

GEOTECH
CONSULTANTS, INC.

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RECEIVED

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DEPT. OF ECOLOGY

July 30, 1991

JN 1056

ARCO Petroleum Products
P.O. Box 2570
Los Angeles, California 90051-0570

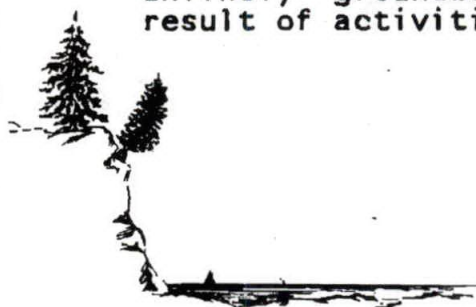
Attention: Brad Jones

Subject: Proposed Vapor Extraction System and Cost Estimate
Proposed AM/PM Mini-Market
6th Street at Naval Avenue
Bremerton, Washington

Dear Mr. Jones:

In response to our discussions with you, Geotech Consultants, Inc. has conducted a feasibility study for constructing a vapor extraction system to remove petroleum contaminants from the site of a proposed ARCO AM/PM Mini-Market to be located at 6th Street at Naval Avenue in Bremerton, Washington.

As indicated in our report entitled "Preliminary Hydrocarbon Evaluation, Proposed AM/PM Mini-Market," there appear to be three stratified "zones" in which residual hydrocarbon concentrations are present. These hydrocarbon concentrations are due to former underground storage tanks which have been removed. Attached to this letter is a sketch illustrating our estimation of the geologic section at the AM/PM site and indicating areas of hydrocarbon concentrations. This sketch is taken from our letter dated April 17, 1991 to Brad Linskog with ARCO Petroleum Products. Plate 2, also from an attachment to that letter, illustrates the locations of the site explorations and interpretive zones of contamination. As shown on this drawing, the petroleum contamination is in the northeast corner of the site. Hydrocarbon concentrations were measured in three of the borings, including B-1, B-2, and B-3. The depth of contaminated soils ranged from 10 feet in B-2 to 30 feet in B-1. We estimate that the amount of contamination is relatively small and the depth of groundwater is estimated to be over 150 feet. We concluded in our preliminary report that it is unlikely groundwater has been exposed to contamination as a result of activities on the subject property.



Proposed Vapor Extraction System

The proposed system consists of two air inlet wells, two vapor extraction wells, gathering lines, and vapor extraction unit equipment. An industrial blower is used to pull a vacuum in the soil pores through the extraction well. Air is provided at atmospheric pressure through air inlet wells. The air, being at atmospheric pressure, flows underground due to the pressure differential in the soil, created by the extraction wells. The air flow rate through the underground soil depends on soil permeability, the distance from the air inlet wells to the extraction wells, and the vacuum developed by the blower. Using the Darcy flow equation with a combination of a linear and radial flow system for the process, the air flow rate through the soil, using a blower that would develop a maximum vacuum of 4.3 inches of mercury and a maximum flow of 127 standard cubic feet per minute (SCFM), was determined to be 2.8 SCFM. This would result in displacing one pore volume of the area in approximately 4 days. If the soil has a higher permeability than that using the flow equation of 100 milliDarcys, the time to displace one pore volume of the contaminant area would be less. The calculated time of operation for the vapor extraction process, if the hydrocarbon contamination exists in the vapor phase and if the soil permeability is 100 milliDarcys with the recommended system, would be approximately 35 days. However, we anticipate that the system will need to be in operation at least three months. Plate 3 shows a schematic of the vapor extraction system, and the locations of the wells are illustrated on Plate 4.

Determination of Flow Rate Through the Soil

The air flow pattern for the vapor extraction process is shown on Plates 5 and 6. The idealized geologic cross section of the site showing the area of hydrocarbon contamination in relation to the inlet and extraction wells is shown on Plate 7. The well pattern consists of an air inlet well equidistant on each side of two extraction wells. Each inlet well is a distance of 40 feet from the two extraction wells. The extraction wells are approximately 10.5 feet apart. The inlet and extraction wells are positioned so that the air can effectively sweep the hydrocarbon vapor toward the extraction wells or to the

center of the pattern. A rectangular area enclosing the flow pattern is considered to be the air circulation area for the inlet and extraction wells. Based on the rectangular area of 31 feet x 80 feet and a formation thickness of 25 feet, the bulk volume was determined to be 62,000 cubic feet. Using a 25% porosity for the zones, the pore volume was calculated to be 15,500 cubic feet.

Plate 5 also shows the location and areal extent of the hydrocarbon contamination in relation to the flow pattern. The air flow rate through the soil was determined using the Darcy equation for steady state flow. The rate for a quarter of the rectangular flow pattern (Plate 6) was approximated by using linear and radial flow in series. The flow rate was scaled to include the entire flow pattern area by combining the flow rates for all four sections. The flow equation will determine the air flow rate through the volume of the soil in the flow pattern for a given applied vacuum. A blower that can provide the vacuum and flow rate is then selected from the blower performance curves. The blower performance curve (see Appendix B) shows the vacuum in inches of mercury the blower will provide at a particular suction air flow rate in standard cubic feet per minute (SCFM).

The higher the rate of displaceable pore volumes through the contaminated area in a given time period, the shorter the operational time for the vapor extraction system.

In the Darcy flow equation, two flow rates were calculated using soil permeabilities of 100 milliDarcys and 500 milliDarcys. The two permeabilities are considered to be high and the 100 milliDarcy permeability is probably the most representative of the soil. A blower was selected from the blower performance curves for the particular vacuum and flow rate at which it would operate. Using a blower that would develop a maximum vacuum of 4.3 inches of mercury with a maximum air suction flow rate of 127 SCFM (no load), the air flow rate through the soil, calculated from the Darcy flow equation, at 100 milliDarcys and 500 milliDarcys, was 2.8 SCFM and 14 SCFM, respectively. With the air flow rate through the soil calculated and knowing the pore volume of the flow pattern, the time required to displace one pore volume of the contaminated area was calculated. The time for displacing one pore volume using the soil permeabilities of 100 milliDarcys and 500 milliDarcys was calculated to be 3.8 days and 18.5 hours, respectively. These times are only an approximation because the areal or vertical sweep

efficiencies are not known. Since the sands are homogeneous, the vertical and areal sweep efficiencies should be high. The time period required for displacing a pore volume of the contaminated area is considered short.

Calculations were also performed to determine the time period the vapor extraction system would be in operation. In the Preliminary Hydrocarbon Evaluation report we prepared dated April 9, 1991, the concentration of the hydrocarbon vapors were shown for the different areas and depths of the site. From the lab analysis of the soil, it was reported that no staining was observed on the samples of contaminated soils. It would be reasonable to believe that the hydrocarbon contamination is in a vapor which has saturated the soil pore space and that there is no liquid present in the pore space. From the pore volume of the contaminated soil and the concentration of the hydrocarbon vapor in the pore space, the pounds of hydrocarbon were calculated in Appendix A. It was determined that if the hydrocarbon contamination is in a single phase (i.e. a vapor) then the total hydrocarbon contamination is calculated to be 0.11 pound. After the vapor extraction system is in operation, assuming the result of monitoring the air flow on the suction side of the blower shows the flow rate of 2.8 SCFM and the 10 parts per million (ppm) concentration of hydrocarbon in the air stream, then the operation time to remove the 0.11 pound of hydrocarbon would take approximately 35 days. The calculations are shown in Appendix A.

Monitoring

We considered using driven vapor probes to monitor the performance of the extraction system. However, it may prove difficult to penetrate the soil with vapor probes because of rocks in the dense soil. Therefore, we propose to monitor the concentration of vapors from the outlet of the blower using a TIP organic vapor meter. Changes in the hydrocarbon vapor concentrations could then be measured to detect a decrease in contaminants. The TIP meter also could be used to monitor air in the wells after the system has been shut down. Final verification of the effectiveness of the system and the cleanup effort could be done by additional soil sampling. The cost of soil borings and sampling is not included in the vapor extraction system cost estimate.

Cost Estimate

The cost of installing the system has been estimated to be [REDACTED]. A complete listing of unit costs is attached to this report as Table A. For this estimate, we have assumed that ARCO subcontractors will supply a 220 volt, 20 amp underground circuit from the service building to the electrical panel of the vapor extraction unit. We have also assumed that this contractor would excavate and backfill the trenches for the installation of the piping equipment. Further, we recommend for aesthetic purposes, that a temporary cedar fence be constructed around the system. We have not included the cost for the fencing in our estimate.

The vapor extraction unit would be a system manufactured by Environmental Instruments, Inc., Model EI454XP, which consists of an E G & G Roton regenerative direct drive blower with maximum flow rate of 127 SCFM and a maximum vacuum of 4.3 inches of mercury. It is equipped with a 1.5 horsepower explosion-proof electric motor and starter. This motor operates at 230 volts, single-phase at 9 amps. This unit is equipped with an in-line centrifugal separator with automatic dump valve, air dilution control valve, particulate filter and vacuum gages on the inlet and outlet of the blower. This unit has dimensions of 30 inches by 18 inches by 2.5 feet in height.

Geotech Consultants, Inc. would be pleased to work with ARCO in procuring, designing, installing and monitoring this vapor extraction facility. The work may easily be performed

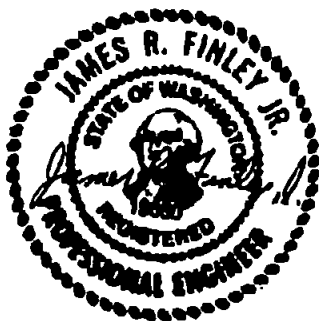
ARCO Petroleum Products
July 30, 1991

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under our existing annual services contract with ARCO which includes work of this nature. If there are any questions or if we can be of further service, please contact us.

Sincerely,

GEOTECH CONSULTANTS, INC.



James R. Finley, Jr. P.E.
for
Richard Phillips
Petroleum/Environmental
Engineer

Don W. Spencer

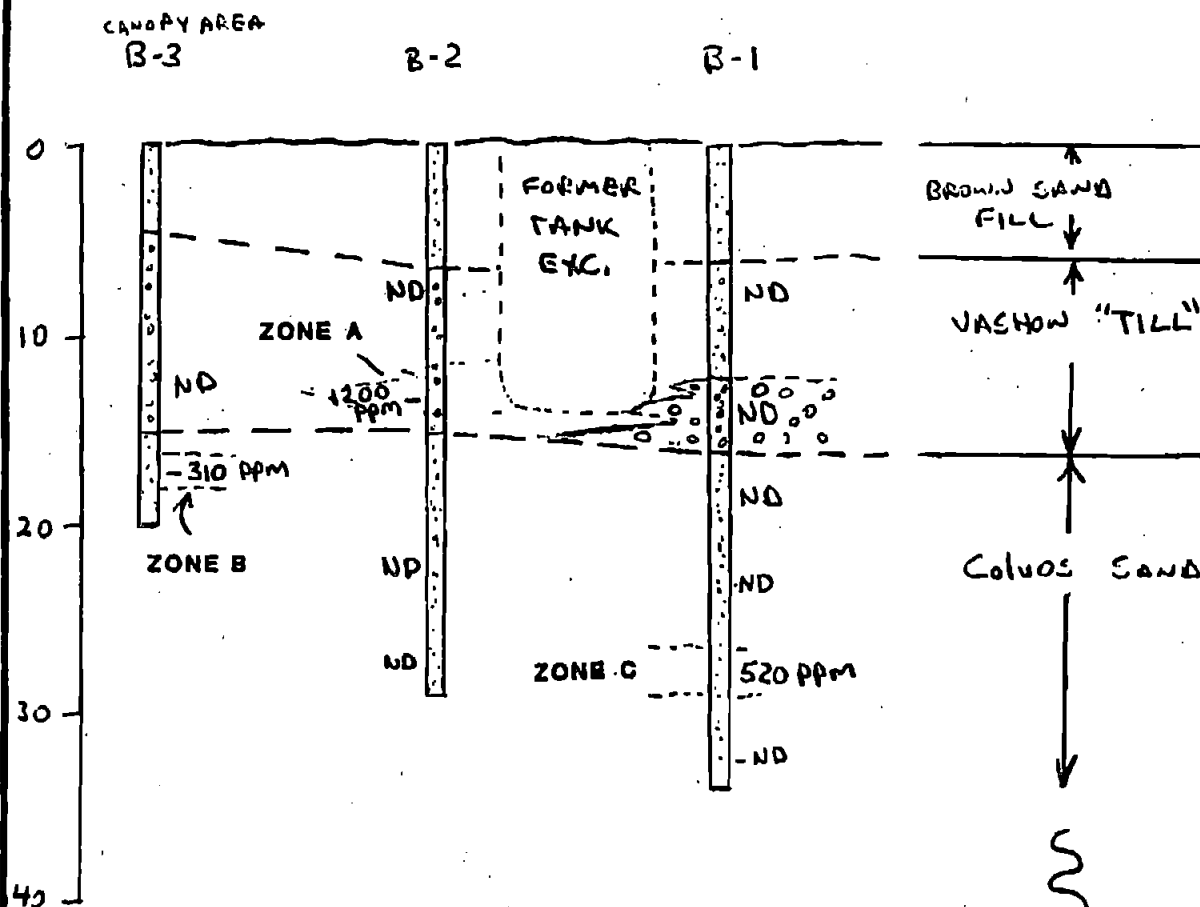
Don W. Spencer, M.Sc.
Vice President
Environmental Services

Attachments:	Table A	Cost Estimate
	Plate 1	Draft Interpretive Geologic Section
	Plate 2	Site Exploration Plan
	Plate 3	Vapor Extraction System Schematic
	Plate 4	Vapor Extraction Well Locations
	Plates 5, 6	Air Flow Patterns
	Plate 7	Idealized Geologic Cross-Section
	Appendix A	Design Calculations
	Appendix B	Regenerative Blower Performance Curves

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← WEST

EAST →



ND: denotes NONE detected

ppm: denotes parts per million by EPA 8015

Petroleum occurrences appear "TRAPPED" in vertically discrete lenses adjacent to former tank hold area. While concentrations in these zones exceed MTCA guidelines, it appears unlikely that condition is extensive and very unlikely that groundwater (150-200 feet down) would be affected.



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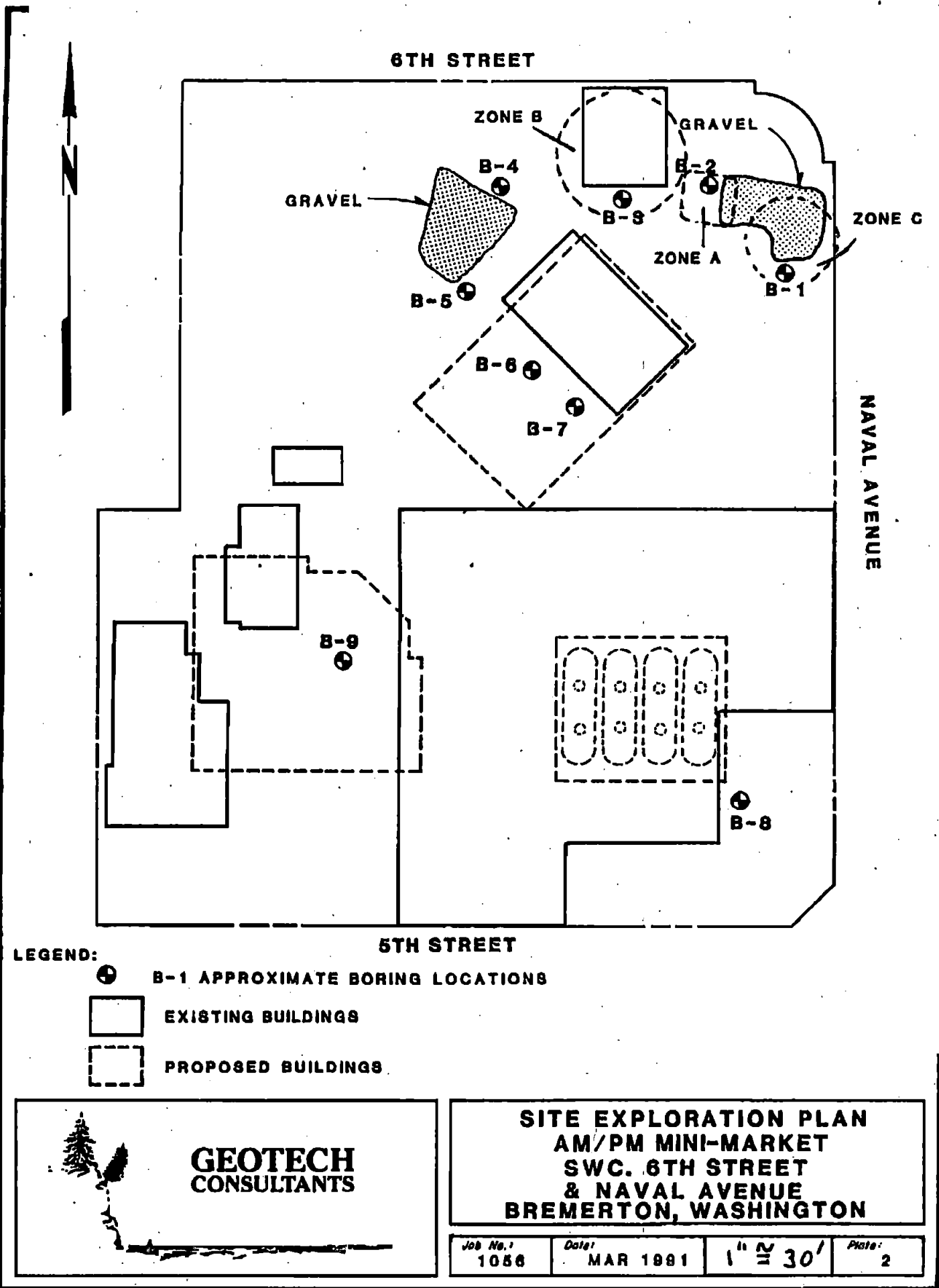
Draft Interpretive Geologic Section
AM/PM site, 6th & NAVAL
Bremerton, WA

Job No.:
1056

Date:
4-1-91

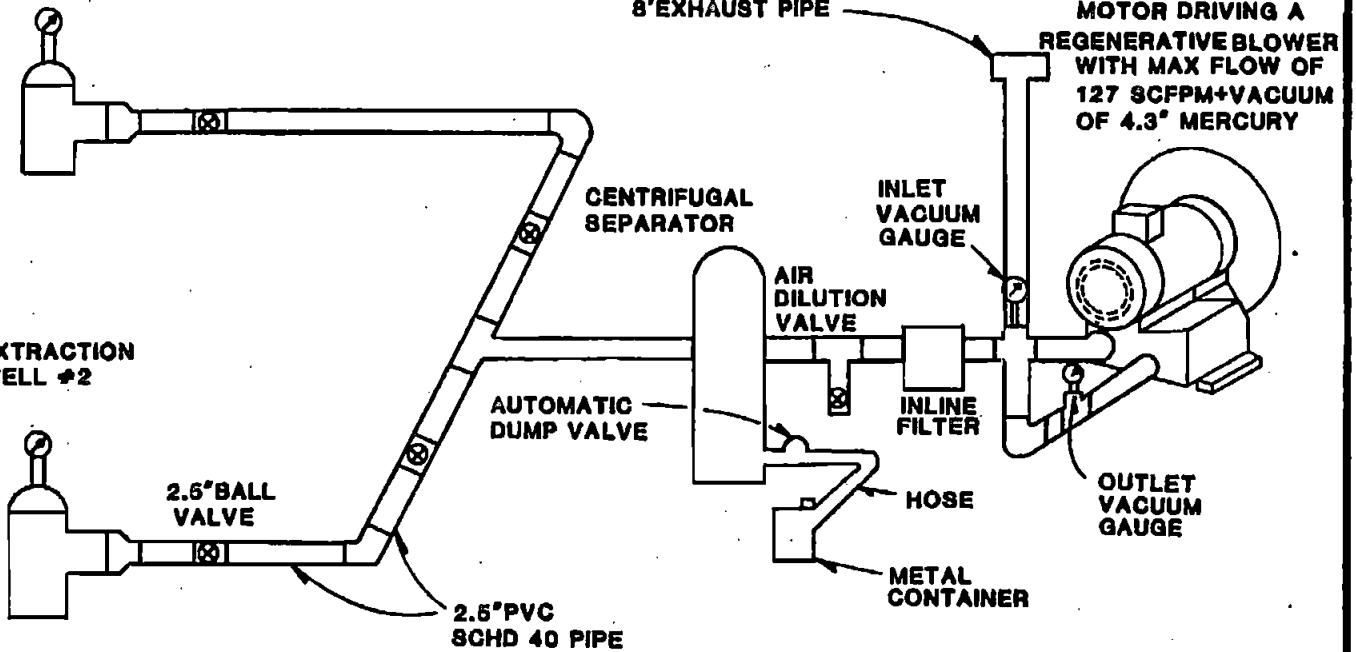
Drawn by:
JD

Plate:
1



EXTRACTION
WELL #1

EXTRACTION
WELL #2



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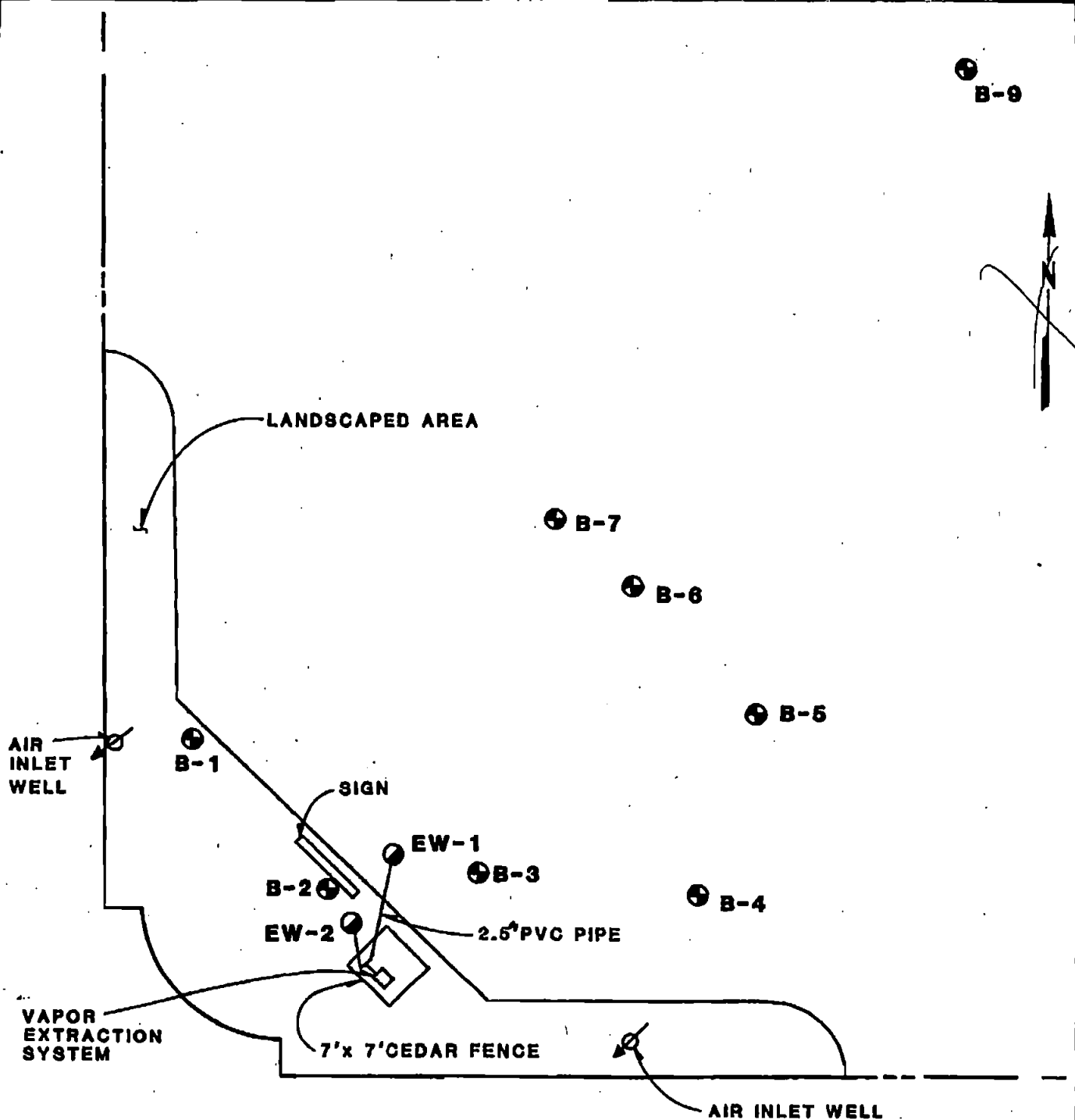
**VAPOR EXTRACTION
SYSTEM SCHEMATIC
AM/PM MINI-MARKET
6th STREET AT NAVAL AVE
BREMERTON, WASHINGTON**

Job No. 1058

Date AUG 1991

N.T.S.

Page 3



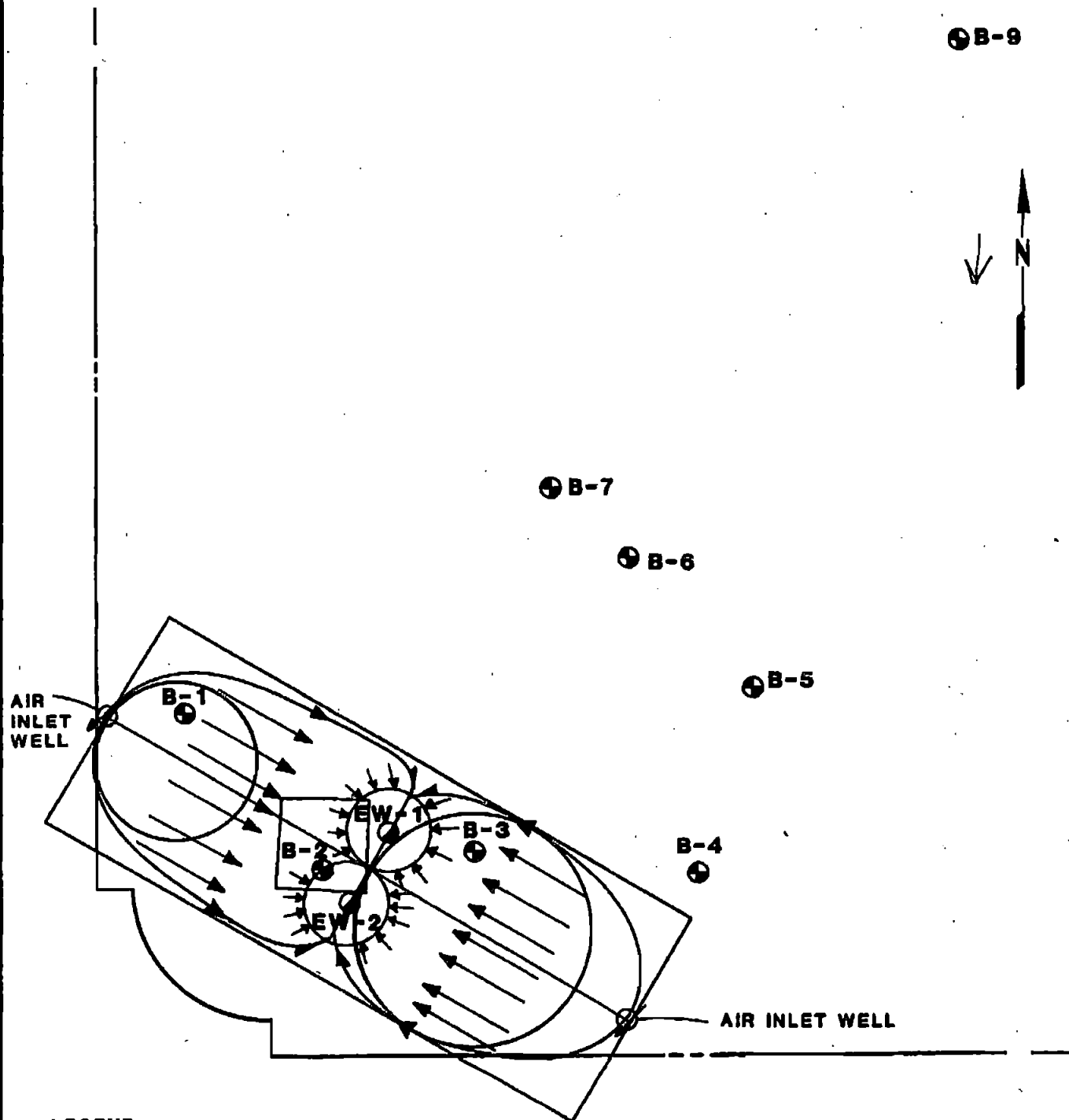
LEGEND:

- ⊕ APPROXIMATE BORING LOCATIONS
- EXTRACTION WELL



**VAPOR EXTRACTION SYSTEM
WELL LOCATIONS
AM/PM MINI-MARKET
6th STREET AT NAVAL AVE
BREMERTON, WASHINGTON**

Job No.: 1056	Date: AUG 1991	1"=20'	Plate: 4
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LEGEND:

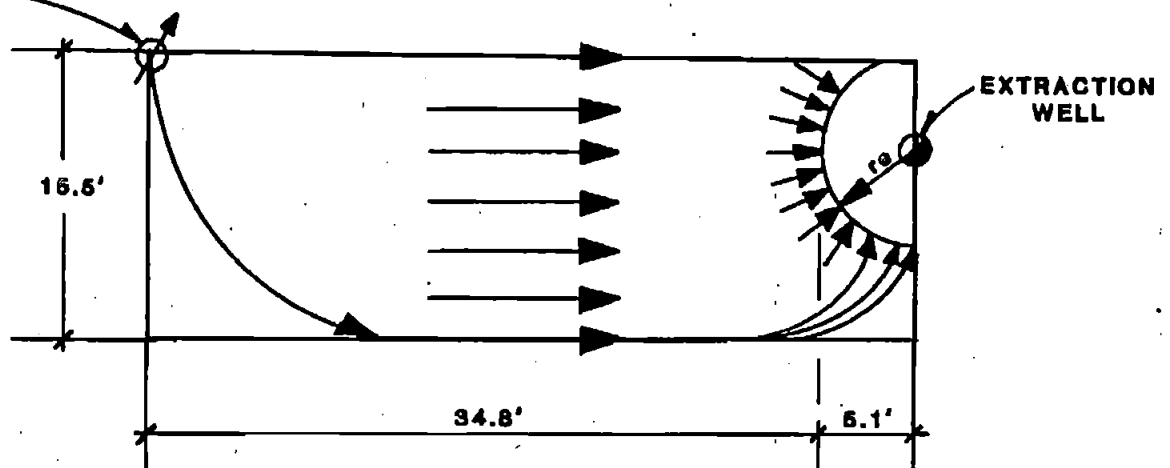
- APPROXIMATE BORING LOCATIONS
- ⊗ APPROXIMATE EXTRACTION WELL LOCATIONS



**AIR FLOW PATTERN FOR
VAPOR EXTRACTION PROCESS
AM/PM MINI-MARKET
6th STREET AT NAVAL AVE
BREMERTON, WASHINGTON**

Job No.: 1068	Date: AUG 1991	1"-20'	Plate: 5
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AIR
INJECTION
WELL



$$(p_1^2 - p_2^2) = \frac{q T_f Z \mu L}{0.112 AK} + \frac{2 q \mu T_f Z \ln(r_e/r_w)}{0.703 Kh}$$

SEE APPENDIX FOR DEFINITION OF TERMS

DARCY FLOW EQUATION WITH A COMBINATION OF LINEAR + RADIAL
FLOW SYSTEMS IN SERIES FOR STEADY STATE CONDITIONS



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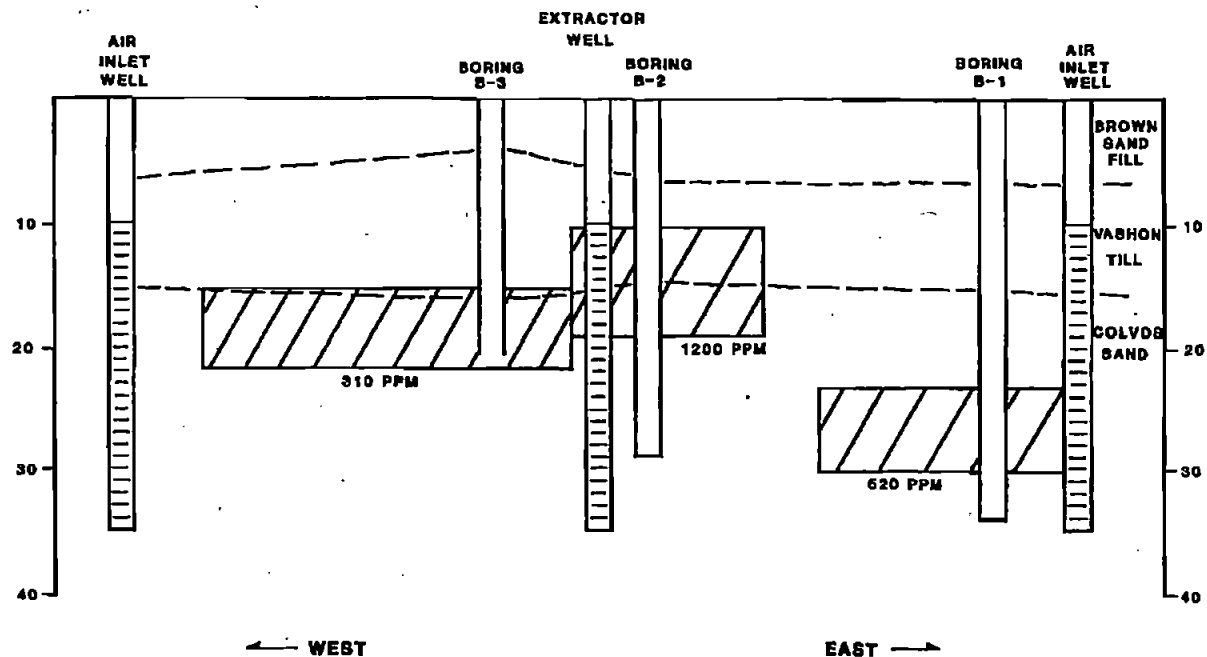
**A QUARTER SECTION OF THE
ENTIRE AIR FLOW PATTERN
AM/PM MINI-MARKET PROJECT**

Job No.:
1056

Date:
AUG 1991

1" = 10'

Plate:
6



LEGEND:



HYDROCARBON VAPOR CONTAMINATION

GROUND WATER 150' FROM SURFACE



**GEOLOGIC CROSS SECTION
AM/PM MINI-MARKET
6th STREET AT NAVAL AVE
BREMERTON, WASHINGTON**

Job No: 1058	Date: AUG 1991	Scale: 1"=10'	Page: 7
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Appendix A

Design Calculations

Calculation of flow rate through soil using Environmental Instruments, Inc. blower system EI454XP and a soil permeability of 100 millidarcys

Max. vacuum on blower = 4.3 inches of mercury
Max. flow = 127 SCFM

$$14.7 \text{ psia} - \frac{4.3 \text{ in. Hg}}{2.992 \text{ in. Hg}} \times 14.7 \text{ psia} = 12.59 \text{ psia} \approx 12.6 \text{ psia}$$

Darcy flow equation with a combination of linear and radial flow systems in series for steady state conditions for 1/4 of the flow pattern area:

$$(P_1^2 - P_2^2) = \frac{q T_f Z M L}{0.112 AK} + \frac{2 q M T_f Z \ln(r_e/r_w)}{0.703 Kh}$$

Where: q = MCF/day, flow rate.

A = area of flow in feet, h = 25 feet;
 w = 15.5 feet
 $15.5 \times 25 = 387.5 \text{ ft}^2$

T_f = formation temperature in $^{\circ}R = (^{\circ}F + 460) =$
 $(60^{\circ} + 460) = 520^{\circ}R$

Z = compressibility factor of gas; at soil flow conditions $Z = 1.0$.

m = viscosity of gas in centipoise; viscosity of the air at standard condition = 0.009.

r_w = feet, well radius, $2 \text{ in.} / 12 = 0.1667 \text{ ft}$

r_e = feet, external radius, 5.165 ft

K = permeability of soil, K is in Darcys,
 $100 \text{ millidarcys} = 0.100 \text{ Darcys}$.

P_1 = psia at air inlet well = 14.7 psia.

P_2 = psia at extraction well = 12.6 psia.

L = feet of length between an air inlet well and extraction well external radius (r_e) = 34.835 feet.

$$(14.7^2 - 12.6^2) = \frac{q (520) (1.0) (0.009) (34.835)}{(0.112) (387.5) (0.100)} + \frac{(2q) (0.009) (520) (1.0) \ln(5.165/0.1667)}{(0.703) (0.100) (25)}$$

APPENDIX A CONTINUED

$$q = 1.02 \text{ MCF/day} = 1020 \text{ SCF/day}$$

$$1020 \text{ SCF/day}/1440 = 0.708 \approx 0.71 \text{ SCF/minute}$$

$$\text{Entire flow area rate} = 4(0.71 \text{ SCFM}) = 2.8 \text{ SCFM.}$$

Now, check blower performance curve to determine if the blower is capable of the 2.8 SCFM air flow at the vacuum used in the Darcy flow equation. After checking blower performance curve there would be no problem with the blower providing this flow rate at the vacuum used in the flow equation.

Calculation of flow rate through soil using Environmental Instruments, Inc. blower system EI454XP and a soil permeability of 500 milliDarcys.

Max. vacuum on blower = 4.3 inches Mercury

Max. flow = 127 SCFM

$$14.7 \text{ psia} - \frac{4.3 \text{ in. Hg}}{29.92 \text{ in. Hg}} \times 14.7 \text{ psia} = 12.6 \text{ psia}$$

Using the Darcy flow equation with a combination of linear and radial flow systems in series for steady state conditions for 1/4 of entire air flow pattern area:

$$(P_1^2 - P_2^2) = \frac{q L T_f Z M}{0.112 AK} + \frac{2 q M T_f Z \ln(r_2/r_w)}{0.703 kh}$$

$$(14.7^2 - 12.6^2) = \frac{(q)(520)(1.0)(0.009)(34.835)}{(0.112)(387.6)(0.500)} + \frac{(2q)(0.009)(520)(1.0)(\ln 5.615/0.1667)}{(0.703)(0.500)(25)}$$

$$q = 5.09 \text{ MCF/day} = 5090 \text{ SCF/day}$$

$$5090 \text{ SCF/day}/1440 = 3.5 \text{ SCFM}$$

$$\text{Entire flow area pattern rate} = 4(3.5) = 14 \text{ SCFM.}$$

Now, check blower performance curve to determine if the blower is capable of providing the 14 SCFM air flow at the vacuum used in the Darcy flow equation. Blower is okay.

Calculation of bulk volume of entire air flow pattern:

Assume porosity of soil = 0.25.

Area of entire air flow pattern = 31 feet x 25 feet
= 775 feet²; length = 80 feet.

$$\text{Bulk volume} = 31 \text{ feet} \times 25 \text{ feet} \times 80 = 62,000 \text{ ft}^3$$

APPENDIX A CONTINUED

Pore volume of entire air flow pattern =
 $31 \text{ ft} \times 25 \text{ ft} \times 80 \text{ ft} \times 0.25 = 15,500 \text{ ft}^3$

Time required to displace one pore volume of entire air flow pattern for soil permeabilities of 100 and 500 milliDarcys:

100 milliDarcy soil

$$q = 2.8 \text{ SCFM}$$

$$15,500 \text{ ft}^3 / 2.8 \text{ SCFM} = 5,536 \text{ minutes}$$

$$5,536 \text{ minutes} / 1440 = 3.8 \text{ days}$$

500 milliDarcy soil

$$q = 14 \text{ SCFM}$$

$$15,500 \text{ ft}^3 / 14 \text{ SCFM} = 1,107 \text{ minutes}$$

$$1,107 \text{ minutes} / 1440 = 0.8 \text{ days or } 18.5 \text{ hours}$$

Time required for removal of vapor at ARCO Mini-Market site:

Zone A: Assume porosity of 25%. 90 cubic yards of contaminated soil.

$$\text{Pore Vol.} = 90 \times 0.25 = 22.5 \text{ cubic yards}$$

$$22.5 \text{ cubic yards} \times 27 \text{ ft}^3 / \text{yd}^3 = 607.5 \text{ ft}^3$$

There is 1200 ppm hydrocarbon vapor in soil.

$$1200 \text{ ppm} \times 29 \text{ lbs/mole of air} \times 10^{-6} = 0.0348 \text{ lbs of hydrocarbons per } 359 \text{ ft}^3 \text{ of air}$$

$$607.5 \text{ ft}^3 \times \frac{0.0348 \text{ lbs hydrocarbon vapor}}{359 \text{ ft}^3 \text{ air}} = 0.0589 \text{ lbs of hydrocarbons in soil of Zone A}$$

Zone B: Assume porosity of 25%. 170 cubic yards of contaminated soil.

$$\text{Pore Vol.} = 170 \text{ cubic yards} \times 0.25 = 42.5 \text{ cubic yards}$$

$$42.5 \text{ cubic yards} \times 27 \text{ ft}^3 / \text{yd}^3 = 1,147.5 \text{ ft}^3$$

There is 310 ppm hydrocarbon vapor in soil.

$$310 \text{ ppm} \times 29 \text{ lbs/mole of air} \times 10^{-6} = 0.009 \text{ lbs of hydrocarbons per } 359 \text{ ft}^3 \text{ of air}$$

$$1,147.5 \text{ ft}^3 \times \frac{0.009 \text{ lbs hydrocarbons}}{359 \text{ ft}^3 \text{ air}} = 0.029 \text{ lbs of hydrocarbons in soil of Zone B}$$

Zone C: Assume porosity of 25%. 90 cubic yards of contaminated soil.

$$\text{Pore Vol.} = 90 \text{ cubic yards} \times 0.25 = 22.5 \text{ cubic yards}$$

$$22.5 \text{ cubic yards} \times 27 \text{ ft}^3 / \text{yd}^3 = 607.5 \text{ ft}^3$$

APPENDIX A CONTINUED

There is 520 ppm hydrocarbon vapor in soil.

$$520 \text{ ppm} \times 29 \text{ lbs/mole of air} \times 10^{-6} = 0.0151 \text{ lbs of hydrocarbons per } 359 \text{ ft}^3 \text{ of air}$$

$$607.5 \text{ ft}^3 \times \frac{0.0151 \text{ lbs hydrocarbons}}{359 \text{ ft}^3 \text{ air}} = 0.026 \text{ lbs of hydrocarbons in soil of Zone C}$$

Total hydrocarbons = 0.114 pounds

Flow rate for entire air flow pattern area with a soil permeability of 100 millidarcys = 2.8 SCFM

$$2.8 \text{ SCFM} \times 1440 \text{ minutes/day} = 4,032 \text{ SCF/day}$$

Assume the concentration of hydrocarbons in the vapor extraction air stream is 10 ppm.

$$10 \text{ ppm} \times 29 \text{ lbs/mole of air} \times 10^{-6} = 0.0003 \text{ lbs hydrocarbons per } 359 \text{ ft}^3 \text{ of air}$$

$$\frac{0.0003 \text{ lbs hydrocarbons}}{359 \text{ ft}^3 \text{ air}} \times 4,032 \text{ SCF/day} = 0.0033 \text{ lbs per day of hydrocarbons that the vapor extraction unit is producing}$$

Time Required for Vapor Extraction Process

$$\text{Total hydrocarbons at site} = \frac{0.114 \text{ lbs}}{0.0033 \text{ lbs/day}} = 35 \text{ days to extract hydrocarbons from site.}$$

Weymouth Gas Flow Equation used to size piping from extraction wellhead to vapor extraction unit.

$$Q_s = 433.45 \frac{T_s}{P_s} \times d^{2.667} \times \left(\frac{P_1^2 - P_2^2}{L s T} \right)^{1/2}$$

where Q_s = flow rate of gas in cubic feet/day at standard condition.

= flow rate for entire air flow pattern at soil permeability of 500 md = 14 SFCM x 1440 min/day = 20,160 SCF/day.

d = inside diameter of pipe in inches.

= 2.02-inch pipe diameter of 2-inch schd 40 pvc.

P_1 = initial pressure in psia.

= ?

APPENDIX A CONTINUED

P_2 = terminal pressure in psia.

= 12.6 psia = 4.3 in. Mercury.

L = length of line in miles.

= 25 feet of pipe = 0.0047 miles.

S = specific gravity of flowing gas air = 1.0.

T = absolute temperature of flowing gas ($^{\circ}\text{F} + 460$)
= 540 $^{\circ}\text{R}$

T_s = standard absolute temperature = 540 $^{\circ}\text{R}$

P_s = standard absolute pressure in pounds/square
inch = 14.7 psia.

Pressure drop is negligible, however manufacturer recommends using next pipe size larger than flanges on blower = 2 inch, therefore go to 2.5-inch pipe.

Regenerative Blower

FEATURES

- Manufactured in the USA
- Maximum flow 127 SCFM
- Maximum pressure 65" WG
- Maximum vacuum 4.3" Hg
- 1.5 HP standard
- Blower construction—cast aluminum housing, impeller and cover
- Inlet and outlet internal muffling
- Noise level within OSHA standards
- Weight: 73 lbs. (33 Kg)

ACCESSORIES

- External mufflers
- Slip-on flanges
- Inlet and/or inline filters
- For details see Accessories Section

OPTIONS

- Smaller horsepower motors
- 575-volt and XP motors
- Surface treatment or plating
- Single or three phase motors
- Gas tight sealing
- Belt drive (motorless) model; for detail see Remote Drive Section

