm.

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