Thank you for signing in early

The webinar will begin promptly at
12:00 pm ET, 9:00 am PT

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SERDP and ESTCP Webinar Series

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- Two options for accessing the webinar audio
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    - (669) 900-6833 or (929) 205-6099
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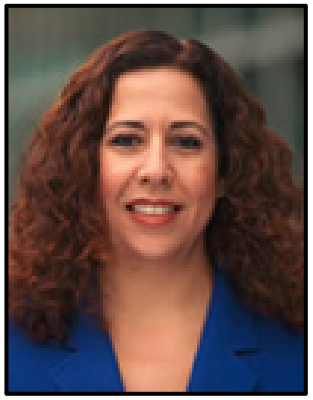
SERDP & ESTCP Webinar Series

Vapor Intrusion: Modeling Tools and Cost-Effective Mitigation

July 11, 2019

SERDP DOD • EPA • DOE | ESTCP

Welcome and Introductions



Rula A. Deeb, Ph.D.
Webinar Coordinator

SERDP DOD • EPA • DOE | ESTCP

Webinar Agenda

- **Webinar Logistics** (5 minutes)
  Dr. Rula Deeb, Geosyntec Consultants
- **Overview of SERDP and ESTCP** (5 minutes)
  Dr. Robin Nissan, SERDP and ESTCP
- **Understanding Transients in Vapor Intrusion** (25 minutes + Q&A)
  Dr. Eric Suuberg, Brown University
- **New Tools for Radon and Volatile Organic Compound Vapor Intrusion Mitigation** (25 minutes + Q&A)
  Dr. Todd McAlary, Geosyntec Consultants, Inc.
- **Final Q&A session**

In Case of Technical Difficulties

- Use a compatible browser (Firefox, IE or Edge)
- If material is not showing on your screen or if screen freezes
  - Key in Ctrl + F5 to do a hard refresh of your browser
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  - Click the arrow next to the "*Join Audio*" button
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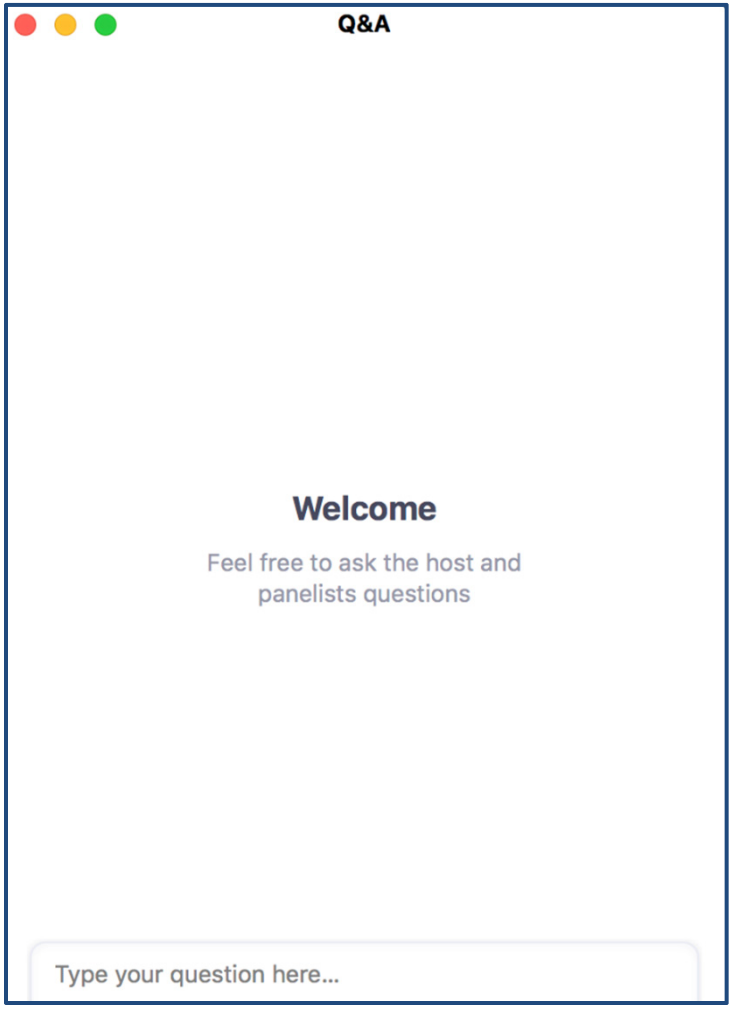
- Find the Q&A button on your control bar and type in your question(s)
- Make sure to add your organization name at the end of your question so that we can identify you during the Q&A sessions



SERDP and ESTCP Overview

Robin Nissan, Ph.D.
SERDP and ESTCP

SERDP
DOD • EPA • DOE

ESTCP

SERDP

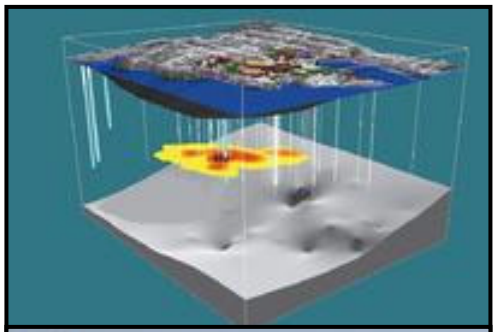
- Strategic Environmental Research and Development Program
- Established by Congress in FY 1991
  - DoD, DOE and EPA partnership
- SERDP is a requirements driven program which identifies high-priority environmental science and technology investment opportunities that address DoD requirements
  - Advanced technology development to address near term needs
  - Fundamental research to impact real world environmental management

ESTCP

- Environmental Security Technology Certification Program
- Demonstrate innovative cost-effective environmental and energy technologies
  - Capitalize on past investments
  - Transition technology out of the lab
- Promote implementation
  - Facilitate regulatory acceptance

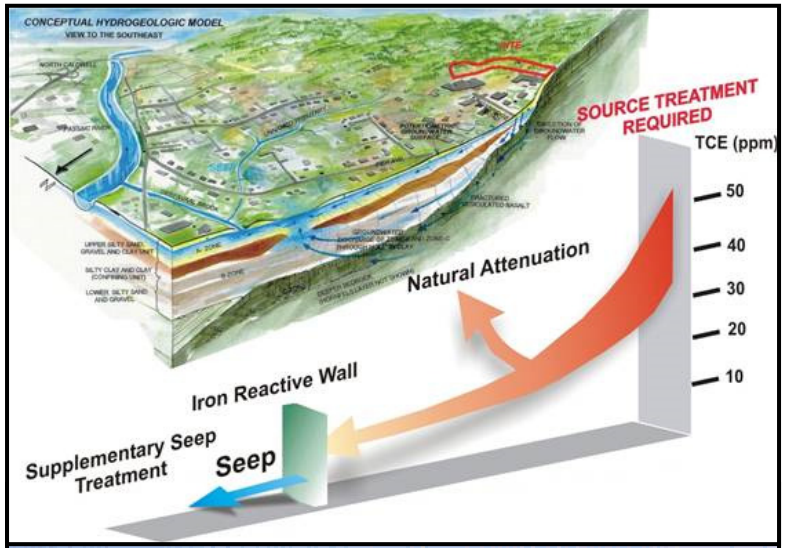
Program Areas

1. Environmental Restoration
2. Installation Energy and Water
3. Munitions Response
4. Resource Conservation and Resiliency
5. Weapons Systems and Platforms



Environmental Restoration

- Major focus areas
  - Contaminated groundwater
  - Contaminants on ranges
  - Contaminated sediments
  - Wastewater treatment
  - Risk assessment



SERDP and ESTCP Webinar Series

Date	Topic
July 25, 2019	Understanding Underwater Munitions Mobility and Behavior on the Beach Face and in Shallow Muddy Environments
August 8, 2019	Building Energy and Water Efficiency Solutions
August 22, 2019	Pacific Island Ecology and Management: Recovery of Native Plant Communities
September 5, 2019	The Use of Advanced Molecular Biological Tools in Groundwater Contaminated with Chlorinated Solvents
September 19, 2019	Life Cycle Assessment and Developmental Environment Safety and Occupational Health Evaluation: Tools for Sustainment and Health

For upcoming webinars, please visit

http://serdp-estcp.org/Tools-and-Training/Webinar-Series

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Save the Date!

SERDP • ESTCP
SYMPOSIUM

A three-day symposium showcasing the latest technologies that enhance DoD's mission through improved environmental and energy performance

December 3-5, 2019

Washington Marriott Wardman Park

Registration is open

Understanding Transients in Vapor Intrusion

Eric M. Suuberg, Ph.D.
Brown University

SERDP DOD • EPA • DOE | ESTCP

Agenda

- Benefits to DoD
- Large variations in vapor intrusion-induced indoor air concentrations
- Statistical analysis and modeling tools
- Site investigation techniques
- Conclusions

Background

- Vapor intrusion – a common problem throughout the world
- Impacts DoD and non-DoD sites
- Vaporization of leaked/spilled contaminants in ground or ground water
- Vapors enter buildings on contaminated sites – long term exposure risk
- Low concentrations matter, but what is the right way to characterize the hazard?

Benefits to DoD

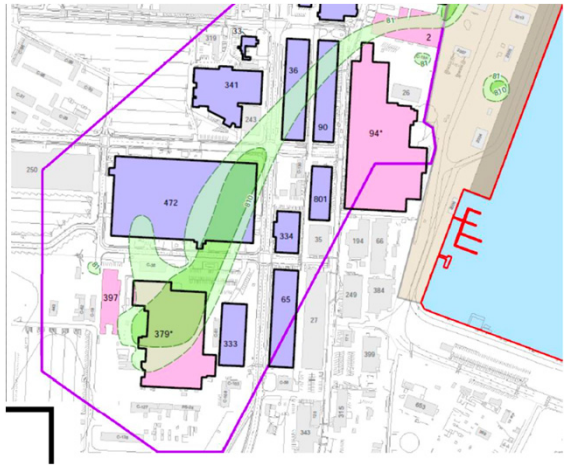
- Mathematical modeling tools
  - Relatively inexpensive
  - Provide a powerful “line of evidence” to understand complex field results
- Identify conditions that can be expected to lead to large temporal variations in observed indoor air concentrations
- Improve site investigations and sampling

Sites Considered

Extensive Temporal Concentration Data Collected

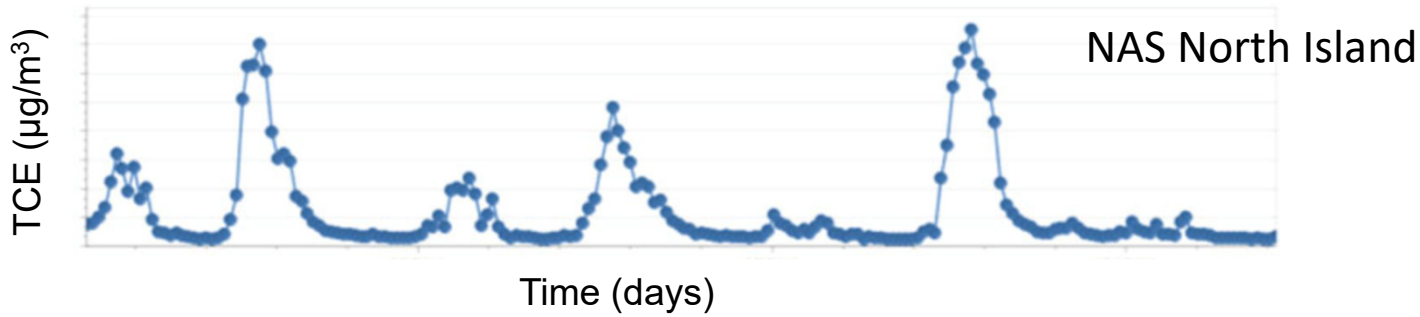
Arizona State University House, Hill AFB, Utah

EPA Indianapolis House (IN)

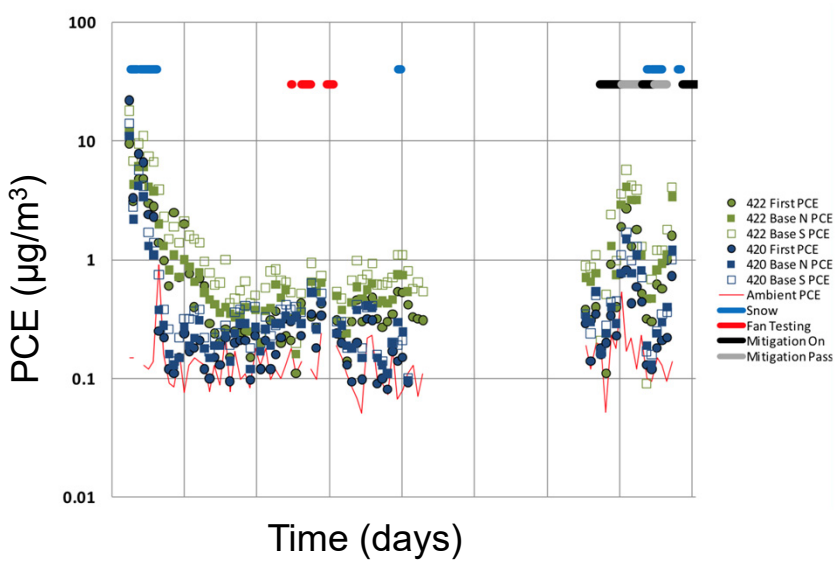


Naval Air Station North Island Coronado (SD), CA

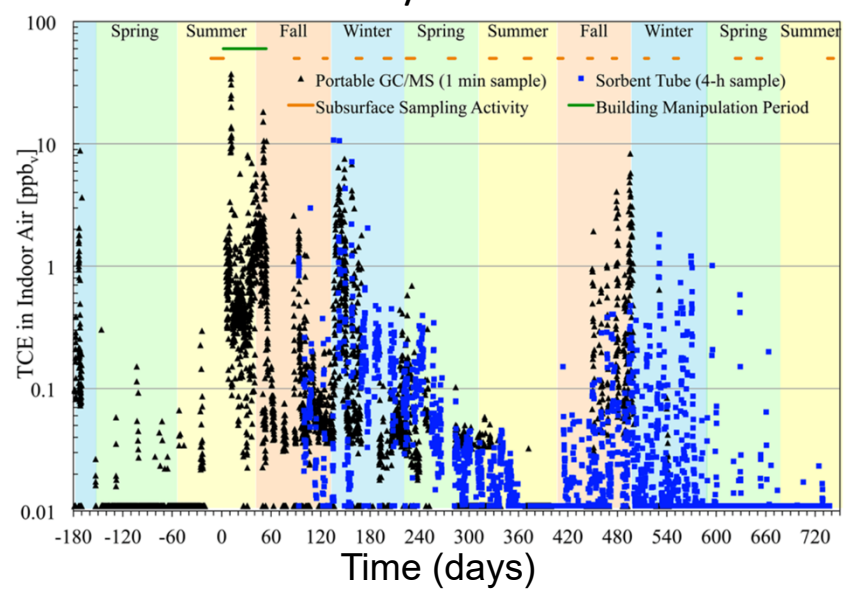
Examples of Transients



Indianapolis

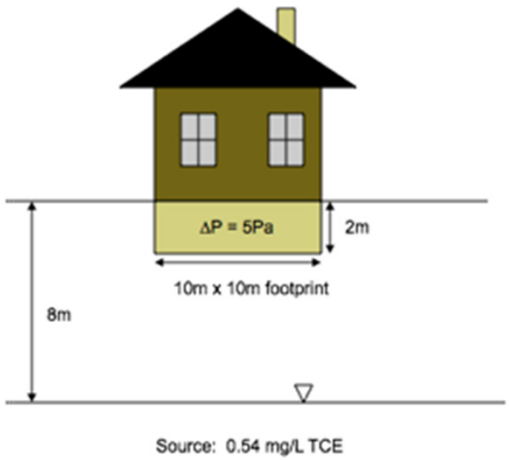


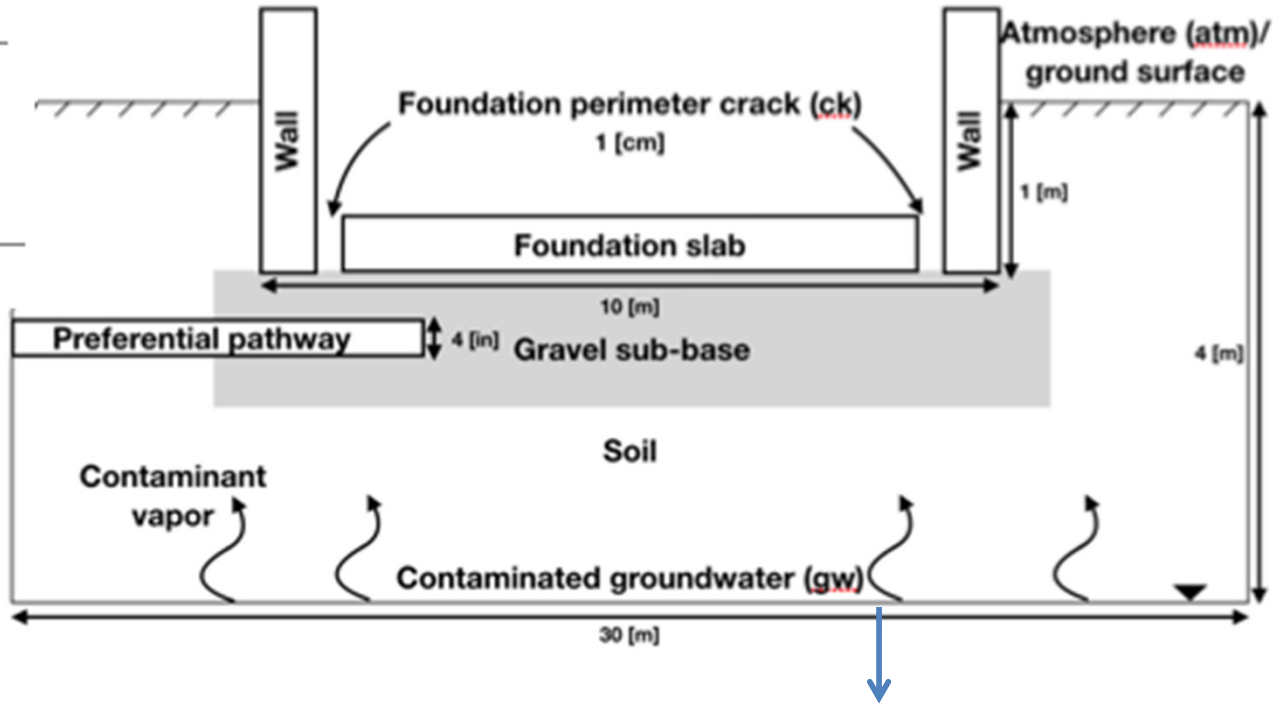
ASU/Hill AFB



Hosangadi et al., Remediation, 2017; Schumacher et al, AEHS, 2013; Holton et al., EST, 2013

Can a Mathematical Model of VI Explain Such Data?





Can a Mathematical Model of VI Explain Such Data?

3-step solution method (finite element)

$$q = \frac{-\kappa\rho}{\mu}\nabla\phi$$

$$\phi = gz + \int_{Po}^{P}\frac{dP}{\rho}$$

Darcy's Law

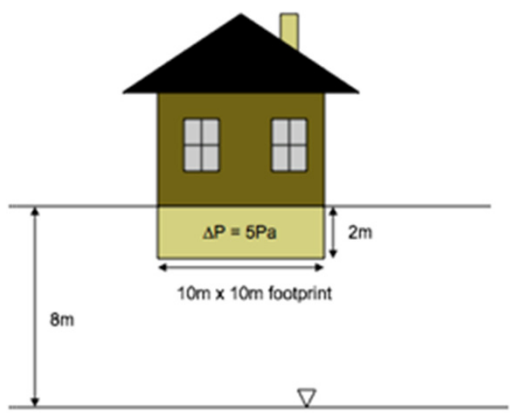
$$J_T = q \cdot C + D_{ig}\nabla C$$

$$D_{ig} = d_i^{air} \cdot \frac{\eta_g^{10/3}}{\eta_T^{2}}$$

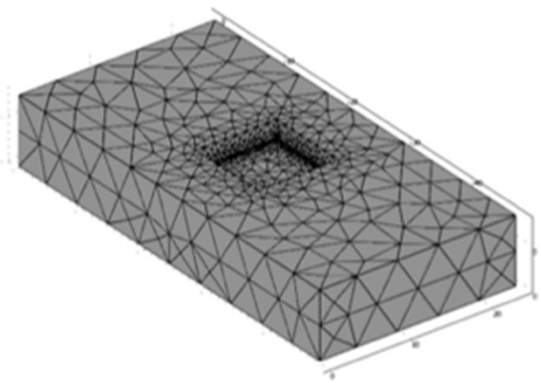
Species Transport

$$C_{indoor} = \frac{J_{Tck}}{A_e \cdot V_b + Q_{ck}}$$

Calculate Indoor Air



Source: 0.54 mg/L TCE



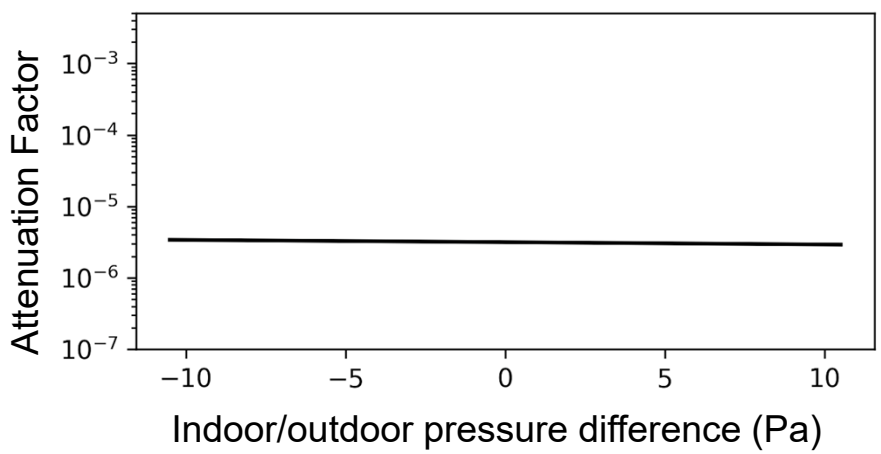
Mesh the domain

Preferential Pathways Do Matter

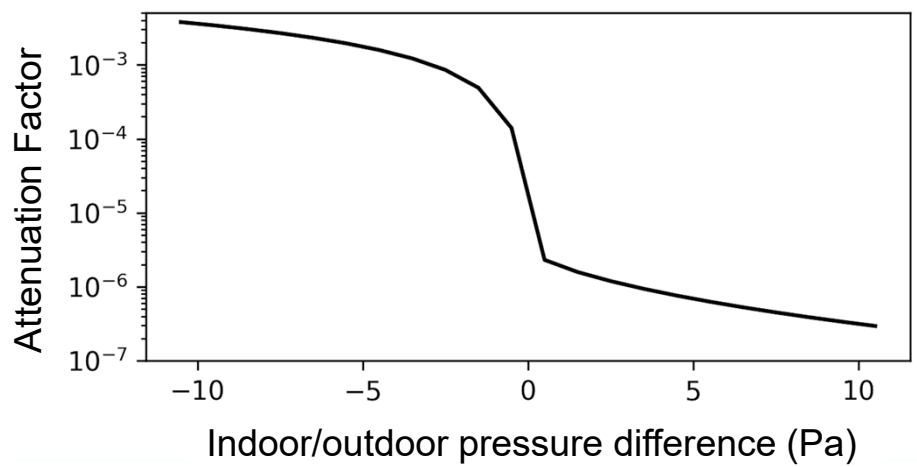
But How Much?

Predictions for a house with a gravel sub-base over clay soil

- No preferential pathway
- Preferential pathway entering gravel sub-base



Diffusion limits transport of contaminant to gravel



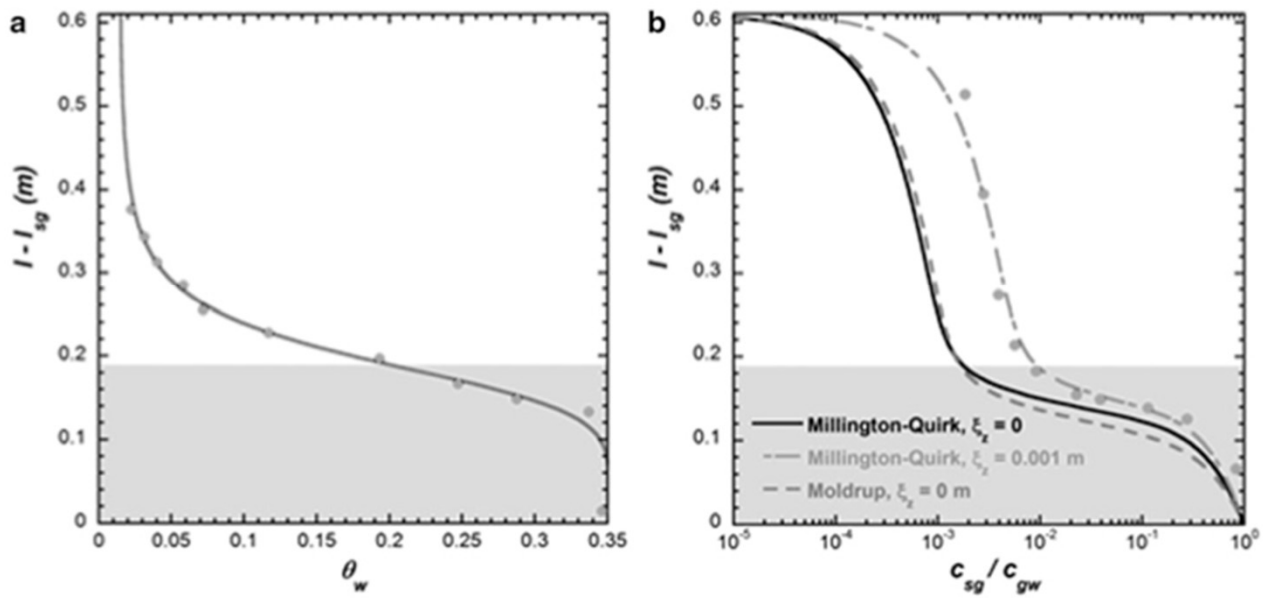
Pressure driving force

Notes: Attenuation Factor = C indoor/C source

Mathematical Models

Complicated Interplay of Factors Governing VI

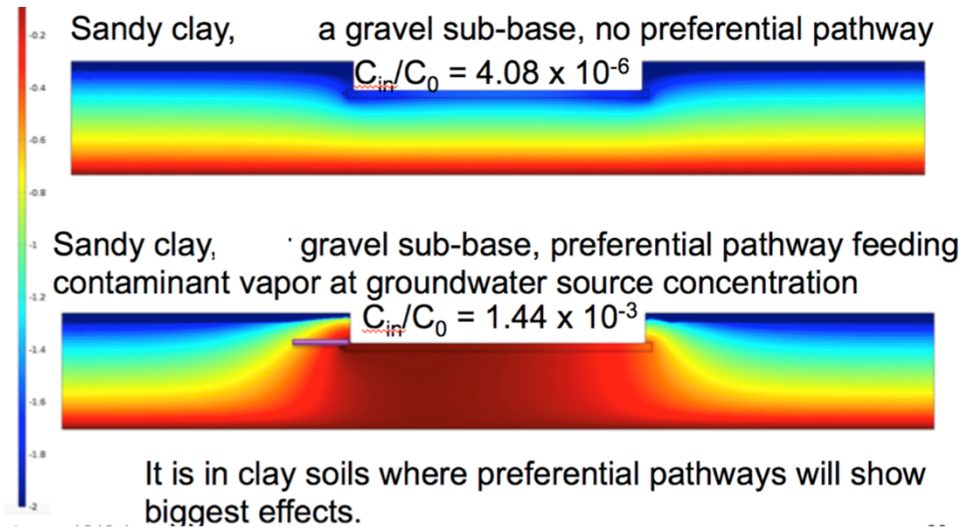
- Example: The effect of the capillary zone on reducing soil vapor concentrations



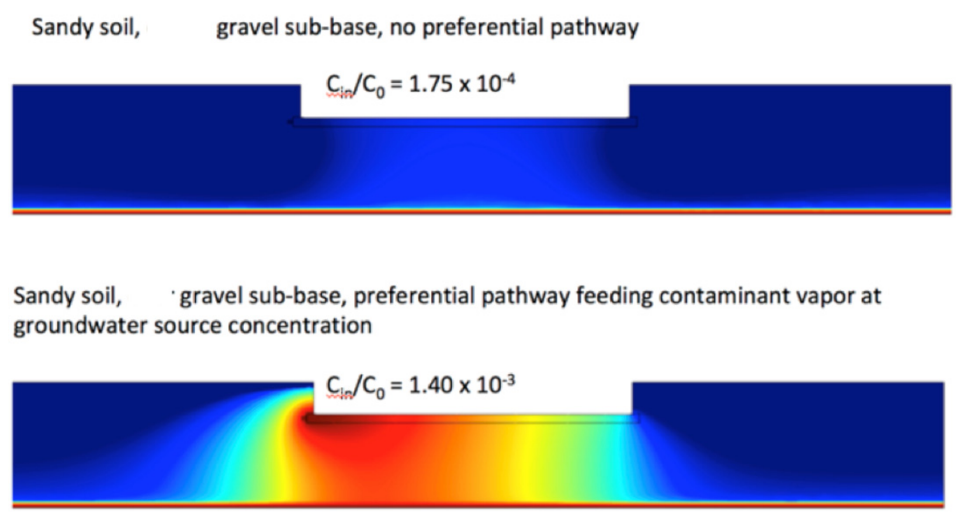
Two order of magnitude reduction in contaminant concentration, compared with Henry's Law prediction

Shen et al., Env. Eng. Sci., 2013

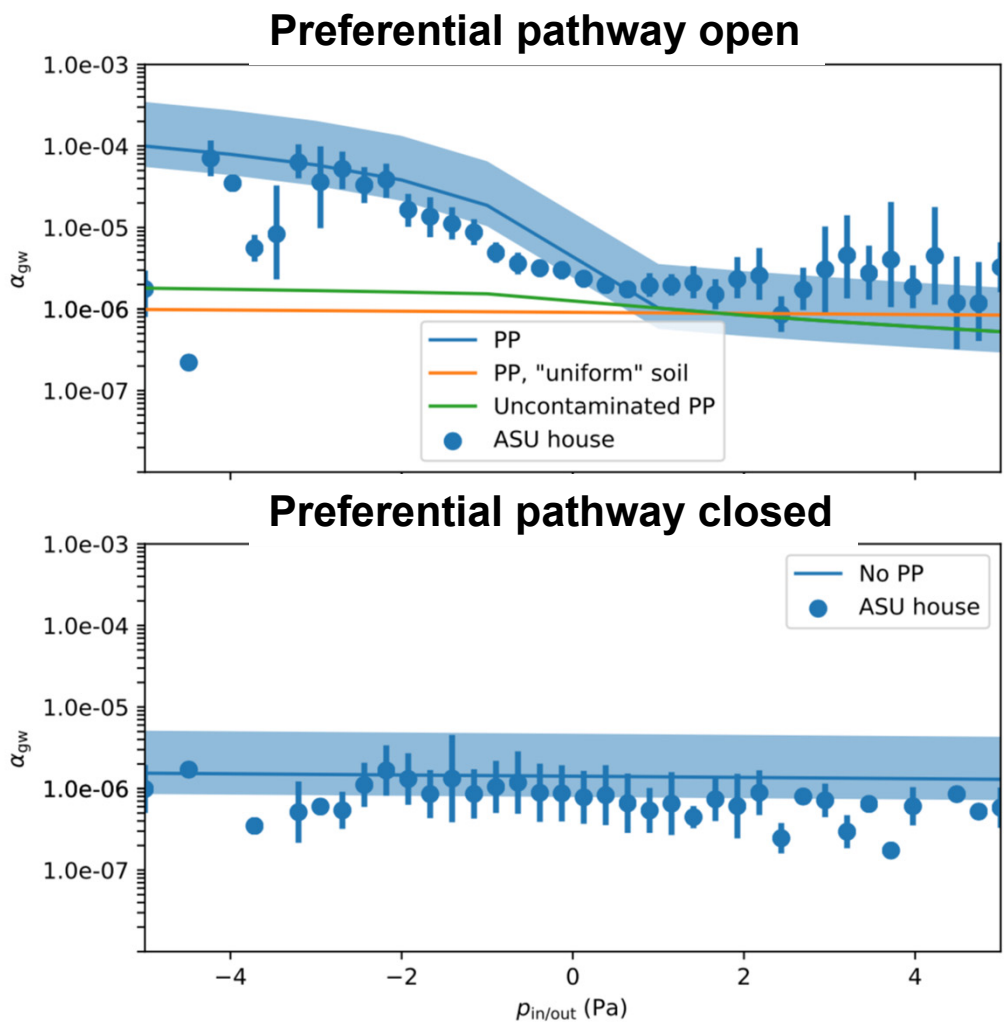
Surrounding Soils Make a Difference



It is in clay soils where preferential pathways will show biggest effects.

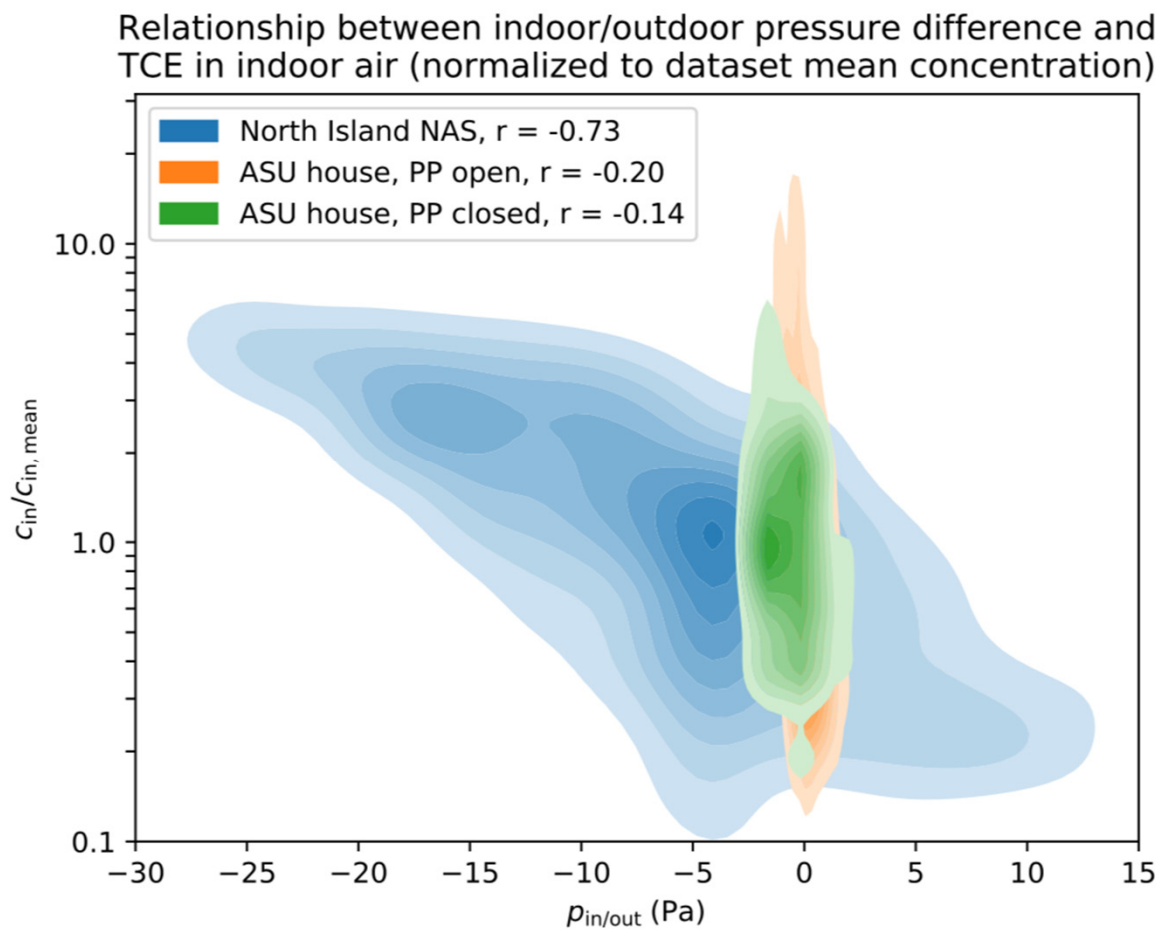


Understanding Real Field Data



Notes: Predictions for a site that is comparable to the ASU site in size and source depth

Other Factors Driving Variability (e.g., NAS North Island)



NAS North Island

Not a preferential pathway site

- How can one explain the comparably great variations in indoor air concentrations reported at NAS North Island, when there is no preferential pathway?
- Statistical analysis of the raw data set explains the difference
  - The pressure driving force is much greater at NAS North Island

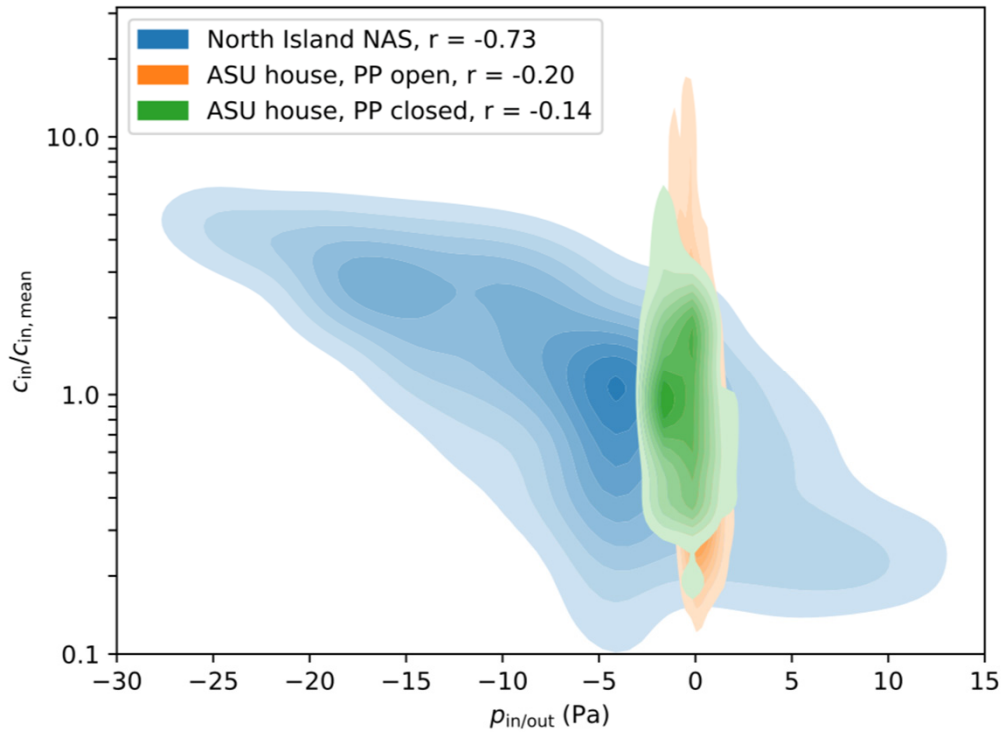
Modeling Inputs Needed

- The above results will not necessarily be apparent from simple regressions
- Modeling showed that subsurface geology determines the role of advection and the steepness of subsurface contaminant gradients
- During investigation need to capture details that determine advective and diffusion potential of the site

ASU House Results

Small pressure driving force, but large variation

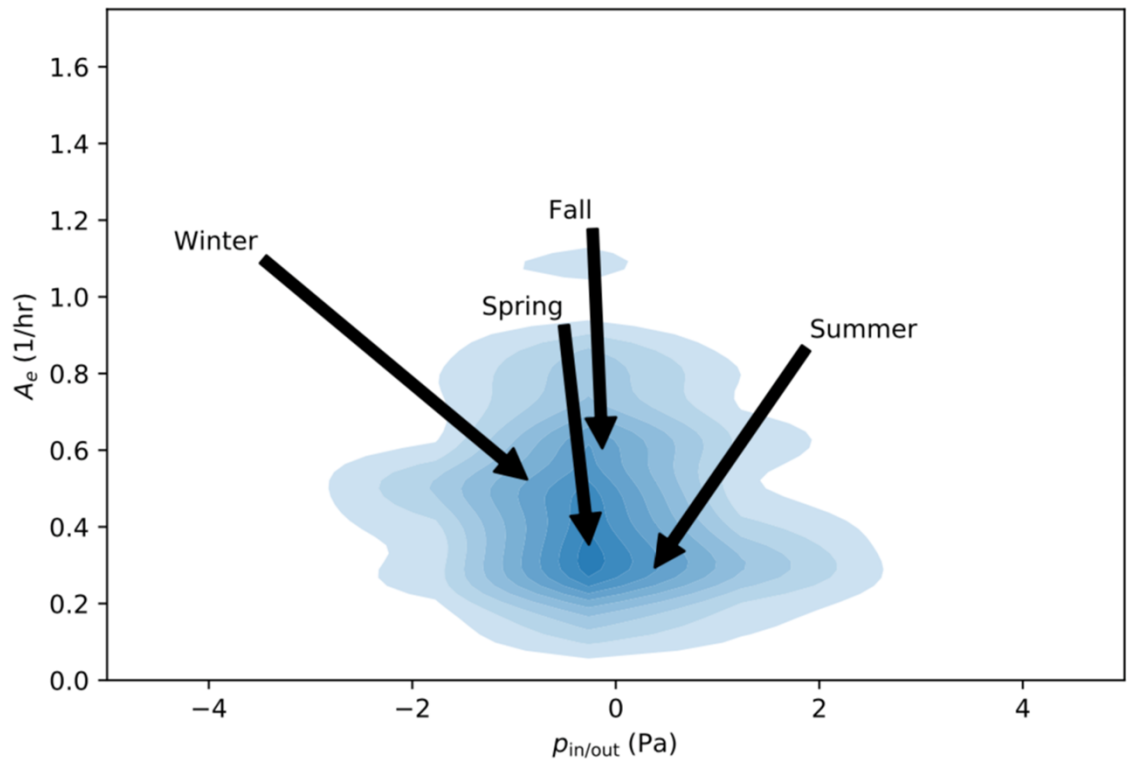
Relationship between indoor/outdoor pressure difference and TCE in indoor air



Why are there large variations when pressure driving force varies so little?

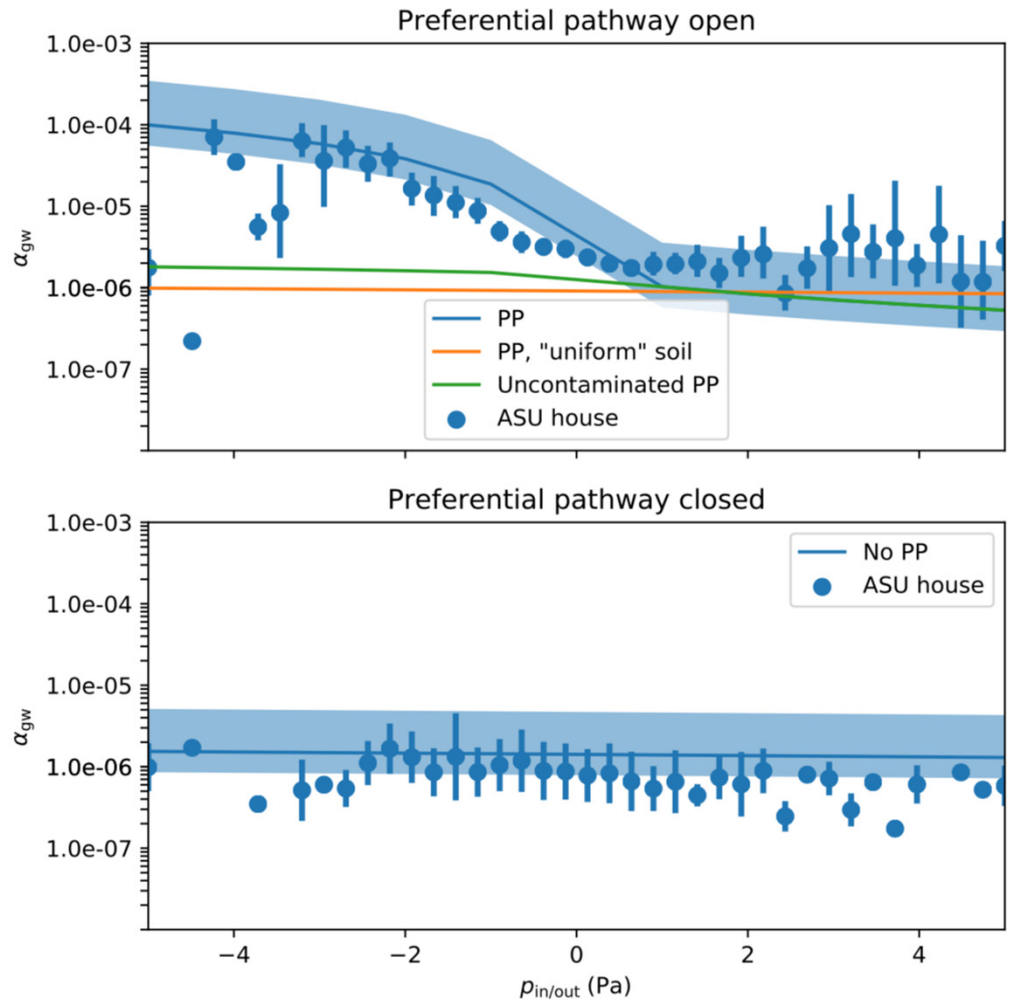
ASU House Results

- There exist distributions of air exchange rate superimposed on pressure driving force



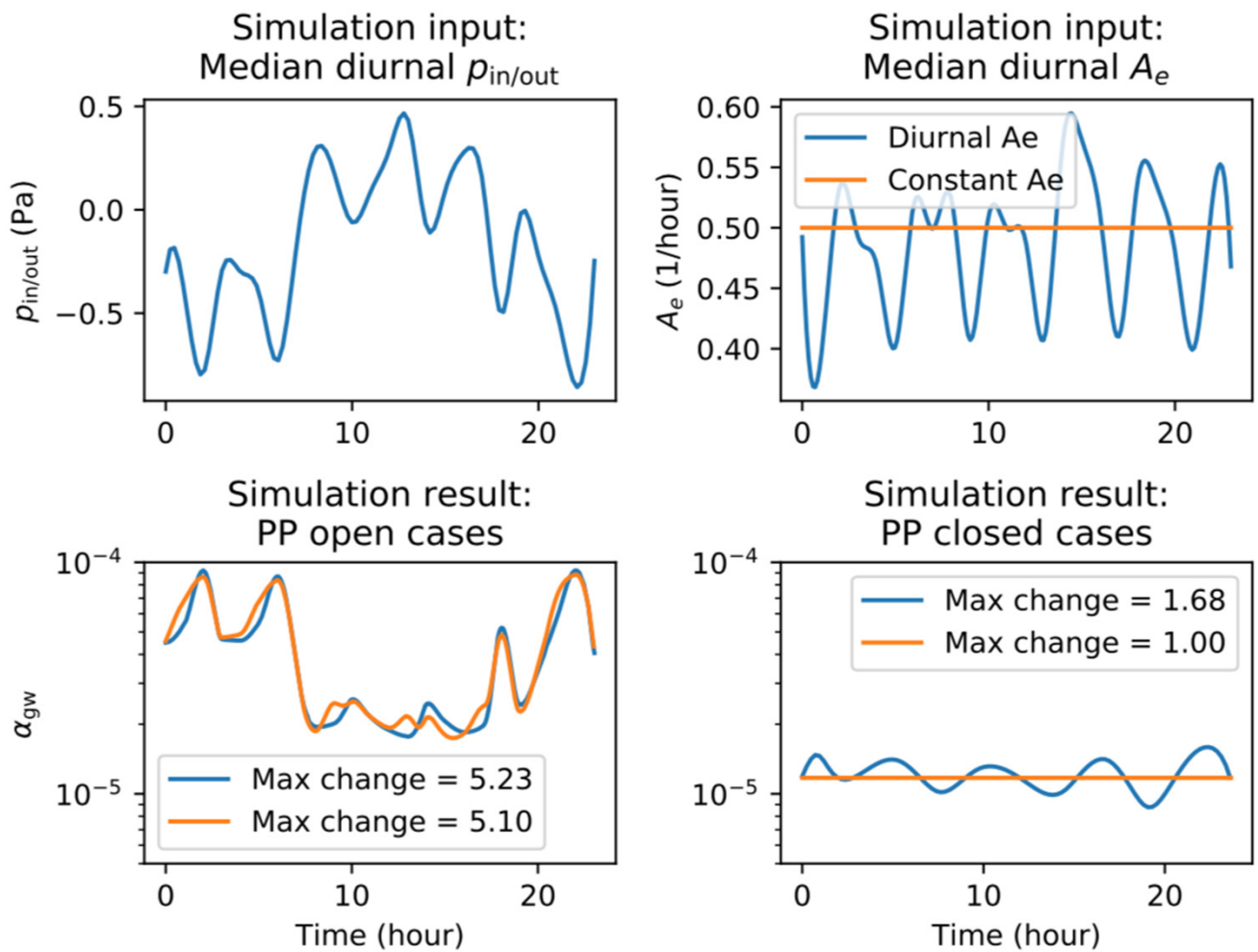
ASU House Results

Showing effect of air exchange rates



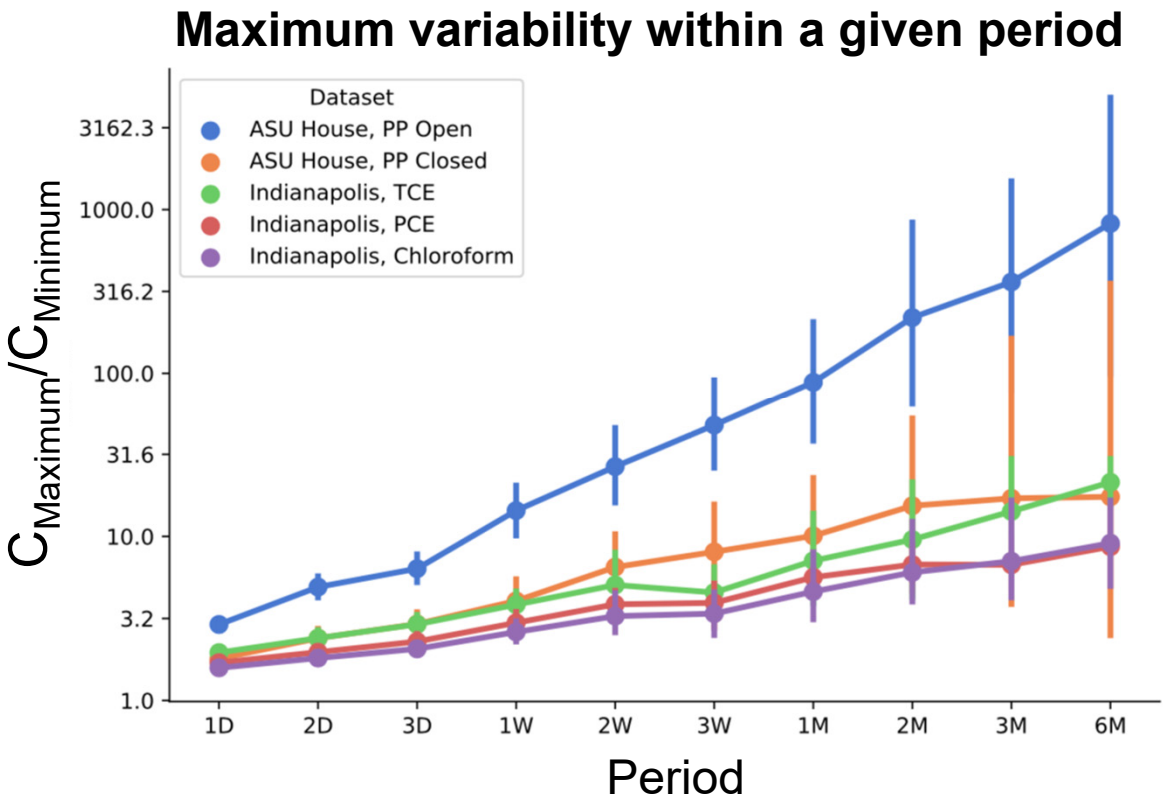
Note: Blue bands indicate the influence of air exchange rate variations

Influence of Air Exchange Rate Fluctuations



Implications for Sampling Indoor Air

- Analysis of actual field data from ASU House and Indianapolis House



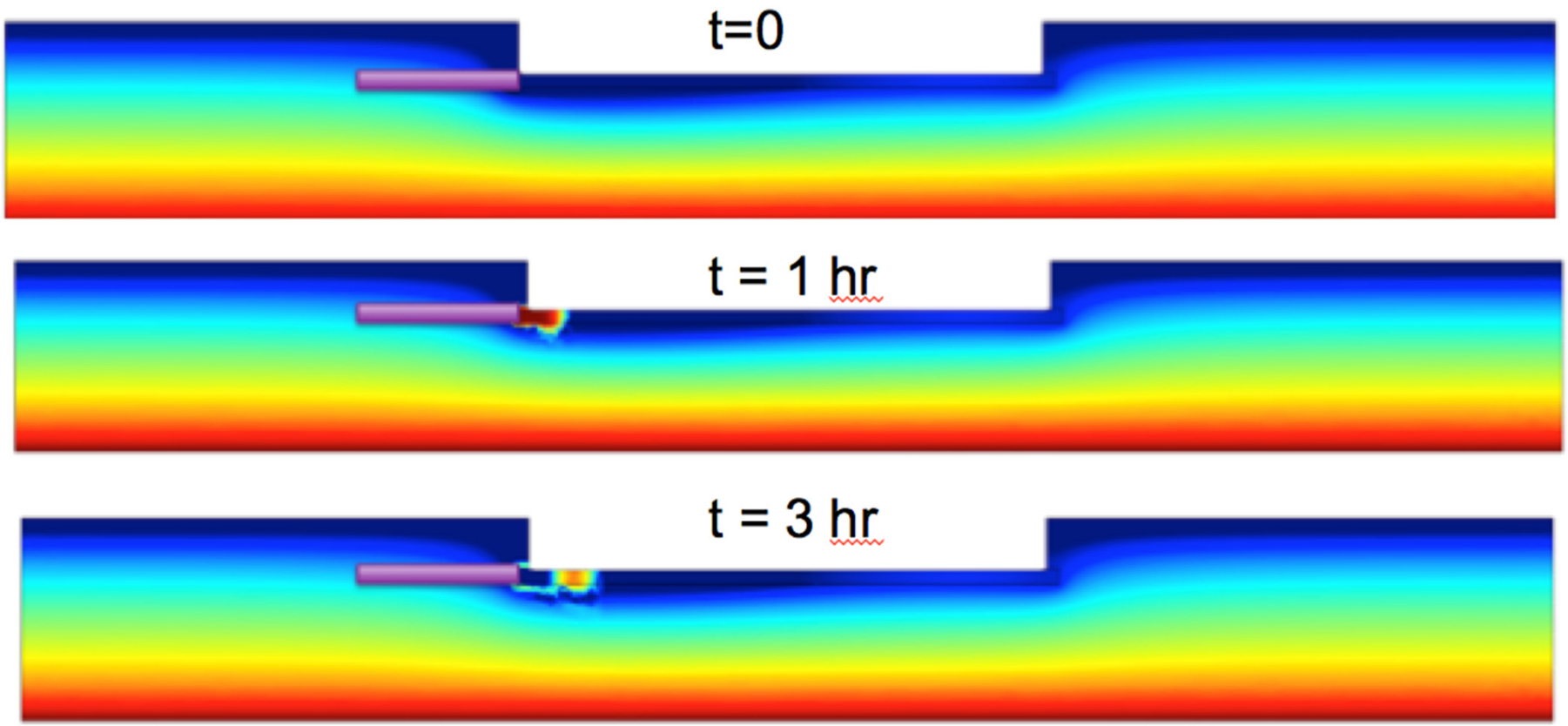
Implications for Sampling Indoor Air

- Suggests 1-day sampling interval will likely result in less than 2-3 factor difference
- Differences of an order of magnitude are typically detected only at longer times (seasonality)

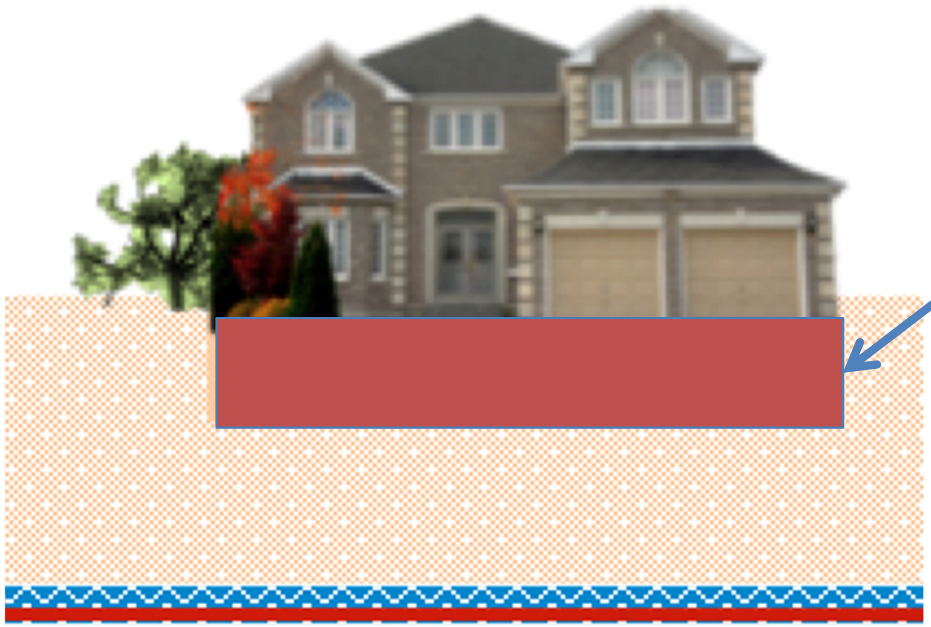
Non-Uniformity

Care needs to be exercised in sampling sub-slab

Transient simulation of an intermittent preferential pathway



Modeling Controlled Pressure Method (CPM) Depressurization



Groundwater Contaminant

Limited zone from which contaminant can be drawn before diffusion too slow to replace it

Modeling CPM Depressurization

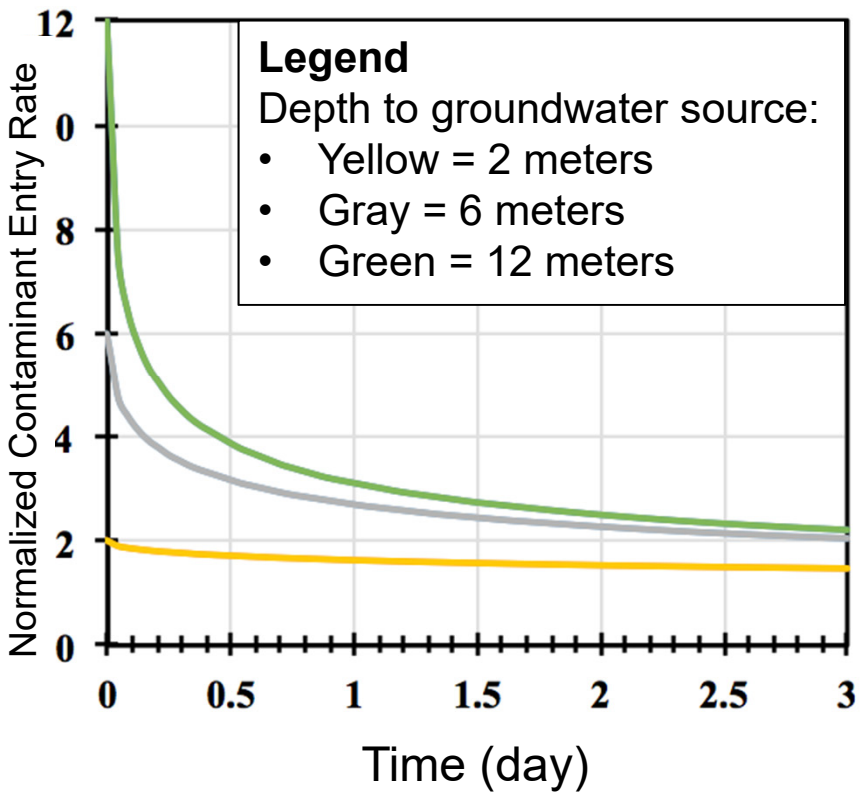
$$\frac{c(z,t)}{c_0} = 1 - \frac{Bi_2}{1+Bi_2}\frac{z}{L} + 2\frac{Bi_2 - Bi_1}{1+Bi_1}\sum \frac{1}{Bi_2^2 + \lambda_n^2 + Bi_2}\exp\left(-\lambda_n^2 \frac{D_e}{a} t\right)\frac{\sin(\lambda_n z)}{\sin(\lambda_n L)}$$

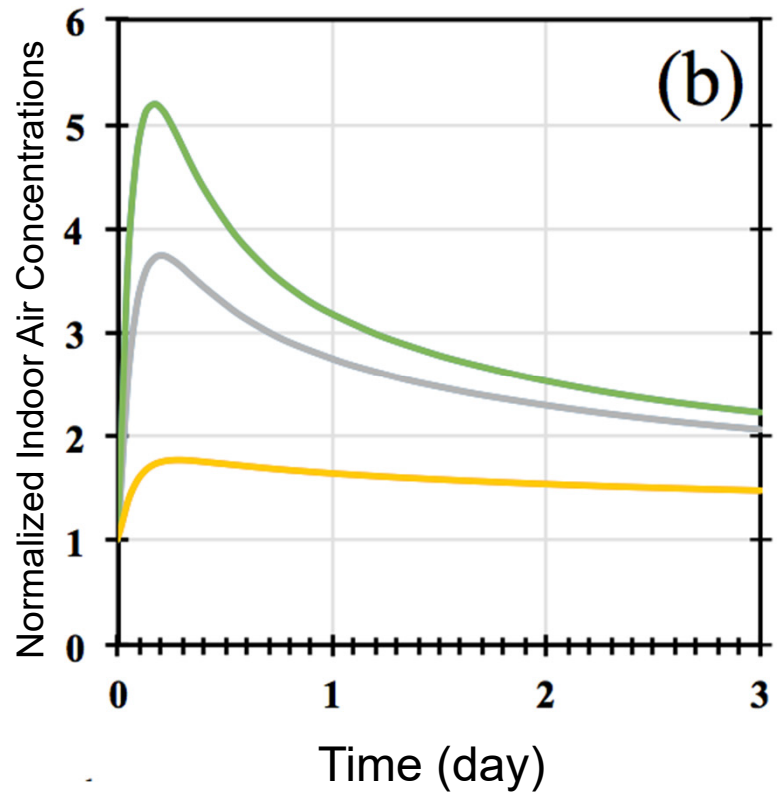
Z is the height above groundwater, 1 refers to the initial condition, 2 to a final steady state, and L is the height above groundwater of the slab, and

$$Bi = \frac{QL}{D_e A}$$

$$\tan(\lambda_n L) = -\frac{\lambda_n L}{Bi_2}$$

Typical Results





Significant transient aspect to predicted results relative to initial steady state

Conclusions

- Models of VI help identify non-obvious results that come from interplay of many factors
- Several order of magnitude transients are the result of “unusual” circumstances (e.g. preferential pathways or high advective driving forces)
- Models can help define effective field sampling strategies
- A combination of statistical analysis of field data with modeling can be a powerful tool for understanding real phenomena

For additional information, please visit
https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Emerging-Issues/ER-201502

Speaker Contact Information

Eric_Suuberg@brown.edu; 401-863-1420

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Q&A Session 1

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New Tools for Radon and VOC Vapor Intrusion Mitigation

Todd McAlary, Ph.D.
Geosyntec Consultants, Inc.

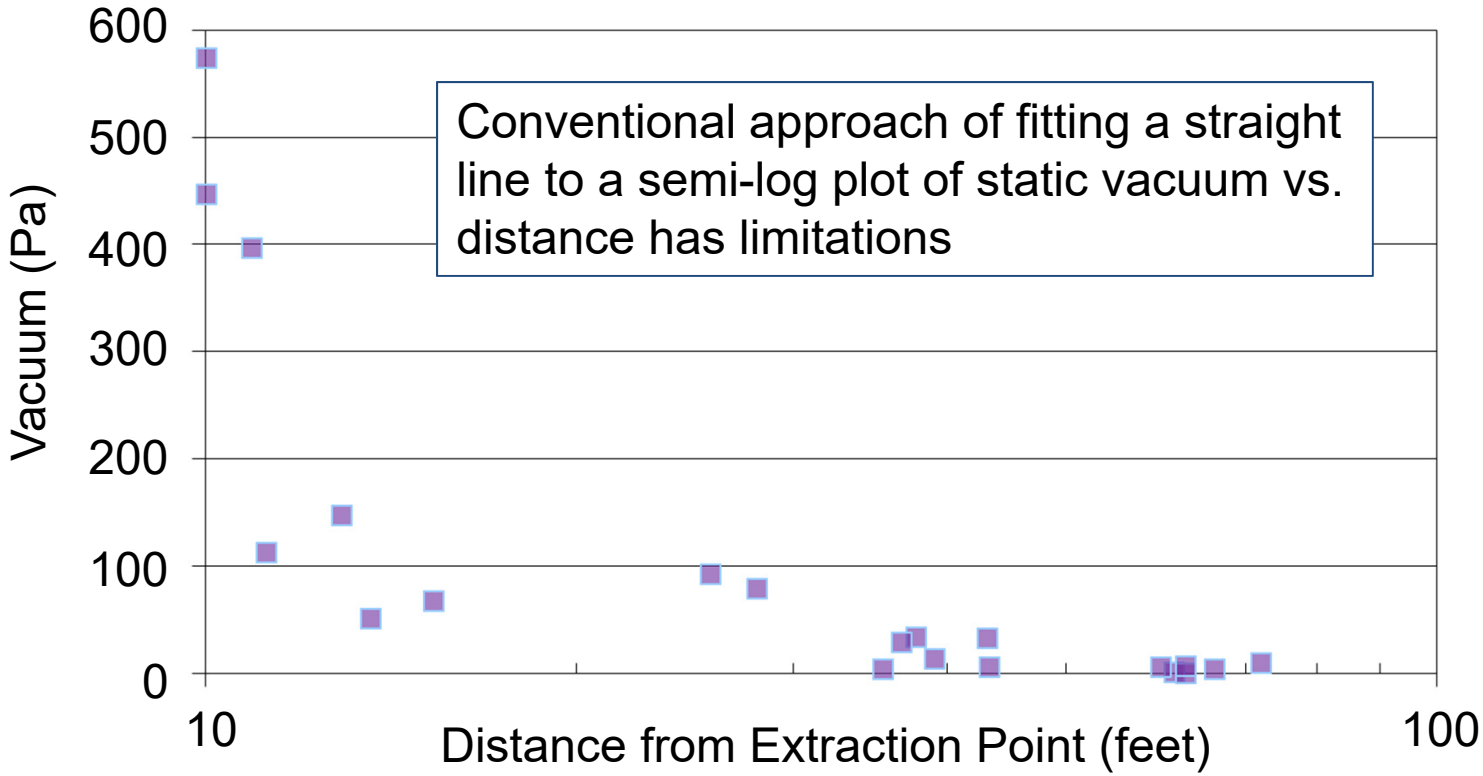
SERDP DOD • EPA • DOE | ESTCP

Agenda

- Research goals
- Scope and methods
- Mitigation optimization
- Spreadsheet model
- Building-specific attenuation factors
- Mass loading
- Preferential pathways
- Conclusions
- Benefits to DoD

Research Goals

- Develop new tools to improve mitigation system design and save money



Research Goals

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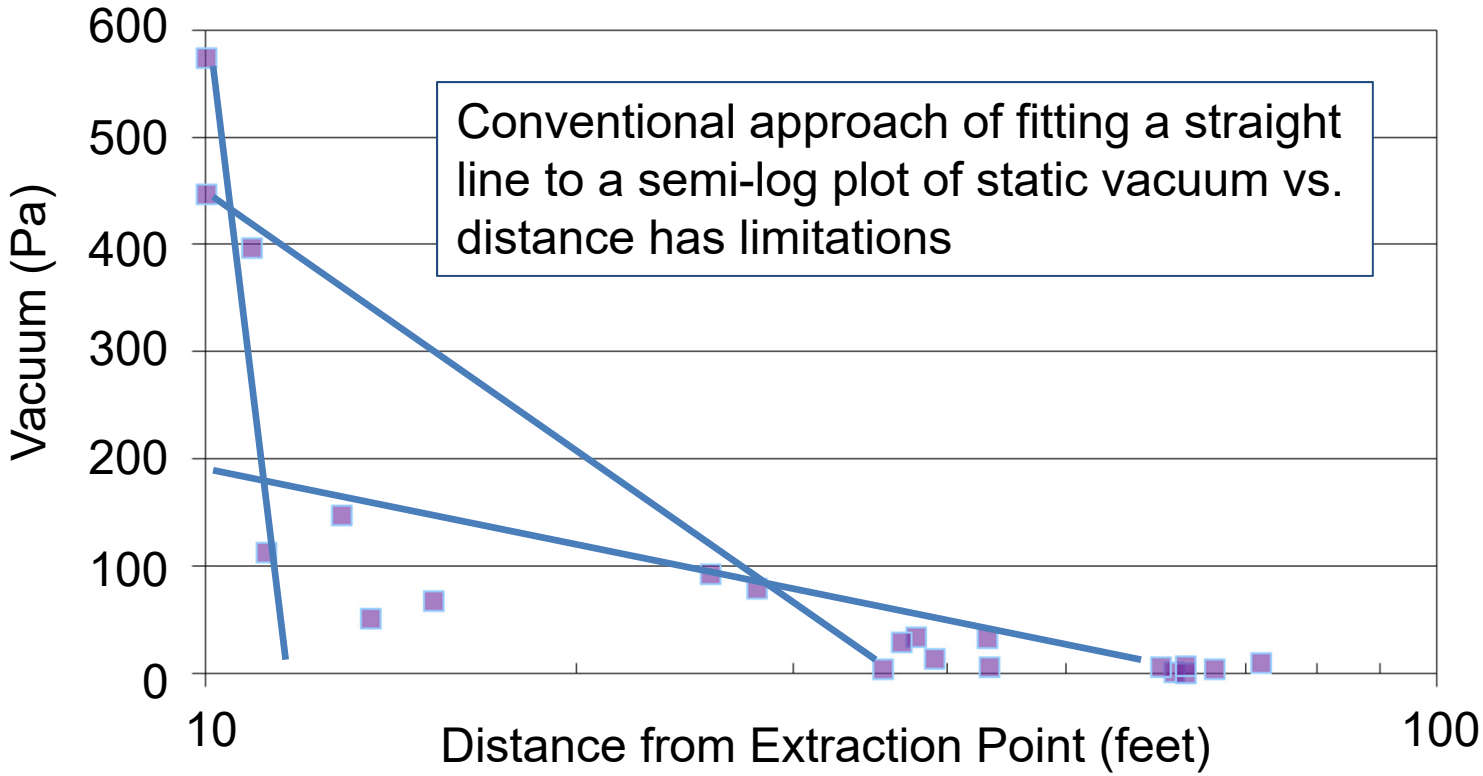
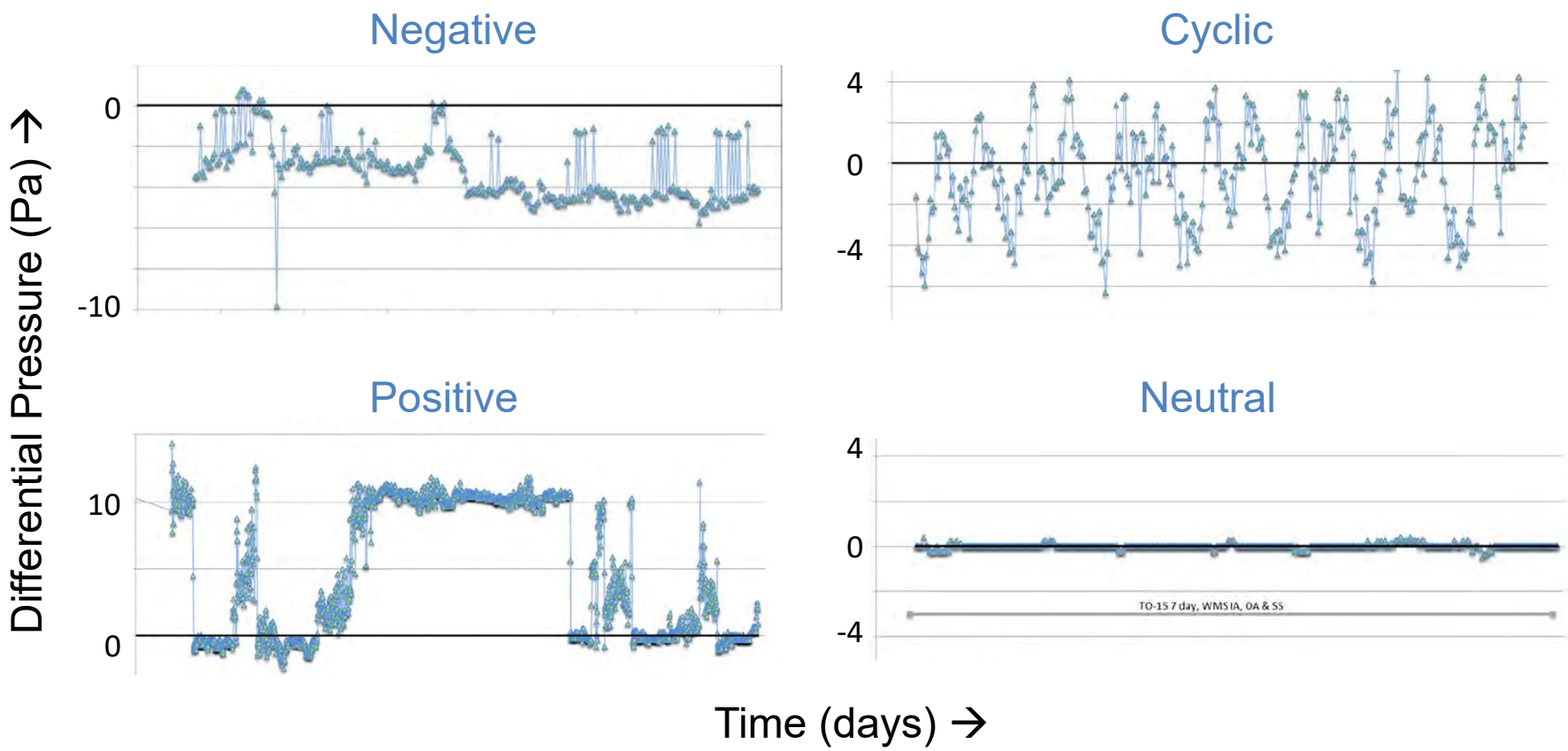
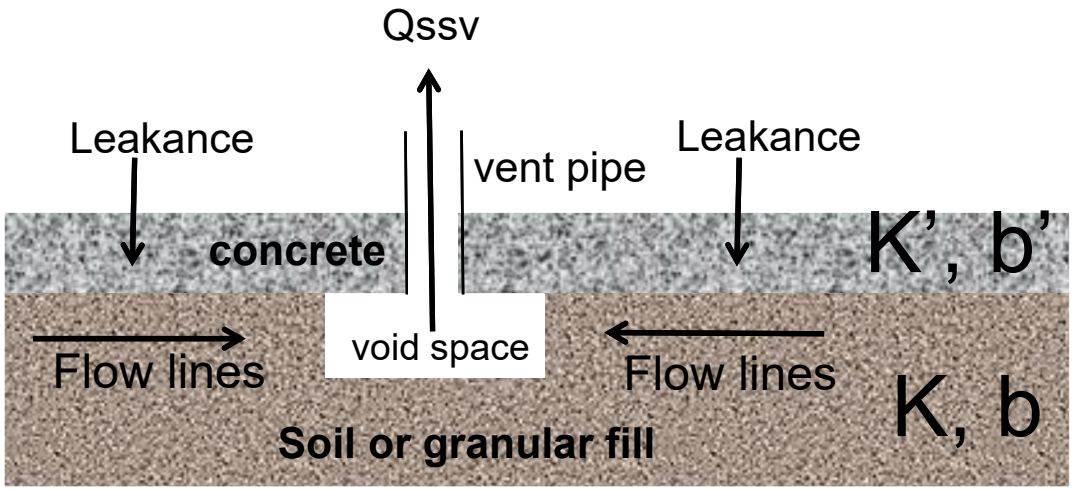


Baseline Building Pressure

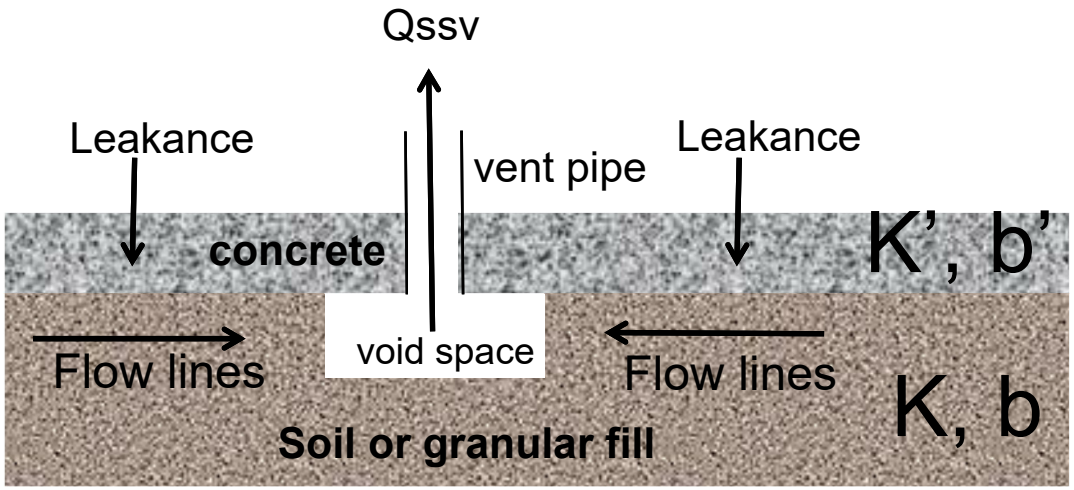


What "target vacuum" level is appropriate?

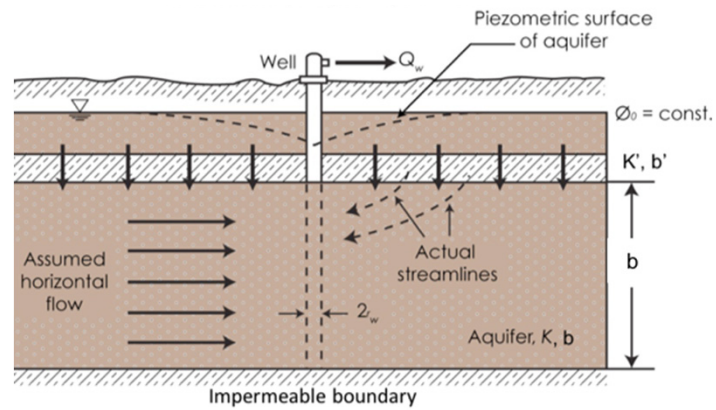
Conceptual Model



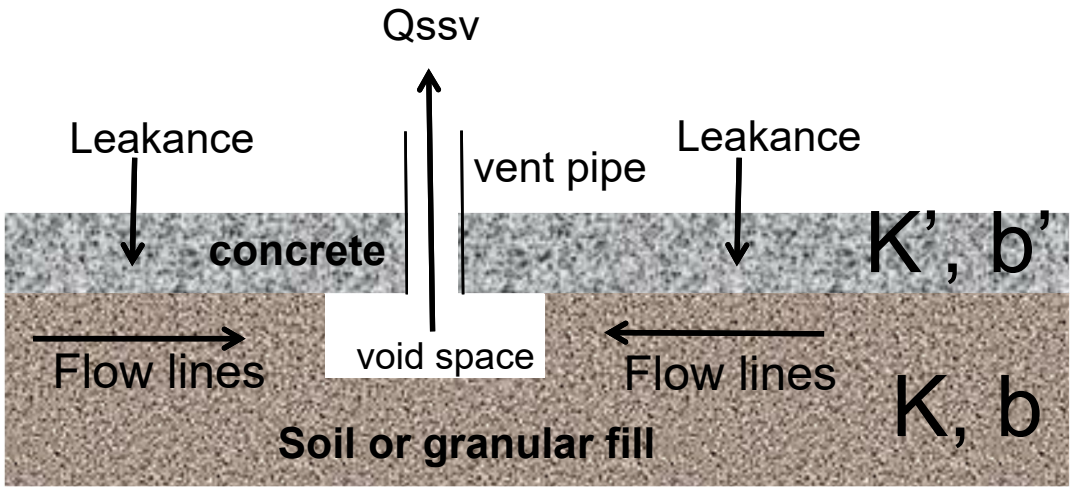
Conceptual Model



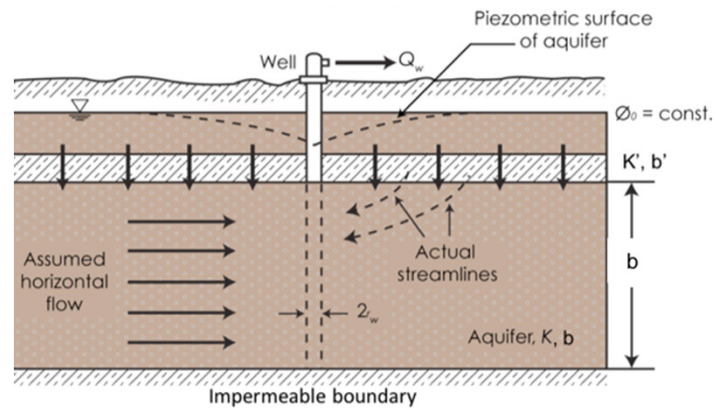
Hantush-Jacob Leaky Aquifer Model



Conceptual Model



Hantush-Jacob Leaky Aquifer Model



$$T = Kb$$

(T) = Transmissivity below the floor (ft^2/day)
(K) = gas conductivity (ft/day)
(b) = thickness (ft)

$$B = \sqrt{\frac{Tb'}{K'}}$$

(B) = Leakance (ft) (this parameter simplifies equations)

Source: Hantush, M.S. and C.E. Jacob, 1955. Non-steady radial flow in an infinite leaky aquifer, Am. Geophys. Union Trans., vol. 36, pp. 95-100

Mathematical Model

Vacuum versus distance:

$$\text{Vacuum} = \frac{Q_w}{2\,\pi\,T} K_0(r/B)$$

Velocity versus distance:

$$Velocity = \frac{Q_w}{2\,\pi\,b\,n} \frac{1}{B} K_1(r/B)$$

Travel time for sub-slab gas
From a given distance:

$$t_{travel} = \int \frac{\partial r}{v(r)}$$

Proportion of total flow
originating below the floor:

$$Q(r)/Q_w = \frac{r}{B} K_1(r/B)$$

Building-specific
attenuation factor:

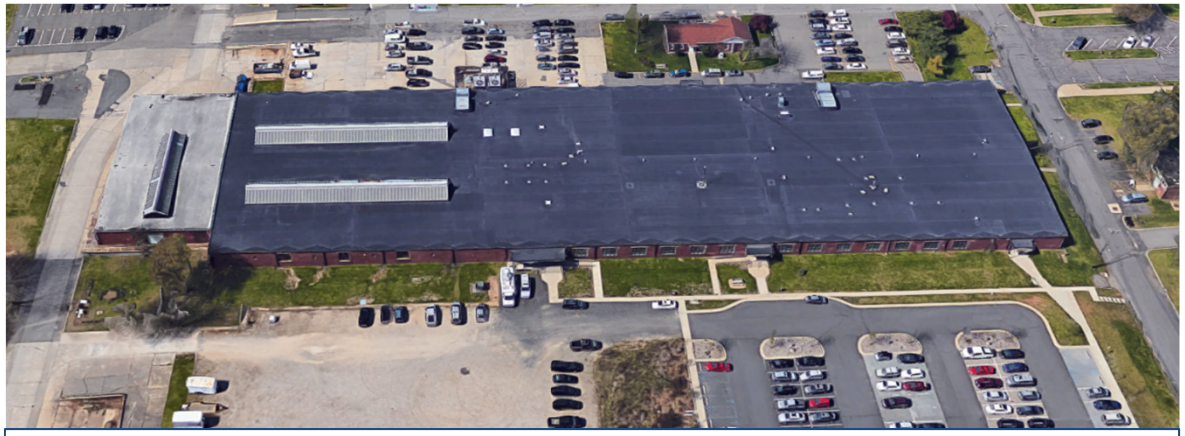
$$AF = \frac{Q_{soil}}{Q_{building}} = \frac{K'i\,A}{l\,w\,h\,AER} = \frac{\frac{Kbb'}{B^2}\frac{\Delta P}{b'}A}{A\,h\,AER} = \frac{T\,\Delta P}{B^2\,h\,AER}$$

Scope

Raritan Arsenal Building 200 (2,000 ft^2)

Vandenberg AFB Building 11193 (11,000 ft^2)

Sun Devil Manor (900 ft^2)



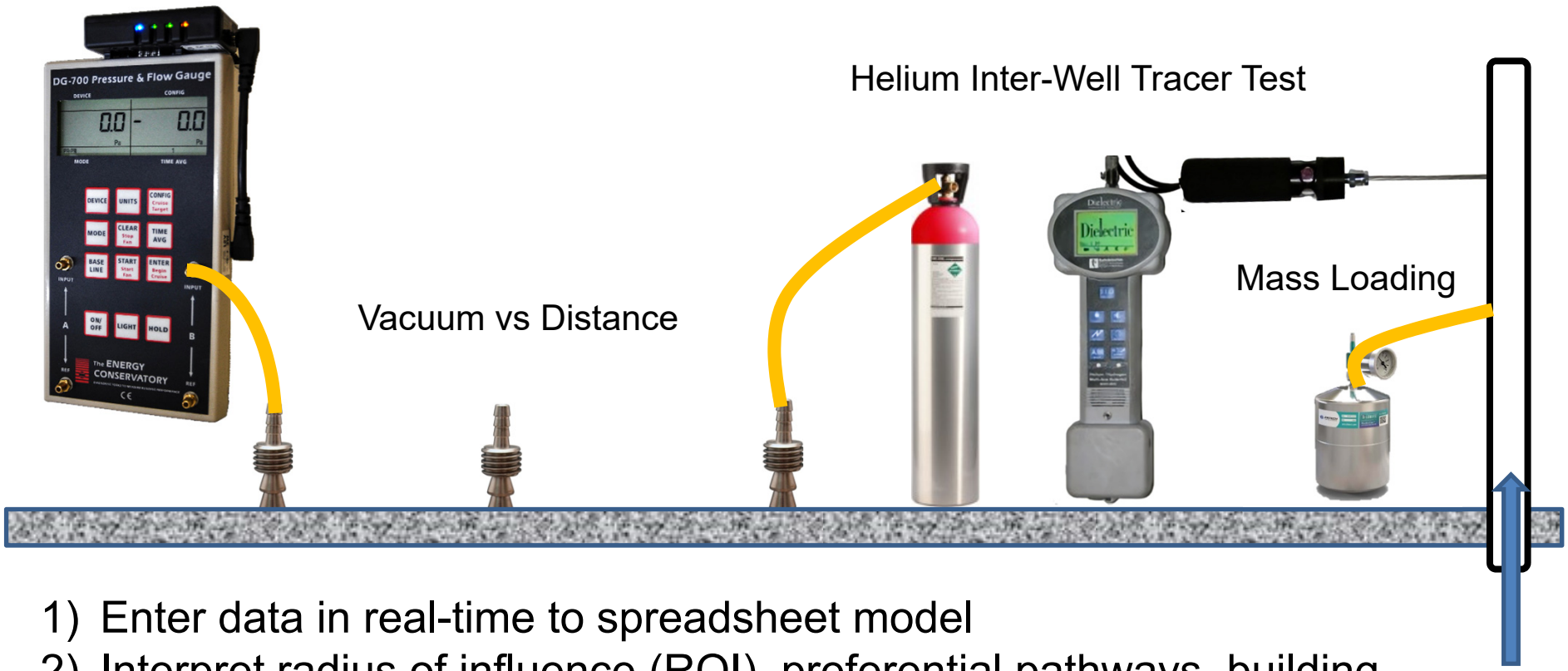
Raritan Arsenal Building 205 (64,000 ft^2)

Methods

Kit and protocols are essentially the same as an SVE pilot test

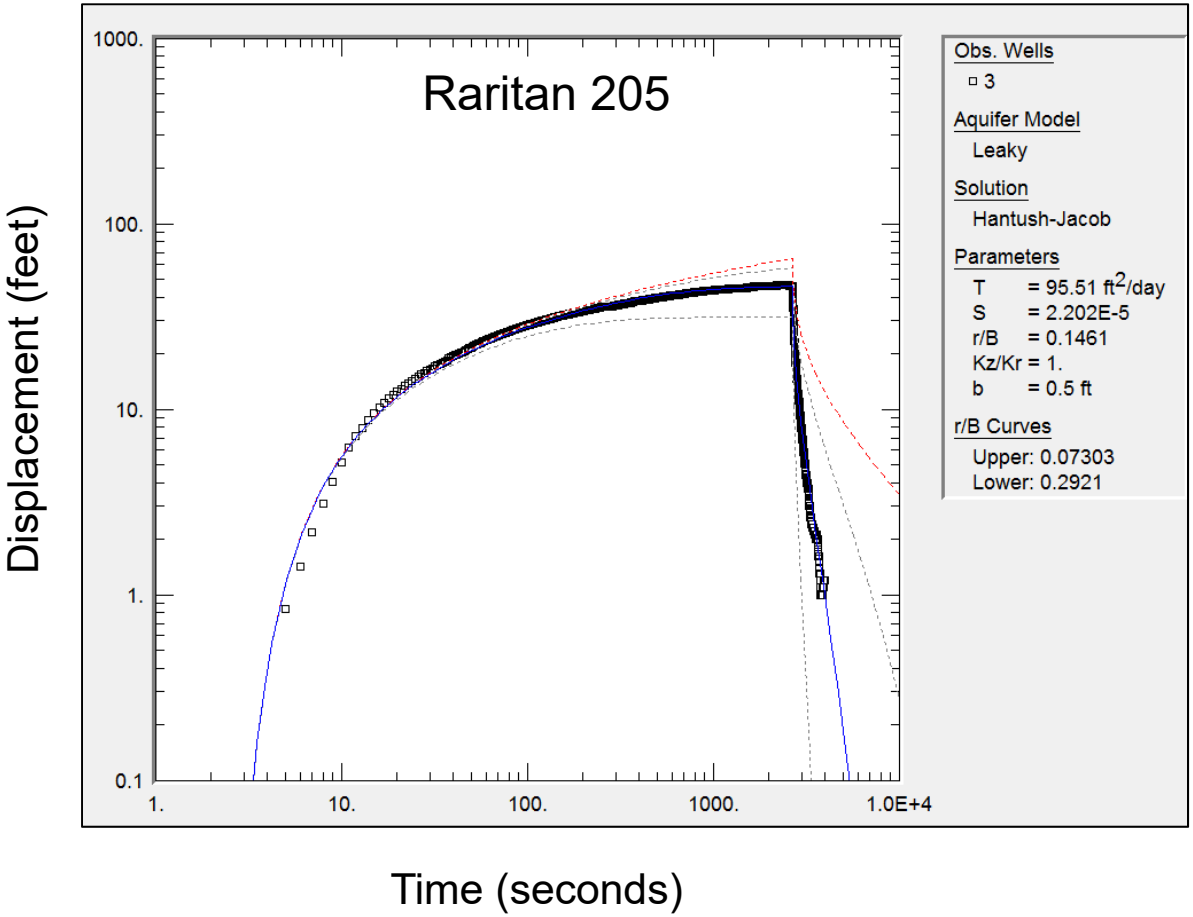
Field Data Collection

Vacuum vs. Time



1) Enter data in real-time to spreadsheet model
2) Interpret radius of influence (ROI), preferential pathways, building-specific attenuation factor

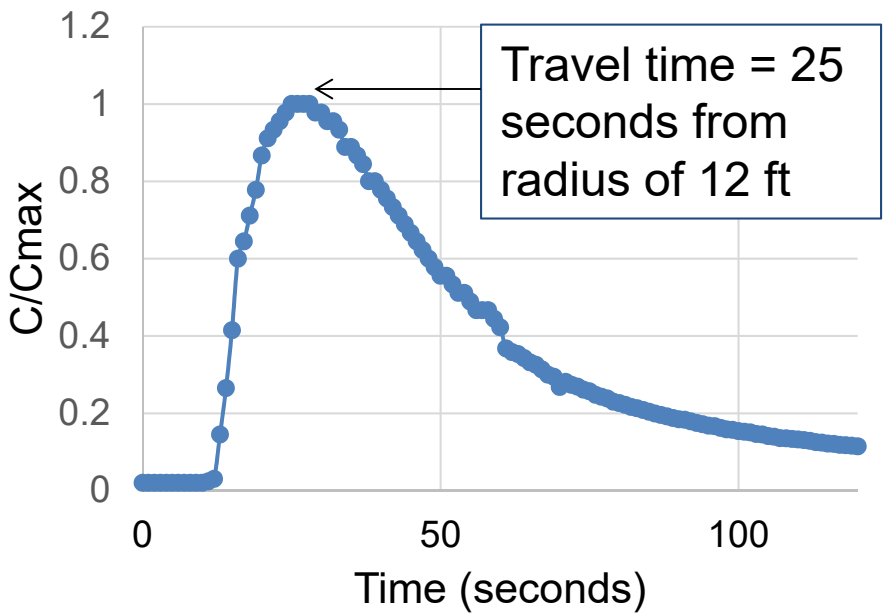
Vacuum Data Analysis



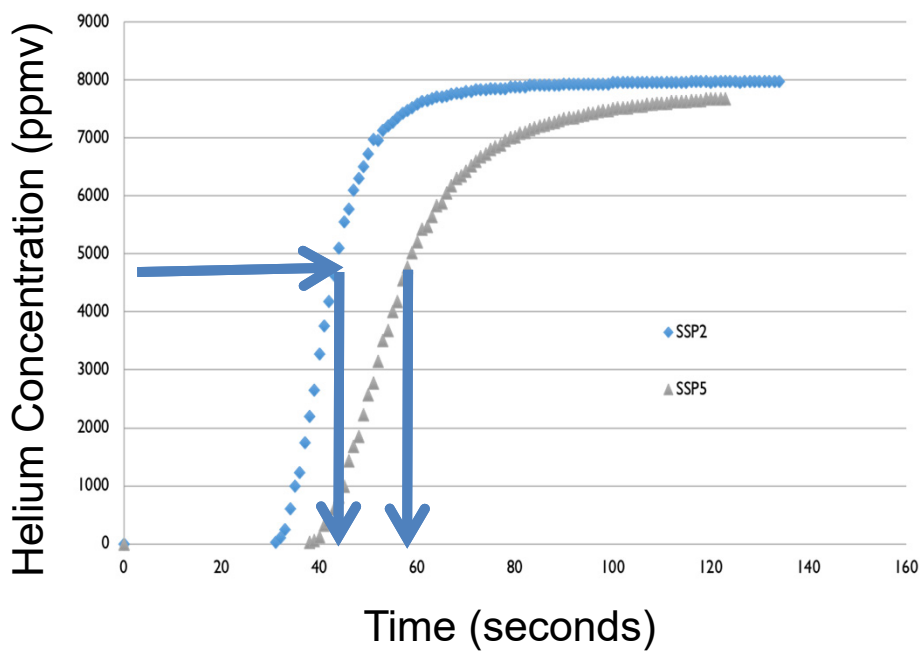
- Data and model very close usually!
- Adds confidence to model
- A difference indicates conditions warrant further assessment

Tracer Tests

Inter-Well Test



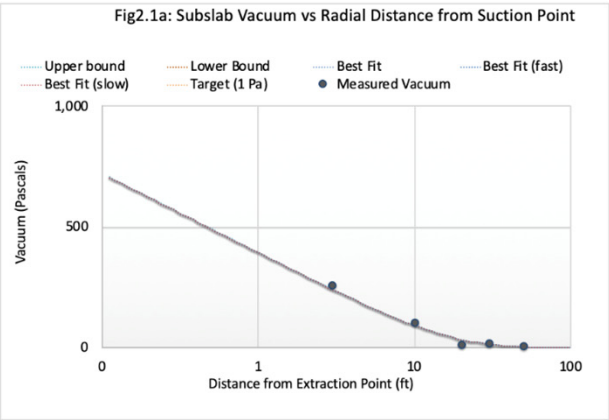
Helium Flood

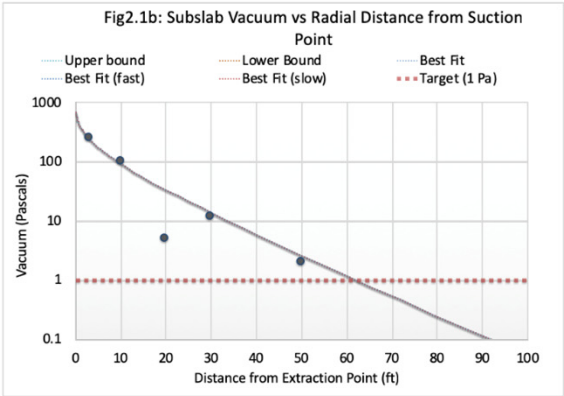


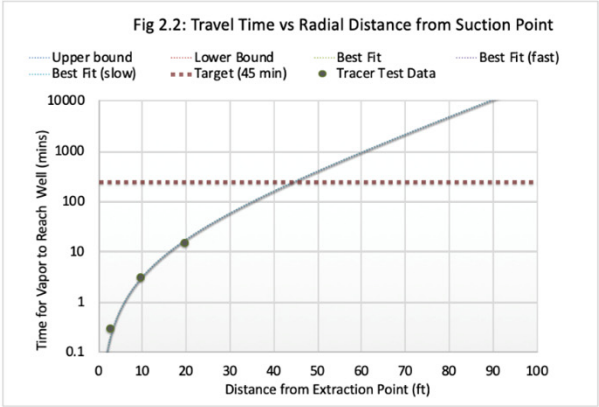
Tests typically take only a few minutes to conduct

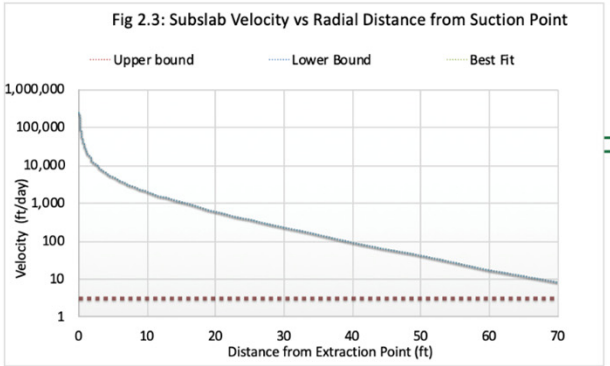
Notes: C/Cmax = Concentration divided by maximum concentration

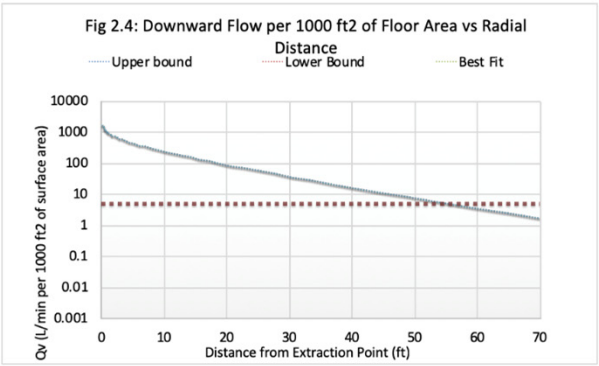
Spreadsheet Model











SENSITIVITY ANALYSIS

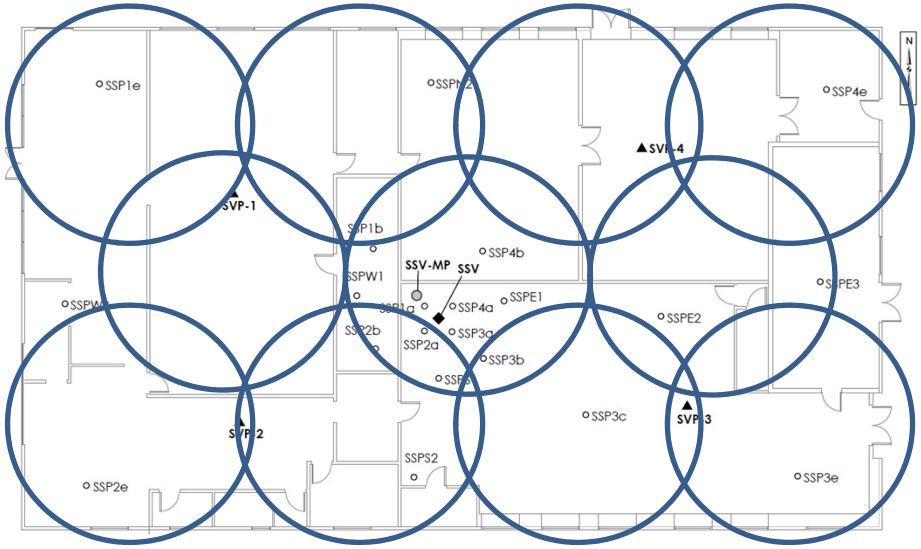
Legend Label	Flow rate, Q	Transmissivity, T			Leakance, B			Thickness, b	Effective Porosity, n
	(ft^3/min)		(ft^2/d)			(ft)		(ft)	(v/v)
Upper bound	15	-	90	+	-	14	+	0.5	0.25
Lower Bound	15	-	90	+	-	14	+	0.5	0.25
Best Fit	15	-	90	+	-	14	+	0.5	0.25
Best Fit (fast)	15	-	90	+	-	14	+	0.5	0.25
Best Fit (slow)	15	-	90	+	-	14	+	0.5	0.25

Radius (ft)	Target Levels	Units	Field Measurments		
	Vacuum		radius (ft)	Vacuum (Pa)	Travel Time (min)
0	1	Pa	3	250	0.3
500	1	Pa	10	100	3.1
	Velocity		20	5	15
0	3	ft/day	30	12	
500	3	ft/day	50	2	
	Travel Time				
0	240	min			
500	240	min			
	Qsoil/Area				
0	5	L/min/1000ft^2			
500	5	L/min/1000ft^2			

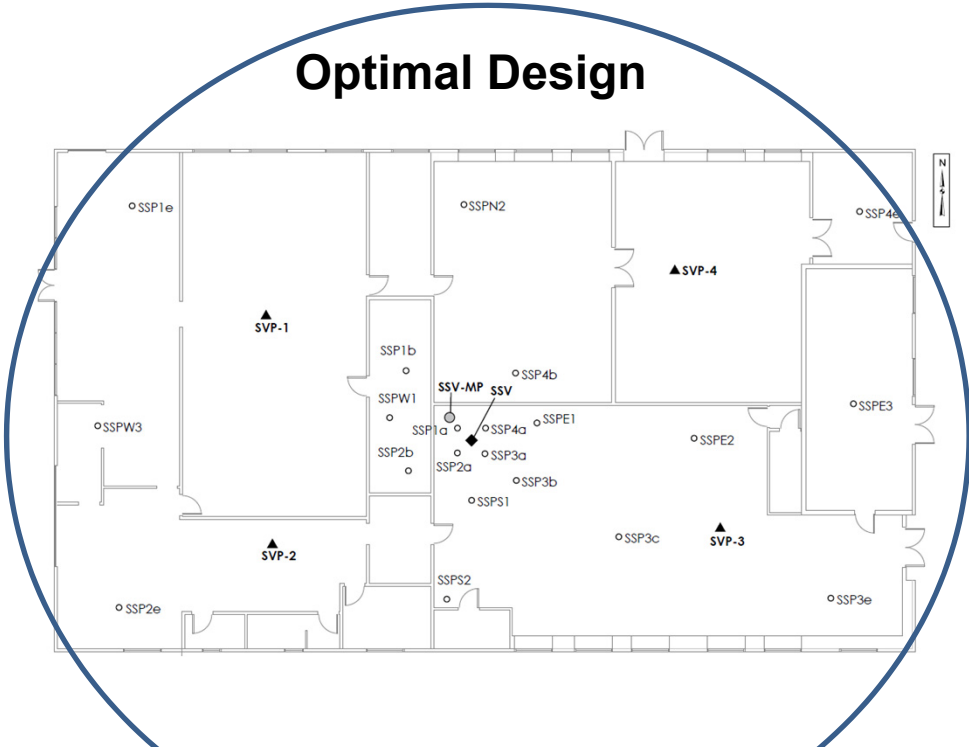
- Inputs: 1) Flow rate, 2) vacuum vs distance, 3) tracer test data
- Variables: Transmissivity (T), Leakance (B), porosity (n) and the thickness of the flow zone (b)
- Outputs: radius of influence (ROI) for target levels of vacuum, velocity, travel time and leakance

Optimize: Vandenberg AFB B11193

Conventional Design



Optimal Design



11 suction points at 50 scfm (ROI = 19 ft)
30 year Net Present Value = $270K

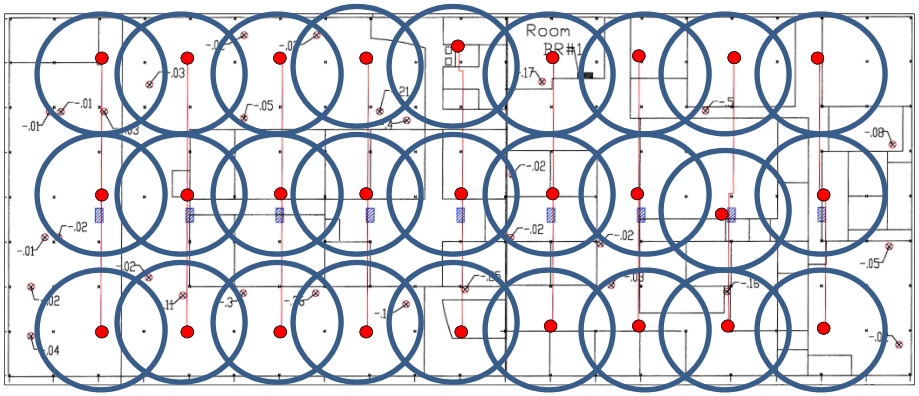
1 suction point at 25 scfm (ROI = 75 ft)
30 year Net Present Value = $93K

Savings = $177K; Incremental Cost = $10K

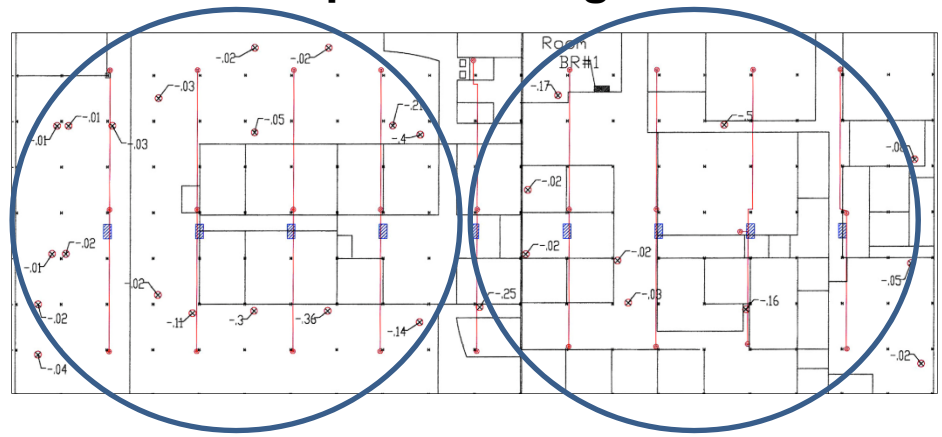
Notes: scfm = standard cubic feet per minute

Optimize: Raritan Arsenal B205

Conventional Design



Optimal Design



27 suction points at 20 scfm (ROI = 28 ft)
30-year Net Present Value = $400K

2 suction points at 50 scfm (ROI = 100+ ft)
30-year Net Present Value = $160K

Savings = $250K; Incremental Cost = $21K

Building-Specific Attenuation Factor

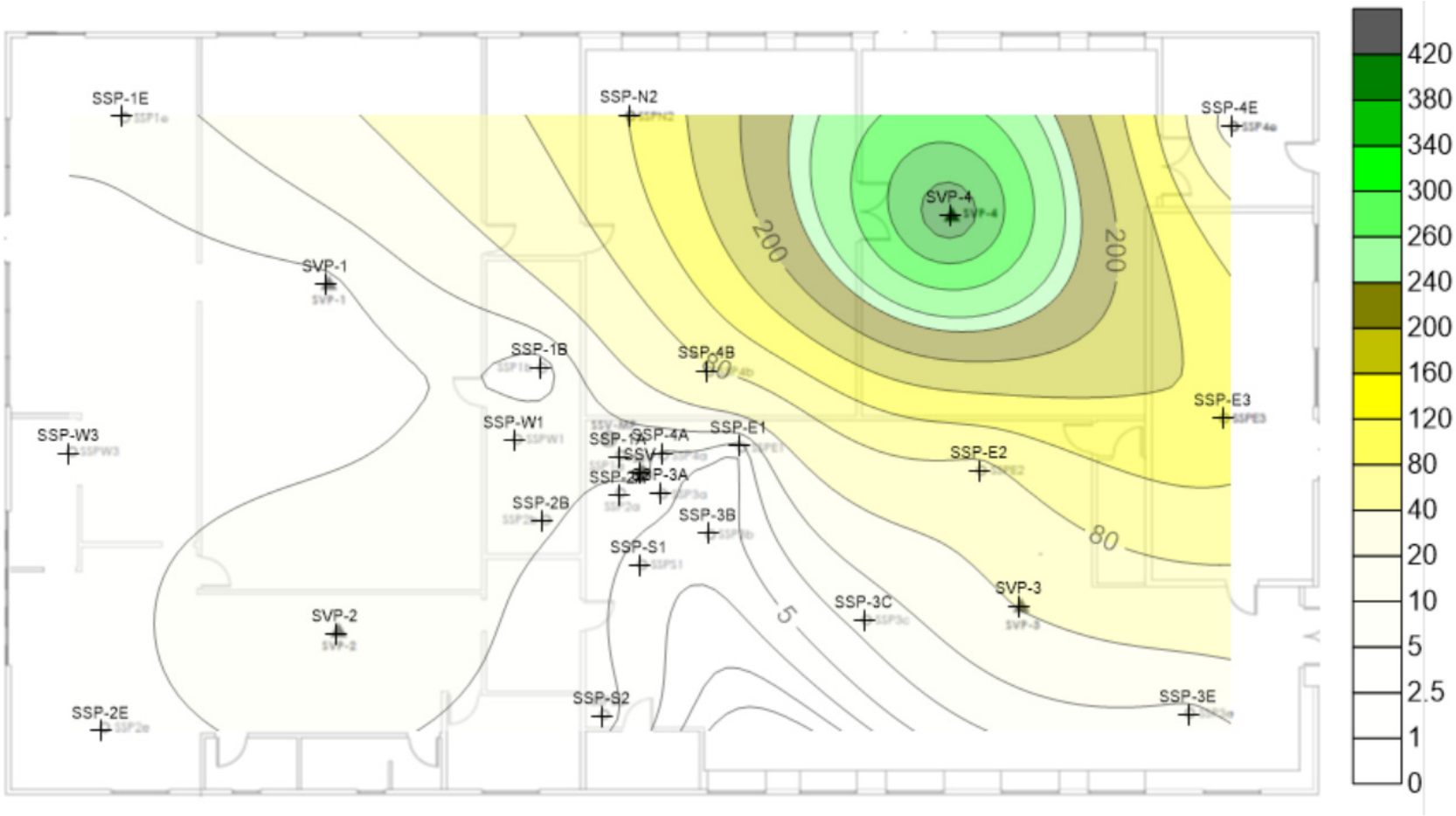
$$AF = \frac{Cindoor}{Csubslab}$$

$$AF = \frac{T\ \Delta P}{B^2\ h\ AER}$$

Building	Empirical AF	Modelled AF
Raritan 205	NA	0.0008
Vandenberg 11193	0.0003	0.0003
Raritan 200	0.002	0.002
Sun Devil Manor	NA	0.02

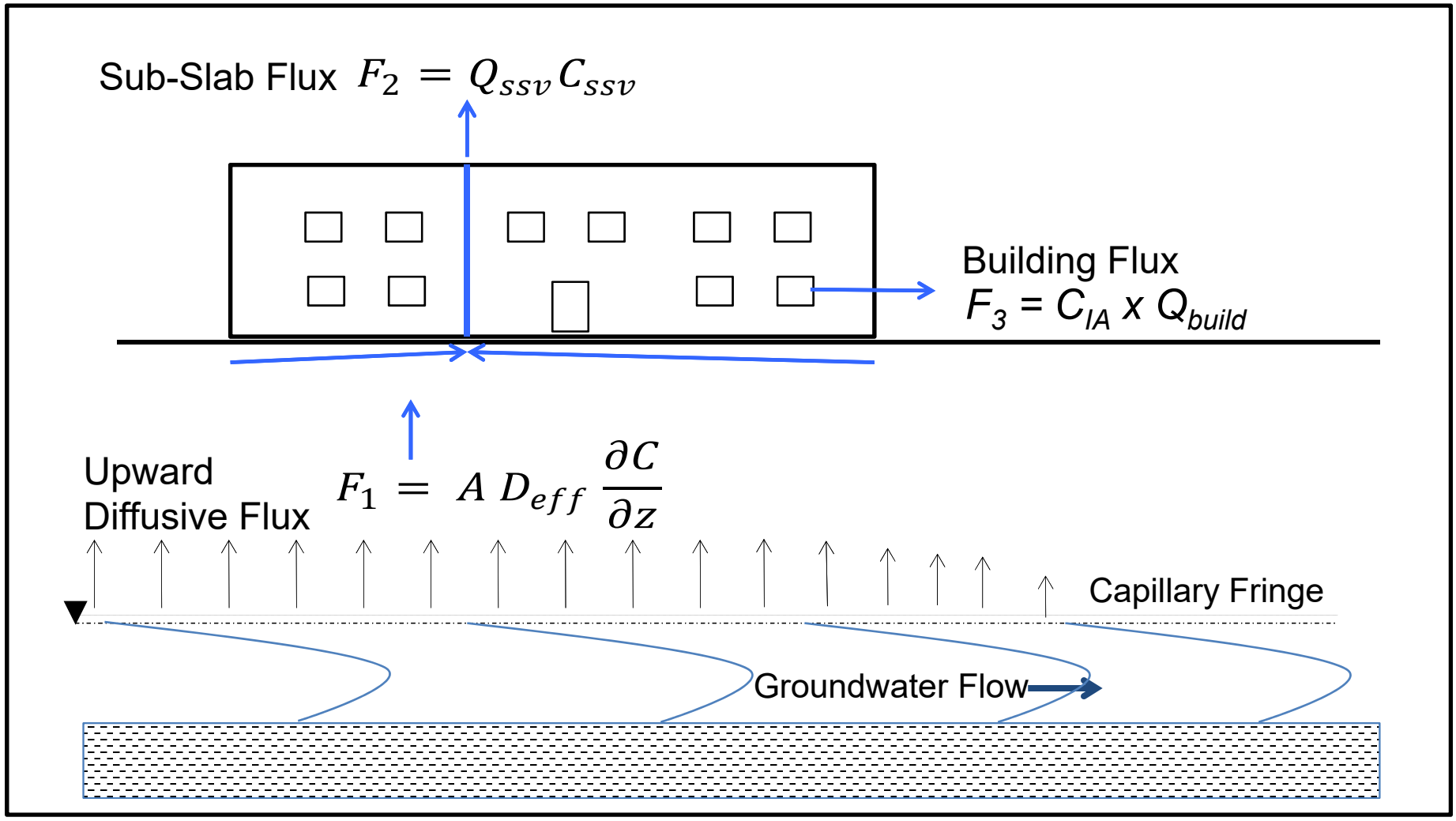
McAlary, T., Gallinatti, J., Thrupp, G., Wertz, W., Mali, D. and H. Dawson, 2018. Fluid Flow Model for Predicting the Intrusion Rate of Subsurface Contaminant Vapors into Buildings, Environmental Science & Technology, 2018, 52(15), pp 8438-8445.

Target Area for Mitigation



Building-specific screening levels can be used to define area requiring mitigation

Mass Loading

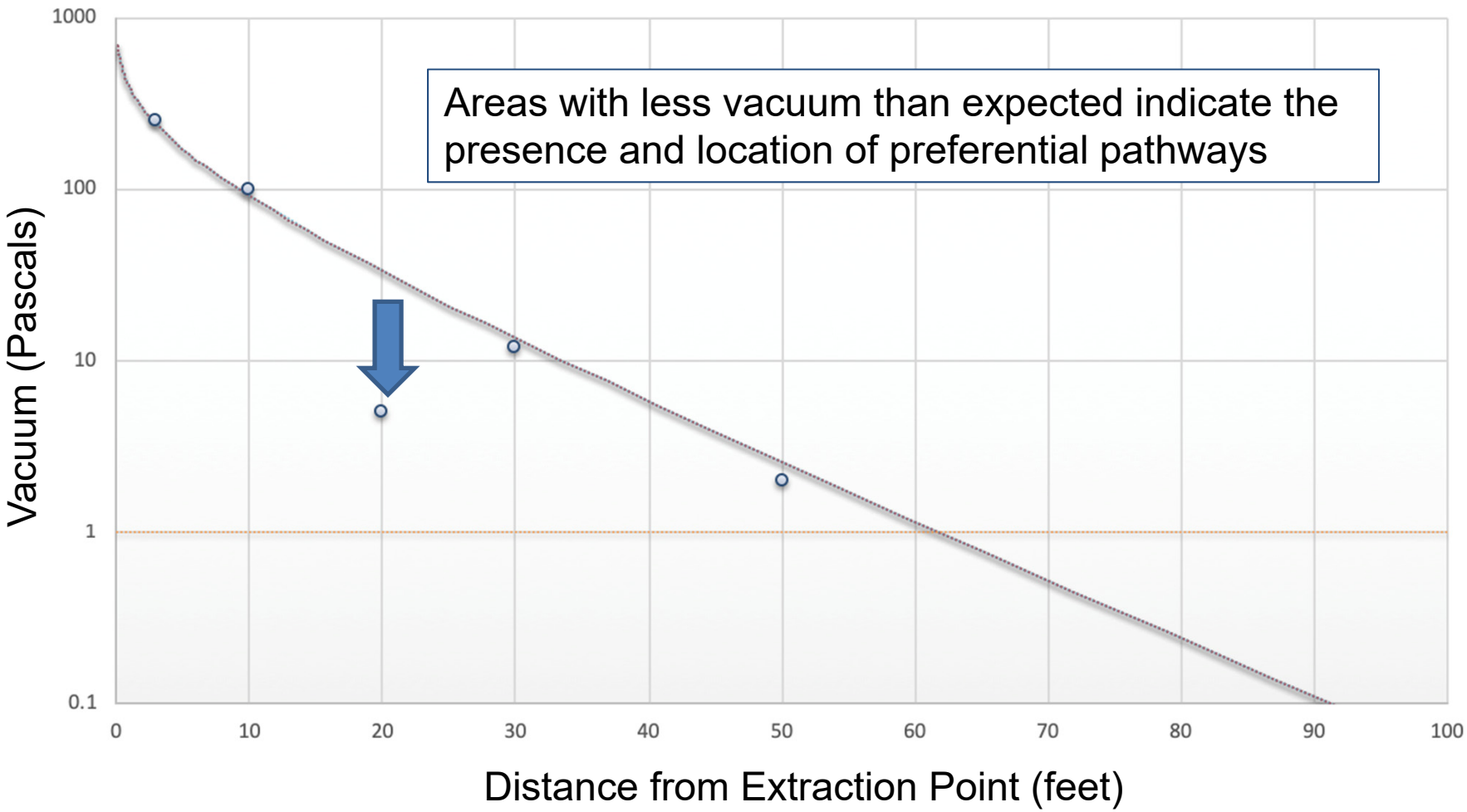


Mass Loading

Building	Subslab Loading (g/day)	Building Loading (g/day)	Threshold Loading (g/day)
Raritan 205	0.5	<0.2	3.6
Vandenberg 11193	22	18	0.2
Raritan 200	0.2	0.1	0.009
Sun Devil Manor (Land Drain Open)	0.3	0.2	0.008

Data for Raritan 205 supports an "exit strategy", which doesn't currently exist

Preferential Pathways



Mitigation Toolkit

Conventional Diagnostics	*Recommended Additions*	*Options*
• Static vacuum (far field) • Indoor air sampling	• Baseline differential pressure • Static vacuum (near field) • Transient vacuum • Helium tracer testing • Spreadsheet model • Vent-pipe sampling	• Building pressure cycling • Differential pressure • Rebound testing/closure

- The recommended additions are all fast and inexpensive – make sense almost always
- Options are a little more expensive – decide on a case-by-case basis whether worthwhile

Conclusions

- Two-layer model matches field data well
- Enables many lines of evidence with minimal incremental effort
- Side benefits
  - Fewer suction points (lower capital cost)
  - Lower extraction rates (lower O&M costs)
  - Mass loading exit strategy (shorter operation)
  - Preferential pathway indications
  - Building-specific attenuation factor

Benefits to DoD

- Much less expensive mitigation systems
- Confidence via multiple lines of evidence
- Building-specific screening levels
- Preferential pathway assessment
- User-friendly spreadsheet model
- New option for an exit strategy

For additional information, please visit

https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Emerging-Issues/ER-201322

Speaker Contact Information

tmcalary@geosyntec.com; 905-339-7066

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Q&A Session 2

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The next webinar is on July 25, 2019

Understanding Underwater Munitions Mobility and Behavior on the Beach Face and in Shallow Muddy Environments

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Survey Reminder

Please take a moment to complete the survey that will pop up on your screen when the webinar ends

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