

**SOIL REMEDIATION PLAN**

**Prepared for:**

**BLACK & DECKER (U.S.) INC.  
Hampstead, Maryland**

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## SECTION 1 INTRODUCTION

### 1.1 OVERVIEW

This Soil Remediation Plan has been prepared to meet the requirements of Condition IV.T. of the Administrative Consent Order between the State of Maryland Department of the Environment (MDE) and Black & Decker (U.S.) Inc. (Consent Order) finalized during April, 1995. Specifically, Condition IV.T. of the Consent Order calls for a description of the proposed methods for soil remediation and a statement of schedules and goals for soil remediation. A final version of this document will become part of the administrative record for the site which is to be maintained at a public repository in the town of Hampstead.

### 1.2 OBJECTIVES

The objective of this Soil Remediation Plan is to provide the information required by Condition IV.T. of the Consent Order. Each of the elements of that condition have been addressed in the plan. Specifically, the primary objectives of this Soil Remediation Plan are to provide a summary of previous site investigations (Section 2), a detailed description of the process options available and the rationale for selecting the recommended soil remediation technologies (Section 3), and a plan for conducting pilot testing of the selected remediation technologies (Section 4). A description of the implementation of the selected soil remediation alternative is presented in Section 5. A schedule for implementation of the soil remediation is presented in Section 6.

**SECTION 2**  
**PREVIOUS SITE INVESTIGATIONS**

**2.1 INITIAL GROUNDWATER INVESTIGATION**

In April 1984, as part of an effort to determine the impact of a gasoline spill at the Hampstead Exxon service station, water samples of the supply wells at the Hampstead Black & Decker (U.S.) Inc. facility were collected and analyzed by the State of Maryland for volatile organic compounds (VOCs). As a result of the detection of VOCs, a groundwater investigation was conducted at the site to evaluate potential contaminant source areas in the northwestern corner of the property. The field investigation included geophysics, installation and analytical sampling of monitor wells, and aquifer testing. Based on this initial groundwater investigation, it was concluded that several potential source areas may have contributed to the groundwater contamination.

**2.2 PHASE I ACTIVITIES**

In 1987, the Black & Decker Corporation retained Roy F. Weston, Inc. (WESTON®) to conduct a comprehensive environmental investigation of the facility. Phase I of Weston's environmental investigation, conducted in November and December 1987, utilized soil gas sampling, soil borings, geophysical surveying, test pit excavations, surface water (lagoon) and sediment sampling, and groundwater sampling in an effort to identify potential sources of the constituents found in the groundwater. Data collected during the Phase I investigation were evaluated and the resultant conclusions were incorporated in the design of the Phase II investigation. Results of these investigations were presented in the Environmental Investigation Report (EIR), submitted to MDE during April, 1989.

Specifically in the storage tank area, soil gas analysis was one of the investigative techniques used to determine the presence of soil contamination. Nineteen soil-gas samples were collected and analyzed for TCE and PCE from Tank Farm 1 (eight

samples), Tank Farm 2 (three samples), and the aboveground storage tank area (eight samples). Sample locations were concentrated around distribution pipes and the underground and aboveground tanks identified on the site plans.

In addition, soil borings were performed at five locations at the storage tank area based on the soil gas results. Samples were collected from the borings and submitted for TPH and VOC analysis. Sample results indicated that further characterization of the soils in Tank Farms 1 and 2 in Phase II was warranted.

### 2.3 PHASE II ACTIVITIES

Phase II of Weston's environmental investigation, conducted in June, July, and December 1988, involved supplemental monitor well installation, additional soil borings, and groundwater and soil sampling and analysis. These activities aided in further definition of the extent of contamination of the on-site soil and groundwater, characterized routes of migration, and provided preliminary data to be considered in developing remedial alternatives.

During the Phase II investigation, 17 monitor wells were installed across the site (including monitor well RFW-8 at Tank Farm 2). Groundwater samples were collected from the newly installed monitor wells, the previously installed monitor wells, and 3 production wells (wells 5, 6, and 7) and submitted for VOC analysis. The groundwater sample results confirmed that the major contaminants of concern in the groundwater were TCE and PCE and a remediation plan was recommended to recover affected groundwater and prevent its migration off-site. In addition, during Phase II, several sets of water level measurements were collected in order to determine groundwater flow directions at the site.

Specifically in the tank farm area, a total of 13 soil borings were performed at Tank Farm 1 and a total of 14 soil borings were performed at Tank Farm 2 during the Phase II



investigation. Soil samples were collected from borings at both areas and analyzed for VOCs and TPH. TCLP analysis was also conducted on selected samples to provide an indication of the mobility of the contaminants in the soil. An overall assessment of Tank Farm 1 suggested that the TPH and VOCs in the soil were present below concentrations which would impact groundwater on-site. However, an overall assessment of Tank Farm 2 suggested that VOCs, particularly TCE and PCE, in the soil were present at concentrations which could potentially impact the groundwater.

#### **2.4 REMEDIATION SYSTEM DESIGN ACTIVITIES**

Based on the Phase I and II investigations, remediation strategies to recover and treat the contaminated groundwater were proposed in the 1989 EIR. A work plan for soil and groundwater remediation was developed and submitted to MDE in December of 1989. In 1991, after receiving MDE approval of the work plan, Weston initiated a remediation system design investigation. The field investigation for the remedial design of the groundwater recovery and treatment system at the Black & Decker facility involved geophysics, well installation (including monitor well RFW-16 inside the building at the northeast corner), aquifer testing and groundwater sampling.

Specifically at monitor well RFW-16, the field screening results of the soil during drilling and groundwater analytical results indicated that TCE was present at concentrations that suggested the presence of a TCE source area at the northeast corner of the building that would require soil remediation

#### **2.5 REMEDIATION SYSTEM OPERATION ACTIVITIES**

During 1994, Black & Decker completed construction of the groundwater remediation system and, in August 1994, after MDE and DNR approval of the air, water appropriation and NPDES permit applications, the groundwater remediation system began operation. The on-going field activities that are conducted as a part of Weston's remedial system

operation include quarterly groundwater sampling from the ten recovery wells and 18 monitor wells and monthly water level measurements collected in wells specified in the Water Appropriation Permit, issued by the Water Rights Division of the Maryland Department of Natural Resources.

**SECTION 3**  
**SOIL REMEDIATION TECHNOLOGIES**

Black and Decker had originally considered two major options for soil remediation at Tank Farm 2 and the surrounding area. These were (1) excavation and on-site treatment, and (2) soil vapor extraction. Based principally on occurrence of soil contamination underneath the building near RFW-16, which could not be reasonably addressed by an excavation approach, and on other site specific factors, soil vapor extraction (SVE) has been selected as the best technology to address the Tank Farm 2 area and soil beneath the northeast corner of the existing building. This section describes the available variations of the SVE technology and identifies which process options are most suitable. The process options potentially applicable for soil remediation at these two source areas are SVE alone, SVE combined with air sparging, and SVE aided biodegradation (or bioventing). Descriptions of these remedial technologies are provided in subsection 3.1. A summary of previous findings and the rationale for choosing a specific process option for each of these areas are included in subsection 3.2.

**3.1 REMEDIAL TECHNOLOGY DESCRIPTION**

**3.1.1 Soil Vapor Extraction (SVE)**

Soil vapor extraction (SVE) is an effective in-situ technology that has many advantages over the conventional excavation, treatment and disposal approach. The SVE system removes VOCs from the soil by mechanically drawing air through the soil pore spaces. VOCs volatilize into the air as the air moves through the soil. This is accomplished by installing a series of vents in the vadose (unsaturated) zone of the soil and applying a vacuum to the vents by using a blower. The VOC-laden air stream is then collected and discharged or treated, depending upon the concentrations and types of VOCs present. This technology has also been used to remove VOCs from bedrock fractures using vents installed into the bedrock, where there is unsaturated bedrock. The application of SVE is limited only in cases where the permeability of the soil is too low to establish a sufficient

air flow and radius of influence. The radius of influence and final design parameters can be determined by field pilot testing. SVE can achieve remediation with a minimum of site disturbance and can be installed under buildings to address inaccessible soils.

### **3.1.2 SVE Combined with Air Sparging**

Because SVE draws air through the unsaturated zone only, SVE does not effectively remediate contamination below the water table. Using air sparging in conjunction with SVE is an emerging hybrid technology which has been shown to extend the effectiveness of the SVE process by providing an effective means for remediating VOCs in the saturated zone. Air sparging involves the injection of clean air below the water table. As the injected air flows up through the saturated soil, adsorbed and aqueous VOCs are volatilized. The injected air is subsequently removed above the water table with SVE. In order to be effective, a sufficient aquifer thickness and hydraulic conductivity are necessary. By forcing air through the saturated zone, air sparging can also significantly increase the concentration of dissolved oxygen (DO) in the groundwater. The increased DO concentrations can potentially increase the rate of aerobic biodegradation of organic contaminants within the saturated zone. This latter mechanism is generally effective only for readily biodegradable organics.

### **3.1.3 Bioventing**

Bioventing is an emerging technology for in-situ bioremediation of unsaturated soils. Application of bioventing relies upon the following concepts: 1) the contaminants in the soils are aerobically biodegradable, 2) the soils contain microbial populations capable of biodegrading the target constituents, 3) biological degradation of the target constituents is limited by oxygen supply, and 4) venting of the soils by SVE or air injection can be used to supplement the oxygen supply and support bioremediation.

Mechanically, bioventing is implemented in a manner analogous to SVE alone. One or more ventilation wells are installed and air is injected or withdrawn by mechanical

blowers, inducing air flow within soil pore spaces. Bioventing differs from SVE alone in that the latter technology induces a high air flow rate to maximize stripping of VOCs from soils, while bioventing uses lower air flow rates in an effort to minimize stripping and supply only sufficient oxygen to meet the biological oxygen demand of the contaminants. In addition, nutrient addition may be provided to enhance growth, depending upon an assay of soil nutrient levels.

To evaluate the feasibility of performing in-situ bioventing in the vadose zone, bioassessments of targeted area soil samples are conducted in the laboratory. Site bioassessments provide general information about site specific conditions which impact bioremediation. Parameters examined during a bioassessment for vadose zone soil include soil solution pH, nutrient analysis, microbial population density and microbial stimulation testing. In addition, field pilot testing is conducted to confirm sufficient air flow and radius of influence and to provide final design information.

### **3.2 PROPOSED REMEDIAL TECHNOLOGY FOR THE TWO PRIMARY SOURCE AREAS**

#### **3.2.1 Tank Farm 2 Area**

##### **3.2.1.1 Summary of Previous Findings**

A source characterization study confirmed that the contaminants of concern in the soils at Tank Farm 2 are petroleum hydrocarbons and the chlorinated hydrocarbons tetrachloroethene (PCE) and trichloroethene (TCE). Total petroleum hydrocarbons (TPH) concentrations in the soils sampled ranged from below detection (ND) to 93,000 ppm; chlorinated hydrocarbons concentrations ranged from ND to 7 ppm. Soils with high chlorinated hydrocarbon concentrations were generally also characterized by high TPH concentrations (see Figure 3-1).

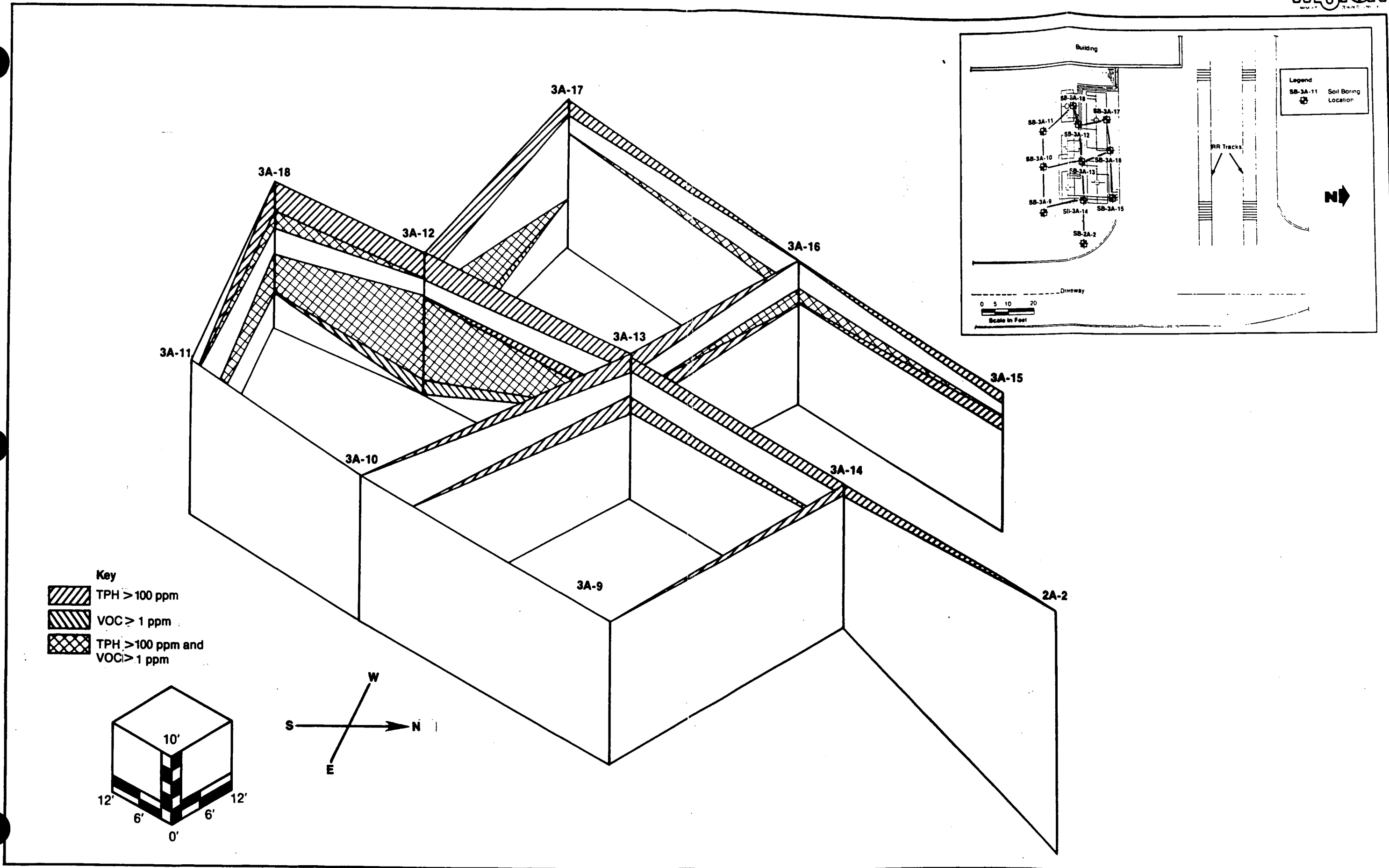


FIGURE 3-1 TANK FARM 2 SOIL PROFILE  
DEPICTING ZONES OF TPH  
CONCENTRATION 100 PPM AND  
VOC CONCENTRATION > 1 PPM

Samples from 11 closely spaced borings around Tank Farm 2 were collected and analyzed for VOCs and TPH to define the horizontal and vertical extent of the soil contamination. The data indicated, as depicted in Figure 3-1, that TPH concentrations >100 ppm and VOC concentrations >1 ppm are distributed in the soils:

- Throughout the tank area above 853 feet MSL (top 6 feet of soil), in an approximately 1,800-square foot area.
- In the central part of Tank Farm 2, closest to the building wall from the surface to 839 feet MSL (20 feet below ground surface).

A TCLP leachate analysis of select samples indicated that chlorinated hydrocarbons were sufficiently mobile in the soils to represent an ongoing potential source of groundwater contaminants.

#### **3.2.1.2 Selection of a Remedial Technology**

SVE alone is not likely to be sufficiently effective for remediation of contaminated soil in the Tank Farm 2 area because of the presence of nonvolatile petroleum hydrocarbons from the cutting oils in addition to the volatile compounds, PCE and TCE. The VOCs may be dissolved in the oils which results in a much lower vapor pressure than for VOCs alone. Therefore, the volatilization rate may be too low. The non-volatile oils would not be extracted due to their low vapor pressure. SVE with air sparging is not applicable to this area because the soil contamination ends above the water table. SVE/bioventing is the most effective option, because it can stimulate in-situ biological activity and bioremediate the cutting oils. Once the cutting oils are degraded, the VOCs may be removed by a combination of bioremediation and soil vapor extraction. The bioventing process is, therefore, selected for soil remediation in the Tank Farm 2 area.

### **3.2.2 Soil beneath the Northeast Corner of Existing Building**


#### **3.2.2.1 Summary of Previous Findings**

One of the primary source areas for VOC contamination of site groundwater is suspected to be the soil below the northeast corner of building floor, adjacent to the aboveground storage tank (AST) area that included a TCE tank. Relatively minor spills have been hypothesized as having potentially occurred in association with loading of TCE from tank trucks to the TCE storage tank, although none were observed or reported by plant personnel. Groundwater samples from monitoring well RFW-16 (located inside the building in this area) consistently showed high levels of TCE (>100 ppm). Chemical data for soils in this area of the building are not available. Because of high concentrations of TCE in groundwater (as indicated by RFW-16), the presence of soil contamination in this area is anticipated.

#### **3.2.2.2 Selection of a Remedial Technology**

The soils in the vadose zone underneath the building in the immediate area of the former TCE tank likely represent an on-going source of groundwater contamination. Remediation of these soils would significantly accelerate the on-going groundwater remediation effort at the site. SVE with air sparging was previously considered potentially applicable for groundwater and soil remediation in this source area. After the groundwater remediation system was started-up, however, the water table in this area was significantly depressed (>44 ft bgs). RFW-16 is currently dry and the water table is believed to be close to the bedrock in this area. Due to the low hydraulic conductivity in the upper bedrock, the feasibility of air sparging below water table is questionable. Therefore, application of air sparging below the water table in this source area was eliminated from further consideration. If the VOCs in this area are the result of unloading hose releases and there are no high concentrations of cutting oil hydrocarbons under the building, this area will respond more rapidly to SVE than to bioventing. Therefore, a SVE system is recommended for soil remediation in the northeast corner of the existing





building. This selection can be verified by sampling soil during the SVE pilot test needed to design the SVE soil remediation system.

## SECTION 4 PILOT TESTING

Pilot tests are needed to verify the effectiveness of SVE for treatment of VOC contaminated soil beneath the northeast corner of the building and SVE aided biodegradation (bioventing) for treatment of soil containing nonvolatile petroleum hydrocarbons together with volatile compounds in the Tank Farm 2 area, and to gather site-specific data to allow for full-scale system design. During pilot system operation, full scale design criteria will be obtained via monitoring of vadose zone air pressures and extracted vapor. The tasks associated with installation and operation of the pilot systems are presented in the following subsections.

### 4.1 TANK FARM 2 AREA

The pilot test for bioventing of hydrocarbons in Tank Farm 2 area soils will be based upon principles and methods outlined in "Test Plan and Technical Protocol for a Field Treatability Test for Bioventing", Air Force Center for Environmental Excellence (AFCEE) May 1992 (the protocol) (Attachment A). The following sections outline the approach to the bioventing pilot test.

#### 4.1.1 Extraction Vent and Monitoring Probe Installation

One extraction vent will be installed approximately at the center of the Tank Farm 2 area. This location corresponds to the soil zone with high concentrations of TPH (>100 ppm) and VOC (>1 ppm) as shown in Figure 3-1, Tank Farm 2 Soil Profile.

The general configuration of the vent is illustrated in Figure 4-1. Considering the shallow depth of contamination in the Tank Farm 2 area (extends to approximately 20 ft bgs), a 3-in. diameter vent is expected to provide adequate airflow for air permeability/radius of influence testing. The soil extraction vent will be installed using hollow-stem auger drilling techniques. The vent will be constructed of schedule 40 PVC, and will be

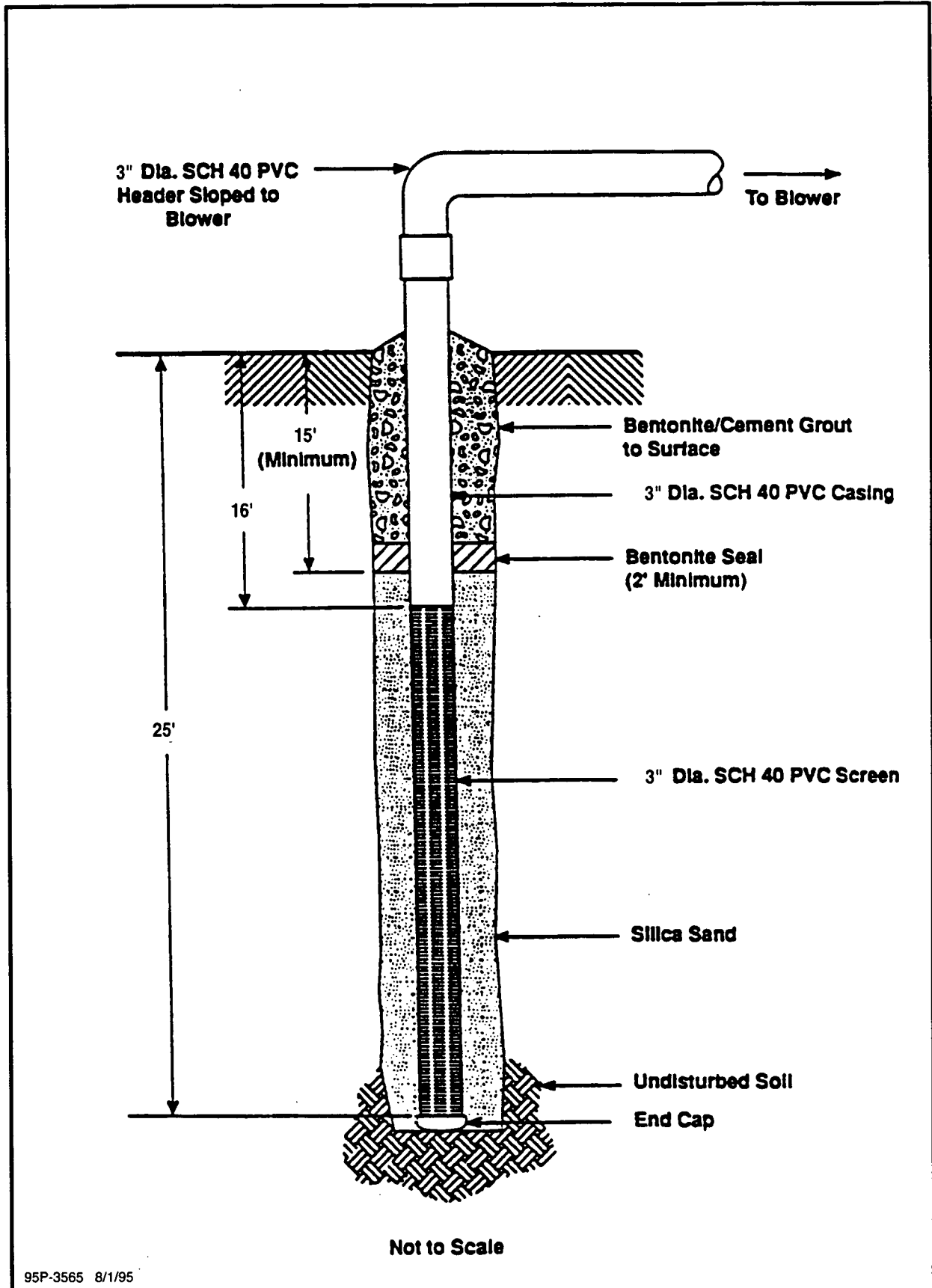


FIGURE 4-1 VACUUM VENT CONSTRUCTION

screened with a slot size that maximizes airflow through the soil. The screened interval will extend from 15 ft bgs to 25 ft bgs. The annular space corresponding to the screened interval will be filled with silica sand or equivalent. The annular space above the screened interval will be sealed with wet bentonite and grout to prevent short-circuiting of air from the surface.

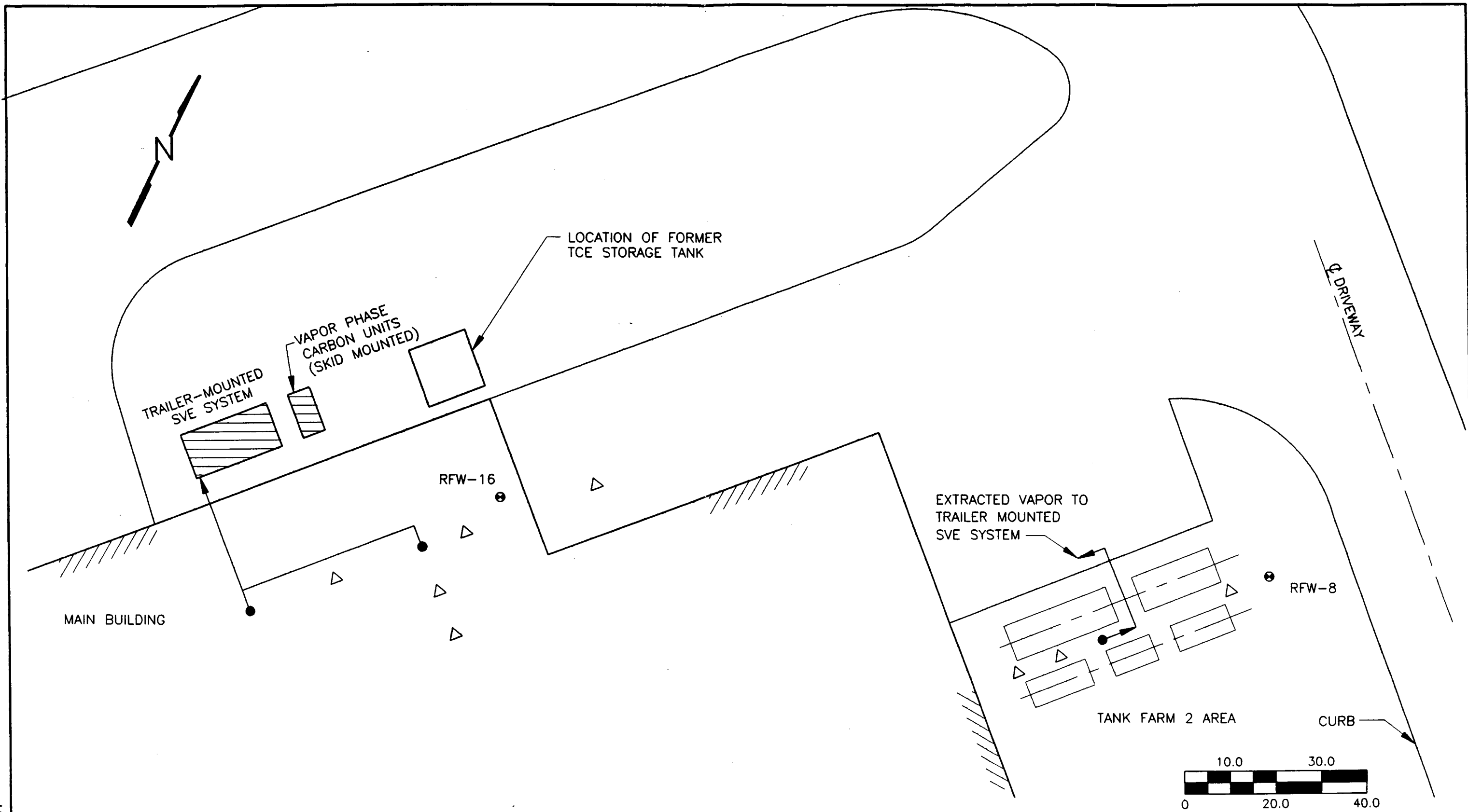
Figure 4-2 shows the layout of the SVE pilot scale system. A trailer-mounted SVE blower system will be used for the pilot test. The trailer-mounted pilot plant consists of the following equipment:

- One knockout tank (moisture separator tank)
- One particulate air filter
- One vacuum relief valve
- One 7.5 HP positive displacement vacuum blower and motor
- Air/Air heat exchanger
- Piping, valves, and instrumentation

Other equipment to be used during the pilot test include above ground piping for extracted vapor and instrumentation.

The vent will have a sampling port for operational measurements, such as static pressure, temperature, and air flow rate. Vapor extracted from the vent will be drawn through the aboveground piping under vacuum to the vacuum blower system. The vapor will pass through the knockout tank (for removing entrained liquids), through the vacuum blower, through the heat exchanger, through two vapor-phase GAC units connected in series, and will then be discharged to the atmosphere. The SVE blower system will have sampling ports for operational measurements at SVE system inlet (velocity and static pressure, temperature, relative humidity) and at heat exchanger inlet and outlet (temperature).

Three (3) pressure monitoring (PM) probes (one on the east and two on the west of the soil vent), each screened to two (2) depths will be installed in a straight line radially from the soil vent. The proposed locations of the nested PM probes are shown in Figure 4-2.



- SOIL EXTRACTION VENT LOCATION
- △ PRESSURE/SOIL GAS MONITORING POINT LOCATION
- ⊙ MONITOR WELL (EXISTING)

**FIG. 4-2**  
**SOIL VAPOR EXTRACTION (SVE)**  
**PILOT TEST SYSTEM LAYOUT**  
**TANK FARM 2 AREA AND**  
**INSIDE BUILDING SOIL REMEDIATION**  
 BLACK & DECKER, INCORPORATED  
 HAMPSTEAD MARYLAND



|              |                 |           |      |                         |
|--------------|-----------------|-----------|------|-------------------------|
| DRAWN<br>JTT | DATE<br>7/20/95 | DES. ENG. | DATE | W. O. NO.<br>2501004001 |
| CHECKED      | DATE            | APPROVED  | DATE | DWG. NO.<br>FIG 4-2     |

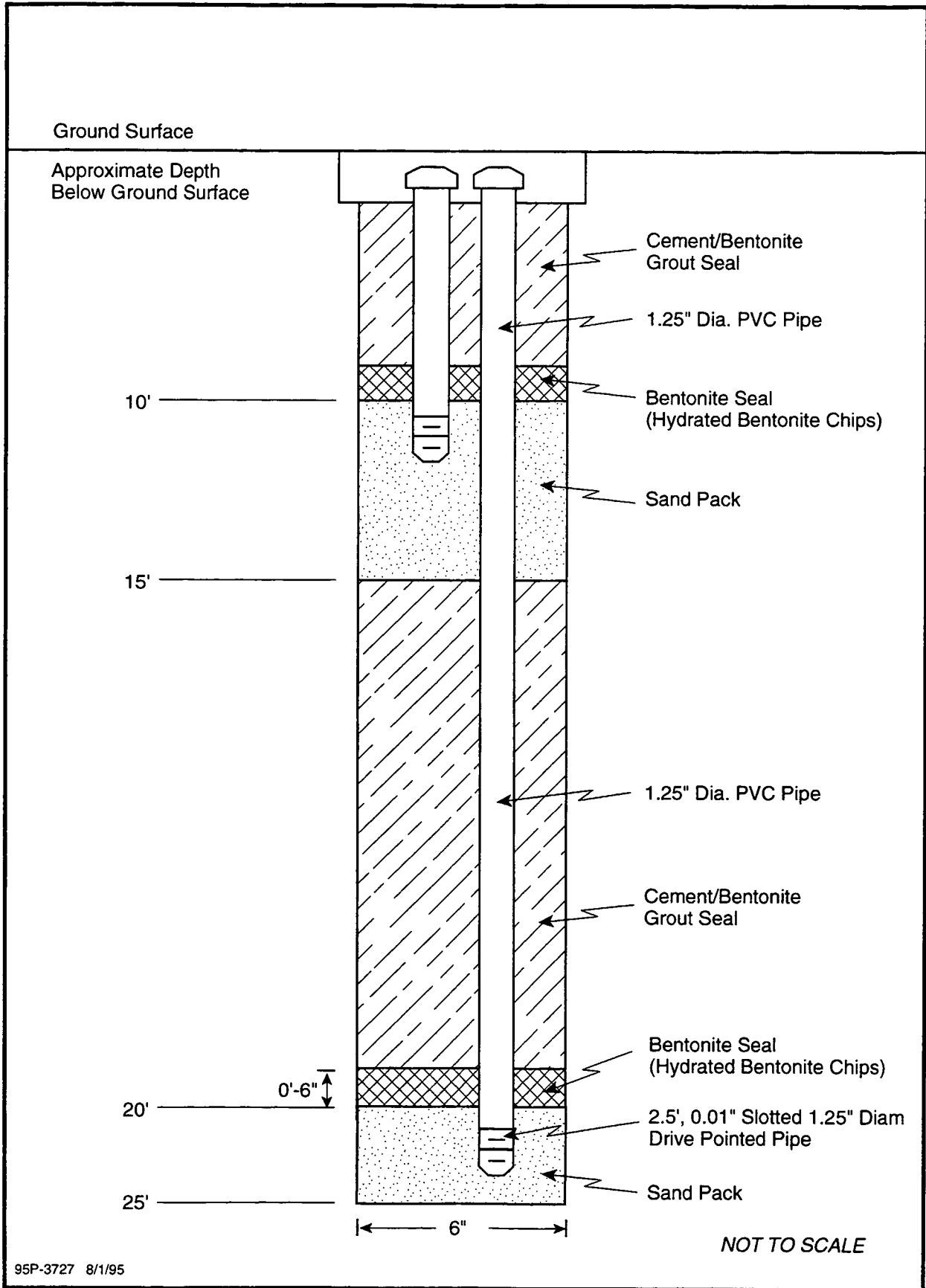
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The nested PM probes on the west side will be positioned at 10 ft intervals and the PM probe on the east side will be located approximately 30 ft from the extraction vent. The deepest probe of the nested PM probe assembly will be installed to a depth of about 23 ft bgs. The shallowest probe will be installed to a depth of about 12 ft bgs. Each probe will consist of a 2.5-ft section of 0.01-inch slotted schedule 40 PVC, and 1.25-inch O.D Schedule 40 PVC riser pipe. A 5-ft sand pack will be placed around the 2.5 ft slotted PVC pipe section for the shallow and deeper probes. The screened intervals for the probes will be located at 11 to 13.5 ft bgs and 21 to 23.5 ft bgs. A layer of hydrated bentonite will be placed on top of the two sand packs. A cement/bentonite grout seal will be used between the shallowest sand pack and the bentonite seal above the bottom interval. The 6-inch borehole for the nested probes will be completed with a cement/bentonite grout seal. The top of the nested probes will be covered with PVC caps, which will have a port for attaching a pressure monitoring gauge. A schematic of the nested soil PM probe assembly is shown in Figure 4-3.

#### **4.1.2 Soil Sampling During Vent and Monitoring Probe Installation**

The extent of VOC and TPH contamination in the Tank Farm 2 area soils has been well documented. During boring installation for the soil vent, split spoon soil samples will be collected from three different depths (target depth intervals being 0 and 7 ft bgs, 7 and 15 ft bgs, and 15 and 25 ft bgs). Sample locations will be determined in the field based on PID readings. Each sample will be analyzed for TPH, TCE and PCE. In addition, three samples will be analyzed for total kjeldahl nitrogen (TKN), total phosphorous, alkalinity, total iron, moisture, hydraulic conductivity, porosity, pH, and total heterotrophic plate count. Samples will also be collected during boring installation for monitoring probes. From zero to three samples will be selected in the field for the same analysis based upon PID readings.

VOC and TPH data will be used to confirm the level and spatial distribution of TCE, PCE and TPH in the Tank Farm 2 soils.



**FIGURE 4-3 SCHEMATIC OF NESTED SOIL PRESSURE MONITORING PROBES**

Nutrient data (TKN and total phosphorous) as well as soil pH will be used to assess the nutrient and chemical suitability of the soils for biological activity. Data on alkalinity and iron will be used to evaluate the potential for fouling of the extraction system. Total heterotrophic microbial counts will demonstrate the existing (indigenous) microbial levels in the soils. Many of the inorganic nutrients needed in trace amounts are naturally present in the soil; however, fixed nitrogen compounds and ortho-phosphate are generally less abundant. Low concentrations of these two nutrients can limit microbial activity. Nutrient requirements will be determined based on soil nutrient data. This will determine whether provisions will be necessary for injection of dilute solutions (1%) of ammonium chloride and/or monosodium phosphate into the contaminated soil zone via an injection well.

#### **4.1.3 Pilot Test Procedures**

The aboveground piping will be installed following the installation of the vent and pressure monitoring probes. Following mobilization of the SVE trailer, the equipment will be connected to the electrical service provided by Black & Decker. The vacuum blower will be tested to verify the proper air flow direction. The piping from the vent will be connected to the knockout tank inlet line. The heat exchanger outlet will be connected to the GAC unit.

The initial step in the pilot test will be an in-situ soil permeability test using the vent well and soil monitoring points. This test will be conducted according to the general procedure outlined in the protocol (Section 5.6.2) to confirm the radius of influence of the vent well (see Attachment A).

After completion of the in-situ permeability test, 3 test runs (each at different negative pressure as measured at the extraction vent) of relatively short duration (each up to 4 hours) will be conducted to determine the optimal operating parameters to yield the maximum contaminant removal. During each test run, operational measurements (such as flow rate, static pressure) at the vent, at the PM probes, and before and after the



blower will be taken at regular time intervals. HNu/OVA measurements after the blower and after the carbon system will also be recorded in the field log book. One air sample will be collected from the blower discharge at the end of each test run for total VOC analysis to be performed at an off-site analytical laboratory. Data obtained from the test runs will be used to estimate the capacity and changeout requirements of activated carbon units, establish air flow rates, and determine VOC removal rates. It is expected that the total duration of pilot test will be about 2 days.

#### **4.2 SOIL BENEATH THE NORTHEAST CORNER OF THE EXISTING BUILDING**

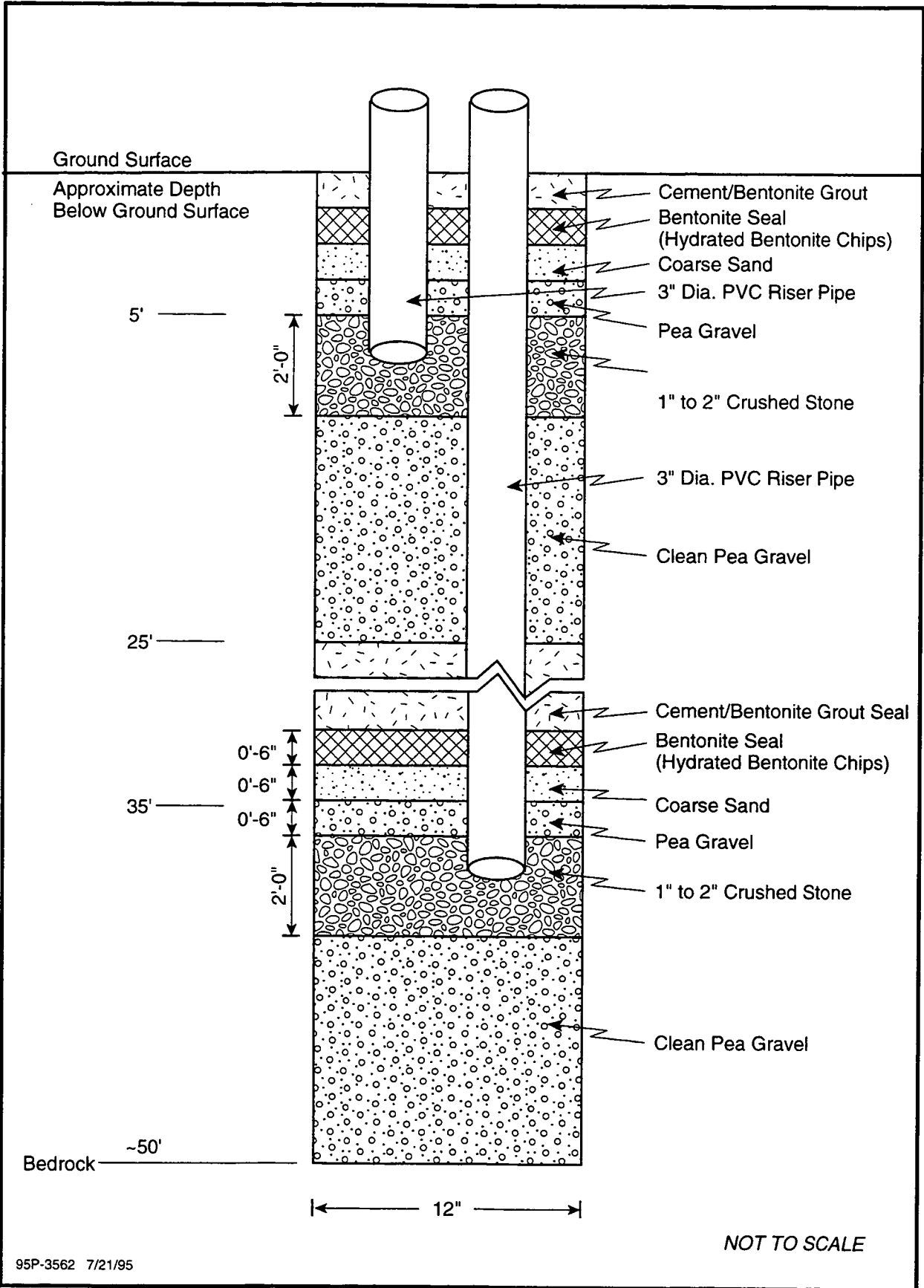
A pilot SVE test for remediating soils underneath the northeast corner of the existing building will be conducted. The following subsections outline the approach to the SVE pilot test.

##### **4.2.1 Extraction Vents and Monitoring Probes Installation**

The pilot SVE test will consist of two soil extraction vents of nested design, spaced 40 feet apart, located inside the northeast corner of the building adjacent to the former TCE storage tank. The soil vents will be of nested design with two treatment intervals, an upper interval to test hydraulic and chemical characteristics of the moderate permeability zone and a lower interval to test the characteristics of the higher permeability zone near the bedrock interface. This will allow optimization of flows and vacuum pressures based upon concentration and conductivity. Figure 4-2 shows the approximate locations of the two soil vents inside the building. We currently estimate that the two treatment intervals will be located at 5 to 25 ft bgs and 35 to 50 ft bgs. The lower interval will extend to approximately the top of bedrock, unless field screening and laboratory data suggest a more shallow treatment zone would be favorable, and unless the water table occurs in the saprolite.

The nested extraction vent depths and construction requirements are illustrated on Figure 4-4. The borehole will be drilled to bedrock refusal or the water table, whichever is reached first. We estimate that this will occur at a total depth of approximately 50 ft bgs. Following completion of the borehole, two 3-inch diameter, schedule 40 PVC, vacuum extraction riser pipes will be installed to total depths of 6 ft bgs and 36 ft bgs. The bottom 13 ft below the deeper riser will be filled with clean pea gravel. The pea gravel will allow drawn air to enter the vent, but will prevent any soil particles from entering the vent. A 2-ft layer of clean crushed stone (washed ASTM C33 Size Number 2 coarse aggregate), with an average diameter of 1 to 2 inches, will be placed on top of the pea gravel. The crushed stone will prevent pea gravel from entering the riser pipe. The pea gravel and crushed stone layers constitute the 15-ft treatment interval from approximately 35 to 50 ft bgs for the deeper riser. Thin layers of pea gravel and coarse sand followed by a 1-ft layer of hydrated bentonite will be placed on top of the crushed stone layer. The bentonite will provide an air-tight seal to prevent short circuiting (i.e., prevent leakage of air from the upper zone). A grout seal consisting of a 8-ft layer of a cement/bentonite mixture will be placed on top of the bentonite seal. For the shallower riser pipe, the treatment interval will consist of 2-ft layer of crushed stone and 18-ft layer of clean pea gravel, from approximately 5 to 25 ft bgs. Layers of pea gravel, coarse sand, hydrated bentonite and cement/bentonite mixture (3-ft) will be placed on top of the crushed stone layer.

The actual radius of influence of each vent will be assessed by measuring subsurface negative pressures at two depths and at various distances from the extraction vents. Pressure monitoring (PM) probes of nested design will facilitate measurement of subsurface pressures at two depths corresponding to the two treatment intervals. PM probes are slotted drive points installed in the subsurface soils that permit subsurface static pressure measurement. The slotted portion of the drive point is typically 2.5 ft in length.



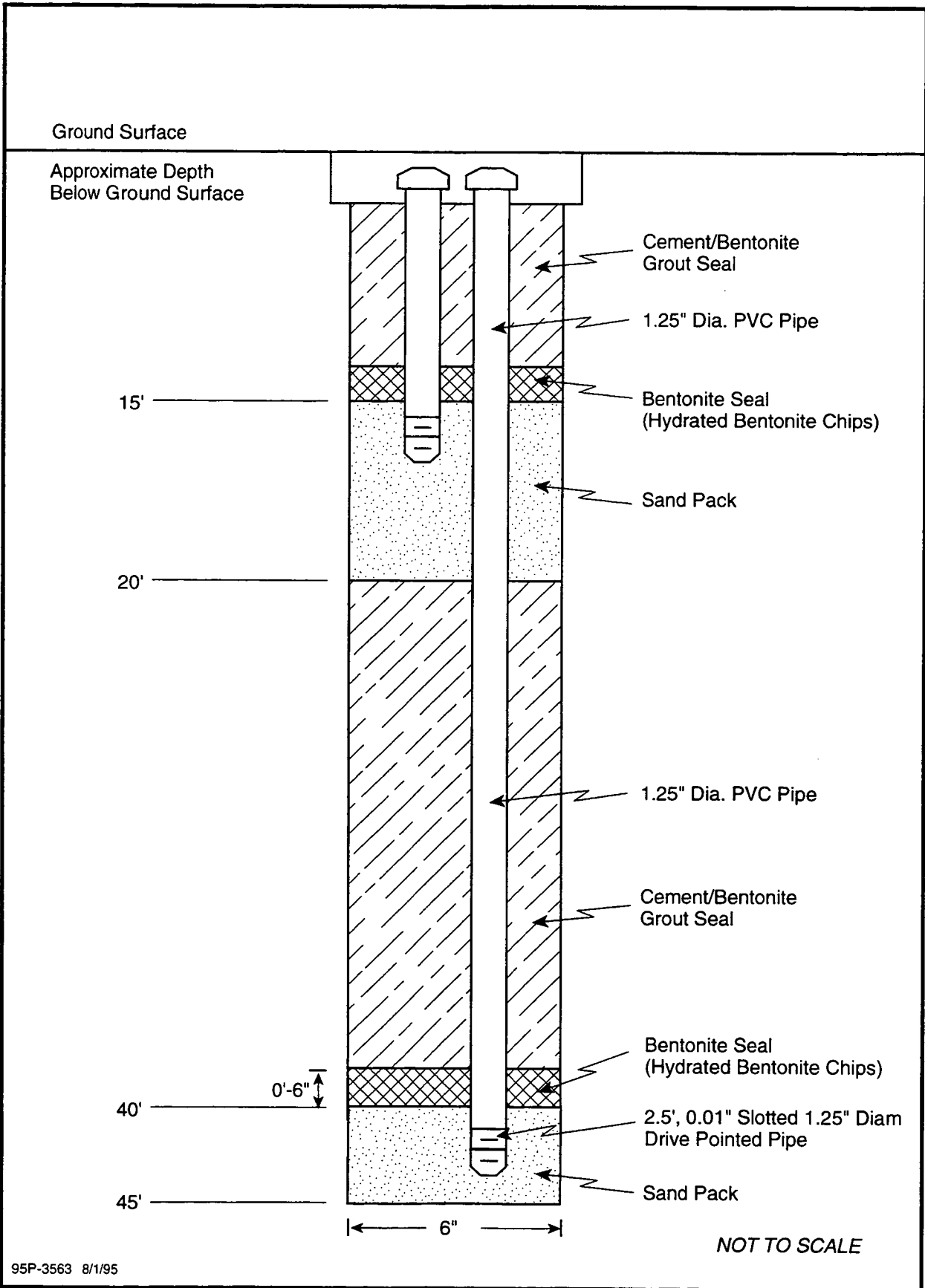
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**FIGURE 4-4 SCHEMATIC OF NESTED EXTRACTION VENTS**

Figure 4-2 shows the proposed locations of the five nested pressure monitoring probes for the soil extraction vents. The construction details for the soil pressure monitoring probes are shown on Figure 4-5. The deeper probe of the nested PM probe assembly will be installed to a depth corresponding to the center of the lower extraction vent zone or about 43 ft bgs. Depending on depth to groundwater measured during the installation, actual probe depth will be field determined. The shallower probe will be installed to a depth of about 18 ft bgs. Each probe will consist of a 2.5-ft section of 0.01-inch slotted schedule 40 PVC, and 1.25-inch O.D. Schedule 40 PVC riser pipe. A 5-ft sand pack will be placed around the 2.5 ft slotted PVC pipe section for the shallow and deeper probes. The screened intervals for the probes will be located at 16 to 18.5 ft bgs and 41 to 43.5 ft bgs. A layer of hydrated bentonite will be placed on top of the two sand packs. A cement/bentonite grout seal will be used between the shallowest sand pack and the bentonite seal above the bottom interval. The 6-inch borehole for the nested probes will be completed with a cement/bentonite grout seal. The top of the nested probes will be covered with PVC caps, which will each have a port for attaching a pressure monitoring gauge.

#### **4.2.2 Soil Sampling During Vent and Monitoring Probe Installation**

During drilling activities, the boreholes will be logged for physical characteristics. This will allow a determination of the soil profile at each vent which may impact air flow patterns when the vacuum is applied to the soils. In order to define the concentration of VOCs (TCE and PCE, in particular) at each vent location prior to treatment, a sampling and analysis program will be implemented. As the boreholes are drilled for the soil extraction vents, three split-spoon samples at different depths per borehole (target depth intervals being 0 and 15 ft bgs, 15 and 30 ft bgs, and 30 and 50 ft bgs) will be collected for laboratory analysis. The soil samples will be analyzed for VOCs (EPA Method 8240). In addition, field screening of the soil will be performed using an OVA or HNu. This field screening will provide a qualitative measurement of the VOC content of the soils, and will be used in conjunction with the analytical results to determine a qualitative degree of soil contamination prior to treatment. After the vent is installed and before it



**FIGURE 4-5 SCHEMATIC OF NESTED SOIL PRESSURE MONITORING PROBES**

is connected to the vapor manifold, it will be temporarily capped for a minimum of 1-hour. Then, the vapor space will be field screened using an OVA or HNu and LEL meter.

Samples will also be collected during boring installation for monitoring probes. From zero to three samples will be selected in the field based upon PID readings. The soil samples will be analyzed for VOCs (EPA Method 8240) and TPH (Modified EPA Method 418.1). In addition, field screening of the soil will be performed using an OVA or HNu.

#### 4.2.3 Vapor Manifold

Figure 4-2 shows the layout of the SVE pilot scale system. After completion of pilot testing in the Tank Farm 2 area, the trailer-mounted SVE blower system will be used for the pilot test in the soil beneath the northeast corner of the building. The SVE vents will be connected to the vacuum blower system via a vapor manifold system. Four-inch PVC pipe will be used to connect the extraction vents to the main vapor manifold header. Individual 4-inch-diameter valves will be installed at the top of each of two riser pipes from each vent. In addition, each riser pipe will have a sampling port for operational (physical) measurements, such as static pressure, temperature, and air flow rate. A bleed air valve will also be included on the vapor manifold. The bleed air valve can be used to supply ambient air to the blower, in the event that the vents cannot supply enough air to meet the minimum blower flow at its design negative pressure.

The main manifold header will be connected to the knockdown drum (located in the trailer), where entrained liquids will be removed from the extracted air stream. Any water collected in the drum will be removed when high levels are observed and transported to the on-site air stripper for treatment via drums. From the knockdown drum, the extracted air will pass through an air filter, which will be mounted prior to the blower inlet, to remove particulate matter. The manifold then connects to the suction side of the positive displacement blower. The blower will be capable of extracting 125 cfm of air at an inlet vacuum of 10-inch Hg with a 7.5 hp motor. Power requirements are 3-phase (60 mH)

230/460 V. Blower inlet and outlet manifolds will have sampling ports for operational (temperature, flow rate, moisture content, and static pressure) and contaminant concentration measurements. The air exiting the blower passes through an air/air heat exchanger to reduce its temperature prior to activated carbon treatment. The heat exchanger is rated to cool blower discharge gas from 197° F to 100° F with 90° F ambient air.

#### **4.2.4 Vapor Treatment System**

A vapor phase activated carbon system will be used to remove VOCs from the extracted vapor from soils beneath the building in the northeast corner as well as from soils in Tank Farm 2 area. The activated carbon system will consist of two carbon bins placed in a series configuration following the heat exchanger. Each carbon bin will have sampling ports to monitor contaminant removal efficiency.

#### **4.2.5 Pilot Test Procedures**

The pilot-scale SVE tests will be divided into three phases: system start-up, test runs, and sustained operations. The system start-up phase will be conducted to ensure proper operation of the SVE system. The test runs will be conducted to determine the feasibility of SVE as a remedial alternative, the radius of influence, and the optimal operating parameters to yield the maximum contaminant removal. Optimal operating conditions will then be used during the sustained operations phase to determine whether the removal rate decline curve could be projected.

##### **4.2.5.1 System Startup**

Following connection of the vent manifold to the aboveground equipment, system startup procedures will be initiated in order to verify the proper installation and operation of the system. An initial start-up inspection of all system components will be conducted as follows:

- Piping - Visually examine for cracks, loose connections and possible leaks.
- Valves - Verify proper operation.
- Blower - Follow manufacturer's inspection procedures (i.e., check oil, belts, etc.).
- PM probes - Verify tight seal on top cap.
- Activated carbon units - Follow manufacturer's inspection procedures.
- Filter - Inspect particulate filter for debris or blockage.

Upon completion of the initial inspection, the blower will be "bumped" to verify the proper air flow direction. Bumping the blower involves turning the blower on briefly, with only ambient air supplied, and checking the air flow direction.

#### **4.2.5.2 Pilot-Scale System Test Runs**

Once the system has passed the inspection, test runs will be performed. These tests will be of relatively short duration and will be designed to determine the range of operating conditions that can be achieved, the range of VOC mass removal rates, the expected capacity of the activated carbon units, and the optimal operating conditions for sustained operations of the SVE system. In addition, data obtained from the test runs will be used to determine air flow rates and the radius of influence of the vents at varying pressures. The duration of the test run phase is expected to be about 5 days.

Up to 4 test runs will be conducted for each vent. These test runs will consist of operating the SVE system at different negative pressures with shallow and/or deep riser pipes connected to the vacuum system. An additional test run will be conducted with the valves for both nested extraction vents fully open. The duration of each run will be approximately 2 to 4 hours with a break between runs to reset test equipment. A list of parameters that will be measured during the startup tests is outlined in Table 4-1.



Table 4-1

Schedule of Measurements To Be Taken During Startup Test Period  
Black & Decker, Hampstead, MD

---

Activated Carbon Unit Stack

- HNu/OVA.

Component SVE System

Individual Vents:

- Air flow rate.
- Static pressure.
- Air temperature.

Pressure Monitoring Probes:

- Subsurface static pressure.

System Manifold and Blower:

- Temperature prior to blower.
- Relative humidity prior to blower.
- System operating pressure (static pressure prior to blower).
- Flow rate prior to blower.
- Temperature after blower.
- Relative humidity after blower.
- Static pressure after blower.
- Flow rate after blower.
- HNu/OVA after blower.
- Total VOCs after blower\*.

---

\*Laboratory sample analyses of air samples for TCE and PCE.

The operational measurements (such as flow rate, static pressure) will be taken at regular time intervals during each test run. HNu/OVA measurements after the blower and after the carbon system will also be recorded in the field log book. One air sample will be collected from the blower discharge at the end of each test run for TCE and PCE analyses to be performed at an off-site analytical laboratory.

#### **4.2.5.3 Sustained Operations**

After completion of startup and system operation test runs, sustained operations will be conducted for a period of approximately 3 to 5 days. During the sustained operations period, the pilot-scale system will be operated continuously at optimal operating conditions for both extraction vents determined during test run phase.

Four to six air samples will be collected from the blower discharge during the sustained operation, one at the start of operation (within the first hour), one sample for every 24 hours of operation, and one at the end of the sustained operations run. These samples will be analyzed for TCE and PCE at an off-site analytical laboratory. The data to be collected during the sustained operations phase of the pilot-scale study are presented in Table 4-2. The operational measurements (temperature, static pressure, etc.) will be taken at regular time intervals during the sustained operations.

During the sustained operations period, based on HNu/OVA measurements at the intake and at the exhaust of the lead carbon unit, the lag carbon unit will be transferred to the lead position, the spent carbon unit will be removed from service, and a fresh carbon unit will be installed in the lag position.

#### **4.2.6 Data Collection Procedures**

This subsection describes the data collection procedures that will be employed to monitor the operating conditions of the pilot-scale study. These procedures will be used for the test runs as well as the sustained operations.

Table 4-2

Schedule of Measurements To Be Taken During Sustained Operations Period  
Black & Decker, Hampstead, MD

---

Activated Carbon Unit Stack

- HNu/OVA.

Component SVE System

System Manifold and Blower:

- Temperature prior to blower.
- Relative humidity prior to blower.
- System operating pressure (static pressure prior to blower).
- Flow rate prior to blower.
- Temperature after blower.
- Static pressure after blower.
- HNu/OVA after blower.
- Total VOCs after blower\*.

Pressure Monitoring Probes

- Subsurface static pressure.
- 

\*Laboratory sample analyses of air samples for TCE and PCE.

#### **4.2.6.1 Static Pressure**

Static pressure will be monitored using magnehelic gauges. A magnehelic gauge measures the differential pressure across a flexible diaphragm. One side of the diaphragm is at atmospheric pressure, and the other side is at the system pressure. The static pressure is obtained by inserting the rigid probe end of the tubing into the sample port. The needle deflection on the gauge, as a result of the movement of the diaphragm, indicates the static pressure.

#### **4.2.6.2 Air Flow Rate**

The flow rate will be measured in accordance with EPA Source Test Methods 1 and 2. The flow rate will be calculated from the velocity pressure as measured using a pilot tube and a magnehelic gauge. In short, the velocity pressure is converted to the air velocity. This is multiplied by the cross-sectional area of the pipe to obtain the air flow rate. The velocity pressure (also known as the dynamic pressure) is the difference of the total pressure (as measured by the tip of the pilot tube) and the static pressure (as measured by the holes on the side of the pilot tube).

#### **4.2.6.3 Temperature and Relative Humidity**

Temperature and moisture measurements will be obtained using a Solomat Model 500e and a 226RH relative humidity/temperature probe. The probe will be inserted in the air stream and, after the reading stabilizes, the temperature and relative humidity will be recorded from the instrument display. A psychrometric chart will be used to obtain moisture from the relative humidity measurement.

#### **4.2.6.4 Subsurface Static Pressure**

The subsurface static pressure will be measured using the same equipment as for static pressure measurement, except that the rigid piece of metal at the end of the flexible

hosing is not employed. The flexible tubing will be attached to the cap of the PM probe and the deflection of the needle on the magnehelic gauge will be recorded.

#### **4.2.6.5 Soil Vapor Organics Concentration**


The contaminant concentration measurement for the SVE system will be performed using a monitoring instrument such as an OVA or HNu and by collecting air samples for laboratory analysis. The monitoring instruments provide real time data and give results that are based on their associated calibration gas; i.e., their readings are not compound-specific. The OVA is typically calibrated to methane, and the HNu is typically calibrated to benzene.

The air samples for laboratory analysis will be collected from specific ports on the system by using an air sampling pump and collection media (carbon tubes). When using carbon tubes, a known quantity of air will be drawn through the collection media and the compounds of concern are adsorbed onto the collection media. An auxiliary pump may be required for samples collected on the negative pressure side of the blower. A "Y" connection will be used to prevent air from being forced into the collection media, thus adding more control to the flow rate through the media. The collection media will then be sealed and sent to an analytical laboratory for analysis.

Air samples from the SVE system will be analyzed for TCE and PCE. The contaminant concentrations and mass removal rates will then be calculated from the analytical results.

### **4.3 DATA ANALYSIS AND REPORTING**

Data will be analyzed throughout the course of the pilot tests and following completion of the pilot system operations. The results of the data analyses will be used for determining the final system design, as discussed in Section 5. Conclusions will be provided concerning the applicability and advantages of SVE to remediate the VOC



contaminated soils at the two source areas, as well as providing the critical design parameters for full-scale implementation.

**SECTION 5**  
**IMPLEMENTATION OF SOIL REMEDIATION**

**5.1 DESIGN**

Based on the results of the pilot tests, critical design parameters for full-scale implementation will be developed. These design parameters will include operating pressures and air flow rates, number of additional vents (if any) and spacing between them, and the capacity and changeout requirements of the activated carbon units.

Nutrient requirements for in-situ bioremediation of Tank Farm 2 area soils will be determined based on the soil nutrient data collected during pilot test program. Method of nutrient injection (if needed) will be established based on the hydraulic permeability and pore volume data.

Locations of the full-scale system components including vacuum blower, heat exchanger and vapor phase carbon units will be finalized in consultation with Black & Decker personnel. Routing of vapor manifold from the extraction vents to the treatment system will be identified.

**5.2 PERMITTING**

The soil remediation will be implemented in accordance with applicable federal, state, and local regulations. Permits that may be required to construct and operate the SVE systems include:

- Request for Determination of Source of Minor Significance from the State of Maryland Department of the Environment (MDE) for air emissions from both pilot and full-scale SVE systems.
- Permit to construct soil extraction vents.

### 5.3 CONSTRUCTION

Following completion of the full-scale system design, submission of the appropriate permitting documents and approval from the State of Maryland Department of the Environment (MDE), the full-scale SVE systems for remediation of the two source areas will be constructed.

### 5.4 OPERATION AND MONITORING

After completion of the construction of the full-scale SVE systems, startup and long term operation of the systems will commence. During the operating period, the soil vapor extraction systems will operate continuously, except for any required (short-term) shut down for repairs and/or monitoring.

Most bioventing systems will require 6 months to 2 years of operation, depending on contaminant levels and volume of contaminated soil requiring remediation, to significantly reduce soil hydrocarbon levels. Periodic performance monitoring will be conducted to evaluate system operation and assess reduction in TPH and VOC concentrations in soils.

During the long-term operation of the SVE systems based on HNu readings, as measured at the exhaust of the primary carbon unit and at the intake of the primary carbon unit, the secondary carbon unit will be transferred to the primary position, the spent carbon unit will be removed from service, and a fresh carbon unit will be installed in the secondary position.

During long-term operation of the SVE systems, operational measurements including static pressure, flow rate and temperature, and HNu/OVA measurements after the blower and after the carbon system will be taken periodically and recorded in the log book. Also, air samples from the blower discharge will be collected at an estimated frequency of 1 to 2 samples per month and analyzed for TCE and PCE.



It is anticipated that treatment would continue until monitoring of collected vapors indicate that continued operation of the system would not result in significant reductions in the concentrations of contaminants detected. Determination of system shut-off would be made consistent with the Technical Impracticability guidance referenced in paragraph IV.N of the Consent Order.

#### 5.5 REPORT

Following completion of design of the SVE systems, Black & Decker will submit a Soil Remediation Implementation Report. This report will include a synopsis of the applicability of applying SVE and the system modifications needed for the final soil remediation program.

**SECTION 6**  
**SCHEDULE**

Consistent with Condition IV.T. of the Consent Order, it is anticipated that implementation of the tasks described in the Soil Remediation Plan will begin as soon as MDE approves the remediation technologies and the permitting, design and construction efforts are completed. The work will begin with mobilization and planning activities, to be followed by pilot testing as described in Section 4. The MDE will be notified five business days prior to mobilization.

**ATTACHMENT A**

**SOIL GAS PERMEABILITY TEST PROCEDURES**

**[Source:**

**Section 5.6.2, Page 47, "Test Plan and Technical Protocol for a Field Treatability Test for Bioventing," Air Force Center for Environmental Excellence (AFCEE), May 1992]**

## Soil Gas Permeability Test

After the system check, and when all monitoring point pressures have returned to zero, the soil gas permeability test will begin. Two people will be required during the initial hour of this test. One person will be responsible for reading the Magnehelic™ gauges, and the other person will be responsible for recording pressure (P') vs. time on the example data sheet (see Appendix Table A-2). This will improve the consistency in reading the gauges and will reduce confusion. Typically, the following test sequence will followed:

1. Connect the Magnehelic™ gauges to the top of each monitoring point with stopcock opened. Return the gauges to zero.
2. Turn the blower unit on, and record the starting time to the nearest second.
3. At 1-minute intervals, record the pressure at each monitoring point beginning at  $t = 60$  s.
4. After 10 minutes, extend the interval to 2 minutes. Return to the blower unit and record the pressure reading at the well head, the temperature readings, and flow rate from the vent well.
5. After 20 minutes, measure P' at each monitoring point in 3-minute intervals. Continue to record all blower data at 3-minute intervals during the first hour of the test.
6. Continue to record monitoring point pressure data a 3-minute intervals until the 3-minute change in P' is less than 0.1 in. of H<sub>2</sub>O. At this time, a 5- to 20-minute interval can be used. Review data to ensure accurate data were collected during the first 20 minutes. If the quality of these data is in question, turn off the blower, allow all monitoring points to return to zero pressure, and restart the test.
7. Begin to measure pressure at any groundwater monitoring points that have been converted to monitoring points. Record all readings, including zero readings and the time of the measurement. Record all blower data at 30-minute intervals.

8. Once the interval of pressure data collection has increased, collect soil gas samples from monitoring points and the blower exhaust (if extraction system), and analyze for  $O_2$ ,  $CO_2$ , and hydrocarbons. Continue to gather pressure data for 4 to 8 hours. The test will normally be continued until the outermost monitoring point with a pressure reading does not increase by more than 10% over a 1-hour interval.
9. Calculate the values of  $k$  and  $R_f$  with the data from the completed test: use of the HyperVentilate™ computer program is recommended. The Appendix shows sample calculation methods for determining  $k$  and  $R_f$ .

## APPENDIX

### RECOMMENDED ESTIMATION METHODS FOR AIR PERMEABILITY

The U.S. Environmental Protection Agency's Risk Reduction Engineering Laboratory recently reviewed several field, laboratory, and empirical methods for determining soil gas permeability ( $k$ ) and for their appropriateness in determining the feasibility of soil vapor extraction (Sellers and Fan, 1991). The conclusion of this literature review was a strong endorsement for a modified field drawdown method (Johnson et al., 1990).

The field drawdown method is based on Darcy's Law and equations for steady-state radial flow to or from a vent well. A full mathematical development of this method and supporting calculations are provided by Johnson et al. (1990). A computer program known as HyperVentilate™ has been produced by Johnson for storing field data and computing  $k$  and  $R_f$ . This program will be used to speed the calculation and data presentation process. The two solution methods for  $k$  are presented below. The first solution is based on carefully measuring the dynamic response of the soil to a constant injection or extraction rate. The second solution for  $k$  is based on steady-state conditions and the measurement or estimation of  $R_f$  at steady state. The limitations and recommended application of each method are presented below. Whenever possible, field data will be collected to support both solution methods, because one or both of the solution methods may be appropriate, depending on site-specific conditions.

#### Dynamic Method

This test method requires that air be extracted or injected at a constant rate from a single venting well, while measuring the pressure changes at several soil gas monitoring points throughout the contaminated soil volume. The equation:

$$P' = \frac{Q}{4\pi m(k/u)} \left[ -0.5772 - \ln(r^2 eu) + \ln(t) \right] - \frac{P_{atm}}{4k} \quad (1)$$

is used to describe the dynamic changes in soil gas pressure/vacuum where:

- $P'$  = "gauge" pressure measured at distance  $r$  from the vent well at time  $t$  ( $g/cm-s^2$ )
- $m$  = stratum thickness, generally the vent well screened interval (cm)
- $r$  = radial distance from monitoring point to vent well (cm)
- $k$  = soil gas permeability ( $cm^2$ )
- $u$  = viscosity of air ( $1.8 \times 10^{-4}$   $g/cm-s$  at  $18^\circ C$ )
- $e$  = soil's air-filled void volume (dimensionless)
- $t$  = time from the start of the test (s)
- $Q$  = volumetric flow rate from the vent well ( $cm^3/s$ )
- $P_{atm}$  = ambient pressure (at sea level  $1.013 \times 10^6$   $g/cm-s^2$ )

Equation (1) predicts that the dynamic range of  $P'$ -vs.- $\ln(t)$  is a straight line with a slope of  $A$  where:

$$A = \frac{Q}{4\pi m (k/\mu)}$$

solving

$$k = \frac{Q\mu}{4A\pi m}$$

The HyperVentilate™ model is based on the dynamic method and a determination of the slope,  $A$ . This method of determining  $k$  requires accurate field measurements of  $Q$  at the vent well and  $P'$ 's-vs.-time at each monitoring point. It is most appropriately applied at sites with less permeable soils where changes in  $P'$  occur over a longer time period (10 minutes or more to monitoring point steady state). This method can be accurate for fine sandy soils where the screened interval extends to depths of over 10 ft and when monitoring points are screened at depths of 10 ft or greater. It is less accurate for sites where a high water table or shallow contamination limits the total depth of the vent well screen and monitoring points to less than 10 ft. In shallow and coarse-grained soils, vacuum or pressure levels reach steady state too rapidly to accurately plot  $P'$ -vs.- $\ln(t)$ . Venting systems on shallow sandy sites are subject to higher vertical airflow which is not as accurately described by this one-dimensional radial flow equation.

### Steady State-Method

This method for determining  $k$  can be used in situations where the dynamic method is inappropriate. This method is based on the steady-state solution to equation (1).

$$k = \frac{Q_u \ln(R_w/R_o)}{H\pi (P_w - P_{atm})} \quad (2)$$

Note: Equation (2) applies only to vent wells operating under a vacuum. If air is being injected into the vent well the equation is modified as shown below:

$$k = \frac{Q_u \ln(R_w/R_o)}{H\pi (P_{atm} - P_w)} \quad (3)$$

where  $Q$ ,  $m$ ,  $\mu$ , and  $P_{atm}$  have been previously defined, and

$R_w$  = the radius of the venting well (cm)

H = depth of screen (cm)

R<sub>1</sub> = the maximum radius of venting influence at steady state (cm)

P<sub>w</sub> = the absolute pressure at the venting well (g/cm-s<sup>2</sup>)

The value of R<sub>1</sub> can be determined by actually measuring the outer limit of vacuum/pressure influence under steady-state conditions, or by plotting the vacuum/pressure at each monitoring point vs. the log of its radial distance from the vent well and extrapolating the straight line to zero vacuum or pressure. An example of this solution method is included in Calculation Data Set Two below.

### Sample Calculations

#### Data Set One

Table A-1 and Figure A-1 present the results of an air permeability test conducted at Beale AFB, CA. The soils on this site were silty with a contaminated interval (and vent well screen interval) extending from 10 to 40 feet below ground surface. Note that the plot of P<sup>2</sup>-vs.-ln(time) is a relatively straight line during the initial 10 minutes. ln(10) = 2.3, making these data good candidates for the dynamic solution method. Data from the initial 10 minutes of this test were entered into the HyperVentilate™ computer model to calculate a range of k values. An example of the input and output data for this model is provided in windows AP7 and AP8.

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### Air Permeability Test - Data Analysis (cont.)

The permeability, k, can then be calculated by one of two methods:

- ① The first is applicable when both Q (flowrate) and m (well screen interval) are known accurately. The calculated slope A is used:

$$k = \frac{Q \mu}{4 A \pi m}$$

- ② The second approach is used whenever Q or m are not known with confidence. In this case, both the slope, A, and intercept, B, are used:

$$k = \frac{7.5 \times 10^{-4} \mu}{4 \rho \mu m} \exp\left[0.5772 + \frac{B}{A}\right]$$

Return

AP7



## Air Permeability Test - Data Analysis (cont.)

Enter radial distances of monitoring points →  $r =$   (ft)       $r =$   (ft)       $r =$   (ft)

① Enter measured times and gauge vacuums

|    | (min) | (in H2O) |
|----|-------|----------|
| 1  | .5    | 0.1      |
| 2  | 1     | 0.21     |
| 3  | 1.5   | 0.62     |
| 4  | 2     | 1.00     |
| 5  | 2.5   | 1.25     |
| 6  | 3     | 1.41     |
| 7  | 3.5   | 1.60     |
| 8  | 4     | 1.8      |
| 9  | 4.5   | 1.98     |
| 10 | 5     | 2.12     |

② Enter (optional):

a) flowrate  (SCFM)

b) screened interval thickness  (ft)

clear

→ Calculate ←       $k =$   darcy (A)       $k =$   darcy (B)

Return      Explanation & Statistics      AP8

## Air Permeability Test - Data Analysis (cont.)

Enter radial distances of monitoring points →  $r =$   (ft)       $r =$   (ft)       $r =$   (ft)

① Enter measured times and gauge vacuums

|   | (min) | (in H2O) |
|---|-------|----------|
| 1 | 5.5   | 2.25     |
| 2 | 6     | 2.37     |
| 3 | 6.5   | 2.48     |
| 4 | 7     | 2.55     |
| 5 | 7.5   | 2.63     |
| 6 | 8.5   | 2.82     |
| 7 | 9.5   | 2.92     |

② Enter (optional):

a) flowrate  (SCFM)

b) screened interval thickness  (ft)

clear

→ Calculate ←       $k =$   darcy (A)       $k =$   darcy (B)

Return      Explanation & Statistics      AP8

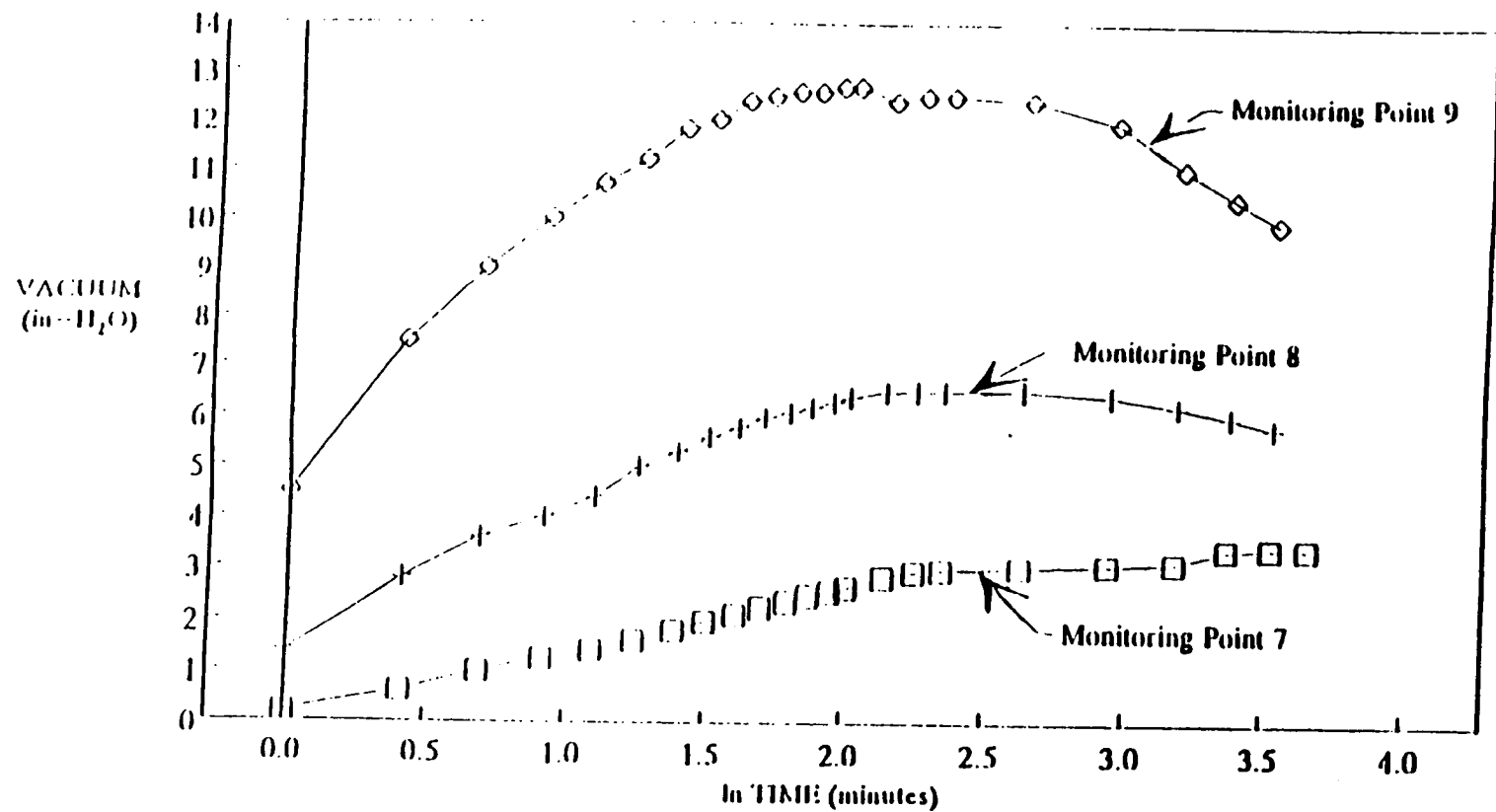
TABLE A-1. Air Permeability Data Set

Steady-State Flow Rate 51 SCFM

| Test Time Elapsed (min) | In Time (min) | Vacuum (inches of water) at Monitoring Points (MPs) |      |      |      |      |      |      |      |       |
|-------------------------|---------------|---|------|------|------|------|------|------|------|-------|
|                         |               | MP 1  | MP 2 | MP 3 | MP 4 | MP 5 | MP 6 | MP 7 | MP 8 | MP 9  |
| 0.0                     | -             | 0.00  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00  |
| 0.5                     | -             | -   | -    | -    | -    | -    | -    | 0.10 | 0.40 | 1.50  |
| 1.0                     | 0.00          | -   | -    | -    | -    | -    | -    | 0.21 | 1.40 | 4.50  |
| 1.5                     | 0.41          | -   | -    | -    | -    | -    | -    | 0.62 | 2.80 | 7.50  |
| 2.0                     | 0.69          | -   | -    | -    | -    | -    | -    | 1.00 | 3.60 | 9.00  |
| 2.5                     | 0.92          | -   | -    | -    | -    | -    | -    | 1.25 | 4.00 | 10.00 |
| 3.0                     | 1.10          | -   | -    | -    | -    | -    | -    | 1.41 | 4.40 | 10.70 |
| 3.5                     | 1.25          | -   | -    | -    | -    | -    | -    | 1.60 | 5.00 | 11.20 |
| 4.0                     | 1.39          | -   | -    | -    | -    | -    | -    | 1.80 | 5.30 | 11.80 |
| 4.5                     | 1.50          | -   | -    | -    | -    | -    | -    | 1.98 | 5.60 | 12.00 |
| 5.0                     | 1.61          | -   | -    | -    | -    | -    | -    | 2.12 | 5.80 | 12.40 |
| 5.5                     | 1.70          | -   | -    | -    | -    | -    | -    | 2.25 | 6.00 | 12.50 |
| 6.0                     | 1.79          | -   | -    | -    | -    | -    | -    | 2.37 | 6.10 | 12.60 |
| 6.5                     | 1.87          | -   | -    | -    | -    | -    | -    | 2.48 | 6.20 | 12.60 |
| 7.0                     | 1.95          | -   | -    | -    | -    | -    | -    | 2.55 | 6.30 | 12.70 |
| 7.5                     | 2.01          | -   | -    | -    | -    | -    | -    | 2.63 | 6.40 | 12.70 |
| 8.5                     | 2.14          | -   | -    | -    | -    | -    | -    | 2.82 | 6.50 | 12.40 |
| 9.5                     | 2.25          | -   | -    | -    | -    | -    | -    | 2.92 | 6.50 | 12.50 |
| 10.5                    | 2.35          | -   | -    | -    | -    | -    | -    | 2.96 | 6.50 | 12.50 |
| 14.0                    | 2.64          | -   | -    | -    | -    | -    | -    | 3.00 | 6.50 | 12.40 |
| 19.0                    | 2.94          | -   | -    | -    | -    | -    | -    | 3.05 | 6.40 | 11.90 |
| 24.0                    | 3.18          | -   | -    | -    | -    | -    | -    | 3.10 | 6.20 | 11.00 |
| 29.0                    | 3.37          | -   | -    | -    | -    | -    | -    | 3.37 | 6.00 | 10.40 |
| 34.0                    | 3.53          | -   | -    | -    | -    | -    | -    | 3.40 | 5.80 | 9.90  |
| 39.0                    | 3.66          | -   | 0.8  | 0.4  | 0.7  | 2.2  | 1.7  | 3.40 | -    | -     |
| 44.0                    | 3.78          | 0.3   | -    | -    | -    | -    | -    | -    | -    | -     |

|           |       |       |       |       |       |       |       |       |                           |
|-----------|-------|-------|-------|-------|-------|-------|-------|-------|---------------------------|
| 27.5-29.5 | 18-20 | 13-15 | 14-16 | 38-40 | 30-32 | 40    | 20    | 10    | <-- Distance from VE - 2  |
|           |       |       |       |       |       | 38-40 | 38-40 | 38-40 | <-- Screen interval depth |



**Figure A-1. Vacuum vs. In Time,  
Test 2, Bioventing Pilot Test,  
Site 22-A20, Beale AFB, California**

Computer window AP7 provides a summary of two mathematical solutions for air permeability (k) using the dynamic method. Window AP8 is the example data entry and solution sheet. The calculated range of k values for this test is shown at the bottom of window AP8. Permeability values of 4 to 14 darcy are based on Equation 1 in window AP7 and provide the most accurate estimate, because both the extraction rate (Q) and the screened interval (m) were known for this test. The more conservative range of 4 to 14 darcy will be used for full-scale design. These air permeability values are approximately one order of magnitude higher than would be expected for silty soils. The presence of 10 to 15% sand (by weight) in this soil has increased the average permeability at this site.

#### Data Set Two

Table A-2 and Figure A-2 are the results from a test conducted in a silty loam with a contaminated interval of only 5.2 ft and a screened interval from 2.7 to 5.2 ft below ground surface. Note that the almost immediate steady state reached at this site does not produce the P'-vs.-ln(time) plot required for the dynamic solution method. In this case the steady-state solution offers the only approximation of k and R<sub>1</sub>.

$$k = \frac{Q\mu \ln(R_w/R_1)}{H\pi P_w [1 - (P_{atm}/P_w)^2]}$$

For this test:

$$Q = 1.4 \times 10^4 \text{ cm}^3/\text{s}$$

$$H = 2 \text{ ft (61 cm)}$$

$$\mu = 1.8 \times 10^{-4} \text{ g/cm-s}$$

$$P_w = 80''\text{H}_2\text{O vacuum} \times 3.61 \times \frac{10^{-2} \text{ psia}}{''\text{H}_2\text{O}} = 2.88 \text{ psia}$$

$$P_w \text{ absolute} = 14.7 \text{ psia} - 2.88 \text{ psia} = 11.82 \text{ psia}$$

$$11.82 \text{ psia} \times 6.9 \times \frac{10^4 \text{ g/cm-s}^2}{\text{psia}} = 8.16 \times 10^5 \text{ g/cm-s}^2$$

$$P_{atm} = 1.01 \times 10^6 \text{ g/cm-s}^2$$

$$R_w = 1 \text{ in.} = 2.54 \text{ cm}$$

$$R_1 = -15 \text{ ft (457 cm)} \text{ based on all monitoring points reported in Table A-2}$$

TABLE A-2. Field Test Data for Soil Determination of Soil Permeability at a Gasoline-Contaminated Site

| Time (min) | Air Flow (cfm) | Vacuum (inches of water) measured at various monitoring points |      |      |      |      |      |      |      |      |      |      |
|------------|----------------|--|------|------|------|------|------|------|------|------|------|------|
|            |                | Unit   | Well | F    | E    | G    | D    | H    | C    | I    | B    | A    |
| 0.0        | 0              | 0  | 2    | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.5        | 30             | 109  | 80   | 1.90 | 0.90 | 0.25 | 0.15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.5        | 30             | 109  | 80   | 1.90 | 0.90 | 0.30 | 0.20 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5.0        | 30             | 109  | 80   | 1.90 | 0.90 | 0.30 | 0.20 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10.0       | 30             | 109  | 80   | 1.90 | 0.95 | 0.30 | 0.20 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 |
| 15.0       | 30             | 109  | 80   | 1.90 | 0.95 | 0.30 | 0.20 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20.0       | 30             | 109  | 80   | 1.90 | 0.95 | 0.30 | 0.20 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 |
|            |                | Distance from well (ft)  |      | 3    | 6    | 9    | 12   | 15   | 18   | 21   | 24   | 27   |

$R_w = 2.54 \text{ cm}$

$\mu = 1.8 \times 10^{-4} \text{ g/cm-s}$

$H = 60.96 \text{ cm}$

$P_{atm} = 8.14 \times 10^5 \text{ Dynes/cm}^2$

$Q = 14.158 \text{ cm}^3/\text{sec}$

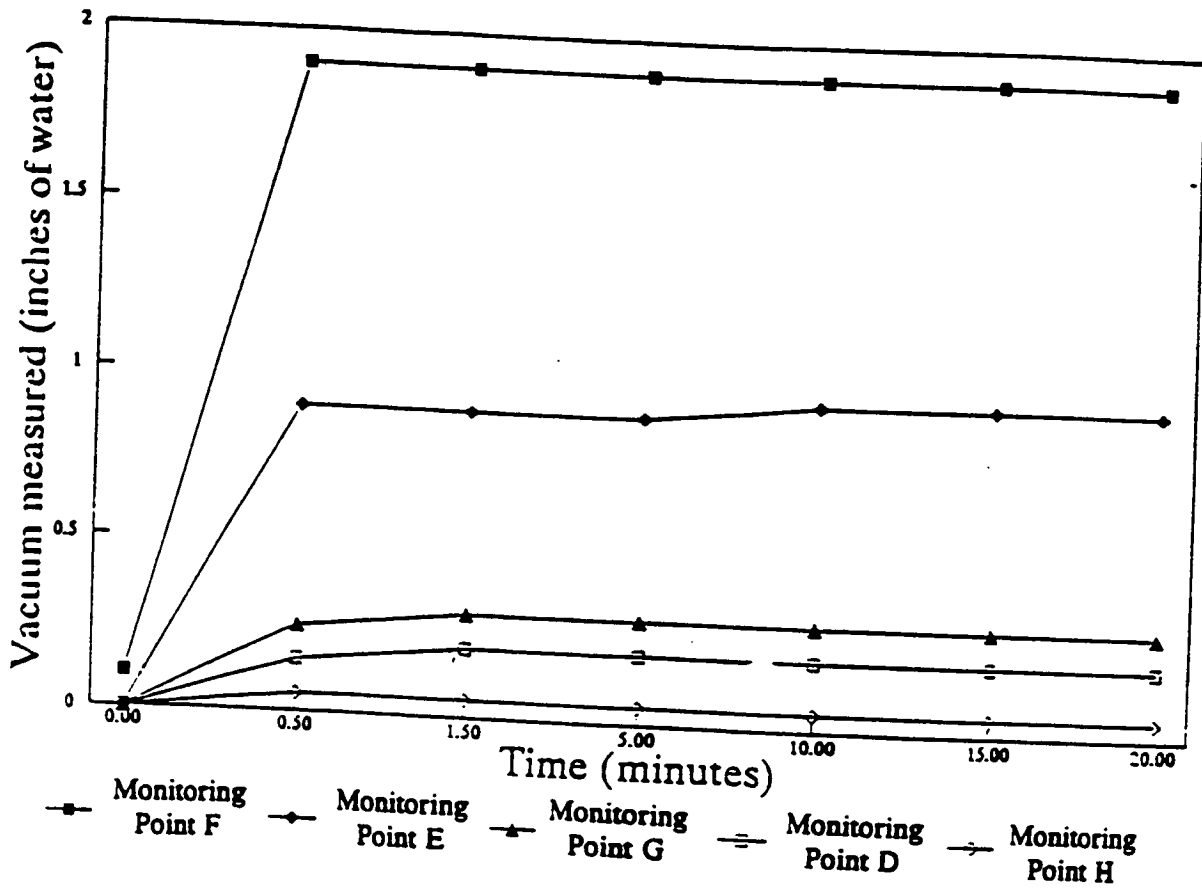


Figure A-2. Results of a Field Test to Determine Soil Permeability to Airflow, k, September 16, 1991

$$k = \frac{(1.4 \times 10^4 \text{ cm}^3/\text{s})(1.8 \times 10^{-4} \text{ g/cm-s})\ln(2.54/457)}{(61 \text{ cm})(3.14)(8.16 \times 10^5 \text{ g/cm-s})(1 - [1.01/0.816]^2)}$$

$k = 1.6 \times 10^{-7} \text{ cm}^2$  or 0.16 darcy, which is typical for silty soils.

#### References

- Johnson, P.C., M.W. Kemblowski, and J.D. Colthart. 1990. "Quantitative Analysis for the Cleanup of Hydrocarbon-Contaminated Soils by In-Situ Soil Venting." *Ground Water* 28(3), May-June.
- Sellers, K., and C.Y. Fan. 1991. "Soil Vapor Extraction: Air Permeability Testing and Estimation Methods." In: *Proceedings of the 17th RREL Hazardous Waste Research Symposium*. EPA/600/991/002, April.