Case Study Abstract

Underground Storage Tanks (USTs)
Bioventing Treatment at Lowry Air Force Base (AFB), Denver, Colorado

Site Name:
Lowry Air Force Base

Location:
Denver, Colorado

Contaminants:
Total Petroleum Hydrocarbons (TPH)
- Total Recoverable Petroleum Hydrocarbons (TRPH) concentrations of 15 to 14,000 mg/kg were measured in soil samples below the area excavated for landfarming
- BTEX concentrations in soil samples were lower than cleanup criteria

Period of Operation:
Status - Ongoing
Report covers - 8/92 to 4/94

Cleanup Type:
Full-scale cleanup (interim results)

Vendor:
Engineering Science, Inc.
1700 Broadway, Suite 900
Denver, CO 80290

SIC Code:
9711 (National Security)

Technology:
Bioventing
- 6 piping manifolds (each consisting of two 10 ft, 2 in diameter screens)
- Placed in excavation at right angles (in a horizontal plane), surrounded with 1 to 2 ft layer of pea gravel
- Aerated to maintain an oxygen concentration greater than 14%
- Carbon dioxide concentration maintained at less than 4%

Cleanup Authority:
State: Colorado

Point of Contact:
Lt. Tom Williams
3415 CES/DEV
Lowry AFB, CO 80230

Waste Source:
Underground Storage Tank

Purpose/Significance of Application:
Bioventing to remediate soils contaminated with heating oil which contained relatively high concentrations of TPH and relatively low concentrations of soluble contaminants (e.g., benzene).

Type/Quantity of Media Treated:
Soil
- No estimates have been made of the quantity of soil treated or hydrocarbon product degraded at the time of this report
- Moist, firm sandy clay in top 10-15 ft
- Medium to coarse-grained sand in next 15-80 ft

Regulatory Requirements/Cleanup Goals:
- Treated soil - TPH < 500 mg/kg; TRPH < 500 mg/kg; and BTEX < 100 mg/kg
- Cleanup conducted under EPA and State of Colorado Underground Storage Tank Regulations and the Colorado Department of Health's Remedial Action Category III (RAC III) action levels

Results:
- Bioventing project was not complete at time of this report
- No TRPH, BTEX, or TPH data are available at this time
- Bioventing system maintained adequate O_2 levels in the contaminated soil and removed CO_2 from the soil

Cost Factors:
- Final cost data were not available
- Total Capital Cost - $28,650 (including equipment, site work, engineering, project management)
- Annual Operating Costs - $32,875 per year (including electricity, maintenance, laboratory charges)

Case Study Abstract

Underground Storage Tanks (USTs) Bioventing Treatment at Lowry Air Force Base (AFB), Denver, Colorado (Continued)

Description:
As a result of a leak of heating oil from an underground storage tank (UST) at Lowry Air Force Base in Denver, Colorado, soil was contaminated with total petroleum hydrocarbons (TPH) and benzene, toluene, ethylbenzene, and xylenes (BTEX). Following excavation of contaminated soil to a depth of 35 to 40 feet below ground level, soil sampling from the bottom of the excavation indicated that TRPH concentrations of 15 mg/kg to 14,000 mg/kg remained in the soils. A bioventing system, consisting of six bioventing piping manifolds, was installed at the bottom of the excavation and began operating in August 1992. The soil was aerated to maintain an oxygen concentration greater than 14% and a CO_2 concentration less than 4%.

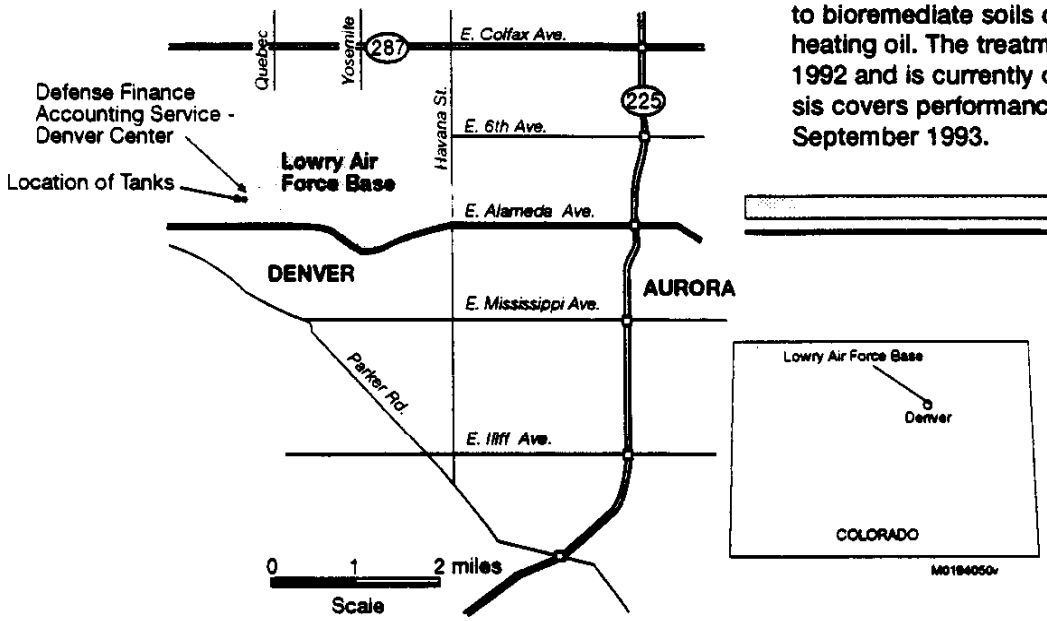
The bioventing of the contaminated soil at this site was ongoing as of April 1994. The target cleanup levels for the soil were TPH to less than 500 mg/kg; Total Recoverable Petroleum Hydrocarbons (TRPH) to less than 500 mg/kg; and BTEX to less than 100 mg/kg. The cleanup is being conducted under the authority of the Colorado Department of Health Underground Storage Tank Program. While no TPH, TRPH, or BTEX data were available at the time of this report, the bioventing system was found to have maintained adequate O_2 and CO_2 levels in the soil.

The total capital cost for this application is $28,650 and the estimated annual operating costs are $32,875. It was noted during this application that key operating parameters for bioventing are soil moisture, oxygen content, and carbon dioxide content; and that more frequent and better reported respiration test results would provide a more complete picture of the progress of the bioventing process, and indicate when final soil samples should be collected.

TECHNOLOGY APPLICATION ANALYSIS

SITE

Figure 1



TECHNOLOGY APPLICATION

This analysis covers the use of bioventing to bioremediate soils contaminated with heating oil. The treatment began 5 August 1992 and is currently ongoing. This analysis covers performance through September 1993.

SITE CHARACTERISTICS

Site History/Release Characteristics

- The Defense Finance Accounting Service - Denver Center (DFAS-DE) is located on Lowry Air Force Base (AFB) at the east edge of the City of Denver, Colorado.
- This project was carried out in response to a suspected release of petroleum hydrocarbons (heating fuel oil) from an UST at the (DFAS-DE), adjacent to building 444.
- A suspected leak of 10,500 gallons of heating fuel oil was discovered by a discrepancy in inventory measurements during February 1992.
- Underground storage tank (UST) removal efforts commenced March 2, 1992, with uncovering of the suspected leaking UST, Tank 424. The soil above the tank was free of hydrocarbon odor.
- Leakage was confirmed by visual inspection of the removed tank on March 16, 1992.
- Initial notification of the release was provided in a letter dated April 7, 1992, to the CDH Underground Tank Program.

Contaminants of Concern

- Contaminants of greatest concern in the soil are BTEX (benzene, toluene, ethyl benzene, and xylenes), heating oil, and diesel fuel.

Contaminant Properties

Properties of contaminants focused upon during remediation are:

Property	Units	Benzene	Ethylbenzene	Toluene	Xylenes*
Empirical Formula		C_6H_6	C_8H_{10}	C_7H_8	C_8H_{10}
Density @ 20°C	g/cm^3	0.88	0.87	0.87	0.87
Vapor Pressure @ 20°C	mm Hg	100	10	36.7	10
Henry's Law Constant @ 25°C	$\frac{(atm)(m^3)}{mol}$	5.59×10^{-3}	6.43×10^{-3}	6.73×10^{-3}	7.04×10^{-3}
Water Solubility @ 20°C	mg/l	1,800	200	500	200
Log Octanol-Water Partition Coefficient; Log Kow		2.13	3.15	2.69	2.77-3.2
Site Specific Soil-Air Partition Coefficient; Kh /Kd	$\frac{ug/l\ air}{mg/kg\ soil}$		0.48	3.42	0.77
Organic Carbon Partition Coefficient; Koc	ml/g	83	1,100	300	240
Ionization Potential	ev	9.25	8.76	8.82	8.56
Molecular Weight		78.12	106.18	92.15	106.18

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

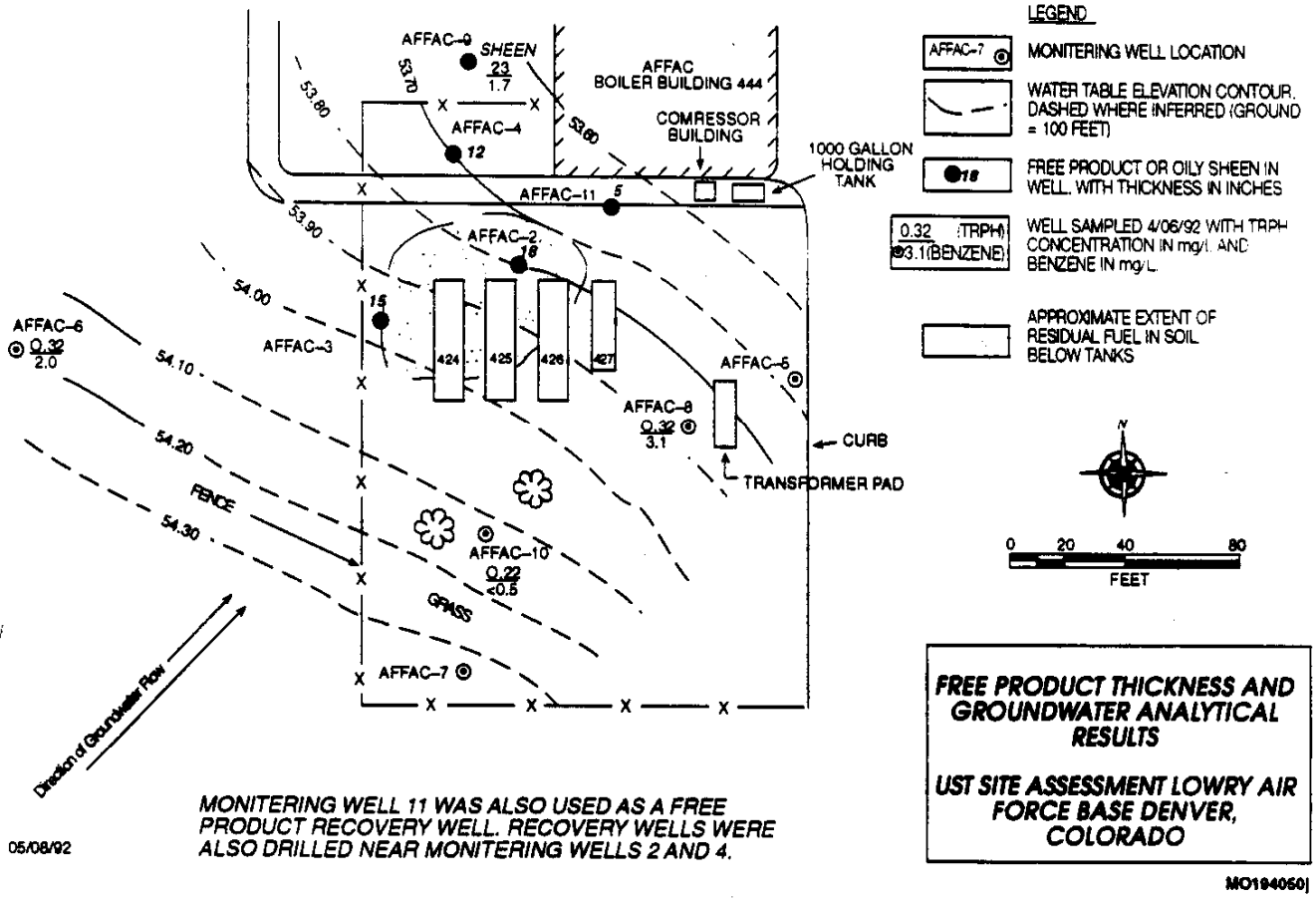
Nature & Extent of Contamination

- 4 USTs (Tanks 424, 425, 426 and 427) were removed.
- It was determined that only Tank 424 leaked.
- Components of the heating fuel oil did not significantly affect the groundwater. Heating fuel oil contains relatively low concentrations of soluble components (such as benzene) compared to lighter petroleum fractions such as gasoline. Groundwater treatment was not deemed necessary, but it was monitored during remediation activities.
- Groundwater benzene concentrations from 4 monitoring wells ranged from 1.7 to 3.1 µg/L. Concentrations of toluene, ethylbenzene, and xylenes were well below State standards and MCLs. Low TRPH concentrations (0.3 mg/L or less) were measured in 3 wells; 23 mg/L of TRPH was observed in the downgradient well.
- The soil was saturated with petroleum product immediately above the water table at 45 feet below ground surface. Residual fuel appeared to be confined with depth in some areas by a layer of finer-grained, dense sand encountered at 35 feet below the ground surface.

Contaminant Locations and Geologic Profiles

Remedial investigation field activities at the site have included:

Plume (Top View)



MONITERING WELL 11 WAS ALSO USED AS A FREE PRODUCT RECOVERY WELL. RECOVERY WELLS WERE ALSO DRILLED NEAR MONITERING WELLS 2 AND 4.

05/08/92

Hydrogeologic Units

- Thicknesses of unconsolidated alluvium >80 feet occur at the location of the DFAS-DE tanks.
- A layer of moist, firm sandy clay occupies the top 10 to 15 feet.
- The next 15 to 80 feet is a medium to coarse-grained sand.
- Aquifer is a water table aquifer.
- Groundwater gradient is roughly 0.4% to the northeast.

Site Conditions

- Elevation is about 5,390 feet.
- Average annual air temperature is 50°F. Diurnal temperature fluctuation averages 29°F. Record high 105°F; record low temperature -30°F.
- 14.81 inches precipitation/year; 58.3 inches of snow/year.
- 70% of possible sunshine.
- On the average, the first freeze is around October 12 and the last freeze is around May 5.
- Direction of groundwater flow is from the southwest to the northeast.

Key Soil or Key Aquifer Characteristics Measured

Property	Units	Range or value
Soil moisture content (landfarm)	%	6% to 11%
Hydraulic conductivity	cm/s	1.8 to 78.4 X 10^{-4}
Depth to groundwater	feet	45
Aquifer thickness	feet	>35
Depth to bedrock	feet	>80

Groundwater levels fluctuate seasonally from 1 to 4 feet in monitoring wells at this site.

TREATMENT SYSTEM

Three remediation technologies are being used to remediate this site. The three technologies selected complement each other and are not competitive, one with another

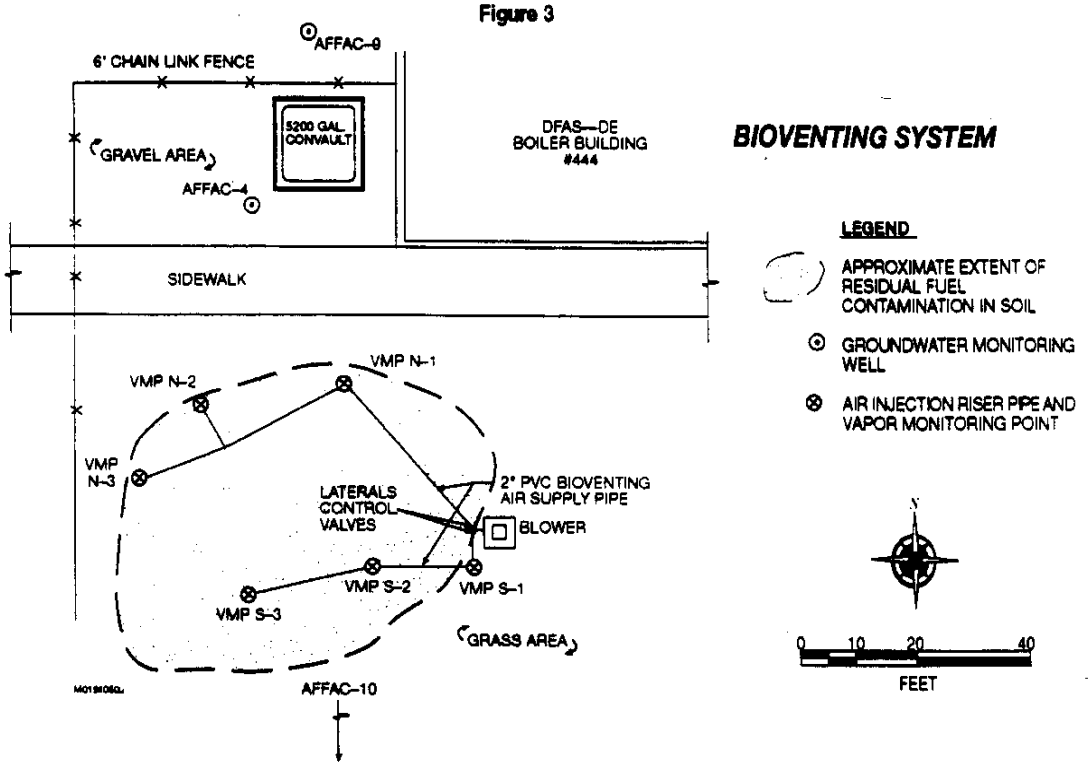
- Landfarming for the soil removed from the excavation.
- Bioventing for the soil remaining in the excavation.
- Product only pumping for the free product found floating on the water table.
- This report addresses bioventing only.

The Treatment System

- 5,400 cubic yards of petroleum contaminated soil was removed from the excavation. Soil that had indications of hydrocarbons present was excavated by a track hoe, hauled to a treatment location and is undergoing above ground biotreatment (landfarming).
- Soil was removed from below the tanks to a depth of 35 to 40 feet below ground surface.
- Soil sampling from the bottom of this excavation indicated that petroleum contamination remains below the excavation and above the water table in the northern part of the excavation. TRPH concentrations of 15 mg/kg to 14,000 mg/kg were measured in bottom soil samples. BTEX concentrations were less than RAC III criteria in all samples. The maximum concentrations of TRPH and BTEX were all observed at the 35 foot depth. The next highest concentrations were observed at the 40 foot depth. Limitations of the reach of excavation equipment and concerns with sidewall stability prevented the removal of contaminated soils at depths greater than 35 or 40 feet, because the groundwater was at 45 feet. As a result, 5 to 10 feet of residual contaminated soil was left in place.
- Before backfilling, 6 bioventing piping manifolds (each manifold consisting of two 10 foot long; 2" diameter polyvinyl chloride [PVC] screen) were installed at the bottom of the excavation in areas determined to contain residual contamination. The 10 foot manifold sections were placed in the excavation at right angles (in a horizontal plane). These screens were surrounded with a 1 to 2 foot thick layer of pea gravel. Each manifold connected to a 2" diameter PVC riser pipe that extended to the ground surface. These bioventing manifolds are aerating the remaining contaminated soil, thereby enhancing biodegradation of the residual fuel by naturally occurring soil microorganisms. The manifolds can also be used to introduce nutrients to the contaminated soils to enhance further biological fuel degradation rates.

Extent of Excavation

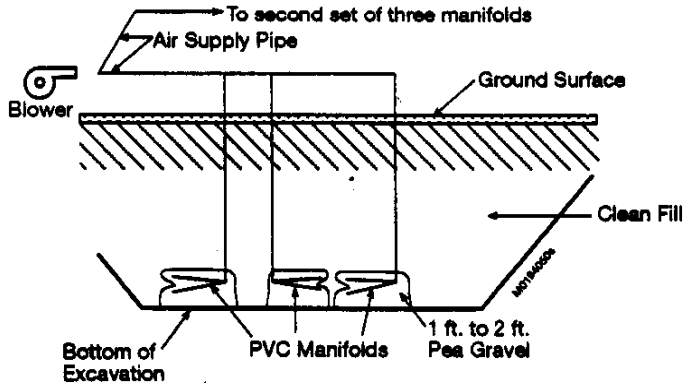
Figure 3



Overall Process Schematic

Figure 4

Process Flow Diagram



Key Monitored Operating Parameters

- Oxygen concentration is maintained at greater than 14%.
- Carbon dioxide is maintained at less than 4%.

PERFORMANCE

Performance Objectives

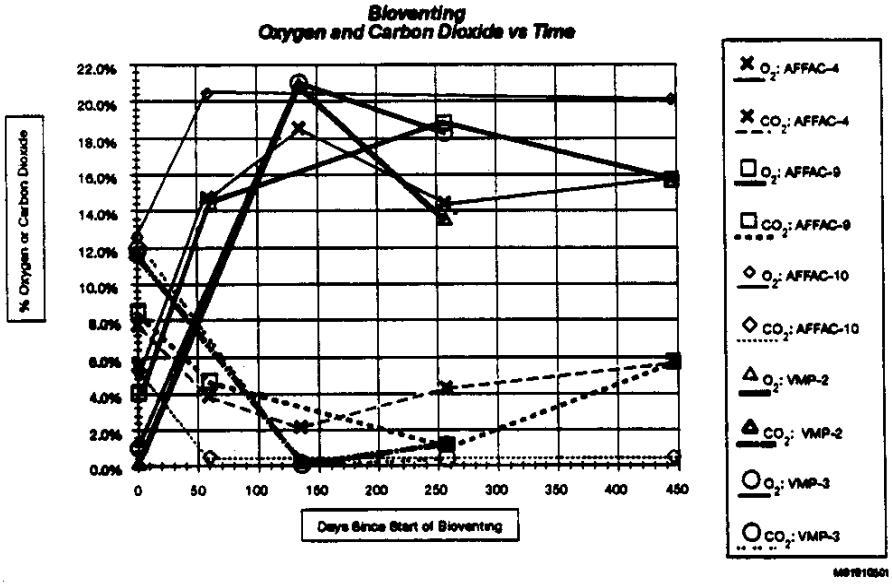
- There are no RODs or FFAs. However, compliance with EPA and State of Colorado UST regulations is required.
- The soil bioventing operations will be completed when composite soil samples indicate TRPH concentrations have been reduced to less than 500 mg/kg.

Treatment Plan

- If within the soil matrix the oxygen (O_2) level is low and the carbon dioxide (CO_2) level is high,it is assumed that microorganisms are degrading the hydrocarbons present. If biodegradation is occurring, then the process is limited by the depleted oxygen level. The microorganisms will consume the hydrocarbons at a high rate if the oxygen used by the microorganisms is replaced by bioventing.
- Wells will be installed and soil samples taken at some future time to confirm that the TRPH has been reduced to below 500 mg/kg.
- The cleaned soils will remain in place after soils bioventing treatment is completed.

Operational Performance

- The radius of oxygen influence created by the bioventing system exceeded the boundaries of soil contamination.
- Figure 5 shows the soil gas concentration of oxygen (O_2) and carbon dioxide (CO_2) at selected monitoring wells (AFFAC-n) and vapor monitoring points (VMP S-n). The data show that the O_2 initially (before treatment) was low, between 2% and 6%. At the same time the CO_2 was high, between 6% and 12%. After the bioventing system was placed in operation, O_2 levels increased and remained high, between 14% and 21%. During this same period, CO_2 levels decreased and remained low, between 0% and 6%. This indicates that lack of oxygen originally was limiting the biological destruction of the fuel oil hydrocarbons. Since bioventing commenced, adequate oxygen is available for bioremediation to take place.



See Figure 2 for the location of monitoring wells (AFFAC-n) and Figure 3 for the location of vapor monitoring points (VMP S-n).

- The bioventing system is effective in maintaining high O_2 levels in the contaminated soil left in place. The system also effectively removed CO_2 from the contaminated soils.

System Downtime

- The bioventing system was down for a short (unspecified) time because of a damaged supply pipe.

Treatment Performance

Total Pounds Contaminants Removed

- No estimates have been made of the quantity of soil treated or the quantity of hydrocarbon product destroyed.

COST

Capital Costs

Equipment	$2,700
Site Work	$3,700
Buildings/Structures	$900
Mechanical/Piping	$650
Electrical	$1,000
Subtotal	$8,950
Engineering	$5,000
Project Management	$2,200
Testing	$10,000
Cumulative Subtotal	$26,150
General & Administrative Overhead Costs @ 9.5%	$2,500
Total Capital Costs	$28,650
Annual Capital Cost (Over 2 years)	$14,325

Operating Costs (per year)

Electricity (@ $0.07/Kwhr)	$1,400
Laboratory Charges	$1,750
Maintenance Labor & Parts	$5,400
Monitoring	$10,000
Subtotal	$18,550
Total Annual Operating Cost	$32,875

REGULATORY/INSTITUTIONAL ISSUES

- The USTs were removed in conformance with American Petroleum Institute Recommended Practice 1604 and the National Fire Protection Association Code 30.
- The EPA and the State of Colorado review all documents produced by this project including the Quarterly Monitoring Reports. In addition, Lowry AFB personnel meet with the EPA and the State of Colorado once/month. Local communities are invited to the monthly environmental meetings.

Cleanup Criteria

- The Colorado Department of Health (CDH) Remedial Action Category III (RAC III) Action Levels are:

Compound	mg/kg
Total (Recoverable) Petroleum Hydrocarbons (TRPH)	500
Total Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX)	100

- The CDH's "Basic Standards for Ground Water" includes:

	µg/L
benzene	1
toluene	1,000
ethylbenzene	680
xylenes	none

- The MCL standard for benzene is 5 µg/L, the MCL for xylenes is 10,000 µg/L, but there is no MCL for TPH.
- Shallow groundwater beneath Lowry AFB is not being used as a drinking water supply and there is little or no likelihood that this will change.
- Target Cleanup Levels/Criteria:

Contaminant	mg/L
TPH	500

SCHEDULE

- There is no "originally planned schedule." Remediation will continue until the site meets the foregoing CDH regulatory requirements.
- As of May 1992, site restoration and assessment activities were completed by June 1992. Estimated time of completion was estimated to be 2 years.
- The bioventing system began operation August 5, 1992, and operates continuously.
- As of April 1994 treatment is not complete.

LESSONS LEARNED

Key Operating Parameters

- The key operating parameters are soil moisture, soil oxygen content and soil carbon dioxide content.
- More frequent and better reported respiration tests would provide a more complete picture of the progress of the soil remediation. It would also indicate when final soil samples should be obtained.

Implementation Considerations

- The time required for biotreatment is longer than other treatment methods such as incineration.
- Can be performed on site, reducing the need to excavate large quantities of soil.

Future Technology Selection Considerations

- Both landfarming (above ground bioventing) and *in situ* bioventing appear to have been successful at this site, but data is insufficient to make a judgment as to which process performed better.

SOURCES

Major Sources For Each Section

Site Characteristics:	1, 2, 6 and 7
Treatment System:	1 and 7
Performance:	1, 3, 4 and 5
Cost:	8
Regulatory/Institutional Issues:	1
Schedule:	1 and 8

Chronological List of Sources and Additional References

1. *Underground Storage Tanks Site Assessment Report and Corrective Action Plan,* Lowry Air Force Base, Denver, Colorado, prepared for Headquarters Air Training Command/DEV, Randolph AFB, Texas, and Armstrong Laboratory/OEB, Brooks AFB, Texas, prepared by Engineering-Science, Inc., May 1992.
2. Underground Storage Tanks Site Assessment Report and Corrective Action Plan, Appendices, Lowry Air Force Base, Denver, Colorado, prepared for Headquarters Air Training Command/DEV, Randolph AFB, Texas, and Armstrong Laboratory/OEB, Brooks AFB, Texas, prepared by Engineering-Science, Inc., June 1992.
3. *Quarterly Monitoring Report, Lowry Air Force Base,* Denver, Colorado, prepared for Headquarters Air Training Command/DEV, Randolph AFB, Texas, and Armstrong Laboratory/OEB, Brooks AFB, Texas, prepared by Engineering-Science, Inc., October 1992.
4. *Quarterly Monitoring Report-January 1993,* Lowry Air Force Base, Denver, Colorado, prepared for Headquarters Air Training Command/DEV, Randolph AFB, Texas, and Armstrong Laboratory/OEB, Brooks AFB, Texas, prepared by Engineering-Science, Inc., January 1993.
5. *Quarterly Monitoring Report-November 1993,* Lowry Air Force Base, Denver, Colorado, prepared for Headquarters Air Training Command/DEV, Randolph AFB, Texas, and Armstrong Laboratory/OEB, Brooks AFB, Texas, prepared by Engineering-Science, Inc., December 1993.
6. *RREL Treatability Data Base,* Version 4.0, EPA, November 15, 1991.
7. *Basics of Pump-and-Treat Ground-Water Remediation Technology,* EPA/600/8-90/003, Robert S. Kerr Environmental Research Laboratory, Ada, OK 74820, March, 1990.
8. *Personal Communication with Kent Friesen,* Engineering-Science, Inc., 1700 Broadway, Suite 900, Colorado 80290 (Phone, 303/ 831-8100).

ANALYSIS PREPARATION

This analysis was prepared by:

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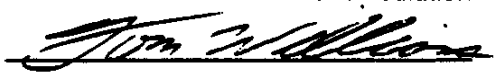
REVIEW

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

X 

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