COST AND PERFORMANCE REPORT

Soil Vapor Extraction
at the
Fairchild Semiconductor Corporation Superfund Site
San Jose, California

Prepared By:

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office

March 1995

Notice

Preparation of this report has been funded wholly or in part by the U.S. Environmental Protection Agency under Contract Number 68-W3-0001. It has been subject to administrative review by EPA headquarters and Regional staff and by the technology vendor. Mention of trade names for commercial products does not constitute endorsement or recommendation for use.

COST AND PERFORMANCE REPORT

EXECUTIVE SUMMARY

This report presents cost and performance data for a soil vapor extraction (SVE) treatment application at the Fairchild Semiconductor Corporation Superfund Site (Fairchild) in San Jose, California. The SVE system, which consisted of 39 extraction wells, operated from January 1989 through April 1990 as part of a remedial action. Contaminants of concern at the site included 1,1,1-trichloroethane (TCA), 1,1-dichloroethene (DCE), tetrachloroethene (PCE), xylene, Freon-113, acetone, and isopropyl alcohol (IPA). This was an early application of SVE at a site with complex hydrogeology, and is notable for its use of aquifer dewatering and slurry wall installation prior to treatment.

The Fairchild site is a former semiconductor manufacturing facility which operated from April 1977 until its closure in October 1983. In late 1981, Fairchild Semiconductor Corporation discovered that an underground organic solvent storage tank had failed, resulting in soil contamination and on- and off-site groundwater contamination by a mixture of solvents, including TCA, DCE, PCE, and xylene. An estimated 60,000 gallons of solvents were released.

In 1985, EPA and the State of California entered into a multi-site cooperative agreement with Fairchild which included the San Jose site. Fairchild conducted site remediation activities, including removal of the failed tank, excavation and disposal of contaminated soil, installation and operation of a groundwater extraction and treatment system, installation and operation of the SVE system, sealing several wells to prevent cross-contamination of aquifers, and construction of a slurry-bentonite wall to contain contaminated groundwater on-site. The California Regional Water Quality Control Board established a soil cleanup goal for this remediation of a total contaminant extraction rate of less than 10 lbs/day, along with specific performance goals for individual wells.

During 16 months of operation, the SVE system removed approximately 16,000 pounds of solvents from the soil. The most rapid reductions in contaminant concentrations occurred during the first two months of SVE system operation. The system achieved an extraction rate of less than 10 pounds per day within 8 months of system operation.

The actual cost for treatment using the SVE system was $3,900,000, consisting of $2,100,000 in capital costs, and $1,800,000 in operating costs, corresponding to a calculated cost of $93 per cubic yard of soil treated (42,000 cubic yards) and $240 per pound of contaminant removed.

SITE INFORMATION

Identifying Information:

Fairchild Semiconductor Corporation

San Jose, California

CERCLIS # CAD097012298

ROD Date: 20 March 1989

Treatment Application:

Type of Action: Remedial

Treatability Study associated with application? Yes (see Appendix A)

EPA SITE Program test associated with application? No

Period of operation: 1/5/89 - 4/20/90

Quantity of material treated during application: 42,000 cubic yards of soil

SITE INFORMATION (CONT.)

Background

Historical Activity that Generated Contamination at the Site: Semiconductor manufacturing

Corresponding SIC Code: 3674 (Semiconductors and Related Devices)

Waste Management Practice That Contributed to Contamination: Underground Storage Tank (failed underground waste solvent tank)

Site History: The Fairchild site, located in south San Jose, California, as shown in Figure 1, is a former semiconductor manufacturing facility. The facility operated from April 1977 until its closure in October 1983. In late 1981, Fairchild Semiconductor Corporation discovered that an underground organic solvent storage tank had failed, resulting in soil contamination and on- and off-site groundwater contamination by a mixture of solvents. An estimated 60,000 gallons of waste solvent were released. [5, 6]

Figure 1. Site Location

Interim remedial cleanup activities of the soil and groundwater at the site began in 1982. Fairchild removed the failed tank and excavated and disposed 3,400 cubic yards of soil in a permitted hazardous waste facility in 1982. Installation of a hydraulic control system in 1982 included groundwater extraction and treatment, to prevent further migration of contaminants and to extract contaminated groundwater from on-site and off-site recovery wells. In 1983, Fairchild sealed wells that provided potential pathways for contaminant migration to prevent contaminated groundwater from the shallow aquifers from entering, and contributing to further contamination of the deeper aquifers. Fairchild installed a slurry-bentonite wall around the site perimeter in 1986 to contain contaminated groundwater on site within the shallower aquifers. [5, 6]

Fairchild conducted remedial actions at the site in accordance with a Remedial Action Plan (RAP) prepared in October 1988. The RAP identified specific activities, including soil vapor extraction of on-site soils, designed to further reduce the concentration of chemical contaminants in soil and groundwater at the site. [5, 6]

Regulatory Context: In 1985, the State of California and EPA entered into a multi-site Cooperative agreement, which included remediation activities at the Fairchild site in San Jose, California. As a result of the agreement, the California Regional Water Quality Control Board (RWQCB) identified site cleanup requirements (SCR) in Order No. 89-16, signed on January 18, 1989, [10] and described in a Record of Decision signed in March 1989. [6] Order No. 89-15, also signed on January 18, 1989, specified requirements for discharge of extracted groundwater to surface waters. [9] As discussed below under Cleanup Goals and Standards, the RWQCB subsequently amended the SCR to allow the expedited completion of soil cleanup activities. [8]

Remedy Selection: Soil vapor extraction was selected as the remedy for contaminated soil at the Fairchild Superfund site based on treatability study results and because it conserves water more than a pump and treat program (i.e., less groundwater extraction). [6]

SITE INFORMATION (CONT.)

Site Logistics/Contacts

Site Management: PRP Lead

Oversight: California Regional Water Quality Control Board

Remedial Project Manager:
Belinda Wei
U.S. EPA Region 9
75 Hawthorne Street
San Francisco, CA 94105
(415) 744-2280

State Contact:
Stephen Hill (primary contact for this application)
California Regional Water Quality Control Board
2101 Webster Street, Suite 500
Oakland, CA 94612
(510) 286-0433

Treatment System Vendor:
Dennis L. Curran
Canonie Environmental Services Corporation
441 N. Whisman Road, Building 23
Mountain View, CA 94043
(415) 960-1640

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Processed Through the Treatment System: Soil (in situ)

Contaminant Characterization

Primary contaminant groups: Halogenated and Nonhalogenated Volatile Organic Compounds

The following solvents were detected in soils at the Fairchild Semiconductor site: TCA, DCE, IPA, xylenes, acetone, Freon-113, and PCE. TCA was measured at concentrations as high as 3,530 mg/kg and xylenes as high as 941 mg/kg. The maximum concentration of total solvents (including TCA, 1,1-DCE, IPA, xylenes, acetone, Freon-113, and PCE) detected in soil samples analyzed from the Fairchild site, prior to the remedial action, was 4,500 mg/kg. As described below under site geology/stratigraphy, and shown in Figure 2, the concentration of certain contaminants (e.g., TCA) was plotted against location in the subsurface, and concentration contours were identified. Figure 2 shows TCA contours for 1, 10, and 100 mg/kg of TCA; contours were also identified for 1,000 mg/kg of TCA at the site. [2]

Matrix Characteristics Affecting Treatment Cost or Performance

The major matrix characteristics affecting cost or performance for this technology and their measured values are presented in Table 1. A particle size distribution for one soil boring (SB-174) is shown in Figure 3.

Table 1. Matrix Characteristics [4,11]

Parameter	Value	Measurement Procedure
Soil Classification	Sands, silts, and clays; U.S.C.S. Soil types SW, SM, ML, and CL.	Sieve Analysis
Clay Content and/or Particle Size Distribution	See Figure 2	Sieve Analysis
Moisture Content	Not Available	-
Air Permeability	0.12-0.83 cm/sec	Aquifer Performance Tests
Porosity	Not Available	-
Total Organic Carbon	Not Available	-
Nonaqueous Phase Liquids	Not Present	-
Transmissivity	69,000-810,000 gpd/ft	Aquifer Performance Tests

MATRIX DESCRIPTION (CONT.)

Site Geology/Stratigraphy

Figure 2. TCA Concentrations in Soil Profile E-E'
Measured in February - June 1987 [14]

Figure 3. Particle Size Distribution for Soil Boring 174 [11]

MATRIX DESCRIPTION (CONT.)

Site Geology/Stratigraphy

The Fairchild site is located in a subarea of the South Bay Drainage Unit known as the Santa Teresa Subarea, or the Santa Teresa Plain. The topography of the floor of the plain is generally flat to gently sloping, with overall valley drainage to the northwest. The floor of the plain is underlain by Quaternary alluvium, which likely was deposited by the ancestral Coyote Creek as it meandered across the basin. [4]

The site consists of 330 to 360 feet of unconsolidated alluvial deposits overlying bedrock. The structure of the alluvium is highly complex, as shown on Figure 2 for site profile E-E′, consisting of layers of water-bearing sand and gravel alternating with silt and silty-clay layers which act as aquitards. Figure 2 also shows the concentration of TCA in the soil at the site, near soil boring (SB)-200.

Four distinct aquifer systems have been identified in the alluvium as aquifers "A", "B", "C", and "D", with "A" being the shallowest at a depth ranging from 10 to 40 feet below ground surface (BGS). The B aquifer ranges from 50 to more than 70 feet BGS. The alternating sand and gravel layers range in thickness from several feet to approximately 140 feet in thickness while the silt and silty-clay layers range from several feet to approximately 60 feet in thickness. An aquitard (silty-clay layer) identified between the "A" and "B" aquifer (the "AB" aquitard) ranges between 20 and 70 feet BGS. Aquifers merge or are absent in some locations in the site area. [2]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology

Soil vapor extraction

Supplemental Treatment Technology

Post-treatment (air) using carbon adsorption

Soil Vapor Extraction System Description and Operation

System Description

The SVE system used at Fairchild consisted of 39 extraction wells, installed in the area of contaminated soil. As shown in Figure 4, the majority of the extraction wells were screened in the "A-B" aquitard. The "A" and "B" aquifers had been dewatered prior to installation of the extraction wells. In addition to the extraction wells, the SVE system contained air inlet wells, installed in areas of uncontaminated soil, to provide a means for bringing additional air into the area of contaminated soil. The vendor performed a treatability study, described in Appendix A, prior to the full-scale treatment activities to determine design parameters for the full-scale application. [12]

A slurry wall and groundwater extraction system were used at Fairchild to dewater the soil. These items also controlled the flow of groundwater and were used to prevent contaminant migration. Groundwater was extracted from recovery wells within the slurry wall enclosures to lower the water elevation inside the slurry wall and maintain inward gradients across the wall. These activities also assisted in control and were used to containment of soil vapors for the SVE system.

Each extraction well was equipped with a submersible pump to remove groundwater that collected in the well. The pumps in the vapor extraction wells were connected by underground piping to the existing groundwater treatment system, which consisted of air stripping and discharge to a surface water. [12]

As shown in Figure 5, the extraction wells were connected to a vapor extraction and treatment system, consisting of vacuum pumps, a dehumidification unit, and vapor phase granular activated carbon (GAC).

TREATMENT SYSTEM DESCRIPTION (CONT.)

Soil Vapor Extraction System Description and Operation (cont.)

Figure 4. SVE System Well Location Plan [12]

Figure 5. SVE System Equipment Location Plan [12]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Soil Vapor Extraction System Description and Operation (cont.)

Two vacuum pumps with a capacity of approximately 4,500 cubic feet per minute (cfm) at 20 inches of mercury (Hg) were used to remove soil vapors. Each vacuum pump was powered by a 250-horsepower high efficiency electric motor. [2, 12]

Five GAC adsorption units were used to capture the organic compounds extracted in the soil vapors. Soil vapors were first routed to two 3,000-pound GAC beds operating in parallel, followed by a secondary set of two 3,000-pound GAC beds operating in parallel, and then to a final, single 3,000-pound GAC bed. [12]

System Operation

The SVE system was designed to operate continuously five days a week. At any one time, the system operated a maximum of 25 of the 39 extraction wells. The system was operated over 427 days for a total of 9,800 hours between January 5, 1989 and April 20, 1990. The vacuum applied to the wells was maintained at a constant level of 15 inches of Hg during the operation. [2]

During the start-up period, several modifications were made to the SVE system, resulting in a 3-month delay in system operation. During this period, unexpectedly high chemical concentrations detected in air samples collected from the well line resulted in contaminant breakthrough and required modifications to the sampling procedures. Circuit breakers and other components in the vacuum pumps did not operate properly and were replaced or modified. The carbon treatment vessels were found to be undersized and replaced with a larger series of units. [12]

Because of the limited exposure of workers to the chemicals, Level D health and safety protective measures were employed, and the work was performed in accordance with the State-approved health and safety plan. [16]

Operating Parameters Affecting Treatment Cost or Performance

The major operating parameters affecting cost or performance for this technology and the values measured for each are presented in Table 2.

Table 2. Operating Parameters [2]

Parameter	Value
Air flow rate	28 scfm (Aquifer A); 144 scfm (Aquifer B); 66 scfm (Aquitard A-B)
Operating Vacuum	15 inches of Hg

TREATMENT SYSTEM DESCRIPTION (CONT.)

Timeline

A timeline for this application is shown in Table 3.

Table 3. Timeline [2]

Start Date	End Date	Activity
04/77	10/83	Fairchild Semiconductor manufacturing facility conducts operations at San Jose location
10/81	-	Discovery of 60,000-gallon waste solvent UST leak
11/81	'89	Interim Remedial measures conducted
4/87	8/87	Pilot-study soil vapor extraction system conducted
10/88	12/88	Start-up activities conducted
1/89	4/90	Full-scale soil vapor extraction system operational
3/89	.	Record of Decision signed
7/89	.	Soil verification samples collected
12/93	.	5-Year Report submitted to CA RWQCB

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards

The State board established cleanup goals for the SVE remedial action for both individual vapor extraction wells and the overall SVE system in terms of contaminant removal rates. The State required air extraction from individual wells until the contaminant removal rate from the well decreased to 10% (or less) of the initial removal rate, the contaminant removal rate declined at a rate of less than 1% per day for 10 consecutive days, or until SVE system operation achieved a total contaminant removal rate less than 10 lbs/day. [2]

Additional Information on Goals

The ROD and the California RWQCB Order originally established soil cleanup goals of 1 mg/kg for each of five contaminants: TCA, DCE, xylenes, Freon-113, and PCE. [6, 9] As a result of an appeal by Fairchild of several aspects of the SCR, the State Board issued an amendment of the Order in May 1990, which established the cleanup goals described above. [8]

Treatment Performance Data

Figure 6 shows the contaminant removal rate in pounds per day for the SVE system as a function of time for the first 11 months of full-scale system operation (January 5 - December 1, 1988). Cumulative mass of contaminants removed is plotted as a function of time on Figure 7. The mass of contaminants removed was calculated using analytical results from charcoal tube samples of extracted soil vapors collected from each extraction well, along with extraction well flow rate data. Samples were collected several times a month for the first 6 months of operation, and approximately once per month during the latter part of the operation. Samples were desorbed in a laboratory and analyzed using EPA SW-846 Methods 8010, 8020, and 8240.

To assess the effect of shutting off individual extraction wells, several wells that met the shutoff criteria were shut off and turned back on between October 1988 and April 1989 at intervals of two, four, and six weeks. Table 4 shows the results from this effort for seven wells.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Treatment Performance Data (cont.)

Figure 6. Contaminant Removal Rate as a Function of Time [2]

Table 4. Effect of Shutting Off Extraction Wells [13]

Extraction Well No.	VOC Concentration at Shutoff (ppmv)	Concentration Following Shutdown Period (ppmv)		
		2 Weeks	4 Weeks	6 Weeks
AE-9A	23.2	17.9	NA	NA
AE-13A	744.3	523.1	NA	NA
AE-14A	627.5	363.0	NA	NA
AE-16A	14.1	13.7	NA	NA
AE-7A	64.5	NA	53.0	NA
AE-15A	27.5	NA	11.6	NA
AE-20(A)	5.7	NA	NA	1.6

TREATMENT SYSTEM PERFORMANCE (CONT.)

Treatment Performance Data (cont.)

Figure 7. Cumulative Mass of Contaminants Removed as a Function of Time [13]

Soil boring samples were collected at several site locations to assess the effectiveness of the SVE system operation on soil concentrations during the first seven months of treatment. Six soil borings were collected in the April to June 1987 period (pre-remediation) and July 1989 (samples taken after approximately 7 months of operation). One of the soil borings was drilled within the area of highest contaminant concentration at the site (SB-271, drilled within the 1,000 mg/kg TCA contour at the site in June 1988); one within a less contaminated area (SB-272, drilled within the 100 mg/kg TCA contour); three within a less contaminated area (SB-273, -274, and -275, drilled within the 10 mg/kg TCA contour), and one within the least contaminated area (SB-276, completed within the 1 mg/kg TCA contour). Soil boring samples were analyzed using SW-846 Methods 8010, 8020, and 8240; the analytical results are shown in Table 5. [13]

Table 5. Comparison of Pre-Remediation and July 1989 Soil Boring Analysis [2,13]

	TCA (mg/kg)		DCE (mg/kg)		Xylenes (mg/kg)		Acetone (mg/kg)		IPA (mg/kg)		Freon-113 (mg/kg)		PCE (mg/kg)	
Soil Boring Number	Pre-remediatio	07/89	Pre-remediatio	07/89	Pre-remediatio	07/89	Pre-remediatio	07/89	Pre-remediatio	07/89	Pre-remediatio	07/89	Pre-remediatio	07/89
SB-271	3530	416	16.6	2.2	941	462	18	281	ND	134	ND	ND	ND	4.1
SB-272	40.6	79	3.4	2.5	19.2	156	ND	1.5	ND	0.9	ND	ND	ND	1.2
SB-273	266	37.3	12.5	1.5	189	85.6	7.7	3.5	0.02	1.8	ND	ND	2.2	0.5
SB-274	12.2	7.8	1.6	0.3	4.8	5.5	7.6	1.9	ND	ND	NA	ND	ND	0.04
SB-275	6.4	5.5	0.5	1.5	ND	1.2	ND	2.9	ND	0.4	ND	ND	ND	ND
SB-276	1.1	0.1	0.05	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND - Not detected
NA - Not analyzed
Pre-remediation samples collected April - June 1987.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Treatment Performance Data (cont.)

Additional soil samples were collected in January 1995 to evaluate the current concentrations in soils. The data from these borings are not available at this time. [16]

Performance Data Assessment

The treatment performance data shown in Figures 6 and 7 indicate that overall SVE system operation removed approximately 16,000 pounds of solvents from the soil during 16 months of operation (January 1989 to April 1990), at which time the system was shut off. The system achieved the cleanup goal of less than 10 lbs/day contaminant removal rate 3.6 lbs/day after 16 months of operation. The extraction rate decreased from a maximum of 130 pounds per day to less than 4 pounds per day when it was shut off.

The SVE system was operated for 8 months after the time when the 10 lbs/day goal was achieved to remove additional contaminants from the soil (i.e., to the point where the soil was believed to no longer leach contaminants to the groundwater).

In addition, Figures 6 and 7 indicate that the rate of contaminant extraction using the SVE system increased rapidly during the initial stages of system operation (2 months) and then decreased at a more gradual rate.

The data in Table 4 indicate that shutting off individual extraction wells did not increase the concentrations in the soil vapors after two, four, or six weeks of well shutdown. The SVE system was shut off on April 20, 1990.

A review of the data in Table 5 indicates that the concentration of many of the chemical contaminants in the soil borings had decreased by July 1988 (seven months of SVE system operation). However, concentrations of several contaminants increased during this period, including acetone in SB-271 and SB-275, TCA in SB-272, xylenes in SB-272 and SB-274, IPA in SB-271 through 273 and SB-275, and PCE in SB-271 and SB-272. The variation in contaminant concentrations in the soil may be attributable to variation in contamination across the areas where the soil borings were collected.

Performance Data Completeness

Data are available for concentrations of contaminants in the soil before treatment and at a mid-point of the treatment process (after 7 of the 16 months of SVE system operation). Confirmatory soil samples were collected by the vendor after the remediation was completed; however, the data from these samples are not available at this time. In addition, data are available for characterizing concentrations of contaminants in soil vapors from each extraction well over the course of the treatment operation.

Performance Data Quality

The QA/QC program used throughout the remedial action met the EPA and the State of California requirements. All monitoring was performed using EPA-approved methods, and the vendor did not note any exceptions to the QA/QC protocols. [2]

TREATMENT SYSTEM COST

Procurement Process

The PRPs contracted with Canonie Environmental to construct and operate the SVE system at the site. Canonie Environmental used several subcontractors to implement specific aspects of the operation. [12]

Treatment System Cost

The treatment vendor provided estimated (projected) and actual treatment cost information to the California RWQCB. The actual treatment cost of $3,900,000 was reported by the vendor in terms of capital costs and operation and maintenance costs. The actual capital costs for the soil vapor extraction program were $2,100,000 (this does not include costs for construction of the slurry wall or for aquifer dewatering), and actual operation and maintenance costs totalled approximately $1,800,000 for 16 months of operation. This corresponds to $240 per pound of contaminants removed and $93 per cubic yard of soil treated.

Because the specific items included in these totals is not available, a cost breakdown using the interagency Work Breakdown Structure (WBS) is not provided in this report.

The total projected costs (based on 24 months of operation) were $4,200,000. The projected capital cost of the soil vapor extraction system, including installation of extraction wells, installation of a vapor-phase treatment system, preparation of the treatment area, and engineering services, was approximately $2,200,000. Projected operation and maintenance costs, including water quality sampling and analysis, water level monitoring, equipment maintenance, engineering services, and carbon regeneration, was approximately $2,000,000. [2, 11]

The actual costs for this project were approximately 7% less than the projected costs because the amount of time required for the remediation was less than originally estimated.

The number of cubic yards of soil treated at Fairchild is an estimate of the amount of soil influenced by SVE, provided by the vendor; the actual amount of soil treated is not available at this time for comparison with the estimate.

Cost Data Quality

Actual and projected capital and operations and maintenance cost data are available from the treatment vendor for this application. A detailed breakdown of the cost elements included in the total actual costs is not available at this time. Limited information on the items included in the total projected costs was provided by the vendor, as discussed above.

OBSERVATIONS AND LESSONS LEARNED

Cost Observations and Lessons Learned

- Actual costs for the SVE treatment application at Fairchild were approximately $3,900,000 ($2,100,000 in capital and $1,800,000 in operations and maintenance), which corresponds to $240 per pound of contaminants removed and $93 per cubic yard of soil treated.
- The actual costs for this project were approximately 7% less than the projected costs because the amount of time actually required for the remediation was less than originally estimated.

OBSERVATIONS AND LESSONS LEARNED (CONT.)

Performance Observations and Lessons Learned

- The treatment system performance data indicate that approximately 16,000 pounds of solvents were removed from the soil over 16 months (427 days totalling 9,800 hours of operation); and that the SVE system achieved the cleanup goal of less than 10 lbs/day extraction rate after 8 months of operation, and less than 4 lbs/day at the end of the 16-month operating period, at which time the system was shut off.
- The most rapid reductions in contaminant concentrations occurred during the first two months of treatment.
- A test designed to evaluate potential rebound in extraction wells revealed that shutting off extraction wells for 2-6 weeks did not cause soil vapor concentrations to increase.

Other Observations and Lessons Learned

- Several startup problems, including electrical problems with the vacuum pump and problems with properly sizing the carbon handling equipment, caused a 3-month delay in beginning full-scale system operation.
- A high powered pump was required for this application because the soil that was treated was very fine grained and had previously been in a saturated zone.
- The heterogeneity of the areas where the soil borings were collected limited the accuracy of the process of matching the pre-remediation and July samples. Due to a planned change in land use, additional soil boring samples were collected in January 1995 to more precisely assess removal efficiency and the extent of residual soil contamination. Data from these borings are not available at this time.
- According to the CA RWQCB, this application revealed limitations concerning the cleanup level that could be achieved by SVE in a previously saturated aquifer. When the project began, a 1 mg/kg total VOC cleanup level for soil was developed based on several soil cleanup standards adopted in other Superfund orders and locally for other applications of SVE for soil in the vadose zone. In the Fairchild application, the system was not able to reach a 1 mg/kg level for treatment of previously saturated aquifers, and the RWQCB accepted a performance goal of no leaching instead of 1 mg/kg.
- The results of the treatability study showed that SVE was capable of sufficiently reducing target contaminant concentrations in site soils, and proved to be useful in designing the full-scale SVE treatment system. The vacuum blower that achieved the best results in the treatability study was used in the full-scale treatment system. Also, the existing monitoring network was used to reduce the number of new wells that were installed.
- This treatment application was part of a multi-faceted cleanup program. Implementation of the slurry wall and dewatering phases of the cleanup assisted in acceleration of contaminant removal rates from both soil and groundwater.

REFERENCES

1. Annual Status Report, January 1, 1992 through December 31, 1992, Canonie Environmental, February 1993.

2. Five-Year Status Report and Effectiveness Evaluation, Canonie Environmental, December 1993.

3. NPL Public Assistance Database, Fairchild, Semiconductor Corp. (South San Jose Plant), California, EPA ID #CAD097012298, March 1992.

4. Revised Draft Report, Remedial Action Plan, Fairchild Semiconductor Corporation Superfund Site, Canonie Environmental, October 1988.

5. Superfund Interim Site Close Out Report, Fairchild - San Jose, California, U.S. EPA Region IX, March 25, 1992.

6. Superfund Record of Decision, Fairchild Semiconductor, S. San Jose, California, March 1989.

7. Memorandum to Steve Hill, California Regional Water Quality Control Board, March 17, 1994.

8. Amendment of Site Cleanup Requirements, Order No. 89-16, for Fairchild Semiconductor Corporation and Schlumberger Technology Corporation, California Regional Water Quality Control Board, May 16, 1990.

9. California Regional Water Quality Control Board, Order No. 89-15, January 18, 1989.

10. Site Cleanup Requirements, California Regional Water Quality Control Board, Order No. 89-16, January 18, 1989.

11. Draft Report, Remedial Action Plan Fairchild Semiconductor Corporation San Jose Facility, Canonie Environmental, Project 82-012, August 1987.

12. Interim Design Report, In-Situ Soil Aeration System, Canonie Environmental, Project 82-012, March 1989.

13. Supplement to Proposal to Terminate In-Situ Soil Aeration System Operation at Fairchild Semiconductor Corporation's Former San Jose Facility, Canonie Environmental, 82-012-021, December 1989.

14. In-Situ Soil Aeration Design, Fairchild Semiconductor Corporation, San Jose Facility, Canonie Environmental, 82-012, April 1988.

15. Personal communication, Steve Hill, California Regional Water Quality Control Board, November 9, 1994.

16. Letter to Ms. Linda Fiedler, EPA/TIO, from Dennis L. Curran, Canonie, Information on costs for cost and performance report, Soil Vapor Extraction at the Fairchild San Jose Site in California, February 15, 1995.

Analysis Preparation

This case study was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Radian Corporation under EPA Contract No. 68-W3-0001.

APPENDIX A—TREATABILITY STUDY RESULTS

SUMMARY

Identifying Information	
Site Location: ROD Date: Historical Activity at Site - SIC Codes: Historical Activity at Site - Management Practices: Dates of Operation: Site Contaminants: Type of Action: Did the ROD include a contingency based on treatability study results?	San Jose, CA 03/20/89 3674 (Semiconductors and Related Devices) Underground Storage Tanks (failed underground waste slovent tank) 1977 to 1983 VOCs, including tetrachloroethylene (PCE), trichlorethane (TCA), dichloroethylene (DCE), Freon-113, acetone, xylenes; and isopropyl alcohol (IPA) Remedial No
Treatability Study Information	
Type of Treatability Study: Duration of Treatability Study: Media Treated: Quantity Treated: Treatment Technology: Target Contaminants of Concern: Conducted before the ROD was signed: Additional treatability studies conducted: Remedial or Removal Action: Technology selected for full-scale application:	Pilot-Scale 04/20/87 through 06/87 Soil (in situ) Not Available Soil Vapor Extraction One extraction well, 16 primary air inlet wells, 12 peripheral monitoring wells, a vacuum pump or blower, and granulated activated carbon units VOCs, including TCA, DCE, PCE, xylene, Freon-113, acetone, and IPA Yes No Remedial Yes
Treatability Study Strategy	
Number of Runs: Key Operating Parameters Varied:	Study was conducted in three stages: Stage 1 utilized a vacuum pump at 25 inches Hg; Stage 2 utilized a vacuum blower at 9 inches Hg; and Stage 3 utilized a vacuum blower at 14.5 inches Hg Vacuum equipment, vacuum pressure

APPENDIX A—TREATABILITY STUDY RESULTS (CONT.)

IDENTIFYING INFORMATION

Type of Treatability Study

Pilot-Scale Soil Vapor Extraction Treatability Study of Soil Contaminated with TCA, DCE, PCE, Xylene, Freon-113, Acetone, and IPA

TREATABILITY STUDY STRATEGY

Treatability Study Purpose

The following purposes were identified for the treatability study:

- To evaluate the technical feasibility of soil vapor extraction (SVE) at the Fairchild Semiconductor site; and
- To provide data to determine design parameters and projected effectiveness of SVE as part of the full-scale treatment application.

The SVE report was submitted to comply with a provision of the Site Cleanup Requirements which required conducting treatability studies and reporting the results to the California Regional Water Quality Control Board (CRWQCB).

The treatability study was conducted in three stages in which the vacuum and extraction equipment were varied. [11]

Cleanup Goals/Standards for the Fairchild Semiconductor Site

Cleanup goals are described in Section 4.1 of the full-scale treatment report for the Fairchild site; however, these goals had not been established at the time the treatability study was conducted.

TREATMENT SYSTEM DESCRIPTION

Treatment System Description and Operation

Treatment System Description

The pilot-scale SVE treatment system, shown on Figure A-1, consisted of one extraction well (RW-23A), 16 primary air inlet wells and 12 peripheral wells for monitoring, a vacuum pump (used in Stage 1 of the study), or a vacuum blower (used in Stages 2 and 3 of the study), and granulated activated carbon (GAC) units for primary and backup treatment of emissions. Location of some wells is shown in Figure 5 of the full-scale report; however, a figure showing all wells used in the treatability study was not included in the available documentation.

The extraction well RW-23A, shown on Figure A-2, was modified from a groundwater recovery well to an air extraction well to draw vapors from the unsaturated portion of the "A" aquifer. Through design and equipment modifications, the well was altered to maintain groundwater at 50 feet below ground surface (BGS) to provide sufficient air flow, and to allow the attachment of a six-inch diameter air flow duct. The 17 primary air inlet wells were installed in eight-inch diameter soil borings drilled using the rotary-stem auger method. The peripheral well network consisted of 12 previously installed observation wells.

In Stage 1 of the study, a Becker Model U2.250 vacuum pump was used to extract air from Well RW-23A. The pump was rated at 160 acfm air flow at 1750 rpm. Stages 2 and 3 of the study used a Roots RCS Model 412 vacuum blower, rated at 680 acfm at 1500 rpm. Both vacuum units were air-cooled, oil-lubricated, and utilized positive displacement.

Extracted air was treated using a primary and secondary set of GAC treatment units. As shown in Figure A-1, both the primary and secondary treatment units each contained five sub-units in parallel, containing 150 pounds of GAC in a modified 55-gallon drum. The primary unit was designed to remove VOCs and SVOCs from the extracted vapors, and the secondary unit was designed to ensure that emission of these compounds did not occur. [11]

APPENDIX A—TREATABILITY STUDY RESULTS (CONT.)

TREATMENT SYSTEM DESCRIPTION (cont.)

Figure A-1. Pilot-Scale SVE System [11]

APPENDIX A—TREATABILITY STUDY RESULTS (CONT.)

TREATMENT SYSTEM DESCRIPTION (cont.)

Figure A-2. Extraction Well RW-23A [11]

APPENDIX A—TREATABILITY STUDY RESULTS (CONT.)

TREATMENT SYSTEM DESCRIPTION (cont.)

Treatment System Operation

The treatability study was conducted in three stages, as described below.

Stage 1 of the pilot study began on April 20, 1987. Initially, the vacuum pump operated at an inlet vacuum of approximately 25 inches of Hg which resulted in an air flow of 50 scfm. After one week of operation, the vacuum at the well head stabilized at 13.5 inches of water. During Stage 1, the air inlet wells were capped to enhance the removal of soil vapor. Measurable vacuums were recorded for sixteen of the 18 primary air inlet wells during Stage 1. The highest recorded vacuum was 0.40 inches of water at both Well AI-4L and AI-4M, 8 feet from the extraction well. The smallest recorded vacuum was 0.05 inches of water at Well AI-9A, located 35 feet from the extraction well.

Stage 2 of the pilot study began on June 16, 1987. The vacuum blower produced a vacuum of approximately 9 inches of Hg at the extraction well head, and could be adjusted by a bleeder valve installed at the well head to control the vacuum and ultimately the air flow through the system. During Stage 2, the bleeder valve was fully open to allow ambient air to enter the extracted vapor flow. The resulting air flows were 175 scfm at the well head and 264 scfm through the bleeder valve. The vendor estimated that 60 percent of the total measured flow was through the bleeder valve, and therefore the remaining 40 percent was extracted from the unsaturated portion of the soil. The highest air velocity of 650 fpm from the primary inlet was recorded at Well AI-3U, 35 feet from the extraction well. The highest vacuum of 2.8 inches of water was recorded from Well AI-4L, during Stage 2.

Stage 3, which began on July 13, was structurally identical to Stage 2; however, the system operation differed. The bleeder valve was adjusted until the maximum design pressure for the blower was achieved. The vacuum measured at the well head during Stage 3 was approximately 14.5 inches of Hg, and the operating speed of the blower was set at 2500 rpm. The highest air inlet velocity from a primary well was 750 fpm at Wells WCC-10A and AI-3U, and the highest vacuum from a primary well was measured at Well AI-4M. A measurable velocity was recorded at inlet Well 115A, which was 205 feet away from the extraction well. All the inlet wells in the peripheral well network exhibited small inlet velocities at some time during the Stage 3 testing. [11]

Procurement Process/Treatability Study Cost

No information regarding the procurement process or cost of the treatability study was included in the available documentation.

APPENDIX A—TREATABILITY STUDY RESULTS (CONT.)

TREATABILITY STUDY RESULTS

Operating Parameters and Performance Data

Table A-1 presents the operating parameters for each stage of the pilot-scale treatability study.

Table A-1. Operating Parameters for the Pilot-Scale Treatability Study [11]

Test Parameter	Value (units)		
	Stage 1	Stage 2	Stage 3
Vacuum Applied	25 inches Hg	9 inches Hg	14.5 inches Hg
Blower Speed (Stages 2 and 3 only)	–	2500 rpm	2500 rpm
Vacuum Measured at Well Head	13.5 inches water	12.5 inches Hg	14.5 inches Hg
Air Flow Rate	50 scfm	500 scfm	320 scfm

Tables A-2 and A-3 present the results of the treatability study. Chemical removal rates were estimated by measured flow rates and chemical concentrations of contaminants in vapor extracted during the three stages.

In addition, soil samples were taken during well installation to characterize approximate top, intermediate, and bottom depths of the unsaturated "A" aquifer and after Stages 1 and 3. These samples were taken at locations and depths corresponding to the sampling efforts during well installation. Air samples were also collected from the air inlet well system prior to conducting the treatability study, and following each stage of operation. [11]

Table A-2. Performance Data from the Fairchild Semiconductor Site Pilot-Scale Treatability Study [11]

Parameter	Value		
	Stage 1	Stage 2	Stage 3
Total VOCs Removed	Not Available	Not Available	Not Available
Time of SVE System Operation*	Not Available	Not Available	Not Available
Chemical Removal Rate (Total)	1.5-2.0 lbs/day	7-12 lbs/day	7-12 lbs/day
Removal Rates of Specific Contaminants			
1,1,1-Trichloroethane (TCA)	1.25-1.75 lbs/day	Not Available	Not Available
1,1-Dichloroethene (DCE)	0.25 lbs/day	4.2-7.2 lbs/day	4.2-7.2 lbs/day
Acetone	No measured removal	No measured removal	No measured removal
Isopropyl alcohol (IPA)	No measured removal	No measured removal	No measured removal
Xylenes	Not Available	0.84-2.4 lbs/day	0.84-2.4 lbs/day

Treatability study report provides the start date for each stage, but does not indicate total hours or the end date of SVE system operation.

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Solid Waste and Emergency Response
Technology Innovation Office

APPENDIX A—TREATABILITY STUDY RESULTS (CONT.)

TREATABILITY STUDY RESULTS (cont.)

Table A-3. Soil Matrix Analysis Results from the Fairchild Semiconductor Site Treatability Study [11]

Soil Boring Number*		Sample Depth (ft)	1,1,1-TCA (mg/kg)	Xylene (mg/kg)	Acetone (mg/kg)	IPA (mg/kg)	Freon-113 (mg/kg)	1,1-DCE (mg/kg)	PCE (mg/kg)
AI-3/SB-222	Pre-Test	7.5-8.0	ND	ND	ND	ND	ND	ND	ND
		18.5-19.0	0.12	ND	ND	ND	0.02	0.12	ND
		34.5-35.0	0.09	ND	ND	ND	ND	0.03	0.02
	Post-Test	18.7-19.0	ND	ND	ND	ND	0.02	ND	ND
		34.7-35.0	ND	ND	ND	ND	ND	ND	ND
		47.0-47.3	0.03	ND	ND	ND	0.08	ND	ND
AI-4/SB-225	Pre-Test	34.0-34.5	0.06	ND	ND	ND	ND	0.03	0.05
		45.5-46.0	0.15	ND	ND	ND	0.05	ND	ND
	Post-Test	12.7-13.0	ND	ND	ND	ND	ND	ND	ND
		34.0-34.3	ND	ND	ND	ND	ND	ND	ND
		39.0-39.3	ND	ND	ND	ND	ND	ND	ND
		45.3-45.7	0.05	ND	ND	ND	ND	ND	ND
		54.0-54.3	0.02	ND	ND	ND	ND	ND	ND
AI-8/SB-223	Pre-Test	21.5-22.0	0.03	ND	ND	ND	ND	0.08	ND
		33.5-34.0	0.21	ND	ND	ND	ND	0.04	ND
		47.0-47.5	0.31	3.3	ND	ND	0.1	0.18	0.07
	Post-Test	21.7-22.0	ND	ND	ND	ND	ND	ND	ND
		26.7-27.0	0.02	ND	ND	ND	ND	0.75	ND
		33.7-34.0	ND	ND	ND	ND	ND	ND	ND
		42.0-42.3	ND	ND	950.00	ND	ND	ND	ND
		47.0-47.3	0.16	ND	ND	ND	ND	ND	ND
		54.3-54.7	27.0	ND	ND	ND	ND	ND	ND
		69.0-69.3	0.11	ND	ND	0.12	ND	ND	ND
SB-190/SB-2	Pre-Test	9.7-10.0	ND	ND	ND	ND	ND	ND	ND
		19.7-20.0	ND	ND	ND	ND	ND	ND	ND
		29.7-30.0	ND	ND	ND	ND	ND	ND	ND
		39.4-39.7	3.7	17	18	ND	ND	ND	ND
		41.4-41.7	1.3	5.2	6.8	ND	ND	ND	ND
		44.7-45.0	2.3	6.7	16	10.00	ND	ND	ND
		49.4-49.7	6	7.6	14	5.8	ND	ND	ND
		69.4-69.7	2.2	ND	ND	4.1	ND	ND	ND
	Post-Test	38.0-40.0	0.99	9.5	860	79	ND	ND	ND
		40.0-42.0	0.51	3.2	740	27	ND	ND	ND
		44.0-46.0	0.85	3.5	17	14	ND	ND	ND
		48.0-50.0	3.8	2.7	10	12	ND	ND	ND
		68.0-70.0	40	22	6.9	ND	ND	0.76	ND

ND = Not detected.
**First number is the pre-test soil boring, second number is the post-test soil boring.*

APPENDIX A - TREATABILITY STUDY RESULTS (CONT.)

TREATABILITY STUDY RESULTS (cont.)

Table A-3 (Continued)

Soil Boring Number*		Sample Depth (ft)	1,1,1-TCA (mg/kg)	Xylene (mg/kg)	Acetone (mg/kg)	IPA (mg/kg)	Freon-113 (mg/kg)	1,1-DCE (mg/kg)	PCE (mg/kg)
SB-205/SB-228	Pre-Test	9.70-10.0	ND	ND	ND	ND	ND	ND	ND
		19.7-20.0	ND	ND	ND	ND	ND	ND	ND
		39.7-40.0	0.33	16	800	1400	ND	ND	ND
		49.7-50.0	ND	3.6	22	17	ND	ND	ND
		55.0-55.3	3.8	2.7	1.2	0.9	ND	ND	ND
		59.7-60.0	19	3.8	3.3	5.4	ND	4.5	ND
	Post-Test	39.7-40.0	ND	2.4	310	ND	ND	ND	ND
		55.0-55.3	2.8	1.8	3.1	ND	ND	ND	ND
		59.7-60.0	303	204	ND	ND	ND	ND	ND
SB-209/SB-221	Pre-Test	9.7-10.0	ND	ND	ND	ND	ND	ND	ND
		19.7-20.0	ND	ND	ND	ND	ND	ND	ND
		29.7-30.0	0.2	ND	ND	ND	ND	ND	ND
		39.7-40.0	0.4	12	15	6.6	ND	ND	ND
		49.7-50.0	0.79	5.4	13	ND	ND	ND	ND
		59.7-60.0	8.7	5.4	2.8	ND	ND	1.3	ND
		71.0-71.3	48	60	ND	ND	ND	1.6	ND
	Post-Test	49.7-50.0	4	3.9	16	3.1	ND	0.4	ND
		55.0-55.3	14.1	14	3.6	ND	ND	ND	ND
		59.7-60.0	29	16	1.9	ND	ND	1.9	ND
SB-200/SB-226	Pre-Test	9.3-9.7	ND	0.36	8.7	6.1	ND	ND	ND
		19.4-19.7	ND	ND	ND	ND	ND	ND	ND
		29.4-29.7	ND	ND	ND	ND	ND	ND	ND
		39.7-40.0	0.14	41.0	570	410	ND	ND	ND
		49.7-50.0	1.7	4.6	9.7	3.8	ND	0.17	ND
		55.30	13	3.7	9.4	2	ND	0.88	ND
		58.0-58.3	50.00	6.30	12.00	6.90	ND	5.70	ND
		63.0-63.3	280.00	500.00	ND	ND	ND	17.00	2.9
		69.7-70.0	0.28	0.35	ND	ND	ND	ND	ND
	Post-Test	38.0-40.0	ND	1.8	130	ND	ND	ND	ND
		44.0-46.0	ND	1.4	ND	ND	ND	ND	ND
		48.0-50.0	0.52	2	ND	ND	ND	ND	ND
		54.0-56.0	7.3	2.2	6.4	ND	ND	0.23	ND
		58.0-60.0	35	13	15	ND	ND	2.80	ND
		62.0-64.0	30	3.3	ND	ND	ND	3.20	ND
		68.0-70.0	3.4	2.1	2	ND	ND	0.19	ND
SB-219/SB-227	Pre-Test	20.5-21.0	ND	ND	ND	ND	ND	ND	ND
		25.7-26.0	0.22	ND	ND	ND	ND	ND	ND
		31.2-31.5	0.35	ND	ND	ND	ND	ND	ND
		36.2-36.5	0.35	2.7	204.0	8.2	ND	ND	ND
		41.2-41.5	0.44	2.2	650.0	1400.0	ND	ND	ND
		45.7-46.0	2.7	14.0	180.0	260.0	ND	0.135	ND

ND = Not detected.
**First number is the pre-test soil boring, second number is the post-test soil boring.*

APPENDIX A - TREATABILITY STUDY RESULTS (CONT.)

TREATABILITY STUDY RESULTS (cont.)

Table A-3 (Continued)

Soil Boring Number*		Sample Depth (ft)	1,1,1-TCA (mg/kg)	Xylene (mg/kg)	Acetone (mg/kg)	IPA (mg/kg)	Freon-113 (mg/kg)	1,1-DCE (mg/kg)	PCE (mg/kg)
SB-219/SB-227 (cont.)	Post-Test	47.7-48.0	2.4	12.0	460.0	330.0	ND	0.23	ND
		49.0-49.3	0.33	6.0	460.0	72.00	ND	0.22	ND
		51.0-51.3	0.87	0.55	14.0	ND	ND	ND	ND
		25.7-26.0	ND	ND	ND	ND	ND	ND	ND
		31.0-31.3	0.47	ND	ND	ND	ND	ND	ND
		36.7-37.0	ND	ND	170.0	ND	ND	ND	ND
		46.0-46.3	0.45	ND	7.90	ND	ND	ND	ND
		48.5-49.0	0.38	2.80	6.00	ND	ND	ND	ND
		51.7-52.0	0.53	ND	4.90	ND	ND	ND	ND

ND = Not detected.
**First number is the pre-test soil boring, second number is the post-test soil boring.*

Performance Data Assessment

The vendor identified the following with respect to performance of the SVE system during the treatability study:

- Chemical removal rates during Stage 1 varied from 1.5 pounds to 2.0 pounds per day, based on analyses of charcoal tube samples. The on-site OVA readings indicated a removal rate of approximately 1.7 to 2.7 pounds per day. The contaminant TCA accounted for 70% of the total chemical removal rate during Stage 1. The system did not effectively remove acetone and IPA from unsaturated soils. The vendor noted that the removal rate for other contaminants increased slightly during the first week of operations, and then declined slightly over time.
- Based on the results of charcoal tube sampling, chemical removal rates varied from 7 to 12 pounds per day during Stage 2. OVA readings indicated removal rates of 4 to 7 pounds per day. TCA accounted for approximately 60% of the total chemical removal rate during Stage 2. The system did not effectively remove acetone and IPA from unsaturated soils. The vendor noted that no clear trend in removal rate over time could be established based on the charcoal tube sampling data results; however, the OVA readings indicated a general decrease in removal rate over time (approximately 40 percent decrease in two weeks).
- Although the extraction rate was increased during Stage 3, the chemical removal rate was approximately equal to that measured during Stage 2. Again, the vendor noted that no clear trend in chemical removal rate over time could be established based on the charcoal tube sampling results; however, the OVA readings indicated a similar, general decrease in removal rate over time as that measured in Stage 2 (approximately 40 percent decrease in two weeks). [11]

Performance Data Completeness

Performance data completeness cannot currently be assessed because information on soil boring locations, contaminant removal over time, extracted soil vapor concentrations, and material balance data are not available at this time.

Performance Data Quality

According to the vendor, data collection and sample analysis was performed in accordance with QA/QC procedures described in

APPENDIX A - TREATABILITY STUDY RESULTS (CONT.)

TREATABILITY STUDY RESULTS (cont.)

the Site Sampling Plan, Quality Assurance/ Quality Control Plan, and Site Safety Plan.

In addition, duplicate samples of extracted air vapors were collected using charcoal tubes and were analyzed at two laboratories. According to the vendor, analytical results from the two laboratories "compared favorably." The calculated relative mean difference indicated an analytical precision of 15 percent. An organic vapor analyzer (OVA) was used to monitor extracted air vapor VOC concentrations during the study. OVA readings were taken 4 to 5 times per day and generally indicated lower concentrations than those measured in the laboratory. The QA/QC procedures and complete analytical data were not included in the available documentation and could not be assessed at this time. [11]

Projected Full-Scale Cost

No projected full-scale costs were provided in the available documentation. However, the vendor noted the following observations that could impact the cost of full-scale treatment:

- A full-scale application would require larger carbon treatment units to replace the 55-gallon activated carbon canisters used during the treatability study; and
- A full-scale treatment application would not require the extensive monitoring of the inlet well network that was conducted during the treatability study. [11]

OBSERVATIONS AND LESSONS LEARNED

The following observations and lessons learned were noted by the vendor:

- The vacuum blower used during Stages 2 and 3 of the treatability study were more effective in removing contaminants than the vacuum pump used during Stage 1.
- The SVE system removal efficiency for TCA, xylene, and DCE was high; however, the system's removal efficiency from unsaturated soils for highly immiscible contaminants such as acetone and IPA was lower.
- The air extraction rate was lower during Stage 2 compared to Stage 3, yet the chemical removal rate was relatively equal during both stages.
- An average of approximately 8 pounds per day were removed during Stages 2 and 3 of the treatability study.
- The radius of influence of the air extraction well was estimated using to be 75 feet during Stage 3 of the study.
- Analyses of soil samples collected from the A-B aquitard (consisting of silty-clay soils at 50-60 feet below ground surface) indicated the highest concentrations of contaminants both before and after treatment. The treatability study results were inconclusive regarding contaminant removal from this depth and type of soil. [11]