# Pneumatic Testing, Mathematical Modeling and Flux Monitoring to Assess and Optimize the Performance and Establish Termination Criteria for Sub-Slab Depressurization Systems

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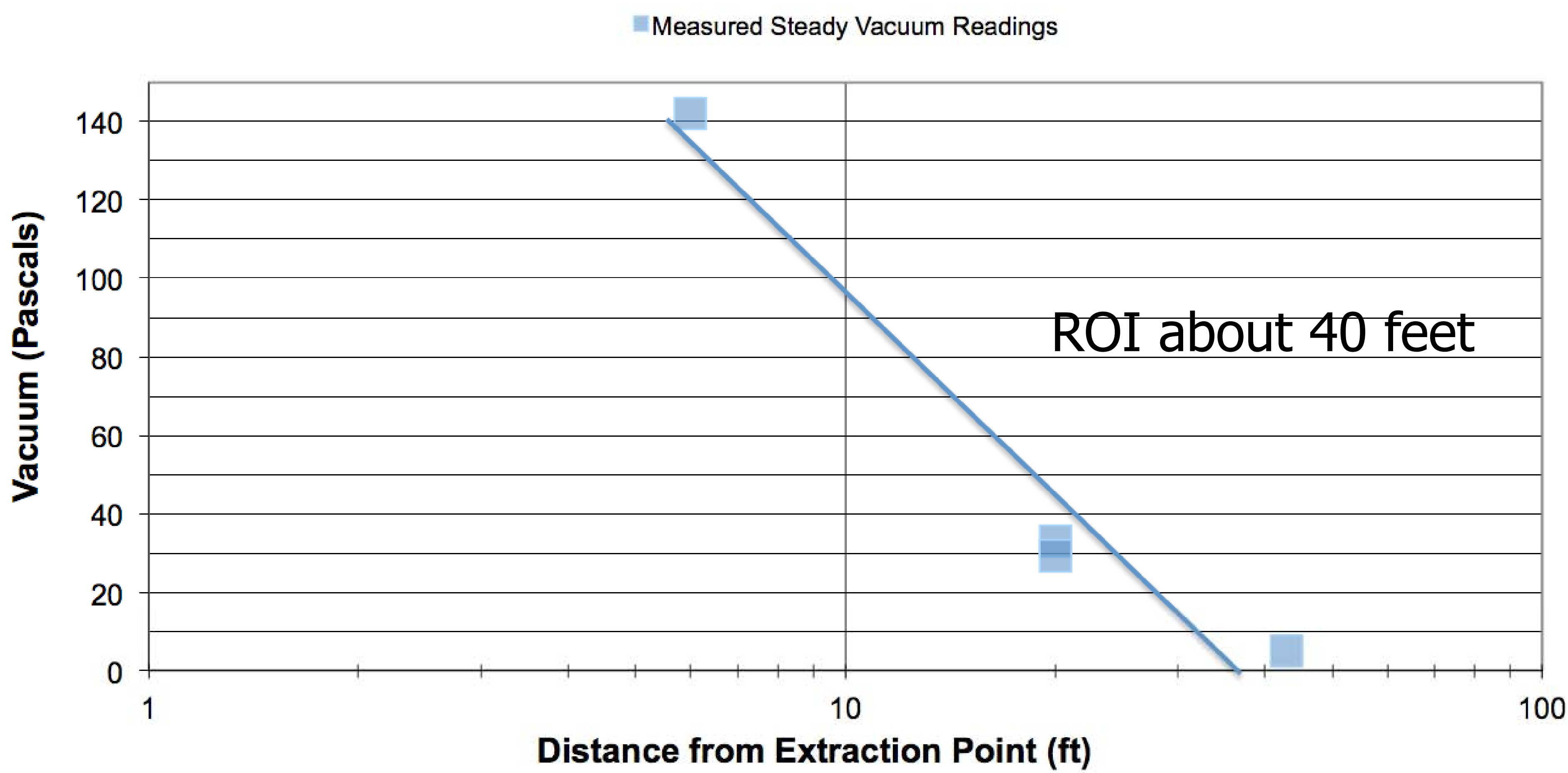
# Optimization Considerations

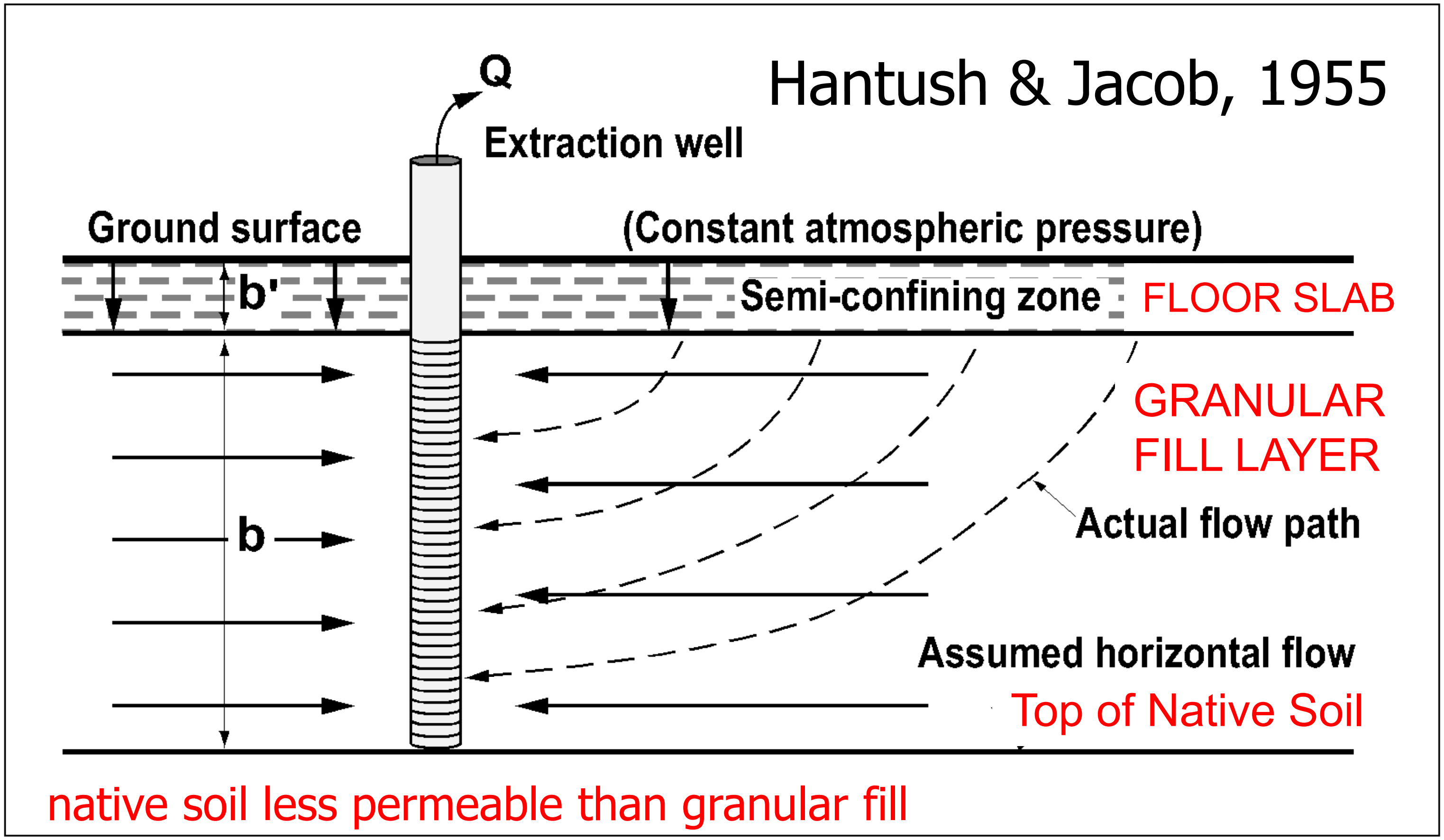
- Current SSD design approach:
  - Apply suction and measure a vacuum
  - ASTM standard suggests 6 - 9 Pascals, but basis for this value is unclear
- Consider flow-based design approach
  - $Q_{soil}$ is about 0.1 to 10 L/min for 100 $m^2$ building
  - Average radon fan draws ~3,000 L/min (overdesigned)
  - Overdesign may not be significant for single family home, but can be costly for commercial / industrial buildings
- Design analogue: groundwater pump & treat
  - Measure permeability and optimize pumping rate

# Conventional Radius of Influence

Case Study: 100,000 ft$^2$ commercial building, slab-on-grade



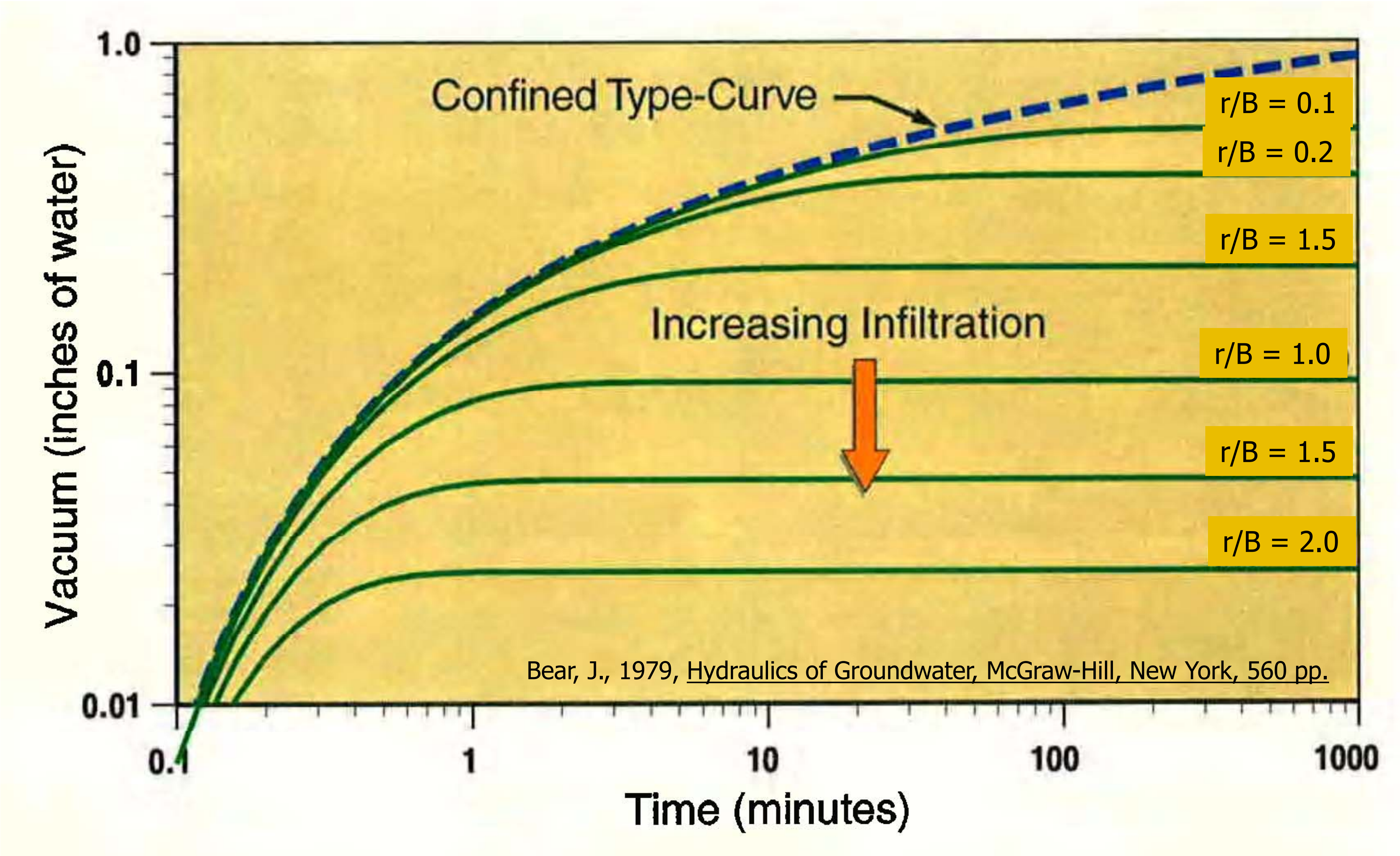
# Leaky Aquifer Model for SSD




Thrupp, G.A., Gallinatti, J.D., Johnson, K.A., 1996, "Tools to Improve Models for Design and Assessment of Soil Vapor Extraction Systems", in Subsurface Fluid-flow (Groundwater and Vadose Zone) Modeling, ASTM STP 1288, Joseph D. Ritchey and James O. Rambaugh, Eds., American Society for Testing and Materials, Philadelphia. pp 268-2

Massman, J. W., 1989, "Applying Groundwater Flow Models to Vapor Extraction System Design," J. of Environmental Engineering, Vol. 115, No. 1, pp. 129-149.

# Leaky Aquifer Type-Curves



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# High Purge Volume Test Kit


Fan or Vacuum

Bleed Valve

Sample Port

Vacuum Gauge

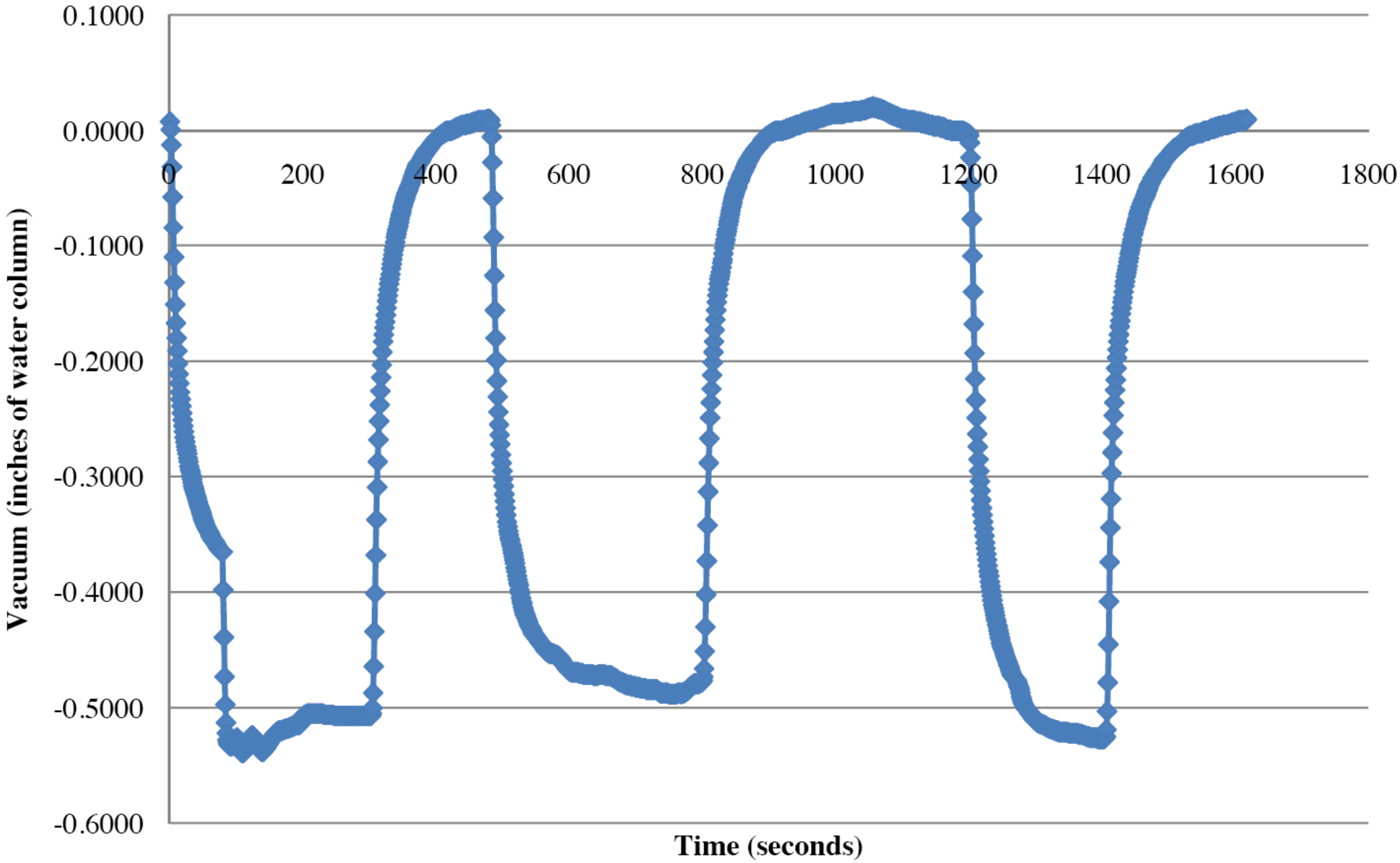
Cored Hole

Lung Box

# Pressure Transducers / Data Loggers

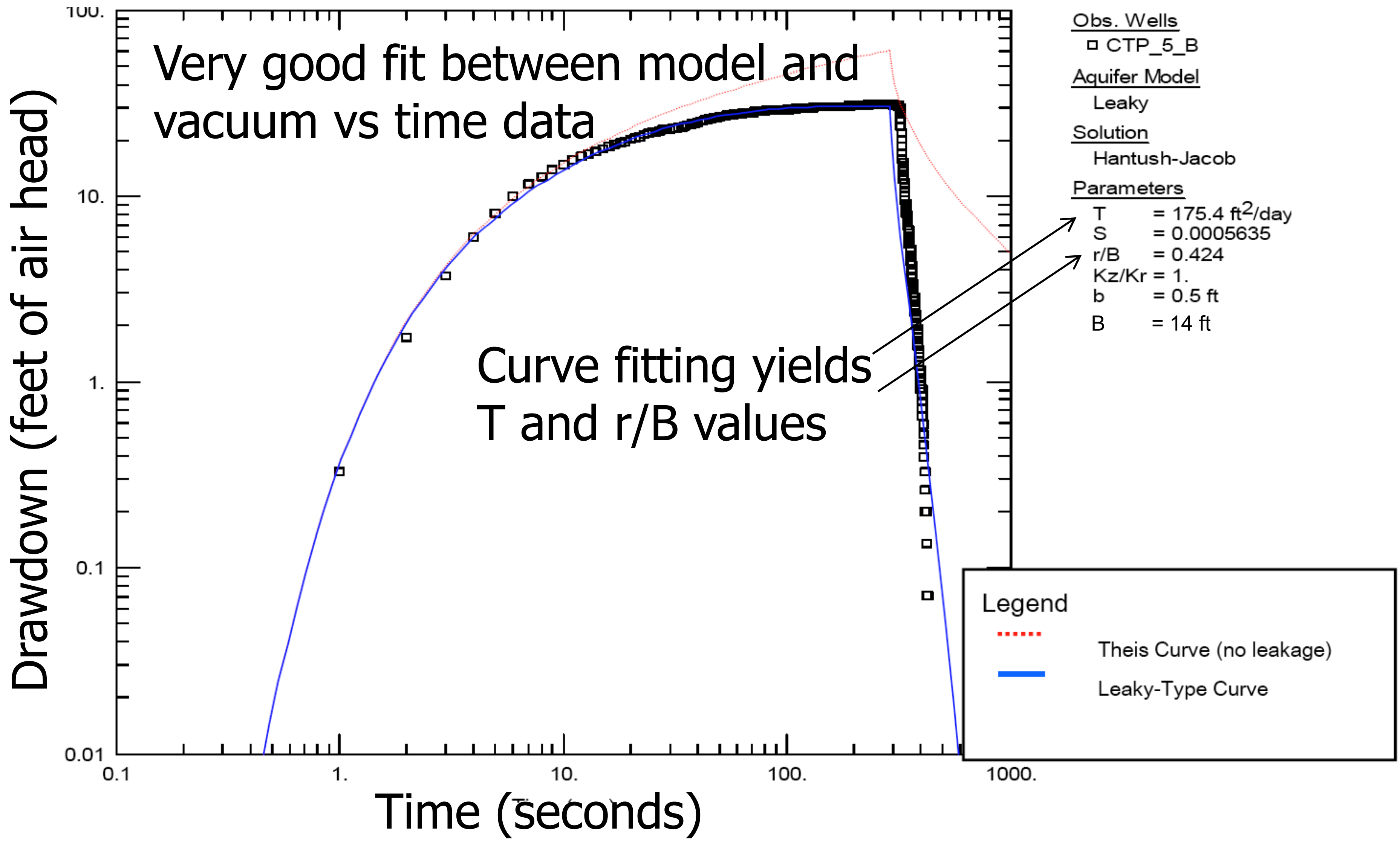

In just a few minutes, you've got "pump-test" data

# Drawdown and Recovery



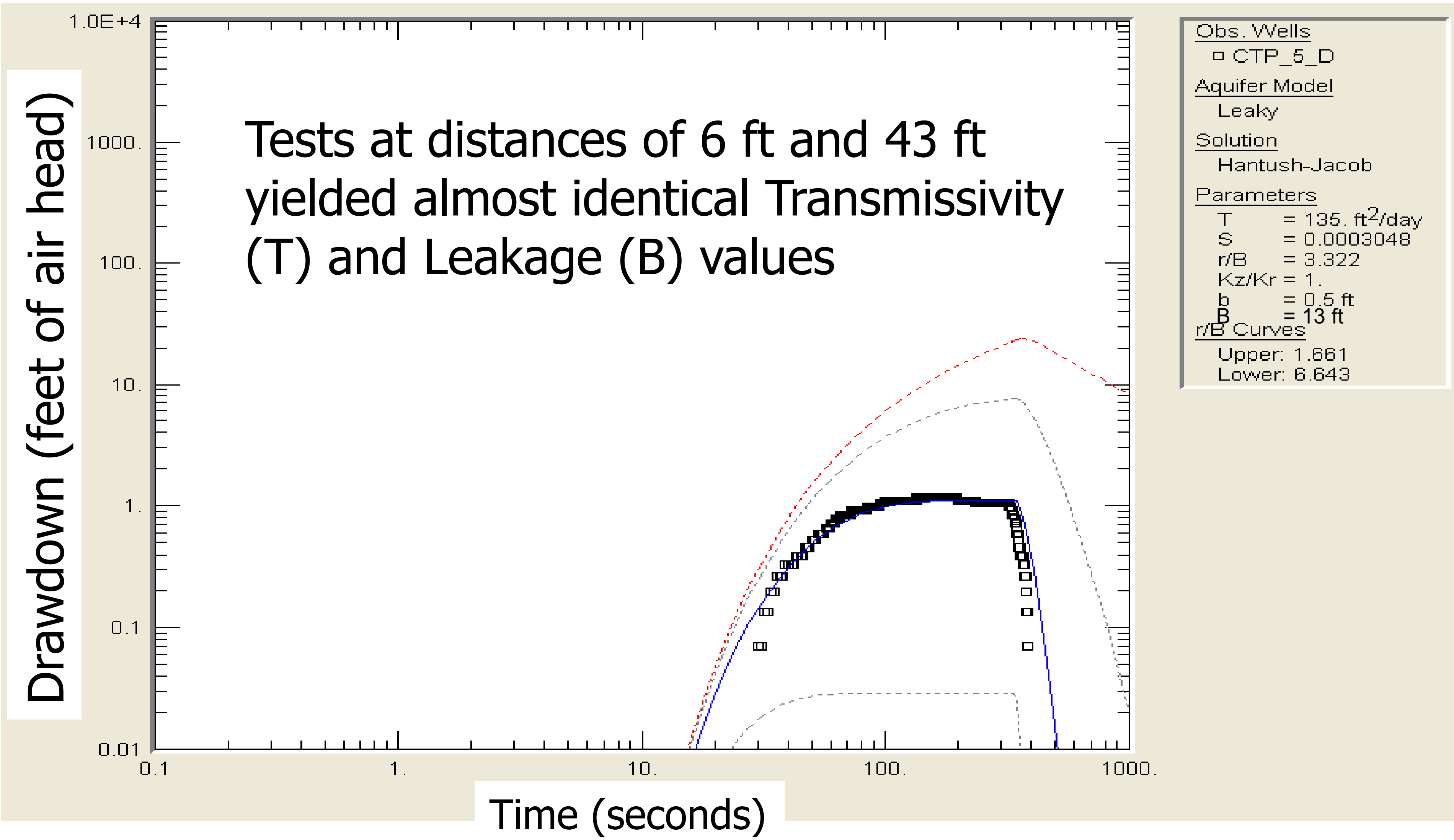
# Hantush Jacob Model Fit

**Vacuum measurements 6 feet from extraction point**



# Hantush Jacob Model Fit

## Vacuum measurements 43 feet from extraction point



# Floor Slab Conductivity

$$K' = \frac{T\,b'}{B^2}$$

$K'$ = vertical pneumatic conductivity of the floor slab [L/t]
$b'$ = floor slab thickness [L], easily measured
$T$ = transmissivity [$L^2$/t], a direct output of the model
$B$ = leakance [L], also output from the model

Therefore, if you know b' (slab thickness), you can calculate the vertical pneumatic conductivity of the slab

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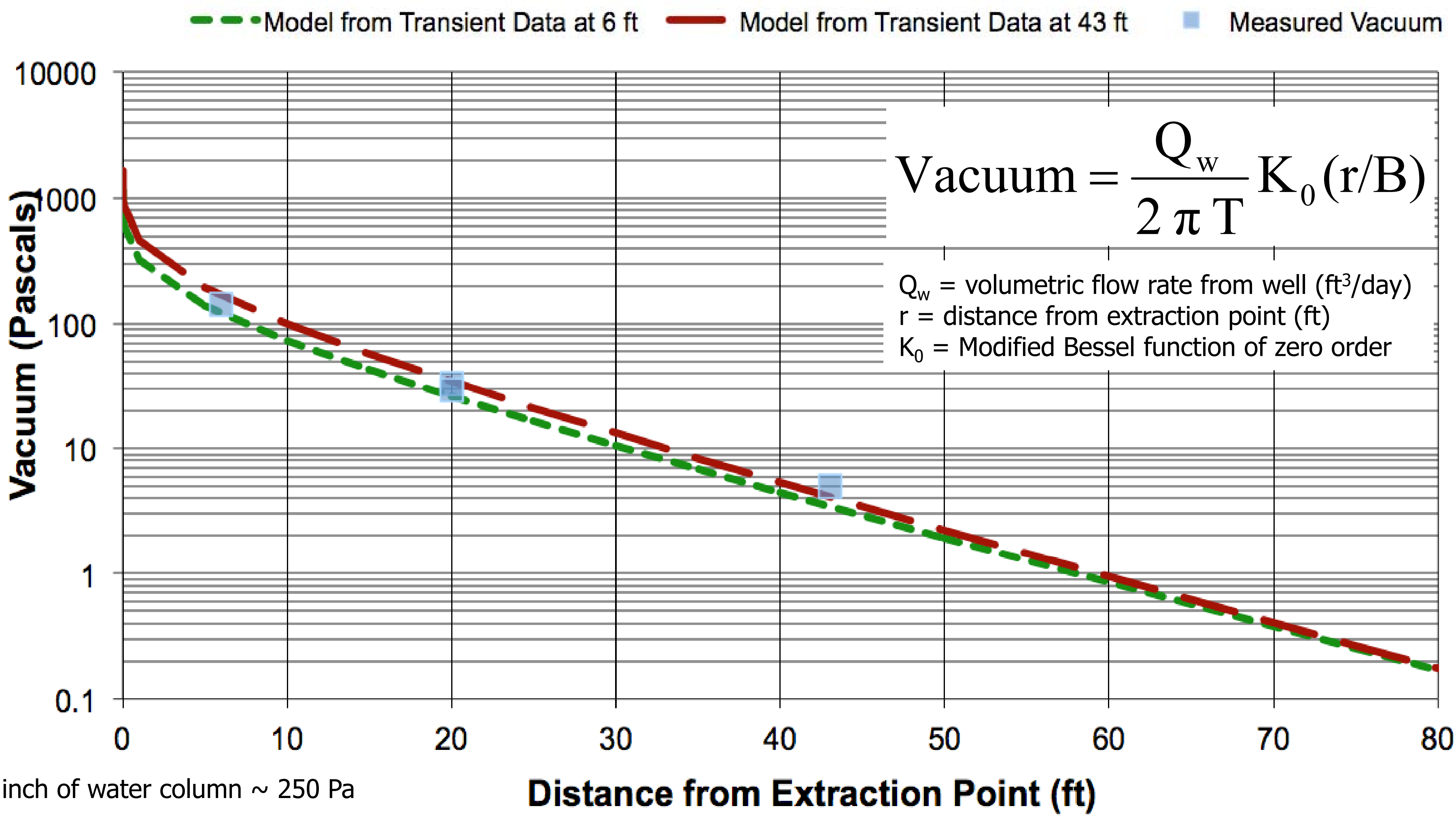
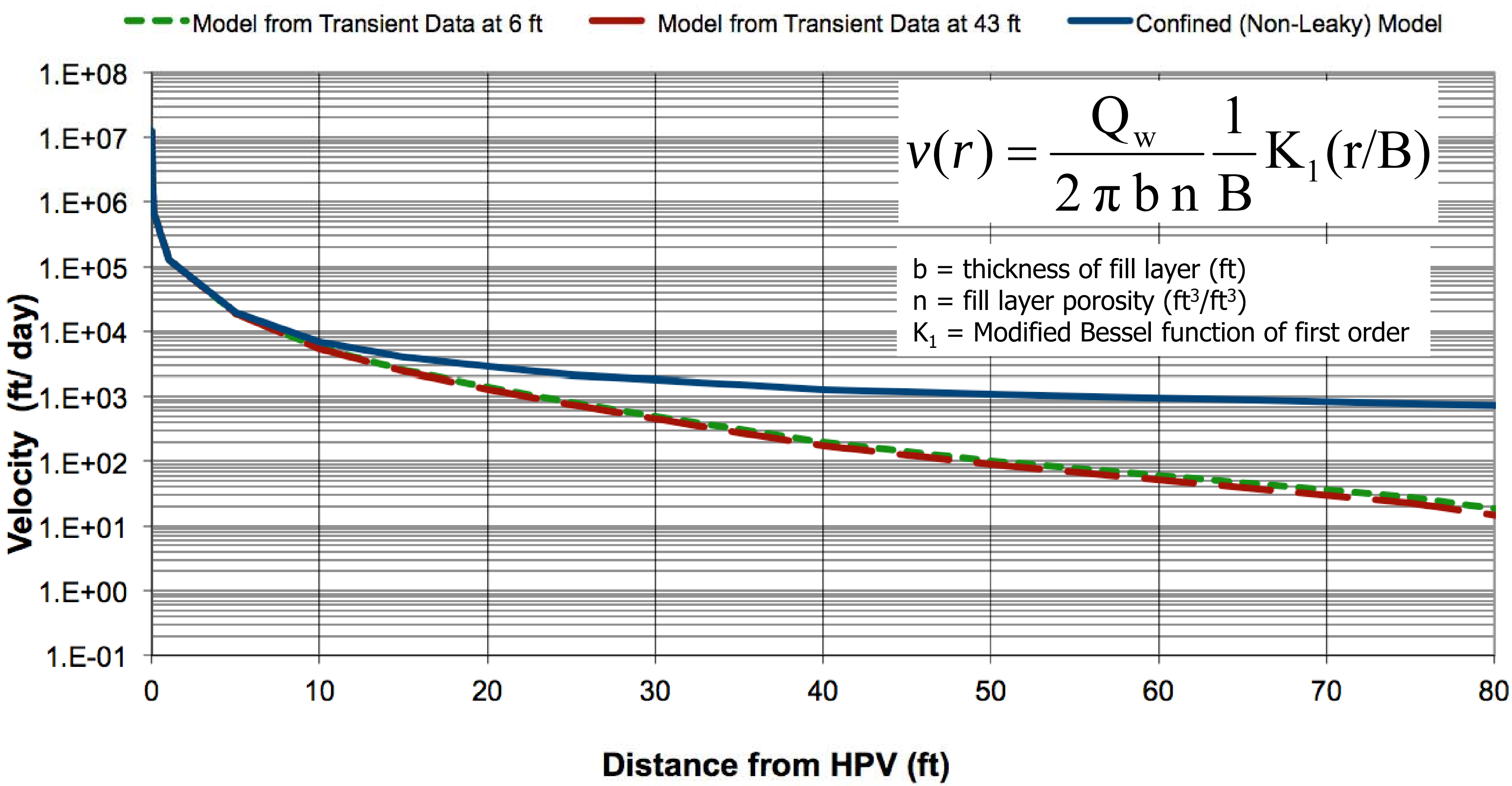
# Measured versus Modeled Vacuum




(1 inch of water column ~ 250 Pa

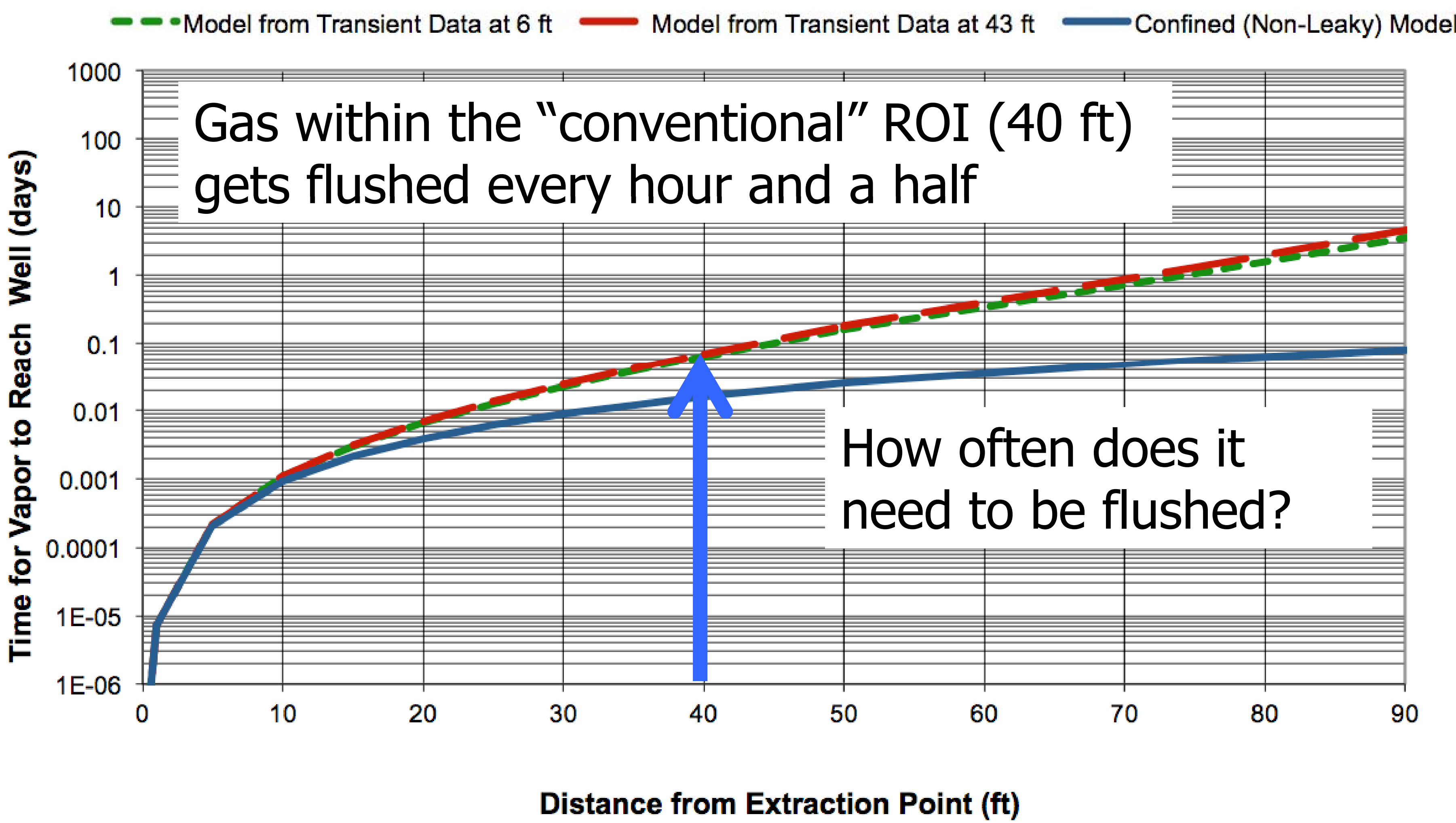
***ALSO*** good fit of model to vacuum vs distance – unique calibration!

# Velocity versus Distance

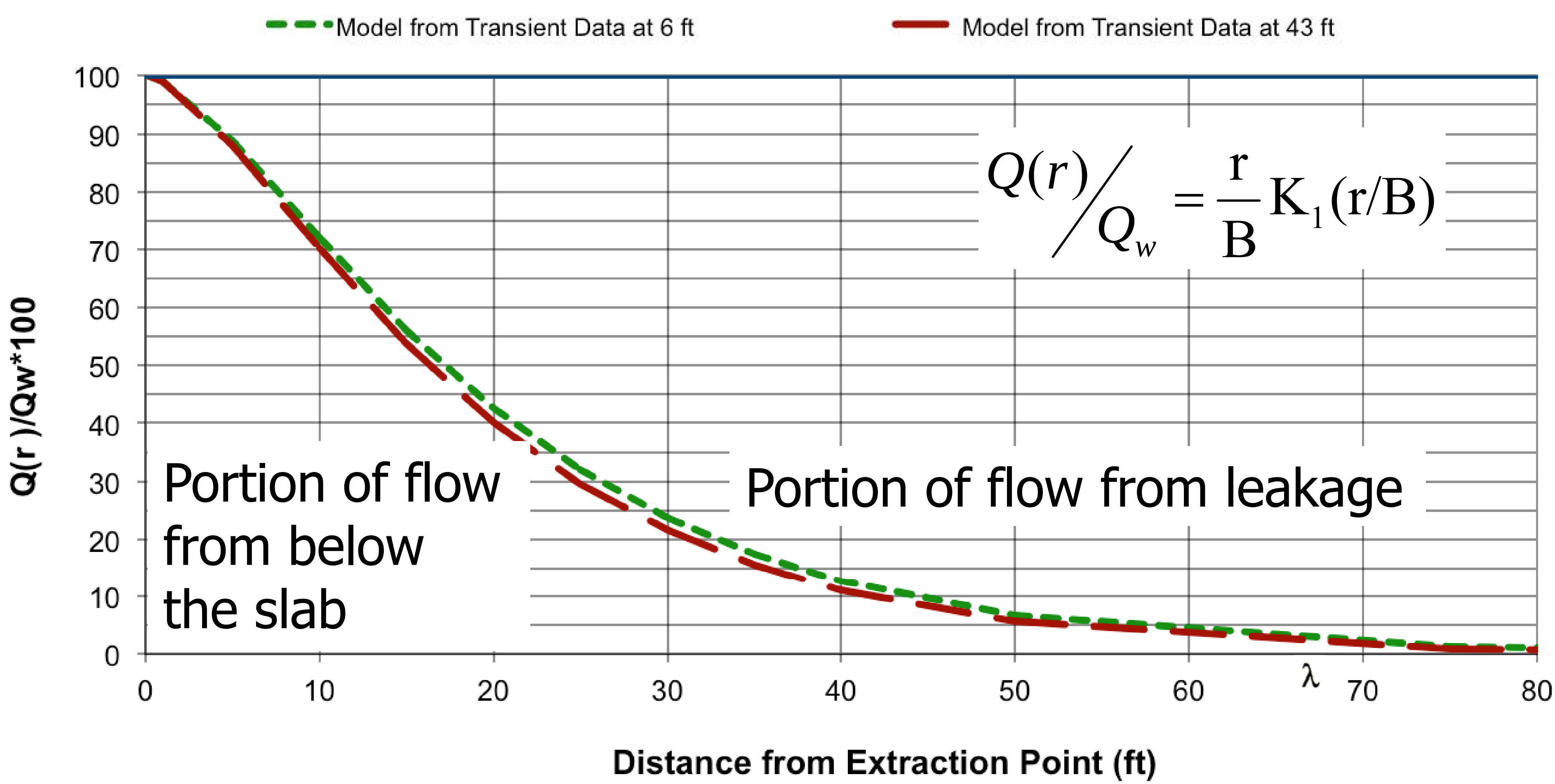



Typical $Q_{soil}$ divided by building area is about 0.05 ft/day

# Purge Time versus Distance

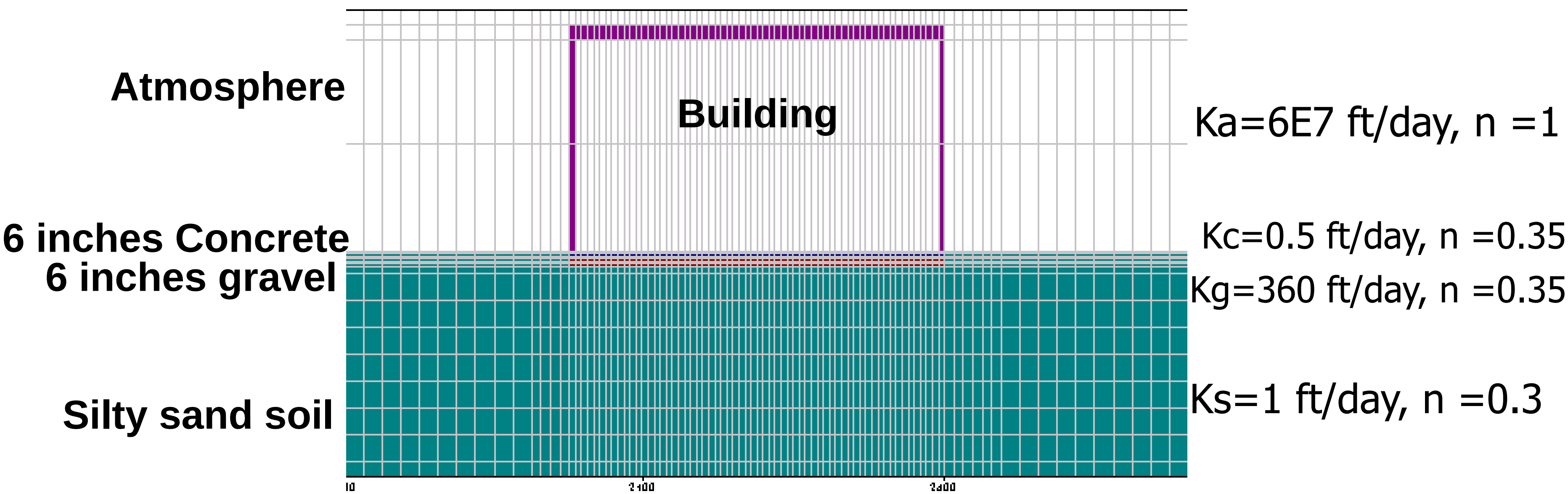


# Radius of Influence as a Function of Leakage



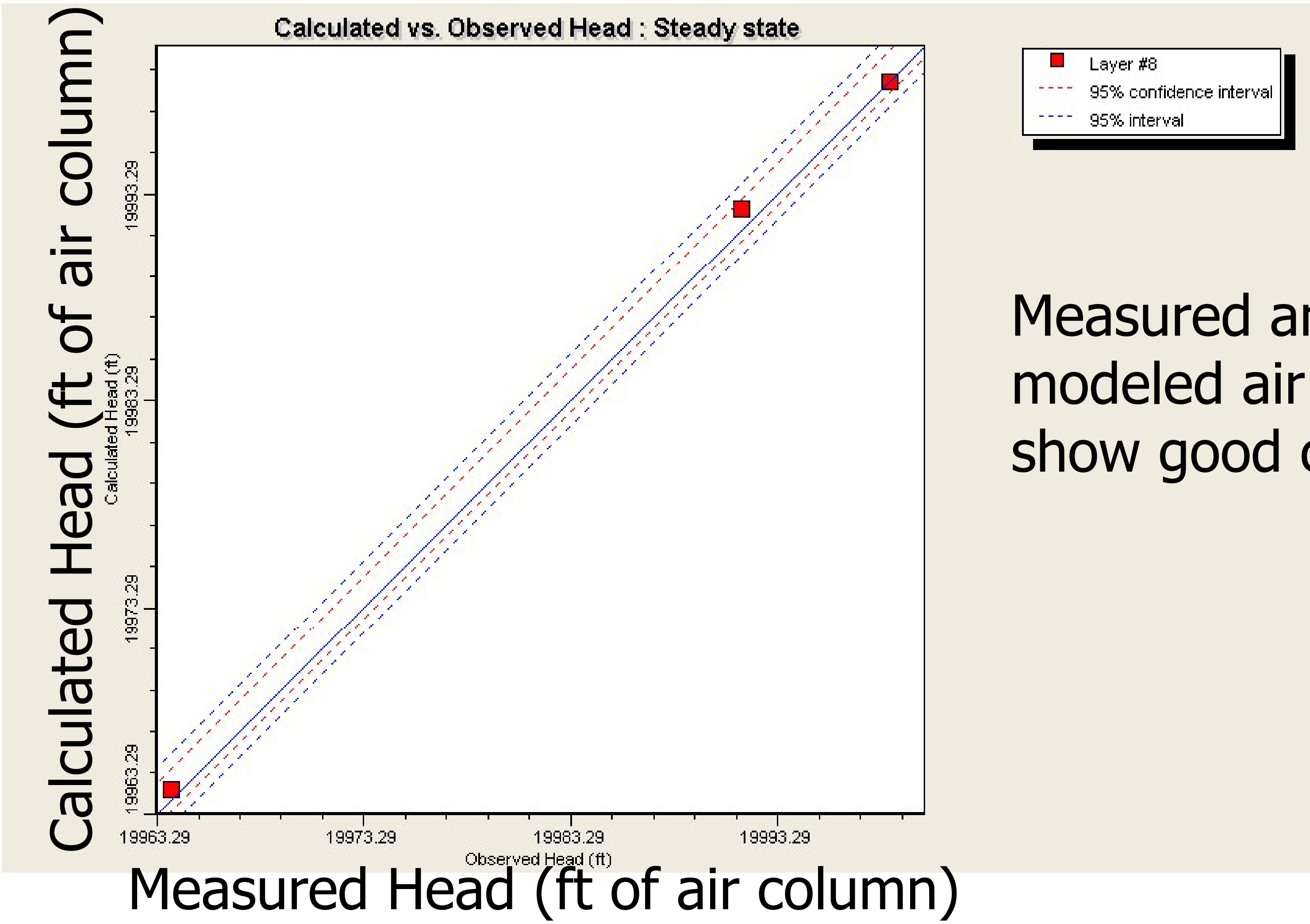
# Soil Gas Flow Modeling as a Tool for Soil Vapor Extraction Design

## Cross Section Showing Model Layers




**Water Table @ 15 ft bgs with ~200 ug/L TCE**

# Calibration to Measured Vacuum




Measured and modeled air pressure show good calibration

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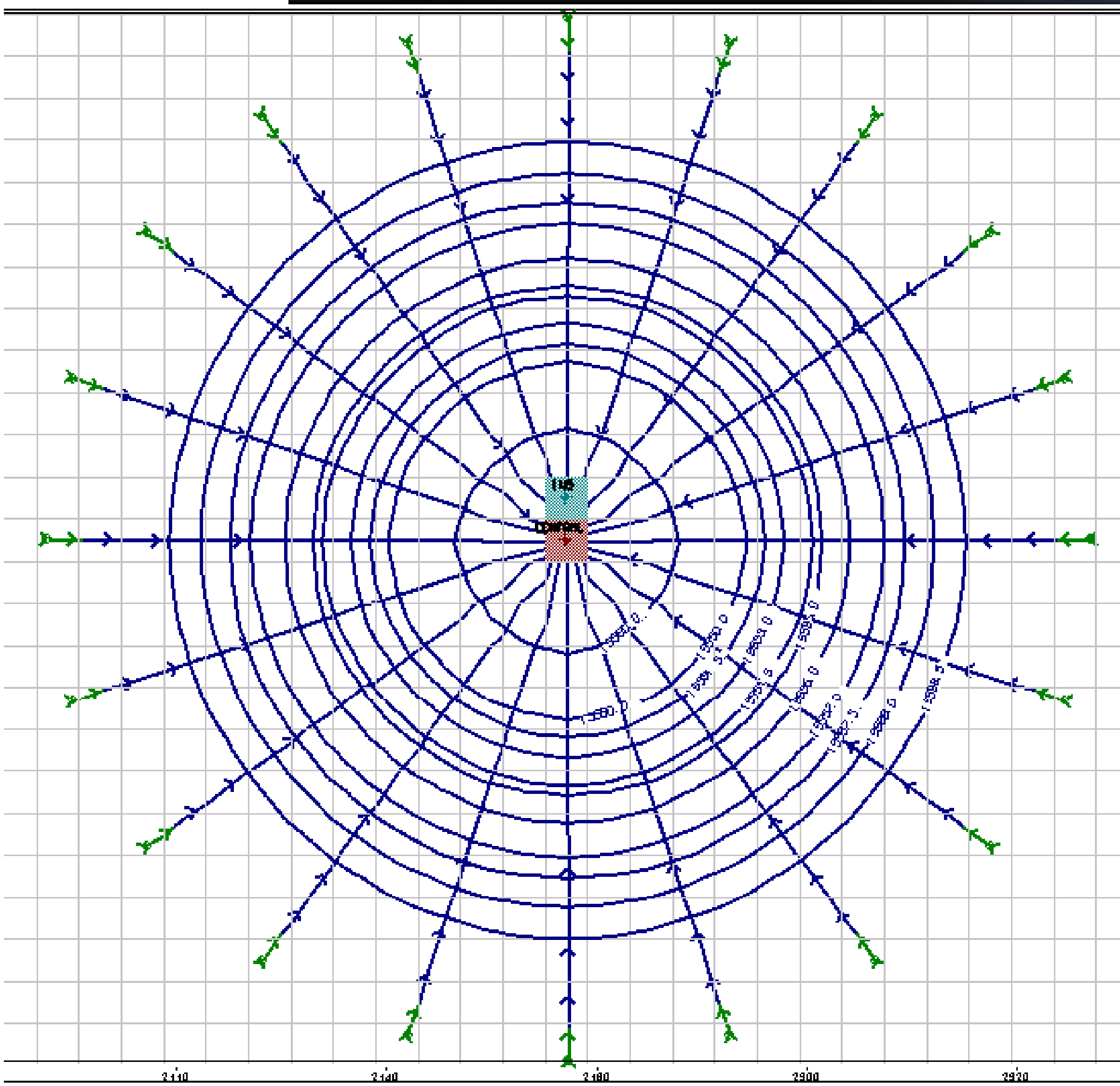
# Particle Tracks in Plan View



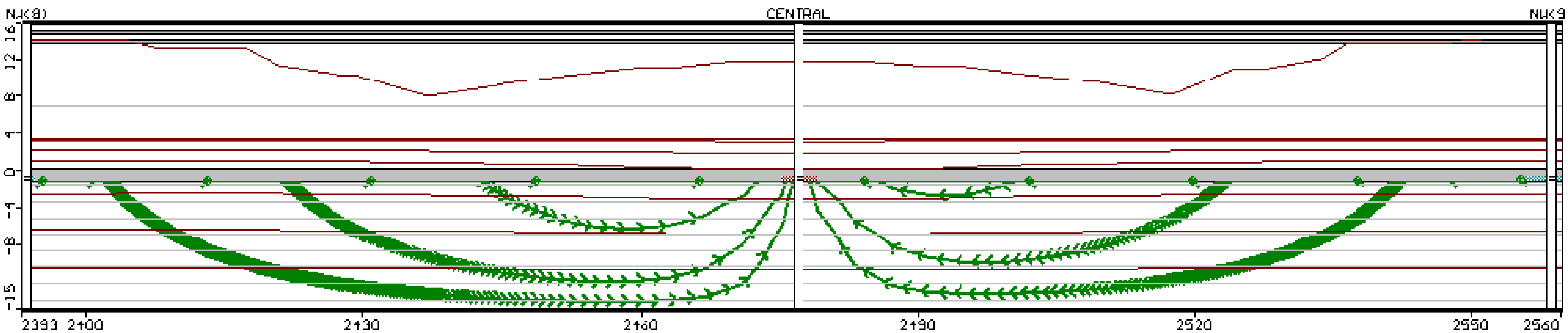
Particles travelling through the gravel layer

Arrowheads are only 1 hour apart - 5 hours to travel from 50 ft away

Numerical model matches analytical model – internal consistency

Q = 27 scfm

# Particle Tracks in Cross Section

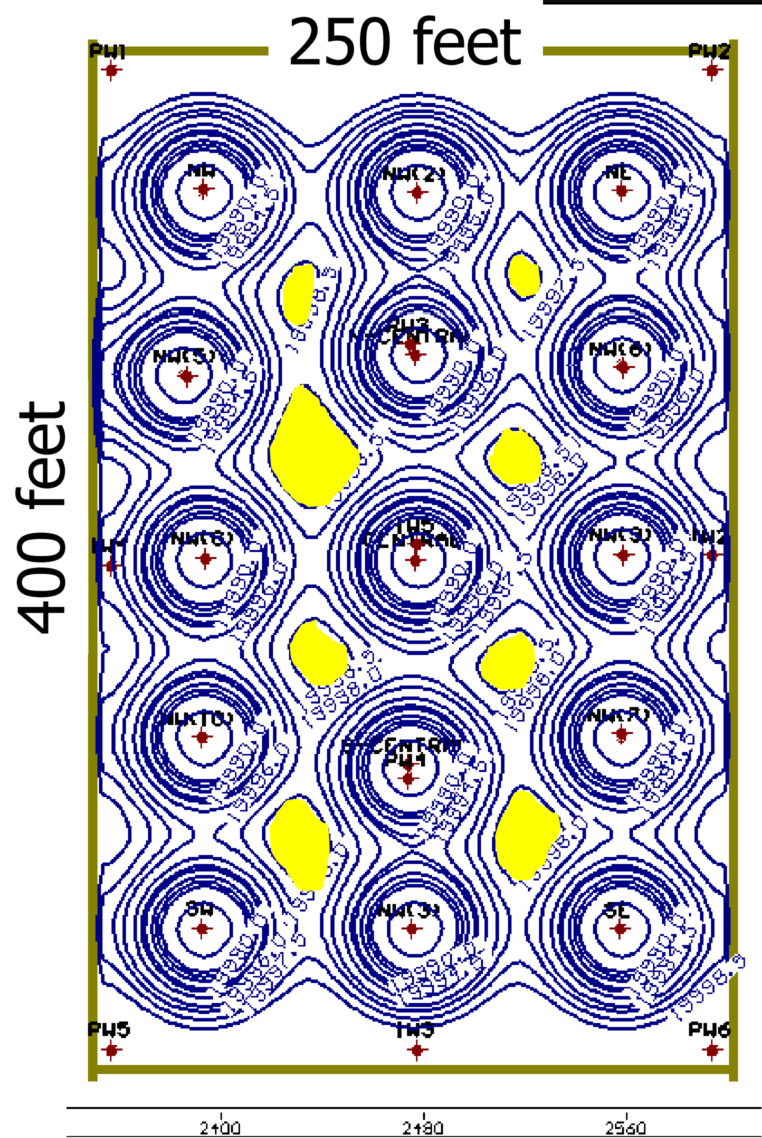



Q = 27 scfm

Limited flow through the native soil

Arrowheads are 1 day apart, so flow through the soil is very slow

# Suction Points Required for 6 Pa




Even with 15 suction points pumping 27 scfm, there are still areas where vacuum would not meet the ASTM spec. of 6 Pa vacuum

Almost 600,000 cubic feet per day of air flows from the building to the subsurface (energy loss)

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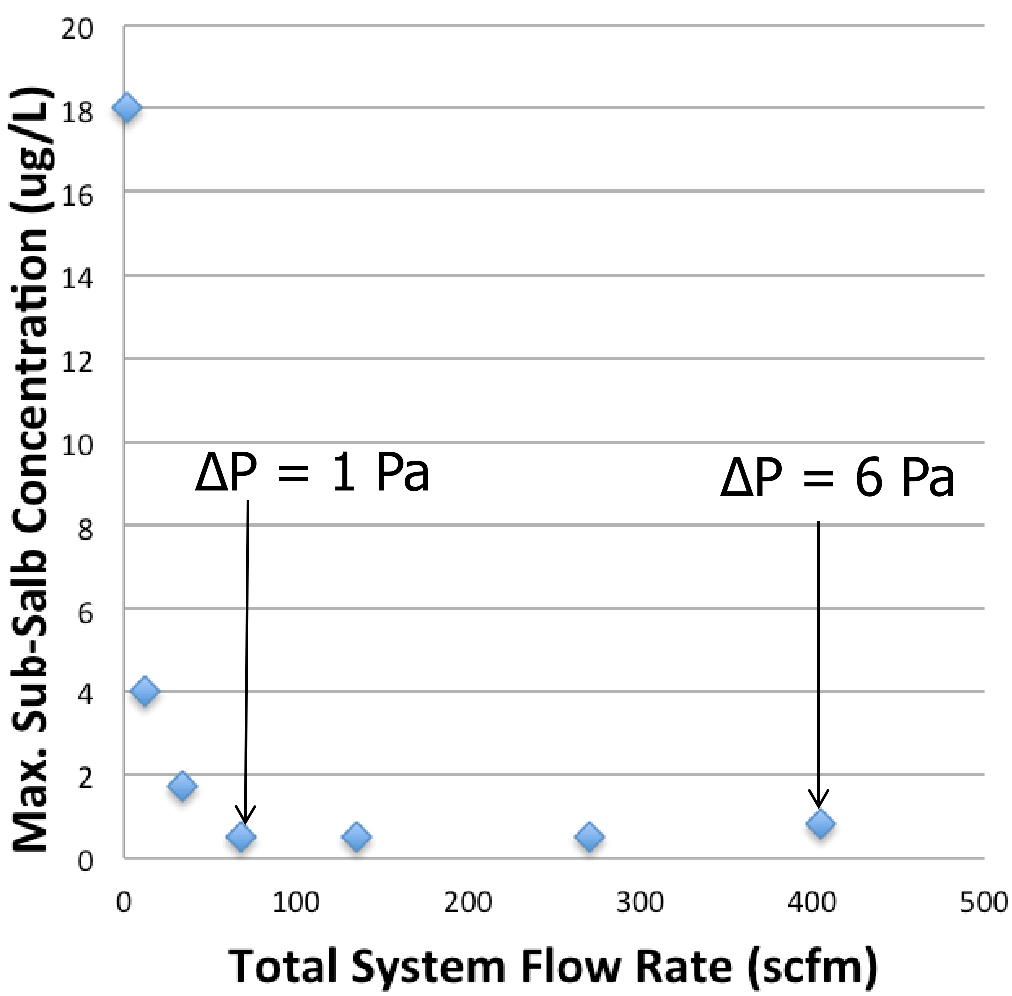
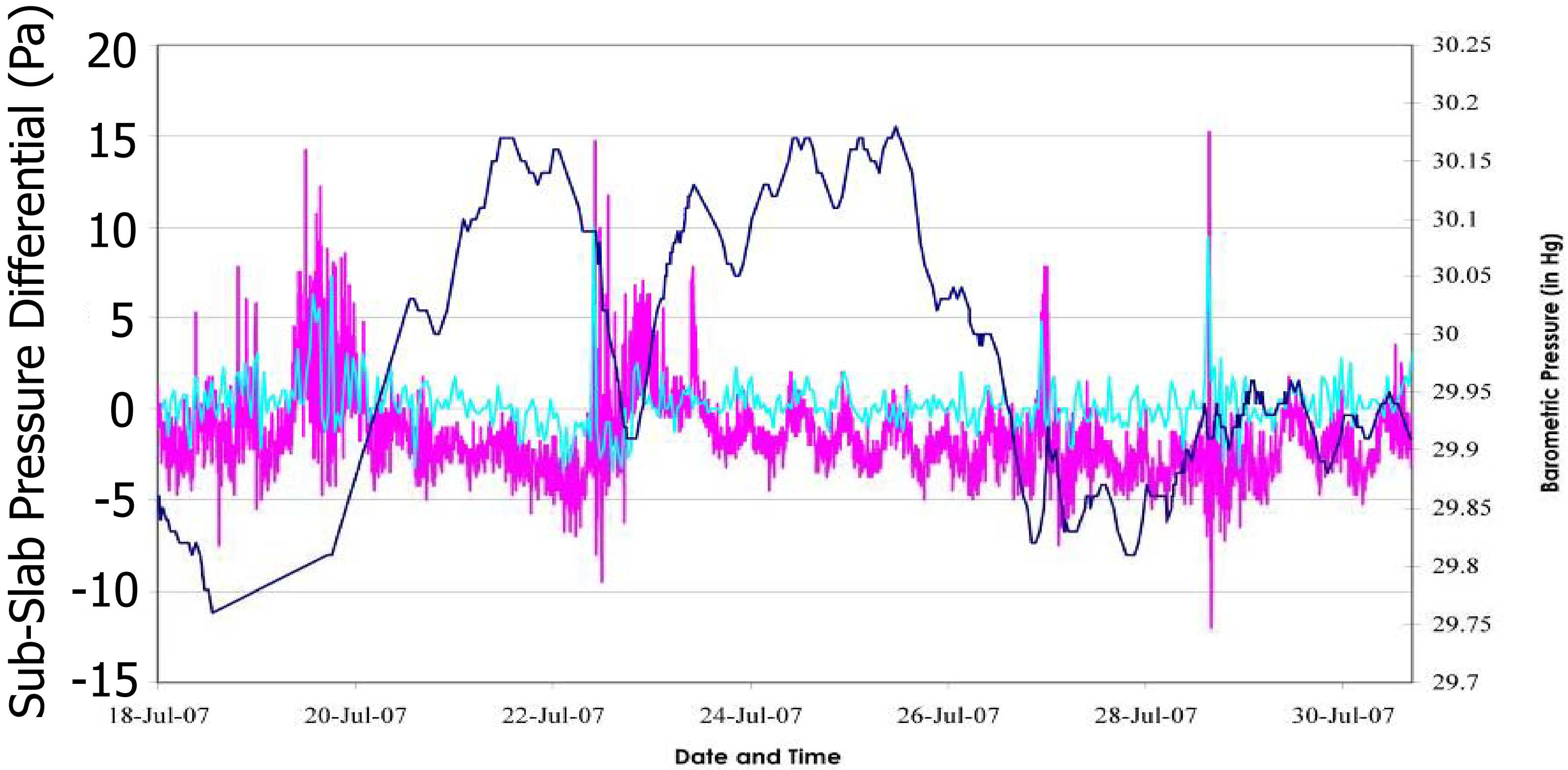
# SSD versus SSV




Maximum sub-slab concentration drops rapidly until total system flow approaches 60 scfm.

Corresponding minimum sub-slab vacuum = 1 Pa (not 6 Pa, per ASTM Spec.)

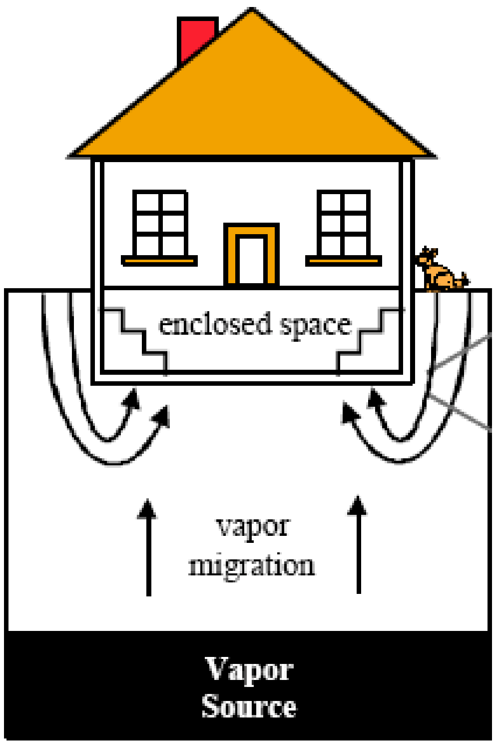
# How To Measure 1 Pa Vacuum?



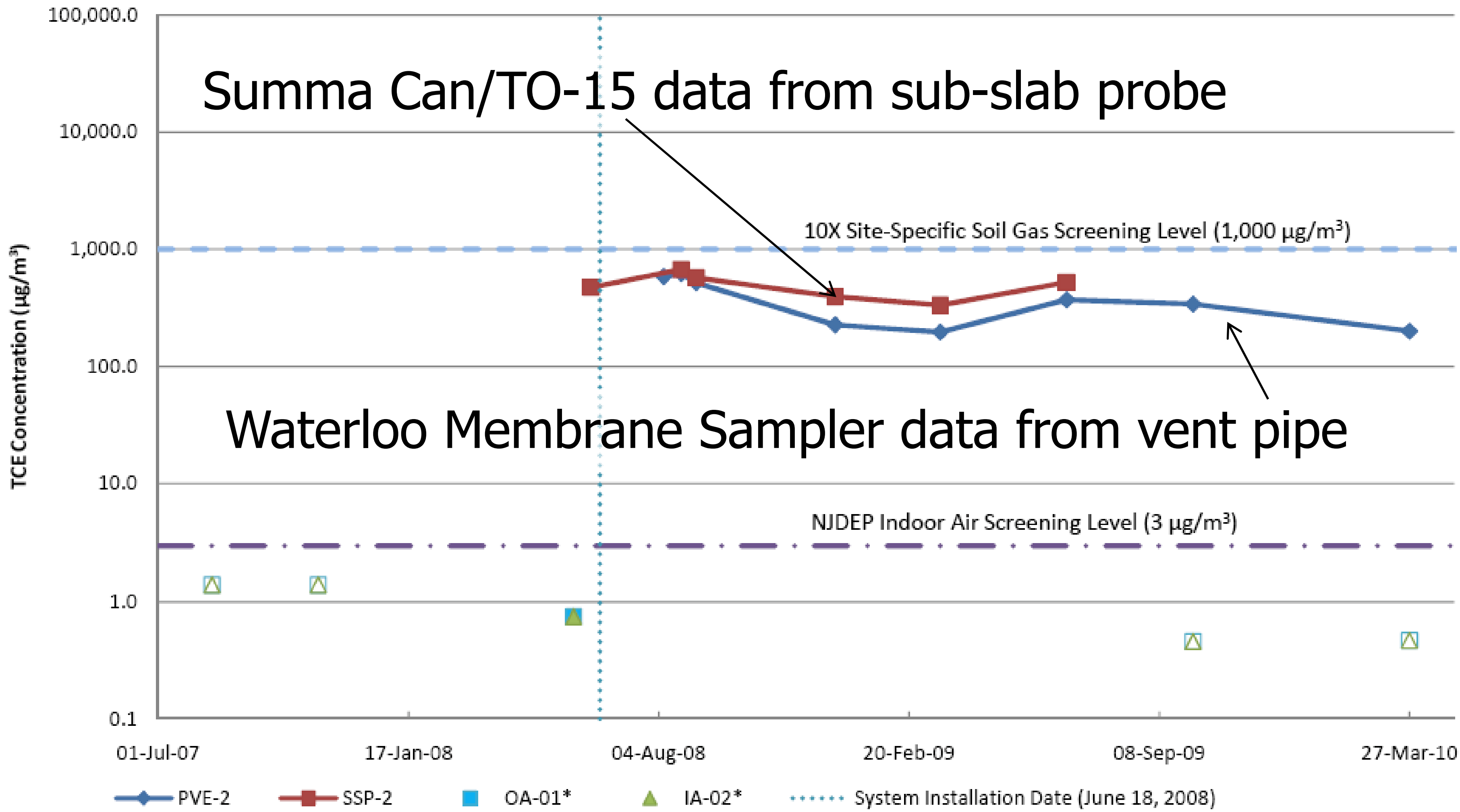

Typical fluctuations in cross-slab pressure are greater than 1 Pa (maybe this is why ASTM specified 6 to 9 Pa vacuum…)

# Consider Mass Flux

- Upward Diffusive Mass Rate ($\dot{M}$) = $D_{eff}$ x $\Delta C/L$ x A (all can be estimated)
- Extracted Mass Removal Rate by Vent Pipes = C x Q (all can be measured)

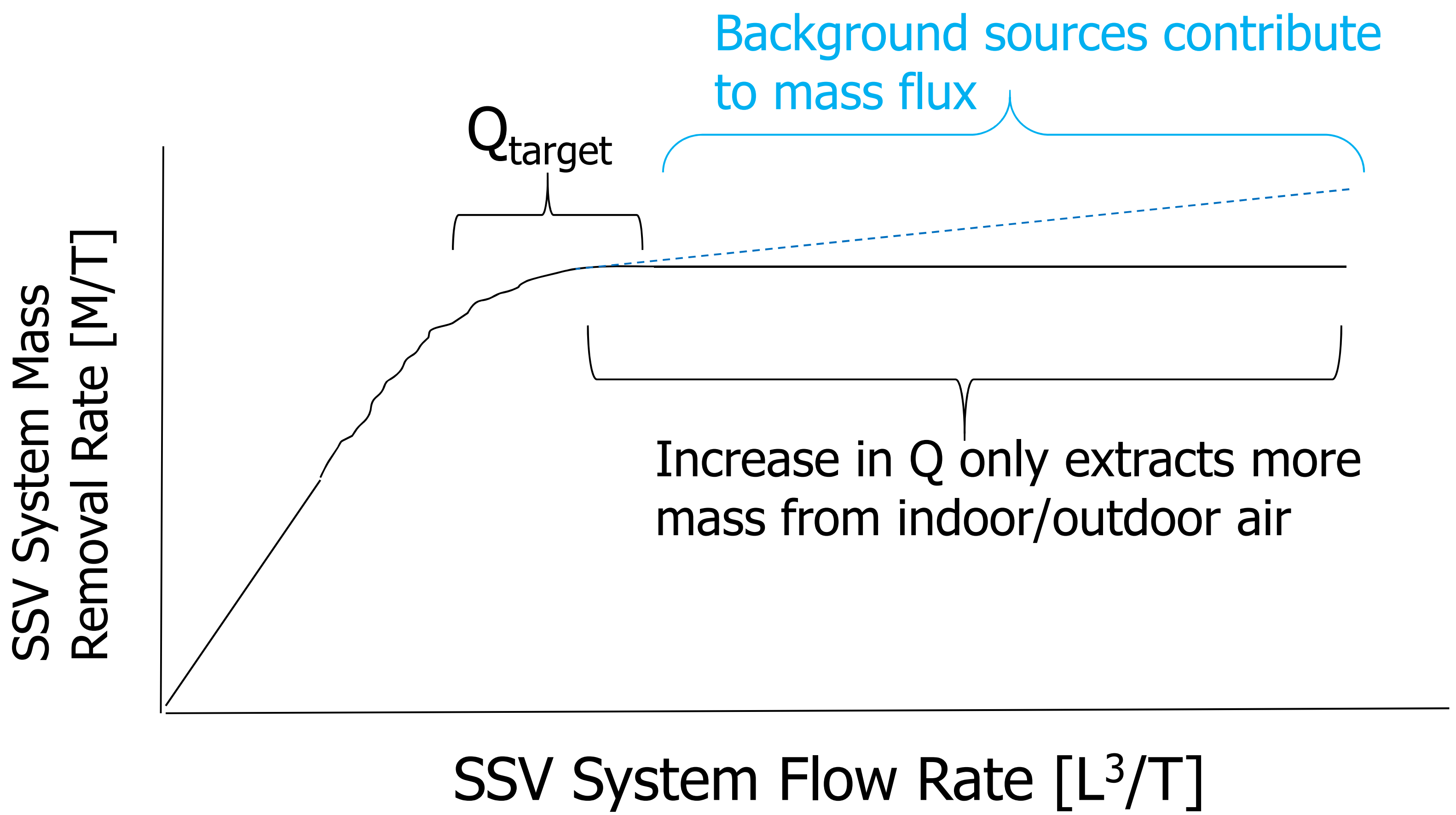



# Example Vent-Pipe Data



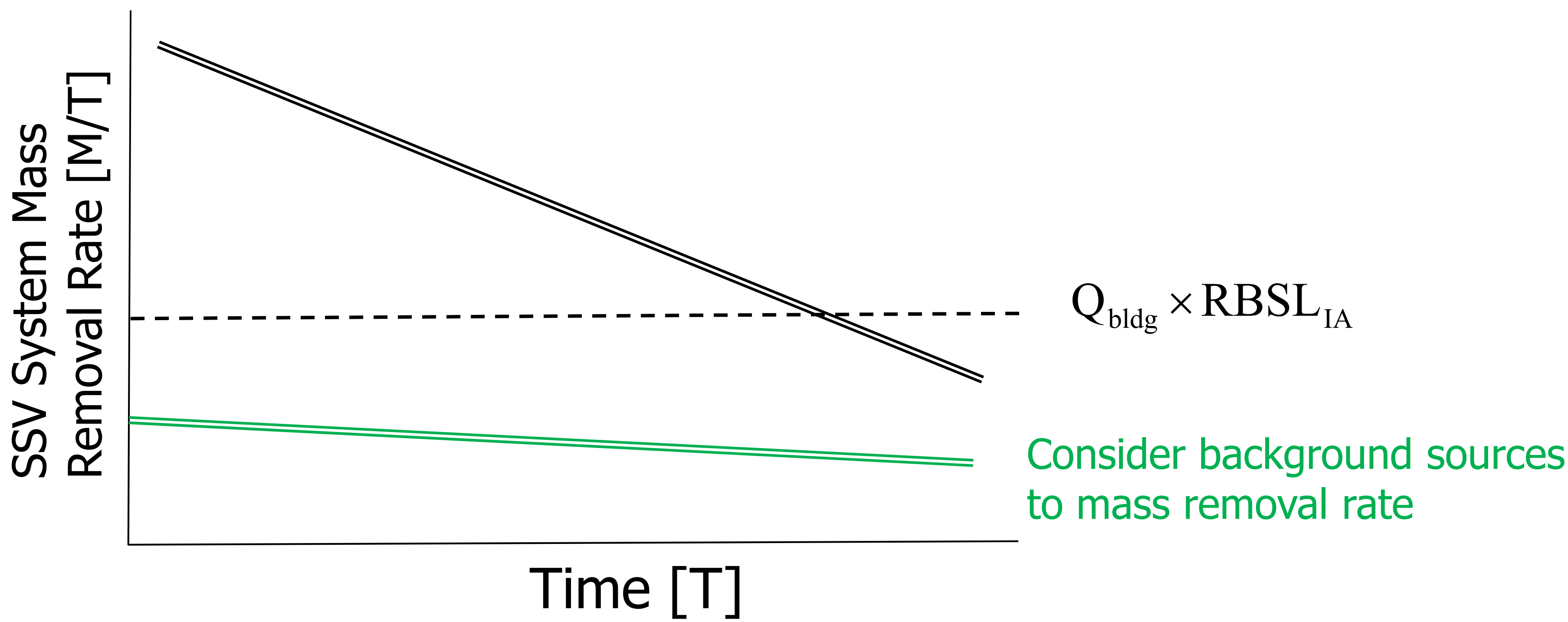
# Optimization Strategy

Measure vent-pipe mass removal rate at different flow rates
Optimize SSV extraction rate to "capture" available vapors



# Exit Strategy

Monitor SSV system mass removal rate over time
Compare to target building mass rate ($Q_{bldg}$ x $RBSL_{IA}$)
Consider rebound testing, similar to SVE systems



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# Take-Home Message

- There are several ways to monitor SSD/SSV systems
  - Vacuum ($\Delta$ P)
  - Venting rate (Q)
  - Flux (Q x C)
- We can reuse math hydrogeologists have used for decades
  - Pump tests, flow modeling, transport modeling, optimization
- Experience has shown comparable results at dozens of sites
  - Consistency in floor slab construction (see building codes)
- This allows us to answer some questions we couldn't before
  - Optimal number of suction points, flow rates
  - Exit strategy

# Questions/Comments?

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