Case Study Abstract

In Situ Soil Vapor Extraction at McClellan Air Force Base California

Site Name:
McClellan Air Force Base Superfund Site, Operable Unit D, Site S

Location:
Sacramento, California

Contaminants:
Chlorinated Aliphatics
Tetrachloroethene (PCE), Trichloroethene (TCE), 1,1-Dichloroethene (1,1-DCE), Vinyl Chloride, 1,1,1-Trichloroethane (TCA), 1,2-Dichloroethene (1,2-DCA), Freon 113

- PCE, TCE, 1,1-DCE, TCA, and Freon 113 account for over 99% of the speciated VOC mass in the vadose zone
- Maximum borehole concentration of VOCs in vadose zone reported up to 2,975,000 μg/kg

Period of Operation:
Status - Ongoing
Report covers - 1993 to 5/94

Cleanup Type:
Field Demonstration

Vendor:
CH2M Hill

SIC Code:
9711 (National Security)

Technology:
Soil Vapor Extraction

- 17 vapor extraction wells in three contamination zones
- 5 vacuum blowers, 2 vapor/liquid separators
- Catalytic oxidizer and scrubber used to control air emissions
- Total system average air flow rate was 2,500 scfm

Cleanup Authority:
CERCLA and State: California
- ROD Date: pending (scheduled for issuance mid-1995)

Point of Contact:
Kendall Tanner
Remedial Project Manager
McClellan, AFB

Waste Source:
Disposal Pit (for fuel and solvents)

Purpose/Significance of Application:
A demonstration of soil vapor extraction to remediate VOCs in waste pit materials and vadose zone soils, and to assess performance of catalytic oxidation and scrubbing.

Type/Quantity of Media Treated:
Soil

- Three zones of contamination - waste pit (landfilled silty sands and sandy silt with oily material, wire wood, debris, etc.); intermediate alluvium; and deep alluvium
- Permeability ranged from 0.001 (for silty clay) to 1.7 (for sand) darcies

Regulatory Requirements/Cleanup Goals:

- Cleanup criteria not yet established for this site at McClellan
- Air Emissions - 95% destruction of total VOCs, required by the Sacramento Air Quality Management District

Case Study Abstract

In Situ Soil Vapor Extraction at McClellan Air Force Base California (Continued)

Results:

- Demonstration not complete at time of report; no soil samples to characterize post-treatment vadose zone were collected at time of report
- Approximately 46,000 lbs of speciated VOCs were extracted and treated during initial 6 weeks of operation; 113,000 lbs during initial 15 weeks of operation
- TCE, 1,1-DCE, and TCA accounted for more than 90% of the mass of contaminants removed
- Up to 150,000 lbs of contaminants (hexane-equivalents) believed to have been biodegraded in situ during initial 6 weeks of operation
- Overall DRE averaged 99% for total VOCs during second and third months of demonstration; lower DRE in first month attributed to operational concerns

Cost Factors:

- Field demonstration budget - $1.8 million for 1993 and $2.0 million for 1994 (including site characterization; air permeability testing; installation and operation of SVE wells; vapor probes and manifold; air/water separators; blowers; scrubber; catalytic oxidizer (rented); resin adsorption (rented); electronic beam technology testing; laboratory analysis; and engineering support)

Description:

The McClellan Air Force Base in Sacramento, California is an Air Force Command Logistics Center that has been in operation since 1943. The base was placed on the National Priorities List in 1987 and Site S within Operable Unit D is one of the areas of confirmed contamination at the base. Site S is the location of a former fuel and solvent disposal pit, used from the early 1940s to mid-1970s. Soil at Site S has been contaminated with chlorinated and petroleum-based volatile organic constituents (VOCs). No cleanup goals had been established for Site S at the time of this report. The report indicates that a Record of Decision for Operable Unit D (which includes the disposal pit site) is scheduled to be issued in mid-1995. A 95% destruction and removal efficiency (DRE) for total VOCs in the extracted vapors was required by the Sacramento Air Quality Management District.

A field demonstration of soil vapor extraction (SVE) at Site S began in mid-1993. This demonstration is being conducted as part of a series of field programs designed to optimize remedial technologies to be used in a full-scale cleanup at McClellan. This SVE system includes 17 vapor extraction wells, vapor/liquid separators, a catalytic oxidizer, and a scrubber. Results from the field demonstration of SVE to date showed that approximately 113,000 pounds of VOCs were extracted in 15 weeks of operation; mostly consisting of TCE, 1,1-DCE, and TCA. In addition, up to 150,000 pounds of contaminants (hexane-equivalents) were believed to have been biodegraded in situ during the initial 6 weeks of the SVE demonstration. The average DRE for total VOCs during the second and third months of the demonstration was 99 percent.

It was noted during this application that the heterogeneity of the soils at this site caused the radius of influence for the extraction wells to vary from 15 to 60 feet for a single well. The calculated mass of contaminants was almost two orders of magnitude less than the mass extracted in the first six weeks of system operation. It was also noted that SVE air pollution control systems should be designed with sufficient capacity to provide for operational flexibility.

TECHNOLOGY APPLICATION ANALYSIS

SITE

McClellan Air Force Base
Site S, Operable Unit D
Sacramento, California

TECHNOLOGY APPLICATION

In situ soil vapor extraction (SVE) was field tested in 1993 and 1994 at a site with **vadose-zone soil and fill materials** containing **volatile organic compounds (VOCs).** The site is representative of many at the base where SVE is a candidate remediation technology. **Catalytic oxidation** and **scrubbing** were used to control air emissions.

SITE CHARACTERISTICS

Site History/Release Characteristics

- McClellan Air Force Base (AFB), an Air Force Command Logistics Center, has been in operation since 1943. The base was placed on the National Priorities List in 1987 as the highest ranked U.S. Air Force installation.
- Operable Unit (OU) D, located in the northwest corner of the facility, is one of ten OUs on the base. Site S, the subject of this report , is located within OU D and is one of 238 sites on the base where contamination has been confirmed.
- Site S was used as a former fuel and solvent disposal pit and is one of 12 waste pits in OU D that were used from the early 1940s until the mid 1970s. Limited excavation of wastes from the pits was performed in the late 1970s and early 1980s, and an impermeable cap was constructed above the former waste pits in 1987. A groundwater pump and treat system was installed in 1987.
- Detailed characterization of the nature and extent of contamination for Site S was completed in June 1992. The full-scale SVE demonstration system that is the subject of this report was field tested at Site S in late 1993 and early 1994.

Contaminants of Concern and Properties

The most prevalent contaminants of Site S are chlorinated and petroleum-based VOCs. Additional contaminants in waste pit materials include: volatile aromatics; semi-volatiles, polychlorinated biphenyls (PCBs) and dioxins.

Seven chlorinated VOCs were identified as contaminants of concern in the risk assessment based primarily on potential impacts to groundwater:

Tetrachloroethene	(PCE)
Trichloroethene	TCE)
1,1- Dichloroethene	(1,1-DCE)
Vinyl chloride	
1,1,1-Trichloroethane	(TCA)
1,2-Dichloroethane	(1, 2-DCA)
1,1,2 - Trichloro-1, 2, 2-trifluoroethane	(Freon 113)

Properties*	PCE	TCE	1,1-DCE	Vinyl Chloride	TCA	1,2-DCA	Freon 113
Density (g/cm^3)	1.62	1.46	1.21	0.91	1.35	1.26	1.58
Vapor Pressure (mm Hg)	1.78	57.9	600	2,660	123	64	2.70
Henry's Law Constant ($atm\text{-}m^3/mole$)	0.0259	0.0091	0.0340	0.0819	0.0144	0.0010	0.526
Water Solubility (mg/l)	150	1,100	2,250	2,670	1,500	8,520	10
Octanol -Water Partition Coefficient (K_{ow})	398	240	69.2	24	316	30.2	100
Organic Carbon Partition Coefficient (K_{oc})	364	126	65	57	152	14	-

** Properties at 20° C*

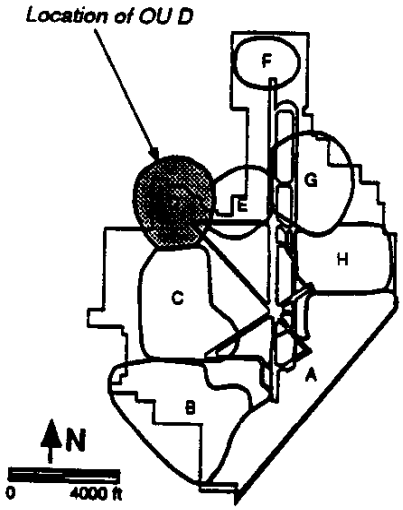
Nature & Extent of Contamination

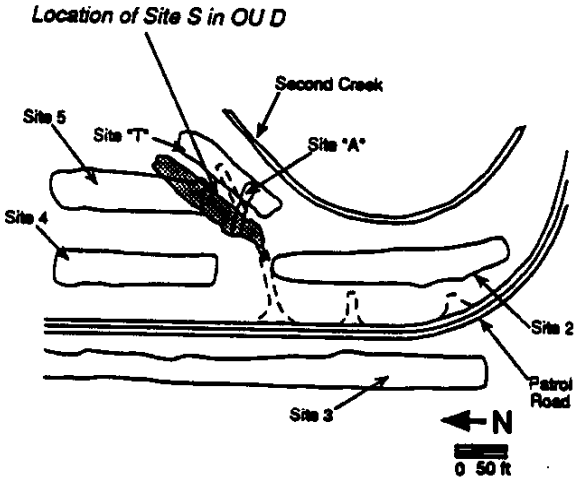
- The highest concentrations of contaminants are contained in residual wastes and fill materials in the former waste pits. Contamination extents to and beneath the 1993 water table, approximately 102 feet below ground surface (BGS).
- PCE; TCE; 1,1-DCE; TCA and Freon 113 account for over 99% of the speciated VOC mass in the vadose zone. TCE accounts for 30 to 40% and TCA contributes 28 to 44% of the total speciated VOC mass in the vadose zone.
- The existing impermeable cap is effectively reducing rainwater infiltration and subsequent leaching of contaminants directly beneath the cap to the groundwater. However, the cap is not preventing the lateral migration of VOCs in soil vapor up to 500 feet beyond the limits of the cap and subsequent leaching to groundwater.
- Modeling indicates that natural attenuation will not be adequate to address vadose zone contamination for sites in OU D.

Contaminant Locations and Geologic Profiles

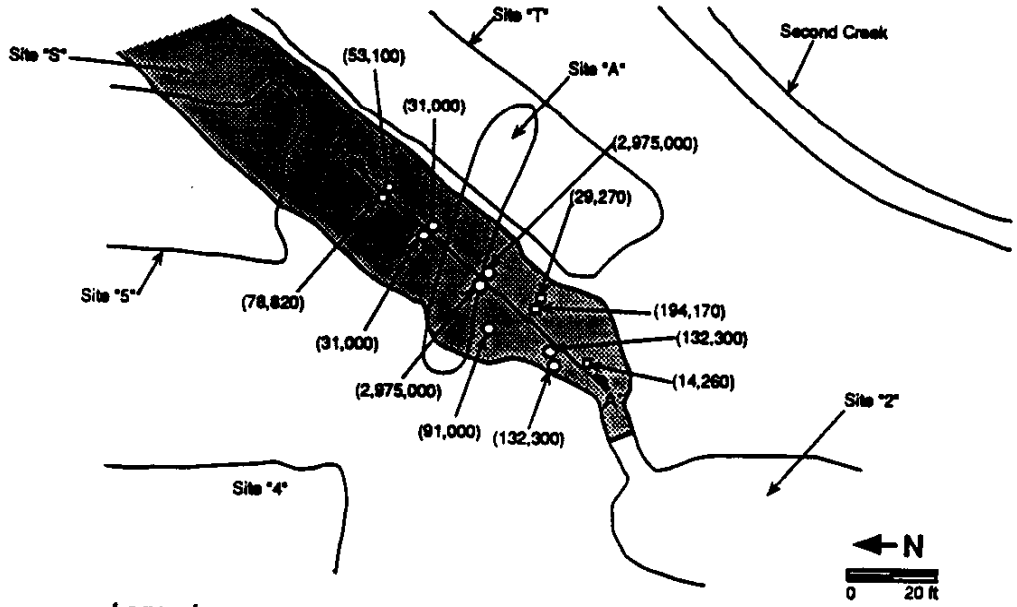
Remedial investigation field activities at Site S have included extensive sampling and laboratory analysis of waste pit fill materials, soil, soil vapor and groundwater for chemical, geotechnical and biological parameters. Field air permeability testing was also performed. Data from some of these investigations is included in this section to provide a general understanding of site conditions.

OU D and Site S Locations





Site S Vadose Zone Contamination

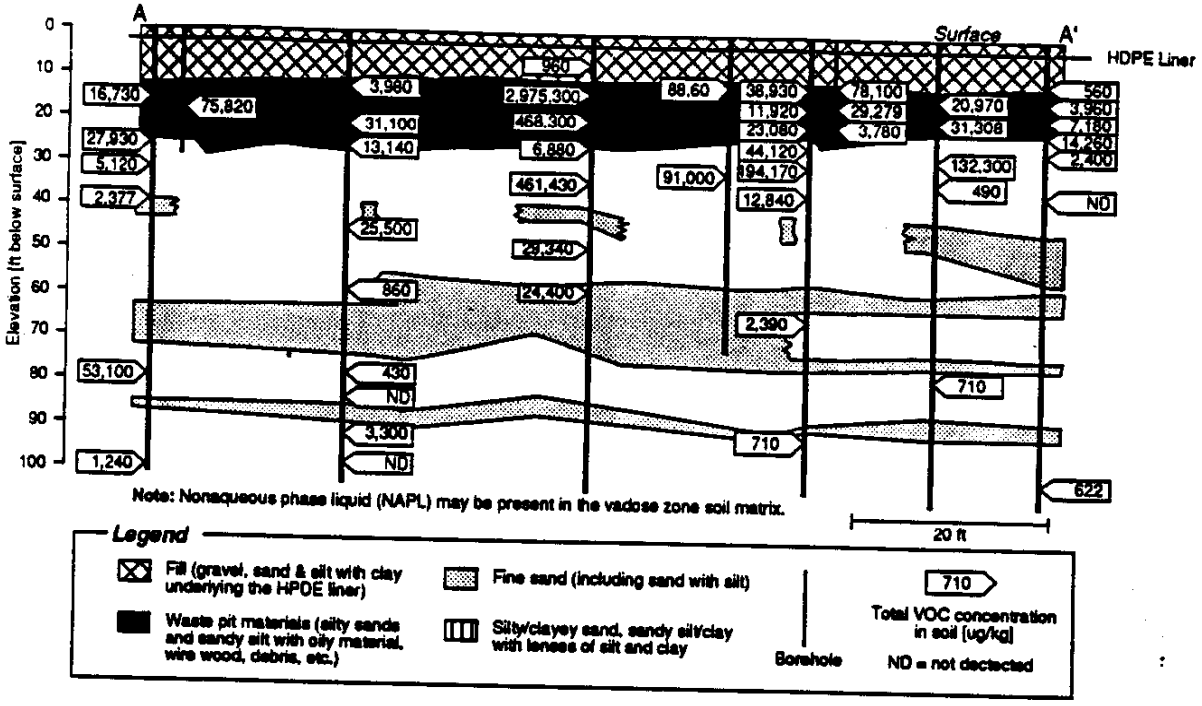


Legend

- SVE Well
- Piezometer Nest
- (29,270) Maximum Borehole Concentration of VOCs (ug/kg)
- Schematic Cross Section Location

Contaminant Locations and Geologic Profiles (Continued)

Vadose Zone Lithology and VOC Distribution (Site S)



Site Conditions

- McClellan AFB occupies 2,952 acres approximately 7 miles northeast of downtown Sacramento.
- Soils and geology at the base are a complex series of alluvial and fluvial deposits that were deposited, eroded, and redeposited. Deposits of anyone lithologic type are limited in horizontal and vertical extent.
- Regional groundwater levels have dropped over 60 feet in the last 50 years due to pumping for agricultural irrigation; levels have declined at a rate of 1.5 to 2 feet/year during the last 10 years. This has resulted in the smearing of contaminants in the soil matrix above the declining water table.
- Three zones of contamination exist at Site S above the current water table:
  1) Waste pit - Very high contaminant concentrations in a matrix of landfilled soils beneath the impermeable cap and averaging 20 feet in thickness (from ~ 5 to 25 feet BGS).
  2) Intermediate alluvium - High contaminant concentrations in an alluvial soil matrix directly below the waste pit and averaging 15 feet in thickness (from ~25 to 40 feet BGS).
  3) Deep Alluvium - Lower contaminant concentrations in native alluvial soils located below the intermediate zone and averaging 62 feet in thickness (from ~40 to 102 feet BGS to the water table).

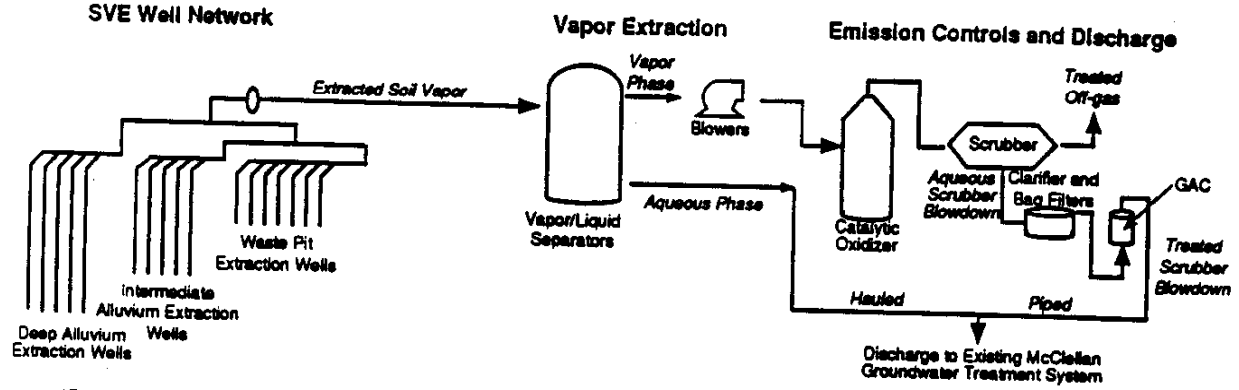
Key Vadose Zone Soil Properties

Property [units]	Sand Units	Silty Clay Units	Comments
Vertical Intrinsic Permeability [darcies]	0.02 to 1.5	0.001 to 0.5	Lower intrinsic permeabilities imply more resistance to contaminant transport either in solution or in gaseous phases.
Horizontal Intrinsic Permeability [darcies]	0.1 to 1.7	0.1 to 1.5	Higher intrinsic permeabilities in the horizontal (versus vertical) direction imply relatively less resistance to contaminant transport either in solution or in gaseous state.
Percent Saturation	47 to 75	63 to 86	As percent saturation increases, the ability of the vadose zone medium to convey air flow decreases.
Fraction Organic Carbon	Not Available	0.001 to 0.006	High organic carbon fractions in the soils allow for more retardation of organic chemicals during transport because they tend to absorb to the organic material in the soil matrix.

Note: Field permeability values of 3 to 200 darcies exceeded the laboratory test results indicated above.

REMEDIATION SYSTEM

Overall Process Schematic



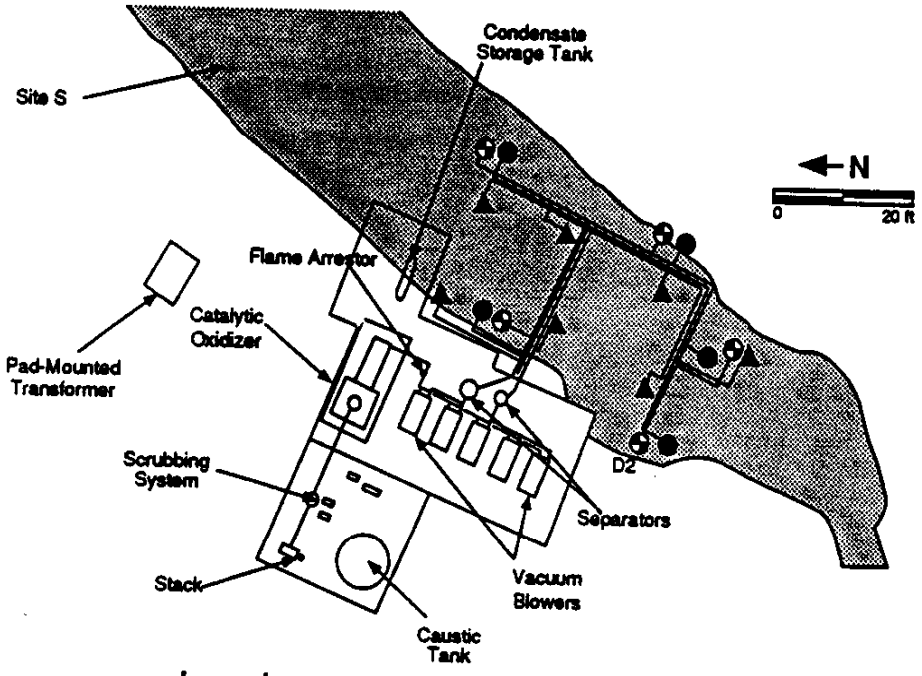
17 vapor extraction wells connected by 2 headers to above-ground equipment for emission control.

Extrained liquids removed by 1 of 2 vapor/liquid separators. 5 vacuum blowers effect in-situ extraction of soil vapor.

Vapor treated by catalytic oxidation to reduce VOC concentrations and counterflow packed bed scrubbing to reduce acid gas emissions.

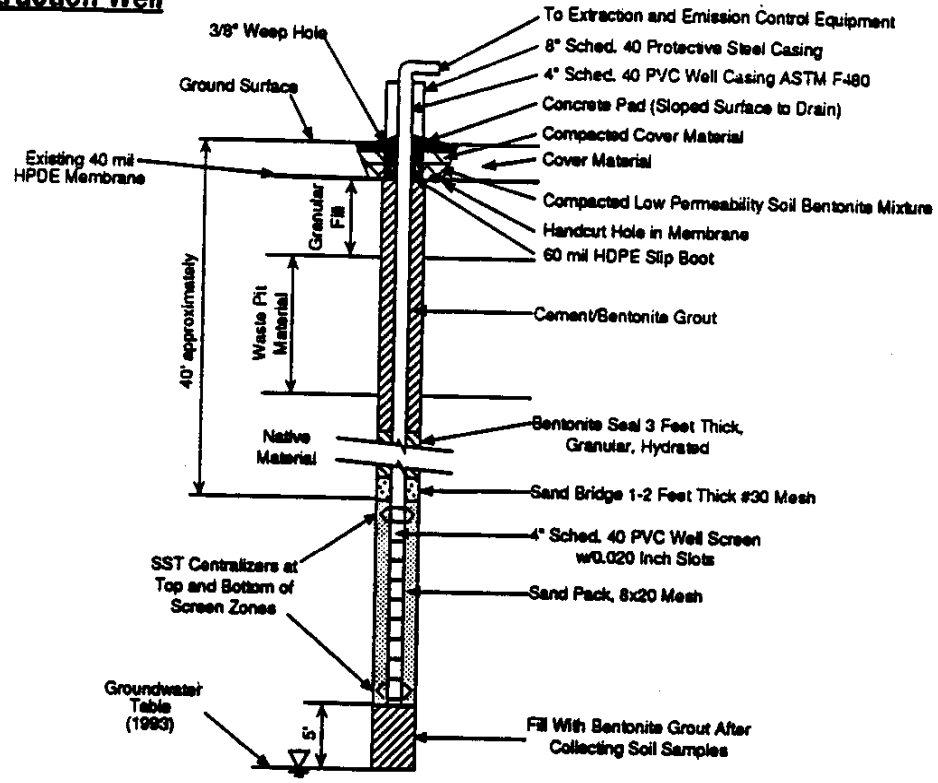
Aqueous scrubber blowdown treated using a clarifier and bag filters to reduce the suspended solids concentration, and granular activated carbon (GAC) to reduce dioxins concentrations.

Extraction Well Network



Extraction Well Detail

Typical Extraction Well



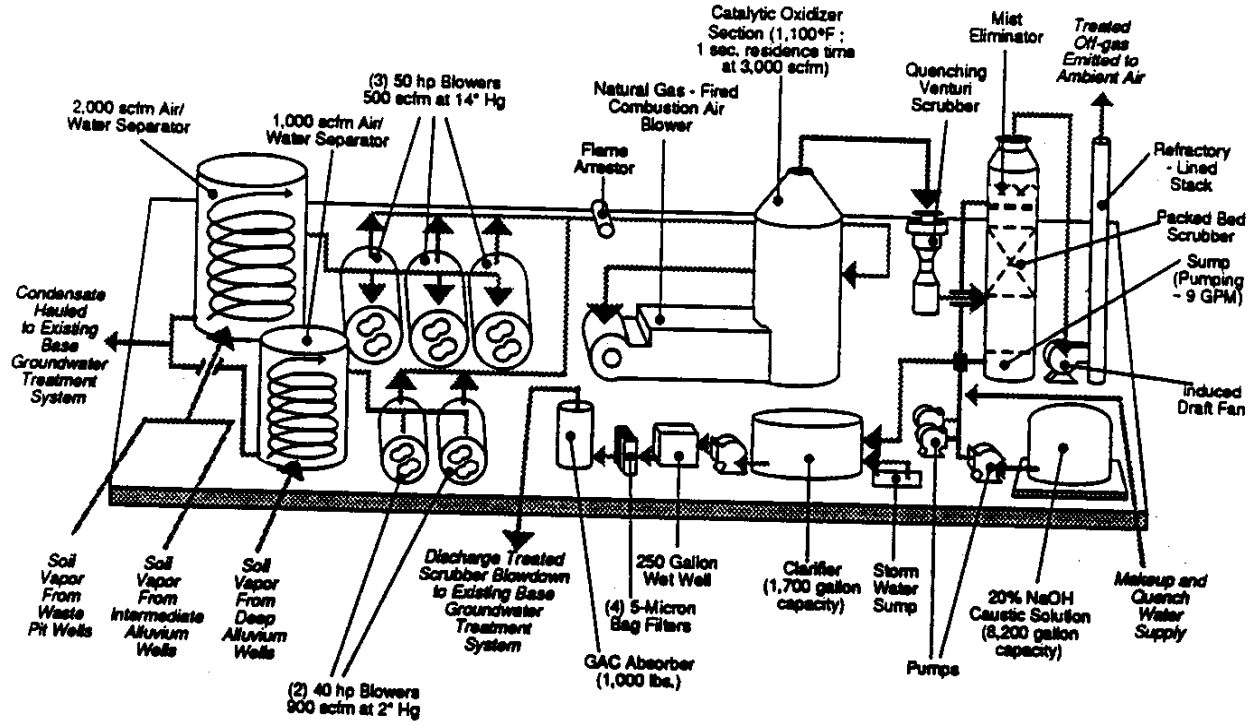
Key Design Criteria

- Extraction of soil vapor containing VOCs from three zones of contamination above the water table (waste pit, intermediate alluvium and deep alluvium).
- Overlapping radius of influence for vapor extraction wells.
- Oxygenating vadose zone soils to effect in-situ biodegradation.
- Maintain catalytic oxidizer VOC destruction efficiency above 95% to comply with Sacramento AQMD requirements.
- Maintain acid gas (HCl) emissions below 30% of the TVL at a maximum loading of 75 pounds/hour HCl prior to scrubbing, the risk assessment limit for on-base workers. This criterion was modified after project initiation to removal of 99% of HCl and by scrubbing emissions from the catalytic oxidizer.
- Maintain dioxins concentrations in the scrubber blowdown below 6 parts per trillion (TCDD equivalents) so that suppliers can regenerate GAC in compliance with federal Resource Conservation and Recovery Act (RCRA) standards.

Key Monitored Operating Parameters

- Extraction well flow rates, vacuum and temperature.
- Extraction well VOC, O_2 and CO_2 concentrations.
- Vapor probe vacuum, temperature, and O_2 and CO_2 concentrations.
- Separators' water discharge flow rates and VOC concentrations.
- Vacuum blowers ' inlet and outlet vacuum/pressure, temperature, moisture content and VOC concentrations.
- Catalytic oxidizer inlet flow rate, LEL, VOC concentrations, moisture content and temperature.
- Catalytic oxidizer outlet VOC concentrations.
- Scrubber oil inlet/outlet flow rate, pressure and HCl, HF, and dioxins concentrations.
- Scrubber blowdown flow rate, pH, conductivity and dioxins concentrations.
- Caustic usage.
- Clarifier solids/sludge thickness.
- Filters' pressure.
- GAC influent/effluent pressure and dioxins concentrations.

Soil Vapor Extraction/Emission Control Systems Schematic



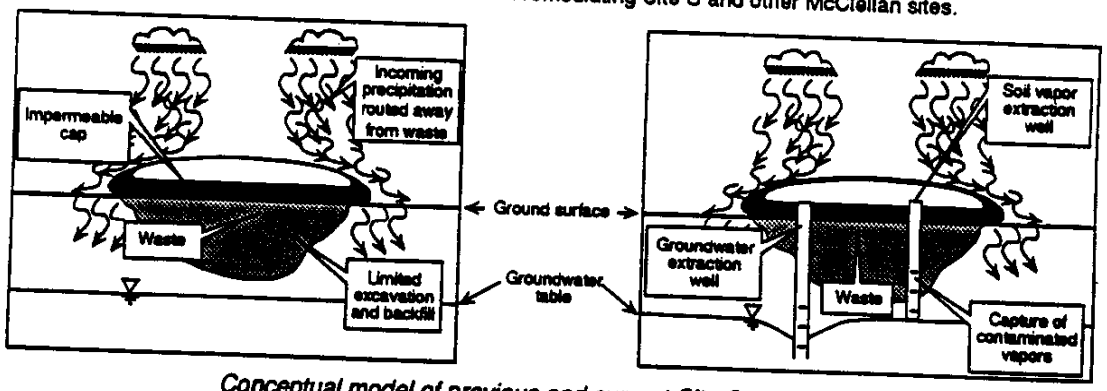
PERFORMANCE

Performance Objectives

- Demonstrate effectiveness of SVE for reducing the concentrations of VOCs in waste pit materials and vadose zone soils for future consideration at multiple McClellan sites with similar conditions.
- Evaluate the potential impact of increasing oxygen concentrations on in-situ bioremediation using SVE.
- Demonstrate the effectiveness of catalytic oxidation for reducing concentrations of VOCs in extracted soil vapor, and scrubbing for reducing acid gas and dioxins emissions produced during catalytic oxidation.

Remedial History and Plan

- Previous remedial actions consisted of limited excavation of waste pit materials, capping and groundwater pumping and treatment. SVE was recently demonstrated as part of an Engineering Evaluation - Cost Analysis (EE-CA) of this technology for potential future use in remediating Site S and other McClellan sites.



Conceptual model of previous and current Site S remediation

Initial Process Optimization Efforts

SVE viability is being tested in a series of field programs:

Current

In-Situ **Air Permeability Testing** (Steady state test of 5 wells over 4 days in 1991)

→ **In-Situ SVE Field Demonstration** (17 wells in 3 zones scheduled to be operated for 5 months) *This analysis focuses upon this portion of the demonstration program*

→ **Conduct Field Test of In-Situ Bioventing** Using SVE System to Evaluate In-Situ Biological Remediation of Contaminants

Future

→ **Conduct Field Test of Hot Air Injection** in Conjunction with In-Situ SVE to Evaluate Increased Physical Removal of Contaminants

Operational Performance

SVE Demonstration System Throughput

- During the initial 6 weeks of the SVE demonstration, ~ 150 million cubic feet of soil vapor was extracted and treated.
- The average (total system) air flow rate was ~ 2,500 scfm.
- ~ 46,000 pounds of speciated VOCs (±30%) were extracted and treated during the initial 6 weeks of the SVE demonstration. ~113,000 pounds of VOCs (± 30%) were extracted through 15 weeks of the demonstration.
- Up to 150,000 pounds of contaminants (hexane-equivalents) are believed to have been biodegraded in situ during the first 6 weeks of the demonstration.

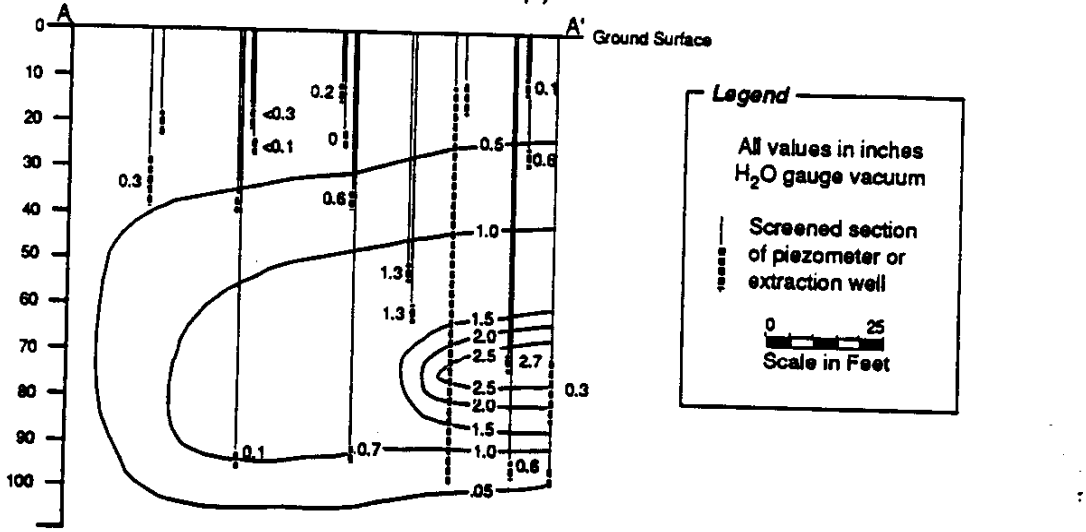
SVE Demonstration System Downtime

- The SVE demonstration system was shut down after ~6 weeks of operation because of base worker complaints about acid gas emissions.
- A scrubber and support systems to reduce acid gas [hydrochloric and hydrofluoric acids (HCl and HF)] emissions was constructed, and operation of the SVE system recommenced in March 1994.
- The operational frequency was ~70 to 75 % after recommencing operation (except for downtime for repairs to an off-site natural gas line and the base groundwater treatment system).

PERFORMANCE (Continued)

Pneumatic Performance

In situ vacuum during the initial period of SVE demonstration system operation exceeded 24 inches H_2O in all piezometers and no apparent "dead flow areas" were identified. Additional vacuum measurements would be required to define the full radius of at the flow rates and the vacuum levels implemented during the demonstration. The radius of influence achieved at Site S during a lower flow rate/vacuum air permeability test performed in 1991 is shown below. (Note the greater horizontal than vertical radius of influence which is attributable to the greater horizontal intrinsic permeabilities and the influence of the cap.)



Extraction System

- The initial 15 weeks of SVE demonstration system operation resulted in the removal of an estimated 113,000 pounds of speciated VOCs (± 30 percent based on the precision inherent in on-site gas chromatographic analysis).
- The deep alluvium well system accounted for 59% of the flow and 61% of the mass of contaminants extracted during this period. Generally, the estimated flow per linear foot of SVE well ranged from 1 to 5 scfm per linear foot of screened interval. Flow rates exceeded this range for 2 wells; the higher flows may have been the result of surface leakage.
- Three contaminants (TCE; 1,1-DCE and 1,1,1-TCA) accounted for > 90 % of the mass of contaminants extracted.
- Almost all of the SVE wells showed a reduction in concentrations for the most volatile species (e.g., vinyl chloride and Freon 113) and a corresponding increase in the concentrations of the less volatile species (e.g., o-xylene and methyl chloride), probably due to the difference in their mass transfer rates. As the concentration flux of more volatile compounds decreases, the mass transfer rate of less volatile species increase because of the increase in their concentration flux.
- VOC concentrations generally increased in the most contaminated deep alluvium SVE well and the waste pit wells. This increase may have been the result of contaminant transfer from newly formed flow paths connecting adjacent waste pits and contaminated sites. The corresponding increase in extraction flow rates for some of these wells is consistent with that theory.
- In situ respiration rates (based on oxygen consumption) and estimated biodegradation rates (expressed as hexane equivalents) were also quantified during the SVE demonstration. Oxygen consumption in the waste pits ranged from 0.16 to 0.79 percent O_2/hour, yielding estimated biodegradation rates of 2.5 to 12.5 mg/kg - day. Over a 1/4-acre site, 25 feet deep, this would correlate with a biodegradation rate of 35 to 175 pounds per day of (hexane-equivalent) contaminants. Oxygen consumption rates for the intermediate and deep alluvium wells were substantially lower, reflecting the lower contaminant concentrations as compared to the waste pit zone.
- Collection and laboratory analysis of soil samples from Site S is planned during later phases of operation and upon completion of the demonstration project for use in assessing SVE performance.

PERFORMANCE (Continued)

Treatment Equipment Performance

Blowers

- Blowers operated within rated capacities without breakdowns during the initial 15 week period.
- Overall system noise levels were 53.4 decibels and were primarily associated with blowers and scrubber system operations.

Separators

- Between 55 and 325 gallons of liquid were collected in each of the three initial months of system operation.
- After laboratory analysis, the liquid was discharged with the scrubber blowdown for treatment (clarification, filtration, GAC and polishing) at the base groundwater treatment system.

Catalytic Oxidizer

- Overall destruction and removal of efficiency (DRE) averaged 99 percent for total VOCs during the second and third months of the demonstration. Lower DRE measured during the first month of operation were attributed to inadequate catalyst fluidization, rapid attrition/elutriation of catalyst, and low 0_2 conditions.
- Flow rates were adjusted to maintain catalyst fluidization and minimize catalyst attrition. Catalyst usage averaged 5 pounds per 10^6 cubic feet of soil vapor treated during a majority of the initial 3 months of system operation. The generation of fines from excessive catalyst attrition required reductions in vapor extraction flow rate and modifications to the catalytic oxidizer to minimize chromium concentrations in the scrubber blowdown.
- Steady state flow rates eliminated flameout and fan surging experienced during initial system startup.
- Low concentrations of dioxins (<2E-9 lbs/hour TCDD-equivalents) were formed during catalytic oxidation of the chlorinated VOCs.

Scrubber

- The scrubber consistently achieved > 99 percent removal efficiency for HCl and < 99.5% for HF. Approximately 65% of dioxins (TCDD-equivalents) were also removed during scrubbing.
- Approximately 0.3 gallons of 25 percent NaOH caustic was consumed per pound of Cl extracted during scrubbing.
- Operational difficulties were experienced, necessitating minor scrubber system modifications. The scrubber tower packing and components accumulated calcium carbonate precipitate, formed as a result of calcium in makeup water, CO_2 in the SVE gas, elevated system temperature, and the high pH of the recycle liquid downstream of the caustic injection point. A swivel spray nozzle was installed in the tower to optimize acid cleaning, and the frequency of acid cleaning was increased to once every 3 to 4 weeks. Acid cleaning takes ~ 2 days to complete. Softening the makeup water to minimize fouling is also being investigated.
- Blowdown flow rates were increased from 6 gallons per minute (gpm) to 8 gpm and then 14 gpm to reduce dissolved salt content. Dioxins concentrations were found to be below detection limits in all of the blowdown effluent samples analyzed.

Clarifier, Filters and GAC

- Lower solids generation, due to modifications to the catalytic oxidizer after 3 months of operation, allowed the clarifier to be bypassed. Clarifier performance was not formally assessed.
- The frequency of changeout of the bag filters varied from between 4 to 36 hours. Factors believed to be contributing to this frequent changeout rate include: higher particulate than anticipated due to catalyst attrition, higher than anticipated blowdown flow rate and intermittent high blowdown flow rates causing solids carryover from the clarifier. Nine micron bag filters were substituted for the 5-micron filters at the time the clarifier bypass was initiated.
- Filters bags and clarifier solids were required to be disposed of as hazardous wastes because the chromium concentrations in waste extracts exceeded the Soluble Threshold Concentration (STLC) of 5.0 milligrams per liter (by a factor of 4 to 5). Catalyst carryover is the source of the chromium.
- Dioxins concentrations are below detection limits in the GAC influent and effluent. Thus the carbon effectively is serving to decrease the apparent chlorine concentration in the blowdown and is a polishing step to remove organics from operational upsets. GAC is changed out once every 1-2 months. Backflushing was implemented in response to solids buildup to extend carbon life.

COST

• The budget for the McClellan Site S SVE demonstration and initial removal action program was ~1.8 million for FY 1993 and ~2.0 million for FY 1994. This budget includes: site characterization; field air permeability testing; installation and operation of SVE wells, vapor probes and connecting manifold; purchase and operation of the air/water separators, blowers, scrubber and support systems; rental and operation of the catalytic oxidizer; short-term rental of a pilot resin adsorption system; electronic beam technology bench testing; laboratory analysis; and engineering support.

• A "baseline cost estimate" was developed for a SVE system in support of McClellan's base wide EE-CA of this technology. The cost estimate, which is based on Site S demonstration experience described in this report, is for a "typical removal action" at McClellan. The baseline cost estimate assumes emissions control equipment has a nominal capacity to process 2,500 scfm of extracted soil vapor containing contaminant concentrations of 3,000 parts per million by volume (ppmv) of chlorinated VOCs and 5,000 ppmv of petroleum hydrocarbons. The baseline cost estimate provided below is based on the the use of a standardized configuration which facilitates equipment design and procurement, which will be essential to installing transportable equipment that will be used at multiple McClellan sites.

Capital Costs of Baseline SVE System

Item	Design Basis	Unit Cost	Item Cost
Site Preparation			
Gas Connection	750 feet of 2 inch polyurethane pipe	$7.50/foot	$5,600
Electrical Connection	1,000 ft. of buried 4 in. conduit	$5.00/foot	5,000
Transformer	12kv to 440v unit	$13,000	13,000
Water Connection	1,000 ft. of buried 2 in. PVC pipe	$14.00/foot	14,000
Grading and Equipment Platform	3,000 sq. ft. of subgrade and concrete	$6.00/sq. foot	18,000
Well Installation	9 wells at total depth of 800 ft.	$75.00/ft. of depth	60,000
Equipment			
Vacuum Blowers 7-12 in. of Hg	4 blowers rated 500-800 scfm @ $17,000	$68,000	
Air-Water Separators @ 18 in. of Hg	2 units, 12,000 & 2,000 scfm rated	$4,000	8,000
Manifold and Piping and support	1,000 ft. of 4-8 in. PVC pipe, fittings	$30.00/foot	30,000
Emissions Control System	Catalytic oxidizer w/scrubber	$355,000	355,000
Engineering*	10% of site and equipment cost		57,700
Mobilization	10% of site and equipment cost		57,000
		Total Capital Cost	**$692,000**

** Excludes site characterization and other study costs.*
Note: Project management costs are excluded from the baseline system estimate.

Operating Costs of Baseline SVE System

Item	Design Basis	Unit Cost	Monthly Operating Costs
Operation and Maintenance	90% uptime, 648 hours per month		
Natural Gas	2,425 scfm	$3.50/1,000 scf	$5,500
Electricity	105 kw/h	$0.075/kWh	5,100
Water	617 gph	$1.00/1,000 gal	400
Scrubber Chemicals	254 pph	$350/ton	28,800
Waste Disposal	500 gph	$3.00/1,000 gal.	1,000
Testing and Monitoring	1 stack test per month, 9 well analysis per month	$2,500/sample	25,000
Operating Labor	90 hrs for 2-part-time techs and part-time sample collector	$70/hour	6,300
Reporting	1 monthly operations report and pro-rated summary report	$6,000/month	6,000
		Total Monthly Operating Costs	**$78,100**
		Total Annual Operating Cost	**$937,200**

Note: At a low VOC concentration (<100 to 200 ppmv), the cost of a carbon adsorption system to control air emissions is comparable to that of a catalytic oxidizer and scrubber. The capital cost of a trailer-mounted carbon adsorption system is ~ $120,000. Carbon consumption is ~ 40,000 pounds per month at a flow rate of 2,500 scfm and inlet VOCs concentration of 200 ppmv. The cost to replace the carbon is ~ $2.00 per pound.

REGULATORY/INSTITUTIONAL ISSUES

- The SVE demonstration was performed as part of a base wide EE-CA of this technology for in situ remediation of vadose zone soil and fill materials containing VOCs. The demonstration program results will be used as the basis for 1.) initiating SVE at Site S as an Initial Removal Action, and 2.) establishing SVE as the Presumptive Remedy for Site "S" other sites at McClellan AFB for removal of VOCs from the vadose zone in accordance with EPA's Superfund Accelerated Cleanup Model (SACM).

- Cleanup criteria for Site S and OU D have not yet been established.

- Catalytic oxidation was selected as the Best Available Control Technology for control of VOCs in extracted soil vapor. The technology complies with the Sacramento Air Quality Management District requirements for 95% destruction of total VOCs and no significant impact on McClellan AFB workers (as determined by a site-specific risk assessment).

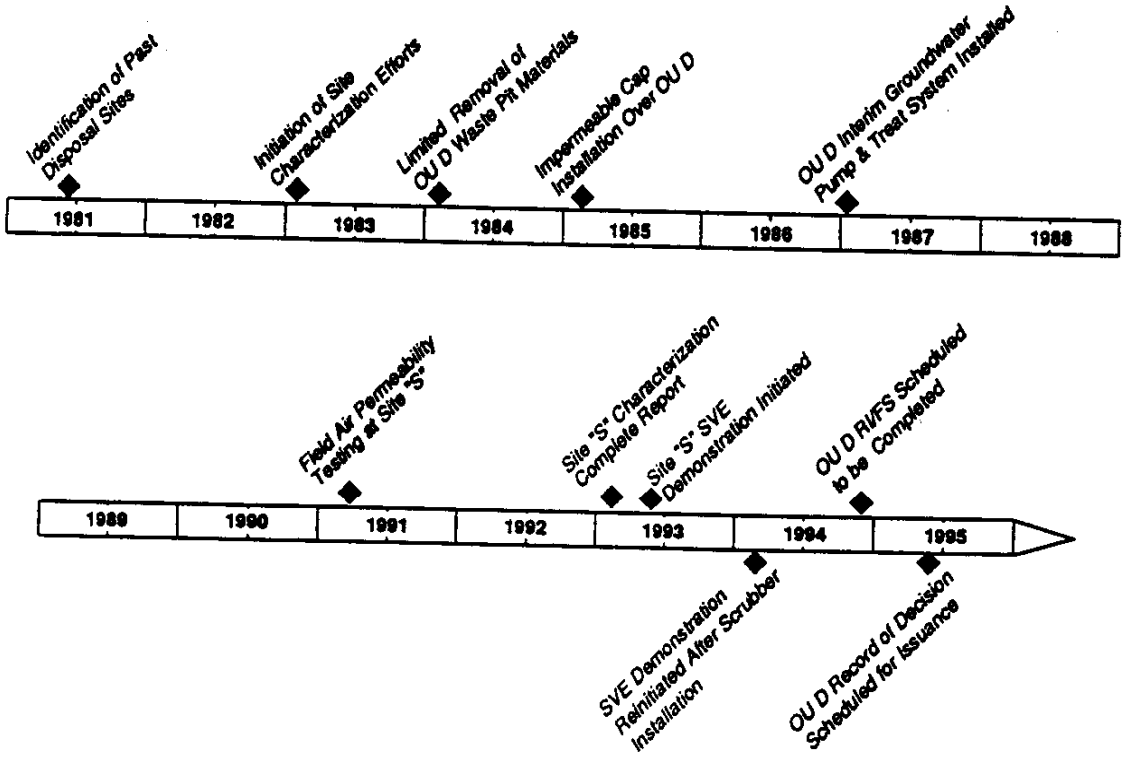
- New sources of nitrogen oxide emissions in the Sacramento area and at McClellan must be offset by removal or reduction from other sources in the region. Minimal nitrogen oxide is produced by the catalytic oxidizer used in the McClellan SVE demonstration because of its low operating temperature. McClellan AFB is currently participating in an offset program to reduce nitrogen oxide emissions from other sources.

- The scrubber and support systems were installed after site workers complained of odors and actual mass emission rates for acid gas were greater than originally anticipated.

- Mufflers were installed on blower intake/discharge lines and acoustically deadened enclosures were installed on blowers to reduce SVE system noise from 53.4 decibels to less than the City of Sacramento's 50 decibels limit.

SCHEDULE

Major Milestones



LESSONS LEARNED

Design and Implementation Considerations

- The radius of influence for SVE wells is dependent on the homogeneity of the soils being remediated. The radius of influence to SVE wells screened in the waste pit material at Site S varied from 15 to 60 feet for a single well, reflecting the heterogeneity of this zone of contamination.

- The mass of contaminants extracted and biodegraded during the initial 6 weeks of the Site S SVE demonstration exceeded the estimated mass of contaminants calculated to be present based on site characterization results by almost 2 orders of magnitude, and the extracted soil vapor concentrations remained relatively constant during the initial demonstration period. These results suggest the possible presence of free product in the waste pit materials and/or alluvial soil in the vadose zone that was not previously identified. Alternatively, the analytical methods used to measure subsurface containment concentrations may have not accurately quantified the total mass of contamination present at the site. Recent studies have indicated that current EPA-preferred analytical methodology for determining soil VOC concentrations, purge and trap, only measures that small fraction of total soil contamination that can be easily removed (pore space and soil surface-bound contamination).

- The initial SVE demonstration indicated that substantial in situ biodegradation was occurring. However, the low inorganic nitrogen and phosphorus concentrations detected in most soil samples could be potentially limit the extent of biodegradation of organic contaminants. In addition, the waste pit fill materials may be somewhat drier than optimum for microbial activity.

- Additional characterization of areas surrounding Site S are required to determine the impact of other contamination sources on SVE operations at Site S.

- Additional vadose zone observation wells are needed in the area surrounding Site S to monitor changes in in situ soil vapor VOC, O_2 and CO_2 concentrations over time.

- The higher the anticipated mass loading rate of chlorinated VOCs in extracted soil vapor resulted in higher acid gas emissions than predicted. Although the actual acid gas (hydrochloric and hydrofluoric acid) emissions were were within regulatory and risk-based limits, the SVE system was retrofitted with a scrubber. The scrubber was installed as a result of odor complaints by base workers.

- Low concentrations of dioxins were formed during catalytic oxidation of the chlorinated VOCs. The presence of dioxins required pretreatment of scrubber blowdown (clarification, filtration and liquid-phase GAC polishing) prior to discharge to the base groundwater treatment system. Close monitoring of dioxins concentrations in the blowdown, clarifier solids, filters and spent carbon is required to comply with hazardous waste regulations and waste disposal contractor specifications.

- Higher than expected generation of fines was caused by catalyst attrition. Initial losses of catalyst may have been caused by potential HF attack or localized high temperature excursions associated with non-uniform catalyst fluidization and low O_2 conditions.

- Higher than anticipated blowdown flow rates, intermittent flow surges, and a higher than anticipated concentration of suspended solids associated with catalyst attrition caused operational difficulties and resulted in the need to modify the catalytic oxidizer and blowdown treatment processes. Future SVE air pollution control systems should be designed with sufficient capacity to provide for operational flexibility.

- Fines in scrubber blowdown contained sufficient concentrations of chromium to cause clarifier solids and bag filters to managed as hazardous wastes.

Technology Limitations

- Cleanup criteria have not been established for vadose zone soils within OU D, including Site S. The ability of SVE to meet cleanup criteria in both the waste pit fill materials and alluvial soils will be an important consideration in determining whether the technology will be selected for full-scale remediation at McClellan AFB.

- It is uncertain whether the rate for diffusion for VOCs in soil micropores and soil organic matter is significant to the remediation of vadose zone soils using SVE. Additional investigation is planned at McClellan AFB to address this uncertainty prior to selecting one or more technologies for final remediation of VOC contaminated vadose zone soils.

Future Technology Selection Considerations

- The SVE demonstration equipment was designed with excess capacity that will allow it to be used for remediation of Site S after additional extraction wells and manifold are installed.

- Enhancements to SVE are planned for mid to late 1994 as part of the on-going demonstration program. Soil vapor extraction rates will be decreased to promote aerobic in-situ biodegradation rather than volatization of organic contaminants (bioventing). As part of another field pilot test at Site S, hot air injection will be conducted in conjunction with SVE to assess its ability to enhance volatization of semi-volatile organic contaminants.

- A vapor phase resin adsorption system was field tested during early 1994 to evaluate its potential as an alternative to catalytic oxidation and scrubbing. A performance evaluation based on the pilot test was not complete as of May 1994. However, preliminary results indicate operating difficulties occurred, including preferential adsorption of some of the many organic contaminants and frequent regeneration of the resin beds.

- Electron Beam Technology (EBT) was bench-tested to evaluate its potential application to the treatment of extracted soil vapor at McClellan. The test results did not support using the technology without the addition of promoters (e.g., hydrogen peroxide) for treatment of the chlorinated VOCs in soil vapor extracted from Site S. There is currently insufficient data on optimizing process parameters with the use of promoters (e.g., hydrogen peroxide) for EBT to be considered by McClellan.

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CERTIFICATION

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SOURCES

Major Sources For Each Section

Site Characteristics:	Source #s (from list below) 1, 3, 4, 10, and 11
Remediation System:	Source #s 1, 3, 4, 5, 6, 11, 12, 13, 14, 15, and 16
Performance:	Source #s 4, 5, 6, 7, 9, 13, 14, 15, 16, and 17
Cost:	Source #s 6, 12, 15, 17, 18, and 19
Regulatory/Institutional Issues:	Source #s 8, 15, 16, and 17
Schedule:	Source #s 8, 9, 10, 13, 14, 15, 16, 17, and 19
Lessons Learned:	Source #s 2, 5, 6, 7, 8, 12, 13, 14, 15, and 16

Chronological List of Sources and Additional References

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2. *An Evaluation of Vapor Extraction of Vadose Zone Contamination*, prepared by Oak Ridge National Laboratory, Document No. ORNL/TM-12117, May 1992.

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9. *Technical Review Committee Meeting Minutes, McClellan Air Force Base*, October 23, 1993.

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15. *Data Package provided by J. Steven Hodge*, Remedial Project Manager, Operable Unit D, Environmental Restoration Division, Environmental Management Directorate, McClellan Air Force Base, April 14, 1994.

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17. Personal Communications with J. Steven Hodge, Remedial Project Manager, Operable Unit D, Environmental Restoration Division, Environmental Management Directorate, McClellan Air Force Base, April - June, 1994.

18. *Basewide Engineering Evaluation - Cost Analysis for Soil Vapor Extraction, General Evaluation Document, McClellan Air Force Base*, Undated .

19. *Basewide Engineering Evaluation - Cost Analysis for Soil Vapor Extraction, Site Specific Document OU D/Site S, McClellan Air Force Base*, Undated.