FINAL

Remedial Process Optimization Report for Building 3001

Tinker Air Force Base
Oklahoma

Prepared For

Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks Air Force Base
San Antonio, Texas

and

Oklahoma City Air Logistics Center
Tinker Air Force Base, Oklahoma

December 2000

PARSONS
PARSONS ENGINEERING SCIENCE, INC.
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REMEDIAL PROCESS OPTIMIZATION REPORT FOR BUILDING 3001 TINKER AIR FORCE BASE, OKLAHOMA

Prepared For

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
TECHNOLOGY TRANSFER DIVISION
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OKLAHOMA CITY AIR LOGISTIC CENTER
TINKER AIR FORCE BASE, OKLAHOMA

DECEMBER 2000

Prepared By

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EXECUTIVE SUMMARY

Parsons Engineering Science, Inc. (Parsons ES) has prepared a draft final remedial process optimization (RPO) handbook for the Air Force Center for Environmental Excellence, Technology Transfer Division (AFCEE/ERT). The handbook will be used by AFCEE to review the performance of existing remediation systems, implement performance enhancements on existing systems, perform 5-year Record-of-Decision (ROD) reviews, and prepare documentation for operating properly and successfully (OPS) certification for sites at Air Force facilities. Parsons ES is field-testing the approach described in the draft final handbook at multiple Air Force sites, including Building 3001 at Tinker Air Force Base (AFB), Oklahoma. Lessons learned from the RPO field tests will be incorporated into the final RPO handbook. The Air Force goals for the RPO program are to: 1) assess the effectiveness of particular remedial actions; 2) enhance the efficiency of the remedial actions examined; and 3) when possible, identify annual operating, maintenance, and monitoring (OM&M) cost savings in excess of 20 percent for each system evaluated.

At Building 3001, which is an active facility used for aircraft maintenance and repair, the Air Force is operating a groundwater extraction and treatment system that is intended to remediate groundwater contaminated with volatile organic compounds (VOCs), primarily chlorinated aliphatic hydrocarbons (CAHs), and hexavalent chromium. The primary contaminants of concern (COCs) in groundwater are trichloroethene (TCE) and hexavalent chromium. The combined flow from the 33-well extraction system is pumped to a central plant for treatment and eventual discharge to an industrial waste treatment plant. The appropriateness, adequacy, and efficiency of the existing groundwater extraction and treatment system have been evaluated in several previous efforts. In light of these efforts, the scope and purpose of this RPO evaluation have been narrowed to focus on a recommendation made in a previous assessment: to evaluate soil vapor extraction (SVE) as a supplemental remedial technology for the removal of VOCs from vadose zone soils at the site. If shown to be feasible, implementing SVE may result in accelerated remediation of source area soils, preventing a potential long-term impact on groundwater quality. If it is demonstrated that SVE cannot be cost-effectively applied at the Building 3001 site, then this RPO evaluation may form the basis for a future Technical Impracticability (TI) waiver.

The objectives of the RPO evaluation for Building 3001 include:

- Evaluating the feasibility and economics of SVE as a contaminant mass removal technology at Building 3001 through field pilot testing;

- Comparing the effectiveness and efficiency of contaminant mass removal using SVE with that of the existing groundwater extraction and treatment system at Building 3001; and

- Providing recommendations for the optimization of contaminant mass removal.

A SVE pilot test was performed at Building 3001 in March through May 2000 to achieve the RPO evaluation objectives. These activities included the installation of a new

vapor extraction well (VEW) and four new soil vapor monitoring points (VMPs); collecting and analyzing soil and soil vapor samples for VOCs to establish baseline conditions; and the performance of SVE pilot tests at three wells: 1.) the newly-installed vertical SVE well, designated as 01VEP0001; 2.) horizontal groundwater extraction well P-13, which is an active component of the Building 3001 groundwater extraction and treatment system; and 3.) horizontal SVE well HW-2, which was installed in 1991 and 1992 as part of a previous SVE pilot testing effort (Camp, Dresser, and McKee [CDM, 1993]). Rebound soil vapor samples were collected one month after the SVE pilot test was completed at 01VEP0001 to determine the impact of SVE on static concentrations of VOCs in the soil vapor.

EVALUATION OF CURRENT GROUNDWATER EXTRACTION AND TREATMENT SYSTEM WITH REGARD TO VOC MASS REMOVAL

Because the primary objective of this RPO evaluation was to determine the feasibility of using SVE to remediate source-area soils, a detailed RPO evaluation of the groundwater extraction and treatment system was not conducted. However, the following discussion is included for the purpose of comparing costs and VOC mass removal rates being achieved using the groundwater extraction and treatment system versus those that could be achieved using SVE. The cumulative VOC mass removal, total capital and OM&M costs, and cost per pound of VOC removed during the first five years of system operation are illustrated in Figure ES.1.

Contaminant mass removal rates from groundwater have varied during the operation of the groundwater extraction and treatment system through February 2000, but have not yet reached asymptotic levels. The groundwater extraction and treatment system has removed approximately 8,625 pounds (lbs) of VOCs, from the beginning of system operation in June 1994 through February 2000 (Buehler, 2000), for an average VOC removal rate of about 130 lbs per month. The recovered contaminants have consisted primarily of TCE (about 75 percent) with the remainder consisting of benzene, toluene, perchloroethene (PCE), and 1,2-dichloroethene (1,2-DCE) (Buehler, 2000).

The cumulative costs expended to date for design, installation, and operation of the groundwater extraction and treatment system at Building 3001 are summarized in Table ES.1. Based on estimated capital and OM&M costs for the system at Building 3001 and the total mass of VOCs removed from the beginning of system operation in June 1994 through February 2000 (8,625 pounds over 5 2/3 years), the average cost per pound of VOCs removed from groundwater has been approximately $1,700 per pound as of June 2000. It should be noted that these unit treatment costs are biased high, since the Building 3001 groundwater treatment system also includes unit processes for the removal of hexavalent chromium.

RESULTS OF SOIL VAPOR EXTRACTION PILOT TESTS

SVE pilot testing activities were conducted by Parsons ES at Building 3001 between March 14 and May 11, 2000. Four VMPs, designated as 01SG0001 through 01SG0004, and one VEW, designated as 01VEP0001, were installed. The VMPs were used to monitor vacuum response, changes in groundwater elevation, and changes in soil gas chemistry (oxygen [O_2], carbon dioxide [CO_2], and VOCs) at varying depths and distances from 01VEP0001. The only VOC detected in the soil sampling and analysis program was methylene chloride at concentrations ranging from 20 to 67 micrograms per kilogram (µg/kg). Because methylene chloride was also detected in several laboratory blank samples, it is possible that these detections are the result of cross-contamination in the laboratory. Following the installation of the new VEW and VMPs, background soil gas conditions were characterized at the VEW and each of the new VMPs, and baseline groundwater levels were measured at these locations and at groundwater monitoring well 1-70B. TCE was present in the 01VEP0001 pilot testing area at concentrations ranging from 310 to 530 parts per million, volume per volume (ppmv), and PCE was present at concentrations ranging from 22 to 72 ppmv. A positive displacement blower system was set up on the site and plumbed to 01VEP0001 and well P-13.

SVE pilot testing was conducted in two phases. The first phase consisted of two start-up tests at 01VEP0001. The second phase was an eight-day test planned at 01VEP0001 and well P-13 mainly to determine VOC mass removal rates resulting from extracting soil gas from 01VEP0001 and well P-13. At the beginning of the second phase of testing, high extraction vacuums and low extraction flow rates (< 1 standard cubic foot per minute [scfm]) were observed at horizontal well P-13, demonstrating that the well screen at well P-13 was saturated, and vapor extraction using well P-13 could not be accomplished. Because well P-13 was found to be unsuitable for SVE, testing at this location was terminated. Horizontal well HW-2 was selected as a substitute for P-13. HW-2 is an SVE well that was installed in the vadose zone as part of a previous pilot testing effort performed by CDM (CDM, 1993). P-13 was disconnected from the SVE blower system, and well HW-2 was plumbed for SVE and used for the remainder of the pilot test. Although an array of VMPs had been installed previously by CDM in the vicinity of the screened interval of HW-2, these VMPs were inaccessible during the SVE pilot test at HW-2. A baseline soil gas sample collected from HW-2 prior to implementing SVE contained TCE, PCE, and *cis*-1,2-DCE at concentrations of 3,000 ppmv, 2,500 ppmv, and 120 ppmv, respectively, indicating that the well screen of HW-2 was installed in a significant source area for chlorinated VOCs.

Several conclusions were drawn from the data collected during the SVE pilot test:

- Based on vacuum response and soil gas chemistry measured at the VMPs, the effective treatment radius for one vertical VEW exceeds 43 feet at an average extraction flow rate of 3.1 scfm.

- Due to the fine-grained soil in the pilot test area, a vacuum of between approximately 70 and 95 inches of water applied to 01VEP0001 was required to induce an extraction flow rate of 3.1 scfm. Vacuums both higher and lower than this range resulted in reduced flow rates.

- The results obtained during testing at 01VEP0001 suggest that vertical groundwater extraction wells with portions of their screened intervals exposed to vadose zone soils may be retrofitted for use as SVE wells. However, the sustainable vapor extraction flow rates from these wells are expected to be less than 5 scfm. SVE flow rates greater than 5 scfm will cause an increased vacuum to develop in the well casing, which will cause the groundwater level within the casing to rise and eventually saturate the entire well screen. Vertical wells are expected to be feasible for SVE only if the VOC concentrations in soil vapor from the well are very high (in the tens of thousands of parts per million range or higher).

- The results obtained during testing at well P-13 suggest that existing horizontal groundwater extraction wells cannot be retrofitted for use as SVE wells due to the well screens being saturated. If full-scale SVE is to be implemented at Building 3001, a new array of horizontal wells may be required.

- Flow rates achieved at HW-2 were 78 scfm (1.1 scfm per foot of well screen) at a vacuum of 110 inches of water, and 38 scfm (0.54 scfm per foot of well screen) at a vacuum of 82 inches of water. These results show that a horizontal well configuration is preferable for remediation of soils at Building 3001. A horizontal SVE well screened approximately mid-way between the ground surface and the potentiometric surface of the perched aquifer of the USZ is the optimal SVE well configuration.

- Based on laboratory VOC results and measured soil gas extraction flow rates, the mass removal rate for HW-2 averaged 89.2 lbs per day of total VOCs, 47.7 lbs per day of TCE, and 39.8 lbs per day for PCE. A total of 517 lbs of VOCs, which included 277 lbs of TCE and 231 lbs of PCE, were removed during the 6-day pilot test at HW-2.

COST EFFECTIVENESS OF AQUEOUS-PHASE VERSUS VAPOR-PHASE VOC REMOVAL AT BUILDING 3001

The actual costs, VOC mass removal rates, and unit costs per pound of VOCs removed from the groundwater extraction and treatment system at Building 3001 were compared against those that may be achieved if full-scale SVE were to be implemented at the site. This comparison provides the basis for determining if SVE is a cost-effective supplemental treatment technology at Building 3001.

To allow for a comparison against aqueous-phase VOC mass removal being achieved with the existing groundwater extraction and treatment system, a conceptual full-scale SVE system for vapor-phase VOC mass removal was designed, and a cost estimate for system installation and five years of system OM&M was prepared. Table ES.1 summarizes the estimated costs for the design, installation, and the first five years of OM&M for the conceptual full-scale SVE system at Building 3001, and compares them against those of the existing groundwater extraction and treatment system. Figure ES.1 illustrates the estimated cumulative VOC mass removal, capital and OM&M costs, and cost per pound of VOCs removed by the conceptual full-scale SVE system, and compares them against those for the existing groundwater extraction and treatment system. As shown, VOC mass removal can be accomplished much more cost effectively using SVE than the existing groundwater extraction system. A projected 35,000 pounds of VOCs may be removed by the conceptual full-scale SVE system over five years of operation, versus approximately 8,000 pounds that has been removed by the groundwater extraction and treatment system over the same time period. Cumulative costs for the groundwater extraction and treatment system after five years of operation have amounted to $15.6 million, versus a projected total of $4 million for the conceptual full-scale SVE system. Based on estimated capital and OM&M costs for the existing groundwater extraction and treatment system at Building 3001 and the total mass of VOCs removed, the average unit cost for VOC mass removal from groundwater amounted to approximately $1,700 per pound after nearly 6 years (i.e., 68 months) of operation. For the conceptual full-scale SVE system, the unit cost for VOC mass removal from vadose zone soils is estimated at approximately $120 per pound, meaning that vapor-phase VOC mass removal is approximately fourteen times less expensive than aqueous-phase VOC mass removal, although the groundwater extraction and treatment system also provides plume containment and removal of hexavalent chromium.

RPO RECOMMENDATIONS FOR BUILDING 3001

The SVE pilot test conducted at HW-2 in March 2000 demonstrated that vapor-phase VOC removal rates greatly exceeded the aqueous-phase VOC removal rates being achieved by the existing groundwater extraction and treatment system. Based on the results of the SVE pilot test performed at HW-2, SVE utilizing horizontal wells may be an effective technology for removing VOCs from contaminated, unsaturated soils beneath Building 3001. However, the cost of installing a full-scale system utilizing additional horizontal wells beneath Building 3001 would be considerable, and many of the parameters required for full-scale system design, such as the radius of influence of a horizontal SVE well, the long-term VOC mass removal rates (i.e., those that could be achieved over one year of operation), and the magnitude and extent of VOC contamination within the vadose zone are not yet known. Therefore, additional low-cost SVE pilot testing using HW-2 is recommended to confirm that SVE will be effective for the remediation of soils beneath Building 3001, and to determine full-scale SVE design parameters.

Objectives of additional SVE pilot testing would be to determine:

- the maximum effective treatment radius of a single horizontal SVE well;
- the optimal well spacing and screened length;
- the VOC mass removal rates that could be achieved over one year of treatment; and
- requirements for the treatment of extracted soil vapor and condensate.

The recommended scope of the long-term SVE pilot test would include the following elements.

- Installation of additional VMPs inside Building 3001 in the vicinity of HW-2 to determine the maximum effective treatment radius of this well. There are currently 8 VMPs and 3 combination groundwater monitoring wells/VMPs installed at distances ranging from approximately 5 to 60 feet from the well screen of SVE well HW-2. However, Parsons ES believes that the effective treatment radius of this well may exceed 150 feet. The VMPs are located too close to the well screen to define the treatment radius. At least three additional VMPs are recommended for installation at distances of about 75, 100, and 200 feet perpendicular to the centerline of HW-2 and at least two additional VMPs should be located at 50 and 75 feet east of HW-2, along the extension of the well centerline. At least one soil sample should be collected from the most contaminated interval of each borehole and submitted for laboratory analysis of VOCs to establish initial concentrations and allow an estimate of the mass of contamination within the treatment zone.

- Installation of a blower system hard-wired to the Base electrical system. The pilot testing blower should have, at a minimum, the capacity to extract soil vapors at a rate of 80 scfm at a vacuum of 120 inches of water.

- Installation of a vapor treatment system to limit VOC emissions to a level below the *de minimus* level of 1,200 pounds per year. Based on removal rates observed during the March 2000 pilot test, granular activated carbon will be required for off gas treatment.

- Collection and analysis of soil vapor samples from the VMPs and HW-2 to establish baseline soil vapor chemistry.

- Operation of the SVE system for a period of 1 year. During this period of operation, the system should be periodically shut down when soil vapor VOC concentrations reach asymptotic levels to observe the rebound of soil vapor VOC concentrations.

- Implementation of a tracer test using inert tracer gases (e.g. helium and sulfur hexafluoride) to supplement vacuum response data, determine soil vapor flow directions in the subsurface, and to determine the maximum treatment radius.

- Measurement of SVE flow rates and extraction vacuums.

- Periodic collection of soil vapor samples from the SVE well, VMPs, and the vapor treatment system exhaust for field screening and laboratory VOC analysis.

- Measurement of vacuum response at VMPs and groundwater monitoring wells in the pilot test area with screens extending above the saturated zone.

- Although the pilot testing performed under the RPO project demonstrated that existing horizontal groundwater extraction wells could not be used for SVE, it is possible that they could be retrofitted for air injection. Air injection may be beneficial in controlling the vacuum gradients and ultimately the soil vapor flow directions in the subsurface at Building 3001. The possibility of using existing horizontal groundwater extraction wells for air injection, and the benefit of air injection for expanding the treatment radius of HW-2 could be evaluated during the long-term test.

- Following the completion of the SVE pilot test, it is recommended that soil samples be collected from the same approximate locations as those initially collected to determine the VOC mass reductions achieved through SVE.

TABLE ES.1
COMPARISON OF COSTS FOR THE CURRENT GROUNDWATER EXTRACTION AND TREATMENT SYSTEM VERSUS A CONCEPTUAL FULL-SCALE SOIL VAPOR EXTRACTION SYSTEM
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

Item	Current Groundwater Extraction and Treatment System	Conceptual Full-Scale Soil Vapor Extraction System
Design cost	$674,000 [a/]	$575,000 [b/]
Capital Cost	$12,000,000 [a/]	$2,350,000 [c/]
Estimated annual OM&M[d/]	varies from $450,000 to $500,000 [e/]	varies from $90,000 to $600,000 [f/]
Projected total cost (after 5 years)	$15,600,000	$4,000,000
Projected total cost (after 30 years)	$25,900,000	NA [g/]

[a/] Information provided by Keith Buehler, Tinker AFB, Oklahoma.

[b/] Includes cost of 1-year soil vapor extraction pilot test at horizontal well HW-2.

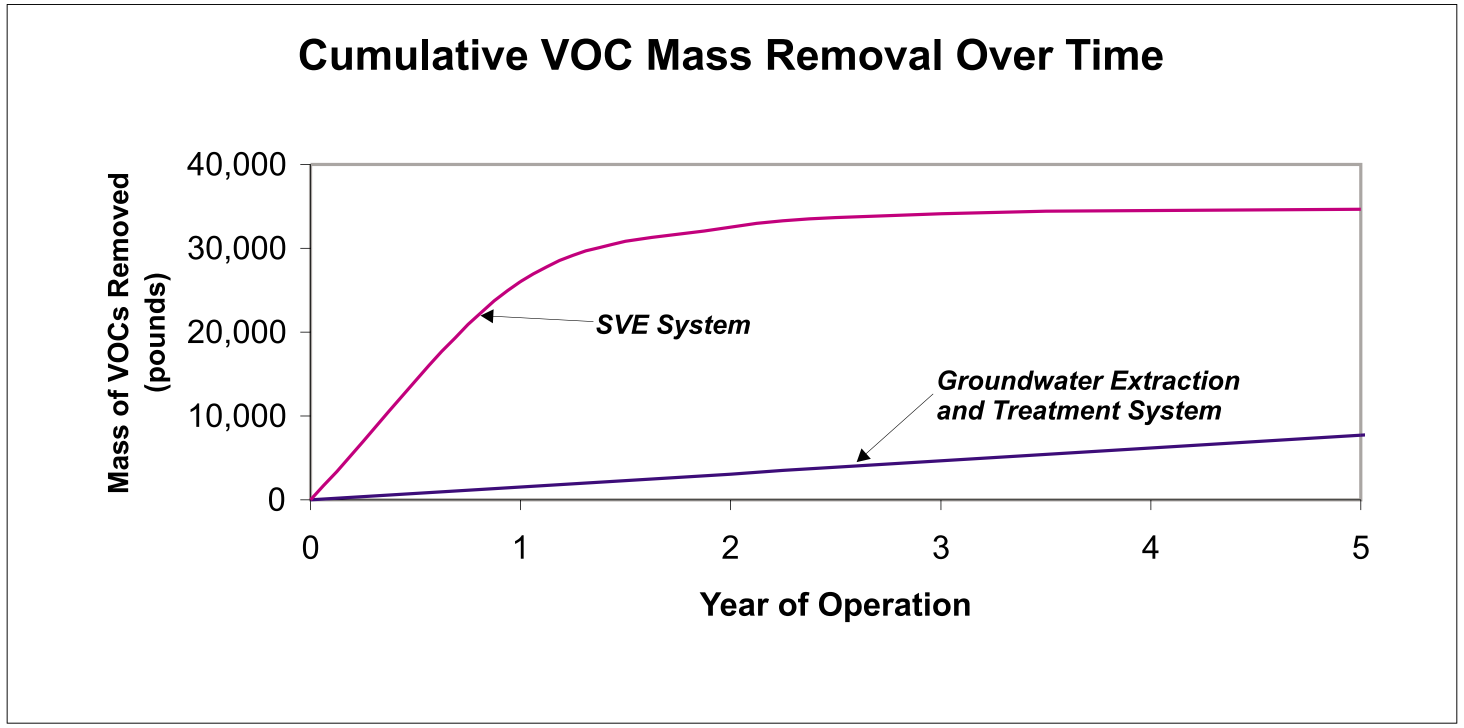
[c/] Estimate was made assuming that four additional horizontal wells are required for full-scale coverage.

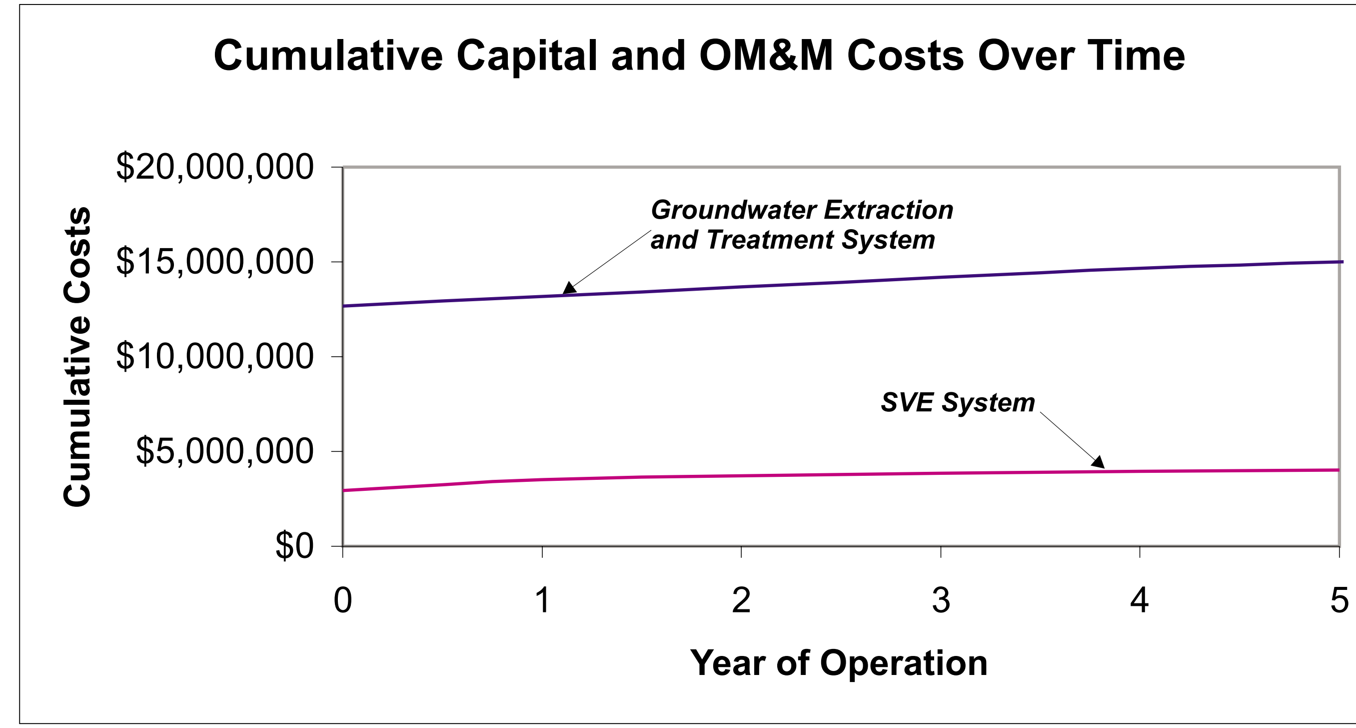
[d/] Operations, Maintenance, and Monitoring.

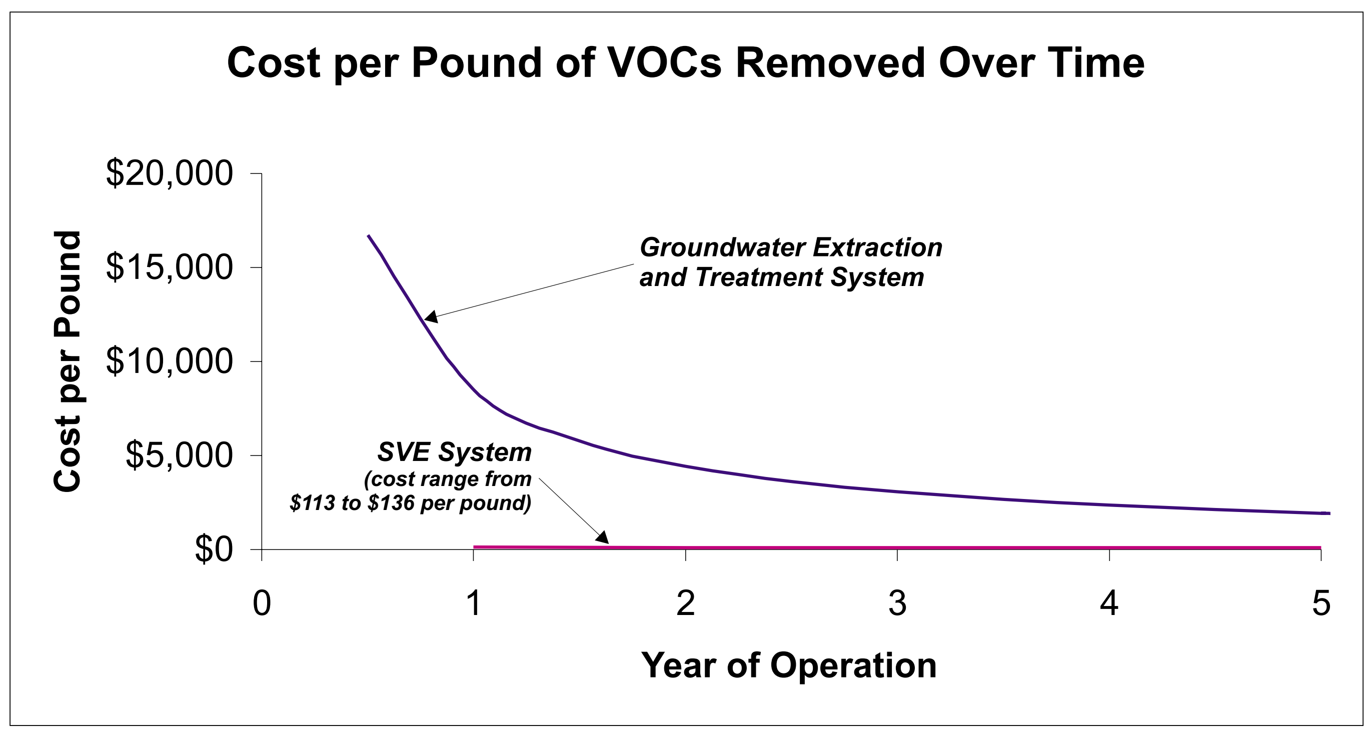
[e/] Parsons ES estimates based on information provided by Keith Buehler, Tinker AFB, Oklahoma.

[f/] Estimates were made assuming that activated carbon would be used for vapor treatment and that the total VOC mass removal rate and composition over time from the four additional horizontal wells matched those observed at well HW-2 during March 2000 SVE pilot testing.

[g/] Soil vapor extraction will not occur for a 30-year length of time at Building 3001. VOC mass removal rates will reach asymptotic levels long before 30 years of operation.







Note: All graphs assume that groundwater extraction VOC mass removal rate remains constant (approximately 130 pounds per month).

FIGURE ES.1

COMPARISON OF CURRENT GROUNDWATER EXTRACTION AND TREATMENT SYSTEM VERSUS A CONCEPTUAL FULL-SCALE SOIL VAPOR EXTRACTION SYSTEM

Building 3001
Remedial Process Optimization
Tinker AFB, Oklahoma

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LIST OF ACRONYMS AND ABBREVIATIONS

µg/L	microgram(s) per liter
µg/kg	micrograms per kilogram
1,2-DCA	1,2-dichloroethane
AFB	Air Force Base
AFCEE/ERT	Air Force Center for Environmental Excellence/Technology Transfer Division
AMC	Air Mobility Command
B&V	Black & Veatch, Inc.
bgs	below ground surface
CAH	chlorinated aliphatic hydrocarbon
CDM	Camp, Dresser, and McKee
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
ChOC	chain-of-custody
CO_2	carbon dioxide
COC	contaminant of concern
DCE	dichloroethene
DNAPL	dense nonaqueous-phase liquid
ES	Engineering-Science, Inc.
FY	fiscal year
g	gram
gpm	gallons per minute
GWTP	groundwater treatment plant
hr	hour
IDW	investigation derived waste
in.	inches
IRP	Installation Restoration Program
IWTP	Industrial Wastewater Treatment Plant
K	Kelvin
KV	kilovolt
L	liter
lbs	pounds
LSZ	lower saturated zone
MCL	maximum contaminant level
mg/L	milligrams per liter
min	minute
MNA	monitored natural attenuation
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NTA	North Tank Area
O&M	operations and maintenance
O_2	oxygen
OC-ALC/EMR	Oklahoma City Air Logistics Center, Environmental Management
ODEQ	Oklahoma Department of Environmental Quality

OM&M	operating, maintenance, and monitoring
OPS	operating properly and successfully
OU	Operable Unit
Parsons ES	Parsons Engineering Science, Inc.
PCE	tetrachloroethene
PID	photoionization detector
ppb	parts per billion
ppmv	parts per million, volume per volume basis
PVC	polyvinyl chloride
PZ	production zone
QA/QC	quality assurance/quality control
Radian	Radian International
RAO	remedial action objective
RCRA	Resource Conservation and Recovery Act
RI	remedial investigation
ROD	record of decision
RPO	remedial process optimization
scfm	standard cubic feet per minute
SVE	soil vapor extraction
SVOC	semi-volatile organic compound
TCE	trichloroethene
TCLP	toxicity characteristic leaching procedure
TI	Technical Impracticability
TOC	top of casing
TVH	total volatile hydrocarbons
USACE	US Army Corps of Engineers
USAF	US Air Force
USCS	United Soil Classification System
USEPA	US Environmental Protection Agency
UST	underground storage tank
USZ	upper saturated zone
VEW	vapor extraction well
VMP	vapor monitoring point
VOC	volatile organic compound
WS	water supply well

SECTION 1

INTRODUCTION

This remedial process optimization (RPO) report was prepared by Parsons Engineering Science, Inc. (Parsons ES) for the Air Force Center for Environmental Excellence, Technology Transfer Division (AFCEE/ERT) as part of a delivery order under the US Air Force (USAF) Air Mobility Command (AMC) contract F11623-94-D0024, RL 72. The scope of this delivery order includes preparing a guidance document for RPO, and evaluating the approach described in the RPO guidance document at selected Air Force demonstration sites. This report outlines the results of the RPO field evaluation for the Building 3001 site at Tinker Air Force Base (AFB), Oklahoma. The Air Force goals for the RPO program are to:

- Assess the effectiveness of remedial actions;
- Enhance and/or augment the efficiency of remedial actions; and
- When possible, identify annual operating, maintenance, and monitoring (OM&M) cost savings in excess of 20 percent for each system evaluated.

The primary objective at most of the Air Force RPO demonstration sites is to evaluate the performance of an existing remedial system using the guidance presented in the *Remedial Process Optimization Handbook* (Parsons ES, 1999), which is being used by AFCEE to review the performance of existing remediation systems, implement performance enhancements on existing systems, perform 5-year record-of-decision (ROD) reviews, and prepare documentation for "operating properly and successfully" (OPS) certification.

The appropriateness, adequacy, and efficiency of the existing groundwater extraction and treatment system at Building 3001 have been evaluated in several previous efforts (Parsons ES and Battelle, 1996, 1997, and 1998; Parsons ES, 1997). In light of these efforts, the scope and purpose of the Building 3001 RPO evaluation has been narrowed to focus on a recommendation made in a previous assessment: to evaluate soil vapor extraction (SVE) as a supplemental remedial technology for the removal of volatile organic compounds (VOCs) from vadose zone soils at the site. If shown to be feasible, implementing SVE may result in accelerated remediation of source area soils, preventing a potential long-term impact on groundwater quality. If it is demonstrated that SVE cannot be applied at the site in a cost-effective fashion, then this RPO evaluation may form the basis for a future Technical Impracticability (TI) waiver.

This effort required the performance of the following tasks:

- Reviewing data to evaluate previously completed site characterization and treatability studies;
- Preparing a site-specific work plan (Parsons ES, 2000) and a site-specific addendum to the project health and safety plan (Parsons ES, 1998);
- Installing one vapor extraction well (VEW) and four multiple-depth soil vapor monitoring points (VMPs) using hollow-stem auger drilling techniques in a suspected source area west of Building 3001 known as the Northwest Tank Area;
- Collecting soil and soil vapor samples to establish baseline (e.g., prior to the SVE pilot tests) conditions in the subsurface;
- Performance of SVE pilot tests at the newly-installed VEW, at one existing horizontal groundwater extraction well (well P-13), and at one existing horizontal SVE well (well HW-2);
- Collecting rebound soil vapor samples 30 days after the completion of the SVE pilot test at the newly-installed VEW; and
- Interpretation of pilot testing results, including a comparison of mass removal rates and unit mass removal costs that could be achieved with SVE versus those being achieved by the existing groundwater extraction and treatment system.

The results of the RPO evaluation conducted at Building 3001 are presented in this report.

1.1 DESCRIPTION OF THE RPO PROCESS

RPO is a systematic approach for evaluating and improving the effectiveness and efficiency of site remediation so that maximum risk reduction is achieved for each dollar spent. The overall objective of RPO is to protect human health and the environment using technical and management solutions that represent current "best practice" methods. Although RPO is frequently associated with the optimization of remediation systems and *how* the cleanup will be completed, it can also be used to review *why* certain cleanup goals have been established, and updates those decisions based on new regulatory options. Just as the technical approach to remediation should be reviewed and revised to take advantage of scientific advances and evolving standard practice, changes in regulatory framework such as risk-based cleanup goals and the growing acceptance of monitored natural attenuation (MNA) should be considered in the optimization process. An effective RPO program pursues a wide range of optimization opportunities.

1.2 REPORT ORGANIZATION

This report is organized into six sections, including this introduction, and five appendices. An overview of site conditions and previous investigations is provided in the remainder of Section 1. A brief evaluation of the existing groundwater extraction and treatment system is presented in Section 2. Section 3 provides a description of the SVE pilot testing performed by Parsons ES at Building 3001, the testing results and an interpretation of the results. Section 4 presents a comparison of the existing groundwater extraction and treatment system versus a conceptual full-scale SVE system, with regard to VOC mass removal rates and total costs. Section 5 presents recommendations for future work at Building 3001. References cited are provided in Section 6. Photographs taken during drilling, VEW/VMP installation, and SVE pilot testing are provided in Appendix A. Geologic boring logs for boreholes drilled during this evaluation are included in Appendix B. Soil analytical results and chain-of-custody (ChOC) forms for sampling performed during this evaluation are provided in Appendix C. Soil vapor analytical results and ChOC forms for sampling performed during this RPO evaluation are provided in Appendix D. Calculations for long-term VOC mass removal using SVE are included in Appendix E.

1.3 SITE INFORMATION

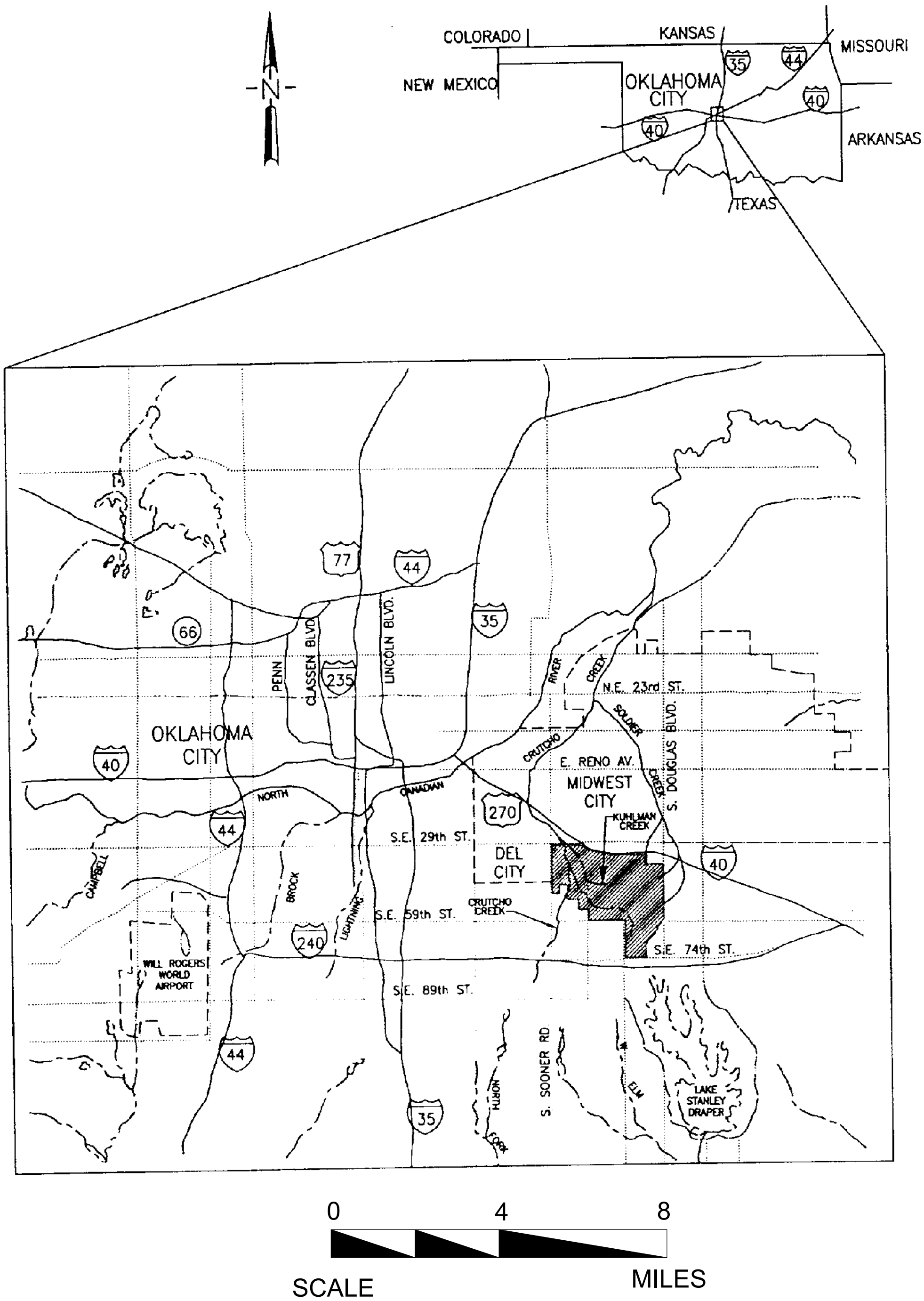
1.3.1 Site Description and Operational History

Tinker AFB is located in Oklahoma County in central Oklahoma, approximately 8 miles southeast of downtown Oklahoma City (Figure 1.1). The installation comprises approximately 5,041 acres and is bounded by Sooner Road on the west, Douglas Boulevard on the east, Interstate 40 on the north, and Southeast 74th Street on the south. The Base has supported air operations since its founding as the Midwest Air Depot in July 1941. The Base was formally activated by the Air Force in March 1942, and currently serves as an international repair depot for a variety of aircraft, weapons, and engines.

The Soldier Creek/Building 3001 National Priorities List (NPL) site is located within the northeastern quadrant of Tinker AFB and has been subdivided into operable units (OUs). Each OU corresponds to an area of the site where specific industrial operations and/or waste management activities have taken place. Currently, four OUs have been designated at Soldier Creek/Building 3001: Building 3001 (OU-1), Soldier Creek Sediment and Surface Water (OU-2), Soldier Creek Off-Base Groundwater (OU-3), and Industrial Wastewater Treatment Plant (IWTP) Groundwater (OU-4) (Figure 1.2).

OU-1 includes the Building 3001 complex (covering 50 acres), Pit Q-51, the North Tank Area (NTA), and surrounding areas encompassed by the lateral extent of a groundwater contaminant plume emanating from Building 3001. OU-1 is located in the northeastern quadrant of the Base and covers an area of approximately 220 acres (Figure 1.2).

The Building 3001 complex remains active, and is involved in reconditioning, modifying, and modernizing aircraft, including jet engine overhaul and missile repair. These industrial activities used or generated solutions containing organic chemicals, including trichloroethene (TCE), tetrachloroethene (PCE), and metals such as chromium and nickel. Industrial solvents and wastewater were contained in subsurface, steel- or concrete-lined pits and trenches inside Building 3001. Fuels for the boiler system included No. 2 fuel oil stored at the NTA. Diesel fuel, gasoline, and waste oil were also stored at the NTA. Over time, the waste pits and trenches leaked, and wastes percolated into shallow groundwater. Also, some of the solvents and wastewater from the Base's industrial operations were drained into the storm drain system beneath the building. Leakage from storm drainpipes probably occurred, allowing waste migration into the perched aquifer.



LEGEND

- HIGHWAY OR INTERSTATE
- MAJOR ROAD
- RIVER OR CREEK
- OTHER BOUNDARIES
- TINKER AFB

FIGURE 1.1

TINKER AIR FORCE BASE LOCATION MAP

Building 3001
Remedial Process Optimization
Tinker AFB, Oklahoma

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Denver, Colorado

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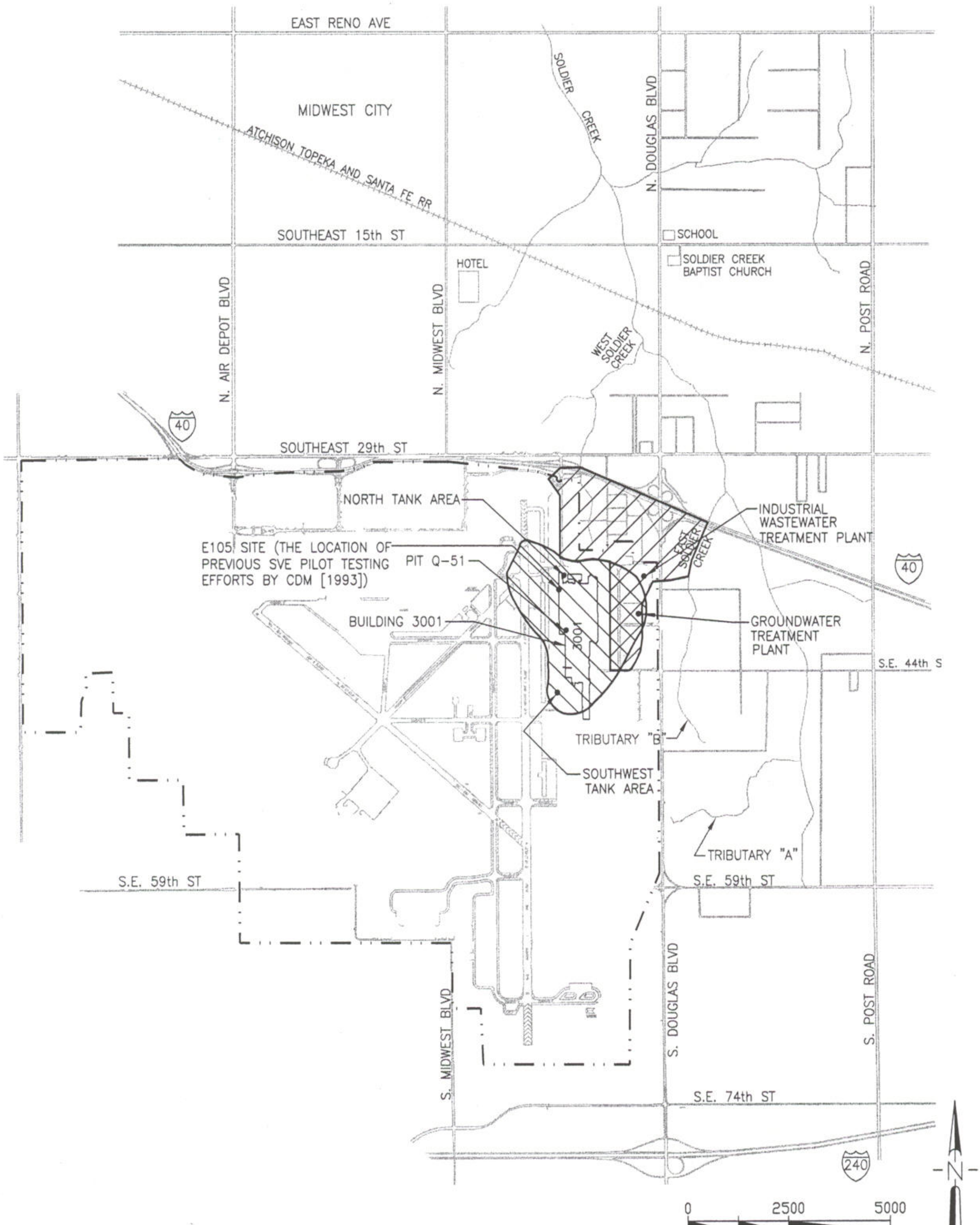

LEGEND

- SOLDIER CREEK AND TRIBUTARIES
- UNDERGROUND PORTION OF CREEK
- BOUNDARY OF TINKER AIR FORCE BASE
- BUILDING 3001 OPERABLE UNIT
- INDUSTRIAL WASTEWATER TREATMENT PLANT/SOLDIER CREEK OFF-BASE GROUNDWATER OPERABLE UNITS

OPERABLE UNITS

BUILDING 3001 – OU-1

SOLDIER CREEK SEDIMENT AND SURFACE WATER – OU-2

SOLDIER CREEK OFF-BASE GROUNDWATER – OU-3

INDUSTRIAL WASTEWATER TREATMENT PLANT (IWTP) – OU-4

Soucre: Parsons ES and Battelle, 1998

FIGURE 1.2

OPERABLE UNITS OF SOLDIER CREEK BUILDING 3001 NPL SITE

Building 3001
Remedial Process Optimization
Tinker AFB, Oklahoma

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Denver, Colorado

1.3.2 Previous Investigations

The Air Force Installation Restoration Program (IRP) Phase I investigation identified potential sources of contamination through record searches and reviews of waste management practices (Engineering-Science, Inc. [ES], 1982). The first report of a contaminant release to the environment occurred in 1983 during routine wellhead sampling and testing. TCE and PCE were detected in two of the Base water supply wells (WS-18 and WS-19) at Building 3001 (Radian International [Radian], 1985a and 1985b). A Phase II IRP investigation was conducted in 1984 to confirm and quantify contamination resulting from past waste storage practices at Building 3001. Sampling also was initiated at East and West Soldier Creek in 1984. Sampling results indicated the presence of chromium and solvent contamination in sediment and surface water. In 1985, fuel and free product contamination were found at the NTA (Battelle, 1993). In September 1987, the Soldier Creek/Building 3001 site was evaluated under the hazard ranking system. The site received a score of 42.24 and was placed on the NPL.

Remedial investigations (RIs) were conducted at the Building 3001 OU during 1986 and 1987 to determine the nature and extent of contamination associated with Building 3001, the NTA, and Pit Q-51. The areas with highest concentrations of groundwater contamination were located beneath Building 3001, the NTA, and the Southwest Tank Area (Figure 1.2). TCE and hexavalent chromium were considered the primary groundwater contaminants because their maximum concentrations were greater than concentrations of other contaminants, and they were consistently detected across a large portion of the site. Other significant contaminants included dichloroethene (DCE), PCE, acetone, toluene, benzene, xylenes, lead, nickel, and barium.

Samples collected from sludge in Pit Q-51 in 1986 indicated TCE, cadmium, chromium, and lead contamination (US Army Corps of Engineers [USACE], 1988a and 1988b). Leakage from this pit and other similar structures is considered to be the primary source of soil and groundwater contamination beneath Building 3001.

Fuel product in the form of No. 2 fuel oil was discovered beneath a leaking 235,000-gallon underground storage tank (UST) at the NTA. As a result, soils and groundwater beneath the NTA and the northern end of Building 3001 were heavily contaminated with fuel and other organic compounds.

A possible additional source of chlorinated solvents in the groundwater at the 1-70 well cluster is from activities that occurred at the Northwest Tank Area, located at the railroad junction west of the northern end of Building 3001. The Northwest Tank Area facility was installed in 1955 for the storage and disposition of solvents used in Building 3001. The facility consisted of three 25,000-gallon steel underground storage tanks, with an underground transfer station. In the 1970's, the facility was converted to a vehicle fueling station for the dispensing of gasoline and diesel fuel. In 1989, the tanks were converted for storage of jet propulsion fuel JP-5. In 1991, the tanks were emptied and removed from active service. The tanks were partially filled in place with sand in 1994. In order to comply with the December 1988 UST requirements, the tanks were excavated and removed in June 1998 for permanent closure (Oklahoma City Air Logistics Center, Environmental Management [OC-ALC/EMR], 1998)

Groundwater used by residents and the work force of Tinker AFB was identified as an exposure medium. Potential points of exposure included water supply wells and discharge to surface water bodies. Exposure with long-term health effects was deemed a possibility in the 1988 baseline risk assessment (USACE, 1988b). A chronology of the investigations leading to the NPL listing is provided in Table 1.1.

TABLE 1.1
CHRONOLOGY OF ACTIVITIES FOR BUILDING 3001
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

Investigation/Activity	Description	Event Date (Source)
IRP Phase I records search	Records search conducted to identify past waste disposal activities that may have caused environmental contamination.	1981 (ES, 1982)
USTs removed at North Tank Area	Two tanks (800-gallon waste oil tank and 13,000-gallon gasoline tank) removed at NTA.	1983-1985 (Battelle, 1993)
IRP Phase II Confirmation/Quantification investigation	TCE detected in groundwater in the vicinity of Building 3001.	1983 (Radian, 1985a and 1985b)
Supply wells in Building 3001 taken out of service	Water supply wells (WS-18 and WS-19) located inside Building 3001 taken out of service.	1984 (Engineering Enterprises, 1984)
Supply wells in Building 3001 plugged	Water supply wells (WS-18 and WS-19) located inside Building 3001 plugged.	1986 (Dansby & Associates, 1986)
Remedial investigation and risk assessment	Pit Q-51 identified as containing hazardous contaminants. Investigation conducted to determine nature and extent of contamination.	1986-1987 (USACE, 1988a and 1988b)
NPL listing	Soldier Creek/Building 3001 added to the NPL	July 22, 1987

1.3.3 Site Setting

1.3.3.1 Topography and Surface Hydrology

Tinker AFB is located within the Central Redbed Plains section of the Central Lowland physiographic province, an area characterized by nearly level to gently rolling hills, broad flat plains, and well-entrenched main streams. The principal drainages for the

Base are Crutcho and Soldier Creeks, which flow north into the North Canadian River. Building 3001 is located on generally flat terrain in the Soldier Creek drainage. On the west side of Building 3001, surface runoff is collected in storm sewers, and is discharged into a ditch between the building and the flight line.

1.3.3.2 Hydrogeology

Building 3001 is underlain by the Garber-Wellington Formation, which consists of lenticular and interbedded sandstone, shale, and siltstone. The Central Oklahoma aquifer underlying the Building 3001 site was divided into five discrete hydrostratigraphic units (Parkhurst et al., 1993). These units in descending order are the upper saturated zone (USZ), the upper shale, the lower saturated zone (LSZ), the lower shale, and the production zone (PZ). Figure 1.3 illustrates the hydrostratigraphic sequence that occurs in the vicinity of Building 3001. Hydrostratigraphic nomenclature evolved from 1986 to 1993, and is fully described in recent reports. (Parsons ES and Battelle, 1996 and 1997). The additional zones (layers) shown on Figure 1.3 are fully discussed in these reports.

In the northeastern quadrant of Tinker AFB, the USZ is the saturated zone above the upper shale. The USZ ranges in thickness from roughly 0 to 35 feet with an average saturated thickness of about 14 feet. The LSZ consists of the saturated interval between the upper and lower shale units. The sediments that comprise the LSZ vary in thickness from about 88 to 179 feet with an average thickness of about 151 feet. Where the upper shale unit is present, the entire column of LSZ sediments exists and generally ranges in thickness from 130 to 170 feet. Beyond the extent of the upper shale horizon, much of the LSZ sediment has been removed by erosion, reducing the thickness of LSZ sediments, especially along the stream drainages. The PZ is the saturated zone beneath the lower shale and above the base of fresh groundwater. Sediments that comprise the PZ range in thickness from about 720 to 788 feet with an average thickness of about 753 feet.

The upper shale, which occurs at a depth of approximately 30 to 40 feet below ground surface (bgs), produces a perched water table in the USZ underlying Building 3001. The upper shale in this area ranges in thickness from roughly 5 to 200 feet where it has not been removed by erosion. The lower shale unit occurs at a depth of about 200 feet beneath Building 3001 and is approximately 20 feet thick. The observed range in hydraulic heads measured in the northeastern quadrant is about 160 feet. This range in head indicates that the vertical component of groundwater flow is significant.

1.3.4 Nature and Extent of Contamination

1.3.4.1 Soil

The soils and bedrock (above the perched water table) have been contaminated in localized areas beneath Building 3001 as a result of contaminant migration. Concentrations of TCE, 1,2-DCE, PCE, methylene chloride, benzene, and methyl ethyl ketone have been detected in localized areas beneath the building. Chromium, lead, barium, and cadmium also are present in these areas. Although most of the industrial process sources have been remediated, the soils beneath Building 3001 are expected to act as a continuing source of groundwater contamination for many years (USACE, 1990).

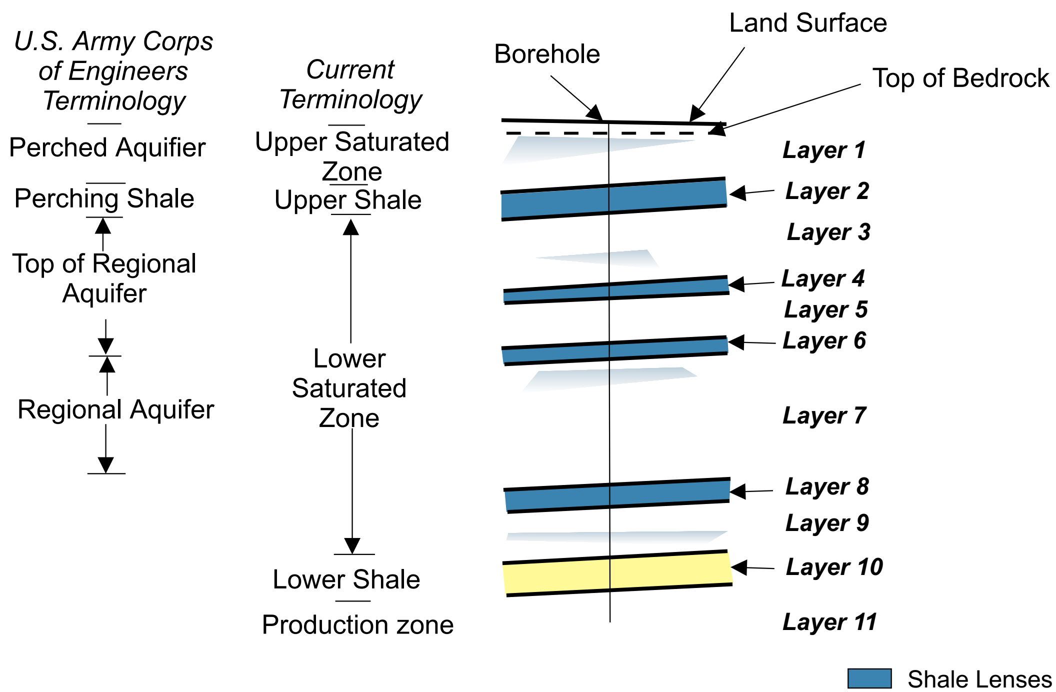

FIGURE 1.3

AQUIFER ZONE TERMINOLOGY AND NORTHEAST QUADRANT GROUNDWATER FLOW MODEL LAYERS

Building 3001

Remedial Process Optimization

Tinker AFB, Oklahoma

PARSONS

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

Source: USACE, 1990.

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1.3.4.2 Groundwater

Thirty-two chemical constituents (24 organics and 8 inorganics) were identified in groundwater during the RIs. Based on the Building 3001 risk assessment (USACE, 1988b), seven indicator chemicals were selected as indicator contaminants of concern (COCs): benzene, TCE, PCE, nickel, hexavalent chromium, lead, and barium. Other groundwater contaminants include 1,2-DCE, acetone, toluene, and xylenes. TCE and hexavalent chromium are the primary contaminants of concern (COCs) due to their frequency of occurrence and broad distribution in the groundwater. TCE and hexavalent chromium isopleth maps reflecting November 1997 USZ data are shown on Figures 1.4 and 1.5, respectively (Parsons ES and Battelle, 1998).

1.3.4.3 Current Building 3001 Groundwater Conditions

A summary of groundwater conditions underlying Building 3001 as of November 1997 is presented in this section. Because the RPO evaluation focused on vadose zone soils and the USZ, only the USZ (formerly known as the perched aquifer) portion of the aquifer system underlying Tinker AFB is evaluated in this discussion. A map of the northeast quadrant of Tinker AFB showing the location of Building 3001, the GWTP, and associated groundwater extraction wells is provided on Figure 1.6.

Dense nonaqueous-phase liquid (DNAPL) TCE has not been identified at the Building 3001 site, but it is inferred to be present based on the observed concentrations of TCE in the groundwater. According to the US Environmental Protection Agency's (USEPA) Dense Nonaqueous Phase Liquids Workshop Summary: "groundwater concentrations of 1 percent or less of effective solubility can be found even in the immediate proximity of the DNAPL." The effective solubility of TCE is approximately 1,000 milligrams per liter (mg/L); therefore, concentrations greater than 10 mg/L may indicate the presence of DNAPL. Concentrations of TCE in the USZ are as high as 260 mg/L (at groundwater monitoring well 1-70B); therefore, DNAPL is expected to be present.

Evaluation of USZ

The USZ is a shallow, water-table aquifer that is known to be perched in the vicinity of Building 3001. The lower boundary of the USZ is the upper shale. The saturated thickness of the USZ ranges from 0 feet on the east side of OU-1, where the upper shale subcrops along Soldier Creek, to 33.9 feet on the west side of OU-1, where the depth of the upper shale reaches 50 feet bgs. The mean thickness of the USZ is 15.1 feet.

Figure 1.4 shows the distribution of TCE in the USZ in November 1997. TCE concentrations ranged from less than 1 microgram per liter (µg/L) to a maximum of 260,000 µg/L (at groundwater monitoring well 1-70B). Since 1994, concentrations have generally decreased at the edges of the plume and in the northern and southern portions of the plume. Concentrations in the center of the plume, in the vicinity of extraction wells P-8 and P-9 increased. The increase in concentration is considered to be the result of mobilization of TCE to those extraction wells. Northwest of Building 3001, TCE has been detected in groundwater monitoring well 2-162B at 1,100 µg/L. Although significant, contamination in this area probably is not related to Building 3001. Southeast of Building 3001, TCE contamination is present at groundwater monitoring well 1-72B (18 µg/L), but Building 3001 is probably not the source.

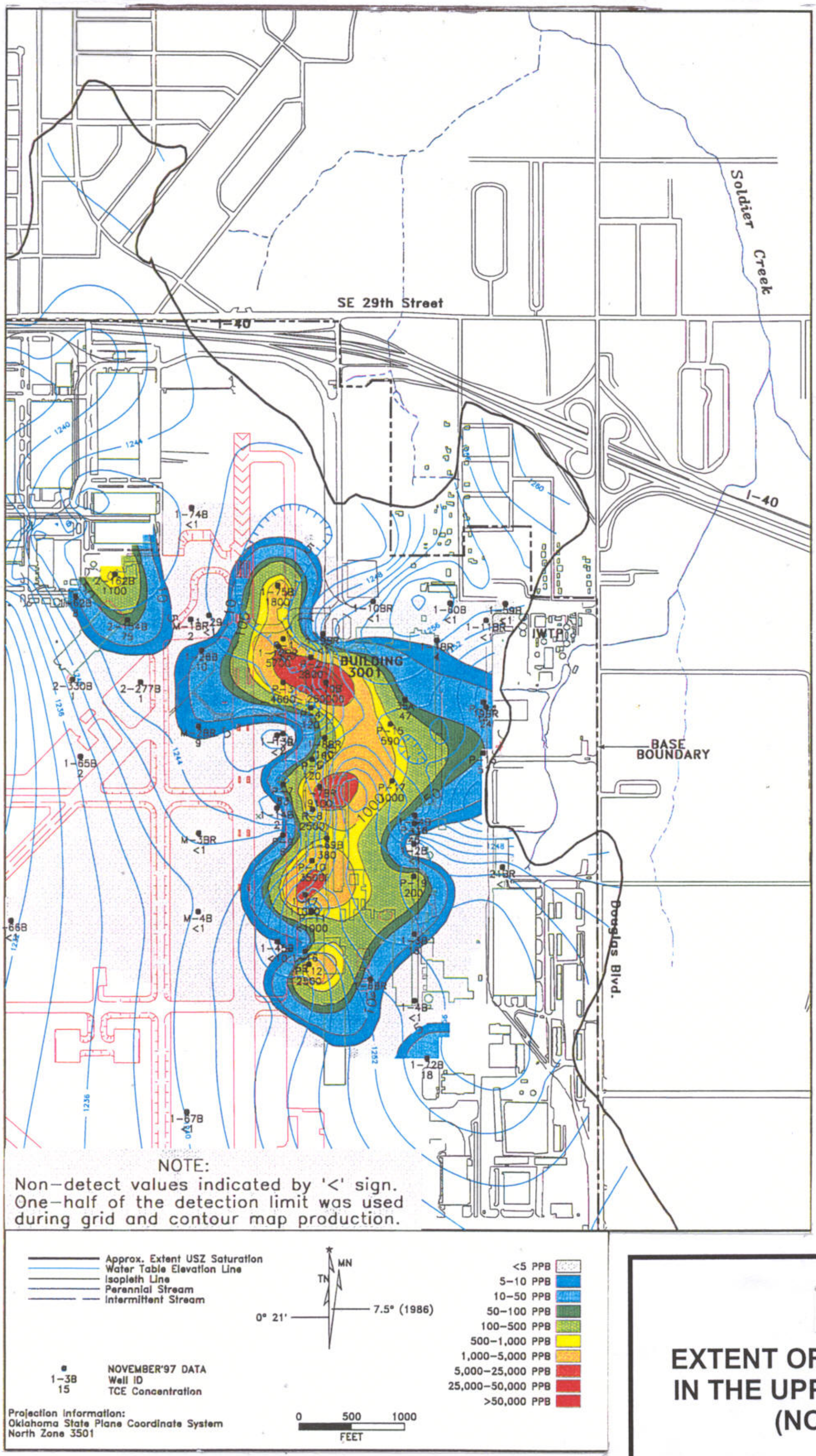

FIGURE 1.4

EXTENT OF TCE CONTAMINATION IN THE UPPER SATURATED ZONE (NOVEMBER 1997)

Building 3001

Remedial Process Optimization

Tinker AFB, Oklahoma

PARSONS

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Denver, Colorado

Source: Parsons ES and Battelle, 1998

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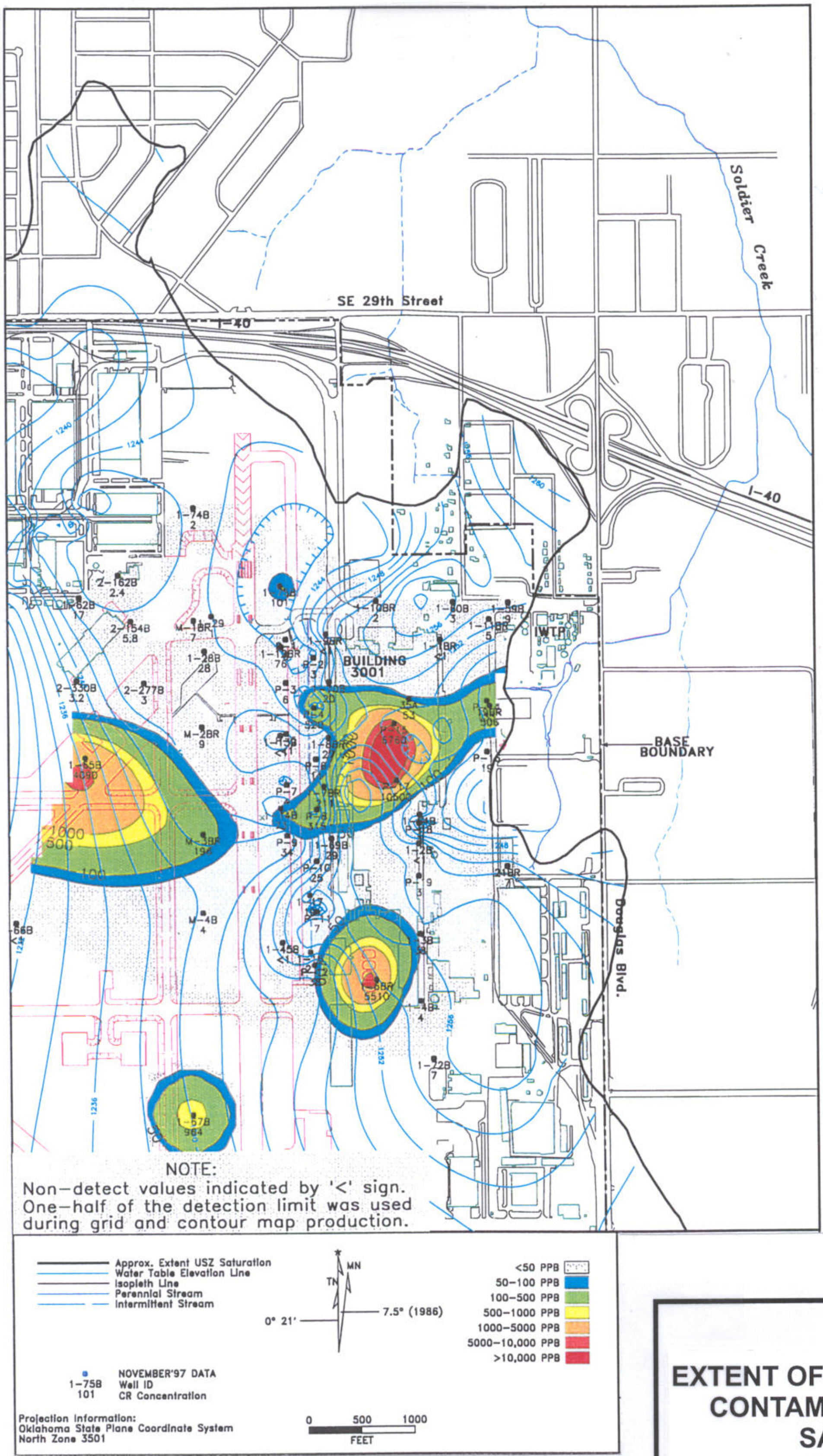


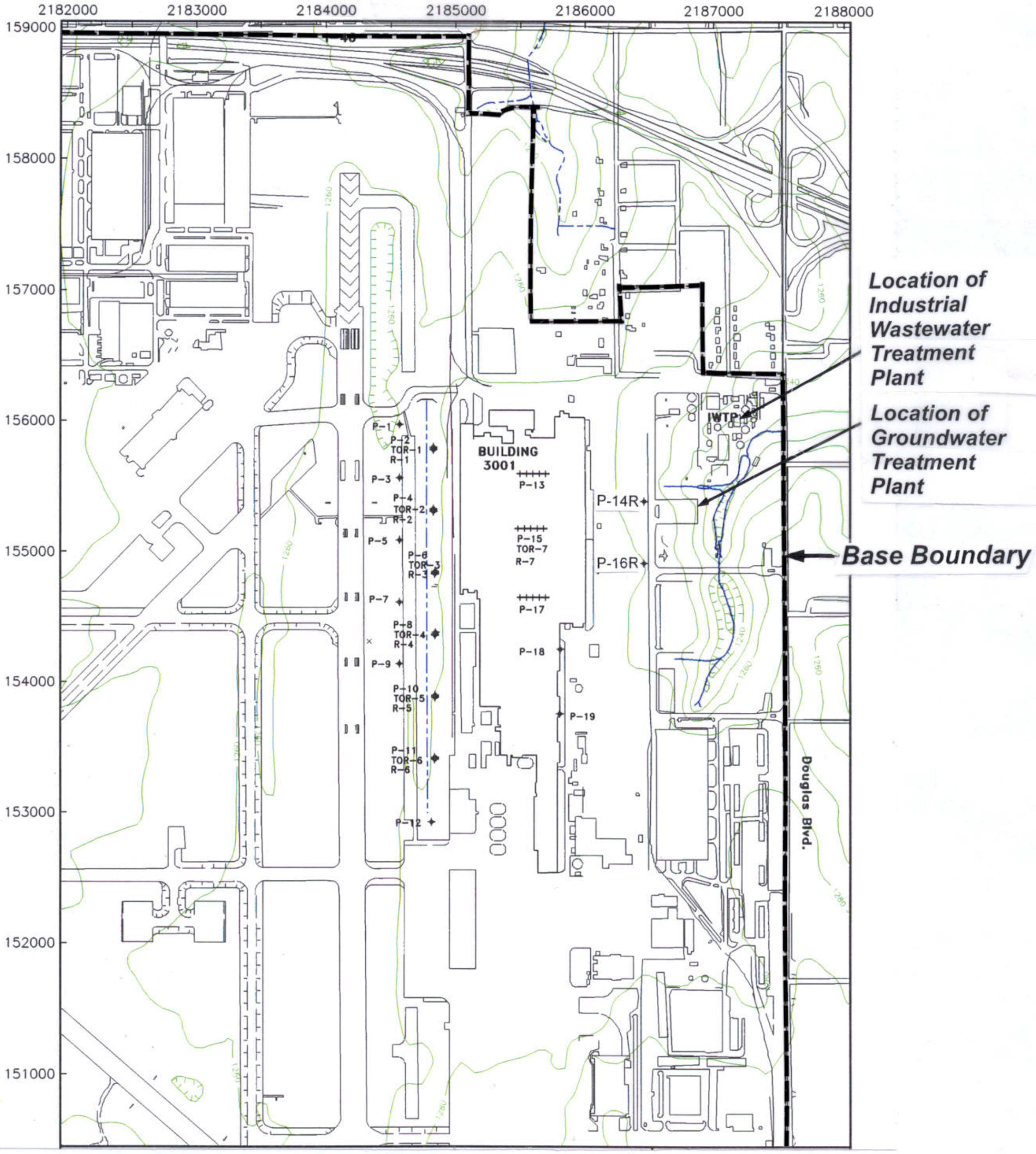
FIGURE 1.5

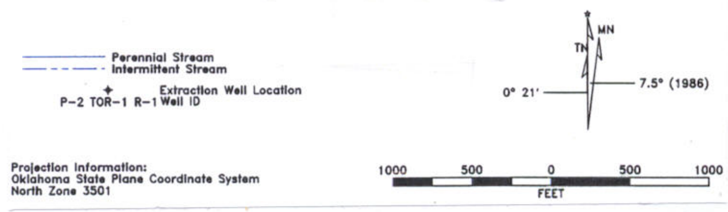
EXTENT OF HEXAVALENT CHROMIUM CONTAMINATION IN THE UPPER SATURATED ZONE (NOVEMBER 1997)

Building 3001
Remedial Process Optimization
Tinker AFB, Oklahoma

PARSONS
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

Source: Parsons ES and Battelle, 1998.





Source: Parsons ES and Battelle, 1998

FIGURE 1.6

BUILDING 3001 GROUNDWATER OU EXTRACTION WELLS AND TREATMENT SYSTEM

Building 3001
Remedial Process Optimization
Tinker AFB, Oklahoma

PARSONS
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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Figure 1.5 shows the distribution of hexavalent chromium in the USZ in November 1997. Hexavalent chromium concentrations ranged from less than 10 µg/L to a maximum of 10,500 µg/L (groundwater extraction well P-17). Since 1994, the chromium plume beneath Building 3001 has been decreasing in concentration, particularly near extraction wells P-15 and P-17. However, at several other locations across the site, chromium concentrations have generally increased. The most pronounced increase has been observed at wells 1-65B and 1-67B, located more than 2,000 feet west and southwest of Building 3001, respectively (Figure 1.5). Based on the distance between these wells and Building 3001, and the historic distribution of chromium, it is believed that the chromium detected in these wells is not related to Building 3001.

Water table elevation maps for the USZ generated from water levels measured in June 1998 are shown on both Figures 1.4 and 1.5. The June 1998 water levels show the depression of the water table near the Building 3001 extraction system immediately west of the building. A trough beneath the north-central portion of Building 3001 coincides with the locations of the horizontal extraction wells, and indicates that the water table in this area also has been lowered by pumping. Figure 1.6 shows the locations of Building 3001 extraction wells. With the exception of well P-18, the capture zones of the extraction wells located along the eastern side of the building are much less pronounced.

1.3.5 Remedial Action Objectives

Remedial Action Objectives (RAOs) can be divided into two categories: general and specific. General RAOs may be applied to all Comprehensive Environmental Restoration, Compensation, and Liability Act (CERCLA) sites. Specific RAOs reflect site-specific conditions. The RAOs for Tinker AFB as presented in the ROD (USACE, 1990), are summarized below.

- Reduce groundwater contamination to meet federal maximum contaminant levels (MCLs) for TCE (5 µg/L) and chromium (50 µg/L) in a cost-effective and timely manner;

- Meet requirements of the National Pollutant Discharge Elimination System (NPDES) permit;

- Meet emission standards for designated air contaminants to protect the public health and welfare; and

- Meet Resource Conservation and Recovery Act (RCRA) requirements for the management of hazardous waste.

The RAOs pertaining to groundwater cleanup led to the installation of the remediation system described in the following section.

1.3.6 Remediation System Description

The current remediation system at Building 3001 consists of a groundwater extraction and treatment system with the following operating components:

- Thirty-three groundwater extraction wells (5 horizontal wells and 28 vertical wells) installed in three water-bearing zones; and

- A 200-gallon-per-minute (gpm) groundwater treatment plant (GWTP) that treats water from multiple OUs.

The system is designed to remediate groundwater contaminated with VOCs, chlorinated aliphatic hydrocarbons (CAHs), and chromium. The groundwater treatment process is illustrated on Figure 1.7. The diagram presented on this figure was taken from the system operation and maintenance (O&M) plans (Black & Veatch, Inc. [B&V], 1992). Additional system details are presented in those plans. The locations of the GWTP and groundwater extraction wells are shown on Figure 1.6.

1.3.6.1 Extraction Well Field and Groundwater Transport System

The Building 3001 extraction well network consists of 33 extraction wells installed in three aquifer zones, as listed in Table 1.2. It should be noted that the top-of-regional-aquifer wells are completed primarily in the upper portion of the LSZ, but two of the wells also penetrate the lower portion of the LSZ.

Each well is surrounded by a well vault containing the well head, piping from the well into the pipe manifold that transports the water to the GWTP, electrical equipment, and instrumentation. A submersible pump in each well pumps with sufficient head to carry the extracted water to the influent holding tank of the GWTP (Figure 1.7).

1.3.6.2 Groundwater Treatment Plant

The GWTP is contained in a pre-engineered metal building that also contains chemical storage facilities, a maintenance area, and a control room with office space. The GWTP is located east of Building 3001 (Figure 1.6) and lies within the secured area of the Base.

The GWTP consists of the following components (Figure 1.7):

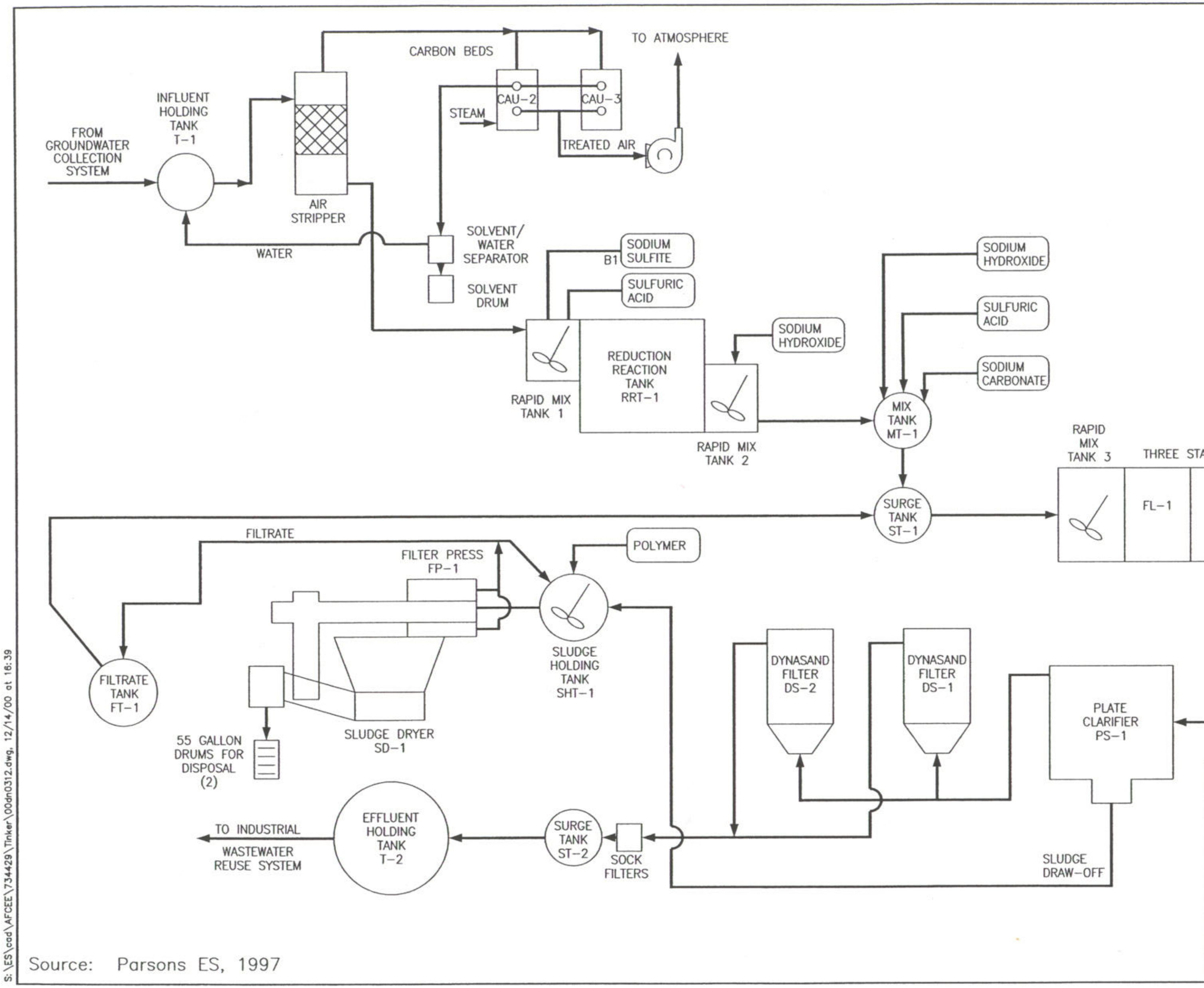
- An influent holding tank to which the extracted water is pumped;

- An air stripper coupled with a vapor-phase activated carbon system for the removal of volatile organics;

- A chemical addition or mixing system for the reduction of soluble hexavalent chromium to insoluble trivalent chromium;

- A chemical flocculation system for the precipitation and removal of trivalent chromium and other metals. This system consists of chemical addition systems, flocculation, and sedimentation in an inclined plate clarifier;

- Granular media filtration for the removal of additional suspended solids. This filter is a "moving bed" type (Dynasand® brand);



Source: Parsons ES, 1997

FIGURE 1.7

SIMPLIFIED GROUNDWATER TREATMENT PROCESS FLOW DIAGRAM

Building 3001
Remedial Process Optimization
Tinker AFB, Oklahoma

PARSONS
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TABLE 1.2
GROUNDWATER EXTRACTION WELLS BY HYDROGEOLOGIC ZONE
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

Tinker AFB (1994) Groundwater Conceptual Model	USACE (1988a)	Number of Horizontal Wells	Number of Vertical Wells
USZ	P-1 through P-19 (Perched Aquifer)	3	16
LSZ (upper)	TOR-1 through TOR-7 (Top of Regional Aquifer)	1	6
LSZ (lower)	R-1 through R-7 (Regional Aquifer)	1	6

- Sludge handling using a sludge-holding tank, recessed plate filter press, and thermal sludge dryer. Dried sludge is disposed of at a RCRA landfill certified to receive CERCLA wastes; and
- An effluent holding tank from which the treated water is pumped for industrial reuse.

1.3.7 System Monitoring

A system monitoring program has been implemented to evaluate the performance of the Building 3001 remediation system. The following is a summary of performance monitoring of the extraction wells.

1. Extraction wells are sampled every 6 months and analyzed for VOCs, metals, and semi-volatile organic compounds (SVOCs).
2. Plant operators inspect each extraction well every 2 weeks to:
   a. Measure amperage across motor (checking for out-of-specification operation),
   b. Record flow meter totalizer readings,
   c. Measure water level in the well,
   d. Inspect system for visible faults (e.g., leaking pipes, accumulation of water in the vault, etc.), and

e. Record any maintenance performed, parts replaced, adjustments made to the system, or observations made.

3. Plant operators continuously monitor individual well flow rates and well cycle rates from the GWTP computer.

1.3.8 Previous SVE Pilot Testing Efforts at Building 3001

In 1991 and 1992, Camp, Dresser, and McKee (CDM) performed an evaluation of horizontal wells at the E105 site, located on the west side of Building 3001 (CDM, 1993) as shown on Figure 1.2. The main objective of this effort was to determine if horizontal wells would be effective for both groundwater extraction and SVE at the site. As part of this effort, CDM installed two horizontal wells underneath Building 3001 using conventional directional mud rotary drilling methods in conjunction with a magnetic guidance system. One horizontal well, designated as HW-1, was installed in the USZ for groundwater extraction and the other well, designated as HW-2, was installed in vadose zone soils for implementing SVE. In two mobilizations that occurred in August 1991 and July 1992, CDM also installed seven groundwater monitoring wells, eight soil vapor monitoring points (VMPs), and three combination groundwater monitoring wells/VMPs to monitor groundwater and soil vapor conditions during the testing. The locations of the CDM pilot testing components are illustrated in Figure 1.8.

The water table at the E105 site was measured at a depth of approximately 19 feet bgs in January 1992, and at 18 feet bgs in September 1992. Subsurface material consisted of the concrete floor underlain by gravel fill from 0 to 2 feet bgs, with weathered red clay from 2 to 10 feet bgs and sands from 10 to 21 feet bgs. An interbedded zone of silty clay, clay, and soft shale was encountered from 21 to 25 feet bgs, and sand and sandstone was encountered from 25 feet bgs to 41 feet bgs, the maximum depth at which drilling was terminated.

Results of soil and groundwater sampling conducted at the E105 site showed significant concentrations of chlorinated hydrocarbon compounds in vadose zone soils, saturated soils, and groundwater. The primary contaminants detected in soils during the 1991 groundwater monitoring well/VMP installation and sampling event were TCE, PCE, and 1,2-DCA. The highest concentrations occurred at the southeast corner of the site, near the cleaning area, in the upper five feet of the soil column in BH10 and MW11. TCE, PCE, and 1,2-DCA concentrations were 6,070, 8,590, and 4,330 micrograms per kilogram (µg/kg), respectively, in the 5.0 to 5.5 foot depth interval of BH10; and 2,230, 7,870, and 2,290 µg/kg, respectively, in the 6 foot interval of MW11. In an August 1991 groundwater sampling event, TCE concentrations ranged from 26 to 85 mg/L, with the highest concentration observed at MW8 (Figure 1.8). PCE concentrations ranged from 4.5 to 14 mg/L, with the highest concentrations found in MW6.

Additional soil sampling was conducted during drilling for installation of wells C1, C2, and C3 in July 1992. Compounds detected in soils during drilling for installation of well C1 included TCE, at concentrations ranging from 18 µg/kg at a depth of 12 feet bgs to 4,800 µg/kg at a depth of 6 feet bgs, and PCE, at concentrations ranging from 19 µg/kg at 12 feet bgs to 3,200 µg/kg at a depth of 6 feet bgs. Compounds detected in soils during drilling for installation of well C2 included TCE, at concentrations ranging from 120 g/kg

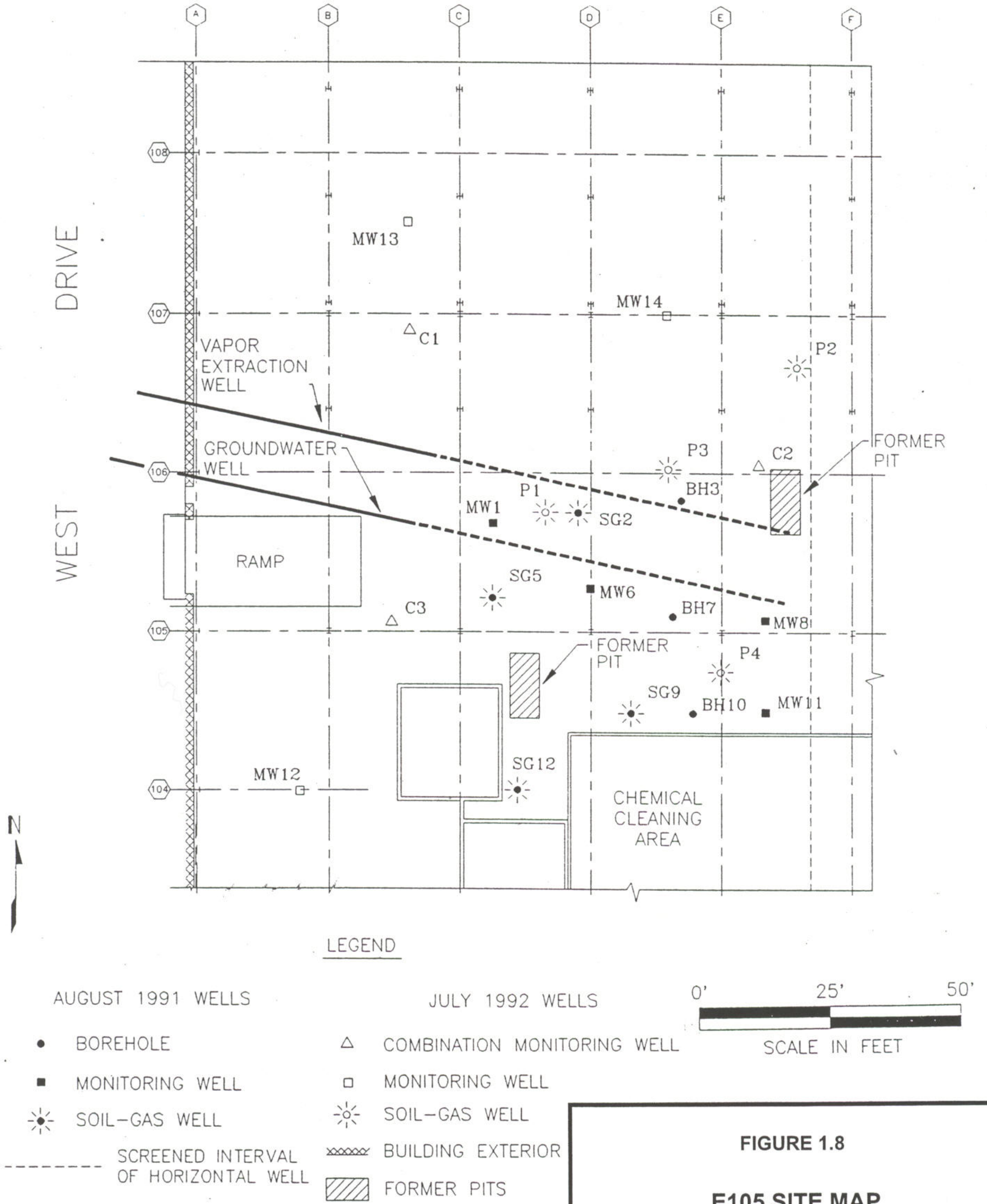

FIGURE 1.8

E105 SITE MAP

Building 3001
Remedial Process Optimization
Tinker AFB, Oklahoma

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Source: CDM, 1993.

at a depth of 23 feet bgs to 240,000 µg/kg at a depth of 6 feet bgs, and PCE, at concentrations ranging from 140 µg/kg at 29 feet bgs to 1,900,000 µg/kg at a depth of 3 feet bgs. Compounds detected in soils during drilling for installation of well C3 included TCE, at concentrations ranging from 8 µg/kg at a depth of 12 feet bgs to 14,000 µg/kg at a depth of 6 feet bgs, and PCE, at concentrations ranging from 31 µg/kg at 12 feet bgs to 3,500 µg/kg at a depth of 6 feet bgs.

HW-1 and HW-2 were installed in 1991. HW-1 was installed for groundwater extraction from the USZ, and it was constructed using 70 feet of 6-inch diameter stainless steel screen with 0.012-inch slots, connected to a 210-foot length of 6-inch schedule 40 PVC casing. The screen for well HW-1 was installed at a depth of approximately 26 feet bgs. HW-2 was installed for SVE from vadose zone soils, and it was constructed using 70 feet of 6-inch-diameter PVC screen with 0.012-inch slots, connected to a 210-foot length of 6-inch schedule 40 PVC casing. The screen for well HW-2 was installed beneath Building 3001 at approximately 14 feet bgs.

SVE pilot tests were performed in 1992 at various vacuums and flow rates using HW-2. The primary objectives of the test were to determine the average permeability of vadose zone soils in the pilot testing area, to estimate the area of influence of well HW-2, and to determine the flow rates and VOC mass removal that could be achieved using well HW-2. The tests were run in conjunction with a groundwater pumping test at HW-1 to more accurately reflect actual proposed operating conditions.

Prior to starting the SVE pilot tests, soil gas samples were collected from each of the monitoring points under static conditions and analyzed for VOCs using a field photoionization detector (PID), onsite gas chromatograph, and laboratory analysis using USEPA Method SW8020. The field PID indicated total VOC concentrations of 1,000 to 2,000 ppmv in the majority of the monitoring points, but the field GC and laboratory analyses indicated total VOC concentrations of only about 1 ppmv. The discrepancy between the field PID readings and the field GC/laboratory analytical results (three orders of magnitude) suggests that there were some significant shortcomings to the soil vapor sampling and analysis techniques being used.

A total of five SVE tests were conducted. The first four tests were performed using a 5-horsepower regenerative blower system capable of providing a flow of 60 standard cubic feet per minute (scfm) at a maximum vacuum of 90 inches of water, and one using a vacuum pump capable of producing a vacuum of 340 inches of water at a flow of approximately 25 scfm. The longest test duration was only 24.5 hours, at a system vacuum of 40 inches of water. The concentrations of VOCs in the extracted soil vapor stream were monitored throughout the demonstration. Samples were analyzed onsite for oxygen, carbon dioxide, lower explosive limit, and VOC content using both a field PID analyzer and an onsite gas chromatograph. In addition to the onsite analyses of extracted soil vapor, selected samples were collected in Summa canisters for offsite laboratory analysis.

The results indicated an average permeability of 3.5 Darcys for soils in the site area. Vacuum responses resulting from SVE at HW-2 were observed at all VMPs, which were installed at distances ranging from approximately 5 to 60 feet from the horizontal SVE well screen. Vacuum responses ranged from approximately 1.5 to 15 inches of water. Because significant vacuum responses were observed at all VMPs, the area of influence of HW-2 exceeded 60 feet, but could not be accurately determined. The actual VOC mass removal rates could not be determined due to the short duration of the test and uncertainties associated with the soil vapor sampling and analysis techniques that were used. Field PID measurements were consistently one to three orders of magnitude higher than field GC results or laboratory analytical results, indicating that significant error may have been occurring in soil vapor sampling and analysis.

SECTION 2

EVALUATION OF EXISTING GROUNDWATER EXTRACTION AND TREATMENT SYSTEM

As indicated in Section 1, a number of assessment reports have been prepared evaluating the effectiveness and making optimization recommendations for the existing groundwater extraction and treatment system at Building 3001. In an effort to avoid duplication, the work that was performed for this RPO evaluation was intended to further evaluate one of the key recommendations of the assessment reports, which was to optimize contaminant mass removal in the USZ by pilot testing SVE as a supplemental treatment technology.

Because the primary objective of this RPO evaluation was to determine the feasibility of using SVE to remediate source-area soils, a detailed RPO evaluation of the groundwater extraction and treatment system was not conducted. The following discussion of the groundwater extraction and treatment system is included mainly to provide VOC removal rates and unit costs of VOC removal being achieved using the groundwater extraction and treatment system. In Section 4, this information is compared against the VOC removal rates and projected unit costs of VOC removal that could be achieved using SVE. This comparison provides the basis for determining if SVE is a cost-effective supplemental treatment technology at Building 3001.

Section 1.3 described the RAOs for Building 3001 and how the existing groundwater extraction and treatment system was installed to meet the objectives pertaining to groundwater cleanup. The effectiveness and efficiency of the remediation system is directly related to achieving the cleanup objectives specified in the ROD. In the case of Building 3001, the final groundwater cleanup goal is to reduce contaminant concentrations to below federal MCLs for TCE (5 µg/L) and chromium (50 µg/L).

2.1 EFFECTIVENESS/EFFICIENCY DISCUSSION

System effectiveness refers to the ability of the system to achieve the remediation goals at a given site. Efficiency refers to the optimization of time, energy, and costs associated with achieving remediation effectiveness using a specific technology (Parsons ES, 1999). This section provides a brief discussion on the effectiveness of the groundwater extraction and treatment system to date.

A number of assessments have been completed on the effectiveness and optimization of the groundwater extraction and treatment system at Building 3001 as well as evaluating current RAOs (Parsons ES, 1997 and 1998a). The conclusions of these assessments are as follow:

- Attainment of MCLs for TCE in the source area (USZ) is an unrealistic, if not impossible, goal due to the likely presence of DNAPL.

- Additional data should be gathered to support a TI waiver. Such additional data include those to be collected during the SVE pilot test that was conducted as part of this RPO demonstration.

- The best-case outcome of such additional data collection would be the generation of an agreement to limit groundwater extraction to the source area defined as the TI Zone, a releasing of cleanup requirements within that zone, and an agreement to monitor the progress of natural attenuation of TCE and chromium to concentrations less than MCLs before the plumes reach designated point-of-compliance wells in the regional aquifer.

VOC mass removal rates from groundwater have varied during the operation of the groundwater extraction and treatment system through February 2000, but have not yet reached asymptotic levels. The groundwater extraction and treatment system has removed approximately 15 drums (about 8,625 pounds [lbs]) of VOCs, including CAHs, from the beginning of system operation in June 1994 through February 2000 (Buehler, 2000), for an average VOC removal rate of about 130 lbs per month (illustrated on Figure 2.1). The VOC removal rates recorded during fiscal year (FY) 1999 averaged 160 lbs per month, approximately 23 percent higher than the average rate for the entire period from June 1994 through February 2000. During January and February 2000, total VOC removal rates averaged 84 lbs per month (Buehler, 2000), approximately 35 percent lower than the entire period from June 1994 through February 2000. The recovered contaminants have consisted primarily of TCE (about 75 percent) with the remainder consisting of benzene, toluene, PCE, and 1,2-DCE (Buehler, 2000).

These mass removal rates are for the entire groundwater extraction and treatment system (including contributions from both USZ and LSZ extraction wells); however, only a small percentage of the total extracted groundwater is from the USZ wells. Recent pumping rate data show that only about 10 percent (approximately 13 gpm) of the total (approximately 126 gpm) groundwater flow being extracted and treated is from the USZ, with the remainder being from the upper and lower portions of the LSZ (Buehler, 2000). Therefore, the mass removal rates from the USZ are much less than the mass removal rates for the entire system reported above.

USZ groundwater levels in the vicinity of Building 3001 have generally decreased as the result of groundwater extraction. For example, the potentiometric surface of the USZ perched aquifer at groundwater monitoring well 34A was measured at 20 feet below the top of the well casing in 1992, prior to startup of the groundwater extraction system, and was at 26 feet below the top of the casing in October 1999 (Buehler, 2000). This drop in the water level has led to decreased pumping rates, which affects the mass removal rate. Moreover, the drop in the water table has isolated contamination in the smear zone above the saturated interval where it is inaccessible to the extraction wells.

2.2 COST EVALUATION

The cost to design the groundwater extraction and treatment system at Building 3001 was $674,000, and the capital cost for system installation was $12 million, including the

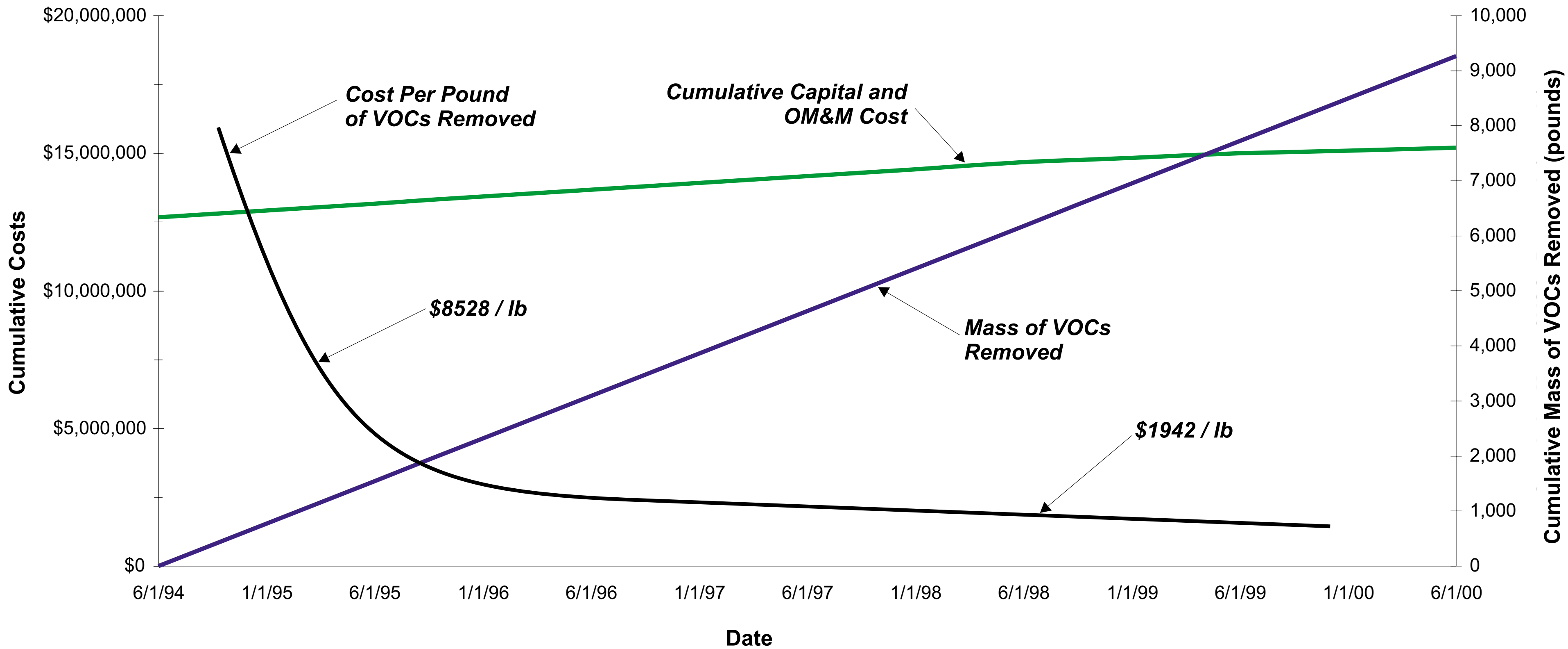

FIGURE 2.1

CUMULATIVE VOC MASS REMOVAL AND COSTS THROUGH TIME FOR THE GROUNDWATER EXTRACTION AND TREATMENT SYSTEM

Building 3001
Remedial Process Optimization
Tinker AFB, Oklahoma

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installation of five horizontal groundwater extraction wells at a cost of approximately $400,000 per well (Buehler, 2000). Annual costs for operating the Building 3001 groundwater extraction and treatment system have been about $500,000 per year through the beginning of FY 1999 (Buehler, 2000). The budget for FY 1999 and 2000 groundwater extraction and treatment system OM&M was $484,000 per year (Buehler, 2000). Parsons ES has estimated that the annual OM&M costs for the Building 3001 system have been $500,000 per year for the first four years of system operation (June 1994 through June 1998), $450,000 per year for the fifth and sixth years of operation (June 1998 through June 2000). Parsons ES has assumed that future annual OM&M costs for the system at Building 3001 will be approximately $450,000 per year.

The cumulative costs expended to date for design, installation, and operation of the groundwater extraction and treatment system at Building 3001 are illustrated in Figure 2.1, along with the cumulative mass of VOCs removed and the estimated total cost per pound of VOCs removed. Based on estimated capital and OM&M costs for the system at Building 3001 and the total mass of VOCs removed for the period from June 1994 through February 2000 (8,625 pounds over 5 2/3 years), the average cost per pound of VOCs removed from groundwater has been approximately $1,700 per pound as of June 2000. It should be noted that these unit treatment costs are biased high, since the Building 3001 groundwater treatment system also includes unit processes for the removal of hexavalent chromium.

A projection for total VOC mass removal and project costs over the next 30 years is illustrated in Figure 2.2. If current VOC mass removal rates can be sustained, approximately 52,000 pounds of total VOCs may be removed by the year 2024. Based on this VOC mass removal estimate and projections for expenditures (projected at $25.9 million in the year 2024), the average cost per pound of VOCs removed may drop to under $600. In reality, the rate of VOC removal will probably decline through time, as concentrations in extracted groundwater will eventually decrease over time. This will result in much longer times than projected to remediate TCE to below its MCL of 5 parts per billion (ppb), and will result in much higher long-term costs per pound of removed VOCs. It is probable that TCE will remain in the saturated zones at concentrations exceeding cleanup goals indefinitely.

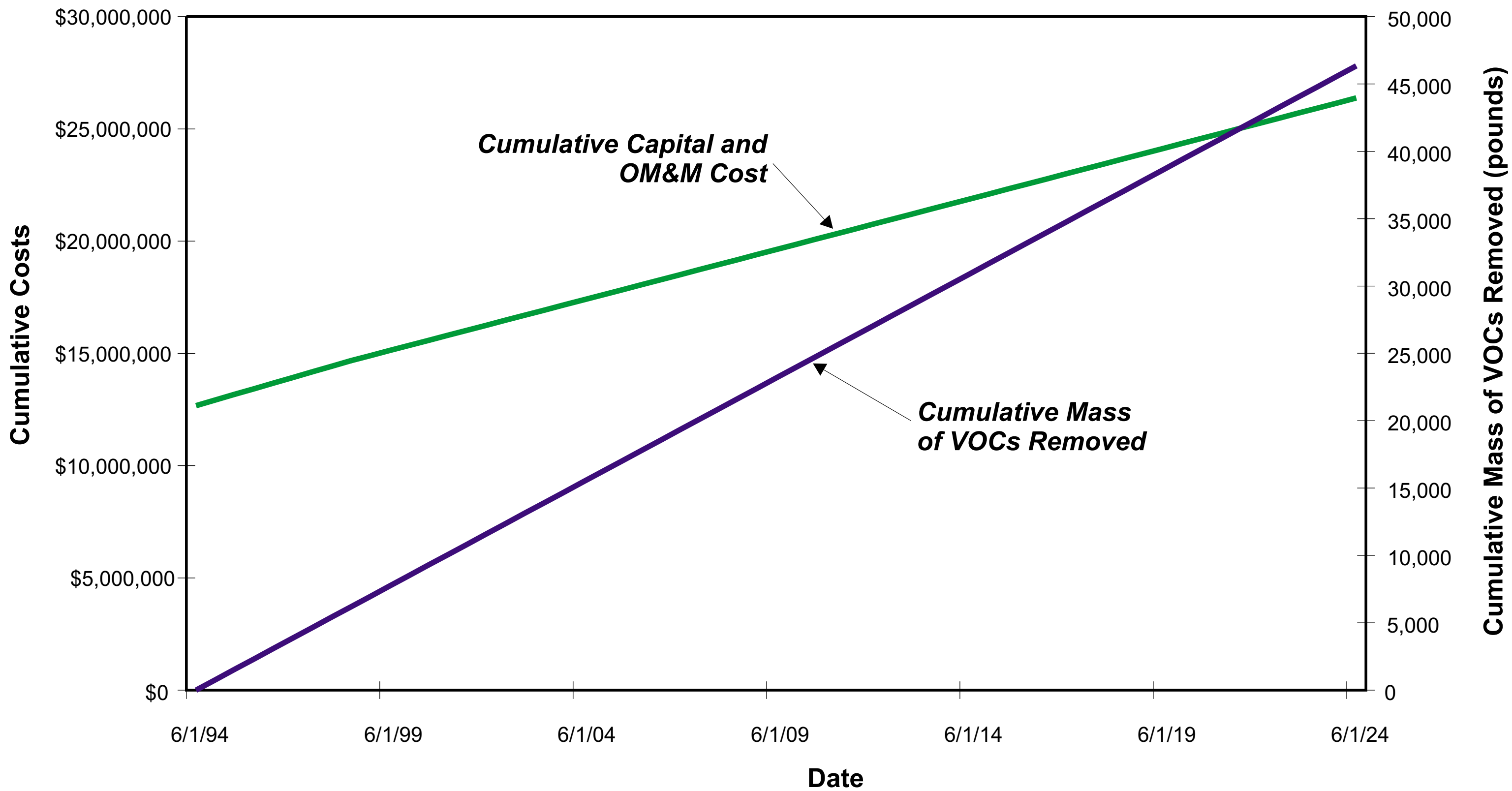

FIGURE 2.2

PROJECTED VOC MASS REMOVAL AND COSTS THROUGH TIME FOR THE GROUNDWATER EXTRACTION AND TREATMENT SYSTEM

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SECTION 3

RESULTS OF SOIL VAPOR EXTRACTION PILOT TEST

3.1 INTRODUCTION

SVE pilot testing activities were conducted by Parsons ES at Building 3001 between March 14 and May 11, 2000. Except where noted, the SVE pilot testing was completed per the *Final Work Plan for Remedial Process Optimization Evaluation at Building 3001, Tinker Air Force Base, Oklahoma* (Parsons ES, 2000).

SVE pilot testing was performed at Building 3001 to:

- Provide data to assess the feasibility of using SVE to physically remove VOCs from source area soils and to reduce source area VOC concentrations;
- Compare VOC mass removal rates that could be achieved using SVE versus those using the existing groundwater extraction and treatment system; and
- If SVE is found to be feasible, make recommendations for future work and estimate costs for a conceptual full-scale SVE system.

Field activities began with the installation of four new VMPs, designated as 01SG0001 through 01SG0004, and one new VEW, designated as 01VEP0001. Each borehole was logged, and one soil sample from each borehole was submitted for laboratory analysis for VOCs. The VEW was installed for the extraction of soil vapor in a suspected source area near well 1-70B. The VMPs were used to monitor vacuum response, changes in groundwater elevation, and changes in soil gas chemistry (oxygen [O_2], carbon dioxide [CO_2], and VOCs) at varying depths and distances from 01VEP0001. Following the installation of the new VEW and VMPs, background soil gas conditions were characterized at the VEW and each of the new VMPs, and baseline groundwater levels were measured at these locations and at groundwater monitoring well 1-70B. The area in which these components are located is called the 01VEP0001 pilot testing area throughout this section. A positive displacement blower system was set up on the site and plumbed to 01VEP0001 and well P-13, an existing horizontal groundwater extraction well that is a component of the Building 3001 groundwater extraction and treatment system, as proposed in the work plan. A site layout illustrating the locations of all SVE pilot testing components is shown on Figure 3.1. A layout of the 01VEP0001 pilot testing area is provided on Figure 3.2.

SVE pilot testing was conducted in two phases. The first phase consisted of a two air permeability/startup tests at 01VEP0001 to:

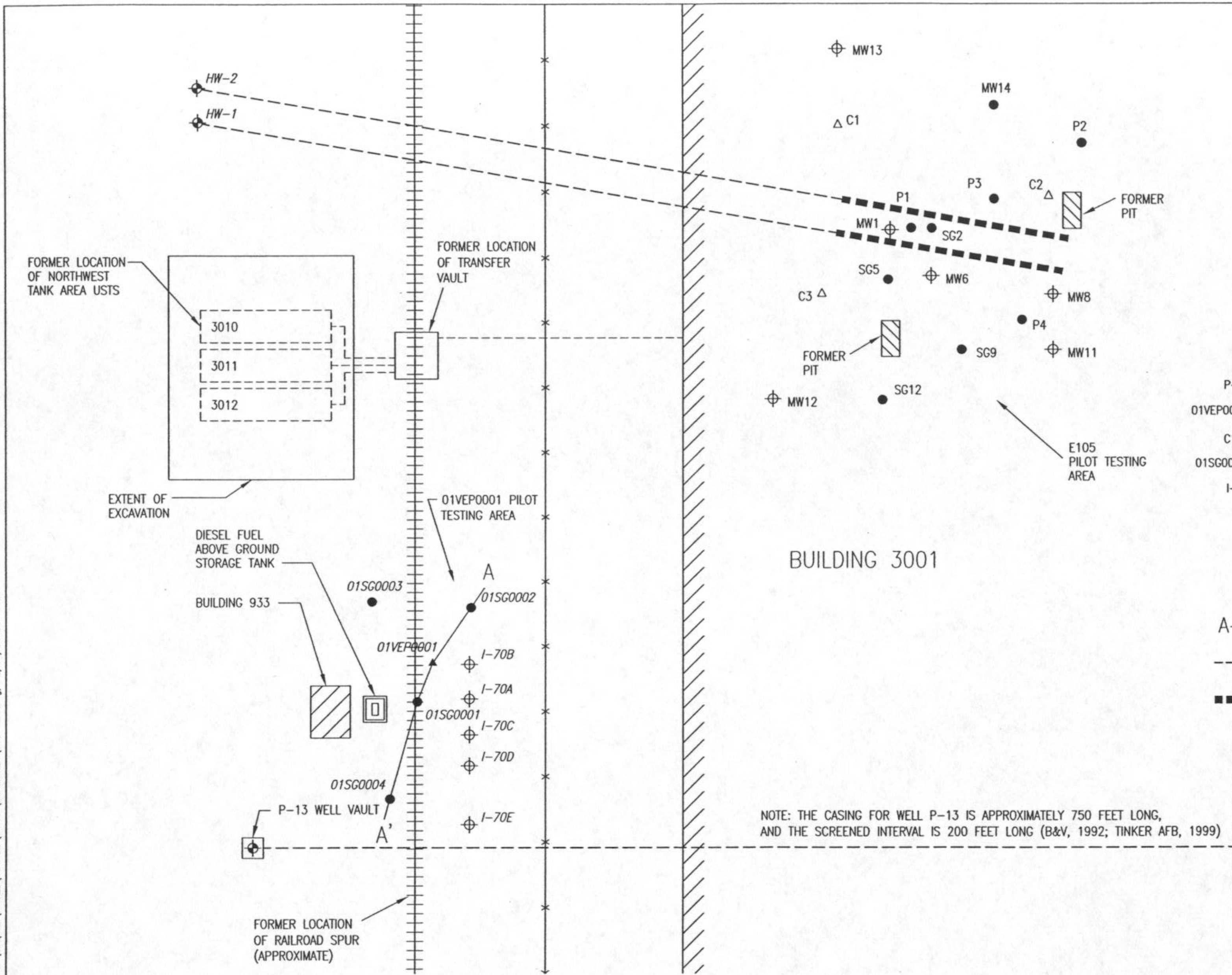

FIGURE 3.1

SITE LAYOUT

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Tinker AFB, Oklahoma

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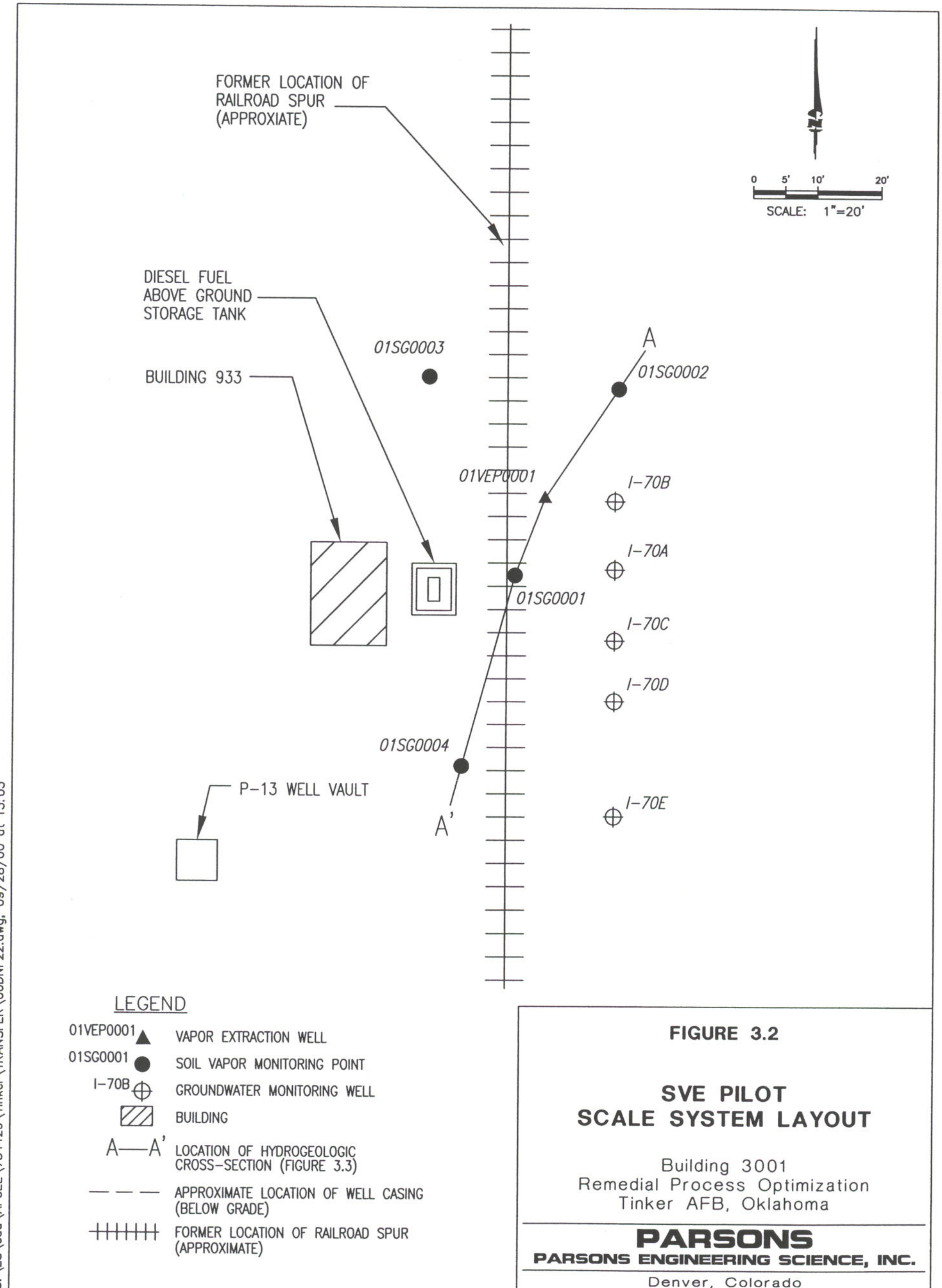

FIGURE 3.2

SVE PILOT SCALE SYSTEM LAYOUT

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- Determine approximate SVE flow rates and vacuum levels that could be expected for the second phase of the test, and

- Confirm that the SVE blower system was operating properly.

The second phase was an eight-day test planned at 01VEP0001 and well P-13 to determine:

- Changes in concentrations of VOCs, oxygen, and carbon dioxide in soil gas at the VMPs,

- SVE system flow rates and vacuum levels,

- VOC mass removal rates resulting from extracting soil gas from 01VEP0001 and well P-13, and

- The long-term effective treatment radius of a single, vertical VEW.

At the beginning of the second phase of testing, high extraction vacuums and low extraction flow rates (< 1 scfm) were observed at horizontal well P-13. These results suggested that the well screen at well P-13 was saturated, and vapor extraction using well P-13 could not be accomplished. Because well P-13 was found to be unsuitable for SVE, testing at this location was terminated. Horizontal well HW-2 was selected as a substitute for P-13. HW-2 is an SVE well that was installed in the vadose zone as part of a previous pilot testing effort performed by CDM (CDM, 1993). P-13 was disconnected from the SVE blower system, and well HW-2 was plumbed for SVE and used for the remainder of the pilot test. Although an array of VMPs had been installed previously by CDM in the vicinity of the screened interval of HW-2, these VMPs were inaccessible during the SVE pilot test at HW-2. Details of the pilot testing components, procedures, and results are presented in Sections 3.2 and 3.3.

3.2 DRILLING, SOIL SAMPLING, AND WELL INSTALLATION

3.2.1 Drilling, Soil Sampling, and Equipment Decontamination

Drilling, soil sampling, and the installation of four VMPs and one VEW took place on March 14 and 15, 2000 under the direction of Mr. John Hall, the Parsons ES field task manager. Drilling services were provided by Davis Environmental Drilling of Mustang, Oklahoma. Photographs of drilling activities are provided in Appendix A.

Boreholes for the VMPs and the VEW were advanced using a truck-mounted drill rig equipped with hollow-stem augers. Borehole diameters for the VMPs and the VEW were 8 inches and 10 inches, respectively. Prior to drilling, the drill rig and other downhole equipment and sampling tools were decontaminated using high-pressure steam. The first few feet of each boring were hand-dug to minimize the chance of damaging buried utilities. Core samples were collected continuously using 5-foot-long split-barrel sampling devices, beginning at a depth of approximately 3 feet below ground surface (bgs) and continuing to the total depth of each boring. Between core samples, the split-barrel sampler was cleaned with Alconox® detergent, followed successively by potable and distilled water rinses.

A lithologic description of each borehole was recorded based on the continuous core samples. Lithologic descriptions of the soil samples were performed in the field by the Parsons ES field task manager. Soil types were classified according to the Unified Soil Classification System and described in accordance with standard Parsons ES soil description format. The geologic boring logs are presented in Appendix B.

A portion of each core sample was used for field headspace screening of total volatile hydrocarbons (TVH) using a PID. The portion of the sample to be analyzed for TVH was placed in a clean 8-ounce self-sealing plastic bag and allowed to equilibrate for approximately 10 minutes. The bag was then pierced with the probe of the PID, and the headspace was analyzed for TVH. The soil headspace screening results are recorded on the geologic boring logs (Appendix B).

TVH headspace analyses were used to evaluate the relative concentrations of VOCs in the soil samples. From each borehole, one soil sample was collected from the depth of greatest apparent contamination (based on TVH screening) and was sent to Barringer Laboratories, Inc., located in Golden, Colorado for laboratory analysis of VOCs by USEPA Method SW8260B. A total of five subsurface soil samples and one composite sample of the drill cuttings were collected at the site and submitted for laboratory analysis. Subsurface soil samples submitted for laboratory VOC analysis were transferred directly from the split-spoon sampling device to pre-cleaned, laboratory-supplied glass jars. Sample bottles were sealed and labeled with the site name, borehole number, sample depth, date of collection, and other pertinent information. Sample bottles were then packaged to prevent breakage, placed in an ice-packed insulated shipping container, and shipped under standard chain-of-custody procedures to the laboratory. The composite soil sample was collected from the drums containing drill cuttings and was transferred directly to pre-cleaned laboratory-supplied containers. The composite sample was sent for laboratory analysis of VOCs by USEPA Method SW8260B; Toxicity Characteristic Leaching Procedure (TCLP) semivolatile compounds by USEPA Method SW1311/8270B; TCLP VOCs by USEPA Method SW1311/SW8240; TCLP metals, herbicides, pesticides, and polychlorinated biphenyls by USEPA Methods SW1311/6010B, SW1311/8081A, and SW8150B; and ignitability, reactivity, corrosivity, and pH. A trip blank sample (designated as TB-01) and an equipment rinseate sample (designated as EB-01) were also submitted to the laboratory with this shipment for analysis of VOCs by USEPA Method SW8260B. The trip blank sample was composed of distilled water in a 40-milliliter vial, and it was analyzed to determine if cross-contamination had occurred during sample shipment. The equipment rinseate sample consisted of distilled water that had been poured down the inside surface of the split-spoon samplers immediately following decontamination. The equipment rinseate sample was submitted to verify that the decontamination procedures used in the field were adequate to prevent cross-contamination.

3.2.2 Management of Investigation Derived Waste (IDW)

Soil cuttings from the VEW and VMP boreholes were placed in 55-gallon steel drums, labeled, and transported to the GWTP for temporary staging. A composite soil sample was collected from the drums and sent to the laboratory for waste characterization analysis. Based on laboratory analytical results of this sample, which are provided in Appendix C, soil cuttings were classified as Industrial Non-Hazardous Waste. On direction from the Base, the soil cuttings were transported to and disposed of at Waste Management's East Oak Landfill & Disposal Facility in Oklahoma City, Oklahoma, a landfill licensed by the State of Oklahoma to receive Industrial Non-Hazardous Waste. TetraTech, the base O&M contractor, performed the IDW disposal.

Decontamination water was containerized, transported to the GWTP, and discharged to the GWTP as directed by the treatment plant personnel.

3.2.3 Site Hydrogeology and Field Screening Results

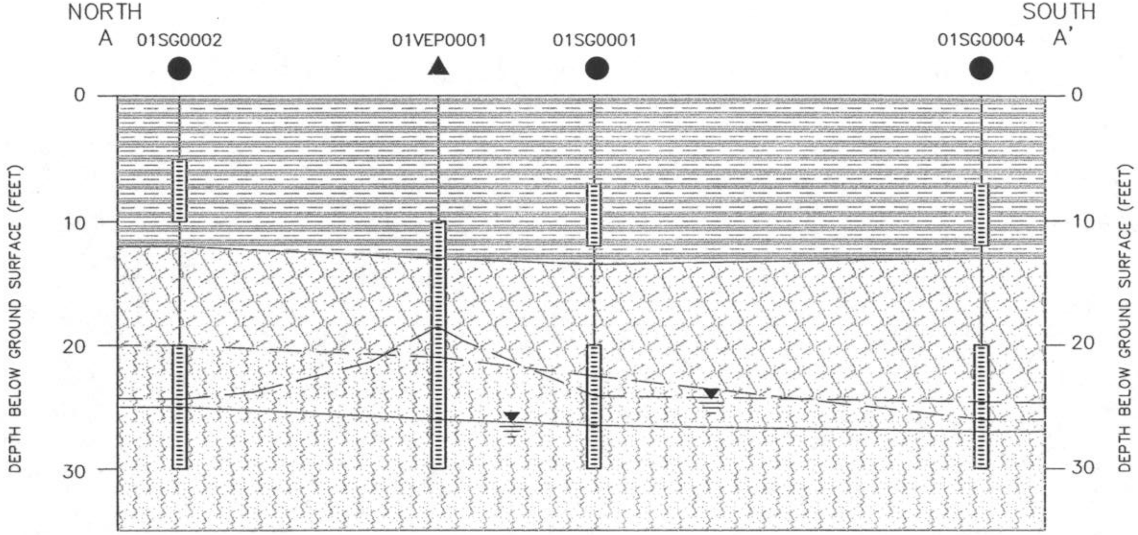
A hydrogeologic cross-section for the 01VEP0001 pilot testing area is presented on Figure 3.3. The trace of the hydrogeologic cross-section is shown on Figure 3.2. Soils at the pilot testing area generally consist of clay underlain by silty, clayey sand. The upper 12 to 13 feet of soil consists of slightly silty, red, moist clay containing thin sandy layers. At 01SG0003, the clay is overlain by 7 feet of wet, fine-grained sand that could be material used to fill the excavation of solvent tanks that were components of the Northwest Tank Area. Very fine-grained, silty sand and silt was encountered in the boreholes from the base of the clay to total depth. Silt content generally decreased, and grain size slightly increased with depth. Gravel ranging up to approximately 1.5 inches in diameter was encountered at 29.5 feet bgs in the 01SG0001 borehole. Hard, cemented layers were encountered in depth intervals from about 14 to 16 and 23 to 30 feet bgs in all boreholes.

Saturated soil was encountered during drilling at all of the boring locations at depths between about 25 and 27 feet bgs. Following the construction of 01VEP0001 and VMPs, the static water levels measured in 01VEP0001, the VMPs, and groundwater monitoring well 1-70B ranged from 25.5 o 26.0 feet bgs (Table 3.1). Each of the wells is flush-mounted, and the top of each casing is a few inches below the ground surface. The hydraulic gradient at the site could not be determined because the elevations of the top of well casing were not surveyed. However, groundwater in this vicinity of the Base historically has flowed to the northwest. Local groundwater flow directions have been altered by the operation of the groundwater extraction system.

Field TVH screening results for soil samples are presented in Appendix B with each geologic boring log. Field TVH screening results suggest relatively low VOC concentrations in site soils. Screening results for soil samples collected from ground surface to 25 feet bgs were near background levels, ranging from 4.2 to 19 ppmv. Soil samples collected from between 25 and 30 feet bgs had field screening results ranging from a minimum of 28 ppmv at 01SG0004 to a maximum of 150 ppmv at 01SG0001. Because samples collected from the 25- to 30-foot intervals were very moist to saturated, it is likely that the elevated headspace measurements are the result of VOCs dissolved in groundwater and not the result of VOCs in soils.

3.2.4 Soil Analytical Results

Five soil samples were collected and analyzed for VOCs by USEPA Method SW8260B. A summary of soil analytical results obtained during the sampling effort is presented in Table 3.2. A complete set of analytical results with ChOC forms is also



LITHOLOGIC DESCRIPTIONS:

CLAY

SANDY SILT

SILTY SAND

LEGEND:

01SG0002 SOIL VAPOR MONITORING POINT

01VEP0001 VAPOR EXTRACTION WELL

SCREENED INTERVAL

GROUNDWATER SURFACE PRIOR TO THE SVE PILOT TEST (MARCH. 16,2000)

LITHOLOGIC CONTACT (DASHED WHERE INFERRED)

GROUNDWATER SURFACE AT THE END OF THE SVE PILOT TEST (MARCH 27,2000)

VERTICAL SCALE 0 5 10

HORIZONTAL SCALE 0 5 10

FIGURE 3.3

HYDROGEOLOGIC CROSS SECTION A-A'

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Remedial Process Optimization
Tinker AFB, Oklahoma

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TABLE 3.1
CHANGES IN WATER LEVELS DURING SVE PILOT TEST
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

Location	Distance from 01VEP0001 (feet)	Water Levels (feet below ground surface)						Final Water Level Change [a/] (feet)
		Pre-Test 3/16/2000	3/18/2000	3/19/2000	3/20/2000	3/24/2000	End Test 3/27/2000	
01VEP0001	0	25.95	17.25	NM [b/]	15.9	18.25	18.05	7.9
01SG0001	12.3	25.95	NM	25.53	NM	24.63	24.63	1.3
01SG0002	21.0	25.45	NM	24.69	NM	24.59	24.59	0.9
01SG0003	25.6	25.70	NM	25.27	NM	24.77	24.67	1.0
01SG0004	43.2	26.05	NM	24.73	NM	24.53	24.53	1.5
1-70 B	11.3	25.85	26.28	27.00	26.46	26.01	25.91	-0.1

[a/] Positive value indicates higher water level; negative value indicates lower water level.
[b/] NM = Not measured.

TABLE 3.2
SUMMARY OF SOIL ANALYTICAL RESULTS
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

Analyte	Units	Sample Location - Depth (feet below ground surface)				
		01SG0001 (20-24)	01SG0002 (14-15)	01SG0003 (24-25)	01SG0004 (9-10)	01VEP0001 (13-14)
1,1,1-Trichloroethane	µg/kg[a/]	< 4[b/]	< 4	< 5	< 4	< 4
1,1,2,2-Tetrachloroethane	µg/kg	< 2	< 2	< 5	< 2	< 2
1,1,2-Trichloroethane	µg/kg	< 5	< 5	< 5	< 5	< 5
1,1-Dichloroethane	µg/kg	< 2	< 2	< 5	< 2	< 2
1,1-Dichloroethene	µg/kg	< 5	< 6	< 5	< 5	< 5
1,2,4-Trichlorobenzene	µg/kg	< 2	< 2	< 5	< 2	< 2
1,2,4-Trimethylbenzene	µg/kg	< 5	< 7	< 5	< 5	< 5
1,2-Dichlorobenzene	µg/kg	< 2	< 2	< 5	< 2	< 2
1,2-Dichloroethane	µg/kg	< 3	< 3	< 5	< 3	< 3
1,2-Dichloropropane	µg/kg	< 2	< 2	< 5	< 2	< 2
1,3,5-Trimethylbenzene	µg/kg	< 3	< 3	< 5	< 3	< 3
1,3-Dichlorobenzene	µg/kg	< 5	< 6	< 5	< 5	< 5
1,4-Dichlorobenzene	µg/kg	< 2	< 2	< 5	< 2	< 2
Benzene	µg/kg	< 2	< 2	< 5	< 2	< 2
Bromomethane	µg/kg	< 5	< 5	< 10	< 5	< 5
Carbon tetrachloride	µg/kg	< 5	< 10	< 5	< 5	< 5
Chlorobenzene	µg/kg	< 2	< 2	< 5	< 2	< 2
Chloroethane	µg/kg	< 5	< 5	< 10	< 5	< 5
Chloroform	µg/kg	< 2	< 2	< 5	< 2	< 2
Chloromethane	µg/kg	< 7	< 7	< 10	< 7	< 7
cis-1,2-Dichloroethene	µg/kg	< 5	< 6	< 5	< 5	< 5
cis-1,3-Dichloropropene	µg/kg	< 5	< 5	< 5	< 5	< 5
Ethylbenzene	µg/kg	< 3	< 3	< 5	< 3	< 3
m,p-Xylene	µg/kg	< 5	< 10	< 5	< 5	< 5
Methylene chloride	µg/kg	51 B[c/ d/]	47 B	20	65 B	67 B
o-Xylene	µg/kg	< 5	< 5	< 5	< 5	< 5
Styrene	µg/kg	< 2	< 2	< 5	< 2	< 2
Tetrachloroethene	µg/kg	< 5	< 7	< 5	< 5	< 5
Toluene	µg/kg	< 5	< 5	< 5	< 5	< 5
trans-1,3-	µg/kg	< 5	< 5	< 5	< 5	< 5
Trichloroethene	µg/kg	< 5	< 10	< 5	< 5	< 5
Vinyl chloride	µg/kg	< 9	< 9	< 10	< 9	< 9

[a/] µg/kg = micrograms per kilogram.
[b/] < = Compound was analyzed for but not detected at the listed reporting limit.
[c/] Values shaded are above the reporting limit.
[d/] B = Analyte was detected in method blank.

provided in Appendix C. The only VOC that was detected was methylene chloride, at concentrations ranging from 20 to 67 μg/kg. Methylene chloride was also detected in the method blanks for four of the five samples, suggesting that the methylene chloride may have been introduced to the samples in the laboratory. These analytical results indicate that there are no residual VOCs present in vadose zone soils in the 01VEP0001 pilot testing area.

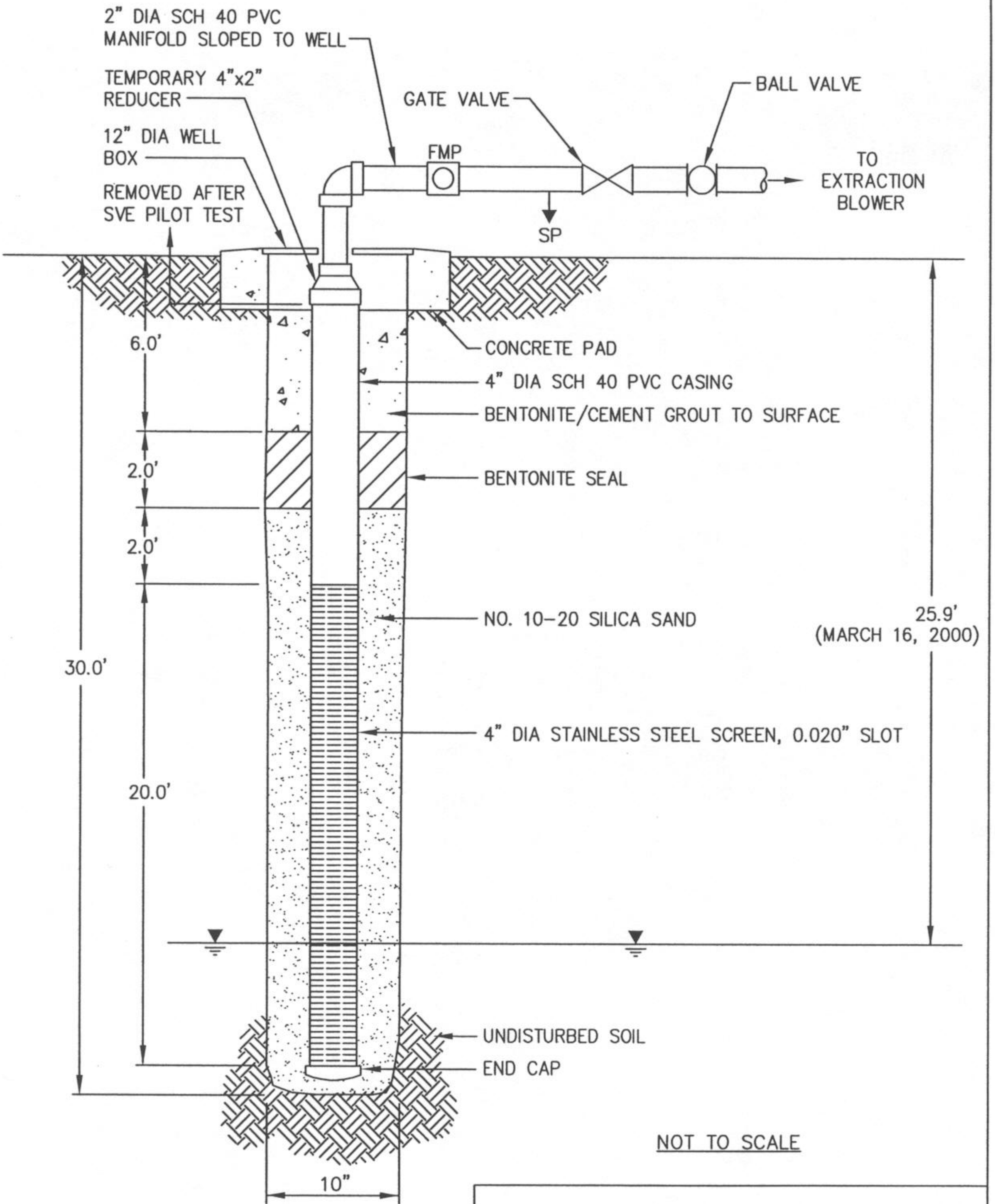
For quality assurance/quality control (QA/QC) purposes, a trip blank sample (designated as TB-01) and an equipment rinseate sample (designated as EB-01) were also analyzed for VOCs by USEPA Method SW8260B. Analytical results are provided in Appendix C. There were no VOCs detected in either sample, indicating that cross-contamination had not occurred during sample shipment and handling, and that equipment decontamination procedures used in the field were acceptable.

3.2.5 Vapor Extraction Well Installation

01VEP0001 was installed east of Building 933, which houses an emergency generator for the flightline, near the center of the pilot testing area, as shown on Figures 3.1 and 3.2. Figure 3.4 illustrates the construction details for 01VEP0001. 01VEP0001 was constructed in a 10-inch diameter borehole using 4-inch-diameter, schedule 40 polyvinyl chloride (PVC) casing and 0.02-inch wire-wound stainless steel screen. The total depth of 01VEP0001 is 30 feet, with a screened interval of 20 feet extending from 10 to 30 feet bgs. The annular space between the well casing and borehole was filled with 10-20 silica sand from the bottom of the borehole to approximately 2 feet above the top of the well screen. A 2-foot-thick layer of granular bentonite was placed above the sand, hydrated in place with potable water, and overlaid with a cement/bentonite grout seal. The top of the well casing was terminated about 4 inches below grade. The surface completion of 01VEP0001 includes a 12-inch-diameter, flush-mounted well box set in a concrete pad matching the grade of the existing asphalt pavement.

3.2.6 Soil Vapor Monitoring Point Installation

Four multi-depth VMPs (01SG0001, 01SG0002, 01SG0003, and 01SG0004) were installed at distances of 12.3, 21.0, 25.6, and 43.2 feet from 01VEP0001, respectively, at locations shown on Figures 3.1 and 3.2. The VMPs were installed at varying distances and radial directions from 01VEP0001 to allow for an accurate determination of the radius of influence during the SVE pilot test. Construction details for the VMPs are shown on Figure 3.5. Each VMP was constructed in an 8-inch diameter borehole using two sections of 1-inch-diameter schedule 40 PVC well screen and casing. The VMP screens were placed at different depths (Figure 3.5) to allow for discrete-level soil vapor monitoring. The shallow and deep screened intervals are identified throughout this report using the suffixes "S" and "D", respectively (e.g., 01SG0001-S describes the screened interval at 01SG0001 extending from 7 to 12 feet bgs, and 01SG0001-D is used to identify the screened interval at 01SG0001 extending from 20 to 30 feet bgs). A filter pack consisting of 10-20 silica sand was placed around the deep VMP screen, and granular bentonite was placed above the sand pack and hydrated in place to prevent short-circuiting between the VMP depth intervals. A second filter pack, also consisting of 10-20 silica sand, was placed in the annular space around the shallow MP screen and a second granular bentonite seal was placed above the sand pack and hydrated in place to prevent short-circuiting between the atmosphere and the shallow screened interval. At



LEGEND

FMP – FLOW MONITORING POINT
SP – SAMPLE POINT

FIGURE 3.4

VAPOR EXTRACTION WELL DETAIL

Building 3001
Remedial Process Optimization
Tinker AFB, Oklahoma

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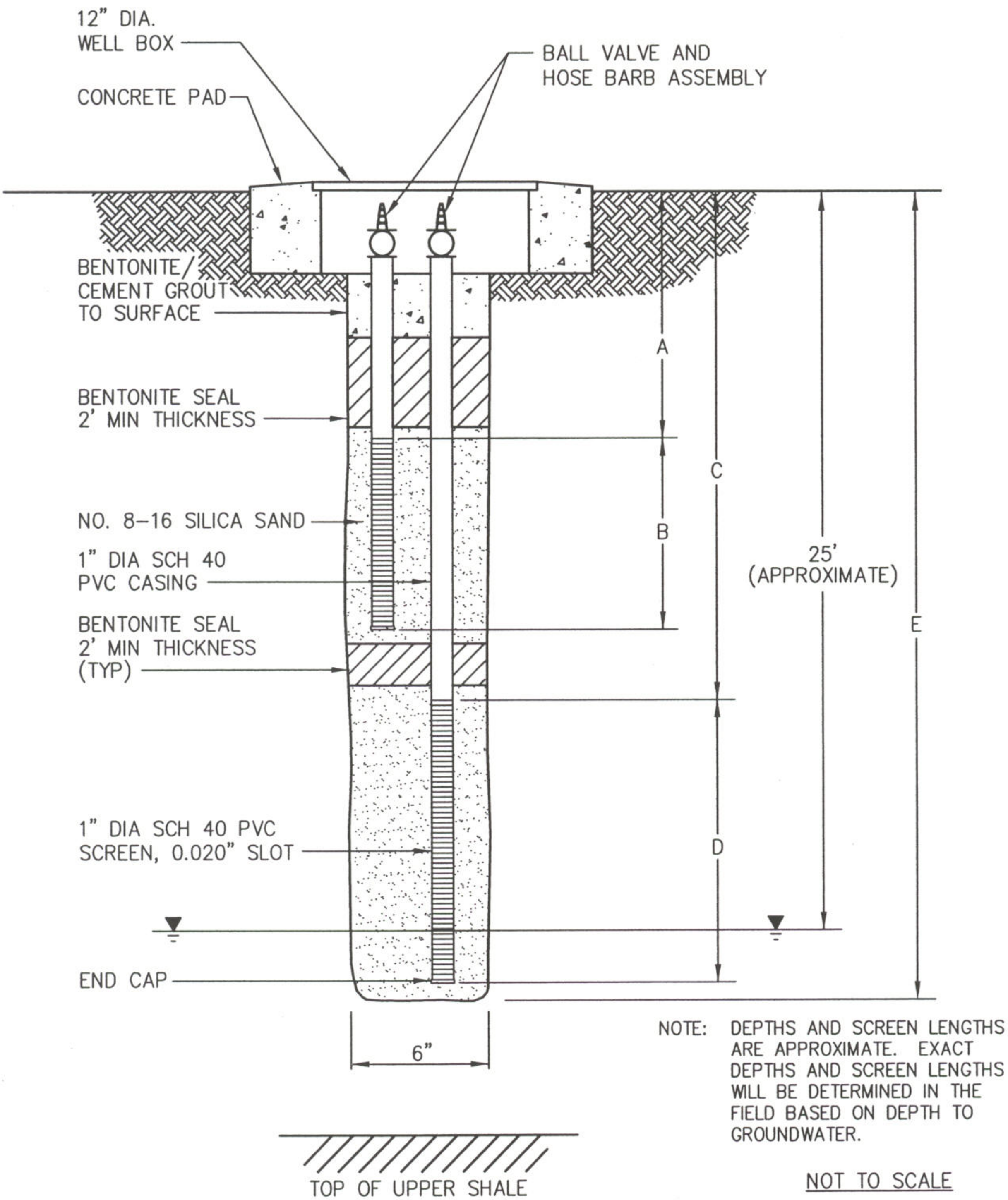

NOTE: DEPTHS AND SCREEN LENGTHS ARE APPROXIMATE. EXACT DEPTHS AND SCREEN LENGTHS WILL BE DETERMINED IN THE FIELD BASED ON DEPTH TO GROUNDWATER.

NOT TO SCALE

	A	B	C	D	E
01SG0001	7.0'	12.0'	20.0'	30.0'	30.0'
01SG0002	5.0'	10.0'	20.0'	30.0'	30.0'
01SG0003	10.0'	15.0'	20.0'	30.0'	30.0'
01SG0004	7.0'	12.0'	20.0'	30.0'	30.0'

FIGURE 3.5

VAPOR MONITORING POINT DETAILS

Building 3001
Remedial Process Optimization
Tinker AFB, Oklahoma

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the top of each VMP casing, a ball valve and a 3/16-inch hose barb were installed below grade. The surface completion of each VMP consists of a 12-inch-diameter, flush-mounted metal well protector set in a concrete pad.

3.2.7 Horizontal Well P-13

P-13 is an existing horizontal groundwater extraction well originally installed beneath Building 3001 by the US Army Corps of Engineers in 1992. As shown on Figure 3.6, the well was constructed with 200 feet of 6 5/8-inch-diameter, 0.02-inch-slotted-high density polyethylene (HDPE) screen with an inner 4-inch diameter 0.01-inch-slot stainless steel screen. This well was damaged and replaced in March 1997.

3.2.8 Horizontal Well HW-2

As discussed in Section 1.3.8, HW-2 was installed in 1991 to evaluate SVE using a horizontal well (CDM, 1993). HW-2 was constructed using 70 feet of 6-inch-diameter PVC screen with 0.012-inch slots. The screen was installed beneath Building 3001 at approximately 14 feet bgs. Construction details of HW-2 are shown on Figure 3.7.

3.3 SOIL VAPOR EXTRACTION PILOT TESTING AND RESULTS

Descriptions of the blower system and discussion of the pilot testing results are presented in this section.

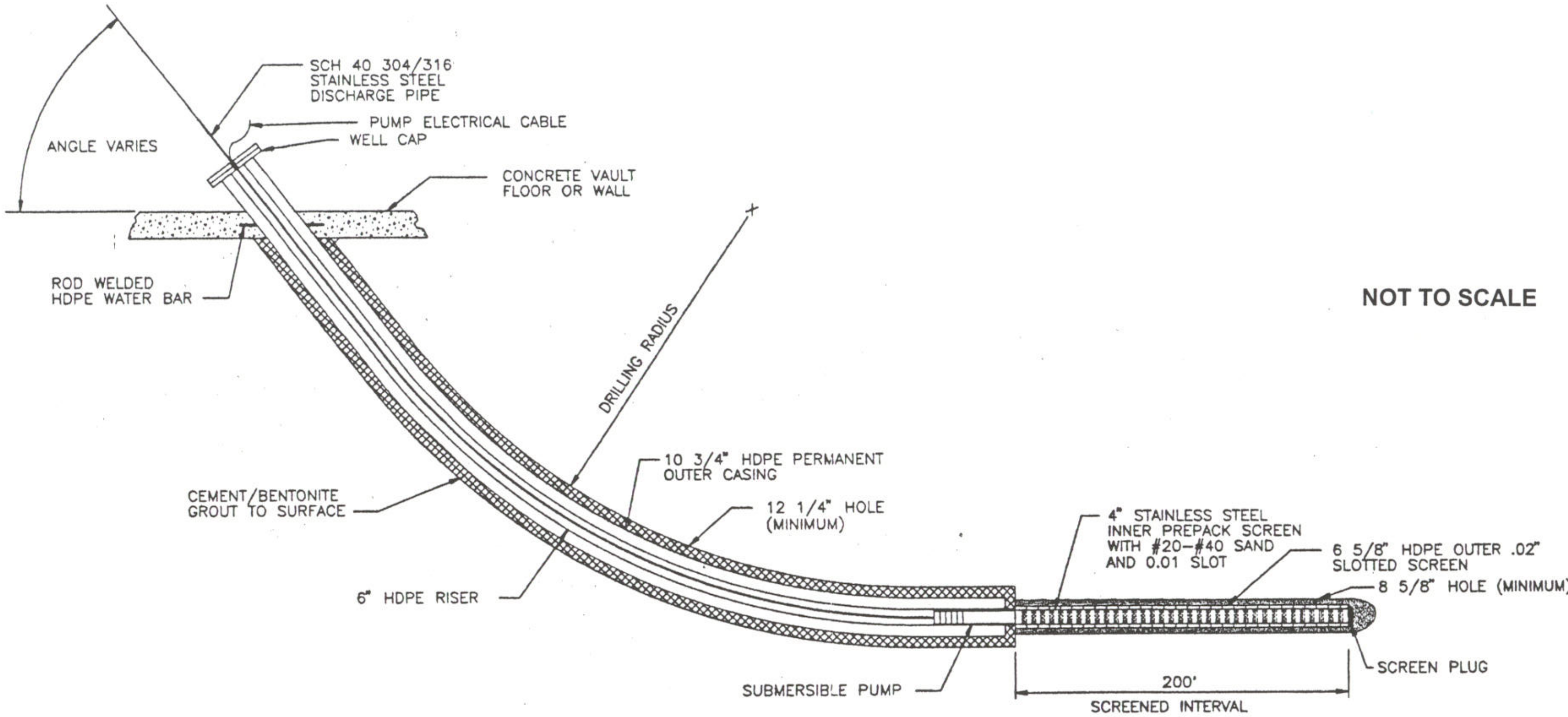
3.3.1 Soil Vapor Extraction Blower, Piping, and Instrumentation

A 10-horsepower Roots® positive-displacement blower unit was used for SVE pilot testing at Building 3001. The blower is rated for a flow rate of 107 scfm at a vacuum of 200 inches of water. The blower system included a moisture separator, inlet filter, inlet and outlet silencers, and a vacuum-relief valve. The blower was energized by a 17-kilovolt (kv) diesel-powered generator. The configuration, instrumentation, and specifications for the pilot test blower are shown on Figure 3.8.

The piping manifold connecting 01VEP0001, P-13, and HW-2 to the blower system consisted of 2-inch-diameter, schedule 40 PVC pipe and fittings. No more than two wells were connected to the blower system at any given time. Soil vapor flow rates from each extraction well were adjusted using manual gate and ball valves. Pressure and temperature indicators were placed in the piping connecting the manifold to the blower system. Pressure, air flow, and soil vapor measurement ports were installed in the piping leading from each extraction well (Figure 3.8).

3.3.2 Baseline Soil Gas Chemistry

On March 16, 2000, prior to initiating the SVE pilot test at 01VEP0001, soil gas samples were collected from each of the VMPs and 01VEP0001 and field-analyzed for oxygen, carbon dioxide, and VOC concentrations using portable gas analyzers, as described in the work plan (Parsons ES, 2000). On March 21, 2000, a soil gas sample was also collected from HW-2, and field-analyzed using portable gas analyzers prior to initiating SVE. Several casing volumes were purged from each VMP and VEW to remove non-representative soil gas prior to collecting each sample for analysis.



NOT TO SCALE

FIGURE 3.6

P-13 CONSTRUCTION DETAIL

Building 3001
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Source: B&V, 1992

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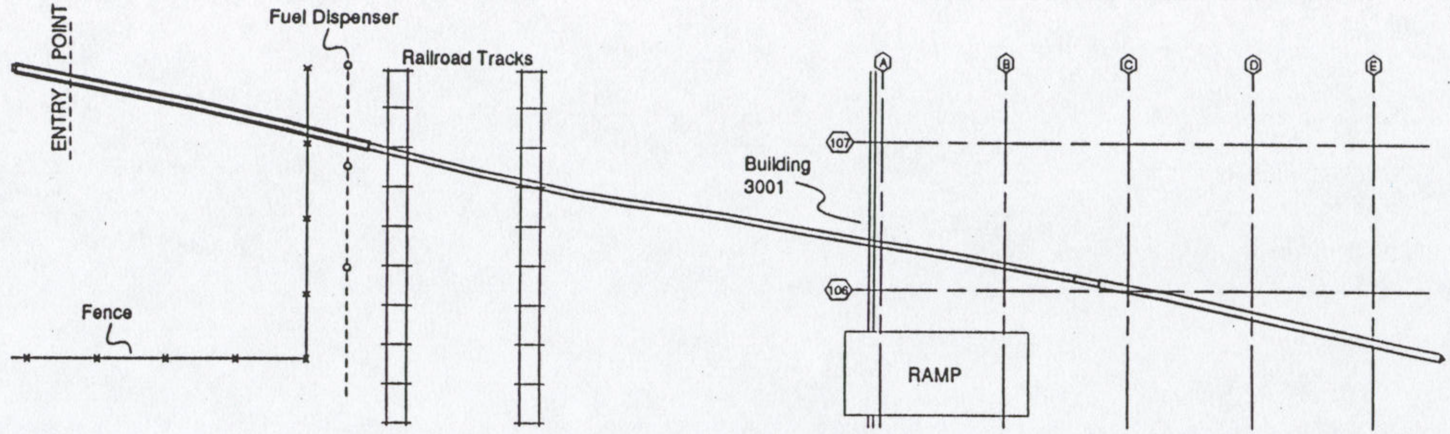
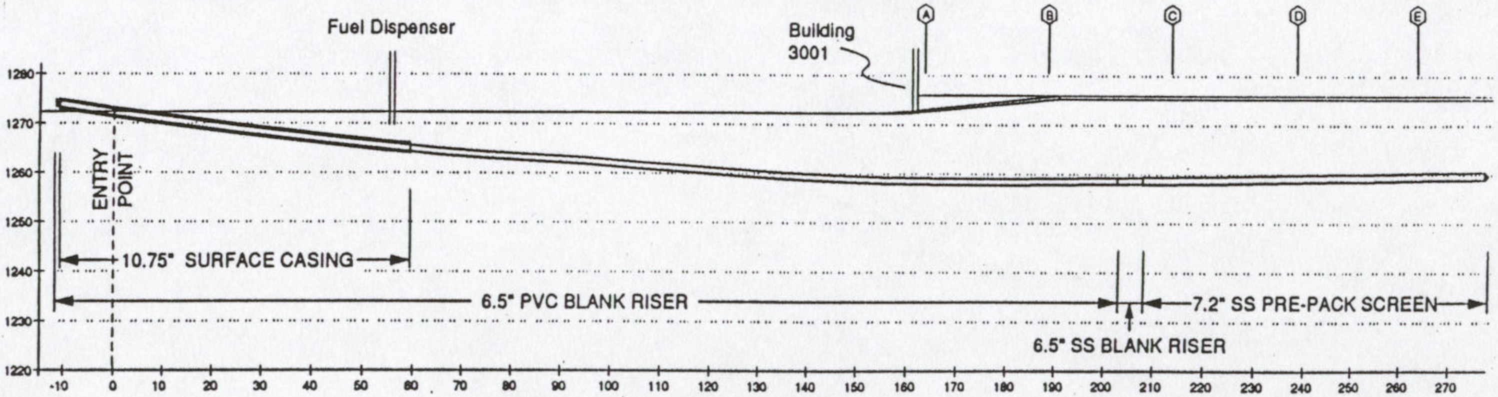


PLAN VIEW OF HW2



CROSS SECTION ALONG HW2

Approximate Scale: 1 in = 38 ft

Source: CDM, 1993

FIGURE 3.7

HW-2 WELL CONSTRUCTION DETAIL

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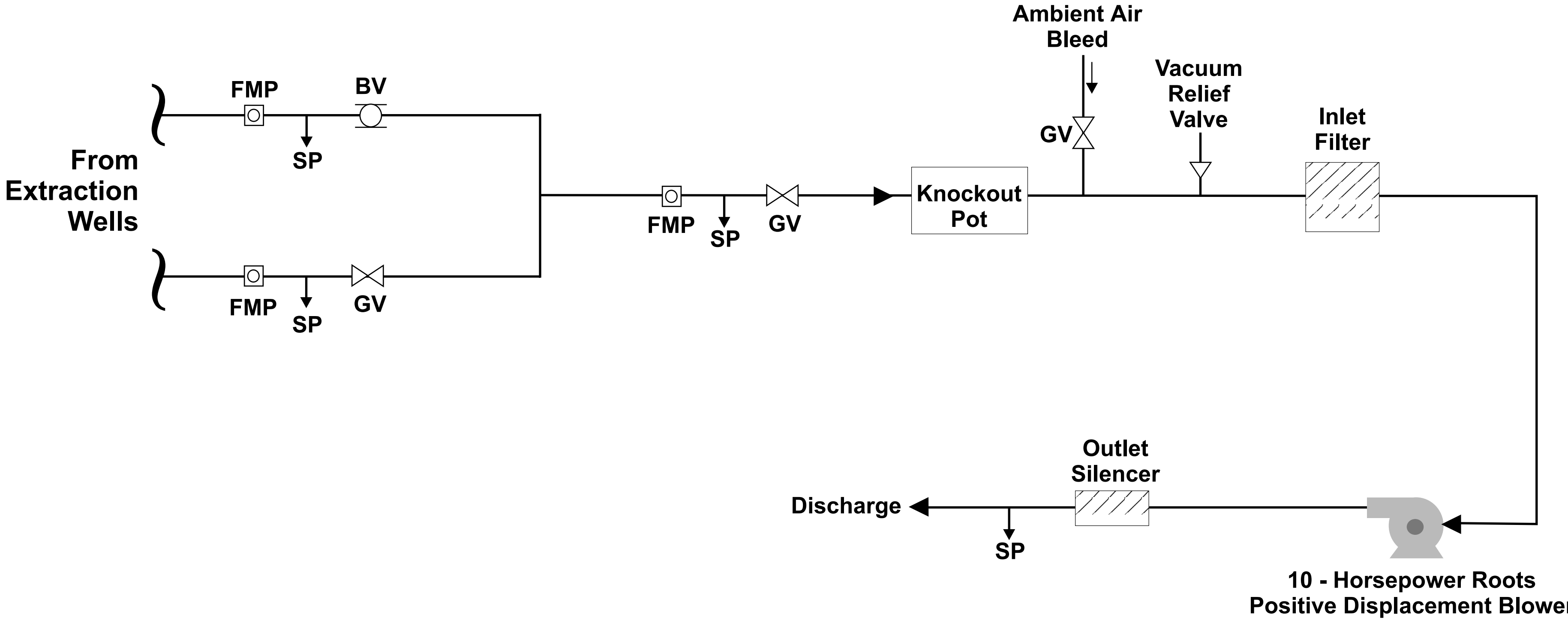

Legend

FMP	Flow Monitoring Port (both flow and temperature)
SP	Sample Port (both air quality samples and pressure/vacuum)
GV	Gate Valve
BV	Ball Valve

FIGURE 3.8

PILOT TEST VAPOR EXTRACTION SYSTEM

Building 3001
Remedial Process Optimization
Tinker AFB, Oklahoma

PARSONS
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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Additionally, soil gas samples for laboratory analysis were collected from 01VEP0001, 01SG0001-D and 01SG0003-D, and HW-2 to verify the field screening measurements and to determine the concentrations of specific VOCs in the soil vapor. Soil gas samples for laboratory analyses were collected in 1-liter SUMMA canisters, and were analyzed for VOCs by USEPA Method TO-14. Baseline soil gas field screening and laboratory results are summarized in Table 3.3. The soil vapor analytical results are provided in Appendix D.

The highest contaminant concentrations in the baseline soil vapor sampling effort were observed at HW-2 (Table 3.3). TCE, PCE, and *cis*-1,2-DCE were detected at concentrations of 3,000 ppmv, 2,500 ppmv, and 120 ppmv, respectively, at HW-2. These VOC concentrations range from nearly one to two orders of magnitude higher than those observed in the 01VEP0001 pilot testing area, indicating that the screened interval of HW-2 has been installed in a significant source of VOC contamination. Oxygen was depleted at HW-2 (13.2 percent, in comparison with the atmospheric concentration of 20.8 percent) and carbon dioxide concentrations were elevated (7.8 percent), indicating that some level of aerobic hydrocarbon biodegradation may be occurring in soils in the vicinity of the screened interval of HW-2.

In the 01VEP0001 pilot testing area, total laboratory VOC concentrations were fairly uniform, ranging from 548 to 573 ppmv. The VOC present at the highest concentration was TCE, which occurred at concentrations ranging from 360 to 530 ppmv in samples collected from 01VEP0001, 01SG0001-D, and 01SG0003-D. PCE was the VOC present at the second highest concentrations, ranging from 22 to 72 ppmv at points sampled in the 01VEP0001 pilot testing area. *Cis*-1,2-DCE was also present, at concentrations ranging from 6 to 12 ppmv. Field VOC concentrations in the 01VEP0001 pilot testing area ranged from 18.5 ppmv at 01SG0004-S to 260 ppmv at 01SG0001-D. Based on observations made in the field and a comparison of field to laboratory VOC concentrations, it is believed that the field VOC analyzer was not functioning properly during the baseline soil gas sampling. Oxygen concentrations were fairly high at 01VEP0001 and the VMPs, ranging from 18.0 to 20.6 percent at all locations except 01SG0002-S. Oxygen was depleted at 01SG0002-D (10.0 percent, in comparison with the atmospheric concentration of 20.8 percent) and carbon dioxide concentrations were slightly elevated (1.9 percent), indicating that some degree of aerobic hydrocarbon biodegradation may be occurring in soils in this vicinity. Carbon dioxide concentrations were also slightly elevated at 01SG0002-D (Table 3.3).

Although a vapor sample was also collected from groundwater extraction well P-13 for field-screening and laboratory analysis prior to the SVE pilot test, it is believed that these results are not representative of actual subsurface conditions. As shown on Table 3.3, the VOC concentrations at P-13 are significantly lower than those observed at other sampling locations, and the oxygen concentration was at the atmospheric level of 21 percent. High vacuums accumulated in the well casing during the purging of P-13, indicating that vapor flow through the well was obstructed, encouraging leakage of atmospheric air into the casing through leaks at the wellhead. It is believed that the screened interval of well P-13 was submerged below the water table over the duration of this pilot test (See Section 3.3.4 for additional discussion of results for well P-13).

TABLE 3.3
BASELINE SOIL GAS CHEMISTRY
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

Sample Location	01VEP0001	P-13	HW-2	01SG0001-S	01SG0001-D	01SG0002-S	01SG0002-D	01SG0003-S	01SG0003-D	01SG0004-S	01SG0004-D
Sample Depth (feet below ground surface)	10-30	30	14	7-12	20-30	5-10	20-30	10-15	20-30	7-12	20-30
Sample Date	03/16/00	03/19/00	03/21/00	03/16/00	03/16/00	03/16/00	03/16/00	03/16/00	03/16/00	03/16/00	03/16/00
Laboratory Analytical Results [a/b/]											
1,2-Dichlorobenzene (ppmv)	2.1	0.14[c/]	< 11[d/]	----[e/]	< 2.1	----	----	----	< 2.1	----	----
1,2-Dichloroethane (ppmv)	< 2	< 0.085[c/]	13	----	< 2.1	----	----	----	< 2.1	----	----
1,4-Dioxane (ppmv)	< 8	0.59[c/]	< 43	----	< 8.5	----	----	----	< 8.4	----	----
2-Butanone (Methyl Ethyl Ketone) (ppmv)	150	2[c/]	< 43	----	< 8.5	----	----	----	11	----	----
Chlorobenzene (ppmv)	2.2	< 0.085[c/]	< 11	----	< 2.1	----	----	----	< 2.1	----	----
cis-1,2-Dichloroethene (ppmv)	12	0.27[c/]	120	----	6.4	----	----	----	6	----	----
Trichloroethene (ppmv)	360	26[c/]	3,000	----	530	----	----	----	470	----	----
Tetrachloroethene (ppmv)	22	17[c/]	2,500	----	37	----	----	----	72	----	----
Total VOCs (ppmv)	548.3	46[c/]	5,633	----	573.4	----	----	----	559	----	----
Field Screening Results											
Oxygen (percent)	18.0	21[c/]	13.2	20.6	20.2	10.0	18.2	20.0	19.6	20.0	19.3
Carbon Dioxide (percent)	0.9	----	7.8	0.6	0.8	1.9	2.2	0.5	1.2	0.7	0.8
Total VOCs (ppmv)	225.0	31.9[c/]	83.1	190.0	260.0	190.0	180.0	145.0	220.0	18.5	94.6

[a/] ppmv = parts per million, volume per volume; VOCs = volatile organic compounds.
[b/] Soil gas analyzed by USEPA Method TO-14. The only analytes presented are those for which at least one concentration above the detection limit was noted. See Appendix D for a full set of soil vapor analytical results.
[c/] Results are not representative of actual subsurface conditions. The screened interval of well P-13 was submerged beneath the water table during sampling.
[d/] < = The compound was analyzed for but not detected at the listed reporting limit.
[e/] ---- = not analyzed.

3.3.3 SVE Pilot Test at 01VEP0001

Three separate SVE pilot tests were performed in two phases at 01VEP0001 during this effort. Two preliminary air permeability/startup tests were conducted in an initial testing phase on March 18 and 19, 2000 to determine soil permeability and the optimal soil gas extraction rates for the subsequent second-phase test. The second phase of SVE pilot testing at 01VEP0001 was conducted between March 19 and 27, 2000. A summary of SVE pilot testing operations is presented in Table 3.4. Test parameters and results are summarized in Table 3.5.

3.3.3.1 Air Permeability/Startup Tests at 01VEP0001

Two air permeability/startup tests were conducted on March 18 and 19, 2000 by extracting soil gas from 01VEP0001 and measuring the vacuum response at the VMPs. The first test was conducted for a duration of 56 minutes at an average flow rate of 18.3 scfm. Vacuum increased from 75 inches of water to 184 inches of water during the test. The second test was conducted for a duration of 290 minutes (4.8 hours) at an average flow rate of 6.6 scfm, with vacuum beginning at 18 inches of water and ending at 99 inches of water. An attempt was made to perform each test at a constant extraction flow rate. However, rising water elevations in 01VEP0001, caused by the high extraction vacuum, resulted in decreasing flow rates during the latter part of each test. Because SVE flow rates and the vacuums measured at the VMPs did not reach equilibrium (i.e., steady state) conditions during these two tests, it was not possible to calculate the air permeability of soils. Soil permeability estimates were therefore calculated using data from the longer duration test at 01VEP0001 (described in Section 3.3.3.2), when equilibrium conditions were approached.

Vacuum was measured at all VMP screened intervals during both start-up tests. During the first test, maximum vacuum responses measured at the most distant VMP (01SG0004, located 43.2 feet from 01VEP0001) were 5.1 inches of water at the shallow screened interval and 7.0 inches of water at the deep screened interval. Maximum vacuums measured at the shallow and deep screens of 01SG0004 during the second test were 13 and 25 inches of water, respectively.

The vacuum response data were inconsistent between the two tests. Lower vacuum responses were measured during the first test, which was conducted at a higher average flow rate and vacuum than the second test. The lower vacuums likely were attributable to the rapidly rising water levels in 01VEP0001 during the first test, which reduced air flow to the deeper vadose zone. Also, the first test was of shorter duration than the second test, allowing less time for peak vacuum response at the VMPs. Because extraction flow rates continued to decrease and vacuums continued to increase during these two tests, it was determined that the longer duration test should be performed using lower flow rates and extraction vacuums.

3.3.3.2 SVE Pilot Test at 01VEP0001

Test Parameters and Procedures. The second-phase SVE test at 01VEP0001 was started on 19 March 2000 and was conducted for 188 hours (approximately 8 days). This test was conducted by extracting soil gas from 01VEP0001 at an average flow rate of 3.1 scfm and an average vacuum of 87 inches of water. The blower system was adjusted

TABLE 3.4
SUMMARY OF SVE PILOT TEST OPERATIONS
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

Extraction Location	Extraction Dates	Test Duration (hours)	Average Extraction Flow Rate [a] (scfm) [b]	Average Extraction Vacuum [a] (inches of water)
01VEP0001				
Preliminary Test 1	3/18/2000	1	18.3	166
Preliminary Test 2	3/19/2000	4.8	6.6	54
Long-Term Test	3/19/2000 - 3/27/2000	188	3.1	87
P-13				
Long-Term Test	3/19/2000 - 3/21/2000	54	0.5	174
HW-2				
Long-Term Test	3/21/2000 - 3/27/2000	140	40.7	83

[a] Time-weighted average.

[b] scfm = standard cubic feet per minute.

TABLE 3.5
VACUUM RESPONSE AT MONITORING POINTS
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

Preliminary Test 1 (non-equilibrium conditions)

Date: 3/18/00

Test Parameters

Extraction Point:	**01VEP0001**
Extraction Vacuum:	75 - 184 inches of water
Flow Rate:	16 - 26 scfm[a/] Average: 18.3 scfm
Test Duration:	56 minutes

Location	Distance From 01VEP0001 (feet)	Screen Depth (feet bgs[b/])	Elapsed Time to Maximum Vacuum (minutes)	Maximum Vacuum Response (inches of water)
01SG0001	12.3	S[c/] (7 - 12)	9.8	11.5
		D[d/] (20 - 30)	15	27
01SG0002	21.0	S (5 - 10)	49.8	21
		D (20 - 30)	50	22
01SG0003	25.6	S (10 - 15)	50.5	27
		D (20 - 30)	50.8	22
01SG0004	43.2	S (7 - 12)	50	5.1
		D (20 - 30)	50	7

Preliminary Test 2 (non-equilibrium conditions)

Date: 3/19/00

Test Parameters

Extraction Point:	**01VEP0001**
Extraction Vacuum:	18 - 99 inches of water Average: 54 inches of water
Flow Rate:	4.6 - 7.6 scfm Average: 6.6 scfm
Test Duration:	290 minutes

Location	Distance From 01VEP0001 (feet)	Screen Depth (feet bgs)	Elapsed Time to Maximum Vacuum (minutes)	Maximum Vacuum Response (inches of water)
01SG0001	12.3	S (7 - 12)	140	2.5
		D (20 - 30)	290	25
01SG0002	21.0	S (5 - 10)	290	29
		D (20 - 30)	290	30
01SG0003	25.6	S (10 - 15)	290	31
		D (20 - 30)	290	30
01SG0004	43.2	S (7 - 12)	165	13
		D (20 - 30)	140	25

TABLE 3.5 (continued)
VACUUM RESPONSE AT MONITORING POINTS
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

Long-Term Test (equlibrium conditions)
Dates: 3/19/00 - 3/27/00
Test Parameters

Extraction Point:	**01VEP0001**
Extraction Vacuum:	Average 87 inches of water
Flow Rate:	Average 3.1 scfm
Test Duration:	188 hours

Location	Distance From 01VEP0001 (feet)	Screen Depth (feet bgs)	Equlibrium Vacuum Response (inches of water)
01SG0001	12.3	S (7 - 12)	18.0
		D (20 - 30)	19.5
01SG0002	21.0	S (5 - 10)	15.5
		D (20 - 30)	20.0
01SG0003	25.6	S (10 - 15)	23.8
		D (20 - 30)	20.8
01SG0004	43.2	S (7 - 12)	0.5
		D (20 - 30)	0.7

[a/] scfm = standardized cubic feet per minute.
[b/] feet bgs = feet below ground surface.
[c/] S = shallow VMP screened interval.
[c/] D = deep VMP screened interval.

during the early part of the test to determine the optimum soil gas extraction flow rate and vacuum. Throughout the test, vacuum response and water levels at the VMPs, and extraction flow rates and vacuum at 01VEP0001, were periodically measured and recorded. Soil gas samples from the VMPs and 01VEP0001 also were periodically field screened for O_2, CO_2, and VOC concentrations. In addition, soil gas samples for laboratory VOC analysis were periodically collected from 01VEP0001 to determine the VOC mass removal rates that were being achieved. Samples for laboratory analysis were collected in 1-liter SUMMA® canisters and submitted for analysis using USEPA Method TO-14. The laboratory analytical data for VOCs are provided in Appendix D.

Extraction Flow Rates and Vacuums. SVE rates ranged between 0.7 and 5.4 scfm at vacuums ranging between 18 and 143 inches of water. The average flow rate was 3.1 scfm at an average vacuum of 87 inches of water. The maximum sustainable flow rate of approximately 3 scfm was obtained using extraction vacuums between approximately 61 and 95 inches of water. Flow rates from 01VEP0001 versus SVE system vacuum are illustrated on Figure 3.9. The optimal SVE flow rate was 3.1 scfm at an average vacuum of 87 inches of water. Higher flow rates could not be maintained because the required higher extraction vacuums caused the water level in 01VEP0001 to rise, thereby submerging much of the well screen. Vacuums both higher and lower than the optimum range of 61 and 95 inches of water resulted in lower flow rates. A total of approximately 35,000 cubic feet of soil gas was extracted during this test.

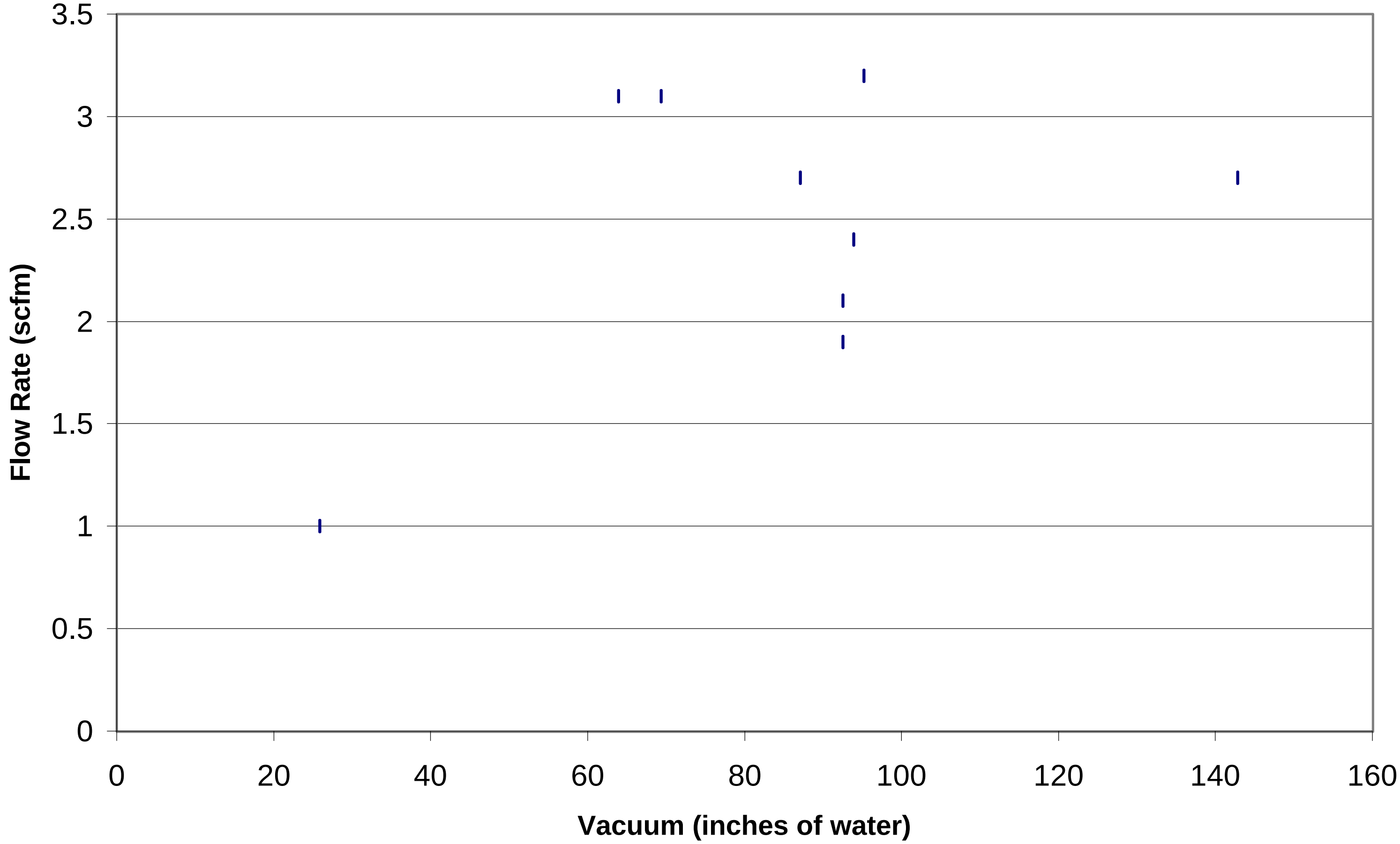
Permeability and Radius of Influence. Pilot test data collected during the long-duration test were used to estimate the radius of vacuum influence of 01VEP0001 and the air permeability for site soils. The steady-state extraction rate and vacuum for 01VEP0001, and vacuum responses measured at each VMP are presented on Table 3.5. Steady-state vacuums measured at 01SG0004, the VMP farthest from 01VEP0001, were 0.5 and 0.7 inches of water, respectively, at the shallow (7 to 12 feet bgs) and deep (20 to 30 feet bgs) screened intervals. These data suggest that the effective treatment radius for a vertical VEW exceeds the distance between 01VEP0001 and 01SG0004 (43 feet) in both deep and shallow vadose zone soils.

As shown in Table 3.5, there was little decrease in vacuum response with distance between 01VEP0001 to 01SG0003, and a much greater vacuum decrease between 01SG0003 and 01SG0004. Because 01SG0004 is located near the edge of a backfilled excavation, low vacuum response measured in this VMP is likely the result of short-circuiting of soil vapor flow through the more permeable excavation backfill. Therefore, the radius of influence of a single, vertical SVE well in an area with undisturbed soils would probably be significantly greater than 43 feet indicated by this pilot test.

The steady-state method was used to calculate the air permeability of site soils. Using the average extraction flow rate of 3.1 scfm, an average vacuum of 87 inches of water, and a radius of influence of 43 feet, a soil gas permeability value of approximately 0.4 Darcy, typical for fine-grained, silty sand, was calculated for this site.

Water Levels. Water levels were measured in 01VEP0001, groundwater monitoring well 1-70B, and the deep screened intervals of the VMPs before, during, and after the SVE pilot test to determine the amount of groundwater mounding resulting from the vacuum induced in the vadose zone. Groundwater levels are summarized in Table 3.1, and increases in groundwater levels observed during the pilot test are illustrated on the

FIGURE 3.9
SVE FLOW RATE FROM 01VEP0001 VERSUS SVE SYSTEM VACUUM
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA



hydrogeologic cross-section shown on Figure 3.3. Groundwater levels increased at 01VEP0001 and all of the VMPs, and decreased at groundwater monitoring well 1-70B during the SVE pilot test. At the completion of the test, water levels increased 7.9 feet in 01VEP0001 and between 0.9 and 1.5 feet in the VMPs. In contrast, water levels measured at well 1-70B (which was open to the atmosphere) decreased 0.1 feet. These new water levels are the equilibrium piezometric surface associated with the applied vacuum. Rising water levels measured in 01VEP0001 reduced the air permeability of the soils, as demonstrated by the observed decreased flow rates at high extraction vacuums.

VOC Mass Removal. Concentrations of VOCs in the extracted soil vapor were measured throughout the pilot test to estimate changes in VOC concentrations with time, VOC mass removal rates with time, and the total mass of VOCs removed during the testing. Soil vapor samples were collected and field-screened for total VOCs using a PID, and additional soil vapor samples were also collected for laboratory analysis to confirm PID field screening results and quantify VOC removal rates and emissions. Field and laboratory analytical results of soil gas samples collected during the long-duration SVE testing are presented in Table 3.6.

Table 3.7 summarizes the concentrations and the cumulative mass removed versus time for TCE, PCE, and total VOCs in 01VEP0001. The cumulative masses of TCE, PCE, and total VOCs removed from the subsurface versus time are also plotted on Figures 3.10, 3.11, and 3.12, respectively. The mass removal was calculated using the following equation:

$$\text{Total Mass Removed} = \frac{C\,[\text{ppmv}] * MW\,[\text{g/mole}] * Q\,[\text{L/min}] * 60\ \text{min/hr} * 1\text{lb}/454\ \text{grams} * \text{Time}\,[\text{hrs}]}{R\,[\text{L-atm/mol-K}] * T\,[\text{K}]}$$

where

C = Average concentration over time

MW = Molecular weight of compound [1]

Q = Standard flow rate[2]

Time = Elapsed time between sampling events

R = Ideal gas constant

T = Inlet temperature of SVE system

[1] A weighted average based on concentrations was used for the MW of total VOCs.

[2] $\text{Standard Flow Rate} = \text{Actual Flow Rate} * \frac{\text{Pressure}_{actual}}{\text{Pressure}_{standard}} * \frac{\text{Temperature}_{standard}}{\text{Temperature}_{actual}}$

TCE concentrations in the extracted soil gas increased rapidly from 360 to 1,000 ppmv during the first day of operation, dropped to 230 ppmv by the third day, then remained

TABLE 3.6
SUMMARY OF LONG-DURATION SVE TESTING SOIL GAS CHEMISTRY
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

Sampling Location	01VEP0001						P-13	HW-2				
Sampling Depth (feet bgs[a/])	10-30						30	14				
Sampling Date	03/19/00	03/20/00	03/21/00	03/22/00	03/25/00	03/27/00	03/20/00	03/22/00	03/23/00	03/24/00	03/25/00	03/27/00
Laboratory Analytical Results [b/] (ppmv)[c/]												
1,2-Dichlorobenzene	< 5.4 [d/]	< 2.2	< 2.2	< 1.0	< 0.86	< 0.88	0.56[e/]	< 11	< 11	< 11	< 5.5	< 5.6
1,2-Dichloroethane	< 5.4	< 2.2	< 2.2	< 1.0	< 0.86	< 0.88	< 0.11[e/]	12	< 11	< 11	6.4	7.5
1,3-Dichlorobenzene	< 5.4	< 2.2	< 2.2	< 1.0	< 0.86	< 0.88	0.21[e/]	< 11	< 11	< 11	< 5.5	< 5.6
1,4-Dichlorobenzene	< 5.4	< 2.2	< 2.2	<1.0	< 0.86	< 0.88	0.23[e/]	< 11	< 11	< 11	< 5.5	< 5.6
2-Butanone (Methyl Ethyl Ketone)	< 22	< 9.0	< 9.0	< 4.2	< 3.5	< 3.5	7.8[e/]	<43	< 43	< 45	< 22	< 22
2-Propanol	36	< 9.0	< 9.0	6.8	< 3.5	< 3.5	< 0.45[e/]	<43	< 43	< 45	33	< 22
Chlorobenzene	< 5.4	< 2.2	< 2.2	< 1.0	< 0.86	< 0.88	0.16[e/]	< 11	< 11	< 11	< 5.5	< 5.6
cis-1,2-Dichloroethene	59	88	54	38	26	19	1.1[e/]	110	99	76	71	68
Freon 113	< 5.4	2.3	2.4	1.5	1	< 0.88	< 0.11[e/]	< 11	< 11	< 11	< 5.5	< 5.6
Methylene Chloride	< 5.4	< 2.2	< 2.2	< 1.0	< 0.86	< 0.88	< 0.11[e/]	< 11	< 11	< 11	5.8	< 5.6
Tetrachloroethene	140	100	140	130	120	150	23[e/]	2000	1600	970	790	770
Trichloroethene	1000	480	230	250	220	260	36[e/]	2600	2400	1800	1500	1900
Total VOCs[f/]	1240	670	426	426	367	429	69.1[e/]	4720	4100	2850	2410	2750
Field Screening Results												
Oxygen (percent)	14.0	16.1	17.2	18.2	18.0	17.9	21[e/]	20.8	17.8	18.0	18.5	18.2
Carbon Dioxide (percent)	----[g/]	1.3	2.5	1.0	----	----	0.6[e/]	1.0	5.0	----	----	----
Total VOCs (ppmv)	54.1	36.4	77.5	113	110	89.0	28.7[e/]	138	200	98.4	202	124

TABLE 3.6 (continued)
SUMMARY OF LONG-DURATION SVE TESTING SOIL GAS CHEMISTRY
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

Sampling Location	01SG0001		01SG0002		01SG0003		01SG0004	
Sampling Depth (feet bgs[a/])	7-12	20-30	5-10	20-30	10-15	20-30	7-12	20-30
Sampling Date	03/27/00	03/27/00	03/27/00	03/27/00	03/27/00	03/27/00	03/27/00	03/27/00
Laboratory Analytical Results [b/] (ppmv)[c/]								
1,2-Dichlorobenzene	<2.3[d/]	---- [g/]	----	----	< 4.4	----	----	----
1,2-Dichloroethane	< 2.3	----	----	----	< 4.4	----	----	----
1,3-Dichlorobenzene	< 2.3	----	----	----	< 4.4	----	----	----
1,4-Dichlorobenzene	< 2.3	----	----	----	< 4.4	----	----	----
2-Butanone (Methyl Ethyl Ketone)	< 9.2	----	----	----	< 18	----	----	----
2-Propanol	< 9.2	----	----	----	< 18	----	----	----
Chlorobenzene	< 2.3	----	----	----	< 4.4	----	----	----
cis-1,2-Dichloroethene	3.8	----	----	----	14	----	----	----
Freon 113	< 2.3	----	----	----	6.2	----	----	----
Methylene Chloride	< 2.3	----	----	----	< 4.4	----	----	----
Tetrachloroethene	69	----	----	----	300	----	----	----
Trichloroethene	590	----	----	----	1300	----	----	----
Total VOCs [f/]	663	----	----	----	1620	----	----	----
Field Screening Results								
Oxygen (percent)	20.5	19.0	19.5	17.0	13.0	16.8	17.8	18.9
Carbon Dioxide (percent)	----	----	----	----	----	----	----	----
Total VOCs (ppmv)	51.2	144	203	155	192	202	24.4	183

[a/] bgs = below ground surface.
[b/] Soil gas analyzed by USEPA Method TO-14. The only analytes presented are those for which at least one concentration above detection was noted. See Appendix D for a full set of soil vapor analytical results.
[c/] ppmv = parts per million, volume per volume.
[d/] < = The compound was analyzed for but not detected at the listed reporting limit.
[e/] Results are not respresentative of actual subsurface conditions. The screened interval of well P-13 was submerged beneath the water table during sampling.
[f/] VOCs = volatile organic compounds.
[g/] ---- = not analyzed.

TABLE 3.7
SVE PILOT TEST CONTAMINANT MASS REMOVAL SUMMARY
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

01VEP0001

Sample Date/Time	Time Elapsed Between Sampling (hrs:min)	Average Pumping Rate Between Sampling (scfm)	TCE				PCE				Total VOCs			
			Sample Concentration (ppmv)	Average Concentration (ppmv)	Mass Removed Between Sampling (lbs)	Total Removed During Test (lbs)	Sample Concentration (ppmv)	Average Concentration (ppmv)	Mass Removed Between Sampling (lbs)	Total Removed During Test (lbs)	Sample Concentration (ppmv)	Average Concentration (ppmv)	Mass Removed Between Sampling (lbs)	Total Removed During Test (lbs)
3/19/2000 9:35			360			0	22			0	548.3			0
	5:45	6.13		680	0.51			81	0.08			891.7	0.64	
3/19/2000 15:20			1000			0.51	140			0.08	1235.0			0.64
	18:10	3.77		740	1.07			120	0.22			952.7	1.38	
3/20/2000 9:30			480			1.58	100			0.3	670.3			2.02
	29:03	4.01		355	0.87			120	0.37			548.4	1.38	
3/21/2000 14:33			230			2.45	140			0.67	426.4			3.4
	18:02	3.91		240	0.36			135	0.25			426.4	0.67	
3/22/2000 8:35			250			2.81	130			0.92	426.3			4.07
	72:35	2.99		235	1.08			125	0.72			396.7	1.92	
3/25/2000 9:10			220			3.89	120			1.64	367.0			5.99
	48:10	2.18		240	0.53			135	0.38			398.0	0.95	
3/27/2000 9:20			260			4.42	150			2.02	429.0			6.94

HW-2

Sample Date/Time	Time Elapsed Between Sampling (hrs:min)	Average Pumping Rate Between Sampling (scfm)	TCE				PCE				Total VOCs			
			Sample Concentration (ppmv)	Average Concentration (ppmv)	Mass Removed Between Sampling (lbs)	Total Removed During Test (lbs)	Sample Concentration (ppmv)	Average Concentration (ppmv)	Mass Removed Between Sampling (lbs)	Total Removed During Test (lbs)	Sample Concentration (ppmv)	Average Concentration (ppmv)	Mass Removed Between Sampling (lbs)	Total Removed During Test (lbs)
3/21/2000 14:22			3000			0	2500			0	5633.0			0
	18:23	77.14		2800	83.78			2250	84.96			5177.5	171.56	
3/22/2000 8:45			2600			83.78	2000			84.96	4722.0			171.56
	23:45	55.48		2500	69.51			1800	63.16			4410.5	134.93	
3/23/2000 8:30			2400			153.29	1600			148.12	4099.0			306.49
	29:15	37.42		2100	48.5			1285	37.45			3472.5	87.44	
3/24/2000 13:45			1800			201.79	970			185.57	2846.0			393.93
	19:25	35.45		1650	23.96			880	16.13			2626.1	41.05	
3/25/2000 9:10			1500			225.75	790			201.7	2406.2			434.98
	48:25	29.26		1700	50.82			780	29.43			2575.9	82.21	
3/27/2000 9:35			1900			276.57	770			231.13	2745.5			517.19

NOTES: TCE = trichloroethene; PCE = tetrachloroethene; VOCs = volatile organic compounds; hrs:min = hours:minutes; scfm = standardized cubic feet per minute; ppmv = parts per million per volume; lbs = pounds.

FIGURE 3.10
TCE CONCENTRATION AND CUMULATIVE MASS REMOVED OVER TIME FOR 01VEP0001
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

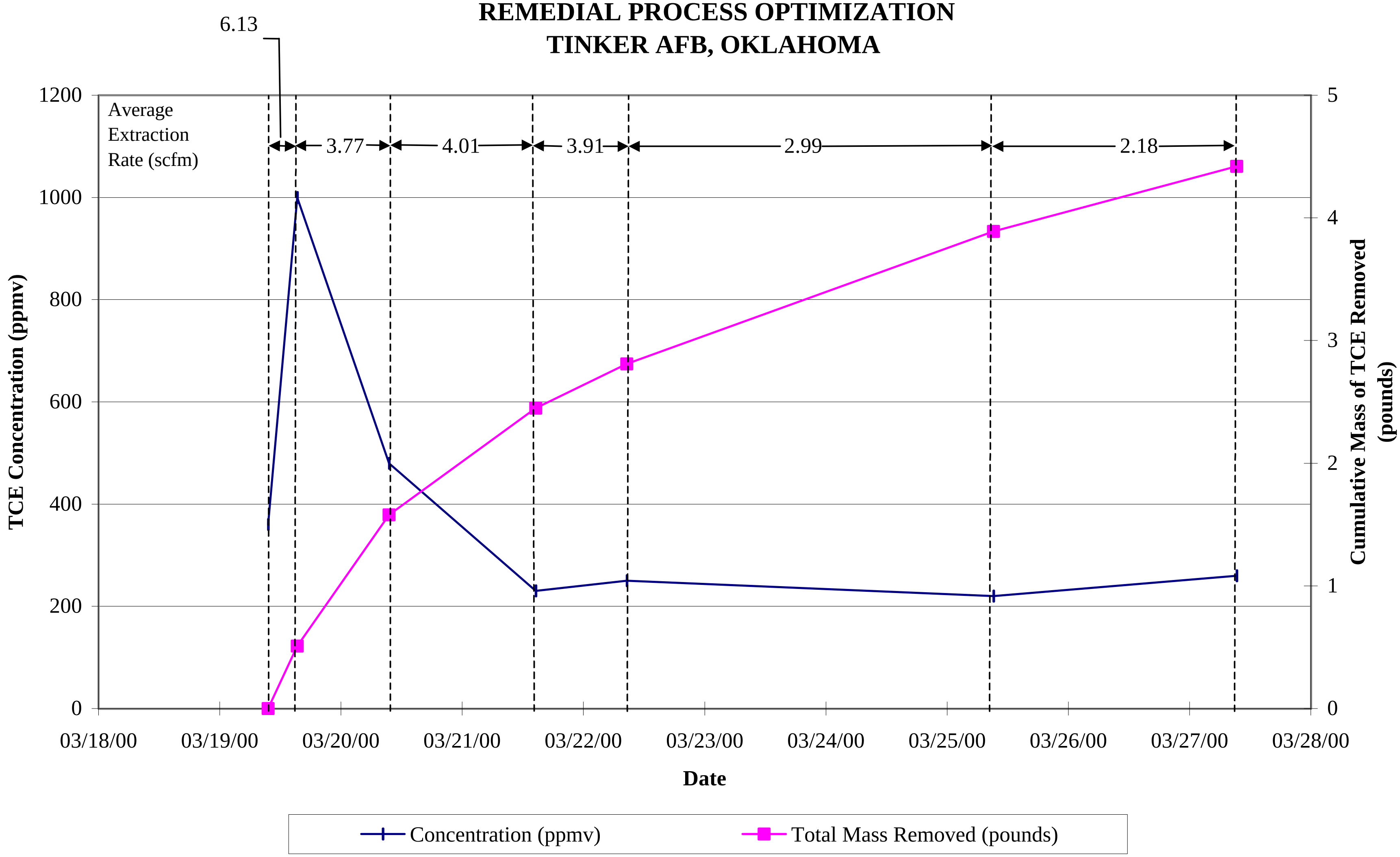


FIGURE 3.11
PCE CONCENTRATION AND CUMULATIVE MASS REMOVED OVER TIME FOR 01VEP0001
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

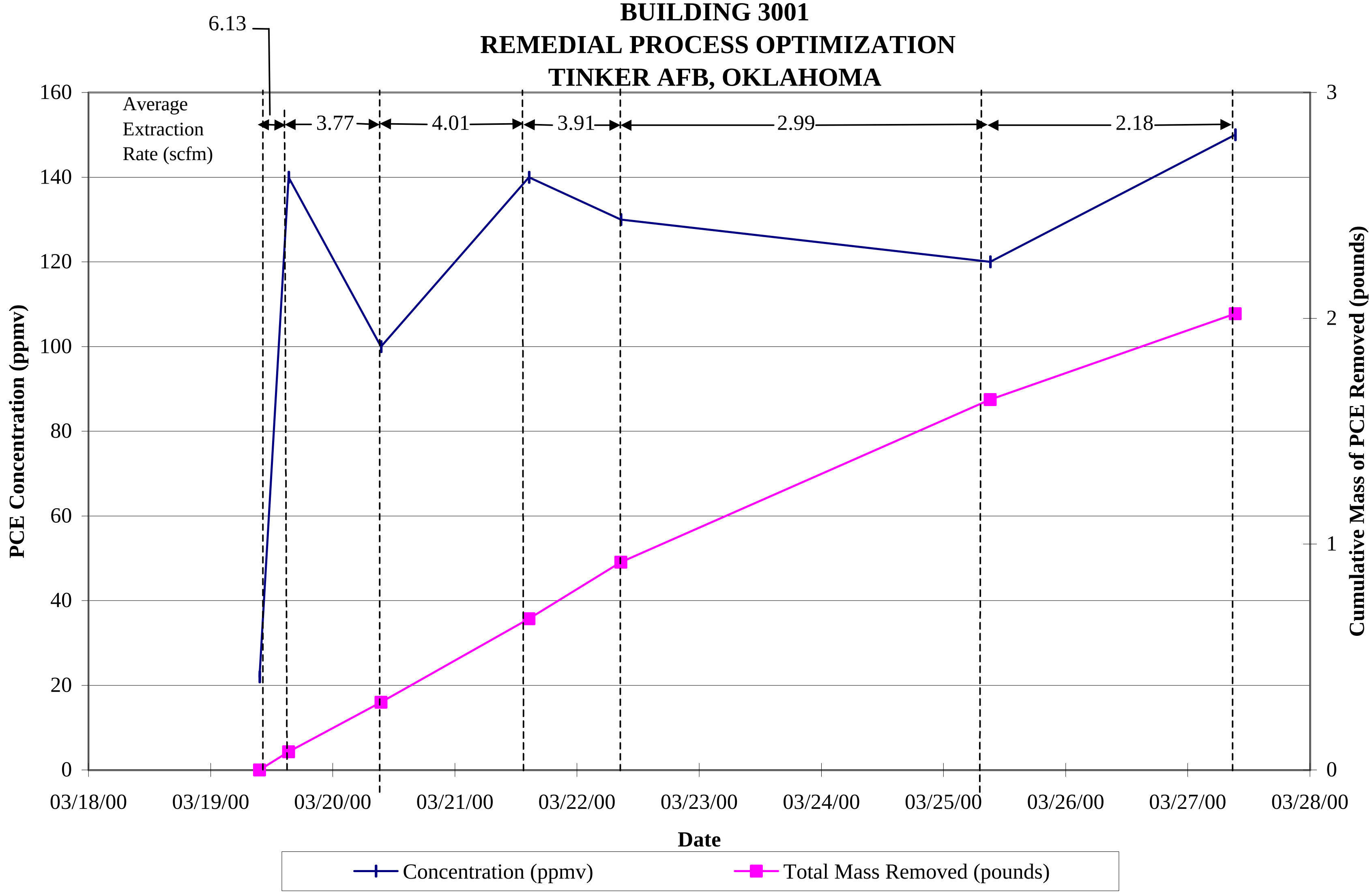
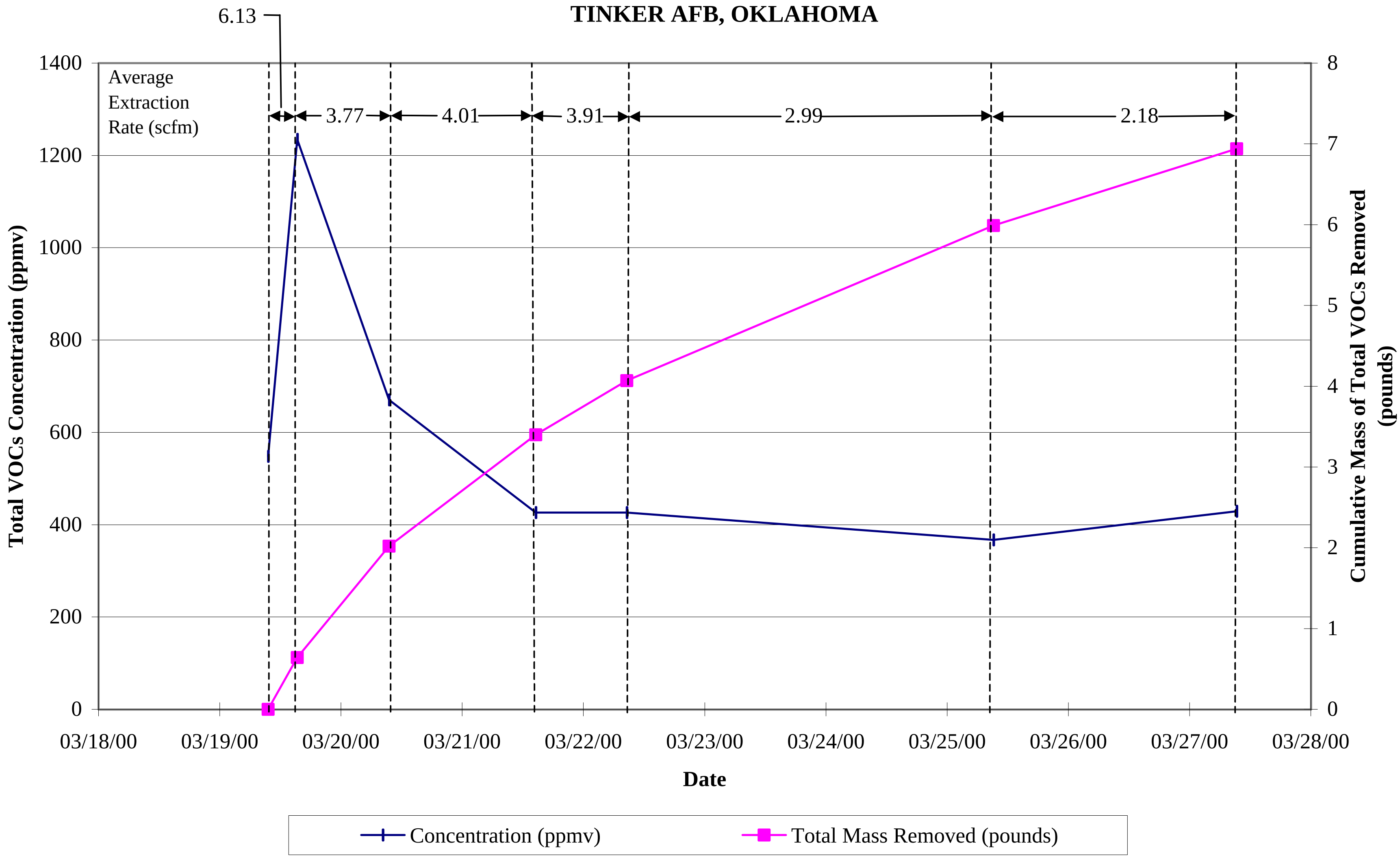


FIGURE 3.12
TOTAL VOCs CONCENTRATION AND CUMULATIVE MASS REMOVED OVER TIME FOR 01VEP0001
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA



between 220 and 260 ppmv for the remainder of the test (Figure 3.10). PCE concentrations also increased rapidly, from 22 to 140 ppmv, the first day of the test, then continued to rise at a slower rate to a maximum concentration of 150 ppmv at the end of the test (Figure 3.11). Total VOC concentrations followed a trend similar to that exhibited by TCE concentrations, increasing from 548 ppmv to 1,235 ppmv during the first day, dropping to 426 ppmv by the second day, then remaining between 426 and 367 during the remainder of the test (Figure 3.12).

Based on laboratory VOC results and measured soil gas extraction flow rates, a total of 6.94 lbs of VOCs was removed from 01VEP0001 during the 8 day test. Of this total, 2.02 lbs were PCE and 4.42 lbs were TCE.

3.3.4 SVE Pilot Test at P-13

Test Parameters and Procedures. The SVE test at P-13 was initiated on 19 March 2000, and was conducted for 54 hours (Table 3.4). This test was conducted by extracting soil gas from P-13 at an average flow rate of 0.5 scfm and an average vacuum of 174 inches of water. As described for the test at 01VEP0001, the extraction flow rate, vacuum, and soil gas chemistry were periodically measured and recorded. This test was terminated after 54 hours due to the high extraction vacuums and low flow rates, indicating that soil vapor could not be withdrawn from well P-13, and that the screened interval of well P-13 was probably below the water table.

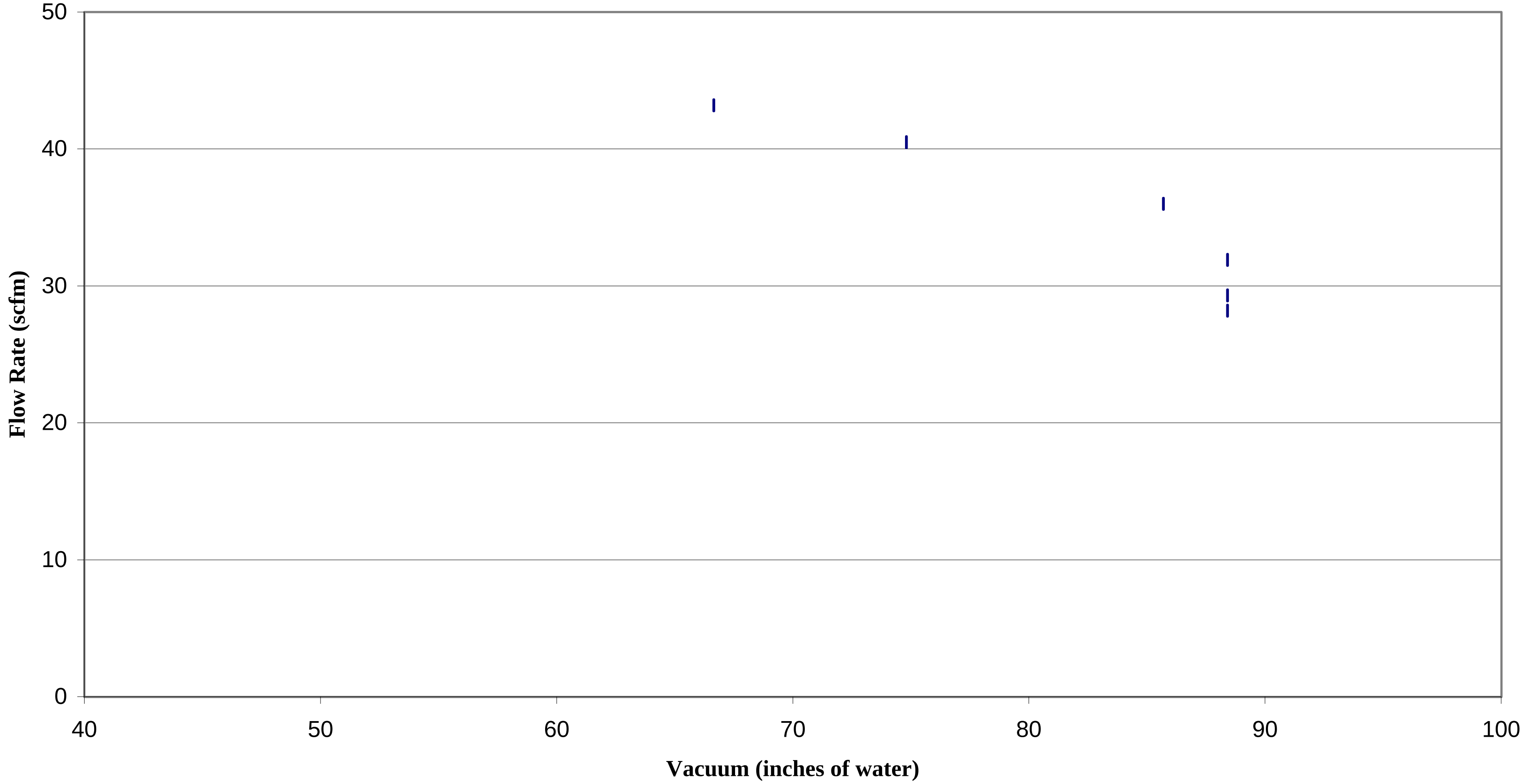
Extraction Flow Rates and Vacuums. SVE rates ranged from 0.3 to 0.8 scfm at vacuums ranging from 143 to 190 inches of water. The average flow rate was 0.5 scfm with an average vacuum of 174 inches of water. Soil gas extraction flow rates were limited, presumably due to saturated conditions at the screened interval of well P-13. A total of approximately 1,500 cubic feet of vapor was extracted during this test, but this is likely from leakage through piping connections rather than soil vapor extraction through the well screen.

3.3.5 SVE Pilot Test at HW-2

Test Parameters and Procedures. The long-duration SVE test at HW-2 was initiated on 21 March 2000, and was conducted for 140 hours (approximately 6 days) (Table 3.4). This test was conducted by extracting soil gas from HW-2 at flow rates of approximately 78 scfm during the first day, and 38 scfm for the remainder of the test. Throughout the test, extraction flow rates and vacuum at HW-2 were periodically measured and recorded. Soil gas samples from HW-2 also were collected and screened in the field for O_2, CO_2, and VOC concentrations. In addition, soil gas samples for laboratory VOC analysis were collected in 1-liter SUMMA® canisters, and analyzed for VOCs using USEPA Method TO-14.

Extraction Flow Rates and Vacuums. During the first day of the test, SVE rates stabilized at 78 scfm at a vacuum of 110 inches of water. For the remainder of the test, flow rates ranged between 27.1 and 46.2 scfm at vacuums of 54 to 88 inches of water. The average flow rate for the entire test was 40.7 scfm at an average vacuum of 83 inches of water. Flow rates from well HW-2 versus SVE system vacuum are illustrated on Figure 3.13. The optimal flow rate was approximately 43 scfm at an average vacuum of

FIGURE 3.13
SVE FLOW RATE FROM HW-2 VERSUS SVE SYSTEM INFLUENT VACUUM
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA



approximately 67 inches of water. A total of approximately 342,000 cubic feet of soil gas was extracted during this test.

VOC Mass Removal. Concentrations of VOCs in the extracted soil vapor were measured throughout the pilot test to estimate changes in VOC concentrations with time, changes in VOC mass removal rates with time, and the total mass of VOCs removed during the testing. Soil vapor samples were collected and field-screened for total VOCs using a PID, and additional soil vapor samples were also collected for laboratory analysis to confirm PID field screening results and quantify VOC removal rates and emissions. Field and laboratory analytical results of soil vapor sampling performed at HW-2 during the pilot test are presented in Table 3.6.

Graphs plotting concentrations and cumulative mass removed versus time for TCE, PCE, and total VOCs in HW-2 are shown on Figures 3.14, 3.15, and 3.16, respectively. The mass removal was calculated using the equation:

$$\text{Total Mass Removed} = \frac{C\,[\text{ppmv}] * MW\,[\text{g/mole}] * Q\,[\text{L/min}] * 60\ \text{min/hr} * 1\text{lb}/454\ \text{grams} * \text{Time}\,[\text{hrs}]}{R\,[\text{L-atm/mol-K}] * T\,[\text{K}]}$$

where

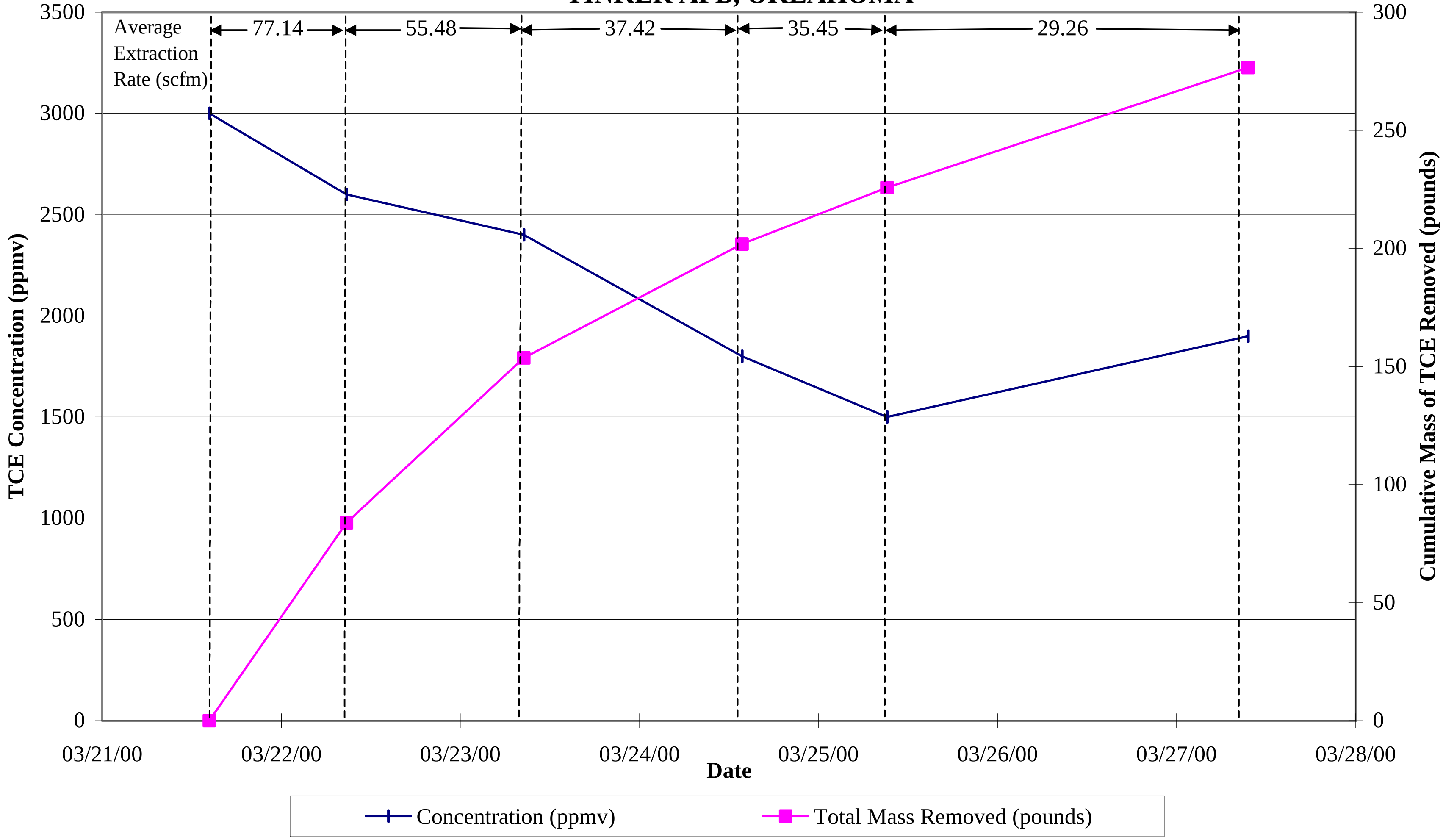
C	= Average concentration over time
MW	= Molecular weight of compound [1]
Q	= Standard flow rate[2]
Time	= Elapsed time between sampling events
R	= Ideal gas constant
T	= Inlet temperature of SVE system

[1] A weighted average based on concentrations was used for the MW of total VOCs.

[2] $\text{Standard Flow Rate} = \text{Actual Flow Rate} * \frac{\text{Pressure}_{actual}}{\text{Pressure}_{standard}} * \frac{\text{Temperature}_{standard}}{\text{Temperature}_{actual}}$

These data are also summarized in Table 3.7. During the test, PCE concentrations continuously decreased from 2,500 to 770 ppmv (Figure 3.15). Both TCE and total VOCs decreased during the first 4 days of the test, then increased slightly during the remainder of the test. TCE decreased from 3,000 to 1,500 ppmv, then increased to 1,900 ppmv by the end of the test (Figure 3.14). Total VOCs decreased from 5,633 to 2,406 ppmv, then increased to 2,746 ppmv (Figure 3.16). The VOC concentrations measured at the end of this test may have resulted from soil vapors from surrounding areas with relatively higher soil VOC contamination being drawn toward HW-2 as the result of SVE. Based on laboratory VOC results and measured soil gas extraction flow rates, a total of 517 lbs of VOCs were removed during the 6-day test. Of this total, 231 lbs were PCE and 277 lbs were TCE.

FIGURE 3.14
TCE CONCENTRATION AND CUMULATIVE MASS REMOVED OVER TIME FOR HW-2
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA



022/734429/tinker/10.xlsFig3.14

FIGURE 3.15
PCE CONCENTRATION AND CUMULATIVE MASS REMOVED OVER TIME FOR HW-2
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

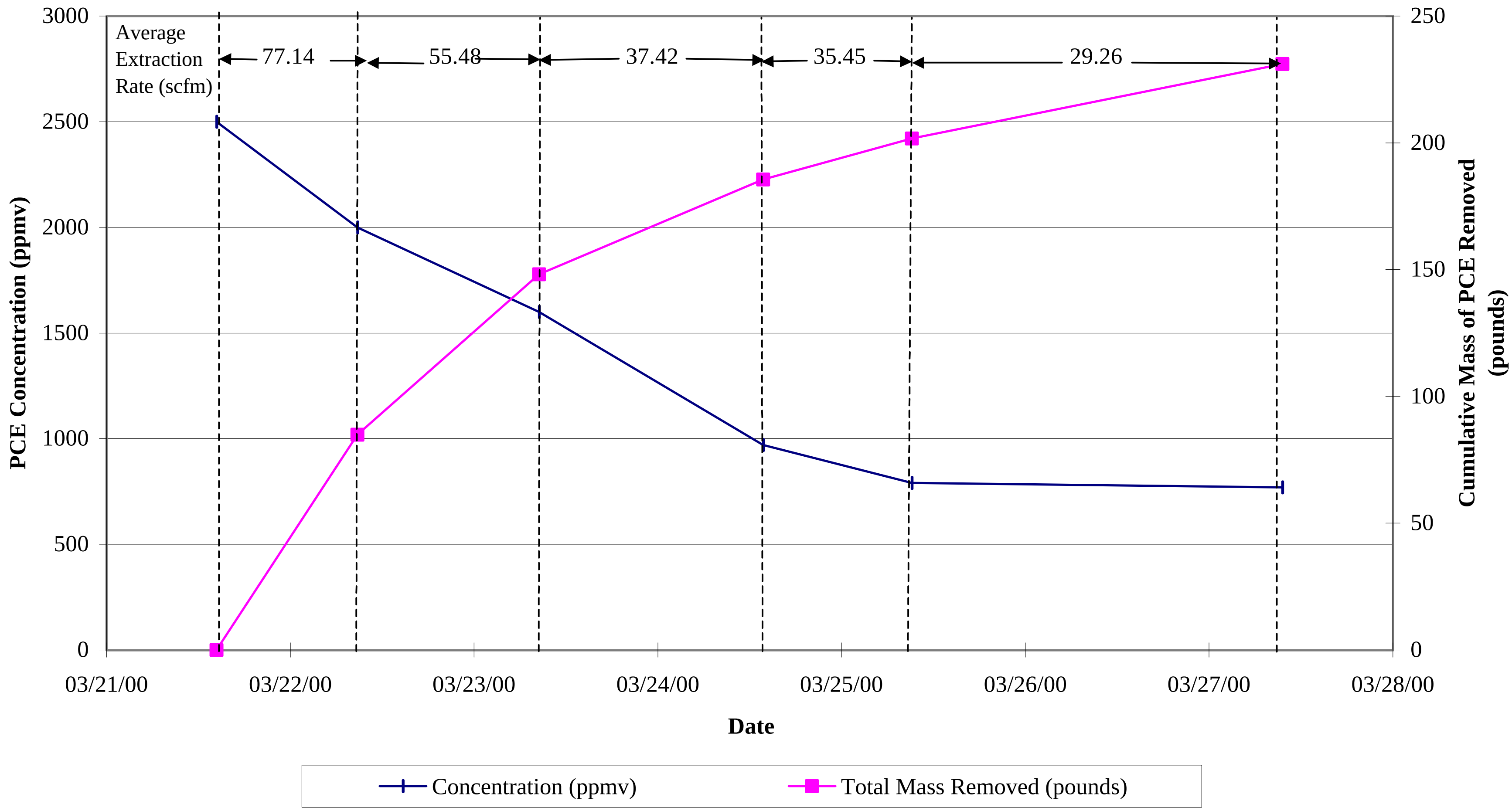
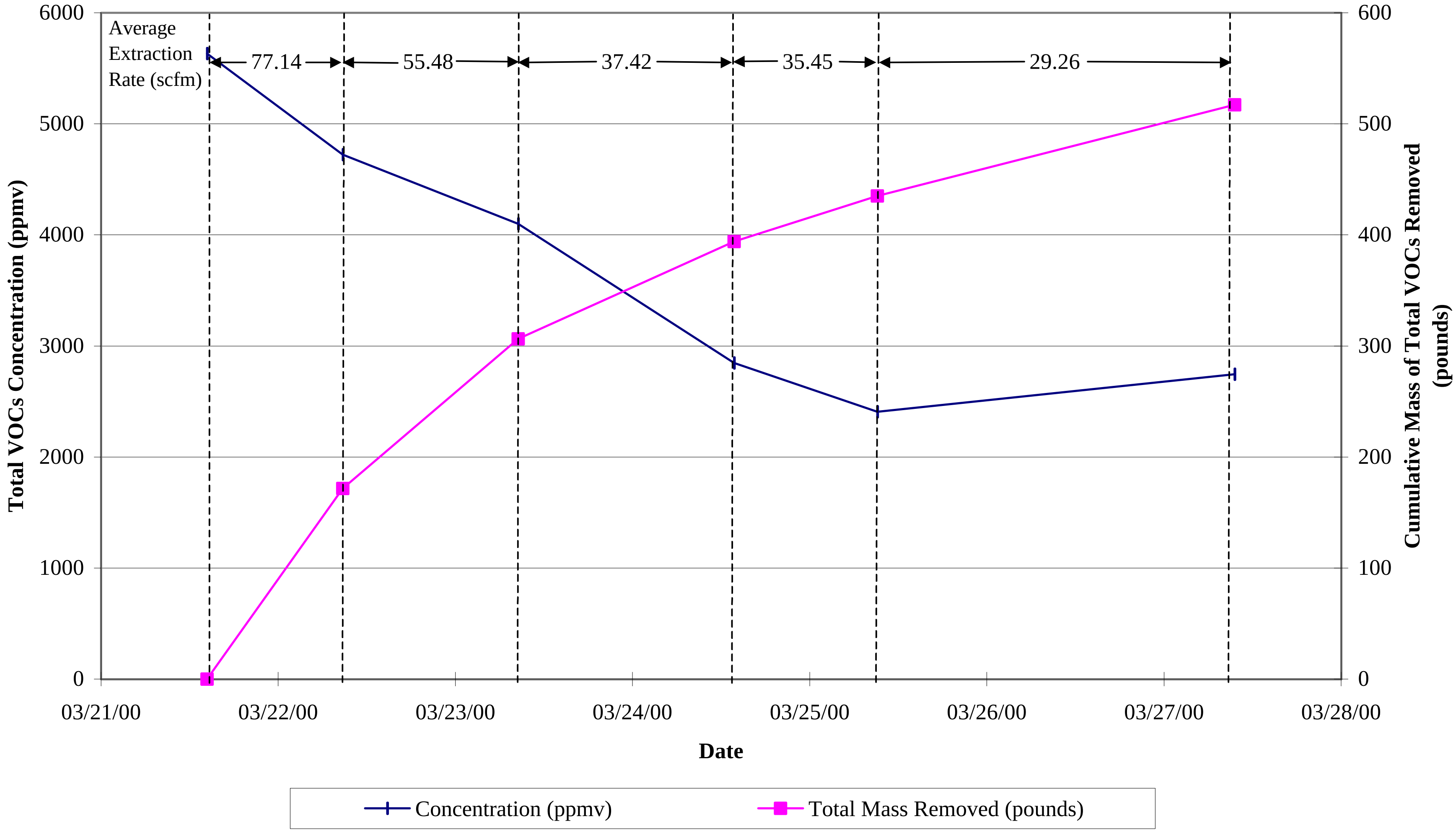


FIGURE 3.16
TOTAL VOCs CONCENTRATION AND CUMULATIVE MASS REMOVED OVER TIME FOR HW-2
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA



3.3.6 Post-Test Soil Vapor Chemistry

To determine how soil vapor concentrations of VOCs would rebound following SVE, additional soil gas samples were collected for VOC field screening and laboratory analysis after SVE pilot testing was completed and soil vapor levels were allowed to equilibrate. Following the extraction tests at 01VEP0001 and HW-2, the SVE system was shut down for a period of 32 days to allow soil vapor levels to equilibrate. At the end of the 32-day equilibration period, soil gas samples were collected from 01VEP0001, HW-2, and all VMP screened intervals. These samples were field-screened for O_2, CO_2, and total VOC concentrations, and samples from 01VEP0001, HW-2, 01SG0001-D, and 01SG0003-D also were submitted to the laboratory for VOC analysis using USEPA Method TO-14. Soil gas rebound sampling results are summarized in Table 3.8. A full set of soil vapor analytical results is provided in Appendix D.

At SVE wells 01VEP0001 and HW-2, total VOC concentrations in soil vapor decreased, indicating that some degree of soil remediation may have occurred at these locations as a result of SVE pilot testing. Total VOC concentrations in soil vapor did not change at 01SG0001-D as a result of SVE pilot testing, and VOC concentrations increased significantly at 01SG0003-D. Because the VMPs screens at 01SG0001-D and 01SG0003-D are located at deeper intervals (20-30 feet bgs) than the screened intervals at 01VEP0001 (10-30 feet bgs) and HW-2 (14 feet bgs), it is possible that the VOC concentrations at the VMPs did not decrease because volatilization of contaminants from the USZ had "recharged" the VOC levels in soil vapor immediately above the capillary fringe.

3.3.7 Management of Extracted Vapor

Per the State of Oklahoma Department Environmental Quality (ODEQ), the *de minimus* level of VOCs that may be released to the atmosphere via SVE is not to exceed 1,200 lbs per year at Building 3001 (ODEQ, 1998). As discussed in the work plan (Parsons ES, 2000), the SVE pilot tests conducted at Building 3001 were exempt from the requirement to treat extracted soil vapor because the total VOC mass removed was expected to be less than the *de minimus* level. The actual VOC mass removed during pilot testing was approximately 525 lbs, well below the *de minimus* level. If a full-scale SVE system is installed at Building 3001, treatment of extracted vapors will be required until VOC mass removal rates become asymptotic and fall to below 1,200 pounds per year.

3.4 CONCLUSIONS

Several conclusions can be drawn from the data collected during the SVE pilot test:

- Based on vacuum response and soil gas chemistry measured at the VMPs, the effective treatment radius for one vertical VEW exceeds 43 feet at an average extraction flow rate of 3.1 scfm.

- Due to the relatively fine-grained soil in the pilot test area, a vacuum of between approximately 70 and 95 inches of water applied to 01VEP0001 was required to induce an extraction flow rate of 3 scfm. Vacuums both higher and lower than this range resulted in reduced flow rates.

TABLE 3.8
SUMMARY OF REBOUND SVE TESTING SOIL GAS CHEMISTRY
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

Sample Location	01VEP0001		HW-2		01SG0001		01SG0001		01SG0002	
Sample Depth (feet bgs[a/])	10-30		14		7-12		20-30		5-10	
Sample Date	03/16/00	04/28/00	03/21/00	04/28/00	03/16/00	04/28/00	03/16/00	04/28/00	03/16/00	04/28/00
Laboratory Analytical Results [b/](ppmv)[c/]										
1,2-Dichlorobenzene	2	< 1 [d/]	< 11	< 4.3	----[e/]	----	< 2.1	< 2.1	----	----
1,2-Dichloroethane	< 2	< 1	13	4.7	----	----	< 2.1	< 2.1	----	----
1,4-Dioxane	< 8	< 4.1	< 43	< 17	----	----	< 8.5	< 8.5	----	----
2-Butanone (Methyl Ethyl Ketone)	150	< 4.1	< 43	< 17	----	----	< 8.5	< 8.5	----	----
2-Propanol	< 8	< 4.1	< 43	70	----	----	< 8.5	< 8.5	----	----
Acetone	< 8	< 4.1	< 43	< 17	----	----	< 8.5	< 8.5	----	----
Chlorobenzene	2.2	1.3	< 11	< 4.3	----	----	< 2.1	< 2.1	----	----
cis-1,2-Dichloroethene	12	15	120	62	----	----	6.4	7	----	----
Toluene	< 2	< 1.0	< 11	< 4.3	----	----	< 2.1	< 2.1	----	----
Methylene Chloride	< 2	< 1.0	< 11	< 4.3	----	----	< 2.1	< 2.1	----	----
Tetrachloroethene	22	77	2,500	480	----	----	37	34	----	----
Trichloroethene	360	160	3,000	1,300	----	----	530	530	----	----
Total VOCs [f/]	548.3	253	5,633	1,920	----	----	573.4	571	----	----
Field Screening Results[g/]										
Oxygen (percent)	18.0	19.1/18.3	13.2	17.9/17.8	20.6	20.1/17.2	20.2	18.5/17.7	10	18.2/19.0
Carbon Dioxide (percent)	0.9	1.4/1.5	7.8	4.2/4.8	0.6	0.7/1.8	0.8	1.5/1.7	1.9	1.0/0.8
Total VOCs (ppmv) [h/]	225	163/197	83.1	373/363	190	----/240	260	320/297	190	----/195

TABLE 3.8 (continued)
SUMMARY OF REBOUND SVE TESTING SOIL GAS CHEMISTRY
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

Sample Location	01SG0002		01SG0003		01SG0003		01SG0004		01SG0004	
Sample Depth (feet bgs[a])	20-30		10-15		20-30		7-12		20-30	
Sample Date	03/16/00	04/28/00	03/16/00	04/28/00	03/16/00	04/28/00	03/16/00	04/28/00	03/16/00	04/28/00
Laboratory Analytical Results [b](ppmv)[c]										
1,2-Dichlorobenzene	---- [e]	----	----	----	< 2.1 [d]	< 4.2				
1,2-Dichloroethane	----	----	----	----	< 2.1	< 4.2	----	----	----	----
1,4-Dioxane	----	----	----	----	< 8.4	< 17	----	----	----	----
2-Butanone (Methyl Ethyl Ketone)	----	----	----	----	11	< 17	----	----	----	----
2-Propanol	----	----	----	----	< 8.4	80	----	----	----	----
Acetone	----	----	----	----	< 8.4	19	----	----	----	----
Chlorobenzene	----	----	----	----	< 2.1	< 4.2	----	----	----	----
cis-1,2-Dichloroethene	----	----	----	----	6	15	----	----	----	----
Toluene	----	----	----	----	< 2.1	5.6	----	----	----	----
Methylene Chloride	----	----	----	----	< 2.1	4.5	----	----	----	----
Tetrachloroethene	----	----	----	----	72	210	----	----	----	----
Trichloroethene	----	----	----	----	470	1,200	----	----	----	----
Total VOCs [f]	----	----	----	----	559	1,530	----	----	----	----
Field Screening Results[g]										
Oxygen (percent)	18.2	18.0/17.5	20.0	11.5/15.8	19.6	15/16.5	20.0	19.0/18.0	19.3	19.0/16.8
Carbon Dioxide (percent)	2.2	2.0/2.1	0.5	4.2/3.0	1.2	3.3/2.9	0.7	0.5/0.9	0.8	0.8/1.3
Total VOCs (ppmv) [h]	180	475/332	145	165/297	220	290/257	18.5	----/45.2	94.6	60.4/119

[a] bgs = below ground surface.

[b] Soil gas analyzed by USEPA Method TO-14. The only analytes presented are those for which at least one concentration above detection was noted. See Appendix D for a full set of soil vapor analytical results.

[c] ppmv = parts per million, volume per volume.

[d] < = The compound was not detected at the listed reporting limit.

[e] ---- = not analyzed.

[f] VOCs = volatile organic compounds.

[g] Initial measurement on 4/28/00; remeasured on 5/11/00.

[h] Total VOCs measured on 5/2/00; remeasured on 5/11/00.

- The results obtained during testing at 01VEP0001 suggest that vertical groundwater extraction wells with portions of their screened intervals exposed to vadose zone soils may be retrofitted for use as SVE wells. However, the sustainable vapor extraction flow rates from these wells are expected to be less than 5 cfm. SVE flow rates greater than 5 cfm will cause an increased vacuum to develop in the well casing, which will cause the groundwater level within the casing to rise and eventually saturate the entire well screen. Vertical wells are expected to be feasible for SVE only if the VOC concentrations in soil vapor from the well are very high (in the tens of thousands of parts per million range or higher).

- The results obtained during testing at well P-13 suggest that existing horizontal groundwater extraction wells cannot be retrofitted for use as SVE wells. If full-scale SVE is to be implemented at Building 3001, a new array of horizontal wells may be required.

- Flow rates achieved at HW-2 were 78 scfm (1.1 scfm per foot of well screen) at a vacuum of 110 inches of water, and 38 scfm (0.54 scfm per foot of well screen) at a vacuum of 82 inches of water. These results show that a horizontal well configuration is preferable for remediation of soils at Building 3001. A horizontal SVE well screened approximately mid-way between the ground surface and the potentiometric surface of the perched aquifer of the USZ is the optimal SVE well configuration.

- Less than 1 quart of water per day accumulated in the moisture separator (from the combined flow from 01VEP0001 and HW-2), suggesting that accumulation of condensate would not be a significant problem with a full-scale system.

- The contaminant mass removal rates from 01VEP0001 averaged 0.87 lbs per day for total VOCs, 0.55 lbs per day for TCE, and 0.25 lbs per day for PCE. A total of 6.94 lbs of VOCs, which included 4.42 lbs of TCE and 2.02 lbs of PCE, were removed during the 8-day pilot test at 01VEP0001.

- The mass removal rate for HW-2 averaged 89.2 lbs per day of total VOCs, 47.7 lbs per day of TCE, and 39.8 lbs per day for PCE. A total of 517.2 lbs of VOCs, which included 276.6 lbs of TCE and 231.1 lbs of PCE, were removed during the 6-day pilot test at HW-2. In comparison, the groundwater extraction and treatment system has removed an average of 160 pounds of VOCs per month during FY1999. In the 6-day pilot test at HW-2, the VOC mass removal rate was equal to that achieved in over three months of groundwater extraction. Vapor-phase VOC removal rates realized during the March 2000 pilot test far exceeded the aqueous-phase VOC removal rates being achieved by the existing groundwater extraction and treatment system at Building 3001.

- Although no off-gas treatment was necessary for the pilot test because the total VOC emissions were less than the *de minimus* level of 1,200 lbs per year, a full-scale or expanded pilot-scale system would require vapor treatment.

SECTION 4

COST EFFECTIVENESS OF AQUEOUS-PHASE VERSUS VAPOR-PHASE VOC REMOVAL AT BUILDING 3001

This section compares the actual costs, aqueous-phase VOC mass removal rates, and unit costs per pound of VOCs removed for the groundwater extraction and treatment system at Building 3001 versus those that may be achieved if full-scale SVE were to be implemented at the site. This comparison provides the basis for determining if SVE is a cost-effective supplemental treatment technology at Building 3001.

4.1 GROUNDWATER EXTRACTION AND TREATMENT SYSTEM

In Section 2, a discussion of the actual costs, VOC mass removal rates, and unit costs per pound of VOCs removed by the existing groundwater extraction and treatment system at Building 3001 was provided. That discussion is summarized in the following paragraphs.

The groundwater extraction and treatment system has removed approximately 8,625 lbs of VOCs, including CAHs, from the beginning of system operation in June 1994 through February 2000 (Buehler, 2000), for an average VOC removal rate of about 130 lbs per month. Removal rates have remained relatively constant over this 5 2/3 year operating period, and have not yet reached asymptotic levels.

The costs for the design, installation, and the first five years of OM&M for the groundwater extraction and treatment system at Building 3001 are summarized in Table 4.1. A projection of total project costs over 30 years is also provided in Table 4.1. The cost to design the groundwater extraction and treatment system at Building 3001 was $674,000, and the capital cost for system installation was $12 million, including the installation of five horizontal groundwater extraction wells at a cost of approximately $400,000 per well (Buehler, 2000). Parsons ES has estimated that the annual OM&M costs for the Building 3001 system have been $500,000 per year for the first four years of system operation (June 1994 through June 1998), $450,000 per year for the fifth and sixth years of operation (June 1998 through June 2000).

Based on estimated capital and OM&M costs for the system at Building 3001 and the total mass of VOCs removed for the period from June 1994 through February 2000 (8,625 pounds over 5 2/3 years), the average cost per pound of VOCs removed from groundwater has been approximately $1,700 per pound as of June 2000. It should be noted that these unit treatment costs are biased high, since the Building 3001 groundwater treatment system also includes unit processes for the removal of hexavalent chromium.

TABLE 4.1
COMPARISON OF COSTS FOR THE CURRENT GROUNDWATER EXTRACTION AND TREATMENT SYSTEM VERSUS A CONCEPTUAL FULL-SCALE SOIL VAPOR EXTRACTION SYSTEM
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

Item	Current Groundwater Extraction and Treatment System	Conceptual Full-Scale Soil Vapor Extraction System
Design cost	$674,000 [a]	$575,000 [b]
Capital Cost	$12,000,000 [a]	$2,350,000 [c]
Estimated annual OM&M[d]	varies from $450,000 to $500,000 [e]	varies from $90,000 to $600,000 [f]
Projected total cost (after 5 years)	$15,600,000	$4,000,000
Projected total cost (after 30 years)	$25,900,000	NA [g]

a/ Information provided by Keith Buehler, Tinker AFB, Oklahoma.

b/ Includes cost of 1-year soil vapor extraction pilot test at horizontal well HW-2.

c/ Estimate was made assuming that four additional horizontal wells are required for full-scale coverage.

d/ Operations, Maintenance, and Monitoring.

e/ Parsons ES estimates based on information provided by Keith Buehler, Tinker AFB, Oklahoma.

f/ Estimates were made assuming that activated carbon would be used for vapor treatment and that the total VOC mass removal rate and composition over time from the four additional horizontal wells matched those observed at well HW-2 during March 2000 SVE pilot testing.

g/ Soil vapor extraction will not occur for a 30-year length of time at Building 3001. VOC mass removal rates will reach asymptotic levels long before 30 years of operation.

4.2 CONCEPTUAL FULL-SCALE SVE SYSTEM

To allow for a comparison against aqueous-phase VOC mass removal being achieved with the existing groundwater extraction and treatment system, a conceptual full-scale SVE system for vapor-phase VOC mass removal was designed, and a cost estimate for system installation and five years of system OM&M was prepared.

Based on the results of the SVE pilot testing presented in Section 3, it was observed that horizontal wells were superior to vertical wells, primarily because the vadose zone at Building 3001 is thin relative to the areal extent of contamination at the site. Therefore, it was assumed that additional horizontal wells would be required to provide the most cost effective coverage in a full-scale system. It was also assumed that a radius of influence of 150 to 175 feet could be achieved using a single horizontal SVE well. To provide a realistic estimate for the areal extent of VOC contamination in the vadose zone, it was assumed that there was residual-phase contamination in soils in the vicinity of all of the former disposal pits within Building 3001. The locations of the former disposal pits are illustrated on a figure provided in Appendix E. Based on the above assumptions, it was estimated that four new horizontal SVE wells, in addition to existing SVE well HW-2, would be required to provide full-scale treatment.

Projections for long-term VOC mass removal using SVE were made based on the results of the March 2000 pilot testing at well HW-2, presented in Section 3, and based on Parsons ES experience and observations at similar sites where SVE was implemented. An exponential curve was fit to the VOC mass removal versus time data from the SVE pilot test at well HW-2, and was extrapolated to estimate the VOC mass removal rates from HW-2 over one year. This VOC mass removal projection is provided in Appendix E. VOC mass removal rates were projected to become asymptotic after the first year of operation. For the conceptual full-scale SVE system, it was assumed that VOC contaminant concentrations and composition in soil in the E105 pilot testing area (where well HW-2 is located) were equal to those found elsewhere within the area of influence of the conceptual full-scale SVE system, and that the VOC mass removal rates over time at the four new horizontal SVE wells would be identical to those projected at well HW-2. Using these assumptions, it was estimated that 26,000 pounds of VOCs would be removed during the first year of system operation, and that a total of approximately 35,000 pounds of VOCs could be removed during five years of treatment.

The conceptual full-scale SVE system includes a centrally located positive displacement blower system that is manifolded to the five SVE wells. It was assumed that granular activated carbon would be used for vapor-phase VOC treatment (although thermal oxidation should also be considered as a treatment option if a full-scale system is designed/installed in the future).

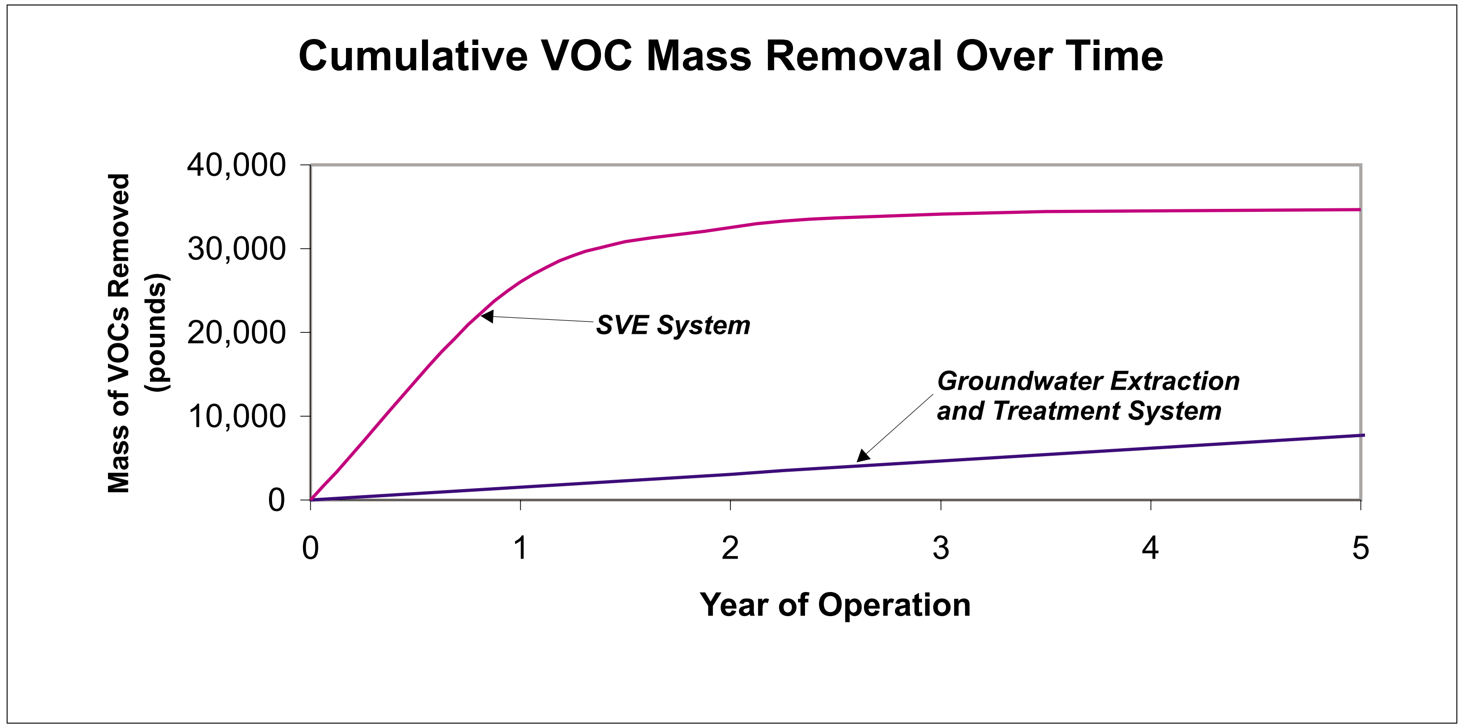
The estimated costs for the design, installation, and the first five years of OM&M for the conceptual full-scale SVE system at Building 3001 are summarized in Table 4.1. The cost to design the SVE system at Building 3001 was estimated at $575,000, including the cost of an extended pilot test that is discussed in more detail in Section 5. The capital cost for SVE system installation was estimated at $2.35 million, including the installation of four additional horizontal SVE wells at a cost of approximately $400,000 per well. Parsons ES has estimated that the annual OM&M costs for the Building 3001 system would amount to $600,000 during the first year of OM&M, and drop to $90,000 during the fifth year of OM&M. One of the primary OM&M cost items is vapor treatment, which contributes significant costs during the first year of system operation but drops markedly as the extracted VOC concentrations reach asymptotic levels.

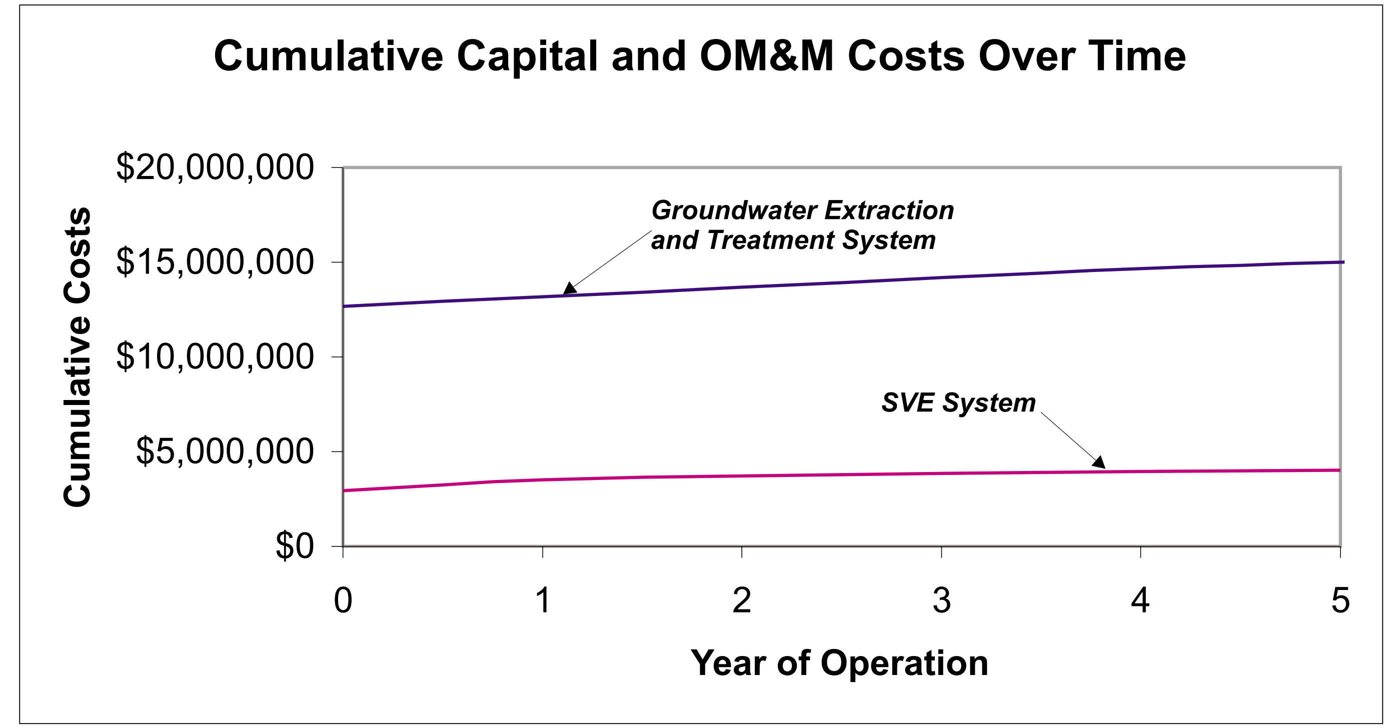
Based on the estimated VOC mass removal that could be achieved using the conceptual full-scale SVE system and projected capital and OM&M costs for a five-year operating period, the average unit cost for VOC mass removal from vadose zone soils is projected at between $110 and $140 per pound.

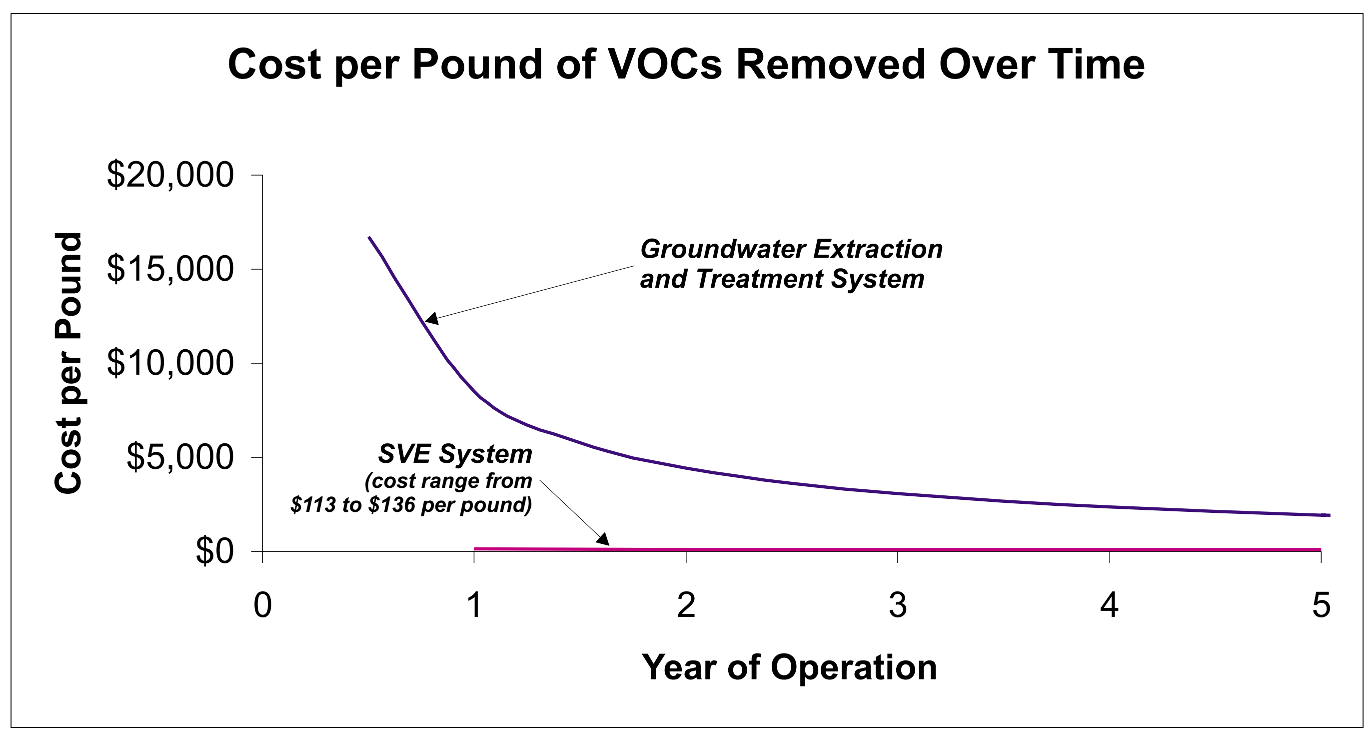
4.3 COMPARISON OF AQUEOUS-PHASE AND VAPOR-PHASE VOC MASS REMOVAL

A comparison of the cumulative VOC mass removal, capital and OM&M costs, and cost per pound of VOCs removed by the existing groundwater extraction and treatment system versus those for the conceptual full-scale SVE system is provided on Figure 4.1. As shown on the figure, VOC mass removal using SVE should be much more cost effective than the mass removal being achieved by the existing groundwater extraction system. A projected 35,000 pounds of VOCs may be removed by the conceptual full-scale SVE system over the first five years of operation, versus approximately 8,000 pounds that has been removed by the groundwater extraction and treatment system over the same time period (Figure 4.1). Cumulative costs for the groundwater extraction and treatment system after five years of operation have amounted to $15.6 million, versus a projected total of $4 million for the conceptual full-scale SVE system.

Based on estimated capital and OM&M costs for the existing groundwater extraction and treatment system at Building 3001 and the total mass of VOCs removed, the average unit cost for VOC mass removal from groundwater has been approximately $1,700 per pound after five years of operation. For the conceptual full-scale SVE system, the unit cost for VOC mass removal from vadose zone soils is estimated at $120 per pound, meaning that vapor-phase VOC mass removal is approximately fourteen times less expensive than aqueous-phase VOC mass removal, although the groundwater extraction and treatment system also provides plume containment and removal of hexavalent chromium.







Note: All graphs assume that groundwater extraction VOC mass removal rate remains constant (approximately 130 pounds per month).

FIGURE 4.1

COMPARISON OF CURRENT GROUNDWATER EXTRACTION AND TREATMENT SYSTEM VERSUS A CONCEPTUAL FULL-SCALE SOIL VAPOR EXTRACTION SYSTEM

Building 3001
Remedial Process Optimization
Tinker AFB, Oklahoma

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Denver, Colorado

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SECTION 5

RECOMMENDATIONS

An expanded SVE pilot test at well HW-2 with a duration of 1 year is recommended to estimate parameters that would be required for the design of a full-scale SVE system at Building 3001. Based on the results of the SVE pilot testing performed at well HW-2 in March 2000, SVE utilizing horizontal wells may be an effective technology for removing VOCs from unsaturated soils beneath Building 3001. The vapor-phase VOC removal rates achieved during the test at HW-2 far exceeded the aqueous-phase VOC removal rates of the existing groundwater extraction and treatment system. However, the parameters required for full-scale SVE system design have not yet been accurately determined.

First, the radius of influence for well HW-2 has not yet been accurately determined. The VMPs in the E105 pilot testing area were inaccessible to Parsons ES during the RPO field effort, so vacuum response measurements could not be recorded. Also, it appears that these VMPs have been installed too close to the screened interval of HW-2 to allow the radius of influence to be accurately determined. During previous pilot testing efforts performed by CDM, significant vacuum response was measured at all VMPs, which are located at distances of 5 to 60 feet from the screened interval at HW-2. The actual radius of influence is expected to greatly exceed 60 feet, but the radius of influence cannot be accurately determined without additional VMPs installed greater than 60 feet from HW-2. Because of the high cost of installing horizontal wells (approximately $400,000 per well [Buehler, 2000]), determining the maximum effective treatment radius is critical for cost-effective design of a full-scale SVE system.

Secondly, the long-term VOC removal rates and requirements for vapor treatment for a full-scale system can not be reliably estimated based on the March 2000 pilot testing. One year of data from SVE well HW-2 would allow VOC concentrations in extracted soil vapor over time to be observed, which would allow vapor treatment to be accurately engineered and would allow the total length of time for system operation to be estimated. To provide an estimated cost for the recommended pilot test, Parsons ES has estimated the mass of VOCs that could be removed from HW-2 in a 1-year timeframe. An exponential curve was fit to the data obtained during the March 2000 pilot test at well HW-2, and extrapolated over a one-year time period. These calculations are included in Appendix E.

Objectives of additional SVE pilot testing would include:

- Maximizing the quantity of TCE that can be removed from the subsurface at the lowest cost by using existing remediation system components;

- Determining the maximum effective treatment radius of a single horizontal SVE well;

- Determining the optimum well spacing and screen length;

- Defining the VOC mass removal rates that could be achieved over one year of operation;

- Determining if air injection at existing horizontal groundwater extraction wells can be used to control subsurface flow and vacuum gradients, and

- Determining if existing horizontal groundwater extraction wells can be used for SVE using a drop-tube (e.g., multi-phase extraction or "slurping") rather than the configuration that was used during the March 2000 test at well P-13;

- Determining requirements for treatment of extracted vapors and condensate.

The recommended long-term SVE pilot test would include the following elements:

- Utilizing the existing HW-2 for the SVE well;

- Installation of additional VMPs inside Building 3001 in the vicinity of HW-2 to determine the maximum effective treatment radius. At least three additional VMPs should be installed at distances of about 75, 100, and 200 feet perpendicular to the centerline of HW-2 and at least two VMPs should be located about 50 and 75 feet east of HW-2, along the extension of the well centerline. Figure 5.1 illustrates the proposed locations of additional VMPs.

- Installation of a blower system hard-wired to the Base electrical system. The pilot test blower should have the capacity to extract soil vapor at a rate of 80 scfm at a vacuum of 120 inches of water.

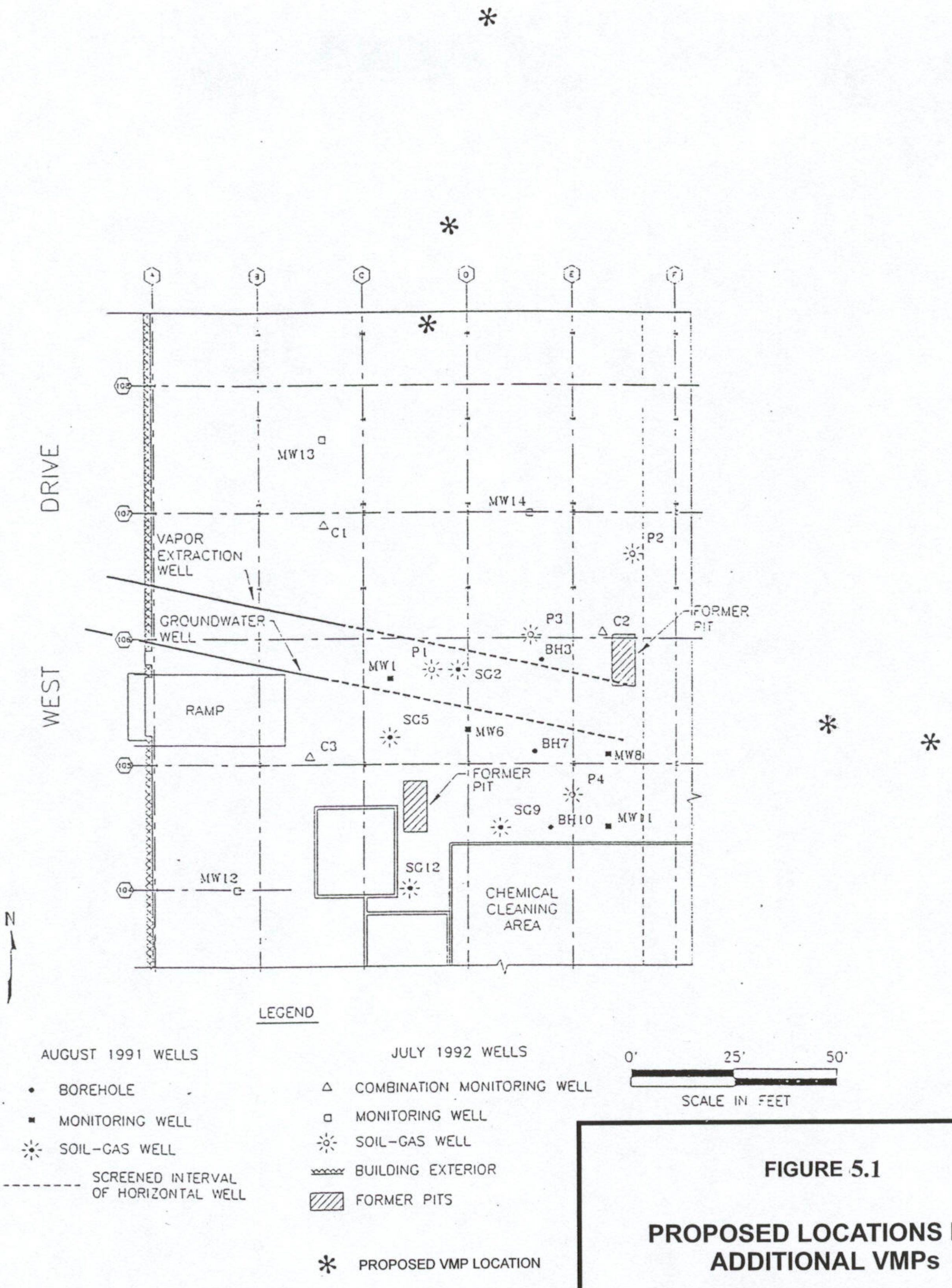
- Installation of a vapor treatment system that would limit VOC emissions to a level below the *de minimus* level of 1,200 pounds per year. Based on removal rates observed during the March 2000 pilot test, activated carbon is recommended for off gas treatment.

- Collection and analysis of soil vapor samples from the VMPs and HW-2 to establish baseline soil vapor chemistry.

- Operation of the SVE system for a period of 1 year. During this period of operation, the system should be periodically shut down when soil vapor VOC concentrations reach asymptotic levels to observe the rebound of soil vapor VOC concentrations.

- Implementation of a tracer test using inert tracer gases (e.g. helium and sulfur hexafluoride) to supplement vacuum response data and to determine the maximum treatment radius.

- Measurement of soil vapor flow rates and extraction vacuums.



Source: CDM, 1993.

FIGURE 5.1

PROPOSED LOCATIONS FOR ADDITIONAL VMPs

Building 3001
Remedial Process Optimization
Tinker AFB, Oklahoma

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- Periodic collection of soil vapor samples from the SVE well, VMPs, and the vapor treatment system exhaust for field screening and laboratory VOC analysis.

- Measurement of vacuum response at VMPs and groundwater monitoring wells in the pilot test area with screens extending above the saturated zone.

- Pilot testing by using air injection into well P-13 or other horizontal groundwater extraction wells. Data gathered during the pilot testing effort indicated that existing groundwater extraction wells could not be used for SVE because the well screens were below the groundwater surface. However, it is possible that these wells could be used for air injection, if required, to provide for additional control over the vacuum gradients and soil vapor flow directions in the subsurface.

- Pilot testing by using alternate methods of SVE from well P-13 or another horizontal extraction well. Installation of horizontal wells is potentially the most expensive element in the addition of a full-scale SVE system, so every effort should be made to use existing components.

The estimated cost for the one-year SVE pilot test using well HW-2 is estimated at $500,000, as shown in Table 5.1.

If the results of the one-year SVE pilot test at HW-2 are successful, a records search and possibly a soil vapor survey is also recommended to determine the extent of vadose zone contamination in the subsurface. The extent of vadose zone contamination would need to be accurately defined before a full-scale SVE system could be designed.

TABLE 5.1
ESTIMATED COST FOR A
ONE-YEAR SOIL VAPOR EXTRACTION PILOT TEST AT HORIZONTAL WELL HW-2
BUILDING 3001
REMEDIAL PROCESS OPTIMIZATION
TINKER AFB, OKLAHOMA

Description	Quantity	Units	Unit Price	Total Dollars
Project Planning and Management	1	lump sum	$91,400.00	$91,400.00
Work Plan and SVE Pilot Test Design	1	lump sum	$30,950.00	$30,950.00
SVE Pilot Test System Installation and Startup Activities				
Labor	1	lump sum	$55,400.00	$55,400.00
Vapor Monitoring Points	5	each	$3,000.00	$15,000.00
Positive Displacement Blower	1	each	$6,000.00	$6,000.00
Blower Shipment	2	each	$500.00	$1,000.00
Blower Shed/Concrete Pad	1	each	$2,000.00	$2,000.00
Field Instruments/Equipment	1	lump sum	$12,000.00	$12,000.00
Soil Vapor Samples (TO-15)	240	each	$250.00	$60,000.00
Sample Shipping	18	each	$25.00	$450.00
Activated Carbon Canisters	1	each	$3,000.00	$3,000.00
Electrician	1	lump sum	$5,000.00	$5,000.00
Misc. piping/supplies	1	lump sum	$2,500.00	$2,500.00
SVE Pilot Test System Operations and Monitoring				
Labor	1	lump sum	$35,400.00	$35,400.00
Activated Carbon	20,000	pounds	$5.00	$100,000.00
Field Instruments/Supplies	1	lump sum	$4,000.00	$4,000.00
Soil Vapor Samples (TO-15)	80	each	$250.00	$20,000.00
Shipping	24	each	$25.00	$600.00
Misc. Demobilization Costs	1	lump sum	$5,000.00	$5,000.00
Report Preparation	1	lump sum	$50,300.00	$50,300.00
			TOTAL	**$500,000.00**

SECTION 6

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APPENDIX A

PHOTOGRAPHS

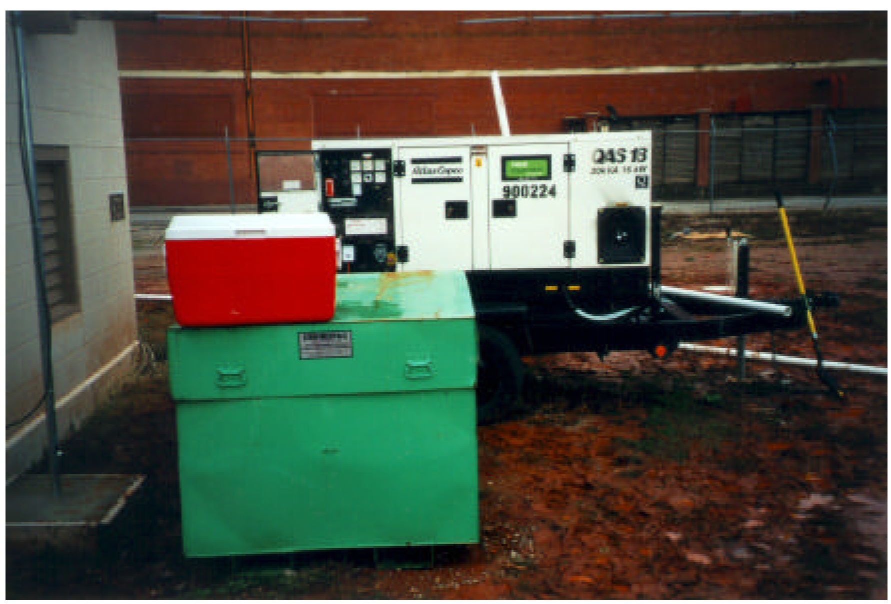
March14,2000

Drillingthroughrailroad tiesat01VEP0001.

March18,2000

Pilot-scaleSVEsystemwithgenerator.

March18,2000



Generator,facingeast.Thegreen box intheforeground containsdieselfuelforthegenerator.

APPENDIX B

GEOLOGIC BORING LOGS

This information is available upon request from
Mr. Pete Guest
Parsons Engineering Science, Inc.
1700 Broadway, Suite 900
Denver, Colorado 80290
(303) 831-8100

APPENDIX C

SOIL ANALYTICAL RESULTS

This information is available upon request from
Mr. Pete Guest
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Denver, Colorado 80290
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APPENDIX D

SOIL VAPOR ANALYTICAL RESULTS

This information is available upon request from
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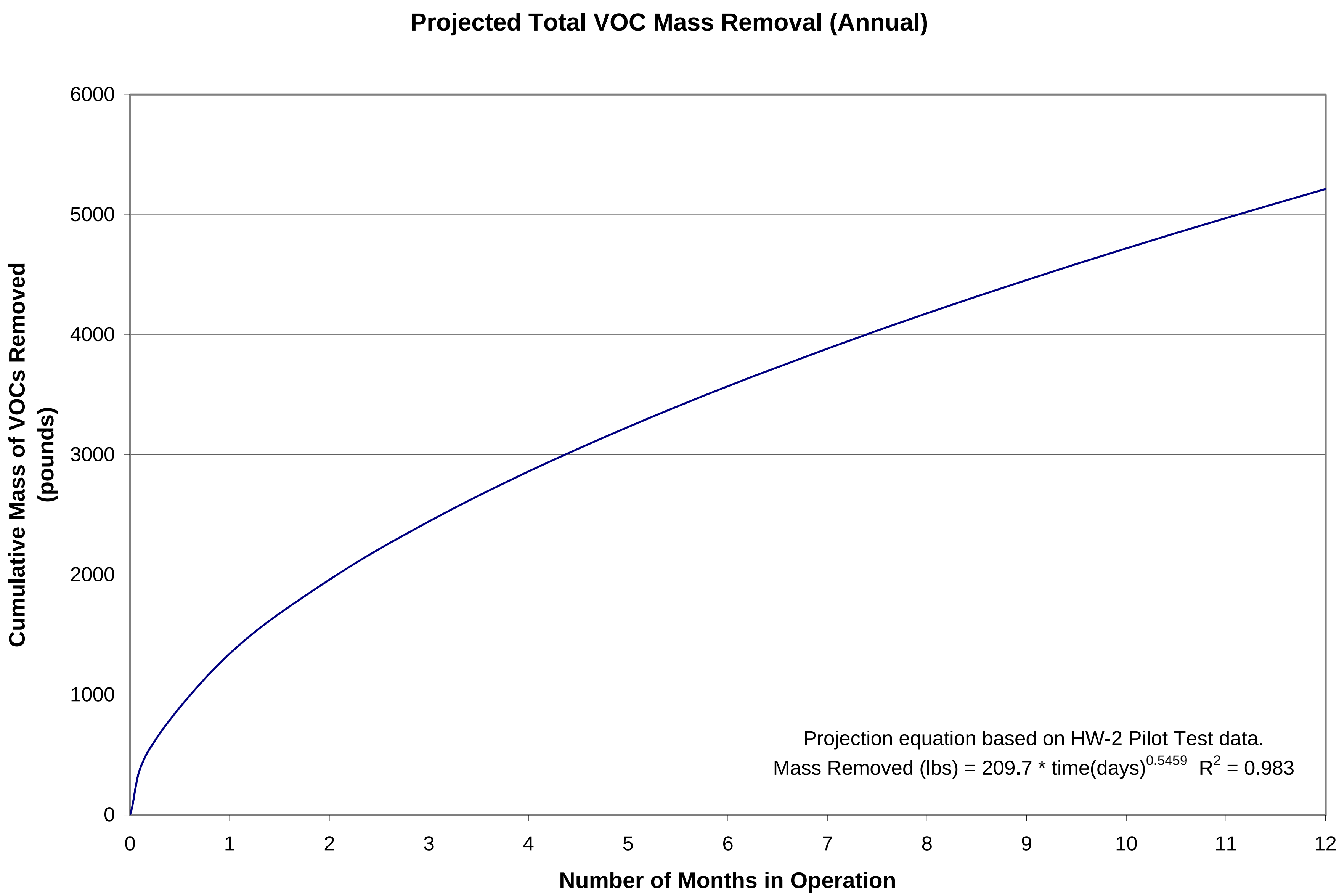
APPENDIX E

CALCULATIONS/SUPPORTING INFORMATION FOR CONCEPTUAL FULL-SCALE SVE SYSTEM

Projections for Contaminant Mass Removal

Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual Mass Removal
TCE	764	385	310	269	243	223	209	197	187	178	171	165	3301
Total VOCs	1343	618	486	416	371	338	313	294	277	264	252	242	5213

All values are in pounds.

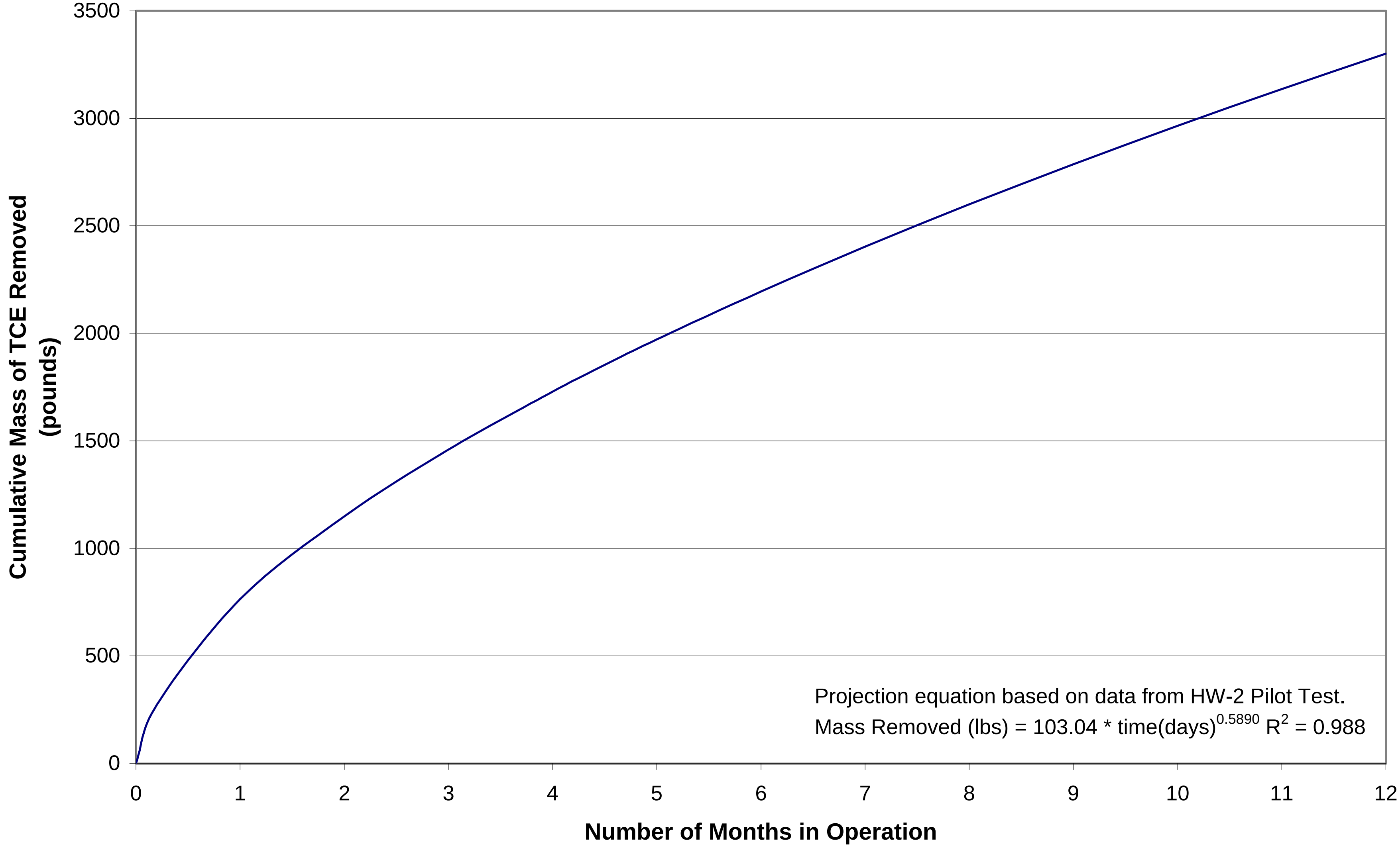


022/734429/TINKER/12.xls/VOC Annual

Calculations for VOC Removal Annually

Actual Hours	Actual Cum Days	Actual Removal	Calc. Removal	Cum Days	Cum Months	Log Function	Power Function
18.383	0.76595833	171.56	181.2951	0	0	0	0
42.13333	1.75555542	306.49	285.1178	6	0.2	516.733	557.6879
71.38333	2.97430542	393.93	380.2066	30	1	789.227	1342.638
90.69333	3.77888875	434.98	433.2928	60	2	906.583	1960.159
139.11	5.79625	517.19	547.2685	90	3	975.233	2445.791
				120	4	1023.940	2861.696
				150	5	1061.721	3232.412
				180	6	1092.590	3570.686
				210	7	1118.689	3884.167
				240	8	1141.297	4177.878
				270	9	1161.239	4455.33
				300	10	1179.077	4719.097
				330	11	1195.214	4971.131
				360	12	1209.946	5212.955

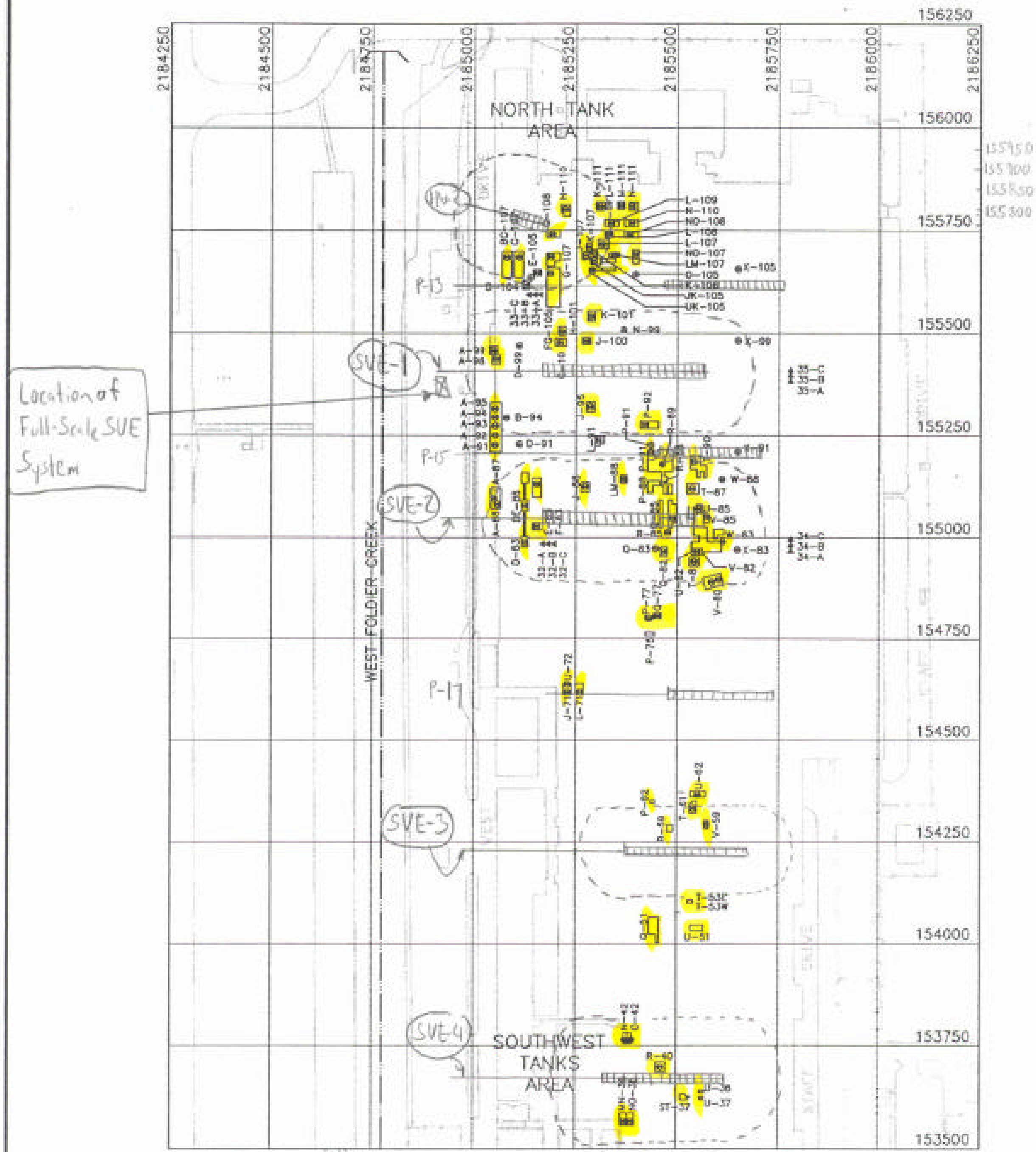
Projected Total TCE Mass Removal (Annual)



Calculations for TCE Removal Annually

Time	Actual Cum Hours	Actual Cum Days	Actual Removal	Calc Removal	Cum Days	Cum Months	Graphed Removal	Squared	Power Function	Linear
3/21/2000 14:22	0					0		0	0	124.91
3/22/2000 8:45	18.383	0.76595833	83.78	79.36738	6	0.2	272.467	-46.603	272.467	272.467
3/23/2000 8:30	42.13333	1.75555542	153.59	157.17551	30	1	423.450	-4584.15	763.889	912.32
3/24/2000 13:45	71.38333	2.97430542	201.79	206.63509	60	2	488.475	-24004.8	1149.045	1699.73
3/25/2000 9:10	90.69333	3.77888875	225.75	229.09529	90	3	526.512	-58261.95	1458.998	2487.14
3/27/2000 9:35	139.11	5.79625	276.57	269.22591	120	4	553.500	-107355.6	1728.397	3274.55
					135	4.5	564.549	-137466.1	1852.561	3668.255
					150	5	574.433	-171285.8	1971.168	4061.96
					180	6	591.537	-250052.4	2194.63	4849.37
					210	7	605.998	-343655.6	2403.217	5636.78
					240	8	618.525	-452095.2	2599.862	6424.19
					270	9	629.574	-575371.4	2786.629	7211.6
					300	10	639.458	-713484	2965.038	7999.01
					330	11	648.399	-866433.2	3136.249	8786.42
					360	12	656.562	-1034219	3301.171	9573.83

from "Groundwater Treatment Plant Technical Assessment Report", draft, Sept 1997



P-13, P-15, and P-17 are existing horizontal groundwater extraction wells.
HW-2 is an existing horizontal SVE well.
SVE-1 through SVE-4 are conceptual locations for horizontal, full-scale SVE wells.

400' 200' 0 400'

Approximate Scale in Feet

LEGEND:

- PERENNIAL STREAM
- INTERMITTENT STREAM
- ▲ MONITORING WELL
- ⊕ SOIL BORING
- ⊖ PIT SAMPLE

SOURCE:
BATTELLE, 1995

FIGURE 2-2

BUILDING 3001
PITS
NORTHEAST QUADRANT
TINKER AFB, OKLAHOMA

PARSONS ENGINEERING SCIENCE, INC.

NEQ-PTS