Single-Interval Gas Permeability Testing

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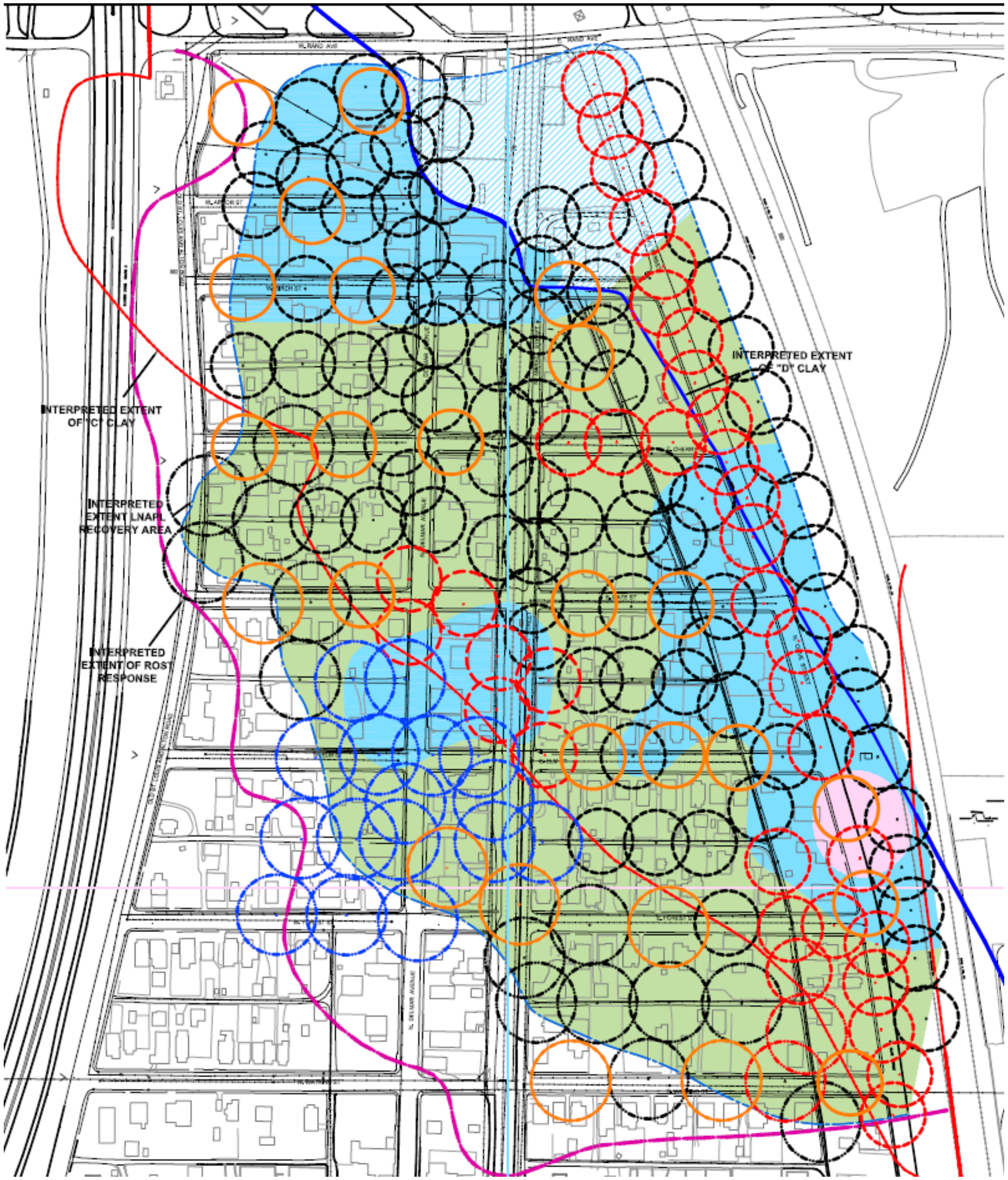
Presented at the:
17th Annual Association for Environmental Health and Sciences (AEHS) Meeting
Workshop on Soil-Gas Sample Collection and Analysis
San Diego, CA
March 21 – 22, 2007

Use of Gas Permeability Testing for Vapor Intrusion:

SVE Design for NAPL Contaminated Soil

Proposed placing of SVE wells to control documented vapor intrusion due free-phase petroleum LNAPL and NAPL contaminated soil in Hartford, IL.

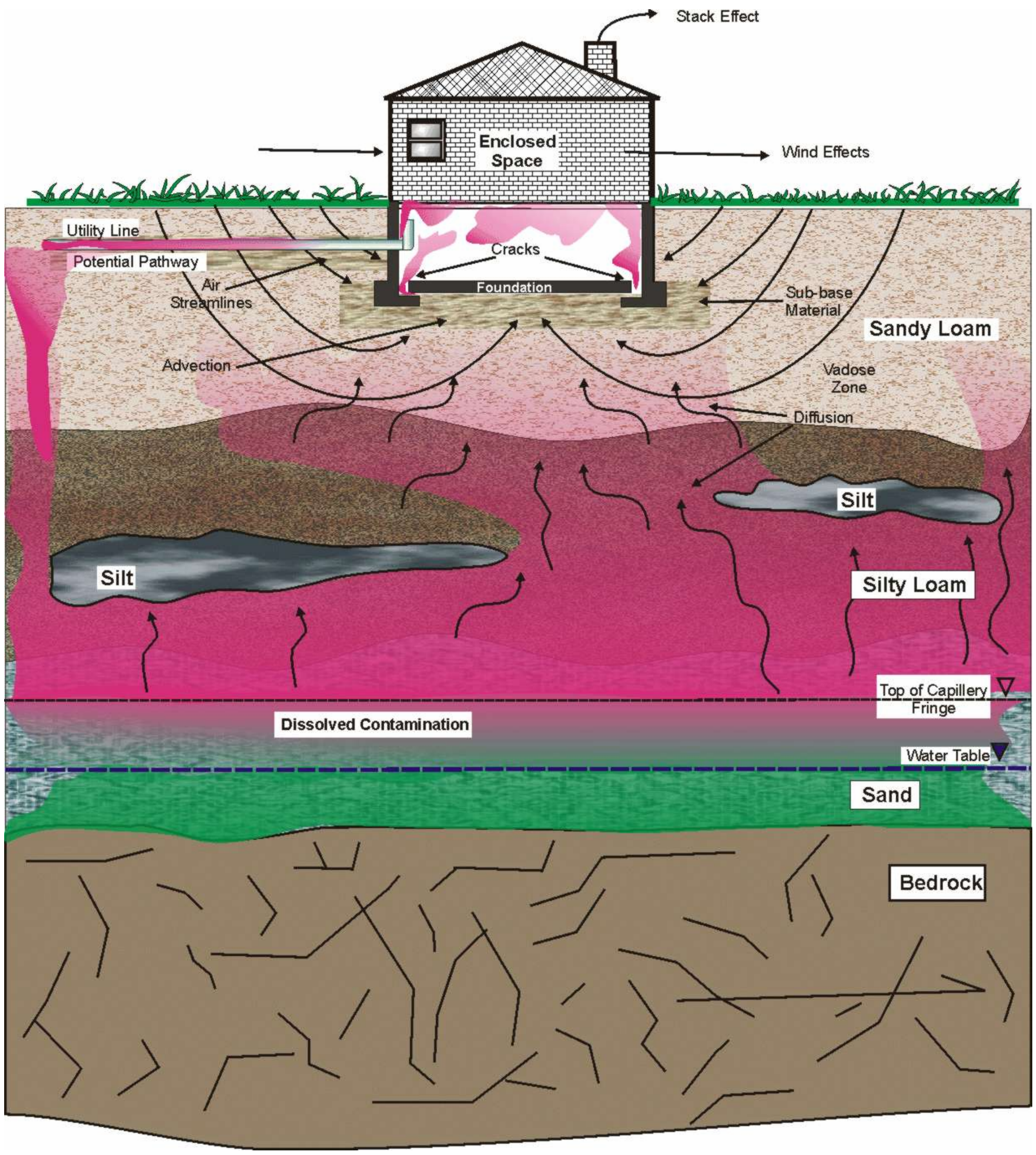


Use of Gas Permeability Testing for Vapor Intrusion:

Design of Sub-Slab Depressurization Systems

Use of Gas Permeability Testing for VI:

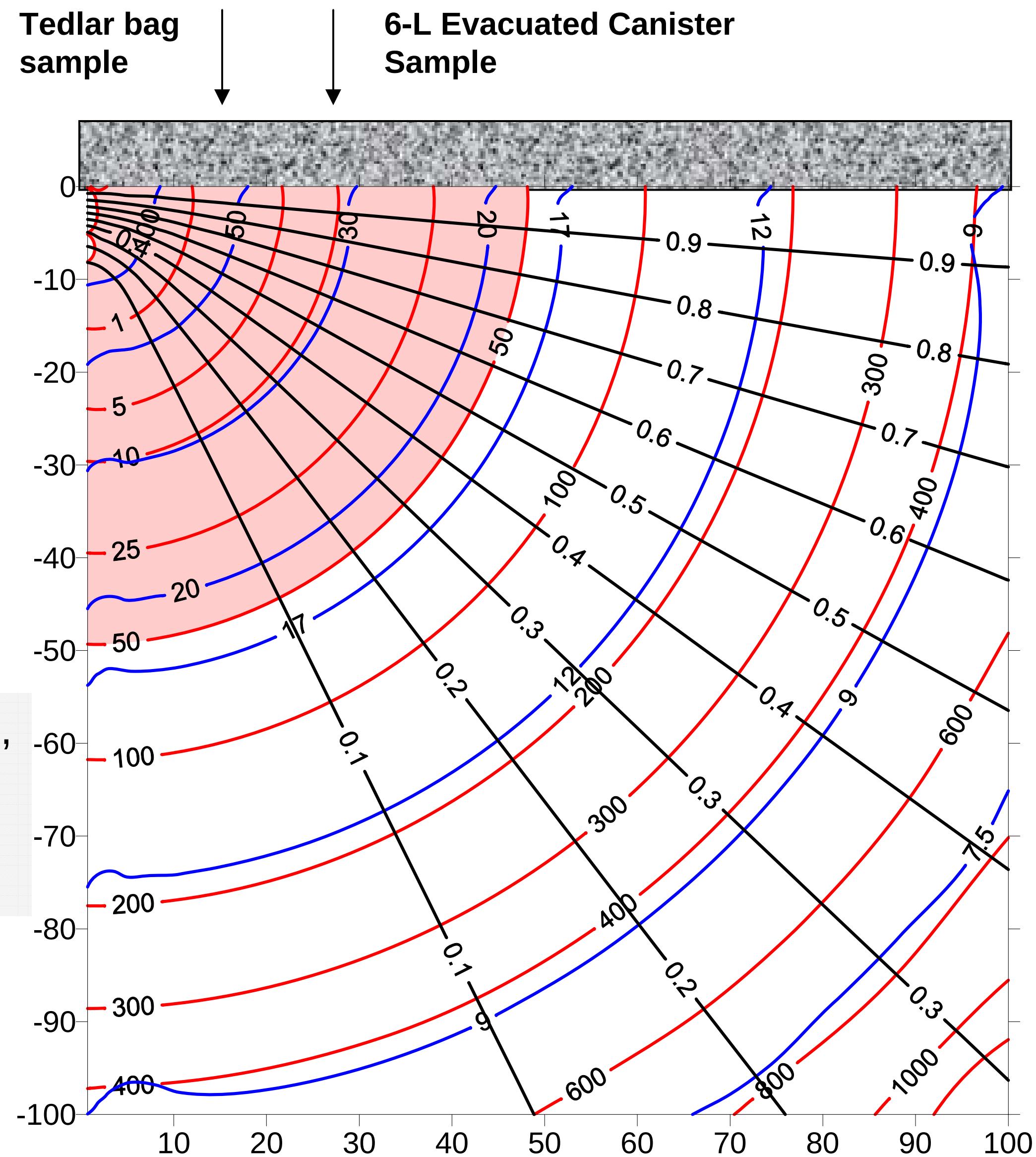
Modeling of Advective Gas Flow Beneath and Around Buildings



Use of Gas Permeability Testing for VI:

Evaluate Effect of Flow Rate and Extraction Volume During Sub-Slab and Soil-Gas Sampling

Simulated pressure differential (Pa), streamlines, and travel time (min) Below a slab during air sampling at 1 LPM



Comprehensive Review of Gas Permeability Testing

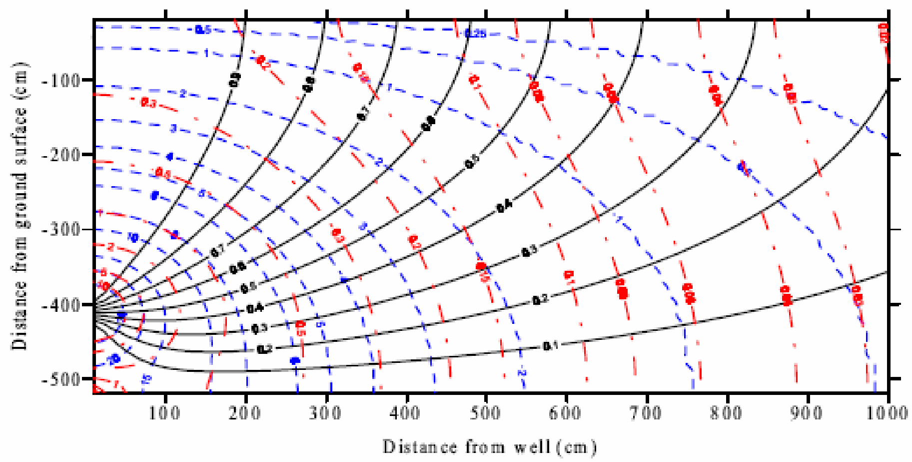
United States
Environmental Protection
Agency

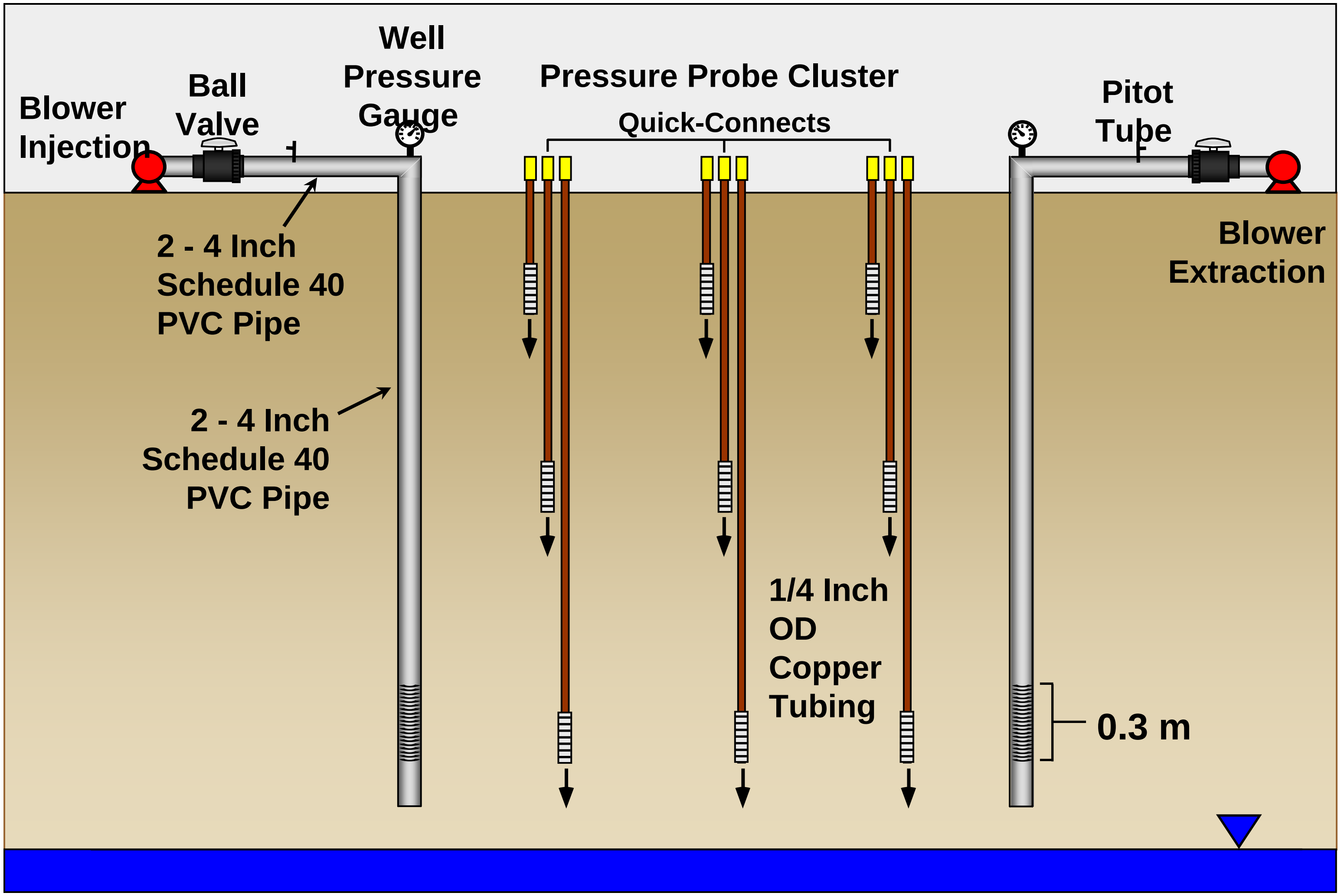
Office of Research and
Development
Washington DC 20460

EPA/600/R-01/070
September 2001

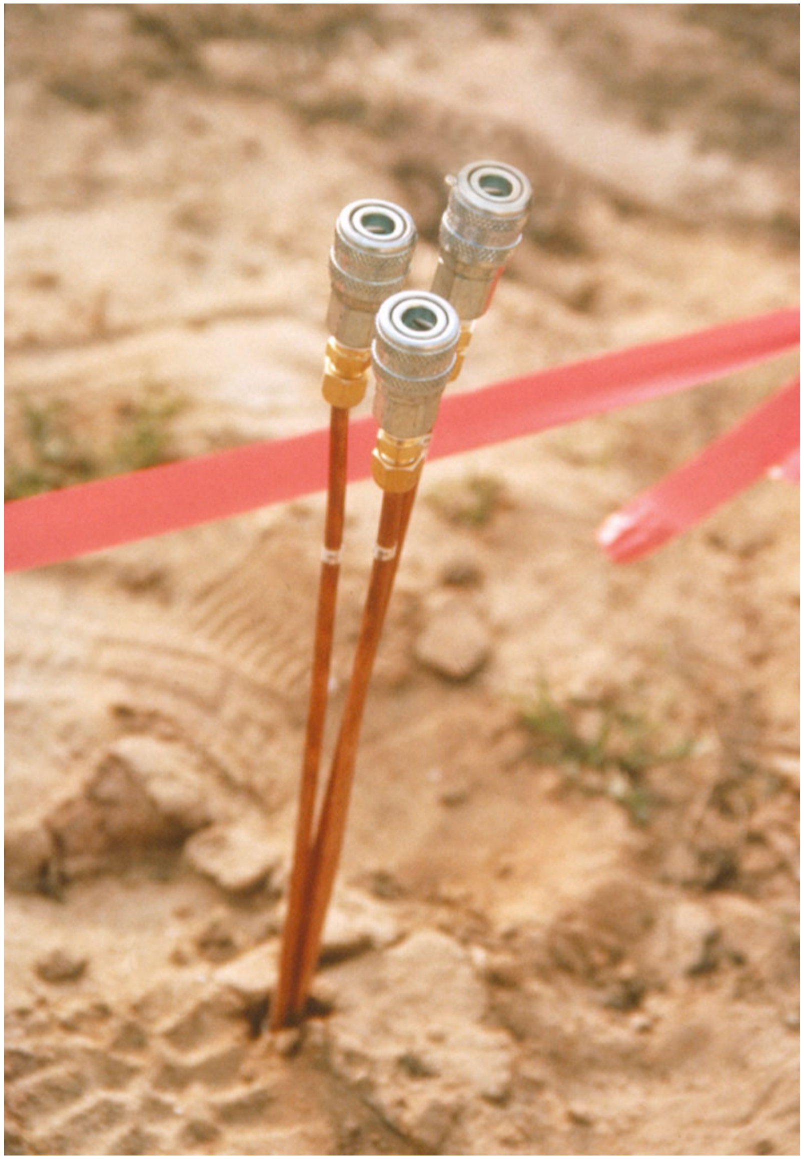
Development of Recommendations and Methods to Support Assessment of Soil Venting Performance and Closure

- Gas Permeability Testing
  - Comprehensive Discussion of Gas Permeability Testing,
  - Computer Codes for Numerous Analytical Solutions (Forward and Inverse Problem),
  - Development of finite-radius transient solution with borehole storage

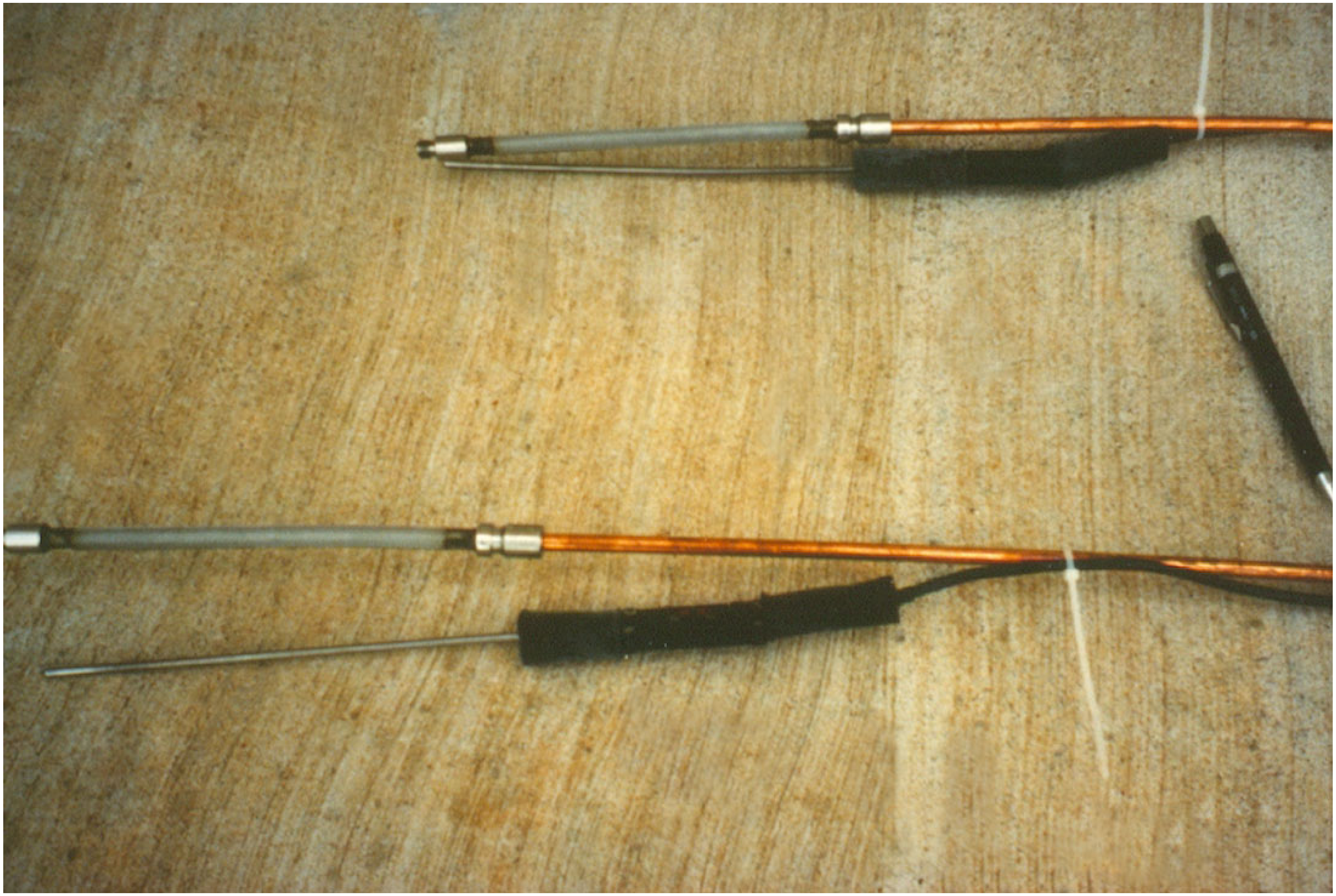




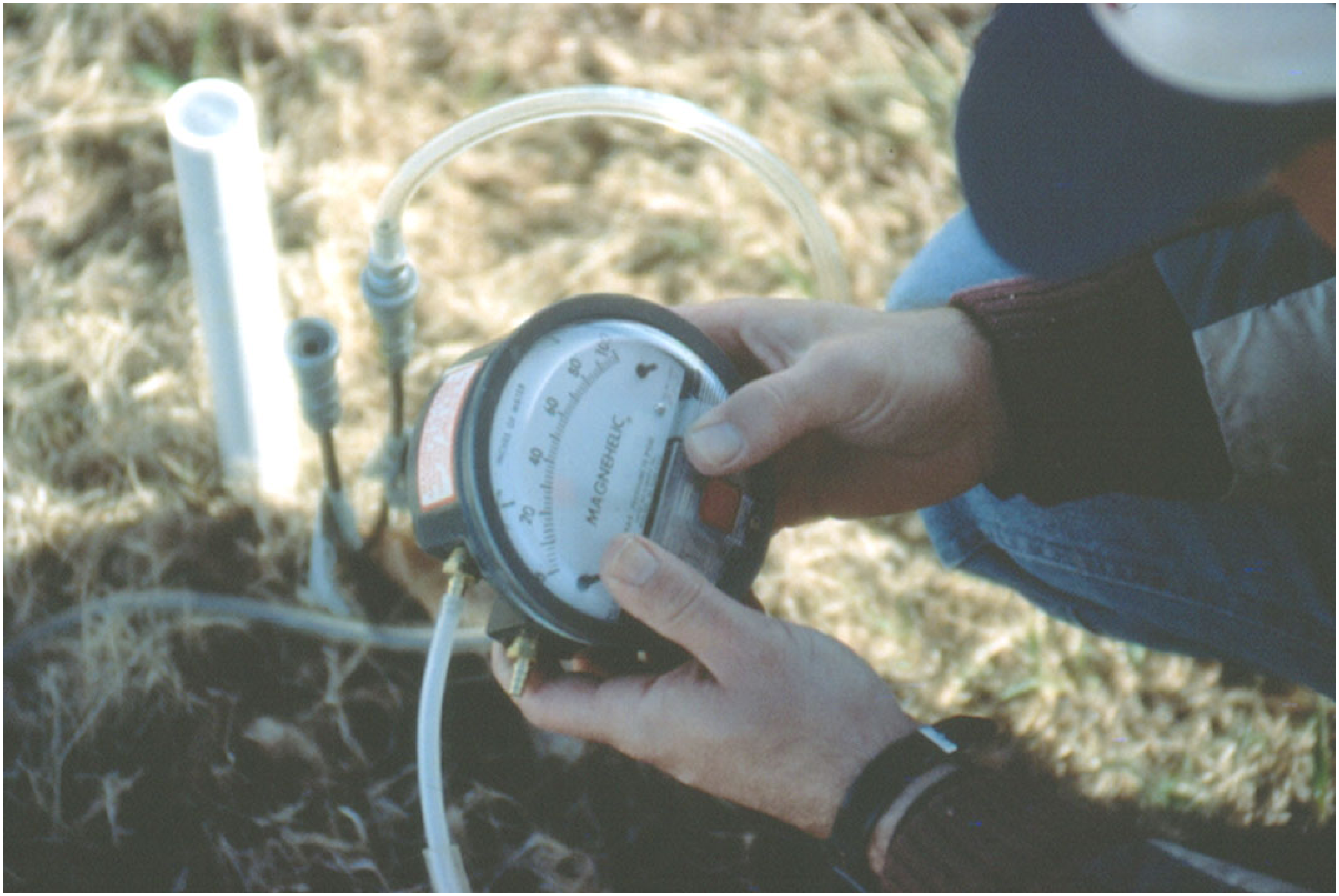
Field-scale gas permeability testing is typically conducted by extracting gas from or into a well and monitoring steady-state pressure differential response in vapor probes spaced at various radial distances. This setup was used at USCG Base Traverse City, MI. This approach is still used to design SVE systems to help mitigate vapor intrusion.



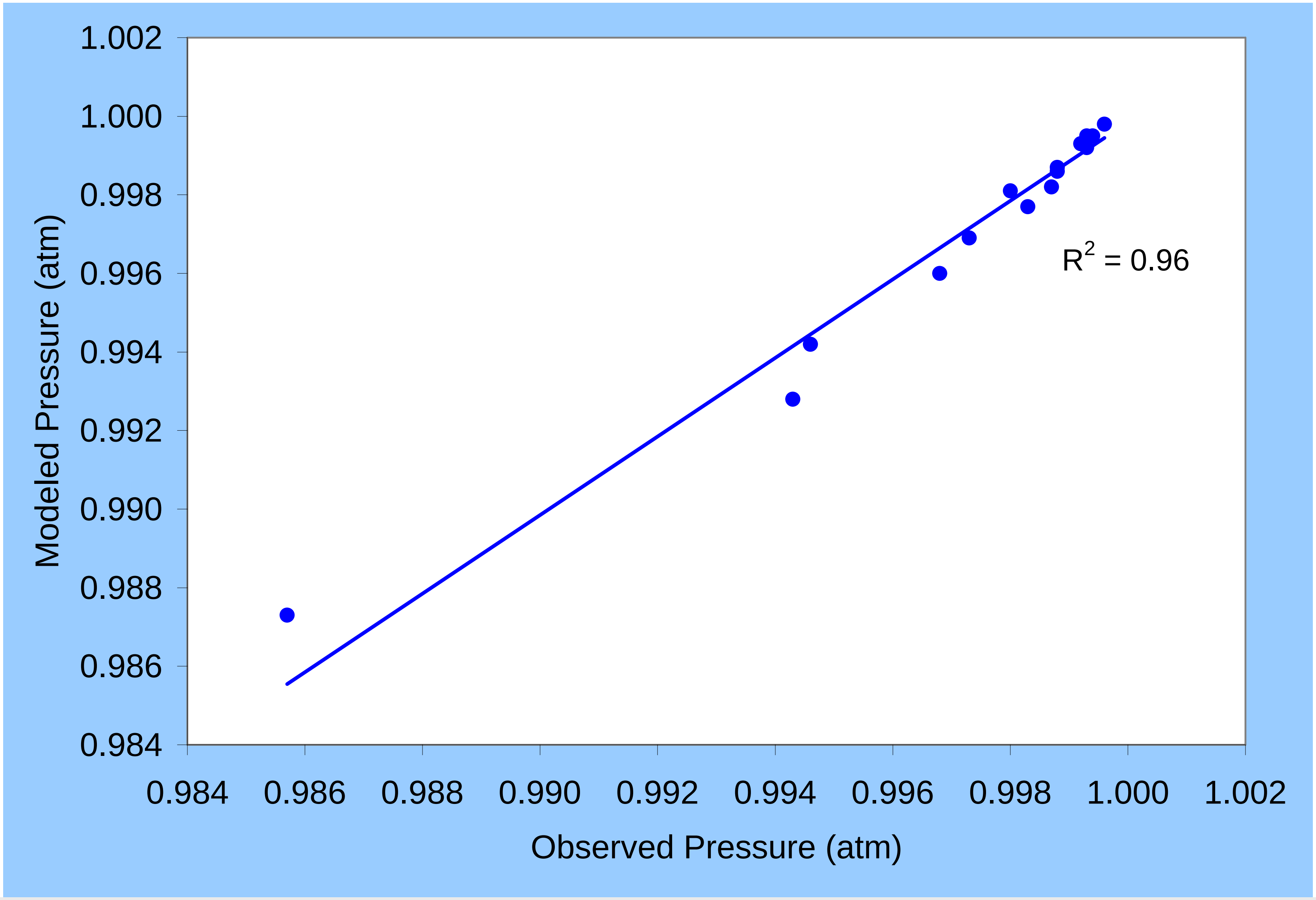
Examples of probes used to monitor pressure and sample soil gas at Traverse City, MI.



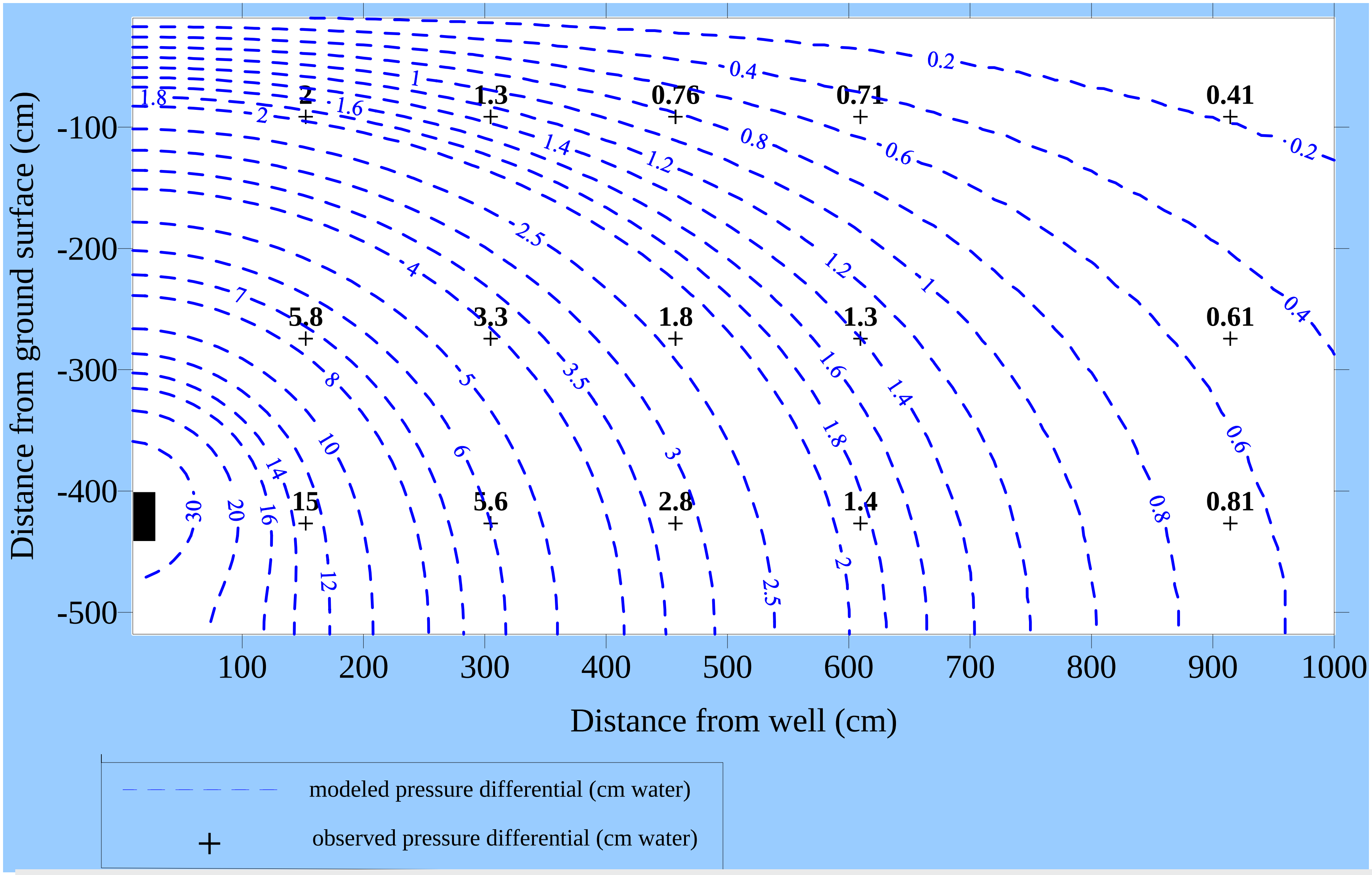
Vapor probes (Geoprobe implants) used for gas permeability testing and soil-gas sampling at Vance AFB, Enid OK



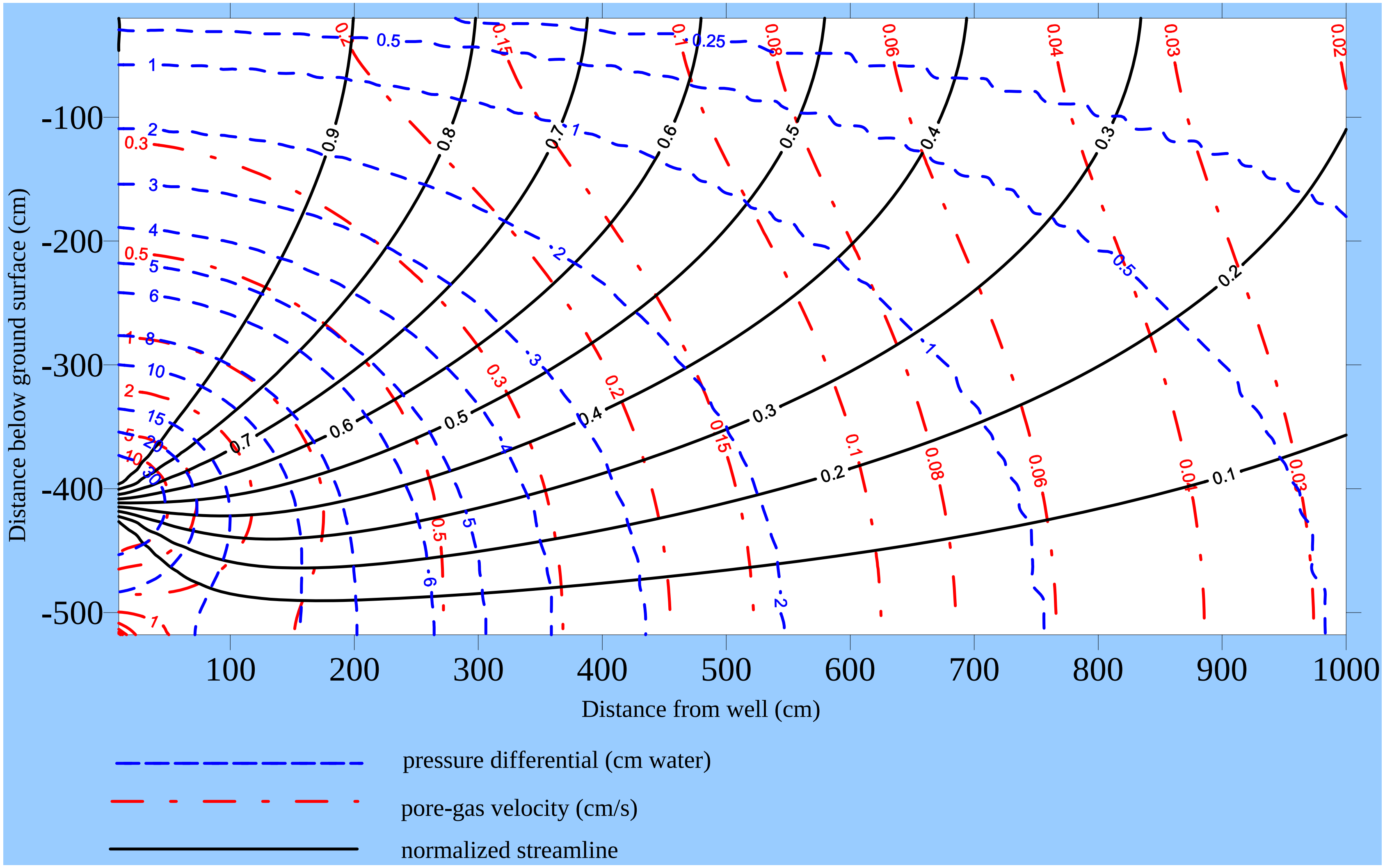
Magnehelic gauge used to monitor pressure during permeability testing at USCG, Elizabeth City, NC.



Modeled versus observed pressure during gas permeability testing at Traverse City – a basic QA test not available for single-interval testing.



Modeled versus observed pressure (two-dimensional) during gas permeability testing at Traverse City – another basic QA test not available for single-interval testing.

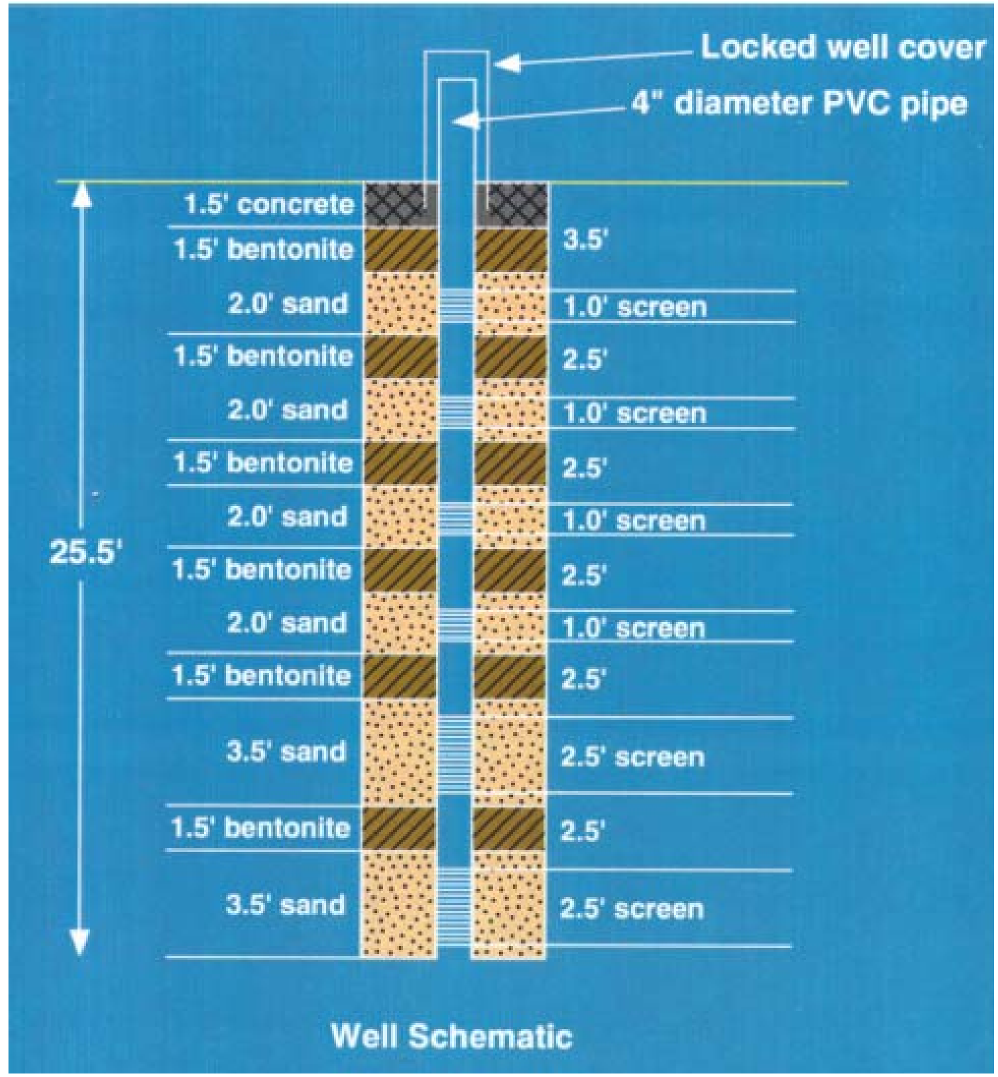


Permeability testing allows simulation of pressure, flowlines, pore-gas velocity, and travel time. This is useful to evaluate extraction volume and flow rate.

Gas Permeability Testing at the Picillo Farm Superfund Site, RI

Plan A - We used a rotosonic rig at the Picillo Farm site to push vertically slotted carbon-steel into the ground. Inflatable packers were to be used to develop a vertical profile of gas permeability in addition to ground-water and soil-gas concentration. The slots clogged with glacial “flour”.

We then used a rotosonic rig to install 13 wells having 6 screened intervals each as illustrated.



“Hydra’s Head”

<u>Plan B</u> - We then installed a multi-level monitoring system. Each screened interval was separated by packers. This approach was abandoned because there was leakage between packers.

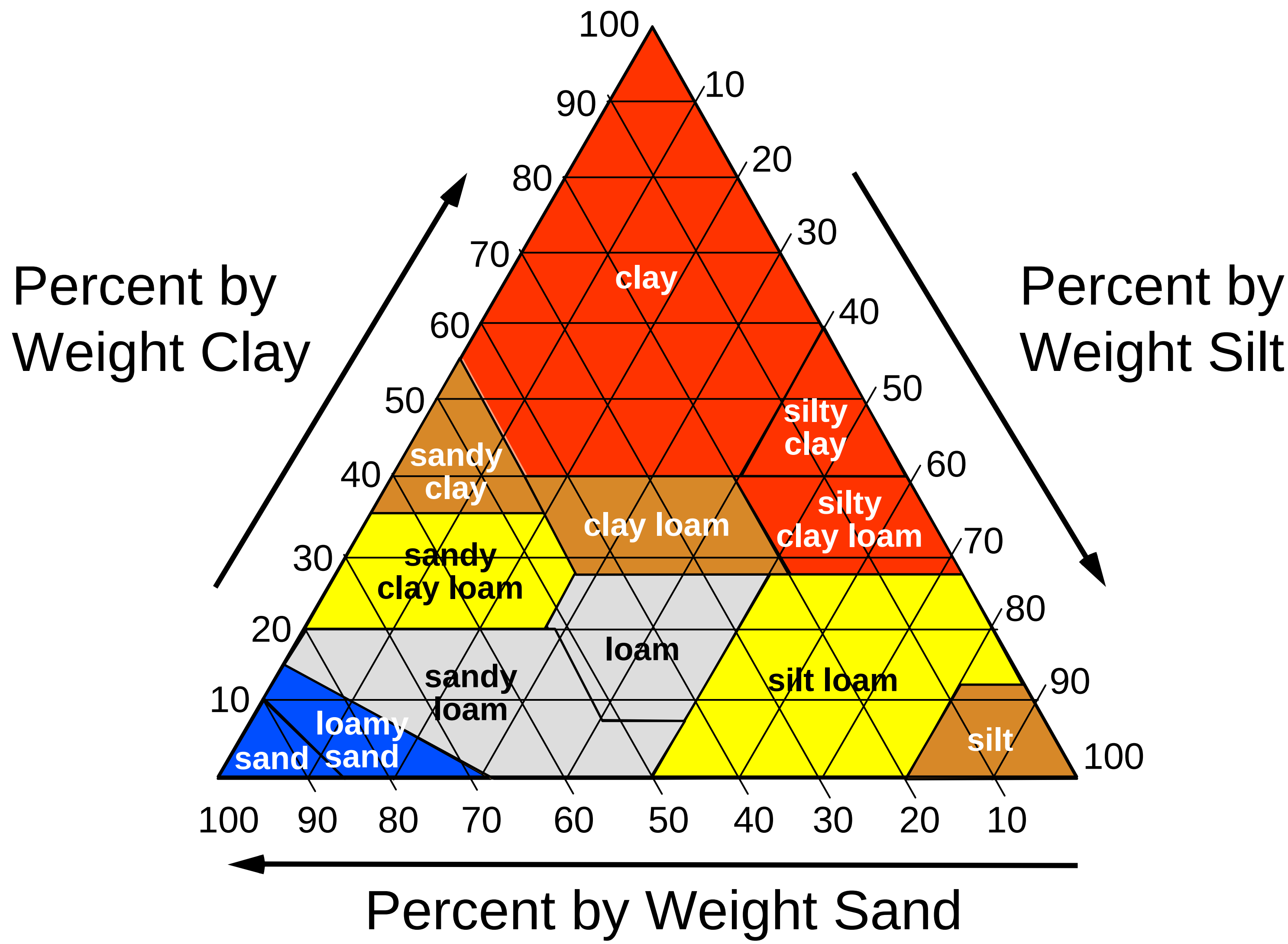
Plan C – We collected ground-water in lower screened intervals. Because of concerns with vapor nonequilibrium we did not bother collecting soil-gas samples. We used packers to conduct single-interval steady-state and transient gas permeability testing. The pressure transducer between the packers was for transient testing.

Equipment used for gas permeability testing.

Basic Lesson Learned from Soil-Gas Sampling and Gas Permeability Testing

Keep it simple stupid.

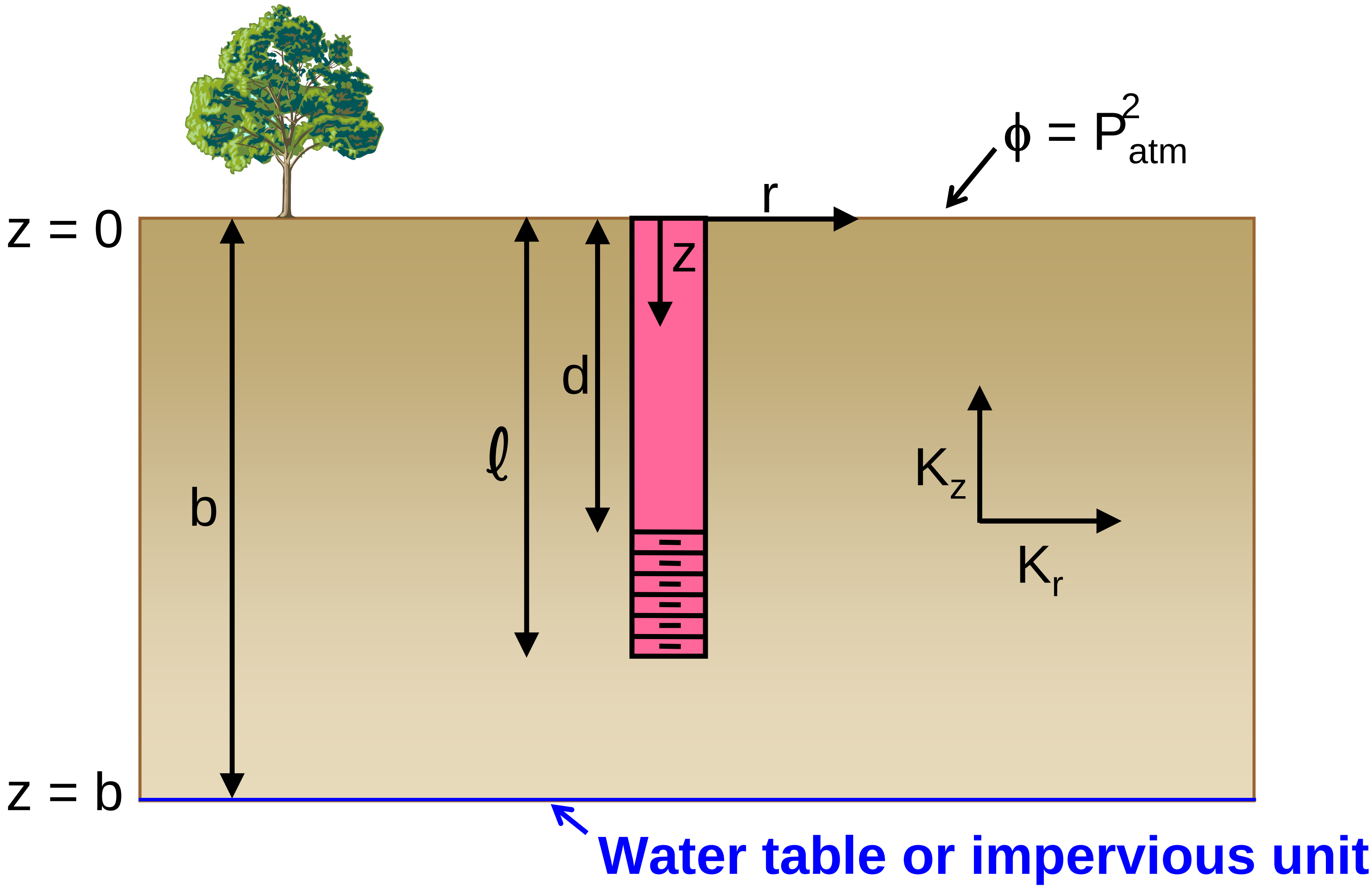
USDA Soil Texture Trilinear Diagram



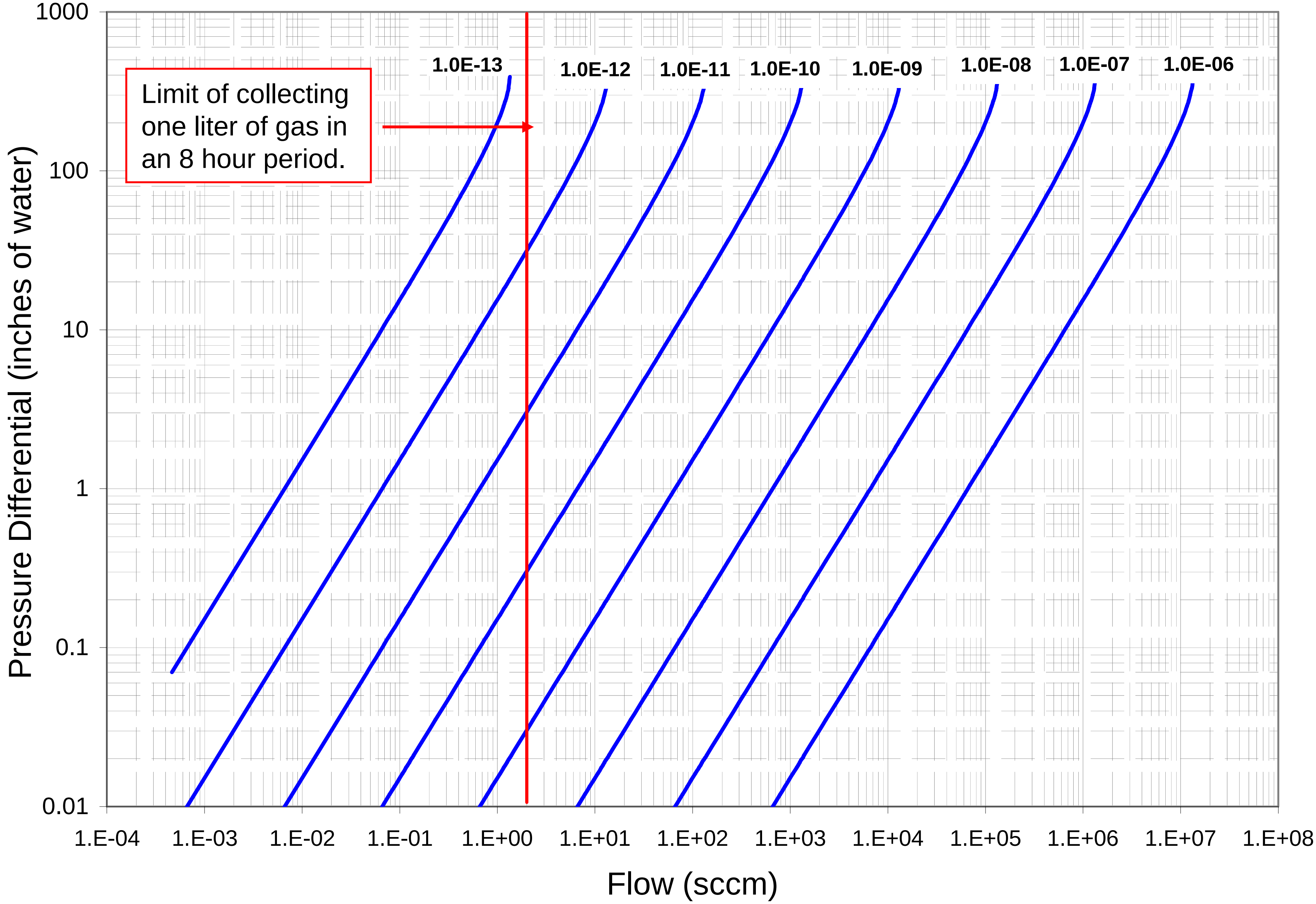
Prior to gas permeability testing, you should have some idea of the soil texture.

Gas Permeability of Various USDA Soil Textures

Texture	k_i (cm^2)	- 0.033 bar k_r	- 0.033 bar k_a (cm^2)	- 15 bar k_r	- 15 bar k_a (cm^2)
Sand	6.07E-08	0.66	4.00E-08	0.89	5.40E-08
Loamy sand	1.77E-08	0.55	9.74E-09	0.82	1.45E-08
Sandy loam	7.55E-09	0.32	2.42E-09	0.68	5.13E-09
Loam	3.81E-09	0.18	6.86E-10	0.59	2.24E-09
Silt loam	1.96E-09	0.12	2.35E-10	0.56	1.10E-09
Sandy clay loam	1.24E-09	0.15	1.86E-10	0.45	5.58E-10
Clay loam	6.71E-10	0.12	8.05E-11	0.42	2.82E-10
Silty clay loam	4.38E-10	0.05	2.19E-11	0.34	1.49E-10
Sandy clay	3.47E-10	0.05	1.74E-11	0.25	8.67E-11
Silty clay	2.60E-10	0.04	1.04E-11	0.26	6.76E-11
Clay	1.73E-10	0.03	5.19E-12	0.22	3.81E-11



Use Baehr and Joss's (1995) analytical solution for two-dimensional, axi-symmetric flow in a homogeneous anisotropic domain open to the atmosphere to generate permeability, flow, and pressure differential charts for various borehole configurations.



Depth to water = 500 cm, screened interval 250 – 280 cm, r_w = 2.5 cm, k_r/k_z = 1.0, T= 283K

A little air flow modeling prior to gas permeability testing helps to design the test. Gas permeability by this crew at Raymark was unsuccessful (no vacuum detected at probes) because of high permeability and insufficient flow application.

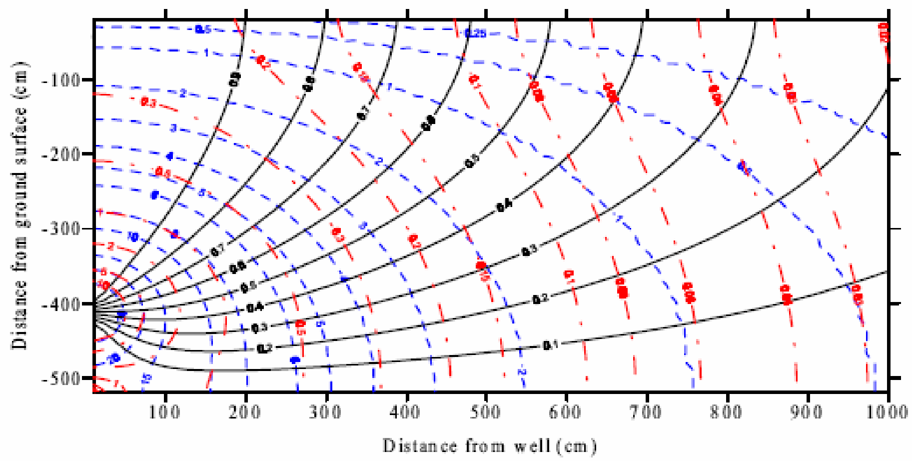
Varadhan's analytical solution for transient flow in a finite-radius well with borehole storage can be used to understand important effects in single-interval testing. Documented in:

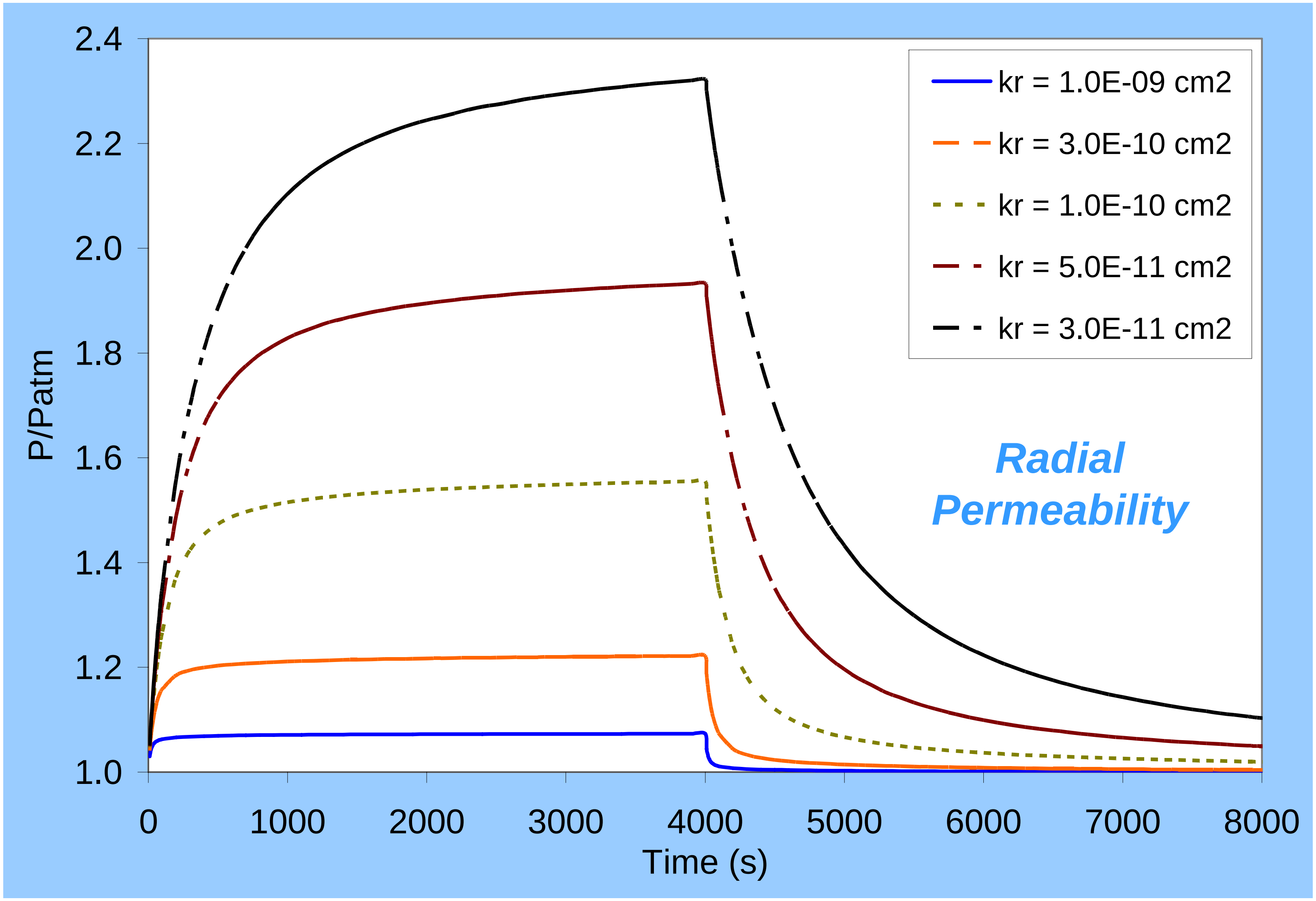
United States Environmental Protection Agency

Office of Research and Development Washington DC 20460

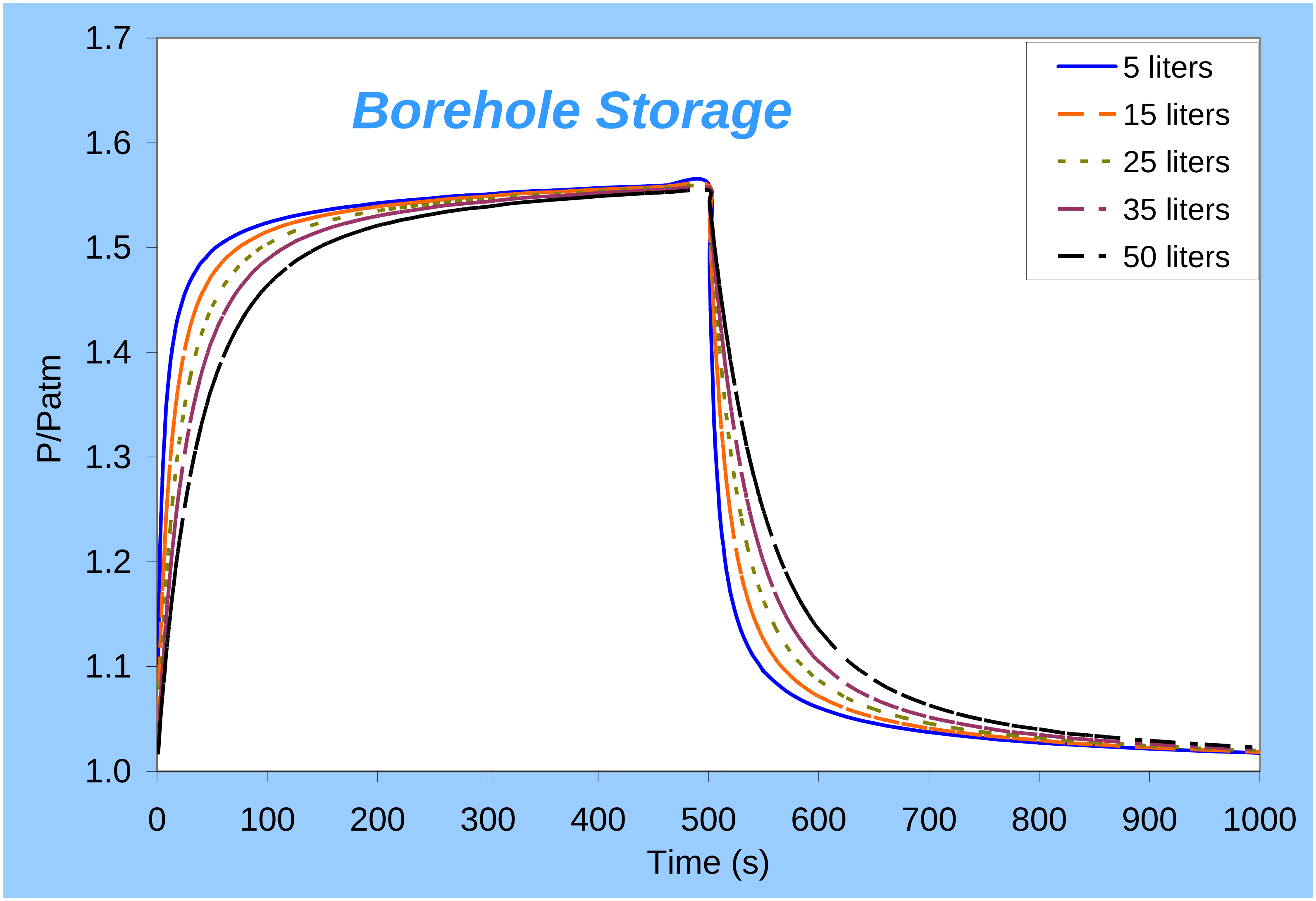
EPA/600/R-01/070 September 2001

Development of Recommendations and Methods to Support Assessment of Soil Venting Performance and Closure

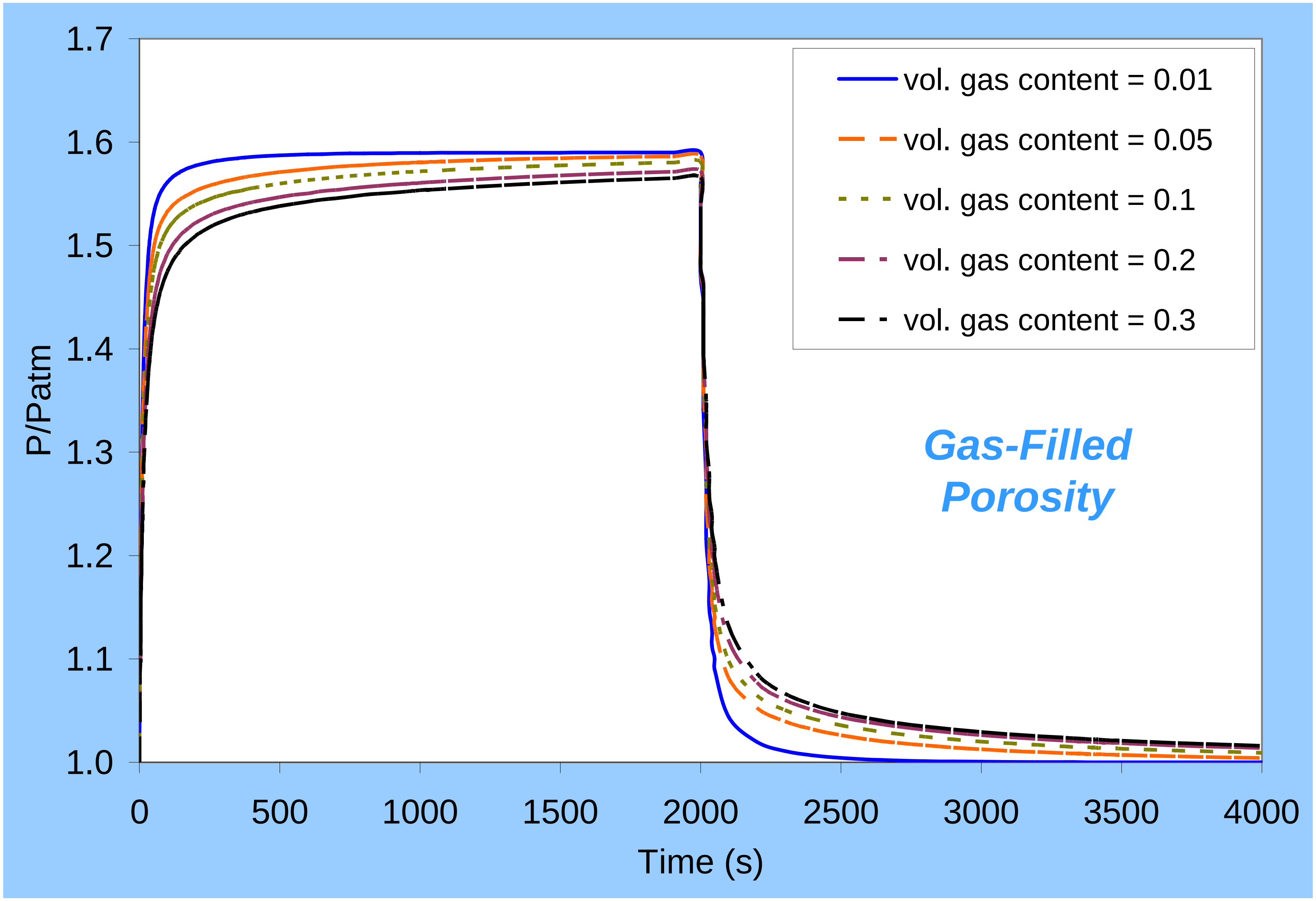




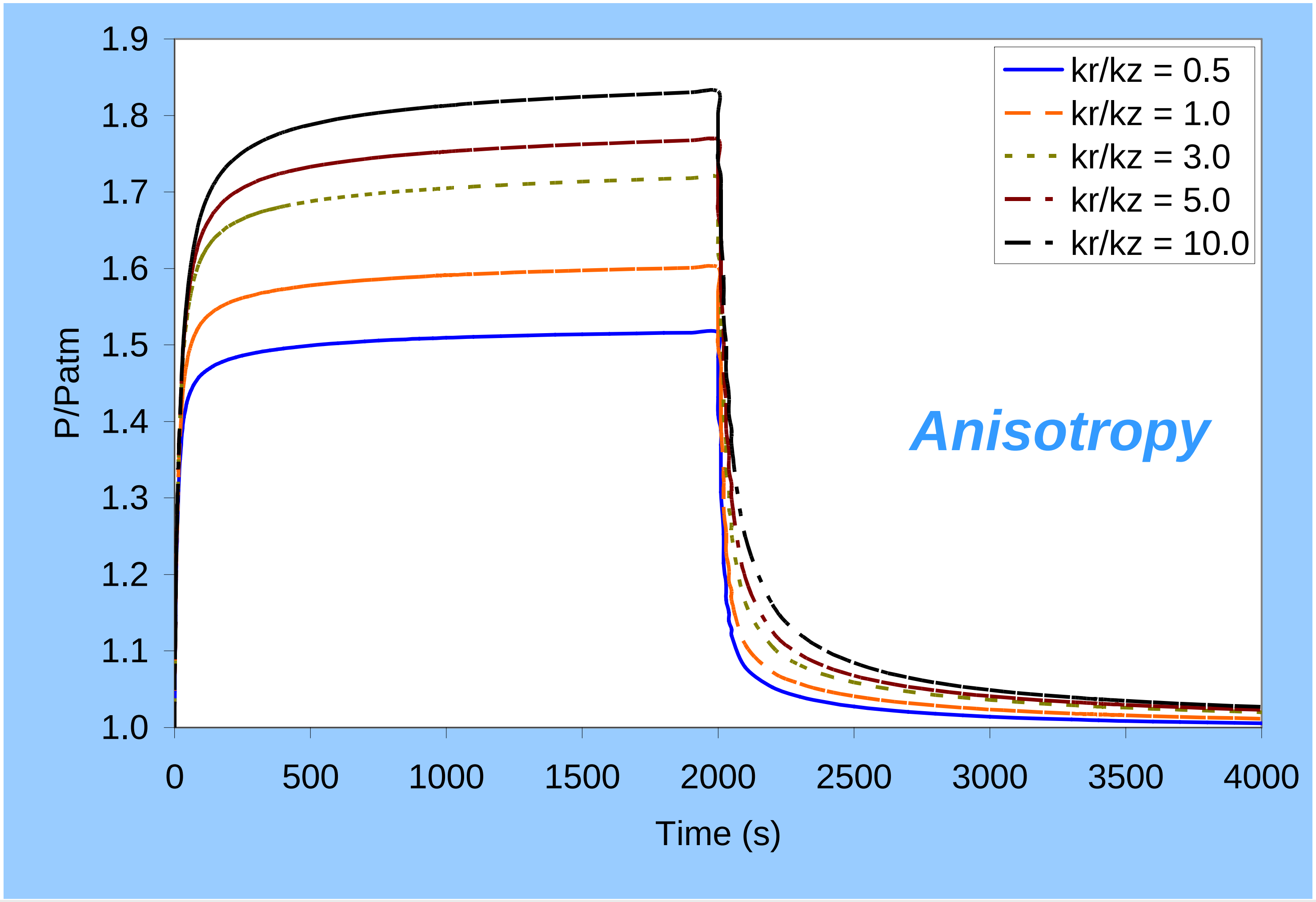
Time to steady-state conditions can be extensive in low media even for single-interval testing. Flow = 0.1 g/s, k_r/k_z = 1.0, borehole storage = 15 L, depth to water = 600 cm, screened interval = 410 – 470 cm, gas-filled porosity = 0.1, well radius = 10 cm, leakance = 1.0E-11 cm



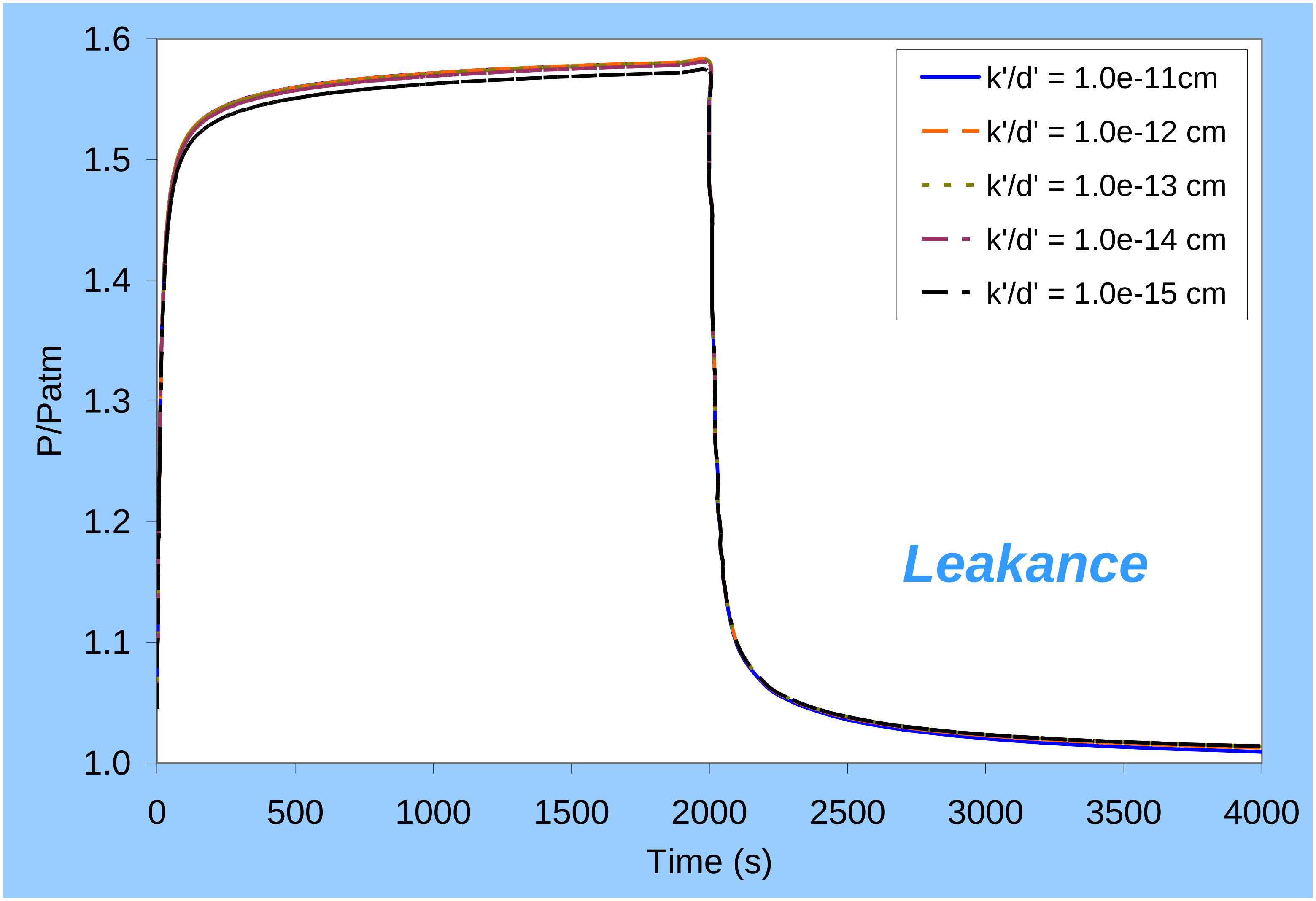
Borehole storage allows easy removal of gas at the start of sampling. It also affects time to steady-state. Flow = 1.0 g/s, k_r = 1.0E-09 cm^2, kr/kz = 1.0, depth to water = 600 cm, screened interval = 410 – 470 cm, gas-filled porosity = 0.1, well radius = 10 cm, leakance = 1.0E-11 cm



Gas-filled porosity is another storage time which affects time to steady-state.
Flow = 1.0 g/s, k_r = 1.0E-09 cm^2, kr/kz = 1.0, borehole storage = 15 L, depth to water = 600 cm, screened interval = 410 – 470 cm, well radius = 10 cm

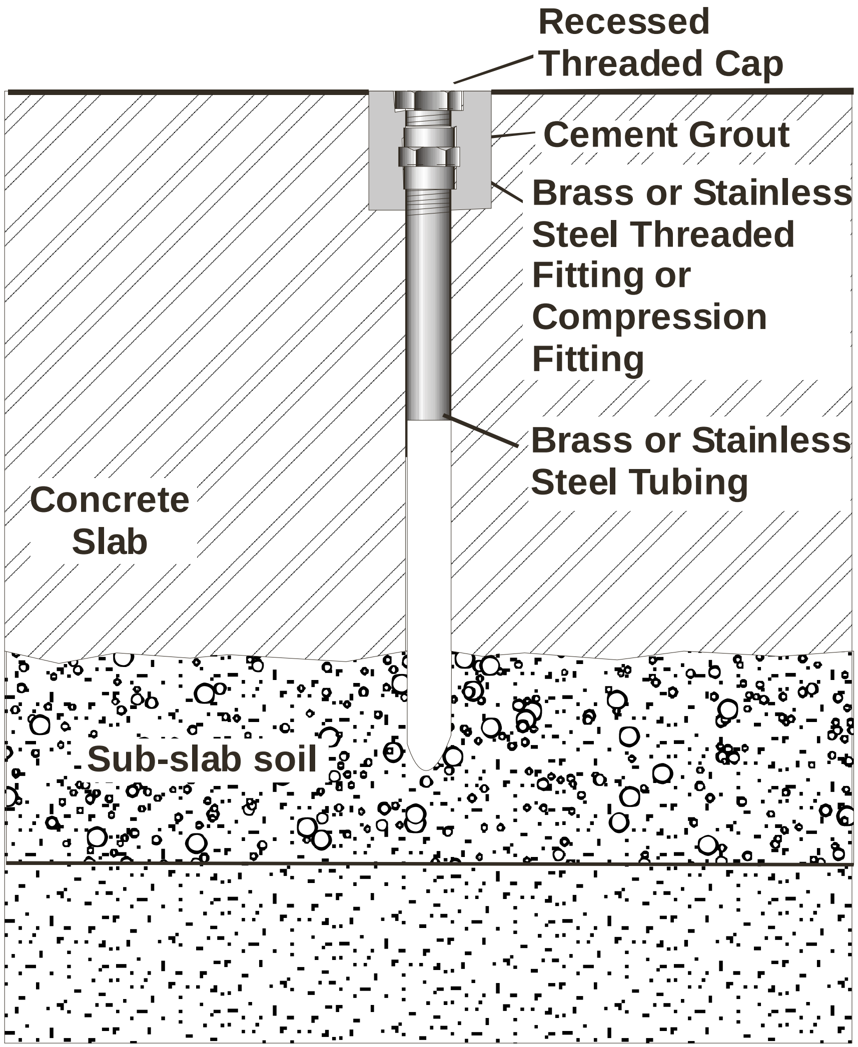


Anisotropy has a strong effect on observed pressure differential. With single-interval testing, there is no way to estimate anisotropy. Hence, estimates of radial permeability are subject to error. Flow = 1.0 g/s, k_r = 1.0E-09 cm^2, borehole storage = 15 L, depth to water = 600 cm, screened interval = 410 – 470 cm, gas-filled porosity = 0.1, well radius = 10 cm, leakance = 1.0E-11 cm



The upper boundary condition has little effect on pressure differential. Hence, it can be ignored during single-interval testing. This simplifies estimation of radial permeability. Flow = 1.0 g/s, k_r = 1.0E-09 cm^2, kr/kz = 1.0, borehole storage = 15 L, depth to water = 600 cm, screened interval = 410 – 470 cm, gas-filled porosity = 0.1, well radius = 10 cm

Example: Single-Interval Steady-State Gas Permeability Estimation in Sub-Slab Media at Raymark



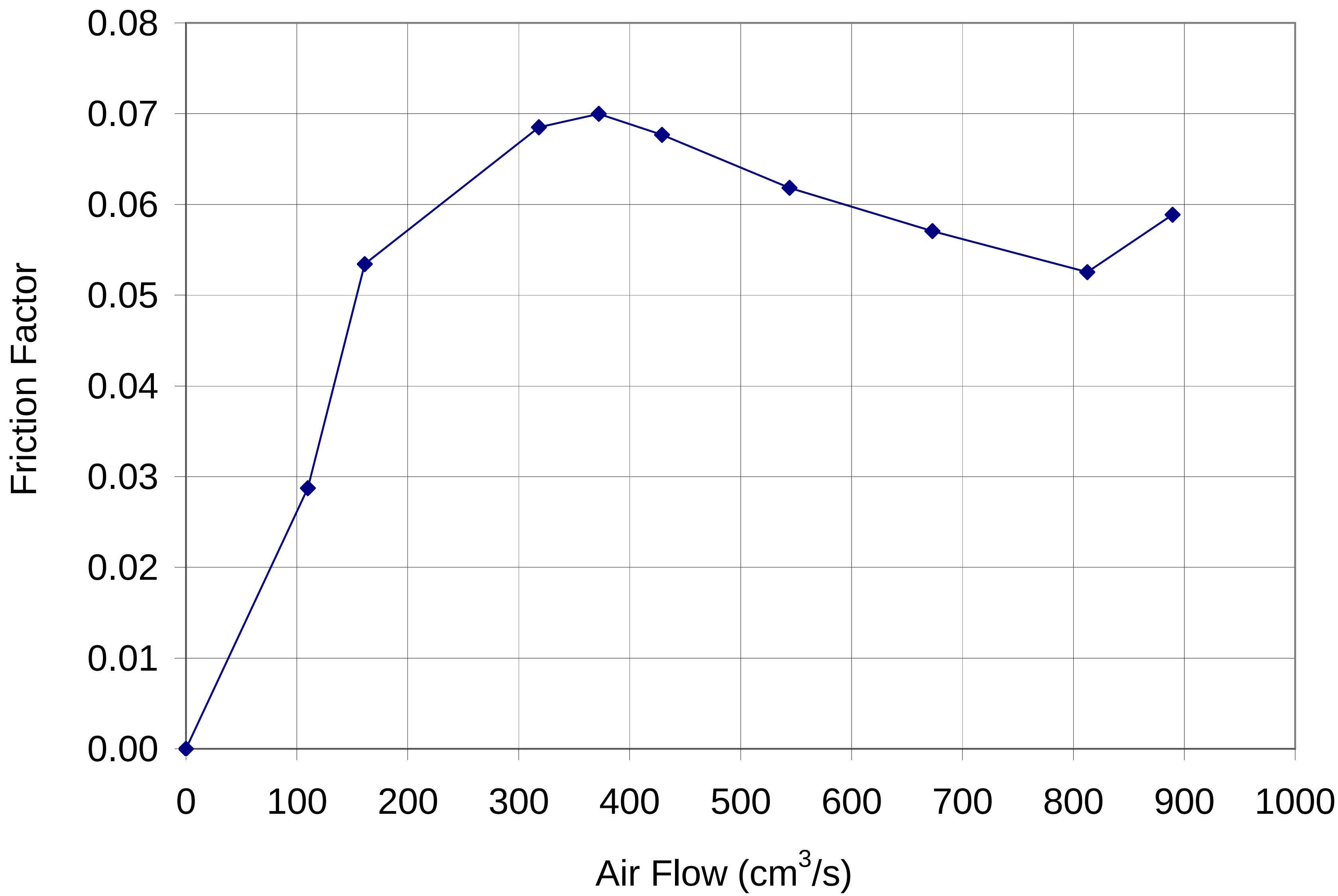
Single-interval, steady-state gas permeability testing requires estimation of pressure at the screened interval from measurement at the surface.

Step 1: Determine friction factors as a function of flow rate. Friction factors are a function of:

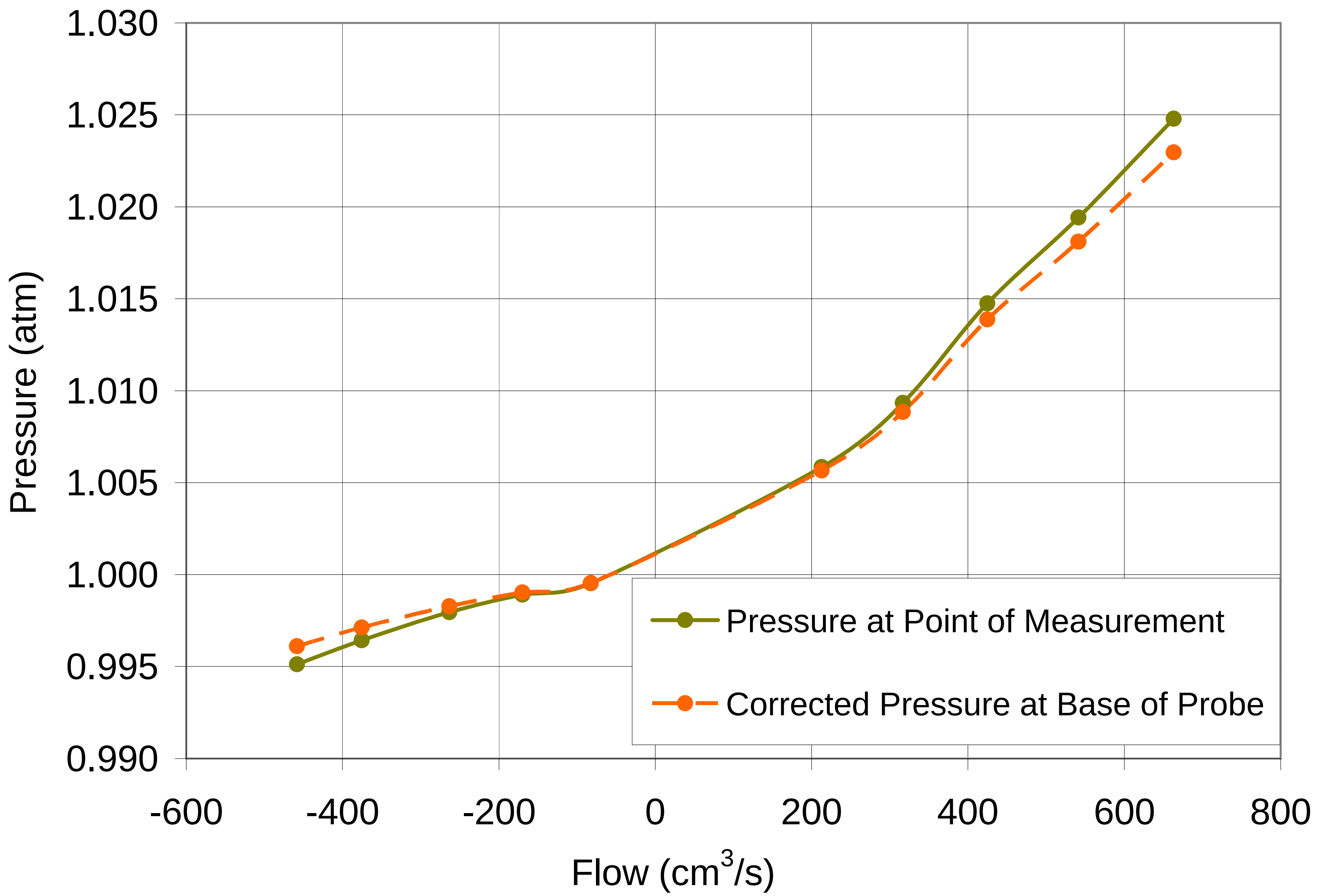
- Flow rate
- Diameter of tubing
- Length of tubing
- Fittings along the way

See equations in Appendix A to calculate friction factors.

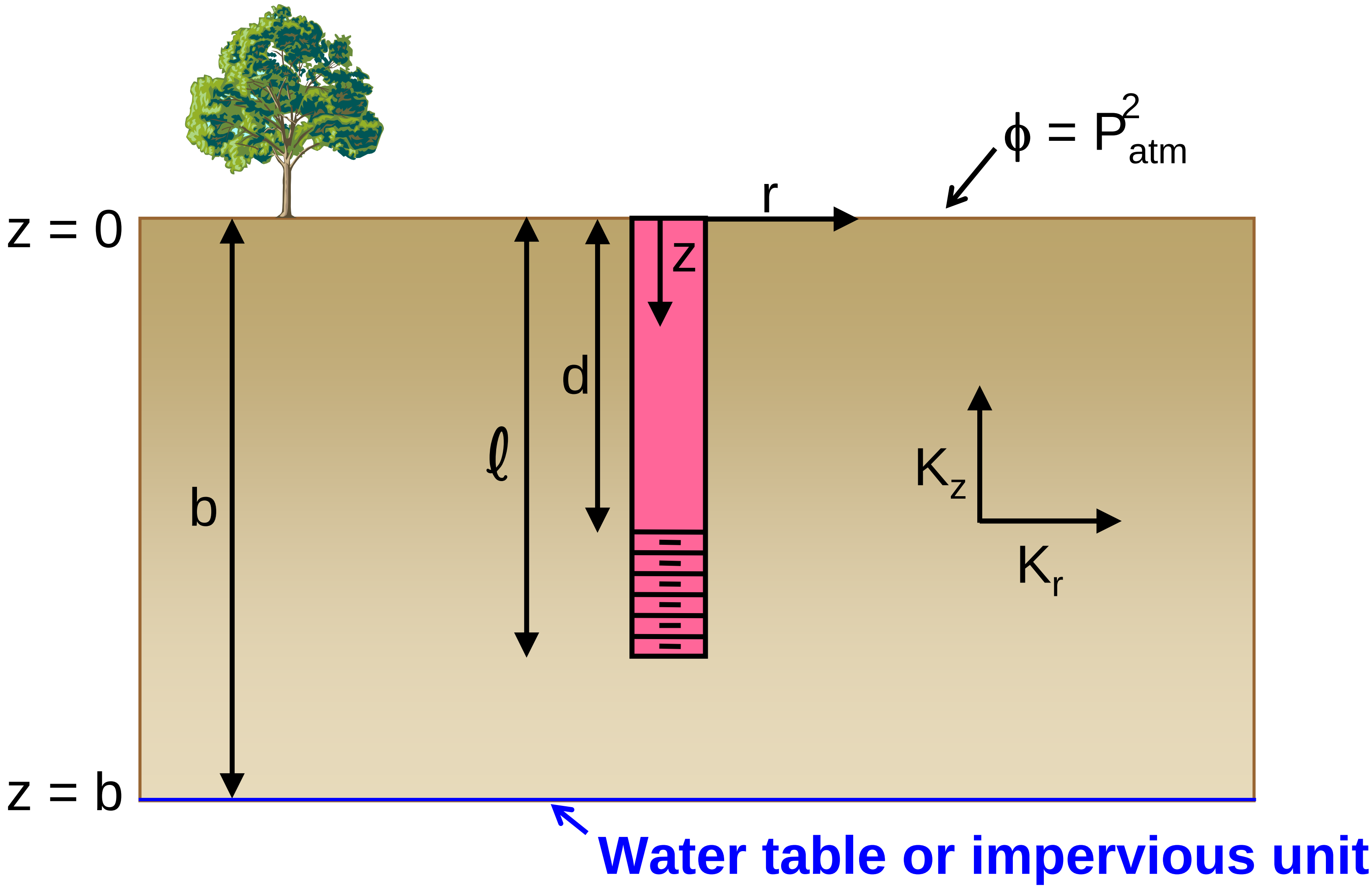
This equipment was also used for determination of sub-slab gas permeability at Raymark.



Friction factors as a function of flow rate for sub-slab probes used at Raymark.



Step 2: Use friction factors and equations in Appendix A to calculate pressure at the screen for a specific flow rate.

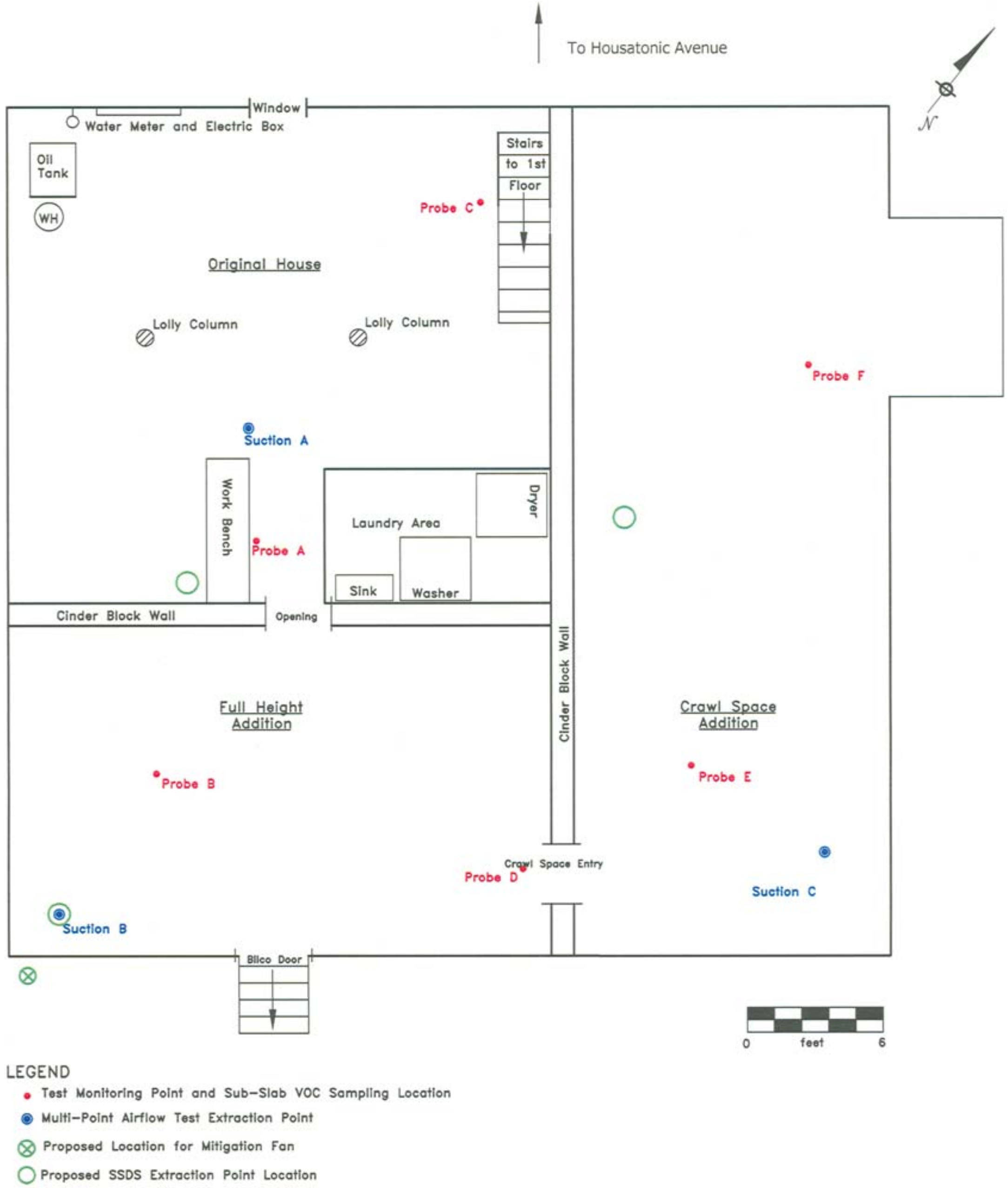


Step 3. Use Baehr and Joss's (1995) analytical solution for two-dimensional, axi-symmetric flow in a homogeneous anisotropic domain open to the atmosphere to estimate radial permeability. Assume isotropic conditions.

Permeability Testing Locations at House C

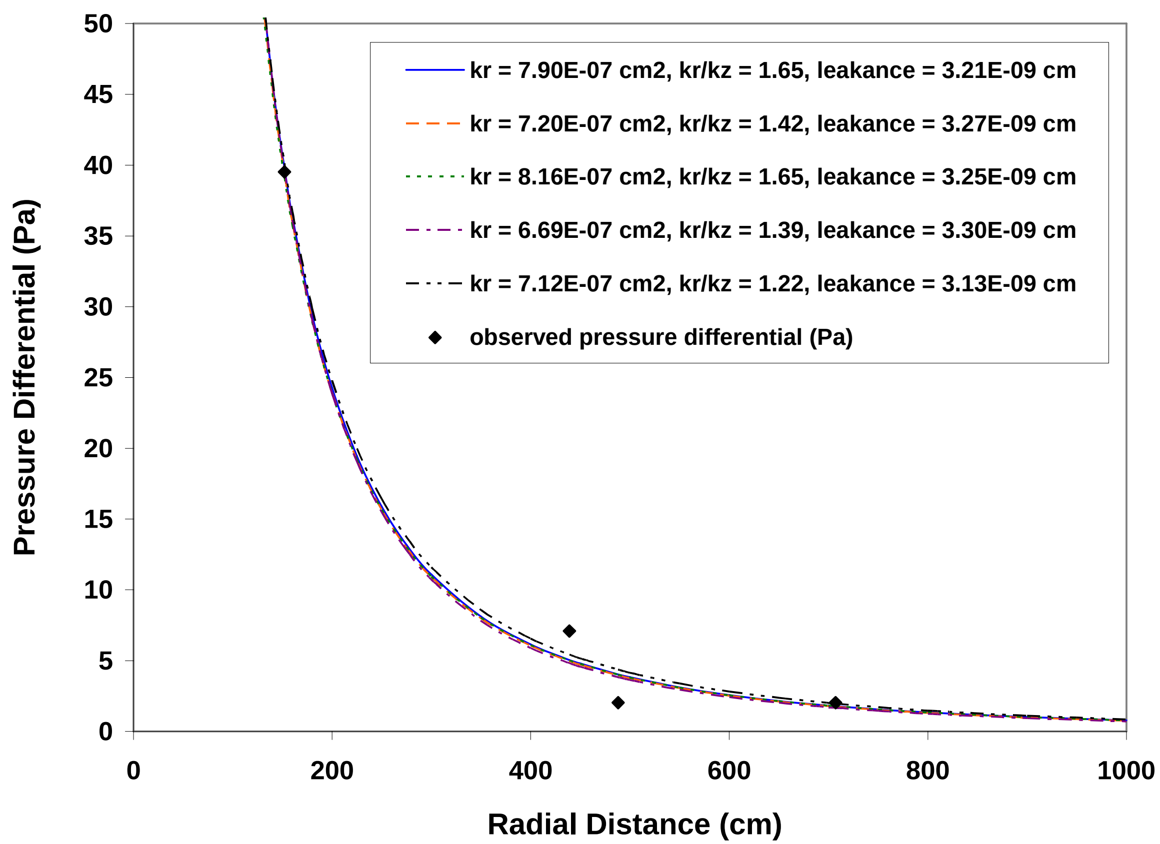
Probe	Mean (cm2)	Stdev (cm2)
A	2.33E-06	1.36E-07
B	5.20E-07	1.71E-07
C	9.73E-07	1.09E-07
D	1.64E-06	4.60E-08
E	9.00E-07	1.00E-07
F	3.85E-07	4.45E-08

Five tests at each probe



Comparison of Single-Interval Testing with Full-Scale Testing

Probe	Mean (cm2)	Stdev (cm2)
A	2.33E-06	1.36E-07
B	5.20E-07	1.71E-07
C	9.73E-07	1.09E-07
D	1.64E-06	4.60E-08
E	9.00E-07	1.00E-07
F	3.85E-07	4.45E-08



Conclusions

- Gas permeability testing is necessary for gas flow modeling which may be helpful in understanding the effect of extraction volume and flow rate on concentration.
- The feasibility of soil-gas sample collection in low permeability media is primarily a function of equipment used for sample collection and maximum acceptable time for sampling. However, there may be a lower limit of gas permeability beyond which active sample collection is impractical.
- Gas flow modeling should be conducted prior to gas permeability testing to optimize testing.
- Time to steady-state conditions can be extensive in low permeability media even in single-interval testing.

Conclusions Continued…

- Friction factors at a number of flow rates for the apparatus used for testing must be determined to estimate pressure at a screened interval.
- Baehr and Joss's analytical solution can be used to estimate radial permeability.
- Isotropic conditions must be assumed in single-interval testing introducing error into estimation of radial permeability.

Questions?

Duct tape can hold anything together.