Case Study Abstract

Low-Intensity Bioventing for Remediation of a JP-4 Fuel Spill at Site 280 Hill Air Force Base, Ogden, Utah

<table>
<tr><td>Site Name:
Hill Air Force Base, Site 280</td><td rowspan="2">Contaminants:
Total Petroleum Hydrocarbons (TPH) and Benzene, Toluene, Ethylbenzene, Xylenes (BTEX)
- Soil TPH concentrations measured as high as 5,040 mg/kg
- Soil gas TPH concentrations measured as high as 11,200 ppm</td><td>Period of Operation:
Status - Ongoing
Report covers - 12/90 to 6/94</td></tr>
<tr><td>Location:
Ogden, Utah</td><td>Cleanup Type:
Full-scale cleanup (interim results)</td></tr>
<tr><td>Vendor:
Not Available</td><td rowspan="2">Technology:
Bioventing
- System consists of 1 injection well and 10 monitoring wells
- Air flow rate on blower discharge ranged from 20 to 117 acfm; operated since 11/93 at 20 acfm
- Blower discharge pressure of 2 in. of Hg</td><td>Cleanup Authority:
State: Utah</td></tr>
<tr><td>SIC Code:
9711 (National Security)</td><td>Point of Contact:
William James
Remedial Project Manager
Hill Air Force Base
Ogden, Utah</td></tr>
<tr><td>Waste Source:
Spills and other releases of JP-4 jet fuel</td><td colspan="2" rowspan="2">Type/Quantity of Media Treated:
Soil
- Soil-gas permeability value - 0.057 darcy
- Porosity 30 to 50%; moisture content 1.4 to 18%; air conductivity 4.7 to 7.8 darcies; particle density 0.3 to 0.5 gm/cm^3 and particle diameter 0.8 to 10 mm; soil bulk density 0.37 to 0.48 gm/cm^3; soil organic content 0.08 to 0.86%</td></tr>
<tr><td>Purpose/Significance of Application:
Bioventing to remediate soils contaminated with JP-4 jet fuel.</td></tr>
<tr><td colspan="3">Regulatory Requirements/Cleanup Goals:
- No specific cleanup goals established at this time
- Cleanup assessment will be conducted subject to "Guidelines for Estimating Numeric Cleanup Levels for Petroleum Contaminated Soils at Underground Storage Tank Release Sites," which are established by Utah Department of Health</td></tr>
<tr><td colspan="3">Results:
- Bioventing project was not complete at time of this report
- Respiration rate tests from 4/91 to 11/93 indicate hydrocarbon degradation is occurring
- As of 11/92, soil gas TPH concentration reduced to less than or equal to 2,600 ppm
- Estimates of the mass of contaminants removed have not yet been reported</td></tr>
<tr><td colspan="3">Cost Factors:
- Total Capital Cost (estimated) - $115,000 (including construction of piping system, buildings, process equipment, and startup)
- Total Annual Operating Cost (estimated over 4 years) - $24,000 (including labor, electricity, lab charges, maintenance, and monitoring)</td></tr>
</table>

Case Study Abstract

Low-Intensity Bioventing for Remediation of a JP-4 Fuel Spill at Site 280 Hill Air Force Base, Ogden, Utah (Continued)

Description:
As a result of spills and other releases of JP-4 jet fuel at the 280 Fuel Storage Lot at Hill Air Force Base in Ogden, Utah, soil was contaminated with total petroleum hydrocarbons (TPH) and benzene, toluene, ethylbenzene, and xylenes (BTEX). TPH concentrations were reported as high as 5,000 mg/kg in the soil and 11,200 ppm in the soil gas. A low-intensity bioventing system was installed at the site and has been in operation since December 1990. No specific cleanup goals have been established at this time. The final cleanup assessment will be conducted subject to "Guidelines for Estimating Numeric Cleanup Levels for Petroleum Contaminated Soils at Underground Storage Tank Release Sites", which are established by the Utah Department of Health.

The bioventing system includes one injection well (100 ft. depth) and 10 monitoring wells (varying depths). During the operation of this system, the air flow rate of the blower discharge had been varied between 20 and 117 acfm (at a discharge pressure of 2 in. of Hg) in order to optimize air flow rates while eliminating volatilization. Available data from respiration rate tests (4/91 to 11/93) indicate that hydrocarbon degradation is occurring. As of November, 1992, soil gas TPH concentrations had been reduced from 11,200 mg/kg to below 2,600 mg/kg. Estimates of the mass of contaminants removed have not yet been reported.

The estimated total capital cost for this application is $115,000. The total annual operating cost, estimated over 4 years, is $24,000 exclusive of final site characterization. During this application, it was noted that biodegradation is enhanced by maintaining adequate soil oxygen, moisture, and nutrient levels and that estimates of biodegradation are more accurate if oxygen depletion is used instead of carbon dioxide formation. In addition, it was noted that air flow rates can be optimized to low levels ranging from 40 to 67 acfm.

TECHNOLOGY APPLICATION ANALYSIS

SITE

Operable Unit: Hill Air Force Base, area around the 280 Fuel Storage Lot as shown on Figure 1.
City, State: Ten miles south of Ogden, Utah

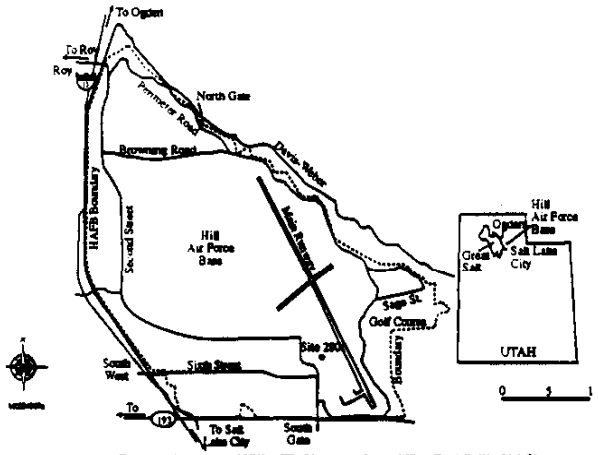


Figure 1. Location of Hill AFB, Utah and Site of JP-4 Fuel Spill (914 Site).

TECHNOLOGY APPLICATION

This summary addresses field application of bioventing and associated investigative methods performed in 1991 and 1992. Remedial activities at the site were carried out by the U.S. Air Force and the USEPA.

SITE CHARACTERISTICS

Site History / Release Characteristics

- Hill Air Force Base has been in operation since 1942, and the 280 Fuel Storage Lot has been in place since 1941.
- In 1989 four underground JP-4 jet fuel storage tanks (25,000 gal. each) were removed and replaced with two above ground tanks (25,000 gal. each).
- The most recent recorded spill in the area occurred in 1982. No other fuel releases are documented; however, others are suspected to have occurred during the life of the system.
- Site remediation began in November 1990. Figure 2 shows a detail of 280 Fuel Storage Lot and various wells and monitoring locations that have been installed.

Contaminants of Concern

- Specific contaminants of greatest concern in the unsaturated zone were: benzene, toluene, xylene, and ethylbenzene (BTEX). Total petroleum hydrocarbon (TPH) concentration was also monitored throughout the remediation due to relative ease of analysis compared to the specific compounds.
- Groundwater was found to be contaminated downgradient of the site. TPH as well as BTEX were found.
- Trichloroethylene was also found in the groundwater but was not a specific target of the bioventing operations.
- The soil vapor at the ground surface was found to have hydrocarbon levels within acceptable limits.

Contaminant Properties

Table 1
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 (20°C)	mm Hg	50	8.5	26	7.7
Henry's Law Constant (atm)(m3)/mol		5.59 X 10-3	6.43 X 10-3	6.37 X 10-3	7.04X 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 and BTEX concentrations as shown in Figures 2, 3, 4 and 5 and as described below.

- Figure 3 shows soil contamination by TPH at several cluster well locations as a function of depth down to the water table as sampled in September 1991. (Note that the wells are not in a straight line and that horizontal distances shown on the figure are the approximate radial distances from the injection well.)
- Figure 4 shows the soil gas TPH concentration in ppm as monitored in September 1991.
- Figure 5 shows the extent of BTEX contamination in the groundwater at the site as monitored in 1992. Note, BTEX plume has migrated downgradient from the fuel tank area.

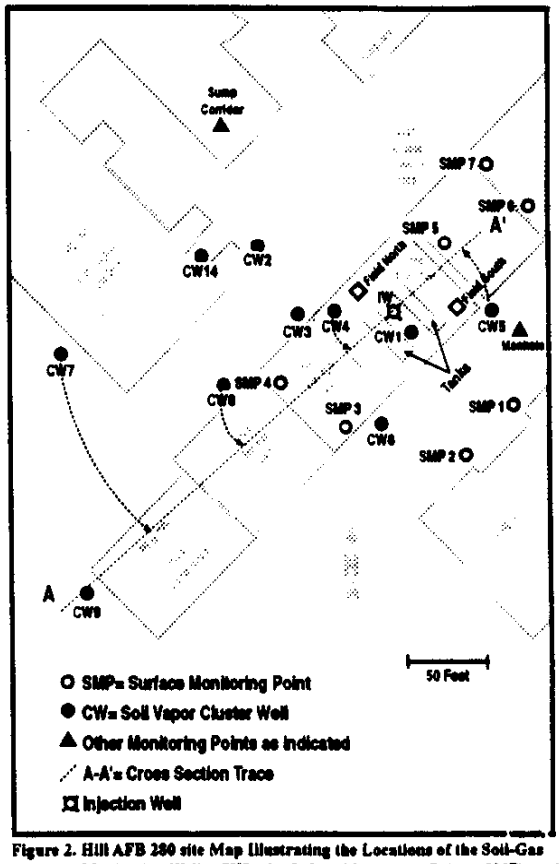


Figure 2. Hill AFB 280 site Map Illustrating the Locations of the Soil-Gas Monitoring Wells (CW), the Suface Monitoring Points (SMP), and the Injection Well (IW).

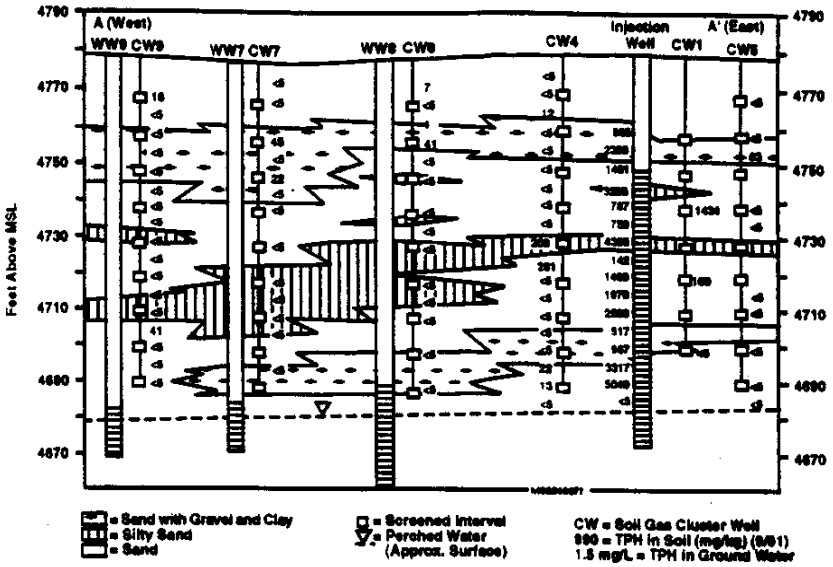


Figure 3. Geological Cross-section of the 280 Site Showing Known Geological Features and Soil Total Petroleum Hydrocarbon Concentrations (mg/kg); Data Collected September 1991.

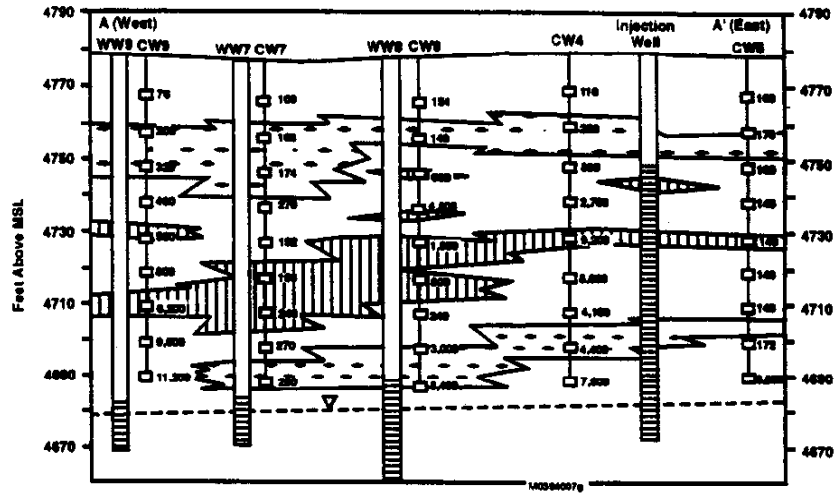


Figure 4. Geological Cross-section of the 280 Site Showing Known Geological Features and Soil-Gas Total Petroleum Hydrocarbon (ppm); Data Collected September 1991.

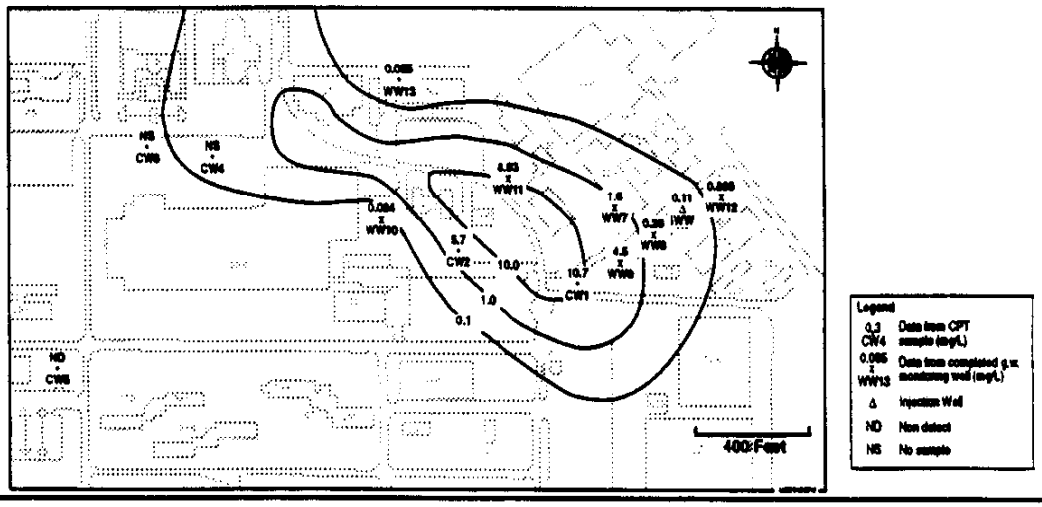


Figure 5. Site 280. Isoconcentration of BTEX Levels Determined from Groundwater Samples Collected During October 1992.

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, silts and gravels with occasional clay lenses. Figures 3 and the similar figures show the typical lithology in cross section.
- The formation extends to a depth of approximately 120 feet and is underlain by a 200 to 300 foot thick clay layer.
- The area contains three aquifers: the shallow aquifer, the Sunset aquifer and the Delta aquifer. The contamination is confined to the shallow aquifer. A water table map of the shallow aquifer (the perched water table) in the vicinity of the 280 Site is shown in Figure 6.
- Groundwater contamination in the shallow aquifer was found but was not an immediate concern to health because the groundwater is present only in discontinuous perched zones. In addition, groundwater is consumed either upgradient from the 280 Site in the shallow aquifer or from the confined Delta or Sunset aquifer.
- The shallow, Sunset and Delta aquifers (in descending order) occur beneath and contiguous to Hill AFB
- The depth to the shallow water table is from 100 to 110 feet bgs.
- The Delta and Sunset aquifers are not contaminated.
- There are buried utilities in the site area. These are not a conduit for contamination movement.
- No potable groundwater supply wells are thought to be affected by the site.

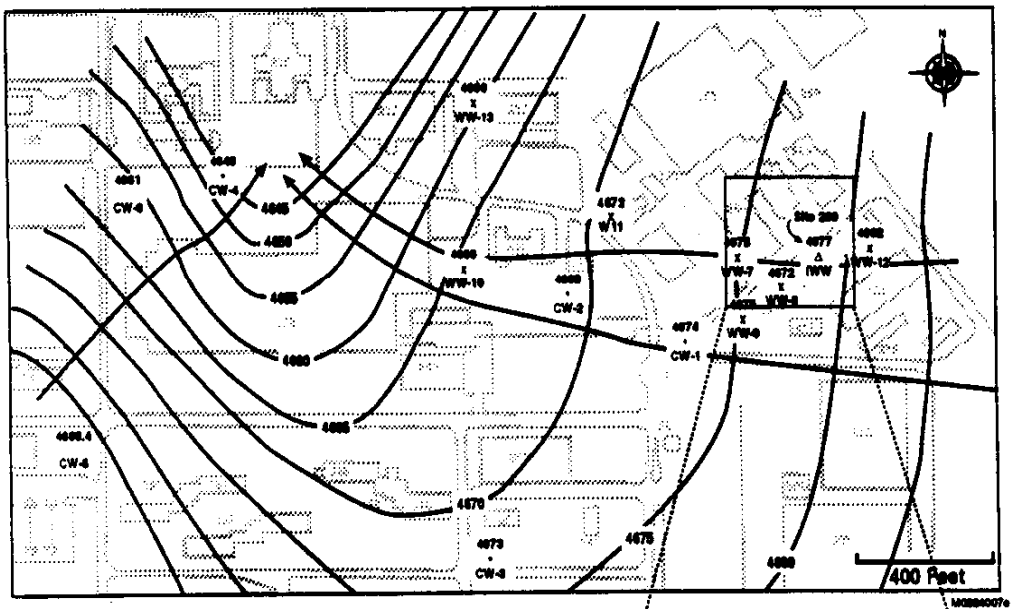
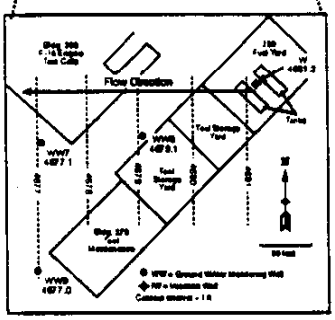
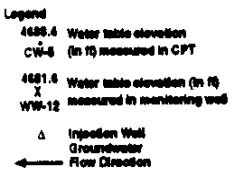


Figure 6. **Contour Map for Perched Water Table at Hill AFB Site 280; Data Collected October 1992.**





Site Conditions

- Hill AFB elevation ranges from 5010 to 4570. The elevation in the vicinity of the spill is 4780 feet.
- The area has an arid climate with average ambient temperature of 58°F. The average minimum temperature 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. Locally, at Site 280, the flow takes a northerly direction.

Key Soil or Key Aquifer Characteristics

Table 2

Property	Units	Range or value
Porosity	%	30 to 50
Particle density	g/cm^3	0.3 to 0.5
Soil bulk density	g/cm^3	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	cm^2	10^{-12} to 10^{-10}
Hydraulic conductivity	cm/s	10^{-12} to 10^{-10} (higher at Site 280 10^{-6} to 10^{-3})
Air conductivity	darcy	4.7 to 7.8
Depth to groundwater	ft	variable due to arid conditions, approximately 110 ft.
Groundwater temperature	°C	10 to 12
Groundwater pH @ 25°C		7.2 to 7.5
Aquifer thickness	ft	10 to 15

TREATMENT SYSTEM

System Description

- The treatment system consists of 1 injection well (IT), 10 monitor wells.
- Although not part of the treatment system, cone penetration tests were used to sample the groundwater at six locations. In addition, the soil vapor at the ground surface was monitored at seven locations (designated SMP on figure 2).
- The rate of diffusion and soil permeability of gas through the vadose zone was studied by several means:
  - Air was injected for several months at a constant rate from a single source and the subsurface pressure distribution and oxygen concentration were monitored.
  - A helium trace test was conducted from December 1992 through February 1993.
- The discharge of the blower is connected to the injection well from which air is distributed through the vadose zone and finally vented through the ground surface to maintain high oxygen concentrations in and remove carbon dioxide from the contaminated soil.

System Operation

- The blower was operated at various flow rates with a discharge pressure of 2 in. Hg. The blower was periodically turned off to allow for installation of additional wells or performance of *in situ* respiration tests.
- The blower flow rate is maintained so that hydrocarbon emission at the ground surface is at an acceptably low concentration.

Well Design Close-up

The well system consists of one injection well (280-IW), soil gas monitoring wells and water monitoring wells as noted the the table below.

Table 3 - Injection and Monitoring Wells

Well Designation	Depth, ft.	Comments	Casing Size, inches	See Figure
280-IW	100	Injection Well	4	2
280-CW1	91	Soil gas monitoring at 10 ft. intervals	1.25	2
280-CW2	91	Soil gas monitoring at 10 ft. intervals	1.25	2
280-CW3	91	Soil gas monitoring at 10 ft. intervals	1.25	2
280-CW4	90	Soil gas monitoring at 10 ft. intervals	1.25	2
280-CW5	90	Soil gas monitoring at 10 ft. intervals	1.25	2
280-CW6	90	Soil gas monitoring at 10 ft. intervals	1.25	2
280-CW7	90	Deep soil gas monitoring well	4	2
280-CW8	90	Deep soil gas monitoring well	4	2
280-CW9	90	Deep soil gas monitoring well	4	2
280-WW7	107	Screened 5 ft. above and 10 ft. below water table and soil gas monitoring at 2.5, 5, 7.5, and 10 ft.	4	6
280-WW8	125	Screen from 90 ft. to 125 ft. and soil gas monitoring at 2.5, 5, 7.5, and 10 ft.	4	6
280-WW9	110	Screened 5 ft. above and 10 ft. below water table and soil gas monitoring at 2.5, 5, 7.5, and 10 ft.	4	6
280-WW10	124	Water Sampling Well	4	6
280-WW11	115	Water Sampling Well	4	6
280-WW12	109.5	Water Sampling Well	4	6
280-WW13	124	Water Sampling Well	4	6
280-WW13	139	Water Sampling Well	4	6
280-WW14	92	Soil gas monitoring at 2.5, 5, 7.5, and 10 ft. Than each 10 ft.	1.25	2

Key Design Criteria

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

- vadose zone air conductivity;
- soil moisture content;
- soil gas oxygen concentration at monitor wells;
- soil nutrient concentration; and
- hydrocarbon composition in the soil;

Key Monitored Operating Parameters

- Total blower flow rate in acfm (actual cubic feet per minute - continuous measurement).
- Soil moisture content (intermittent measurement).
- Soil TPH content (intermittent measurement).
- Air pressure in the vadose zone.
- Soil vapor hydrocarbon concentration (intermittent measurement).
- Soil vapor % oxygen content (intermittent measurement).
- Soil vapor % carbon dioxide content (intermittent measurement).
- Concentration of helium in the vadose zone.

PERFORMANCE

Performance Objectives

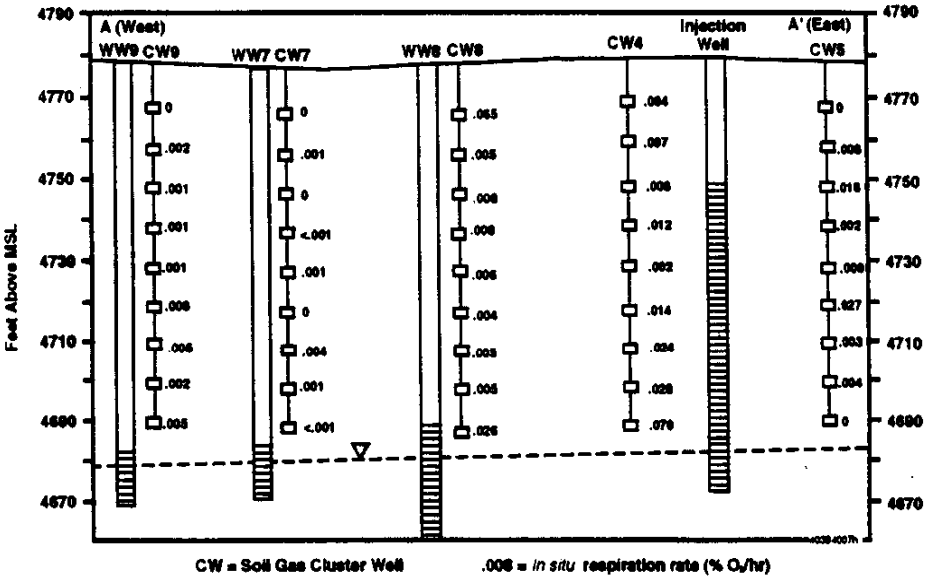
- Remediate the site.
- Optimize the airflow rates to maximize bioremediation while eliminating volatilization.
- Determine the affect of bioventing at the site.
- Determine airflow parameters in the vadose zone.

Treatment Plan

- A study was conducted to determine the extent of contamination at Site 280 by taking soil and gas samples in a number of wells. (See Figures 3 through 5.)
- A pilot scale , low-level bioremediation, treatability study was conducted for site characterization.
- *In situ* respiration tests were performed to determine the effectiveness of each air injection flow rate step in promoting biodegradation. Soil gas O_2 monitoring was used to calculate the mass of hydrocarbon degraded in this phase.
- The extent of site contamination was determined by taking soil samples in the wells at five foot depth intervals and the TPH and BETX concentrations were determined by gas chromatography.
- The treatment of site 280 is ongoing and not complete as of June 1994.

Preliminary Results

- Figures 7 shows the results of the preliminary respiration test at monitor wells CW4, CW5, CW7, CW8 and CW9. Oxygen was consumed at all monitoring the wells tested. This indicates biological degradation occurring when oxygen levels are replenished continuously.



CW = Soil Gas Cluster Well .008 = *in situ* respiration rate (% O_2/hr)

Figure 7. Preliminary In Situ Respriation Profile, September 1992.

Operational Performance

Volume of air circulated

- The following table show the air flow rates overtime and related activities.

Table 4 - Air Injection Flow Rates	
Oct. '90 – Dec. '90	Wells 280-IW, CW-1, CW-2 & CW-3 Constructed.
Dec. '90 – Apr. '91	Air injection at 67 acfm.
Apr. 91 – May '91	No air injection - respiration test.
May '91 – July '91	Air injection at 67 acfm.
July '91 – Aug. '91	well construction.
July '91 – Sept. 91	Blower off - Drilling.
Sept '91 – Sept. '92	Air injection at 67 acfm.
Sept. '92– Oct. '92	No air injection - in situ respiration test.
Aug. '92 – Oct. '92	CPT construction.
Sept. '92	SMP construction.
Oct. '92	280-WW well construction.
Oct. '92 – Dec. '92	Air injection at 45 acfm.
Dec. '92 – Feb. '93	Helium tracer test. Air injection at 67 acfm.
Feb. '93 – Apr. '93	Air injection at 67 acfm.
Apr. '93 – June '93	Air injection at 40 acfm.
June '93 – July '93	No air injection - in situ respiration test.
July '93 – Oct. '93	Air injection at 117 acfm.
Oct. '93 – Nov. '93	No air injection - in situ respiration test.
Nov. '93 – present	Air injection at 20 acfm.

- Figure 8 shows the concentration of soil gas TPH in November 1992, after about 1 1/2 years of blower operation at 67 acfm.

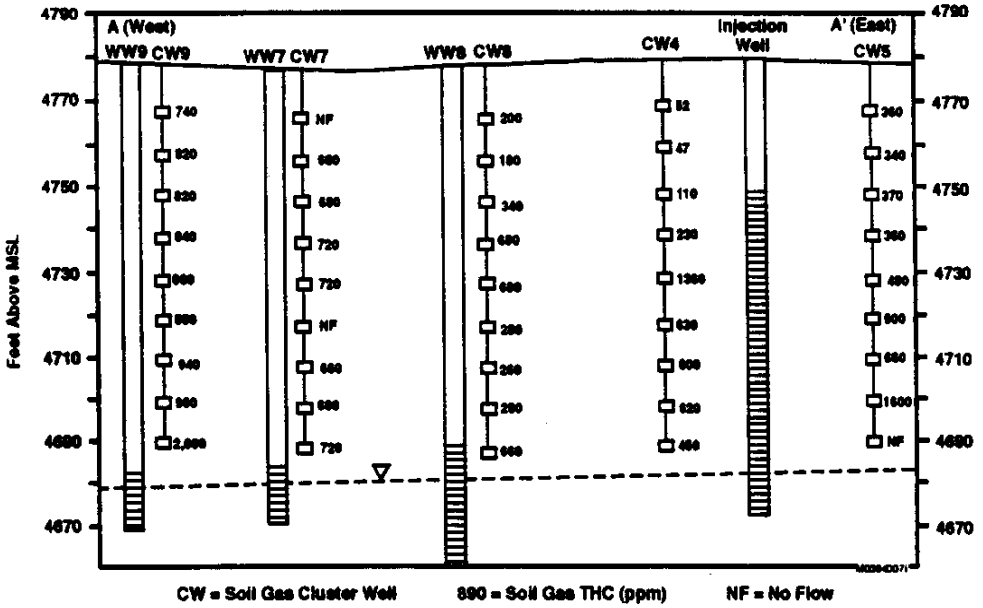


Figure 8. Soil-Gas Total Petroleum Hydrocarbon Concentrations (ppm); November 1992.

- Figures 9 and 10 show the concentration of soil gas oxygen and carbon dioxide, respectively, in November 1992, after about 1 1/2 years of blower operation at 67 acfm.

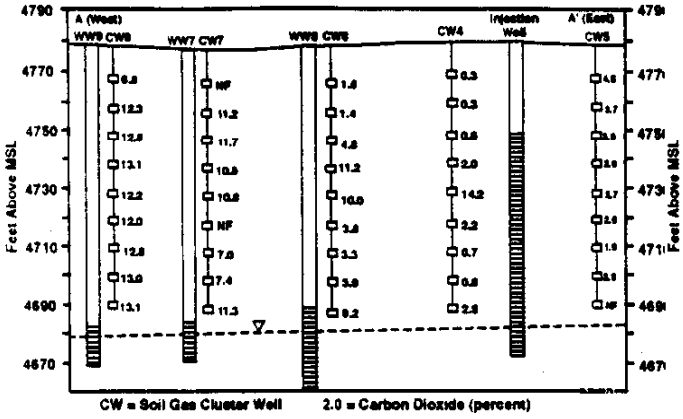


Figure 10. Soil-Gas Carbon Dioxide (percent): November 1992.

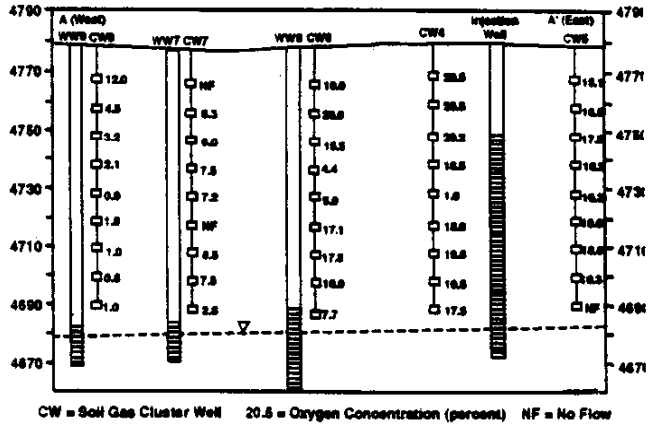


Figure 9. Soil-Gas Oxygen (percent): November 1992.

- The soil vapor TPH concentration at the surface did not appreciably change when the blower was on or off.

Treatment Performance

- Figure 12 shows the results of the respiration or biodegradation rate (mg/kg/day) tests for one well at different times during the test period, April 1991 through November 1993. This is considered representative for the site. These data indicate that the hydrocarbons are being destroyed over time.

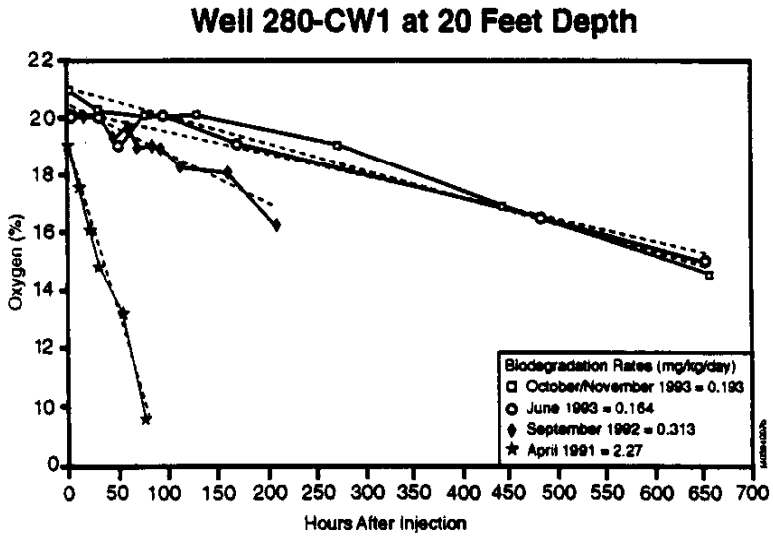


Figure 11. Soil-Gas Monitoring Well 280-CW1 (20 Feet) Biodegradation Data Comparison.

Surface-Emission Testing

- Surface Emission of hydrocarbons were tested for both periods of when the blower was operating and when it was not. Separate sample points were installed for this purpose.
- No significant difference was found between the air-injection and no-air-injection periods.

Soil-Gas Permeability and Radius of Influence

- Based on the air injection and pressure monitoring, the soil-gas permeability value was calculated as 0.057 darcy.
- The radius of influence, based on the air injection test, was estimated to be approximately 200 ft.
- Table 6 is the estimated permeability of the vadose zone at various depths based on the helium test program.

Table 5
Estimated Soil Permeabilities In Vadose Zone
From Helium Test

Depth from Ground Surface (ft)	Permeability (darcy)
30	7.8
40	4.7
50	4.8
60	4.8
70	6.0
80	4.8
90	4.3
Average ± St. Dev.	5.5 ± 1.2

M039-4007p

Total Pounds Contaminants Removed

- The project is not complete at the date of this report nor has the final report been issued. Estimates of the contaminants removed have not been reported as yet.

System Downtime

- The only downtime reported has been associated with the installation of wells, sample points or helium injection equipment was installed. See Table 5, Air Injection Flow Rates

COST

Capital Cost (Estimated)

Construction of Piping System (Construction of Wells and Equipment Costs)	$100,000
Buildings and Structures	N/A
Process Equipment (piping and 2.5 HP blower)	$4,000 to $5,000
Startup Costs	$10,000
Total Capital Cost	$115,000
Annual Operating Costs (Estimated)	
Electricity (@ $0.07/Kwhr) ($1,500 per year for 4 years)	$6,000
Labor	$40,000
Laboratory Charges	$20,000*
Maintenance Labor & Parts	$3,000 to $5,000
Monitoring (per year) (soil gas and in situ respiration)	$25,000
Total (four year O&M estimate*)	$96,000
Total Annual Operating Cost (Estimated over 4 years)	$24,000

** not including final site characterization.*

REGULATORY / INSTITUTIONAL ISSUES

- The site cleanup assessment will be 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 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 will be derived from the criteria for these listed fuels.

Target Cleanup Levels/Criteria:

To be established later.

SCHEDULE

Table 6 - Schedule for Hill AFB, Building 280 Low-Intensity Bioremediation Activities

Task	Date
Installation of Initial Soil Gas Wells and Collection and Analysis of soil Samples	Nov. 1990 to Dec. 1990
Air Injection Installed	Dec. 15, 1990
Gas Flow Rate Test #1	Dew. 1990 to Apr. 1991
Air Injection Turned Off	Apr. 23. 1991
In Situ Respiration Test #1	Apr. 1991
Installation of Additional Soil Gas Wells	July 1991
Collection and Analysis of Soil Sample	July 1991
Air Injection Reinitiated	Sept. 5, 1991
Gas Flow Rate Test #2	Sept. 1991 to Sept. 1992
In Situ Respiration Test #2	Sept./Oct. 1992
Tracer Test	Dec. 1992 to Feb. 1993
Gas Flow Rate Test #3	Oct. 1992 to June 1993
Second Annual Report	Apr. 1993
In Situ Respiration Test #3	June/July 1993
Gas Flow Rate Test #4	July to Sept. 1993
In Situ Respiration Test #4	Oct./Nov. 1993
Gas Flow Rate Test #5	Nov. 1993 to Apr. 1994
EPA Final Report	January 1994
In Situ Respiration Test #5	April/May 1994
Final Site Characterization	Aug. 1994
Hill AFB Final Report	Nov. 1994

LESSONS LEARNED

- Care must be taken to insure that laboratory test methods are consistent throughout the project so results may be compared throughout the test.

Key Operating Parameters

- Biodegradation is enhanced by adequate soil oxygen, moisture and nutrient level.
- Air Flow rates can be optimized to low levels, 40 to 67 acfm in this test.

Technology Limitations

- 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.
- 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 6
Regulatory/Institutional Issues:	Source #s 1, 4, 5
Schedule:	Source #s 1
Lessons Learned	Source #s 1, 4

List of Sources and Additional References

1. *Final Report to U.S.E.P.A.; Bioremediation of Hazardous Wastes at CERCAL and RECLA sites:* Hill AFB 280 Site, Low-Intensity bioreclamation: January 1994.
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.
6. Fax from Greg Smith, Great Lakes Environmental Center, to Roger Long, SWEC, dated 5/5/94.

ANALYSIS PREPARATION

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REVIEW

Project Manager
This analysis accurately reflects the performance and costs of this remediation

x _____

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