SOIL VAPOR EXTRACTION

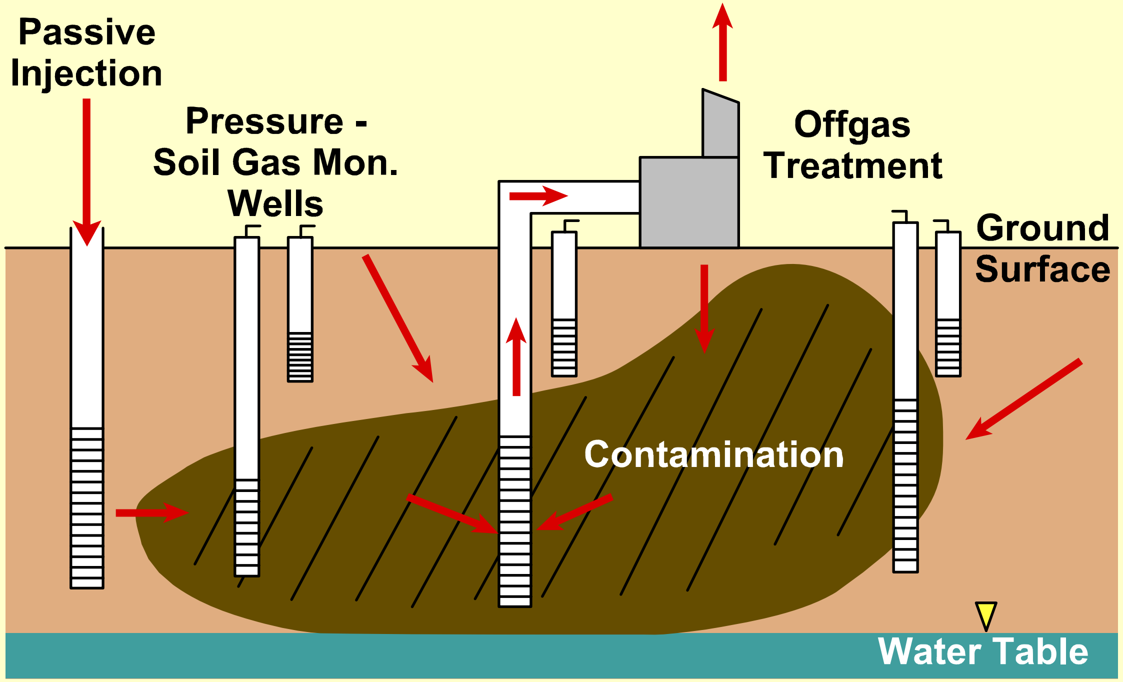
Presentation Objectives

- Describe SVE technology and applicability, including enhancements
- Identify data needs for SVE selection/design
- Recommend pilot testing approach
- Provide design guidance
  - Avoid radius-of-influence approach
  - Consider air throughput
- Consider start-up data collection & evaluation
- Discuss operational strategies
- Compare closure strategies and tools to determine progress toward close-out
- Identify contracting approaches

Soil Vapor Extraction

- Operating principles
  - – Volatile organics evaporate into soil gas
  - – Remove air from vadose zone
  - – This removes vapors, promotes additional evaporation
  - – This removes contaminant mass
  - – Also promotes biodegradation
  - – Passive extraction (and injection)
  - – Soil pile treatment (excavated soil)

Soil Vapor Extraction Schematic



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Applicability

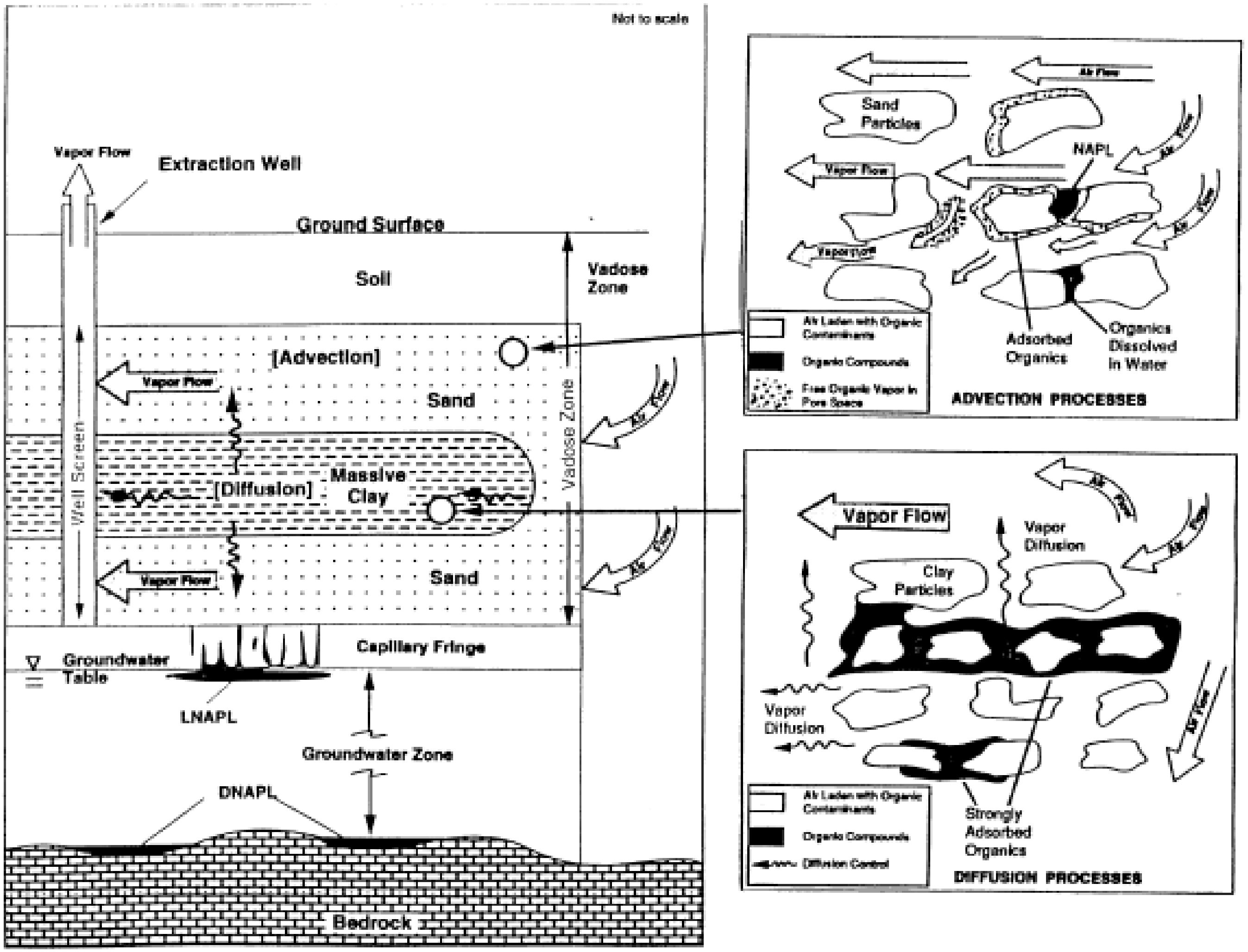
Soil Vapor Extraction

- Soils only
  - Not for groundwater cleanup
  - Require adequate permeability to air
  - May remove minor light floating product
- Volatile components
  - Vapor pressure >0.5 mm hg
  - High henry’s law constant
- Semivolatile/heavy hydrocarbons
  - Indirectly applicable
- Landfill gas control
- Remediation in months to years

Limitations

- Silts and clays very difficult to treat
- Fine soil retains moisture, blocks pores
- Dead-end pores may retain contaminants
- Diffusion limitations important for tight soils
- Geologic heterogeneity may result in non-optimal air paths
- Difficult to SVE implement in fractured rock due to highly anisotropic air flow

Diffusion Limitations



Source: after USEPA 1991c

Air Permeability As Function Of Water Content

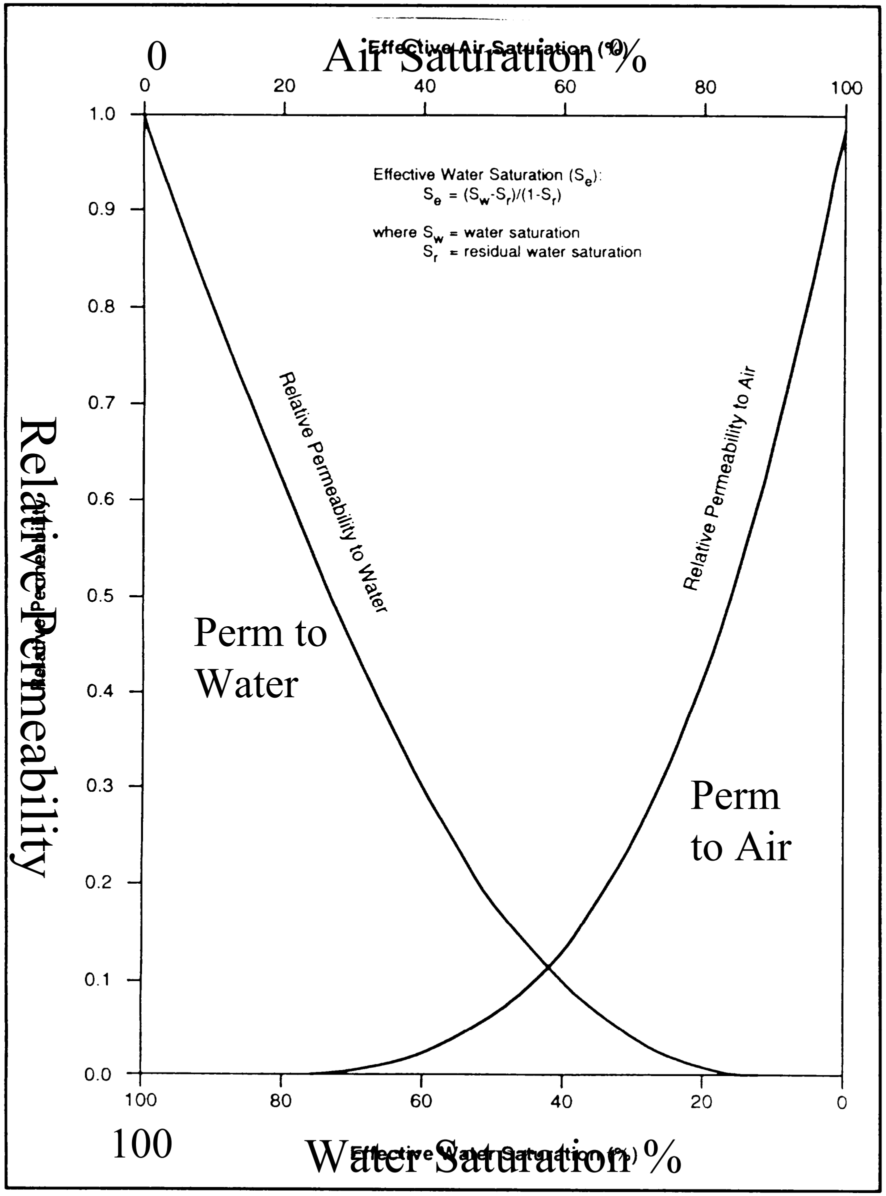


Figure 4-2. Relationship between water saturation and relative permeability to air

Important Processes Governing Air And Contaminant Movement

- Air flow is governed by equations similar to ground water (darcy’s law) but air is compressible
- At low gauge vacuums/pressures, many equations for groundwater can be used for air
- Models available to predict air flow and vacuum/pressure distribution
- Sorption of contaminant, moisture content will affect contaminant transport

Design Data Needs

SVE Design Consideration

- Stratigraphy
  - Take care in logging
  - Note secondary permeability features
- Depth to water table
  - Fluctuations
  - Ground water concentrations - offgasing
- Nature, extent, and mass of contaminant
  - Difficult to determine mass, use method 5035
- Soil vapor concentrations (primary and secondary contaminants)
- Moisture content of soil – very important
- Organic carbon content of soil
- Oxygen content – for biodegradation issues
- Site features: basements, utilities, topography
- Available utilities, sound issues

DESIGN DATA NEEDS

SOIL PARAMETERS

								SOIL PARAMETERS													
TECHNOLOGIES	Temperature	Soil pH	TOC	Kjeldahl nitrogen	Nitrate, Nitrite	Available P (soil), Totat P (water)	Sieve Analysis/Grain Size Analysis	Specific Heat BTU/lb	Moisture Content	Field Capacity	Bulk Density	Particle Densigy	Soil Permeability	Porosity	Soil classification	Alkalinity (HCO3-, CO3=)	Fe III, Mn IV	Soil Oxygen	CO2 (soil gas)	Conductivity (thermal)	Capillary pressure - saturation curve	Strataigraphy
Soil Vapor Extraction (SVE)	X	X	X	O	O	O	X		X		O			O	X			X	X		X	X
Thermally Enhanced SVE	X	X	X				X	O	X	O	O	O	O	O	O	X	O	X	X	O	X	X
Bioventing (BV)	X	X	X	X	O	O	X		X	X	O		O	O	X		O	X	X		O	X

NOTE: "X" Recommneded during early site investigations before any treatment is being considered

"O" Recommended in addition to "X" if the technology is being considered or has been selected

DESIGN DATA NEEDS

WATER PARAMETERS

						WATER PARAMETERS														
TECHNOLOGIES	DO (field)	Temperature (field)	Turbidity	H2S	pH (field)	ORP (field)	Ca++,Mg++,Mn++,Na+,K+	TOC	COD	Total Dissolved Solids (TDS)	Alkalinity (HCO3-,CO3=)	Conductivity (field)	BOD	Phosphorous (total)	Ferrous Iron (Fe II)	Total Iron (Fe II,Fe III)	SO4=, SO3=	NO2-, NO3-	Kjeldahl Nitrogen	Sieve Analysis *
Air Sparging (AS)	X	X	X	O	X	X		X	O	X	X	X	O	O	X		O	O	O	X
Multiphase Phase Extraction (MPE)	X	X	X		X	X	O	X		O	X	X		O		X		O	O	X
In-Well Air Stripping	See AS																			
Free Product Recovery	See MPE																			
NOTE: "X" Recommened during early site investigations before any treatment is being considered																				
"O" Recommended in addition to "X" if the technology is being considered or has been selected																				
* Estimate of soil hydraulic properties in the aquifer where the samples were taken																				

PILOT STUDIES

Typical Objectives

- Determine Mass Removal Rates
  - Typically Highest at Start
  - Exponential Decay Over Time
  - Useful for Offgas Treatment Design
- Determine Air Flow Paths
  - Identify Heterogeneity Effects
- Air Permeability Estimate
  - Critical for Well Layout Design
- Achievable Residual Concentrations (Long Term)
- Amount of Necessary Air Throughput (Long Term)

Pilot Studies

- Typical pilot equipment
  - Similar to ground water pump test
  - Single extraction well
    - Designed as a typical production well (preferred)
    - 10-cm diameter monitoring well with adequate screen above water table
  - Monitoring points
    - Multiple depths to asses
    - Logarithmically increasing distances
  - Rental blower and associated equipment
    - Need power, permit (?), treatment (?)
  - Means to measure flow, vacuum, concentrations

Pilot Studies

Typical Pilot Procedures

- Note barometric pressure lag
- Step test
  - Run blower at different settings of bleed valve (different applied vacuums at well head)
  - Measure flow at stable vacuums
- Air permeability test
  - Pick steady air flow rate from step test
  - Run test at steady rate, measure transient and (pseudo)steady state vacuum at monitoring points
  - Duration: <5 min to >8 hours

Pilot Studies

Typical Pilot Procedures, Continued

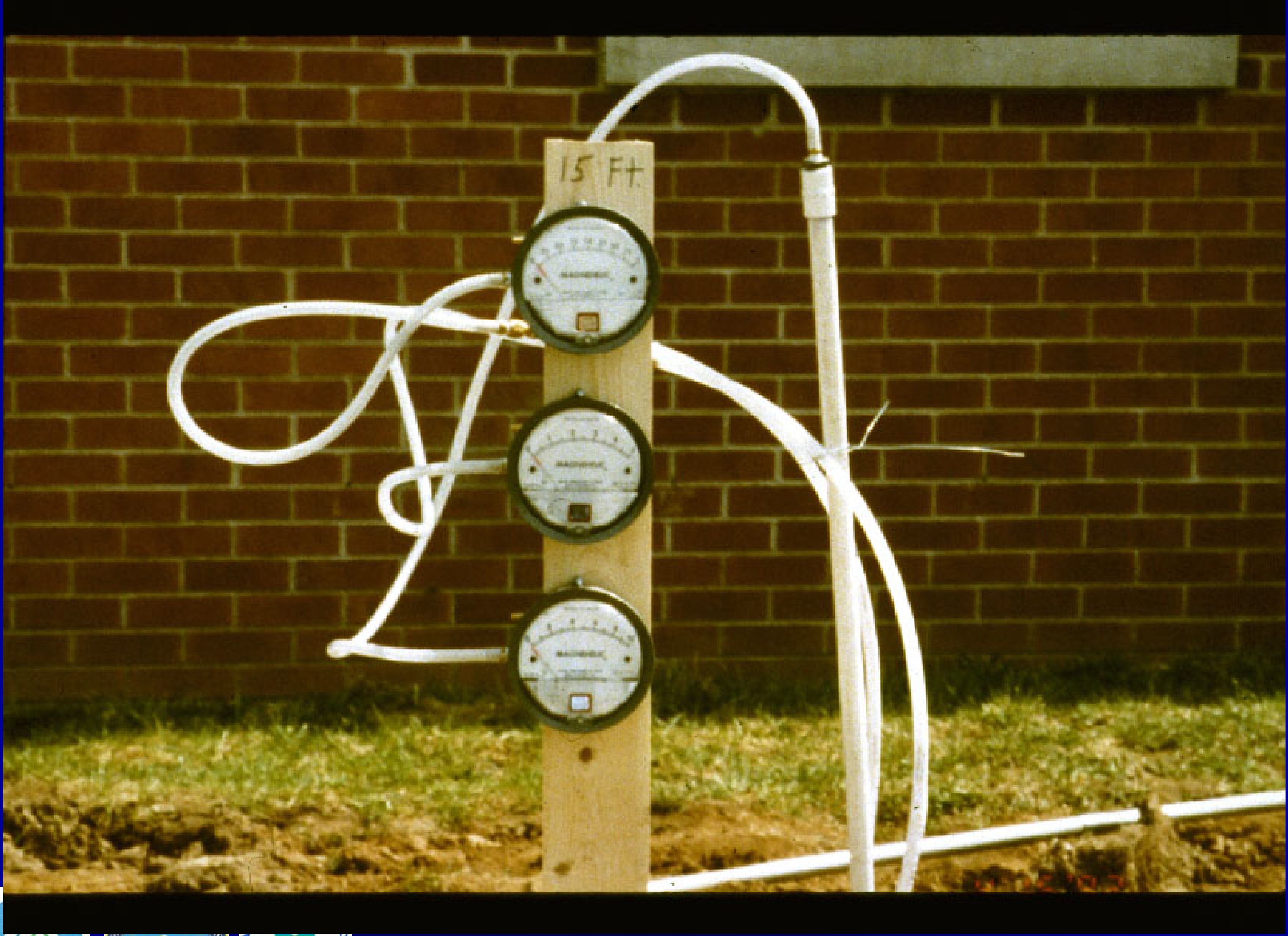
- Long-term concentration trend
  - Continue operation, measure conc. Vs time for weeks/months
  - Monitor gross concentration (PID/FID), some definitive analysis for specific constituents (on- or off-site lab)

Pilot Studies

Data Analysis

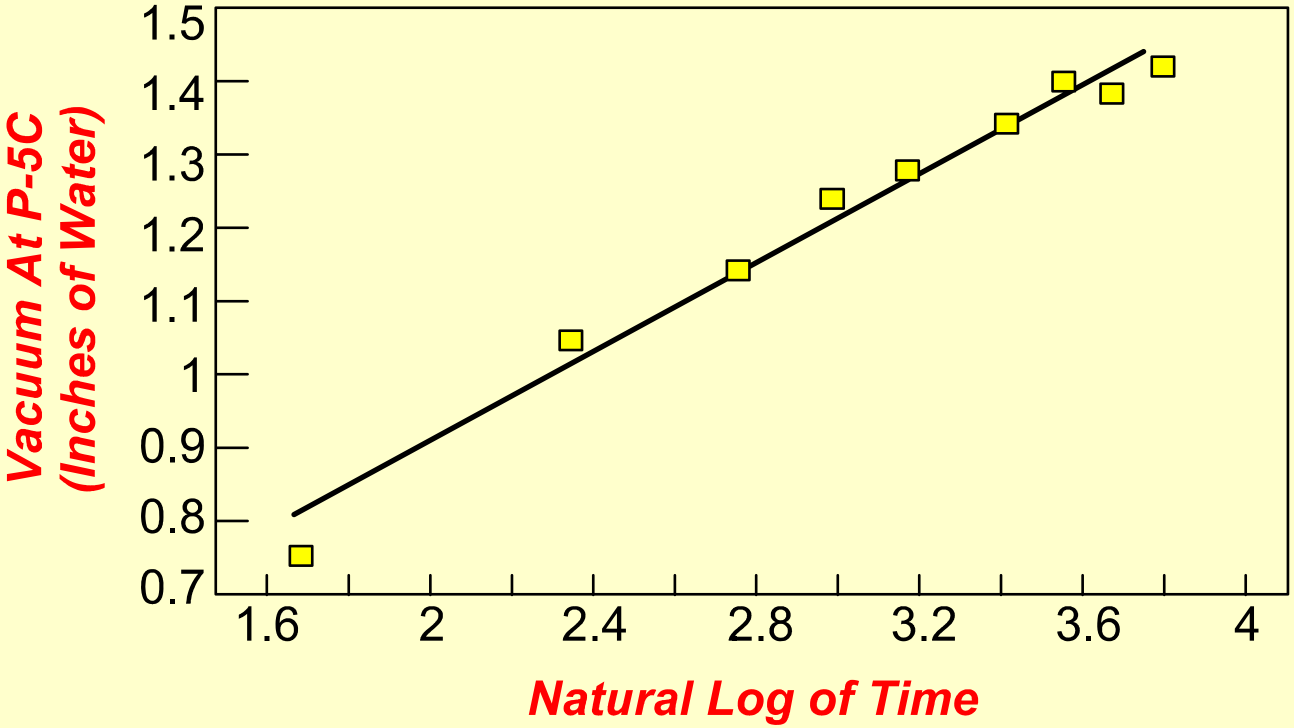
- Step test: graph of flow vs. applied vacuum, look at water table response
- Air permeability (k_a)
  - Similar to groundwater, different boundary conditions
  - Differences between k_w and k_a
  - Johnson et al. 1990 (Johnson, P. C., Stanley, C. C., Kemblowski, M. W., Byers, D. L., and Colthart, J. D. 1990a. A practical approach to the design, operation, and monitoring of in situ soil-venting systems. *Ground Water Monitoring Review*. 10(2):159-78)
  - Shan et al. 1992 (Shan, C., Falta, R., and Javandel, I. 1992. Analytical solutions for steady state gas flow to a soil vapor extraction well. *Water Resources Research* 28(4): 1105-20)
  - GASSOLVE software
- Concentration trend: plot concentrations vs. time for different constituents


ARBTROL
PORATION



Air-Based Remediation Technologies

Typical Pilot Test Result



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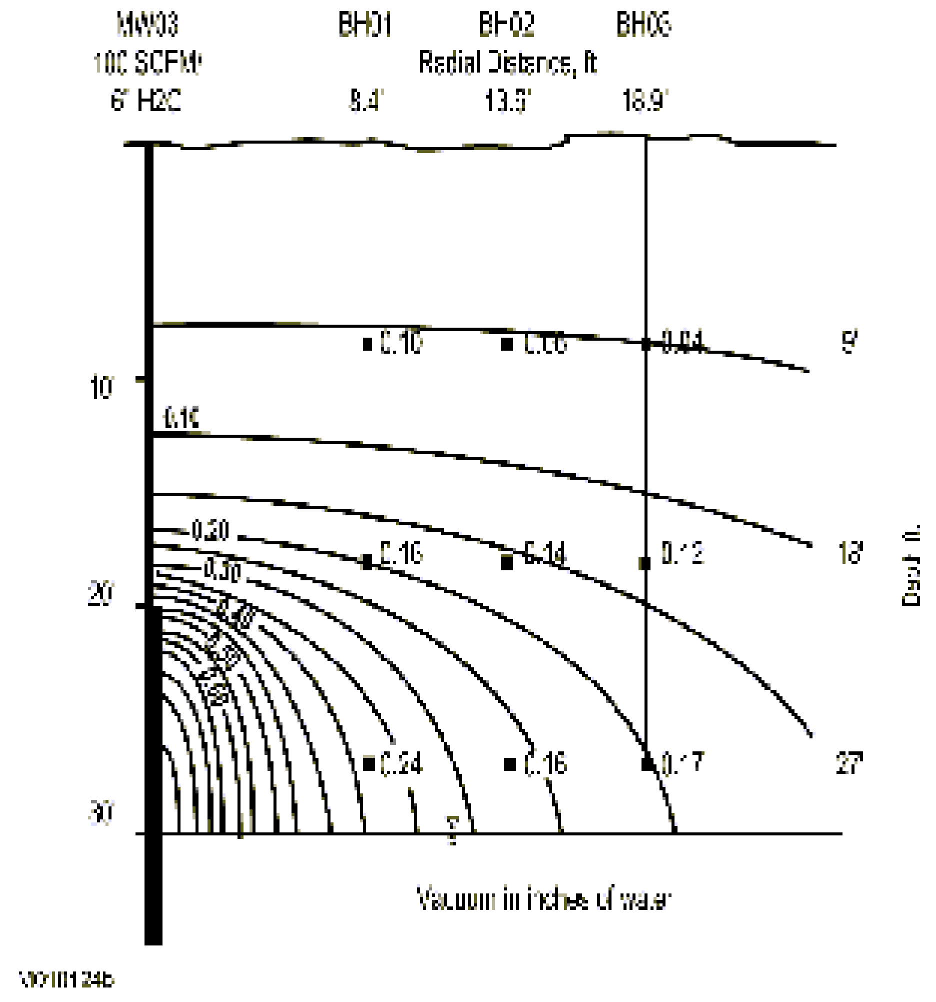
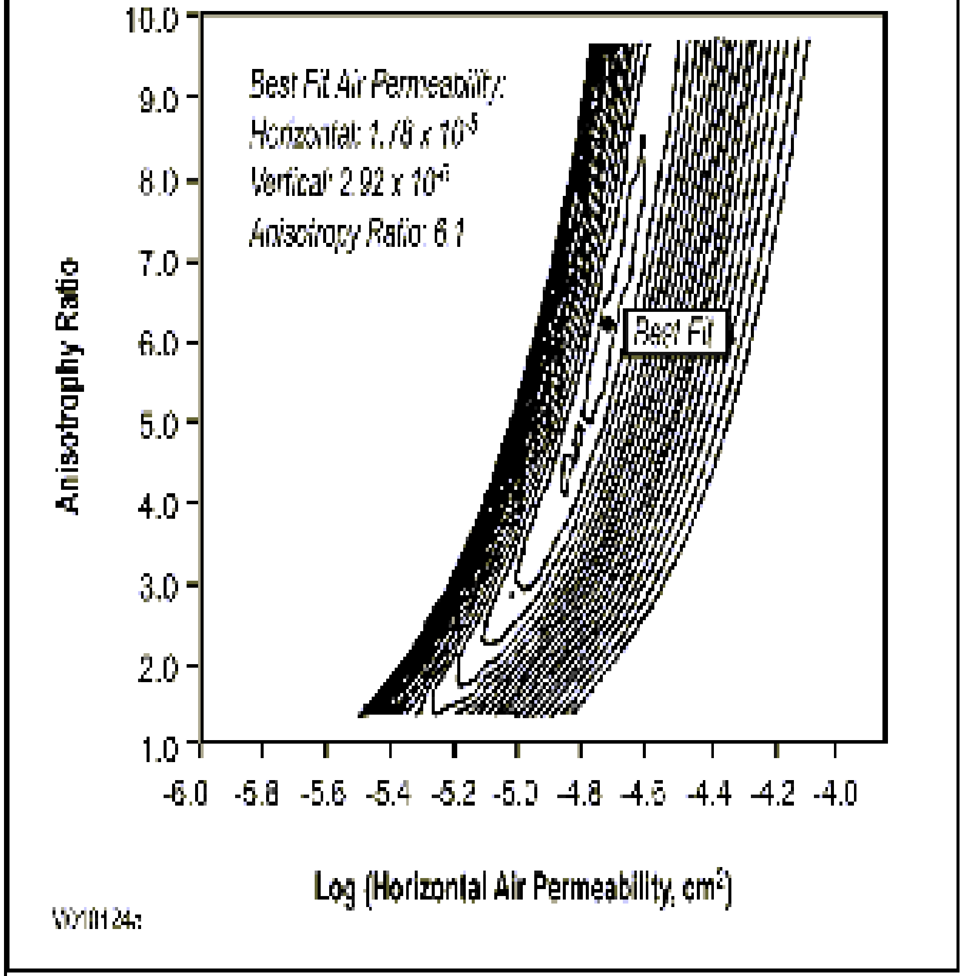
Permeability Estimating Using Best-fit Techniques





System Design

Subsurface Design

Above-Ground Equipment

Well Spacing - Screen Placement

- Well placement
  - Cover 3-dimensional extent with adequate flow to achieve removal in required time
  - Do NOT use radius of pressure influence
  - Key: amount of air moved through target zone
  - Criteria:
    - Travel times for air through target zone
    - Minimum velocities in target zone

Subsurface Design Criteria

- Travel time through contaminated zone that results in adequate air exchanges to achieve goal accounting for diffusion limits
  - Need 100s to 1000s of air exchanges
  - Common criteria: 0.25 – 1 day travel times
- Minimum air velocity of 0.01 cm/sec within contaminated zone
  - Identify stagnation zones – little flow
- Use of pilot test data – permeability, paths
- SVE models, 2DSTREAM
- Nomographs in Shan et al, 1992 and USACE SVE EM

Well Layout Selection

- Assess travel times/velocities for single well
  - Covered and uncovered (open) surface
  - Different equations

$$Q_v^* = \frac{\pi r^2 b n_a}{t_{ex}}$$

$$Q_v^* = \frac{2 \pi b^2 n_a A (L - l) \tau}{t_{ex}}$$

r = horizontal distance from well, b = vadose zone thickness, n_a = air-filled porosity, t_{ex} = time for 1 pore volume, L = depth to water table, l = depth to top of screen, A = k_h/k_v, τ = dimensionless travel time

Travel Time Nomograph

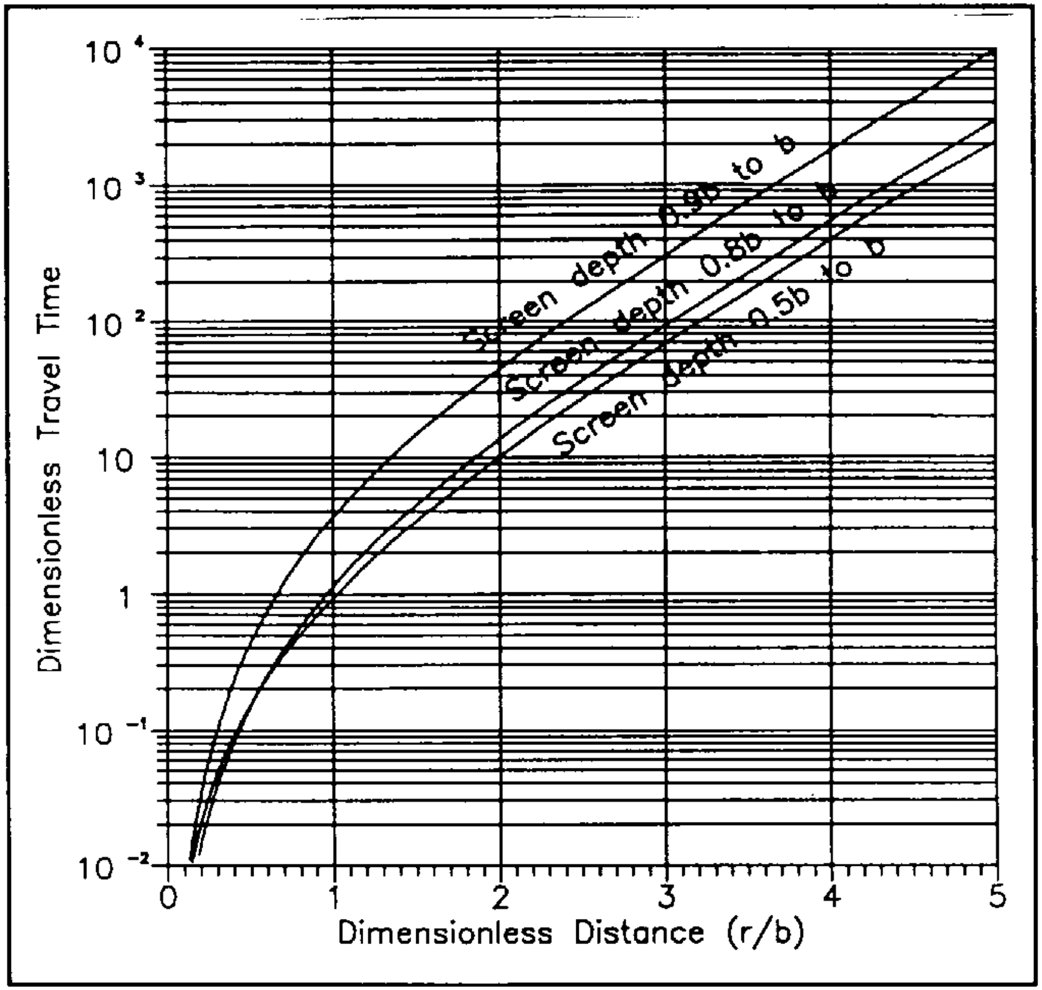
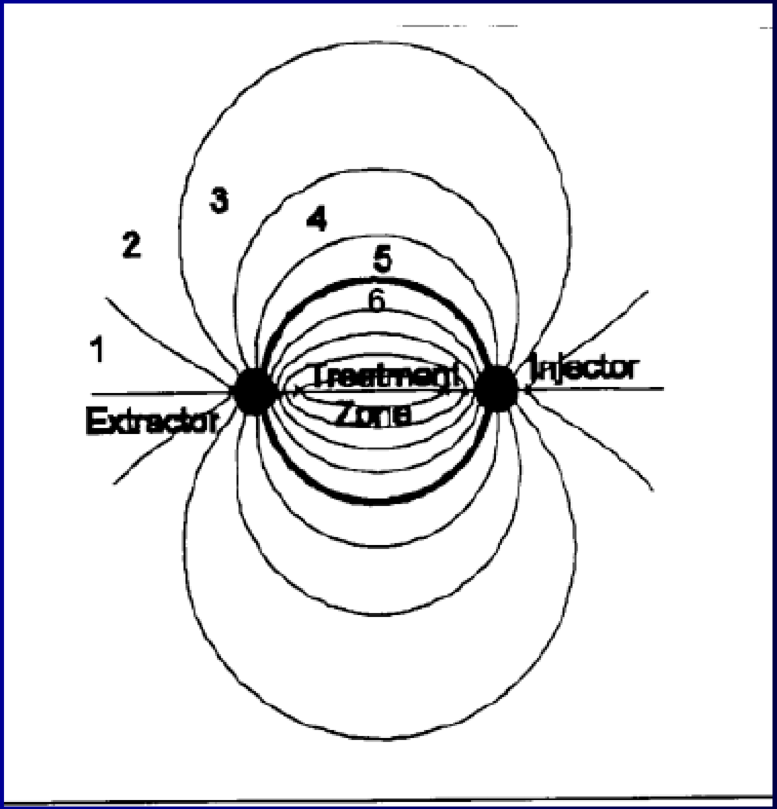


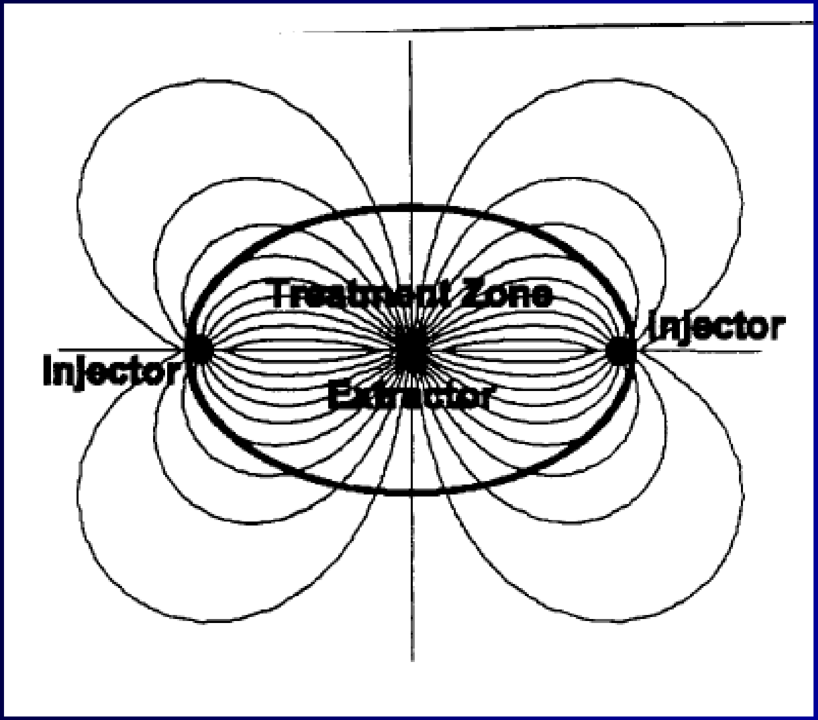
Figure 5-14. Dimensionless travel times at the water table for wells screened within the lower half, fifth, and tenth of the vadose zone (Brailey 1995, unpublished data)

Well Spacing - Screen Placement, Continued

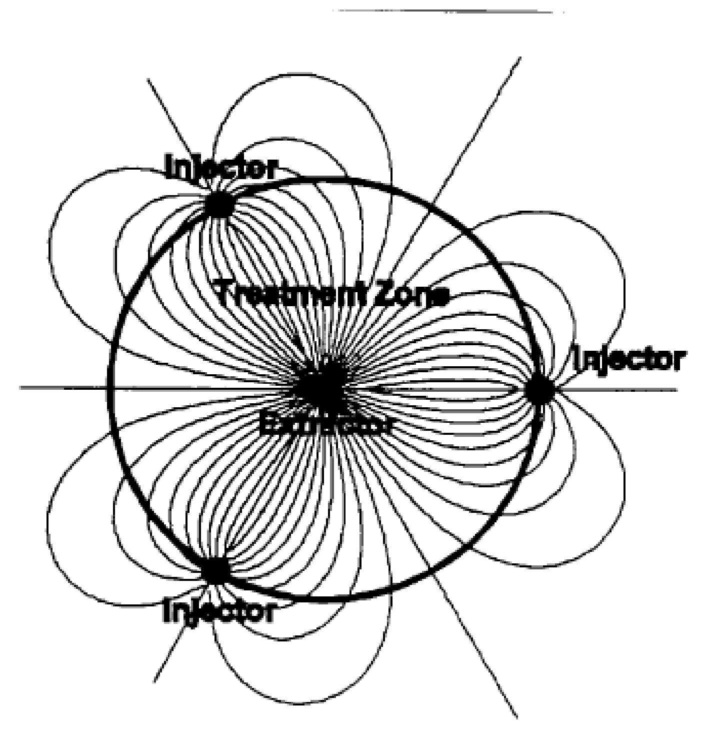
- Active and passive air injection
  - Improve throughput, especially near water table
  - Reduce upwelling
  - Avoid stagnation zones
  - Isolate offsite sources
  - Consider air intrusion into basements, utilities
  - Passive injection: depends on achievable flow
- Screen placement
  - Focus flow in contaminated zone
  - Depths vs. Volume of effective treatment
  - Avoid water table upwelling

Two- And Three-well Systems





Four-well And Multiple Well Systems



- Air-flow modeling can assist in assess flow in larger systems
- Models can assess velocities
- Identify stagnation zones

Subsurface Component Design

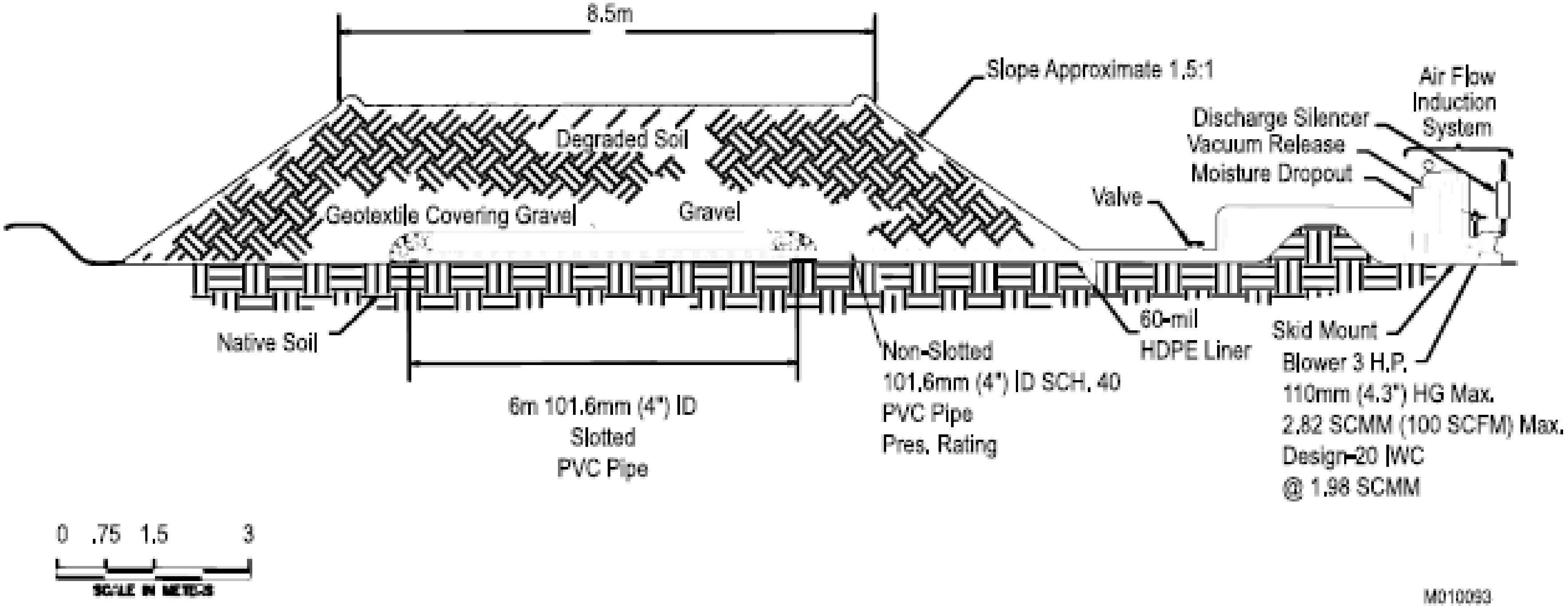
- Well design
  - Drill method: do not use fluids if possible
  - Diameter: minimum 10 cm, larger at high flows
  - Materials: typically PVC, consider others if soil concentrations high or in contact with residual pure solvent or if thermal enhancement possible

Subsurface Component Design

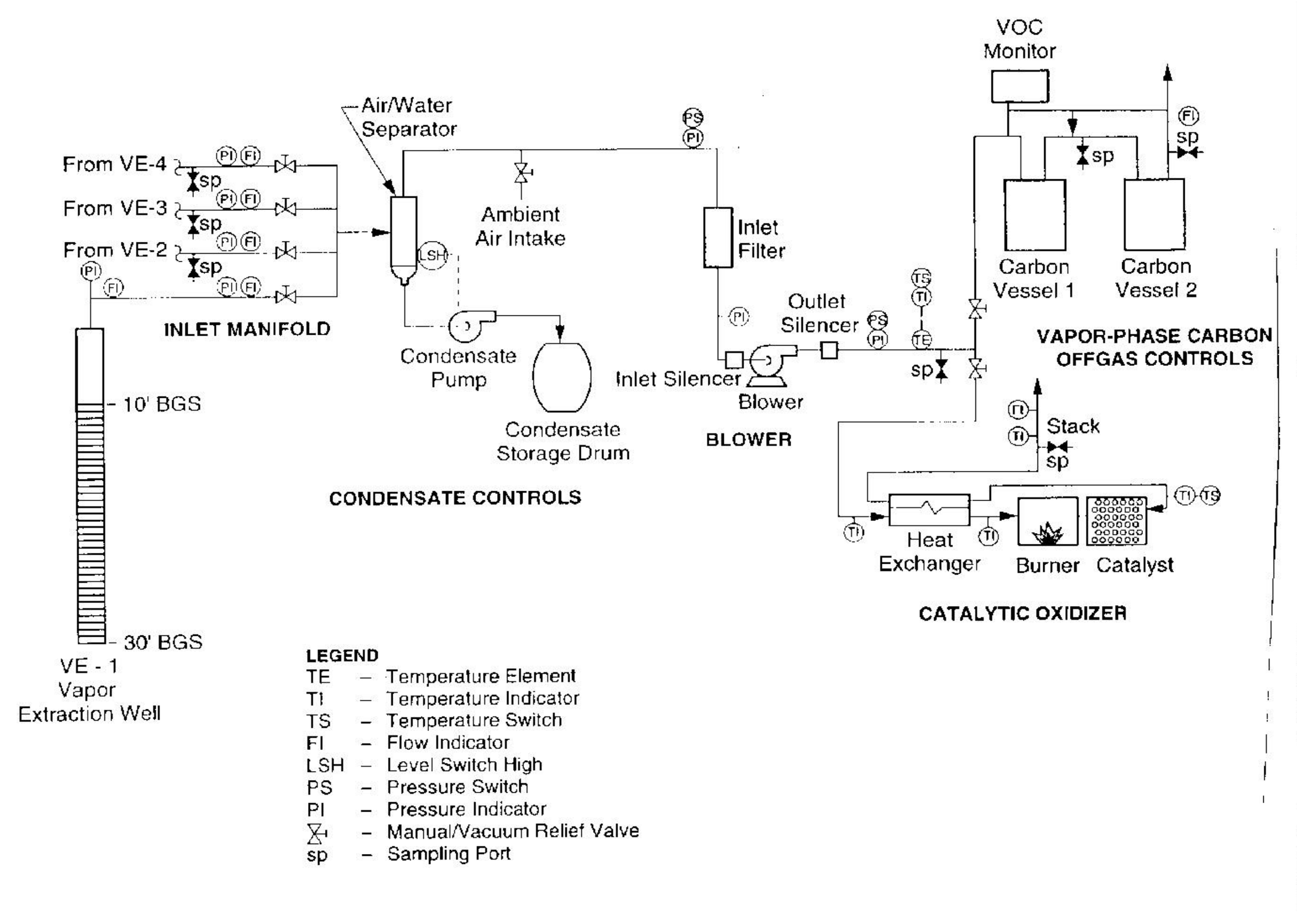
- Well design, continued
  - Screen: continuous wrap, moderate slot size
  - Filter pack: coarse pack or as for water wells,
  - Grout seal important
  - Horizontal wells: most appropriate with shallow water
    - Most methods use fluids (including mud) which may prove problem for effective SVE
    - Trenching may be more effective, need effective seal above trench

Above-Ground Piles

- Excavated soil, less heterogeneity in soil structure
- Control moisture but allow air in, liner under soil
- Extract at bottom of pile



Typical SVE Process Schematic



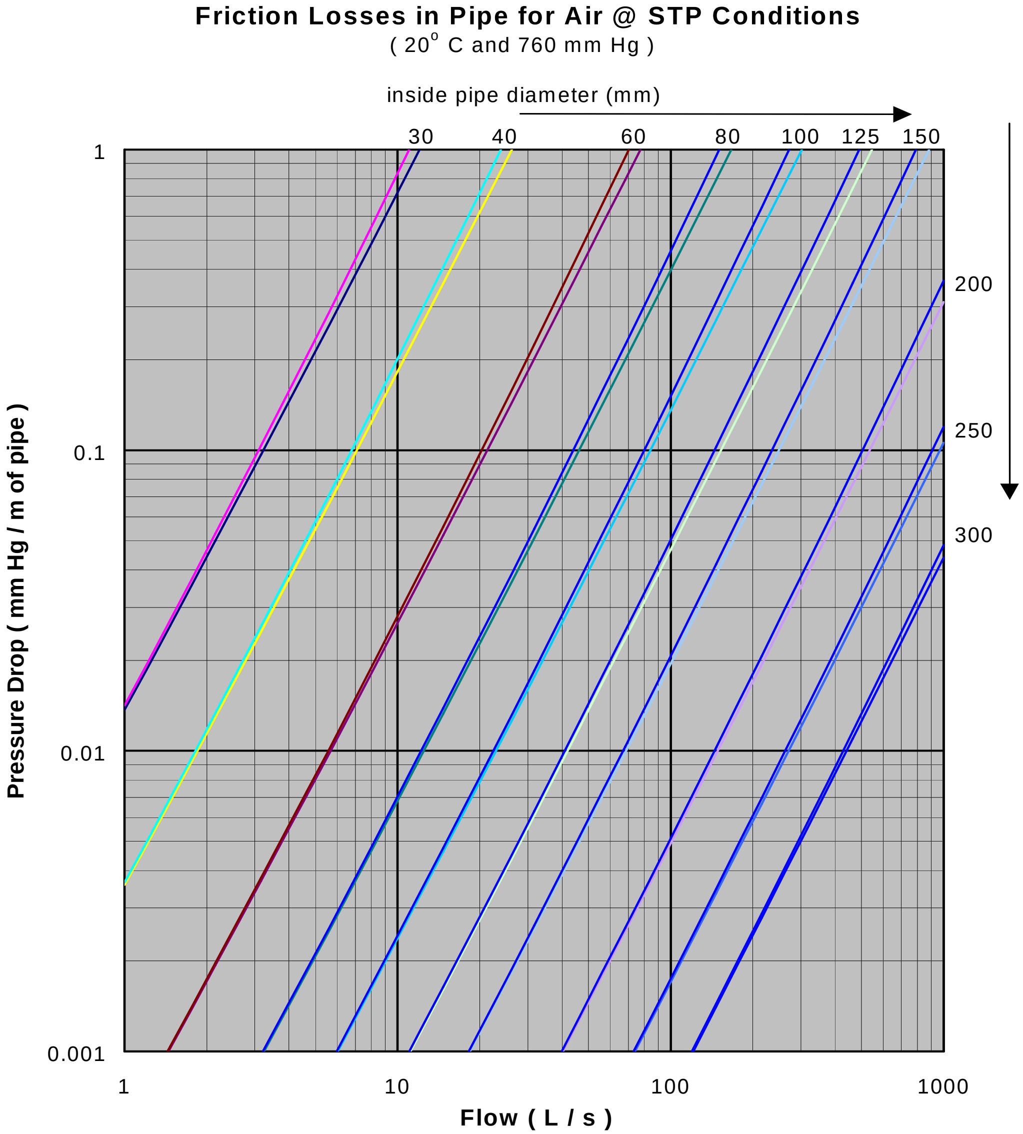
LEGEND

TE	– Temperature Element
TI	– Temperature Indicator
TS	– Temperature Switch
FI	– Flow Indicator
LSH	– Level Switch High
PS	– Pressure Switch
PI	– Pressure Indicator
⋈	– Manual/Vacuum Relief Valve
sp	– Sampling Port

Piping Design

- Often Not Buried Due to Short Duration
- Must Consider Pressure Drop along Piping - Use Adequate Diameter for Flow. Loss Charts Available
- Separate Piping to Each Well Vs. Header Piping
- Consider Drains at Low Points
- Calculate Balanced Flow for Individual Piping Legs
- Spreadsheets Useful to Design
- Materials: Plastic (PVC) Fine for Vacuum, Consider Concentrations, Temperatures. High Temps Deform PVC
- Degradation of PVC in Sunlight

Pressure Loss Chart



Top line of pair for steel pipe and lower line for PVC pipe.

Blower Design

- Types: Typically Regenerative, Positive Displacement (Rotary Lobe, Liquid Ring)
- Positive Displacement Types Develop Vacuum Needed to Generated Desired Flow
- Identify Necessary Flow, Predict Wellhead Vacuum
- Match Blower Performance Curve to System Conditions, Including the Losses in Piping
- Minimize Energy Use, Maximize Speed, Need Flexibility
  - Consider Variable Speed Drive Motors - Flexibility Input From Mechanical Engineers
- Consider Potential for Hazardous Atmospheres

Monitoring System Design

- Parameters: pressure/air flow, soil gas concentrations, barometric pressure
- Permanent probes, small diameter, good seal
  - Multiple depths - use to confirm design
  - Choose representative locations based on geology, contaminants
- Flow control valves, sample port
- Flow measurement device for each wellhead
  - Pitot tubes, orifice plate, rotometers, anemometer
- Temperature, vacuum/pressure measurement before/after blower

Other Components

- Covers - very similar to landfill covers
- Condensate handling
  - Vapor near 100% RH, cooling causes condensation
  - Entrained water
  - Cyclone separator
  - Insulate, heat tracing
  - In-situ moisture control
- Particulate filters
  - Dust generation usually limited to debris in piping
  - Can get dust in fractured piping
  - Filters: ~10 um paper cartridge, others
  - Measure pressure drop across filter

SVE Off-gas Treatment

- Offgas treatment
  - Carbon adsorption, resin adsorption
  - Thermal destruction
  - Catalytic oxidation
- Problems
  - Carbon – high cost, not effective for MEK, VC, etc
  - Thermal destruction & catalytic oxidation
    - High energy
    - Cl-voc can produce acid gases, high corrosion

Control System

- Well suited to unattended operation
- Typically modest level of automation
- Auto-dial for shut-down condition
- Thermal cut-off on blower motor, high condensate tank level, high vacuum/low pressure
- Pressure relief valves, bleed valve
- Automated chemical monitoring

Off-Site Considerations

- Noise < 120 db
- VOC reduction – set by local air board
  - Mass/day, e.g. Purity site 0.3 kg/day
  - 90% reduction of all VOCs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Air-Based Remediation Technologies


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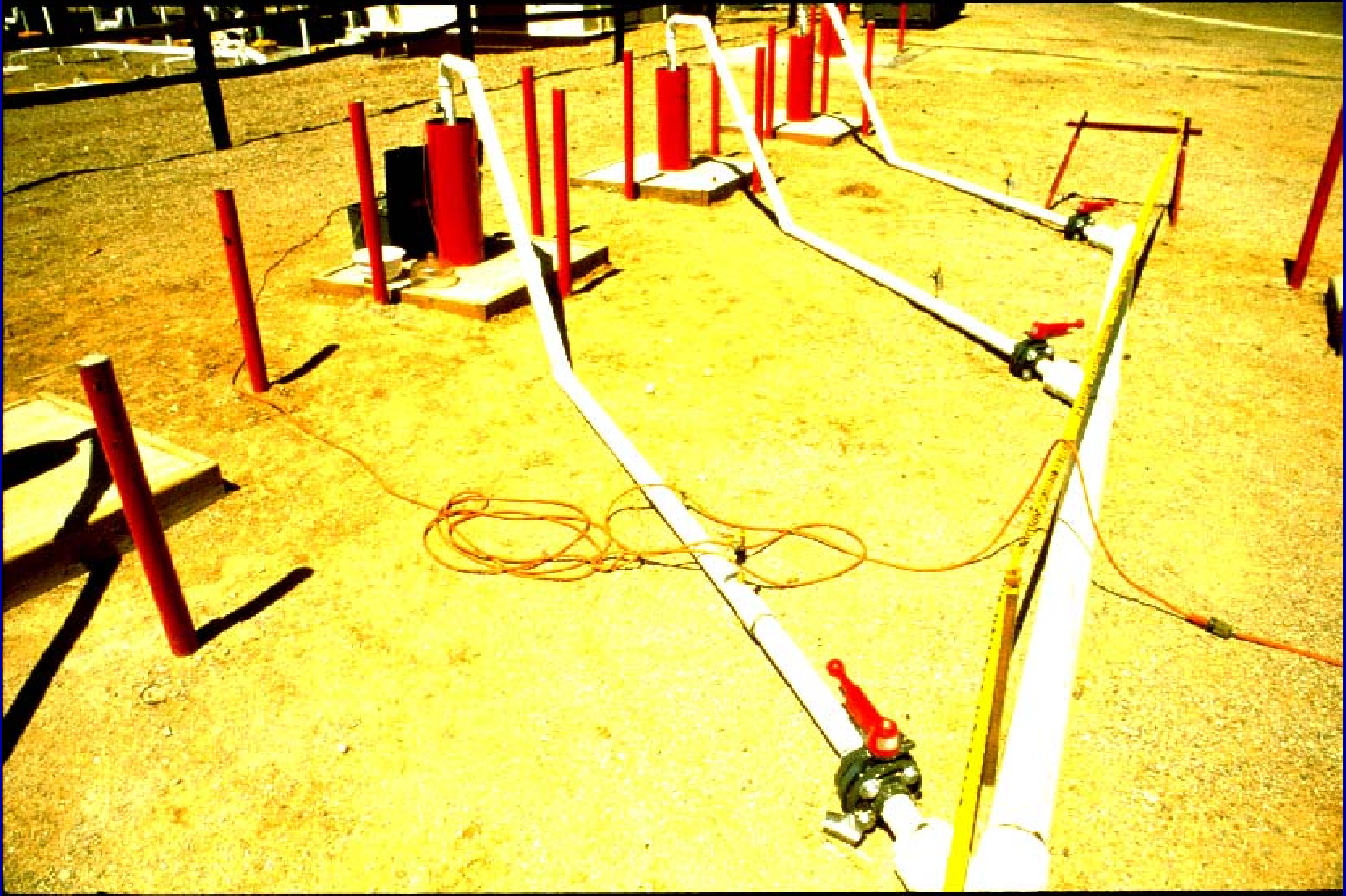

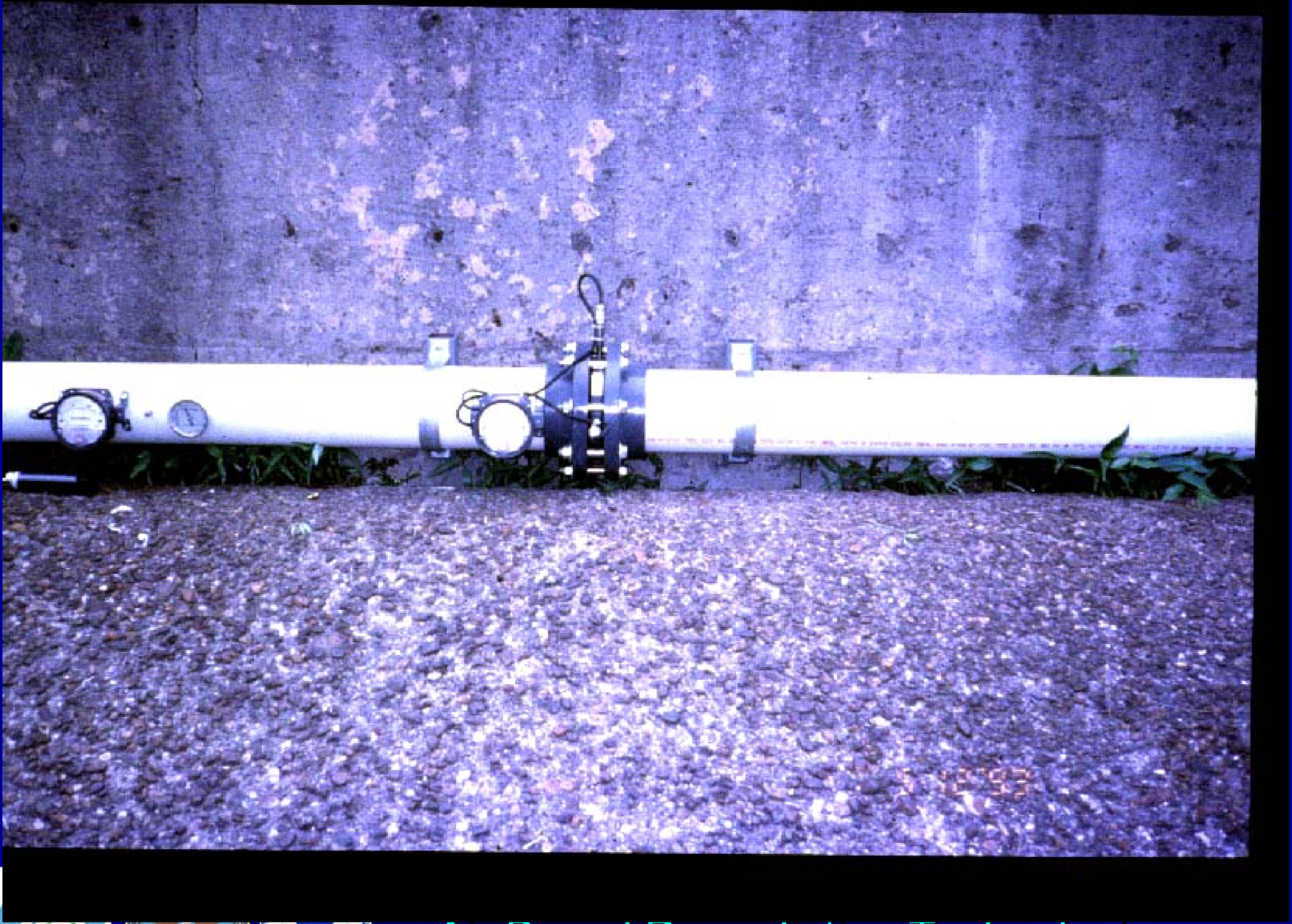

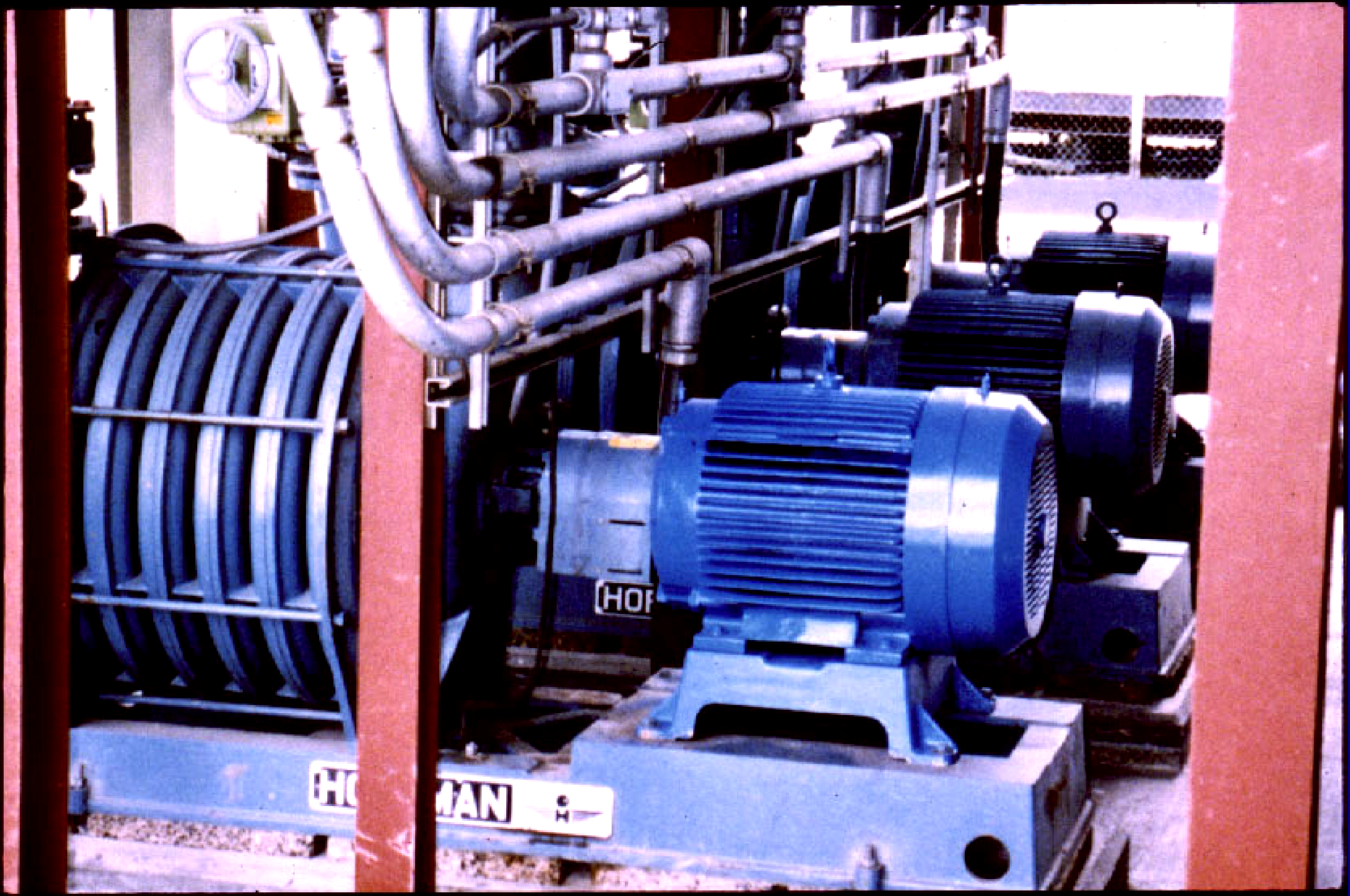
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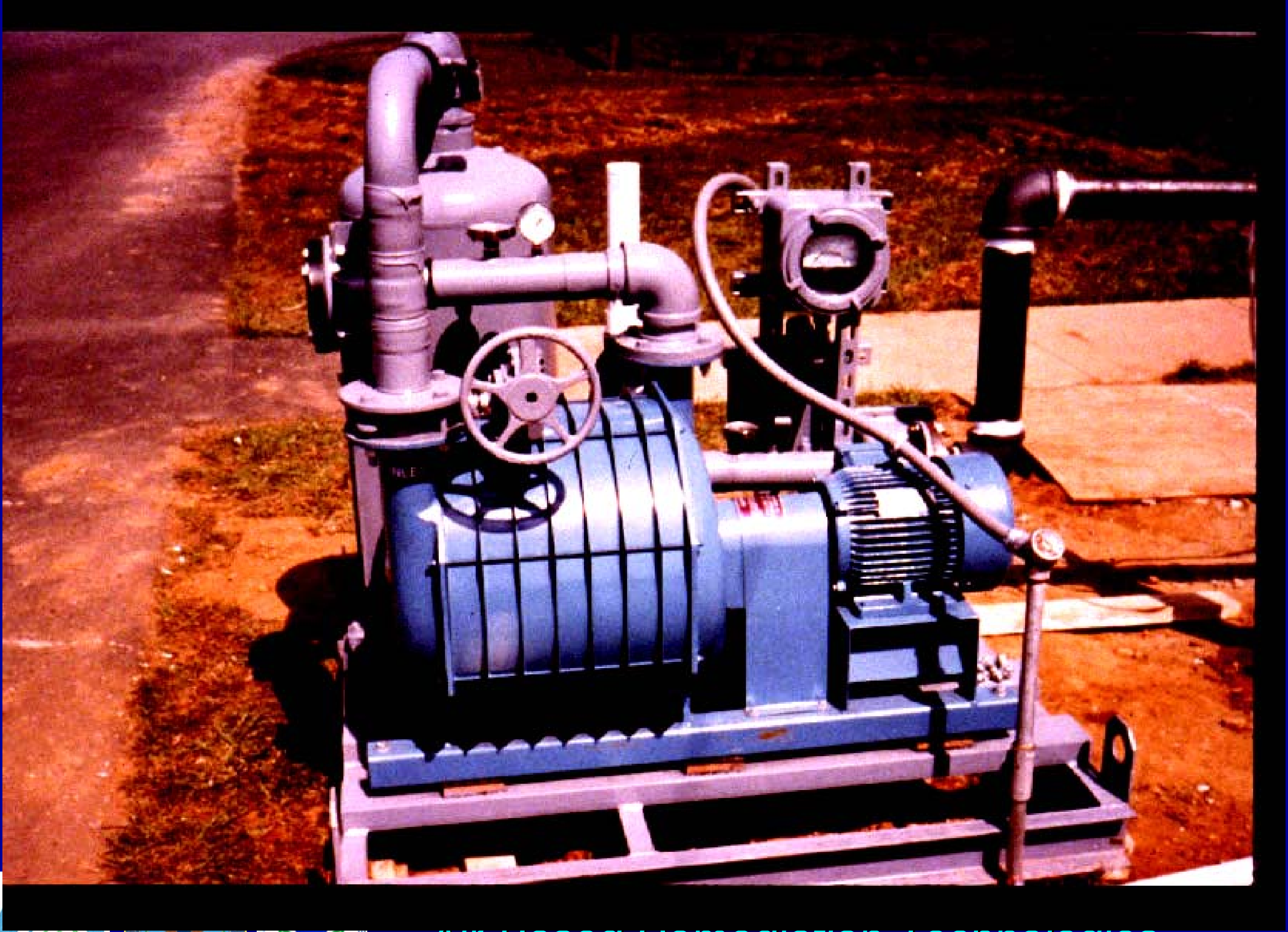

Air-Based Remediation Technologies

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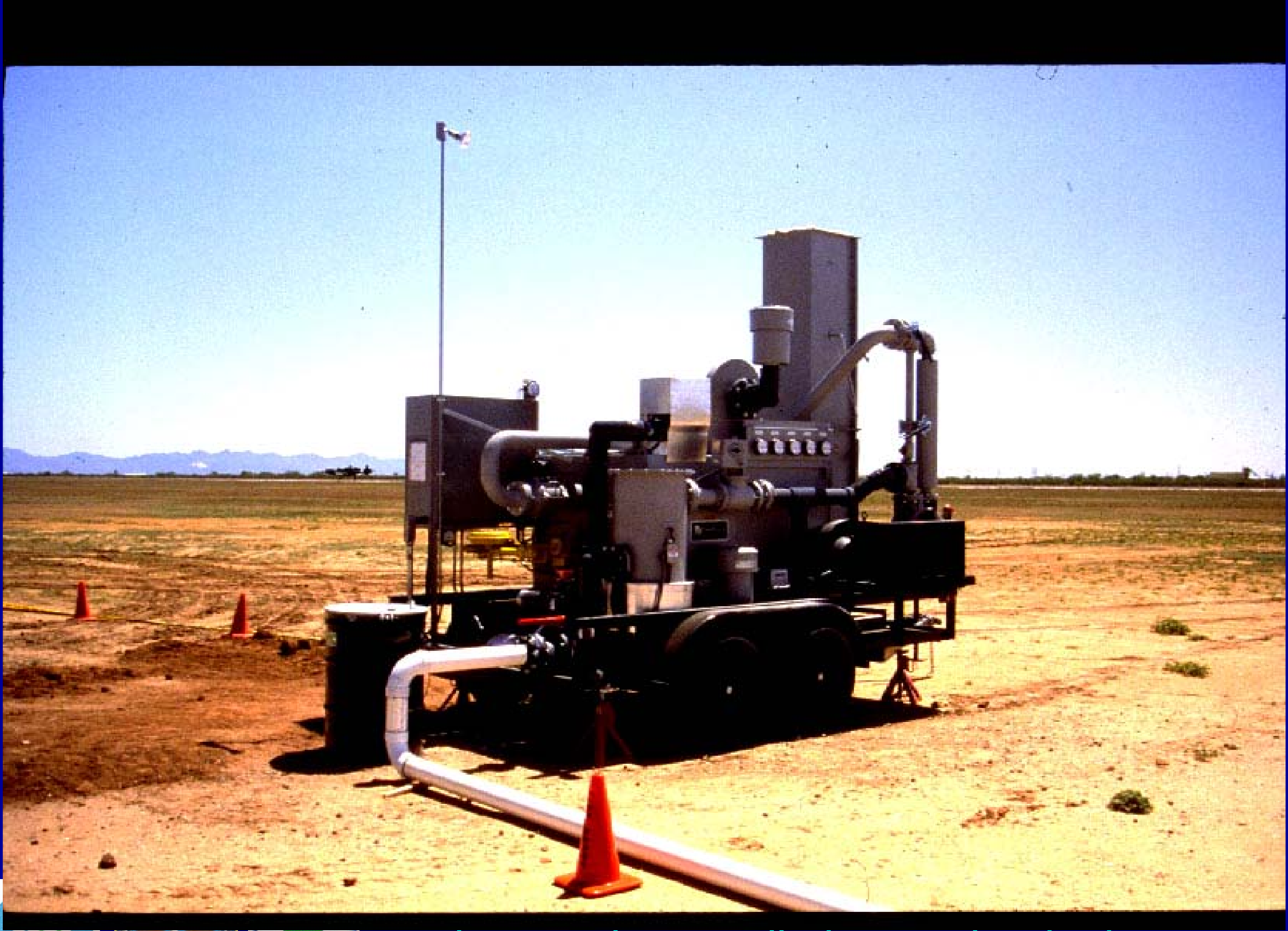


Air-Based Remediation Technologies

Downhole Pressure Transducers

Start-Up and Operation Of SVE Systems

- Construction can take weeks
- Operations often months to few years
  - Some systems have operated for over 7 years
- Safety issues
  - Explosion-proof equipment
  - Safety checks of control equipment – equipment shut-down under certain conditions
  - Covers over rotating equipment or hot piping

Start-up Of SVE Systems

- Objective: operate equipment, gather baseline data, adjust operating parameters to achieve desired air flow, treatment
- Perform checks:
  - Equipment functional performance
  - Safety shutdowns, other safety checks (circuits, etc.)
  - Checklists available
- Initial/baseline monitoring of concentrations
- Pneulog testing of new wells
- Start up: open bleed valve, start blower, gradually close bleed valve - A VFD motor easier
- Highest concentrations typically encountered first, often problem for treatment

Start-up Of SVE Systems, Continued

- Verify vacuum/pressure distribution
- Monitor concentrations in subsurface, influent, effluent
- Monitor equipment performance (current draw, temperature, condensate production)
- Operate equipment - typically much down time

SVE System Operations And Maintenance

- Periodic system checks and routine maintenance
  - Check, lubricate blower
  - Drain condensate, check transfer pump
  - Check/clean particulate filter
  - Attend to offgas treatment system
  - Verify flow rates (total, individual wells)
  - Measure influent and effluent concentrations, temp
  - Balance multi-well system
  - If simple offgas treatment, O&M not costly

SVE System O&M Monitoring Consideration

- Measure the vacuum, flow rates, concentration/composition at each extraction well, not just the header
- Effluent VOC concentration eventually becomes asymptotic – steady-state removal of very low concentration
- A drop in effluent mass does not necessarily mean a drop in available contaminants or system efficiency
  - Chemical speciation
  - Diffusion control
  - Water table upwelling
  - Soil drying
  - Short-circuiting
  - Dilution

DJB2

SVE System O&M Monitoring, Continued

- Effluent Sampling
  - Monitoring often done with screening instruments, e.g. , photoionization detector (PID) / flame ionization detector (FID)
  - Periodic confirmation samples sent for lab analysis
  - Carbon Adsorption Units
    - Measure concentrations between carbon contactors, e.g., PID/FID
    - Lab analysis to confirm, identify changes in composition
    - Measure humidity
  - Other treatment methods – sample stack
- System Monitoring
  - Pressure (P), temperature (T), flow (Q) at various points
  - Influent headers (P,T,Q), either side of blower (P,T), downstream of air inlet (P, T, Q), across particulate filter (P)

DJB2	New Slide Dave Becker, 6/2/2009

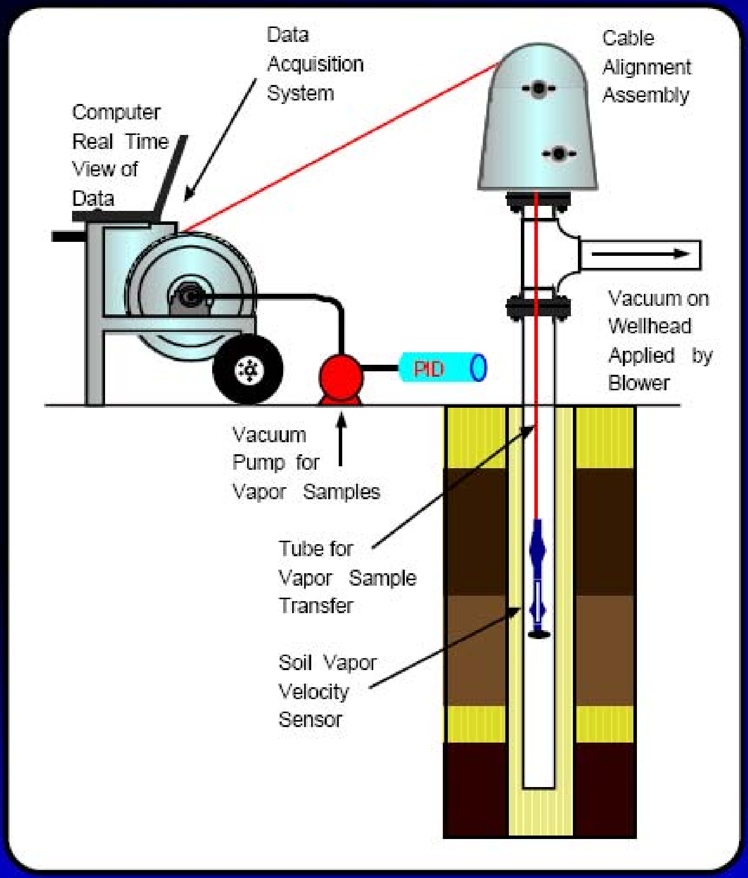
SVE System O&M Monitoring, Continued

- Subsurface monitoring
  - Verify vacuum/pressure distribution
  - Periodic soil gas, extraction wellhead sampling
  - Water level monitoring

SVE System Optimization

- Periodic analysis of monitoring data critical
  - Verify adequacy of air flow
  - Evaluate mass contribution - individual wells
  - Recommend changes in operation
  - Need trained personnel to evaluate
  - Evaluate need for continued offgas treatment
- PneuLog tool - use to clarify source of mass being removed
- System rebound - analysis of data clarifies mass distribution
- Subsurface performance evaluation checklist

What is PneuLog®?



Diagnostic Tool:

measures contamination and air permeability in vadose zone soils during vapor extraction.

Pneulog® Results

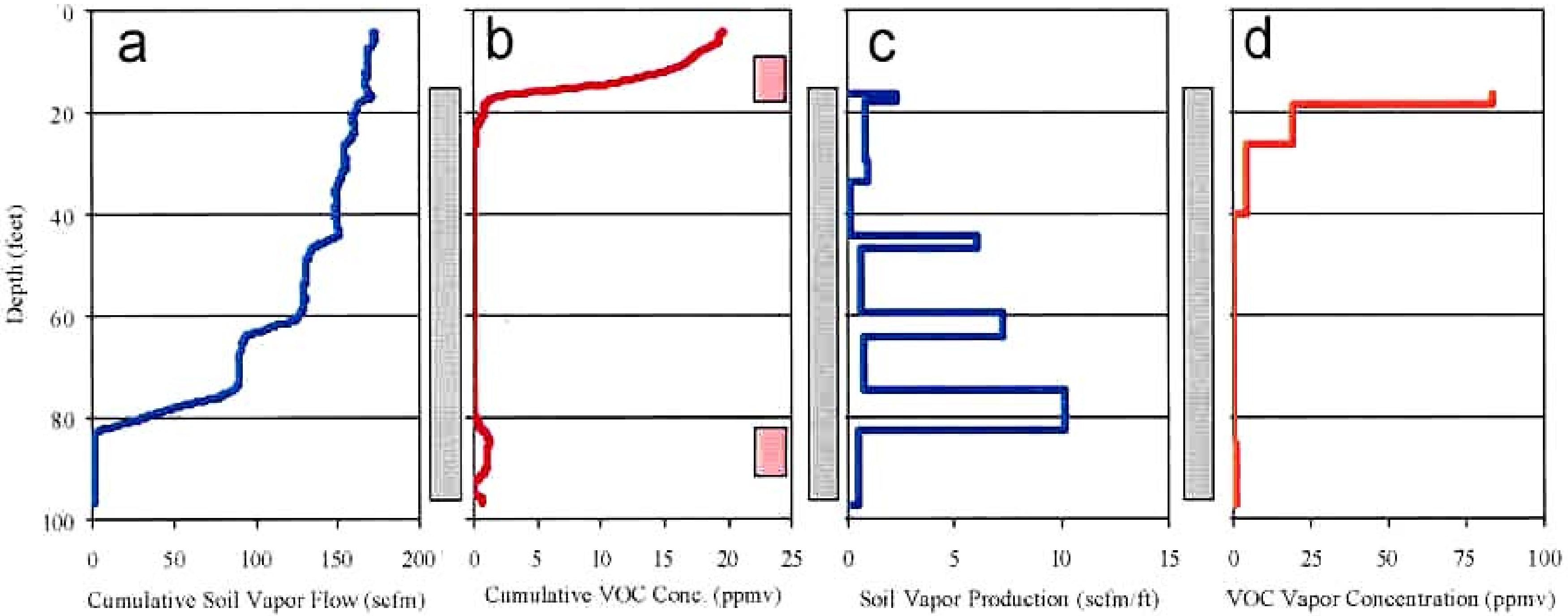


Figure 8. PneuLog from VW-1 Screened 17 to 97 feet.

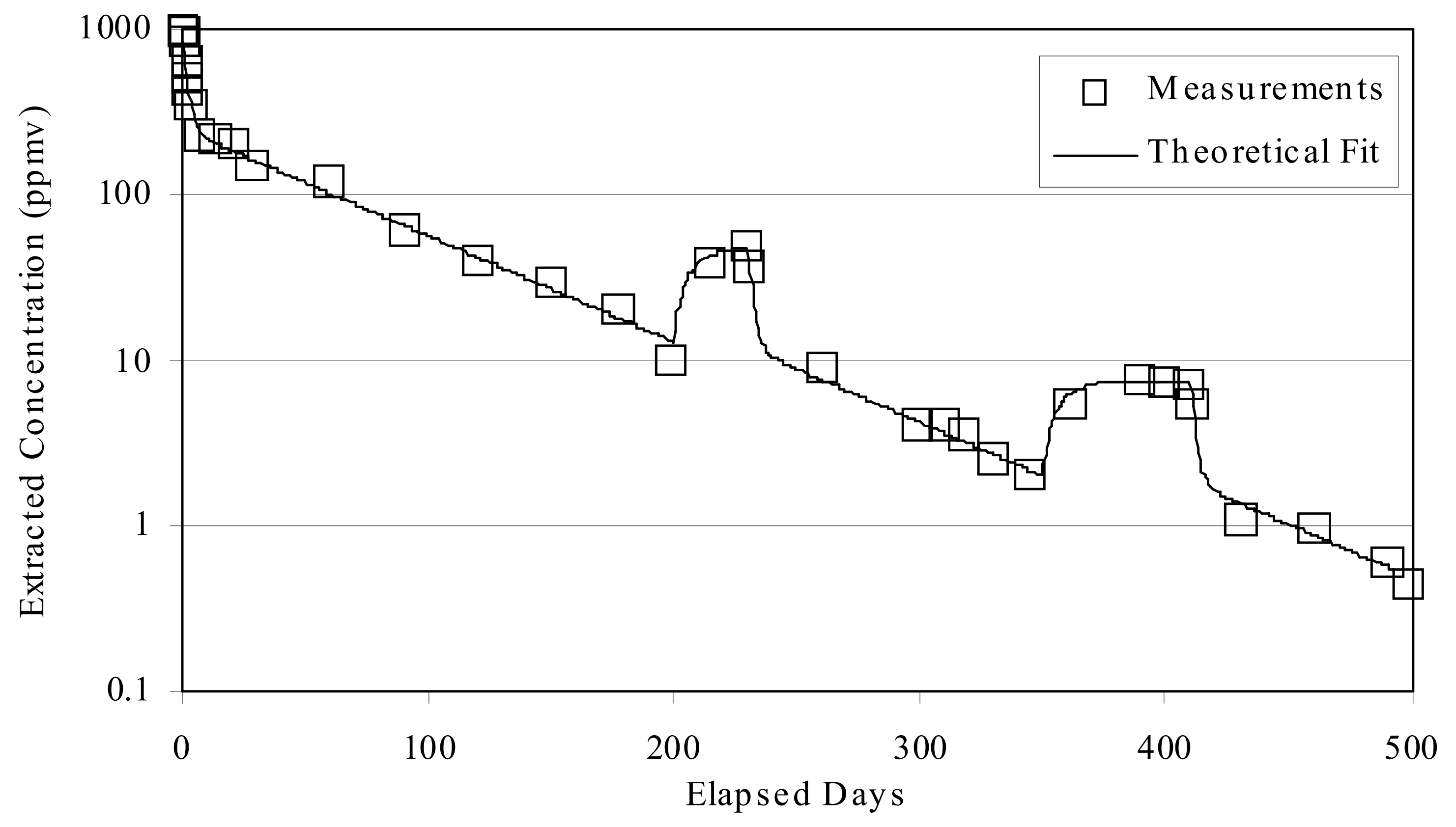
SVE Site Shutdown & Closure

- Closure goals
  - Remove set mass of contaminant
  - Meet absolute concentration in soil
  - Achieve specific max soil gas concentration
  - Minimum rebound
  - Avoid impact on ground water
    - Require modeling, mass distribution
  - Economic analysis of cost for more SVE vs removal by ground water

SVE Site Shutdown & Closure, Continued

- Verification sampling
  - – Soil sampling
  - – Soil gas sampling
    - Monitoring points (especially in areas of stagnation)
    - Extraction wells
    - Influent monitoring (inadequate basis if sole means of monitoring progress)
    - Require adequate purging
    - Offgassing from ground water
  - – Rebound test

Rebound Behavior



SVE Site Shutdown & Closure

- Evaluation:
  - Verify adequacy of operation - adequate distribution of air flow? Water table impact?
  - Reach asymptote? - Consider temporary shut down for rebound (can be only part of system)
  - Rebound test - look for concentrations in monitoring points, extraction wells after temp shutdown
  - Restart system, monitor concentrations
  - Repeat until little rebound occurs or concentrations below target
  - PneuLog study
  - Conduct soil sampling, modeling, cost analysis

SVE Enhancements, Variants

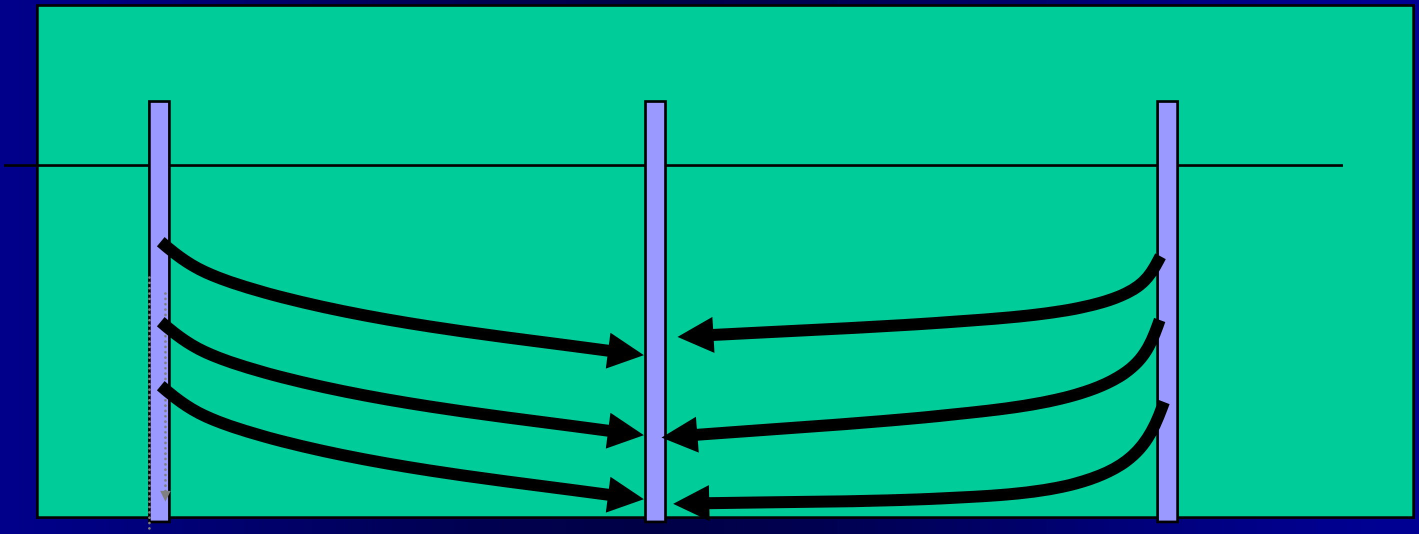
- Soil fracturing
  - Pneumatic, hydraulic
  - Shorten diffusion paths in tight soils
  - Questions on control of fractures
- Thermal enhancement
  - Hot air, electrical resistive heating, conductive heating
  - More later
- Passive SVE (more sustainable configuration)
  - Use barometric pressure changes to remove vapors
  - Check valves on wells - allow one direction of flow
  - Need some isolation of subsurface from atmosphere

References

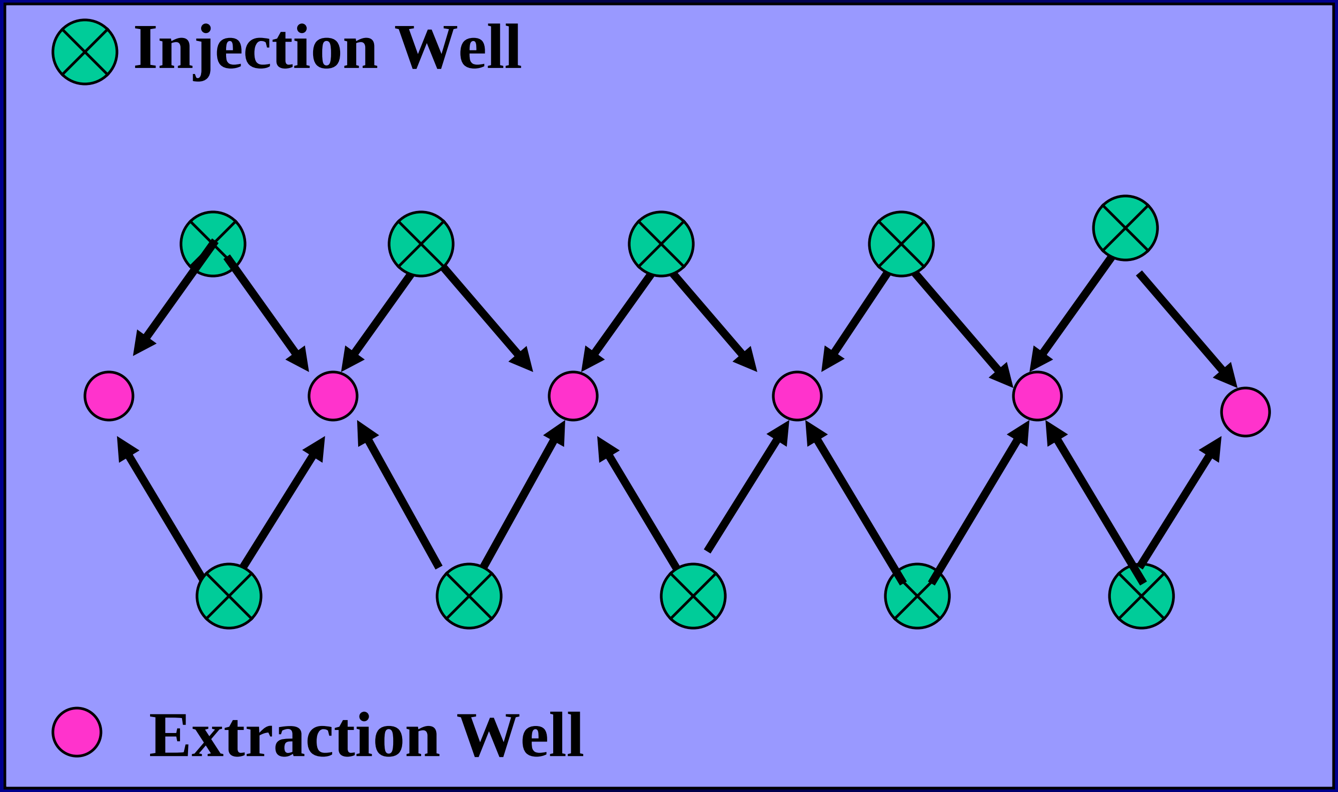
- US Army Corps of Engineers, Engineer Manual 1110-1-4001 SVE/BV http://www.environmental.usace.army.mil/sve.htm
- EPA/540/R-95/513 Review of Mathematical Modeling for Evaluating SVE Systems http://www.geotransinc.com/publications/Modeling-SVE.pdf
- EPA/600/R-96/041 Diagnostic Evaluation of In-Situ SVE-Based System Performance
- EPA Guidance - "Development of Recommendations & Methods to Support Assessment of Soil Venting Performance & Closure" EPA/600/R-01/070, September 2001 http://www.epa.gov/ada/download/reports/epa_600_r01_070.pdf
- Remediation System Evaluation Checklists http://www.environmental.usace.army.mil/rse.htm

Injection/Extraction SVE

- Injection/Extraction
  - Better formation sweep than extraction
  - Sustained higher removal rates



Operational Strategy

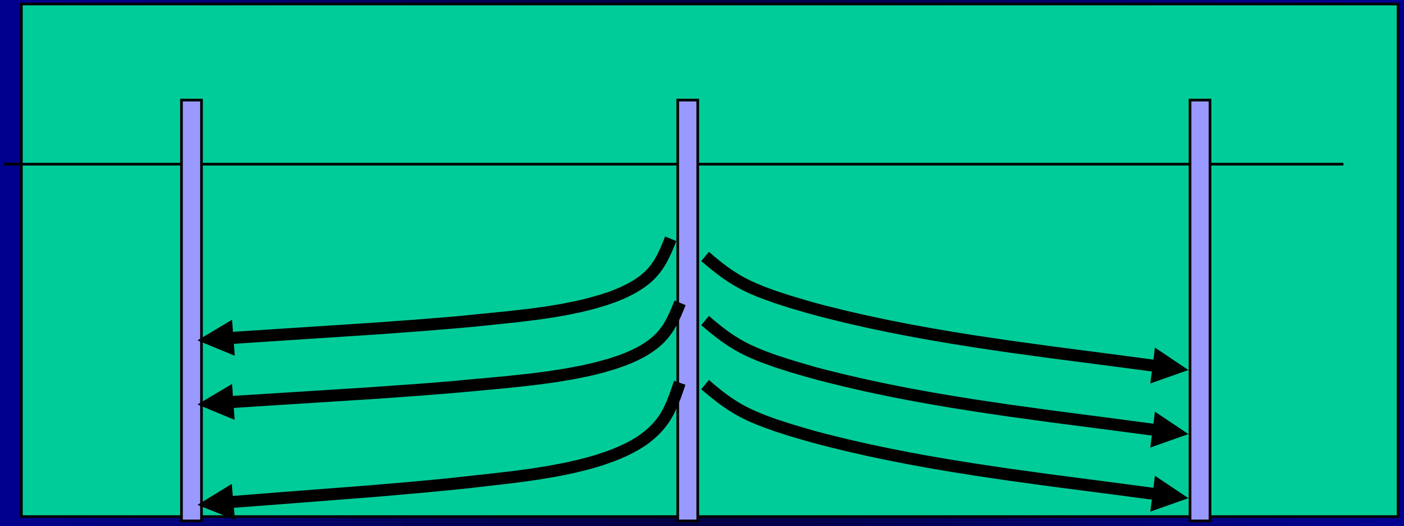


Injection Well

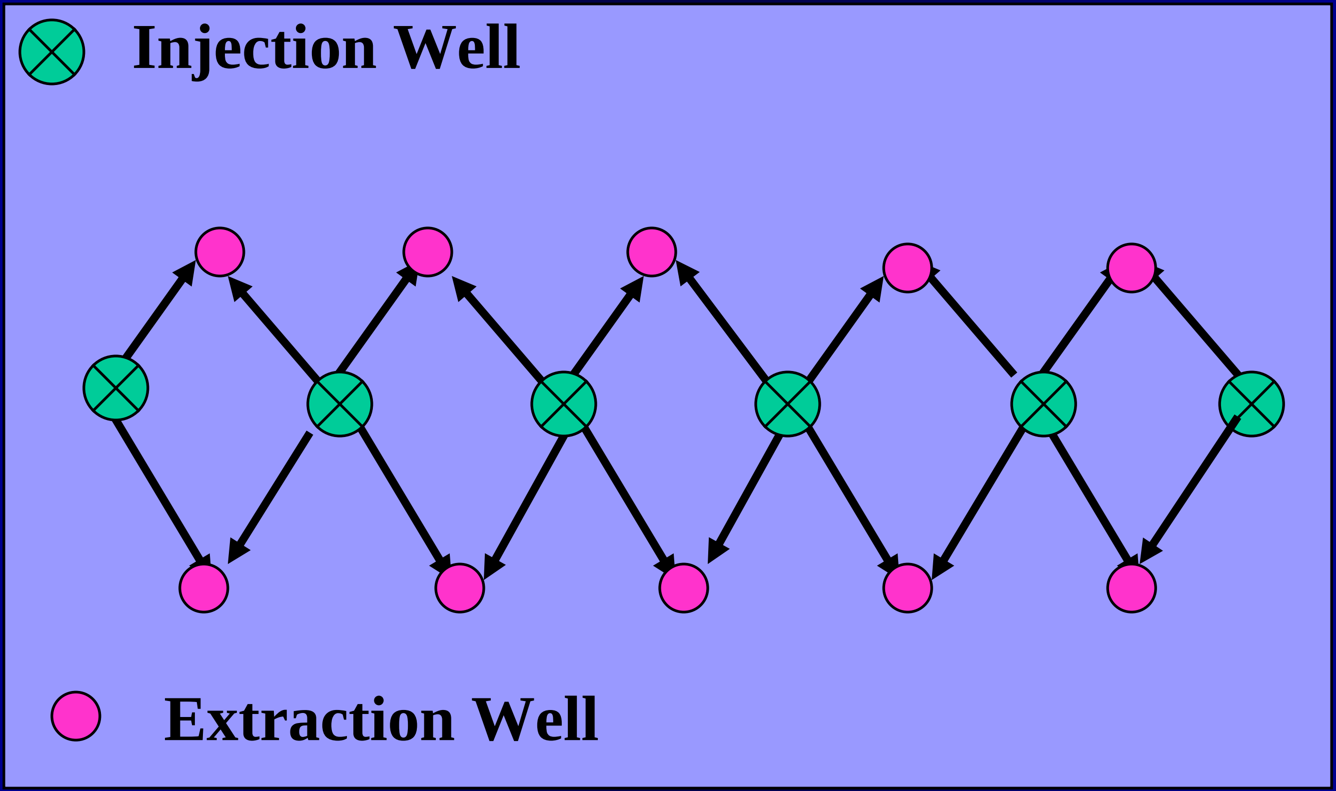
Extraction Well

Injection/Extraction SVE

- Injection/Extraction
  - Better formation sweep than extraction
  - Sustained higher removal rates



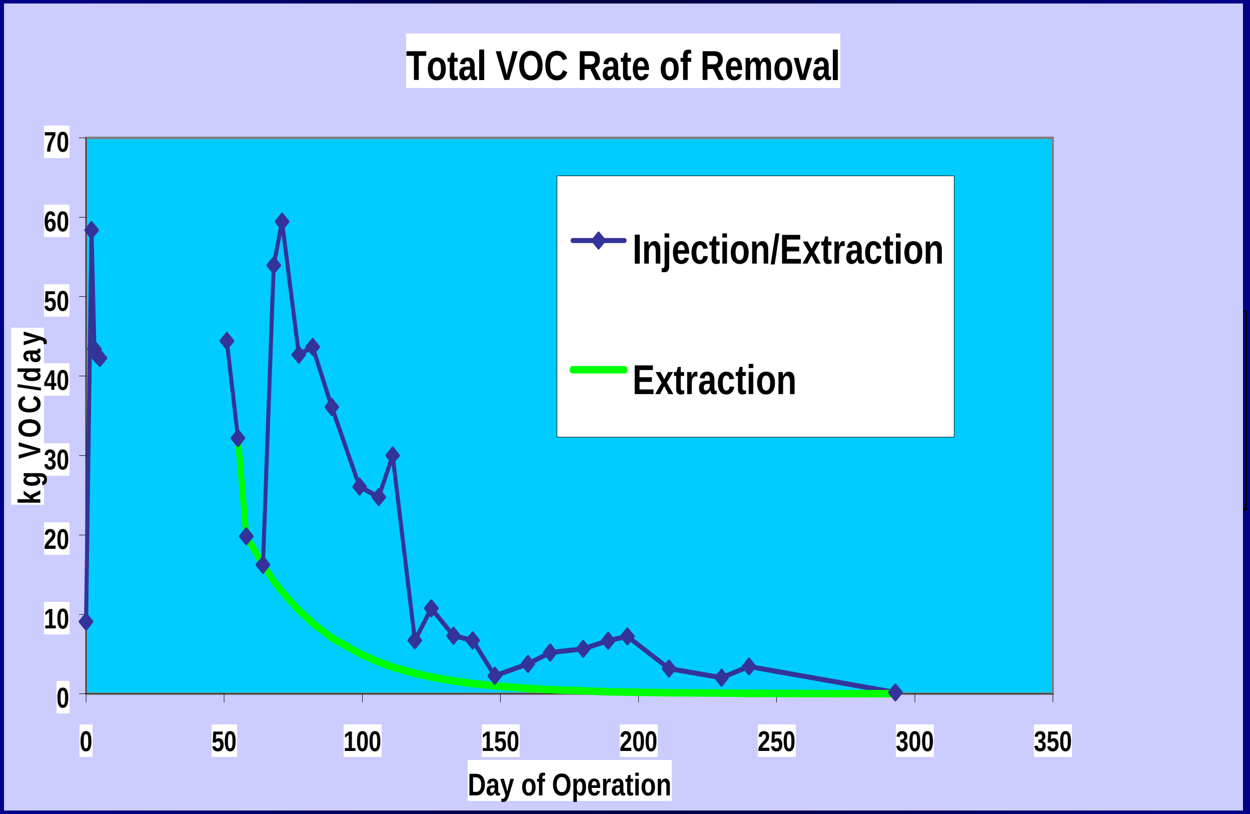
Operational Strategy



Injection Well

Extraction Well

Increased VOC Removal



Presentation Summary

- Applicability: vocs, aerobically degradable organics
- Pilot tests: determine air permeability, concentration trends
- Design:
  - Do NOT use radius of influence
  - Consider air throughput
  - Consider variable speed drive motors for blowers
- Operation:
  - Collect subsurface, above-ground equipment performance data
  - Check/maintain equipment
- Closure
  - Evaluate mass/concentrations remaining, rebound tests
  - Consider impact on ground water, cost
- Enhancements: fracturing, in-situ thermal treatment