Case Study Abstract

Soil Vapor Extraction and Bioventing for Remediation of a JP-4 Fuel Spill at Site 914, Hill Air Force Base, Ogden, Utah

Site Name: Hill Air Force Base, Site 914 **Location:** Ogden, Utah	**Contaminants:** Total Petroleum Hydrocarbons (TPH) - TPH concentrations in untreated soil ranged from <20 to 10,200 mg/kg with average soil TPH concentration of 411 mg/kg	**Period of Operation:** October 1988 - December 1990 **Cleanup Type:** Full-scale cleanup
Vendor: Not Available **SIC Code:** 9711 (National Security) **Waste Source:** Spill of JP-4 Jet Fuel **Purpose/Significance of Application:** One of the early applications involving sequential use of SVE and bioventing technology.	**Technology:** Bioventing Preceded by SVE <u>Bioventing</u> - 4 vent wells (Numbers 12-15) located on the southern perimeter of the spill area; 31 monitoring wells; 3 neutron access probes (for soil moisture monitoring) - Vent wells approximately 50 feet deep with 4-inch diameter PVC casings, screened from 10 to 50 feet below ground surface - Monitoring wells - ranged in depth from 6 to 55 feet with 1-inch diameter PVC casings, screened from 10 to 50 feet below ground surface - No treatment of extracted vapors required (hydrocarbon concentrations <50 mg/L; use of catalytic incinerator not required) - Air flow - 250 acfm - Soil moisture - 6 to 12% - Nutrients added - C:N:P ratio of 100:10:10 <u>SVE</u> - 7 vent wells (Numbers 5-11 located in areas of highest contamination), 31 monitoring wells, 3 neutron access probes (soil moisture monitoring) - Vent wells approximately 50 feet deep with 4-inch diameter PVC casings, screened from 10 to 50 feet below ground surface - Plastic liner installed over part of spill area surface to prevent local air infiltration and bypassing of air flow to the vent well directly from the surface - Monitoring wells - range in depth from 6 to 55 feet with 1-inch diameter PVC casing and a 2-foot screened interval to the bottom of the well - Catalytic incinerator for extracted vapor - Air flow - 1,500 acfm (maximum), 700 acfm (typical)	**Cleanup Authority:** State: Utah **Point of Contact:** Robert Elliot OO-ACC/EMR 7274 Wardleigh Road Hill AFB, Utah 84055

Soil Vapor Extraction and Bioventing for Remediation of a JP-4 Fuel Spill at Site 914, Hill Air Force Base, Ogden, Utah (Continued)

Type/Quantity of Media Treated:
Soil
- 5,000 yds^3 contaminated by spill (surface area of 13,500 ft^2)
- Approximate extent of 10,000 mg/kg JP-4 contour covered area 100 by 150 feet
- Formation consists of mixed sands and gravels with occasional clay lenses
- Air permeability ranged from 4.7 to 7.8 darcies

Regulatory Requirements/Cleanup Goals:
- 38.1 mg/kg TPH
- Cleanup conducted under Utah Department of Health's "Guidelines for Estimating Numeric Cleanup Levels for Petroleum-Contaminated Soil at Underground Storage Tank Release Sites"

Results:
- Achieved specified TPH levels
- Average TPH soil concentrations in treated soil reduced to less than 6 mg/kg;
- 211,000 lbs of TPH removed in approximately 2 years of operation;
- Removal rate ranged from 20 to 400 lbs/day

Cost Factors:
- Total costs of $599,000, including capital and 2 years of operating costs
- Capital costs - $335,000 (including construction of piping and wells, other equipment, and startup costs)
- Annual operating costs - $132,000 (including electricity, fuel, labor, laboratory charges, and lease of equipment for 2 year operation)

Description:
In January 1985, an estimated 27,000 gallons of JP-4 jet fuel were spilled at the Hill Air Force Base Site 914 when an automatic overflow device failed. Concentrations of total petroleum hydrocarbons (TPH) in the soil ranged from <20 mg/kg to over 10,000 mg/kg, with an average concentration of about 400 mg/kg. The spill area covered approximately 13,500 ft^2.

The remediation of this spill area was conducted from October 1988 to December 1990 in two phases: the soil vapor extraction (SVE) phase followed by the bioventing phase. The SVE system included 7 vent wells (Numbers 5-11) located in the areas of highest contamination, 31 monitoring wells, and a catalytic incinerator. The typical air flow rate through the vent wells was 700 acfm, with a maximum of 1,500 acfm. In addition, a plastic liner was installed over part of the spill area surface to prevent local air infiltration and bypassing of air flow to the vent well directly from the surface. Within a year, the SVE system removed hydrocarbons from the soil to levels ranging from 33 to 101 mg/kg. Further reduction of the hydrocarbon concentration in the soil, to levels below the specified TPH limit, was achieved by using bioventing for 15 months. The bioventing system included 4 vent wells (Numbers 12-15), located on the southern perimeter of the spill area, and the monitoring wells used for SVE system. Because hydrocarbon concentrations were <50 mg/L in the extracted vapors, the catalytic incinerator was not required for this phase. Biodegradation was enhanced by injecting oxygen, moisture, and nutrients to the soil. Average TPH concentrations in the treated soil were less than 6 mg/kg.

The total capital cost for this application was $335,000 and the total annual operating costs were $132,000. In monitoring biodegradation rates, oxygen depletion was found to be a more accurate estimator of biodegradation rate than carbon dioxide formation. Carbon dioxide sinks, such as biomass, solubility in water, and reaction with the soil, limited the usefulness of carbon dioxide formation as a process control parameter.

TECHNOLOGY APPLICATION ANALYSIS

SITE

Operable Unit: Hill Air Force Base, area around Building 914 as shown on Figure 1.
City, State: Ten miles south of Ogden, Utah

TECHNOLOGY APPLICATION

This analysis addresses field application of soil vapor extraction (SVE) as well as field and bench scale application of bioventing. The two methods were used sequentially at the site.

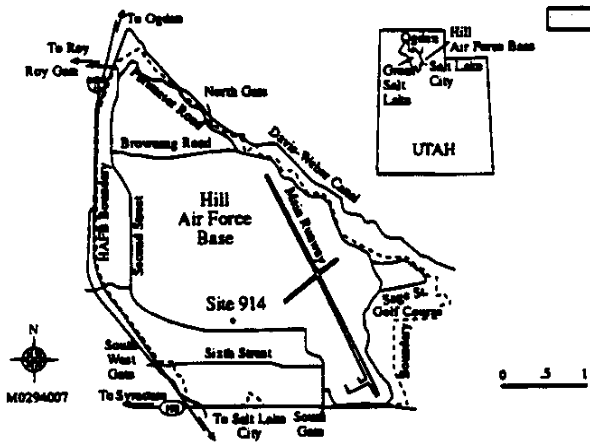


Figure 1. Location of Hill AFB, Utah and Site of JP-4 Fuel Spill (914 Site).

SITE CHARACTERISTICS

Site History/Release Characteristics

- Hill Air Force Base has been in operation since 1942, and Building 914 since 1972.
- In January 1985 27,000 gallons (estimated) of JP-4 jet fuel were released when an automatic overflow device failed. 2000 gallons were recovered as free product.
- The spill had an initial extent (Figure 2) of approximately 13,500 ft^2.
- No other fuel releases are documented; however, others are suspected to have occurred.
- Site remediation began in December 18, 1988.

Contaminants of Concern

- Specific contaminants of greatest concern in the unsaturated zone were: benzene, toluene, xylene, and ethylbenzene (BTEX). However, total petroleum hydrocarbon (TPH) concentration was more frequently monitored throughout the remediation due to relative ease of analysis compared to the specific compounds.
- Groundwater contamination was not an immediate concern because the groundwater is present only in discontinuous perched zones.
- No other specific compounds occurring in the original spill were identified.

Contaminant Properties

Properties of contaminants focused upon during remediation are provided below.

Property	Units	Benzene	Ethylbenzene	Toluene	Xylenes*
Empirical Formula		C_6H_6	C_8H_{10}	C_7H_8	C_8H_{10}
Density @ 20°C	g/cm³	0.88	0.87	0.87	0.87 (avg)
Melting Point	°C	5.5	-95	-95	-47.9 to13.3
Vapor Pressure (25°C)	mm Hg	96	10	31	9
Henry's Law Constant	(atm)(m³)/mol	5.59×10^{-3}	6.43×10^{-3}	6.37×10^{-3}	7.04×10^{-3}
Water Solubility	mg/l	1,750	152	535	198
Octanol-Water Partition Coefficient;	Kow	132	1410	537	1830
Organic Carbon Partition Coefficient; Koc	ml/g	83	1,100	300	240
Ionization Potential	ev	9.24	8.76	8.5	8.56
Molecular Weight		78.12	106.18	92.15	106.18

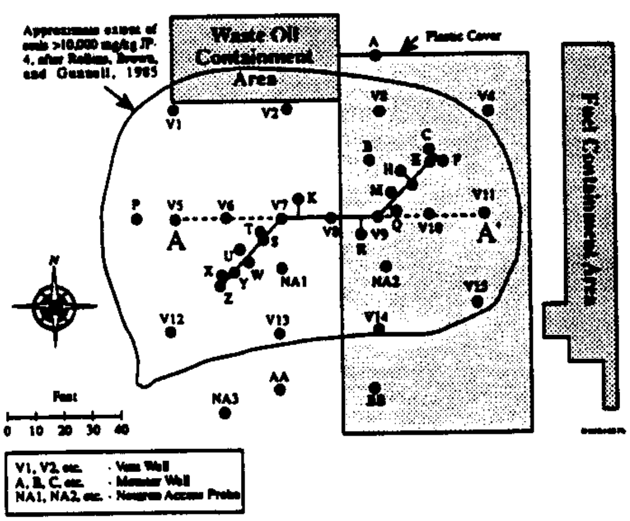
*All 3 isomers (M, O, & P)

Nature & Extent of Contamination

Remedial investigation field activities at the site provided TPH concentrations as shown in Figures 2 and 3 and as described below.

- In January 1985, approximately 27,000 gallons of JD-4 jet fuel were accidentally released, of which about 2,000 gallons were recovered as free product.
- It was estimated that 5000 cubic yards of soil were contaminated by the spill.
- Soil samples were taken at each vent well location at five foot depth intervals down to 66 feet (see Figure 2).
- Soil concentrations were found to vary from <20 to 10,200 mg TPH per kg soil with an average of 411 (as of 10/88).
- Nine of the soil samples were analyzed for concentration of benzene, toluene and xylene. The benzene concentration was <20 mg/kg for all samples. The toluene concentration ranged from <20 to 308 mg/kg. The xylene concentration ranged from <20 to 600 mg/kg.

Figure 2. Hill AFB, Utah, Site Map Illustrating the Locations of Vent Wells and Monitoring Ports.



Contaminant Locations and Geologic Profiles

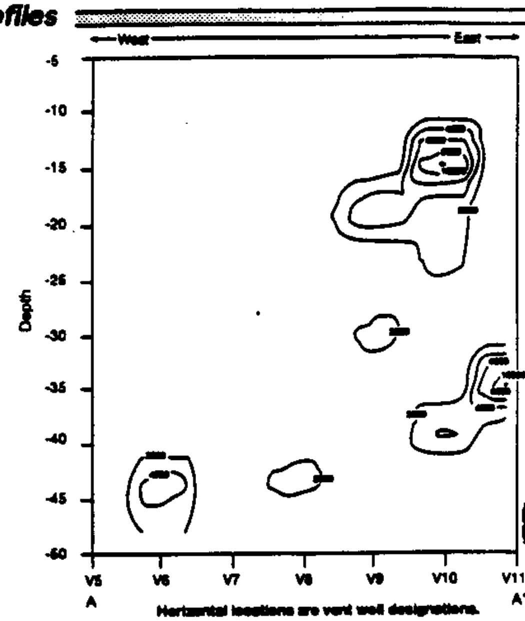


Figure 3. Vertical Isoconcentration View of Sampled Total Petroleum Hydrocarbon Concentration (mg/kg of soil) as a Function of Depth (ft.) Prior to soil Venting (10/88).

Hydrogeologic Units

- The spill is contained in the Provo formation, which is a delta outwash of the Weber River.
- The formation consists of mixed sands and gravels with occasional clay lenses.
- The formation extends to a depth of approximately 50 feet and is then underlain by a 200 to 300 foot thick clay layer.
- Areas of high TPH soil concentration appear to correlate with the presence of clay lenses.

Site Conditions

- Hill AFB elevation ranges from 5010 to 4570. The elevation in the vicinity of the spill is 4760 feet.
- The area has an arid climate with average ambient temperature of 58°F. The average minimum is 22°F, and the average high is 85°F.
- Precipitation averages 20.1 inches per year. With a maximum monthly precipitation of 6.4 inches occurring in May.
- The direction of groundwater flow at the site is from the east to the west.

Key Soil or Key Aquifer Characteristics

Property	Units	Range or value
Porosity	%	30 to 50
Particle density	g/cm³	0.3 to 0.5
Soil bulk density	g/cm³	0.37 to 0.48
Particle diameter	mm	0.8 to 10
Soil organic content	%	0.08 to 0.86
Moisture content	%	1.4 to 18% with average of <6%
Permeability	cm²	10^{-12} to 10^{-10}
Hydraulic conductivity	cm/s	10^{-12} to 10^{-10}
Air conductivity	darcy	4.7 to 7.8
Depth to groundwater	ft	variable due to arid conditions, approximately 50 ft.
Groundwater temperature	°C	10 to 12
Groundwater pH @ 25°C		7.2 to 7.5
Aquifer thickness	ft	10 to 15

TREATMENT SYSTEM

- Both soil vapor extraction (SVE) and bioventing were used at this site. Bioventing is still active.
- Both soil vapor extraction and bioventing use forced air flow through the contaminated formation. However, each method is used for a different purpose and is optimized for different operating conditions.
- SVE normally uses significantly higher air flow rates than does bioventing. The higher air flow acts to strip the hydrocarbons, transferring them from the soil to the gas phase.
- Soil vapor extraction is more applicable to treating high concentrations of volatile hydrocarbons.
- SVE will remove hydrocarbons from the pore space thereby preparing the soil for bioremediation. Some bioremediation also occurs during SVE.
- With bioventing, air flow aerates the soil to promote biological conversion of the hydrocarbon to biomass, CO_2 and H_2O. The CO_2 and the H_2O are removed in the gas phase. Bioventing can be used to treat less volatile hydrocarbons.

Overall Process Schematic

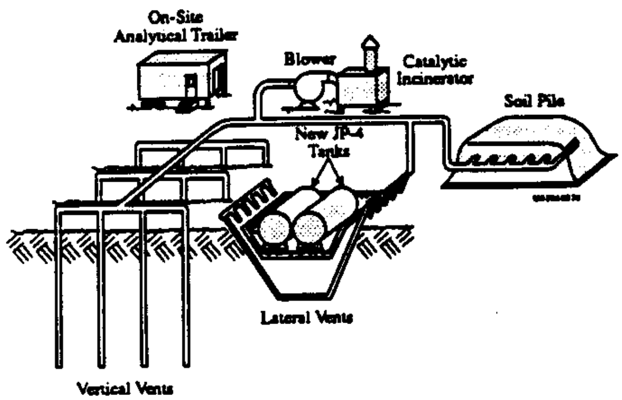


Figure 4. Conceptual drawing of the Hill AFB, Utah, Field Soil Venting Site.

System Description

- The treatment system as shown in Figures 2 and 4 and as described below consists of 15 vent wells, 31 monitor wells and 3 neutron access probes. The system also uses a single background vent well, which is not shown on the figures.
- Vent wells allow for soil gas to be actively removed from the formation. The monitor wells are used to analyze *in situ* soil gas composition and measure vacuum efficiency. The neutron access probes extend to a depth of 50 feet and are used to monitor soil moisture.
- The background vent well is similar in design and operation to the other vent wells but is located 700 feet north of the spill site and is used to establish baseline soil gas conditions in the uncontaminated formation. A separate blower was used with the background vent well.
- A plastic liner was installed over part of the spill area surface to prevent local air infiltration and bypassing of air flow to the vent well directly from the surface.
- Additional equipment shown in Figure 4 includes the blower (two in parallel), catalytic incinerator, and associated manifold piping.

System Operation

Soil Vapor Extraction Phase

- The blower suction is connected via the manifold piping to vent wells 5 through 11 which are located in the contaminated formation.
- Air flow is induced from the ground surface, through the contaminated formation, into the vent manifold, to the blower and finally discharged through the catalytic incinerator.
- A plastic lining restricts air flow directly from the surface to the vent wells, requiring the air flow into a longer path laterally across the formation to the vent wells
- The catalytic incinerator is used to destroy hydrocarbon gasses that are vented from the formation.

Bioventing Phase

- After it was determined that the soil vapor extraction was no longer efficient for removing hydrocarbons from the formation, the bioventing phase was initiated by changing the blower suction manifold to wells 12 through 15, on the periphery of the contaminated formation.
- Soil gas was drawn from the wells (with additional soil gas being drawn from a soil pile remediation project) at a reduced flow rate. At this flow rate, the total hydrocarbon concentration was reduced to below 50 mg/l. The incinerator, therefore, was not required and was permanently removed from service.

Well Design Close-Up

The vent wells are all approximately 50 feet deep. They all have 4 inch diameter PVC casing and a screened interval of 40 feet. The screened interval begins approximately 10 feet below ground surface The depth of the monitor wells varies from 6 to 55 feet. They all have 1 inch diameter PVC casing and a 2 foot screened interval at the bottom of the well. The details of the well design are shown in Figure 5. The following table gives the depth at the bottom of each monitor well designated in Figure 2.

Well	Depth (ft)	Well	Depth (ft)	Well	Depth (ft)
A	30	M	25	W	25
B	6	N	48	X	6
C	40	P	30	Y	55
E	25	Q	30	Z	25
F	25	R	30	AA	30
H	46	S	6	BB	30
J	30	T	55		
K	25	U	6		

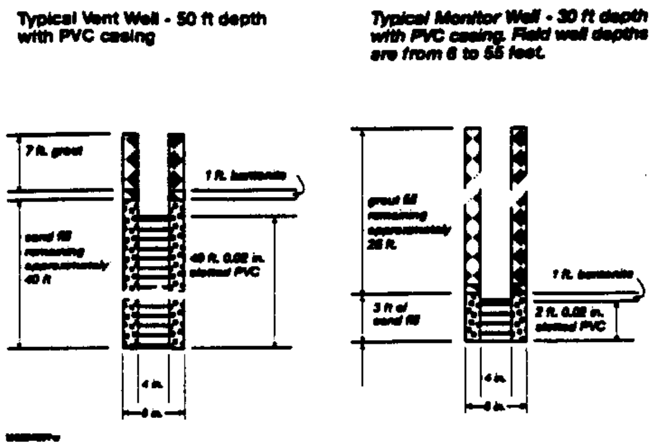


Figure 5 - Typical Well Design

Key Design Criteria

No specific design criteria were established in the document. However, for SVE key design criteria would include the following:

- vacuum pressure in the wells
- air flow rate through the vent wells
- air temperature in the wells
- hydrocarbon composition in the vent gas

For bioventing operations, key design criteria would include:

- soil moisture content
- soil gas oxygen concentration at monitor wells
- soil nutrient concentration
- hydrocarbon composition in the soil

Key Monitored Operating Parameters

SVE parameters monitored

- Total blower flow rate in acfm (actual cubic feet per minute - continuous measurement).
- Air flow Rate for a set of wells (continuous measurement).
- Offgas percent oxygen (continuous measurement).
- Offgas percent carbon dioxide (continuous measurement).
- C13/C12 isotope ratio (intermittent measurement).

Bioventing parameters monitored

- Soil Moisture content (intermittent measurement).
- Soil TPH content (intermittent measurement).
- Soil vapor Hydrocarbon concentration (intermittent measurement).
- *In situ* soil vapor percent oxygen content (continuous measurement).
- *In situ* soil vapor percent carbon dioxide (continuous measurement).

PERFORMANCE

Performance Objectives

- Remediate the site so that soil TPH is within the limit set by the Utah Department of Health (38.1 mg/kg).
- Determine the affect of SVE at the site.
- Determine the affect of bioventing at the site.
- Conduct a bioventing/soil venting study that will generate sufficient data to demonstrate effectiveness and provide support for designs at other similar sites.

Treatment Plan

Initial Phase

- Determine the extent of site TPH contamination by taking soil samples in the wells at five foot depth intervals. The TPH concentration is determined by gas chromatography. A plot of this data is given in Figure 3.

Soil Vapor Extraction Phase (bioventing is not optimized during this phase)

- Perform SVE with a maximum 1500 acfm (700 acfm is typical) flow for the site. Vent gas is collected through vent wells 5-11, which are located in the areas of highest contamination. The system operation is 24 hours per day.
- Measure effectiveness of SVE by monitoring the air flow rate and the exit soil gas concentration. (This data was not presented in the report).
- Measure the effectiveness of bioventing by continuously monitoring the concentration of soil gas O_2 and CO_2. If a typical hydrocarbon composition is assumed, the amount of hydrocarbon degraded can be calculated by comparing either the rise in CO_2 or the decrease in O_2 relative to the background concentrations. This method should give a conservative estimate since hydrocarbon converted to biomass or partially degraded to another organic compound is not accounted for.
- Cease venting operations at three points in time and allow for "natural" biodegradation to occur. Measure the effective respiration as depletion of soil O_2 concentration. This allows for determination of the rate of reaction (biodegradation) and the associated rate constant.
- Qualitatively analyze the CO_2 which occurs in the soil gas. Use the C13 / C12 isotope ratio to determine the origin of the carbon in the CO_2. The testing should be able to differentiate CO_2 which is from the atmosphere, hydrocarbon-based, and derived from carbonate rock .

Interim Phase

- Determine the extent of site TPH contamination by taking soil samples near the wells at five foot depth intervals. The TPH concentration is determined by gas chromatography. Note, this data set is not as complete as the initial data set. No plot is provided.

Bioventing Phase (bioventing is optimized during this phase)

- Reduce the air flow rate from 1500 acfm to 250 acfm. Redirect the air flow so that vent wells on the perimeter of the of the site are used for vapor extraction. These steps increase the residence time for biodegradation. Also, soil moisture is removed at a slower rate at the reduced air flow. The system operation is 24 hours per day.
- Add water to the spill site surface to increase the soil moisture level to between 6 and 12%.
- Add nutrients, such as phosphates, nitrates, and ammonia, with water to the spill site. The nutrients were added in a C:N:P ratio of 100:10:10 based on the soil TPH analysis taken in 9/89.
- Perform *in situ* respiration tests to determine the effectiveness of the steps to promote biodegradation. Soil gas O_2 monitoring was used to calculate the mass of hydrocarbon degraded in this phase.

Final Phase

- Determine the extent of site TPH contamination by taking soil samples in the wells at five foot depth intervals. The TPH concentration is determined by gas chromatography.

Results

- Figures 6 and 7 show the results of three successive respiration tests at monitor wells M and Y, respectively. Oxygen is consumed at a reduced rate at monitor well Y over the course of the respiration tests. The final test shows virtually no oxygen depletion in the area. This indicates a low level of biological degradation occurring. The low rate of degradation may be due to reduced soil hydrocarbon (i.e. remediation is nearly complete) or to low levels of soil moisture. Soil moisture would tend to be depleted due to the relatively high air circulation rates established for SVE. At site M, the O_2 depletion rate (biodegradation rate) increases with successive respiration tests. This is a location below the plastic cover. The data indicates that remediation is not complete and that the area was formerly oxygen starved.
- Figures 8 and 9 show soil gas concentrations of O_2, CO_2, and hydrocarbon at the monitor well locations and the vent well locations after the conclusion of the third respiration test. The data show that high levels of O_2 correlate with low levels of hydrocarbon and CO_2. In general, a high level of oxygen with little carbon dioxide or hydrocarbon suggests that any JP-4 originally in the soil has been removed. Also, note that vent well hydrocarbon levels are all lower than the monitor well levels. This occurs because the 40 foot screen of the vent wells collects a composite sample of the soil gas in the vicinity. As a result, local areas of high concentration are diluted.

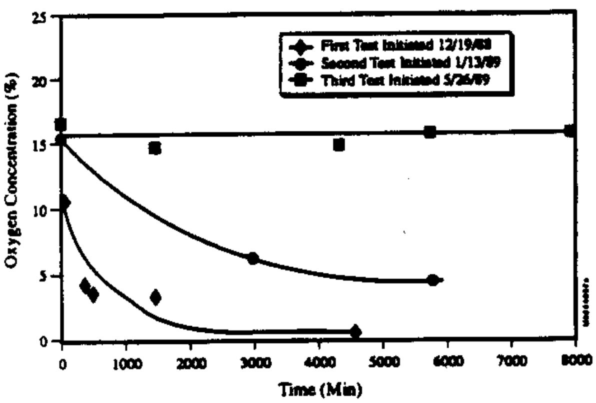


Figure 6. The Results of the Three Successive In Situ Respiration Test at Monitoring Point Y (65 feet below land surface), Hill AFB, Utah.

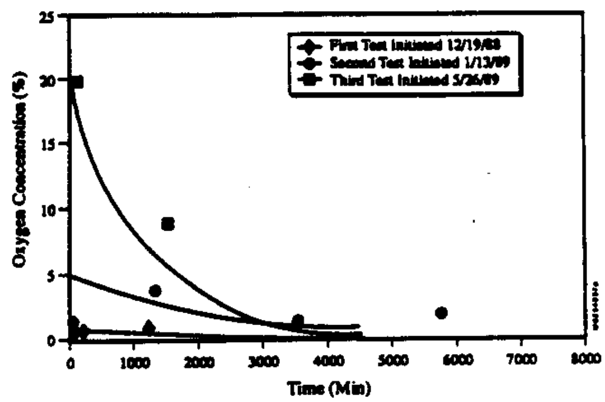


Figure 7. The Results of the Three Successive In Situ Respiration Test at Monitoring Point M (25 feet below land surface), Hill AFB, Utah.

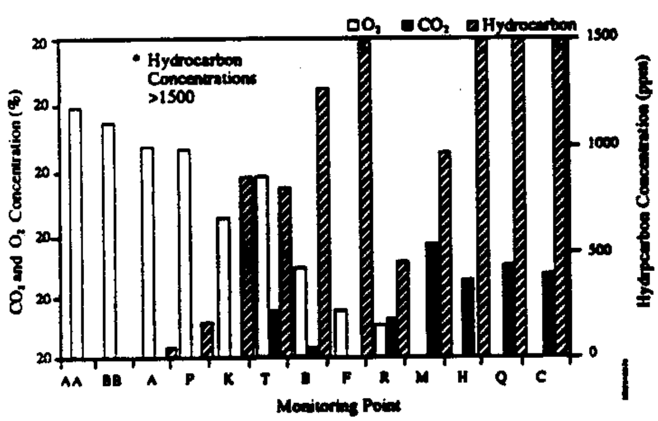


Figure 8. JP-4 Hydrocarbon (HC), O ,and CO ,Concentrations 9 June 1989 in the Monitoring Points at the Conclusion of the Third In Situ Respiration Test.

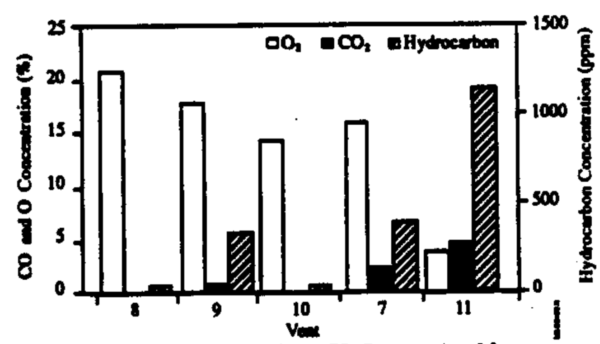


Figure 9. JP-4 Hydrocarbon (HC), O_2 and CO_2 Concentrations 9 June 1989 in the Vents at the Conclusion of the Third In Situ Respiration Test.

- The carbon isotope study is used to determine the origin of CO_2 in the soil gas. The possible sources include the atmosphere, degraded hydrocarbon, and decomposition of carbonate rock in the formation. The isotope ratio is characteristic of a given source of carbon. The laboratory analysis shows that vent gas CO_2 has an isotope ratio characteristic of petroleum and that less than 0.2% of the soil gas volume is due to CO_2 not derived from the JP-4.

Operational Performance

Volume of air circulated

The following table and figure show the air flow volumes and the affect on TPH removal.

As of Date	Total vented soil gas in 1000's of acf
12/18/88	0
12/19/88	42.5
1/13/89	540
4/1/89	8642
5/26/89	45,000
9/30/89	167,000
11/14/90	512,000

- Figure 10 shows how the fraction of hydrocarbon removal due to bioventing has been affected by the changing air flow rates. In general, as the air flow rate is reduced, removal due to SVE decreases. The rate of biodegradation is unchanged, but the relative contribution of biodegradation increases.

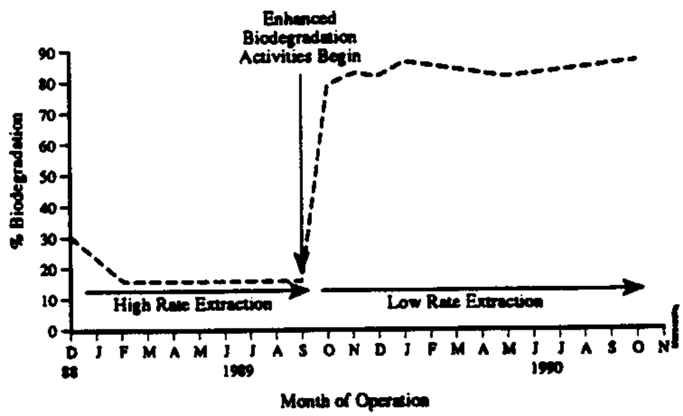


Figure 10. Percent of Recovered Hydrocarbon Attributed to Biodegradation Reactions at the Hill AFB, Utah, Soil Venting Site Based on Oxygen Consumption in the Vent Gas

Volume of water added

As of Date	Total gallons of water added to surface	Average water flow rate - gpm
5/28/90	0	—
9/21/90	1,000,000	30

Mass of nutrients added

- 300 lb of N as ammonium nitrate, 30 lb of P as treble superphosphate were added to the soil.
- Nutrients were added in three phases from 8/10/90 to 9/21/90. The nutrients were applied by direct surface addition, tilling of the first six inches of soil, and irrigation of the area.

System Downtime

SVE system was down for six days because the hydrocarbon vapor catalytic incinerator was out of service.

Treatment Performance

Total Pounds Contaminants Removed

As of Date	Cumulative lbs of TPH removed by vapor extraction	Cumulative lbs of TPH removed by bioventing	Cumulative lbs of TPH removed	Rate of TPH removal lb/day by vapor extraction
12/18/88	0	0	0	200-400
9/30/89	114,400	23,200	137,600	200-400
10/1/89	114,400	23,200	137,600	20
11/14/90	118,200	92,900	211,100	(not given)

- Figures 11 and 12 show the estimated cumulative hydrocarbon removal due to soil vapor extraction and bioventing as a function of time.

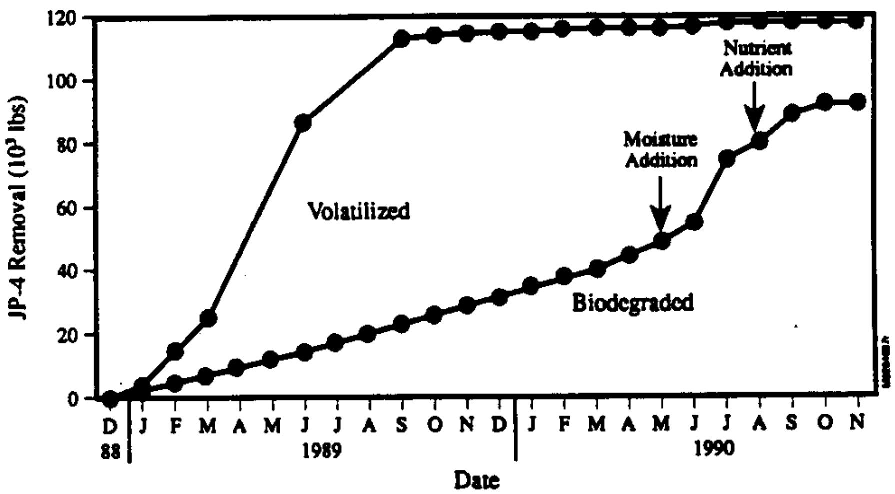


Figure 11. Cumulative Hydrocarbon Removal (Volatilized and Biodegraded) at Hill AFB, Utah, Soil Venting Site (from 18 December 1988 to 14 November, 1990)

Performance Assessment

- It is estimated that 211,000 lb of hydrocarbon were removed from the site as a result of SVE and bioventing. The original spill was estimated at 27,000 gallons. At the time of the spill, 2000 gallons of free liquid were recovered. If a specific gravity of 0.75 is assumed for the remaining hydrocarbon, the mass of the spill would be approximately 156,200 lbs. Despite the discrepancy in the estimates, the soil sampling at the end of the remediation showed that the site was sufficiently cleaned to meet the regulatory requirements.

- Figure 13 shows the average soil hydrocarbon concentrations at initial, intermediate and final phases of the site remediation.

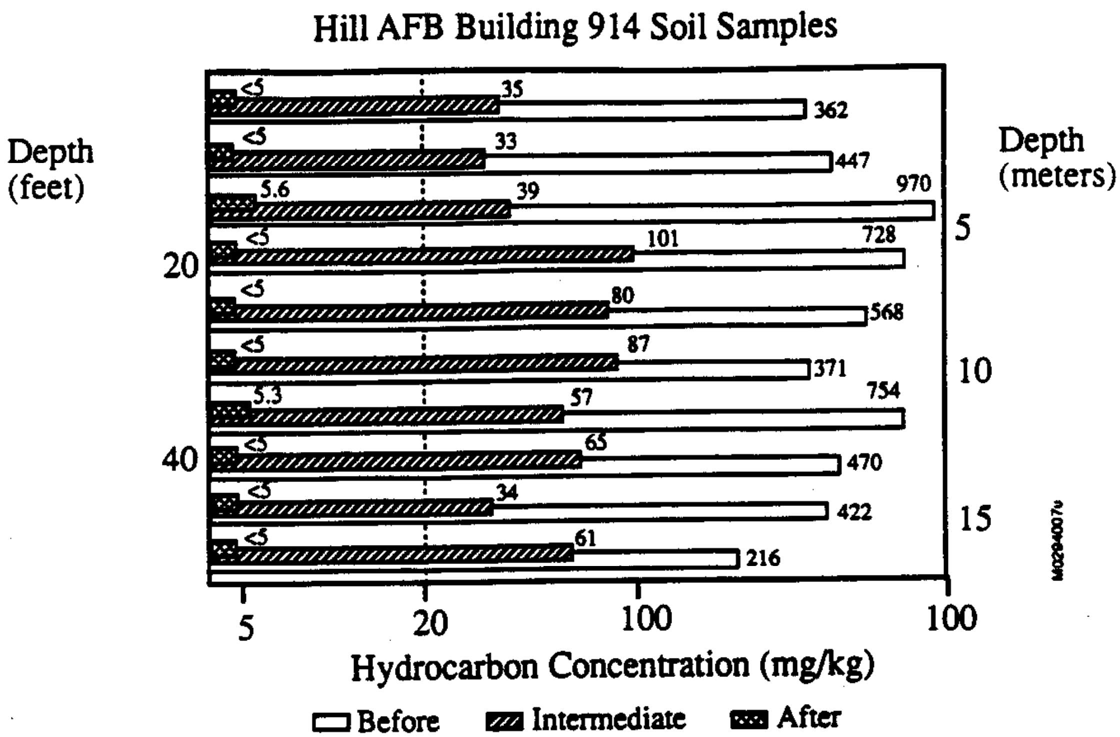


Figure 13. Mean Total Petroleum Hydrocarbon Concentrations at 5-Foot Intervals Prior to Venting (Before), After High RAte Operating Mode Venting but Before Low Flow Operating Mode with Moisture and Nutrient Addition (Intermediate), and After Low Flow Operating Mode with Moisture and Nutrient Addition (After).

- Following the demonstration, the state of Utah approved closure of the site.

COST

Capital Costs (thousands of dollars)

Construction of Piping System	$25
Construction of Wells	$130
Equipment Costs	$150
Startup Costs	$30
Total Capital Cost	$335

Annual Operating Costs (thousands of dollars)

Electricity (@ $0.07/kWhr)$	$13
Propane (@ $1.30/gal)	$24
Labor	$40
Laboratory Charges	$11
Maintenance Labor & Parts	$20
Lease of Incinerator	$24
Total Annual Operating Cost	$132

Cost Sensitivities (thousands of dollars)

Incinerator salvage value $10 (if originally purchased instead of leased)

REGULATORY / INSTITUTIONAL ISSUES

- The Davis County Health Department was involved in the planning stage of the SVE activities (1987).
- The site cleanup assessment was conducted subject to "Guidelines for Estimating Numeric Cleanup Levels for Petroleum-Contaminated Soil at underground Storage Tank Release Sites", which are criteria published by the Utah Department of Health.
- The recommended cleanup levels (RCL's) are presented for TPH, benzene, toluene, xylene, and ethylbenzene. These were derived from the above DOH guidelines by project personnel.
- The numerical levels are assigned based on the source of the spill (gasoline, diesel, or waste oil) and the environmental sensitivity of the area. The jet fuel has physical characteristics which lie between those for gasoline and diesel fuel. The RCL's are derived from the criteria for these listed fuels.
- Three levels of sensitivity are established based on the susceptibility of the groundwater to contamination from the spill leachate. Because of uncertainty in the ranking criteria, RCL's for Level I sensitivity (the lowest set of values) were used to assess the site cleanup.
- During combined SVE and bioventing operations, the catalytic incinerator was removed from service permanently once system modifications were made that reduced the soil vent gas hydrocarbon concentration below the permit limit of 50 mg/l.

Target Cleanup Levels/Criteria:

Contaminant	Level I RCL1 Soil mg/kg	Site maximum Soil mg/kg
TPH	65	38.1
Benzene	<0.2	<0.15
Toluene	<100	18
Xylene	<1000	2.5
Ethylbenzene	<70	<0.15

1. RCL's for specific aromatic compounds are for either gasoline or diesel releases. The RCL for JP-4 is midway between the value for gasoline and diesel.

SCHEDULE

Task	Start Date	End Date	Duration, months
Laboratory Studies	5/87	11/87	6
SVE Phase (ORNL)	10/88	9/30/89	12
Initial site soil analysis	10/88	—	—
First respiration test	12/19/88	12/22/88	—
Second respiration test	1/13/89	1/18/89	—
Third respiration test	5/26/89	6/9/89	—
Intermediate site soil analysis	10/89	—	—
Bioventing Phase (Battelle)	10/1/89	12/90	15
Nutrient addition tests	9/21/90	11/90	2
Final site soil analysis	12/90	—	—

LESSONS LEARNED

Key Operating Parameters

- SVE is preferable if the cleanup is required to proceed at a pace faster than that allowed by typical bioventing rates. However, provisions may be necessary for air emissions control.
- SVE is enhanced by high air flow rates and the presence of volatile hydrocarbons.
- Biodegradation is enhanced by adequate soil oxygen, moisture and nutrient level.
- Soil moisture appeared to have a greater impact than did nutrient level.

Implementation Considerations

- The system modifications required to decrease the soil gas hydrocarbon concentration below the permit limit included use of vent wells only at the periphery of the spill (areas of low soil TPH concentration) and reduced soil gas flow rates. These steps served to decrease the motive force for air stripping and increase the residence time for biodegradation.
- The above steps would enable direct venting to the atmosphere of the untreated soil gas, but the total time required to clean up the site would be increased.
- High air flow rates favor SVE but may retard biodegradation if too much soil moisture is removed or if contaminants do not have adequate residence time in the soil matrix.
- Contaminants (TPH) migrated in the formation over the course of the remediation activities. This was likely due to gravitational flow of the hydrocarbon, entrainment in seeping groundwater, or entrainment in the SVE air stream. Interim and final soil analysis should be sufficiently comprehensive to account for these possibilities.

Technology Limitations

- SVE is limited to hydrocarbons that are sufficiently volatile to allow air stripping.
- Bioventing is limited to hydrocarbons that can be degraded by the local bacteria. In addition, sufficient soil oxygen, moisture and nutrients are required.
- Estimates of biodegradation are more accurate if oxygen depletion rather than carbon dioxide formation is used. Various carbon dioxide sinks exist in the system. These would include biomass, solubility in water, and reaction with the soil. Oxygen is not as sensitive to these sinks.

Future Technology Selection Considerations

- The plastic cover did not result in significant air flow redirection at the spill site. This is probably because vent well screened intervals began at a depth of 10 feet and vertical hydraulic conductivity is lower than horizontal hydraulic conductivity at the site. Air distribution in the formation is in general an important parameter to address.
- Methods to optimize bioventing and SVE as a simultaneous process should be addressed in greater detail. However, at this site it was preferable to maximize bioventing (at the expense of SVE) in order to avoid air quality issues associated with the high vent gas flow rate.
- Soil chemistry criteria should be developed to establish when the application of nutrients would be beneficial to the bioventing process.

SOURCES

Major Sources For Each Section

Site Characteristics:	Source #s 1, 2, 3 (from list below)
Treatment System:	Source #s 1,4,5
Performance:	Source #s 1,4,5
Cost:	Source #s 1,4,5
Regulatory/Institutional Issues:	Source #s 1;4,5
Schedule:	Source #s 1,4,5
Lessons Learned:	Source #s 1,4,5

Chronological List of Sources

1. *Final Report for Hill A.F.B. JP-4 Site (Building 914) Remediation*, Battelle, Hill Air Force Base, Utah, July, 1991.
2. *Basics of Pump-and-Treat Ground-Water Remediation Technology*, EPA-600/8-90/003, Mercer et al., GeoTrans, Inc., Robert S. Kerr Environmental Research Laboratory, Ada, OK.
3. *CRC Handbook of Chemistry and Physics*, R. C. Weast and M. J. Astle, 62 nd ed., CRC Press, Boca Raton, FL., 1981.
4. Notes of telephone conversation between W. White (SWEC) and R. Elliott (Hill AFB) on 3/1/94 and 3/8/94.
5. Response to Stone & Webster letter (2/16/94) by R. Elliott received on 3/7/94.

ANALYSIS PREPARATION

This analysis was prepared by:

Stone & Webster Environmental Technology & Service

P.O. Box 5406

Denver, Colorado 80217-5406

Contact: Dr. Richard Carmichael 303-741-7169

REVIEW

Project Manager

This analysis accurately reflects the performance and costs of this remediation:

X Robert Elliott, P.E.

Mr. Robert Elliot

OO-ACC/EMR

7274 Wardleigh Road

Hill AFB, Utah 84055-5137