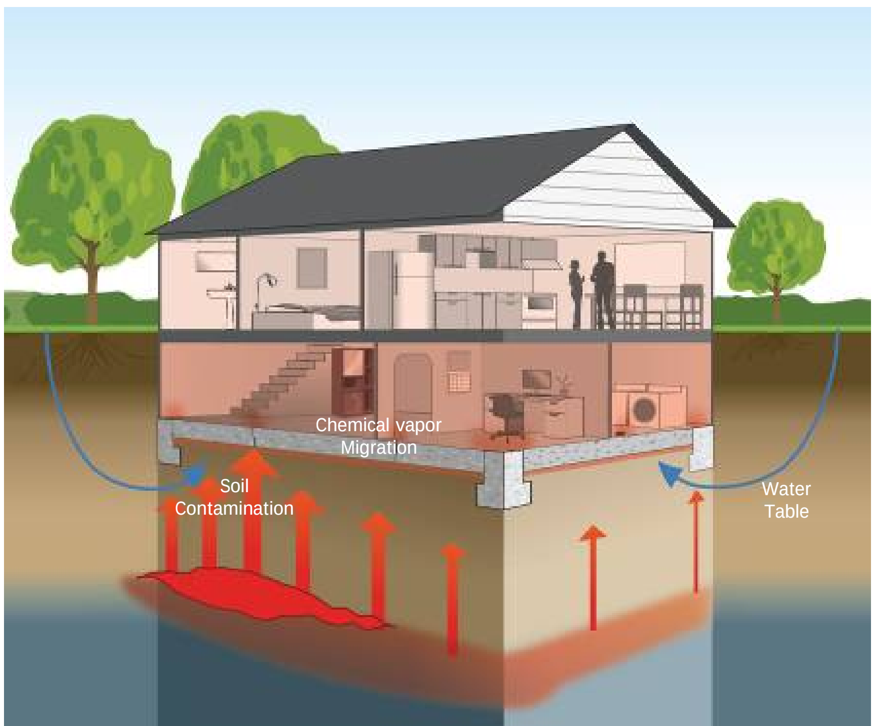
# An Integrated Model for Design of Soil Vapour Intrusion Mitigation Systems

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# Presentation Outline

- Vapour intrusion mitigation overview
- Vapour intrusion mitigation experience
- Modified Johnson and Ettinger model for incorporating venting and barrier
- Civil design module for venting layer design
- Conclusions

# Vapour Intrusion Mitigation Context

- May be required at sites with VOCs (e.g., chlorinated solvents), radon, methane
- Increased emphasis on pre-emptive mitigation at Brownfield/methane generating sites (e.g., ASTM E2600)
- Challenge is no standard practice for design and wide range of options available[1]

1. Some Guidance: UK CIREA 149 & 665; British Standards 8485:2007; Requirements Los Angeles & San Diego

# Vapour Intrusion Mitigation Options

- Passive or active (depressurized) sub-slab venting
- Barrier below building (for new buildings)
- Building-based measures
  - Sealing of floor slab openings
  - Increased building ventilation
  - Building pressurization
- Soil vapour extraction

Key points: Mitigation solution will depend on contaminant type, concentration, flux and building; ►Typically subslab venting with barrier where needed (and feasible) is the most effective solution

# Radon Mitigation Experience

- Sub-slab depressurization (SSD) combined with sealing of cracks most commonly used technology
- Comprehensive USEPA study[1] compared sub-slab depressurization, slab sealing and house pressurization, found that sub-slab depressurization was most effective method
- SSD often > 90 % reduction in radon concentrations
- Sealing floors alone <= 50 % reduction
- Passive venting alone: Vent connected to stack open to atmosphere: 30% reduction in radon entry[2]

1 Installation & Testing of Indoor Radon Reduction Techniques in 40 Eastern Pennsylvania Houses, EPA Report 600/8-88/002 (400 pg)

2 Holford, D.J. & Freeman, H.D. Effectiveness of a Passive Subslab Ventilation System in Reducing Radon Concentrations in a Home. Environ. Sci. Technol. 1996, 30, 2914-2920.

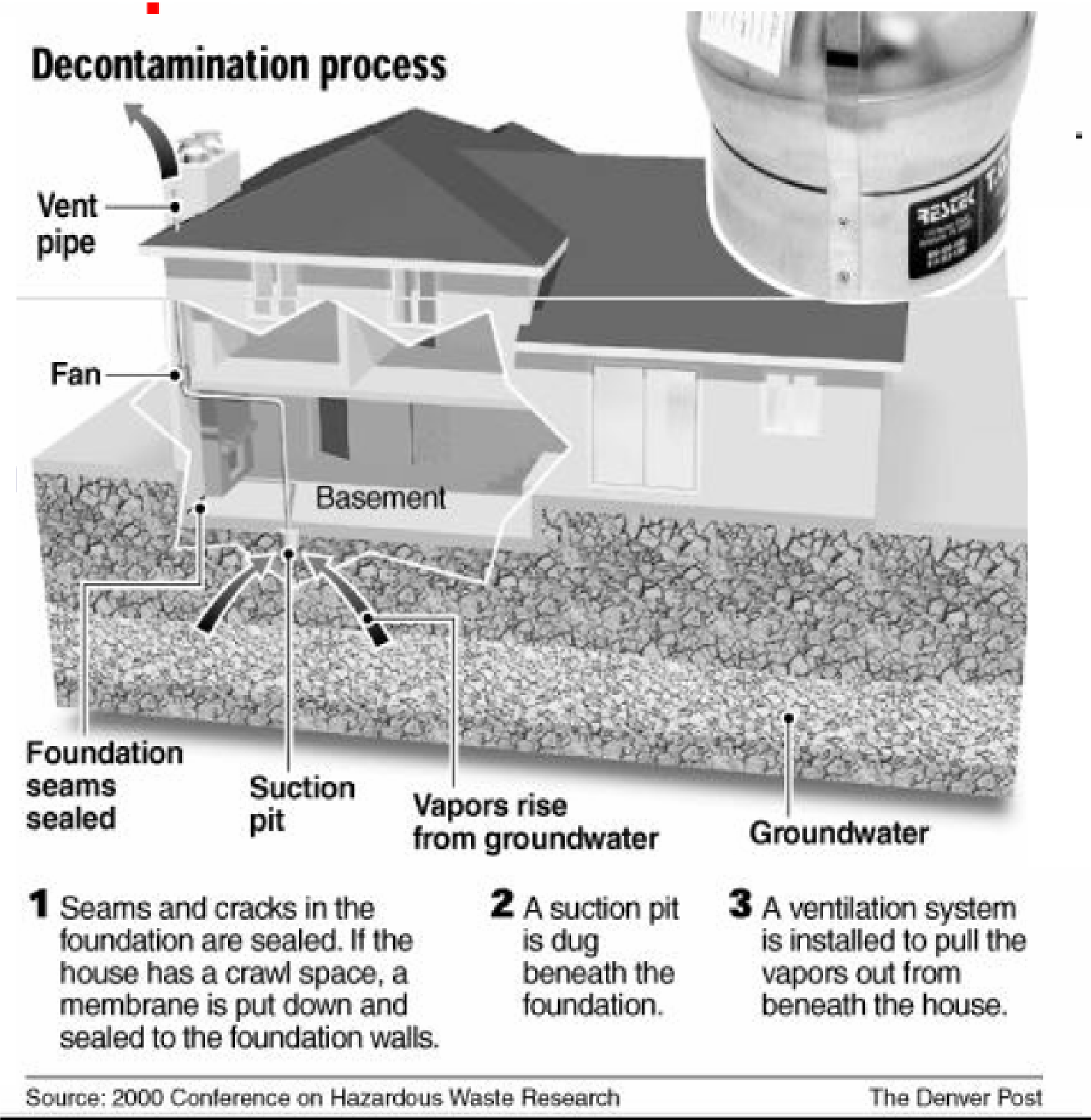
# Residential / Small Commercial

Usually 1 to 2 (“radon”) sumps

90-150 Watt fans

80 to 95% reduction typical

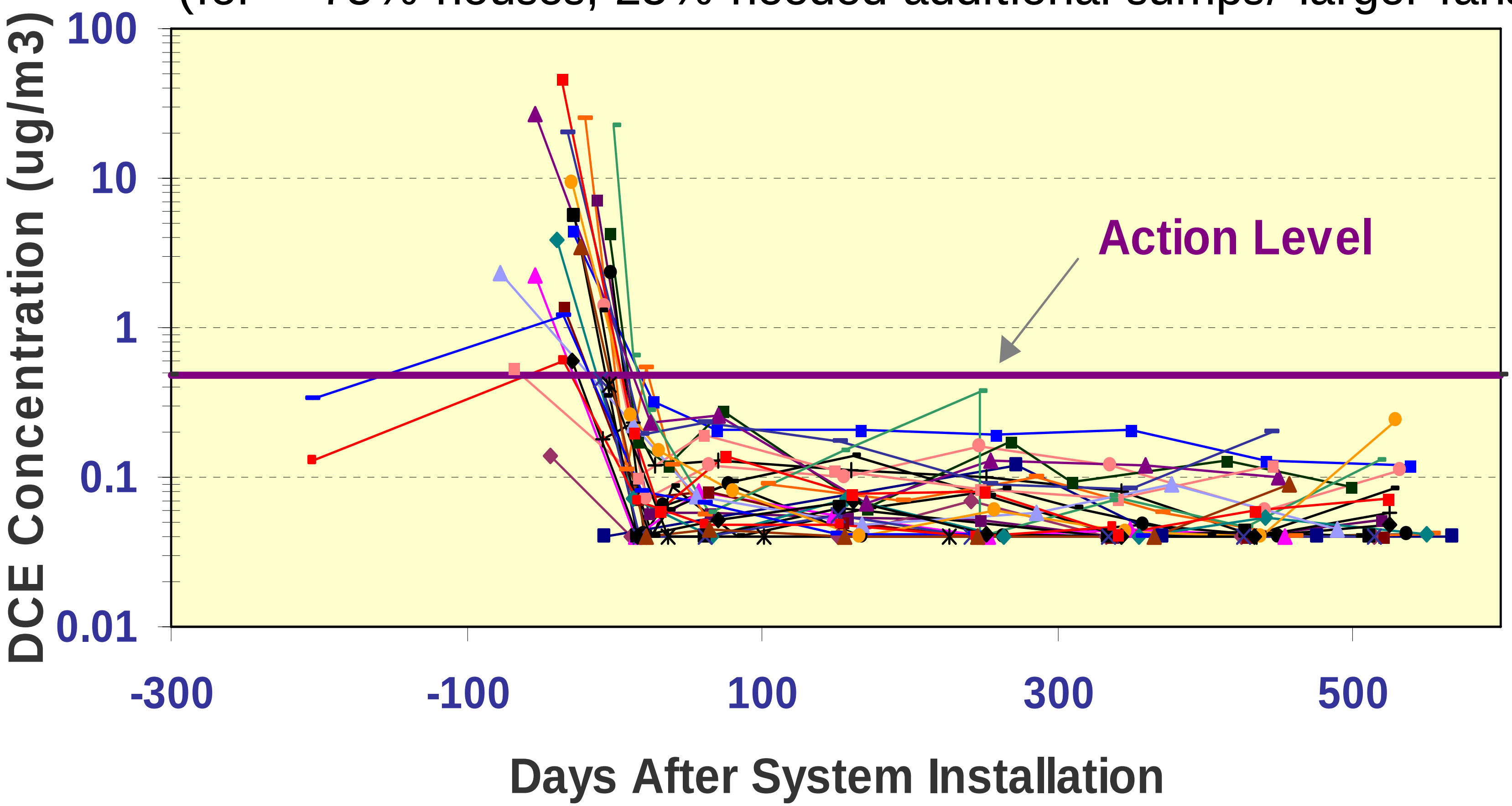
~~ 2-3 $/SF



# SSD Performance
## (Redfield, D.Folkes)

NO MODIFICATIONS REQUIRED

(for ~ 75% houses, 25% needed additional sumps/ larger fans)




**EFFICACY OF SUB-SLAB DEPRESSURIZATION FOR MITIGATION OF VAPOR INTRUSION OF CHLORINATED ORGANIC COMPOUNDS** DJ Folkes* and DW Kurz Indoor Air 2002

# Building-based Vapour Intrusion Mitigation Measures

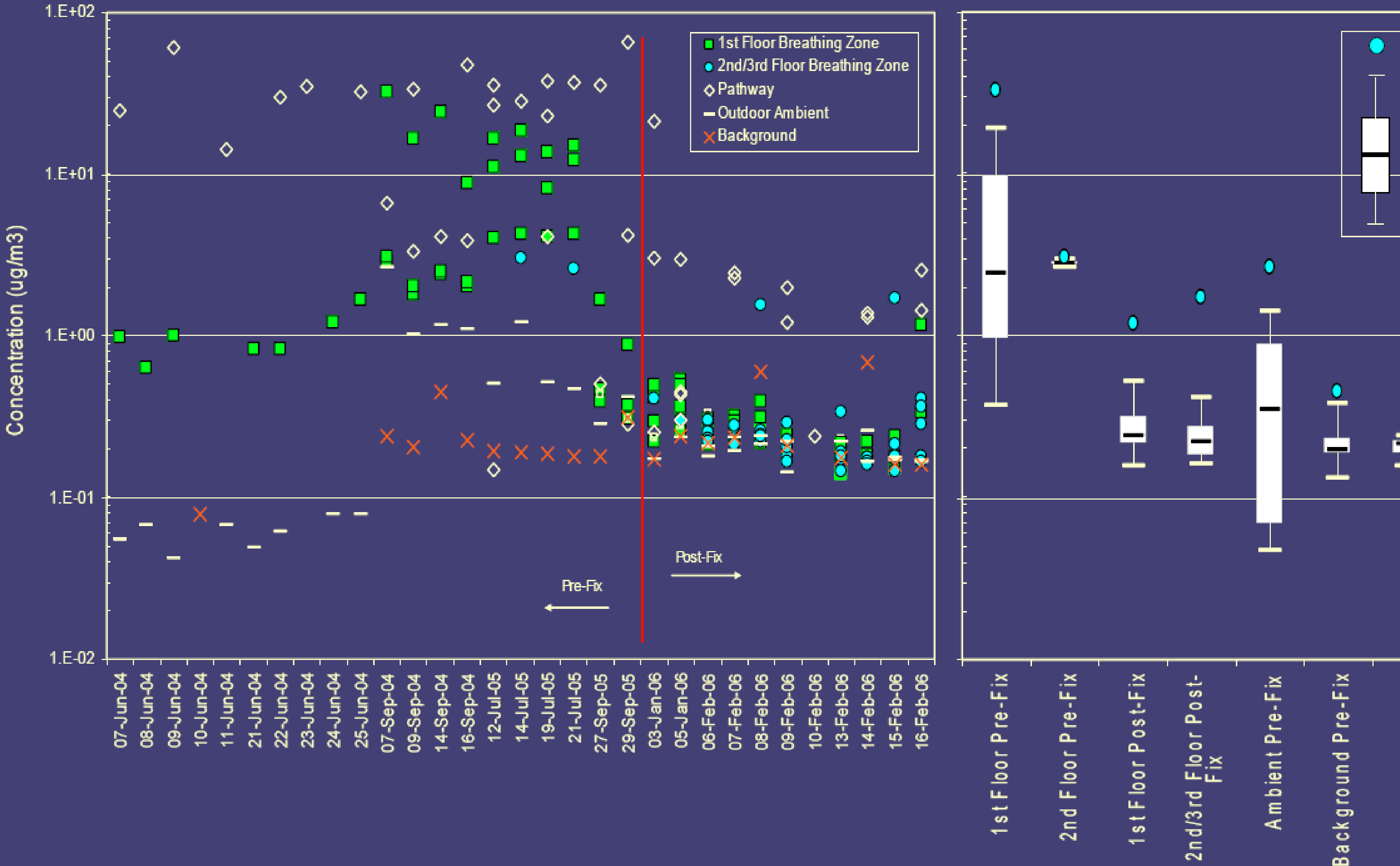
- May be effective for some buildings (e.g., commercial) depending on reduction in vapour concentrations needed
- Increased building ventilation
  - Up to ~ 50% reduction possible, energy cost
  - Can install heat recovery ventilator for houses
- Building pressurization
  - May be difficult to achieve constant positive pressure
  - Energy cost associated with heating outdoor air
- May need expertise of HVAC engineer!

# Moffett AFB Hanger
## (D. Brenner, AWMA, 2006)


TES

# TCE Results

## Moffett AFB D. Brenner, AWMA, 2006

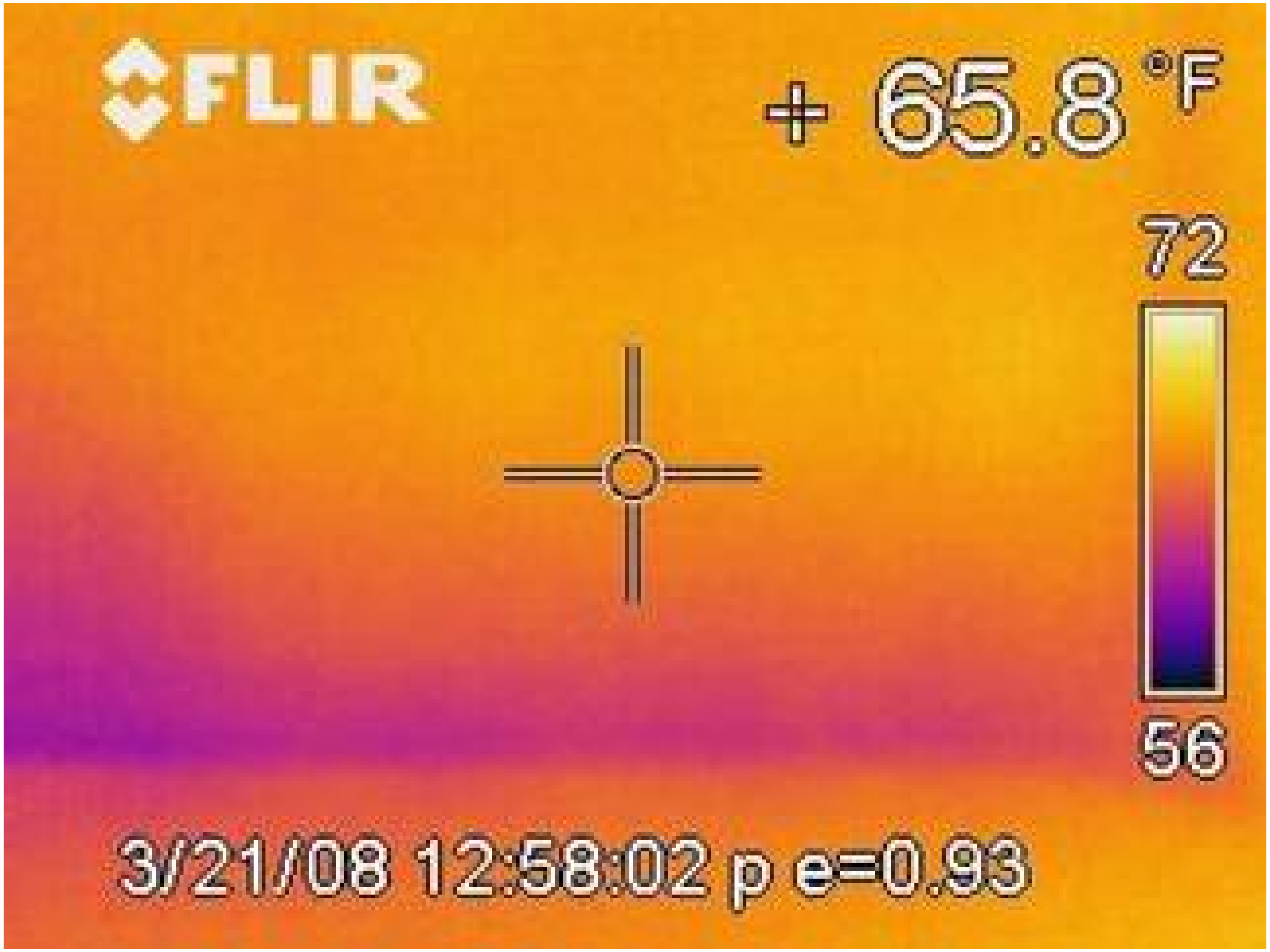


# Diagnosis – Good Seal?

(Pete Granholm, Apex)

# Thermal Image of Same Wall

(Pete Granholm, APEX)

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# Vapour Intrusion Mitigation Matrix

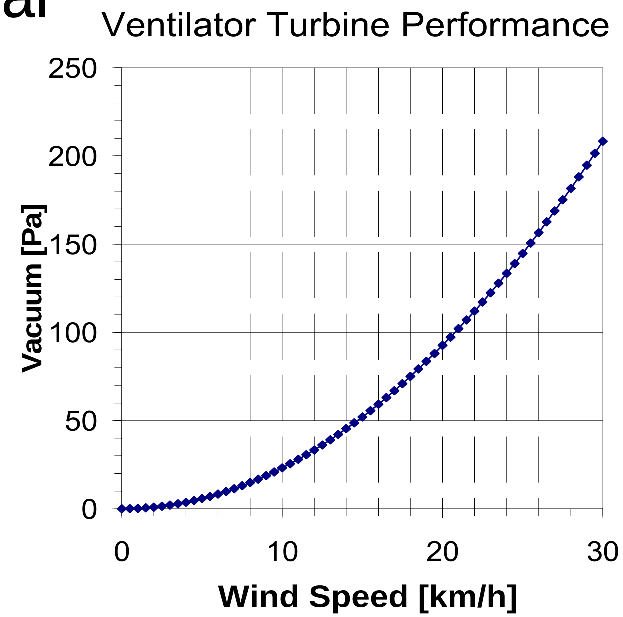
| | | | |
|---|---|---|---|
| **Energy Input** | Passive | Low energy – Wind turbines | Higher energy – Electrical fans |
| **Efficiency** Assumes pipe losses small | Sand | Gravel | Aerated Floor |
| **Barrier** | Concrete Foundation (no additional barrier) | Fine-grained soil | Geomem-brane |

**Increased Protection** →

- Key points: Multiple combinations possible and opportunities for optimization. Be careful of cost implications (e.g., membranes & complex foundation)

# Design Innovations

- Selection of appropriate barrier material
  - **Conventional**: PVC, HDPE
  - **Newer**: PVC alloy, Synthetic fibre-reinforced linear LDPE with aluminium composite, STEGO 15 mil polyolefin resins, Liquid boot asphaltic emulsion, Geoseal
- Wind turbines
  - Golder has developed computer program to optimize design
- Geocomposites
- Aerated floors

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# Surrey, BC Methane Mitigation

Single course, high build, polymer modified asphaltic emulsion

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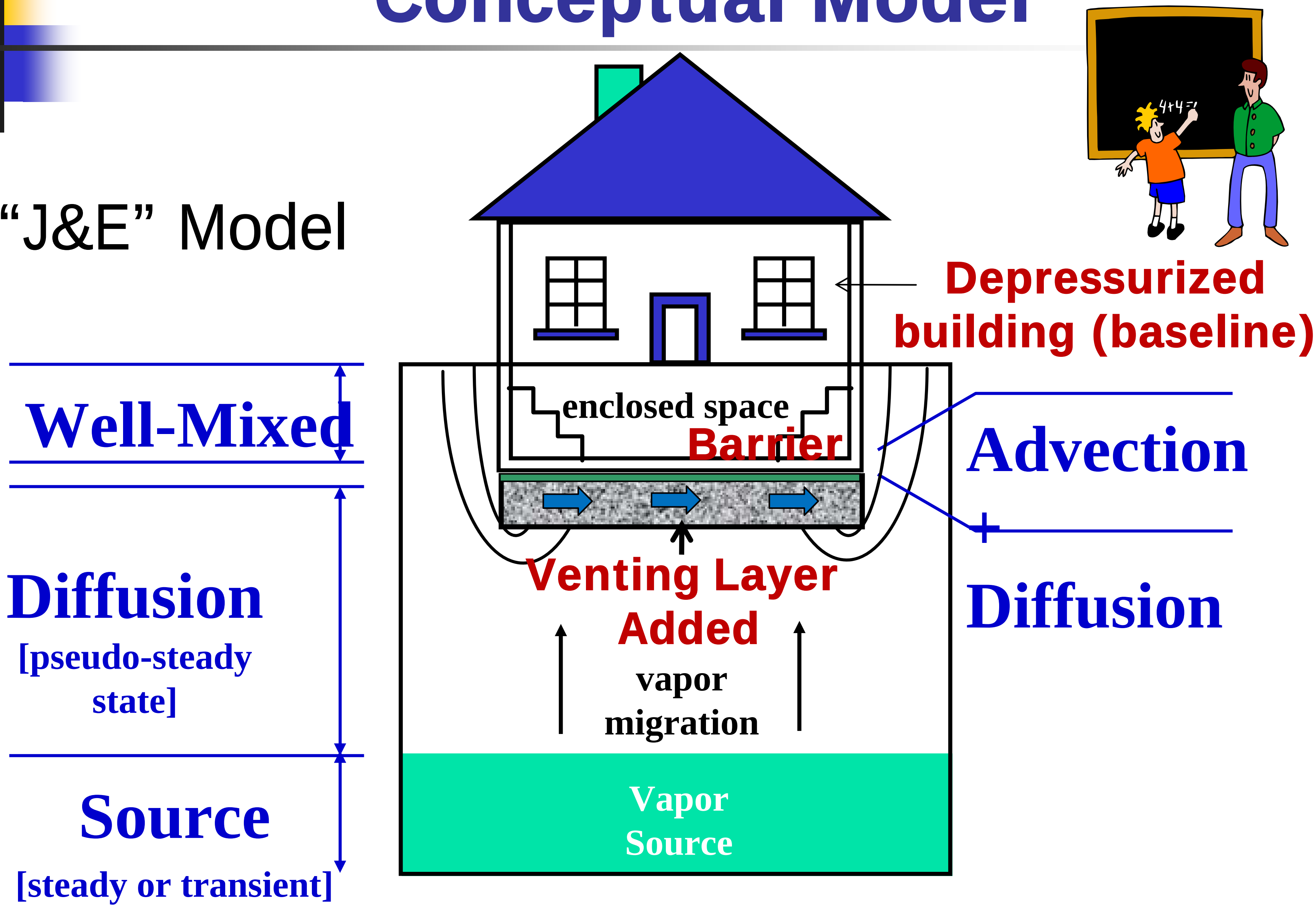
# Cupolex Pontarolo

# Modified Johnson and Ettinger VI Model Case Study

- Commercial buildings proposed at large site with extensive, very high concentrations of chlorinated solvents (trichloroethylene, perchloroethylene, many others)
- Baseline modeling predicted unacceptable risk
- Modified Johnson and Ettinger model to enable simulation of barrier and subslab venting layer
- Objective of modeling provide insight on effectiveness of mitigation (not rigorous design tool!)

# Johnson and Ettinger (1991) Conceptual Model

“J&E” Model

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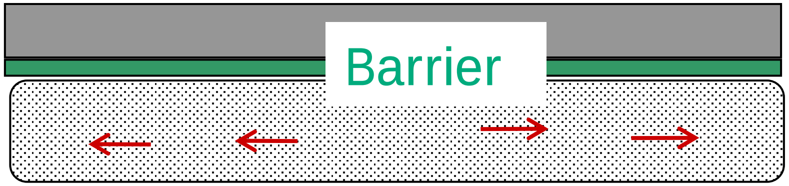
# Barrier Design

- Important property is permeation rate (not the same as vapor diffusion rate)
- Limited literature (Haxo 1984, Park 1995, Sangan and Rowe, 2002; McWatters 2007, product specifications)
  - Liquid Boot 1.5 mm PCE vapor diffusion rates: $2.7 \times 10^{-14}$ to $8.1 \times 10^{-14}$ $m^2$/sec
  - McWatters (2007) BTEX permeation rates BTEX: HDPE $10^{-11}$ to $3 \times 10^{-10}$ $m^2$/sec; PVC $2 \times 10^{-10}$ to $10^{-9}$ $m^2$/sec

Similar to diffusion rate of benzene in water

Be careful if designing system with just barrier (relying on diffusive gradients)

PE

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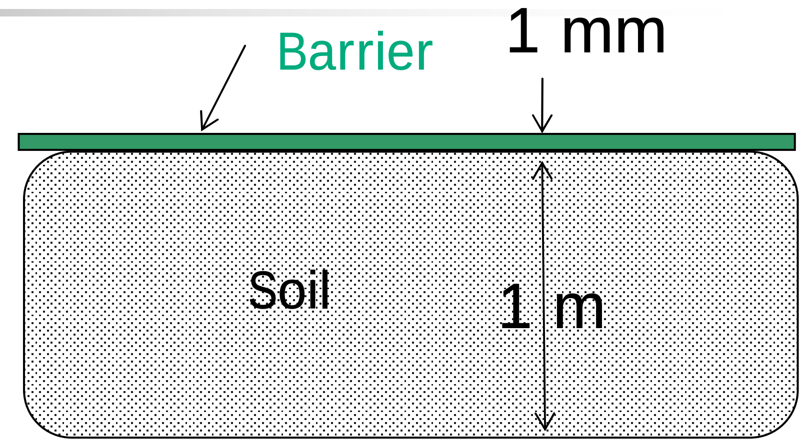
# Barrier Design

- What is effect of 1 mm thick geomembrane on overall effective diffusion rate?




## Effective Diffusion Coefficient

| 1 mm thick Geomembrane | 1 m Sandy Soil | Combined Geomem-brane and Soil |
|---|---|---|
| $1x10^{-9}$ $m^2$/sec (High) | $7.4x10^{-7}$ $m^2$/sec | $4.3x10^{-7}$ $m^2$/sec |
| $8x10^{-14}$ $m^2$/sec (Low) | $7.4x10^{-7}$ $m^2$/sec | $8x10^{-11}$ $m^2$/sec |

- Effect is a little to a lot depending of values used!

# But what about holes in barrier?

- No barrier is 100% effective (utilities, holes in barrier due to construction)
- Diffusion rates through holes and cracks will be much higher than through barrier itself (also advection through cracks)
- For modeling shown on subsequent slides assumed barriers with openings, with diffusion limited to openings
- Assumed 10 leaks that are 10 $cm^2$ in size per 1,000 $m^2$, which corresponds to a crack ratio of $1x10^{-5}$.

# Modified J&E VI Model Scenarios

| Model Scenarios | Air-changes venting layer | Building Depressurization |
|---|---|---|
| Baseline (no mitigation) | 0 | 2 Pa |
| Eliminate pressure gradient | 0 | 0 Pa |
| Venting Layer | 2 per hour | 0 Pa |
| Venting Layer & Barrier | 2 per hour | 0 Pa |

# Modified J&E Model Results

| Model Scenarios | Attenuation Factor |
|---|---|
| Baseline (no mitigation) | $2.5x10^{-5}$ |
| Eliminate pressure gradient (ΔP) | $4.1x10^{-6}$ |
| Eliminate ΔP, add venting layer | $9.3x10^{-7}$ |
| Eliminate ΔP, add venting & barrier | $1.9x10^{-8}$ |

- Eliminate ΔP: ~ 6X reduction in attenuation factor
- Add venting layer: ~ 4X additional reduction
- Add barrier: ~ 50X additional reduction

Key points: Combination of measures needed to meet objectives. Somewhat unexpectedly was limited reduction for venting (for assumptions made)

# Golder Venting Design Module

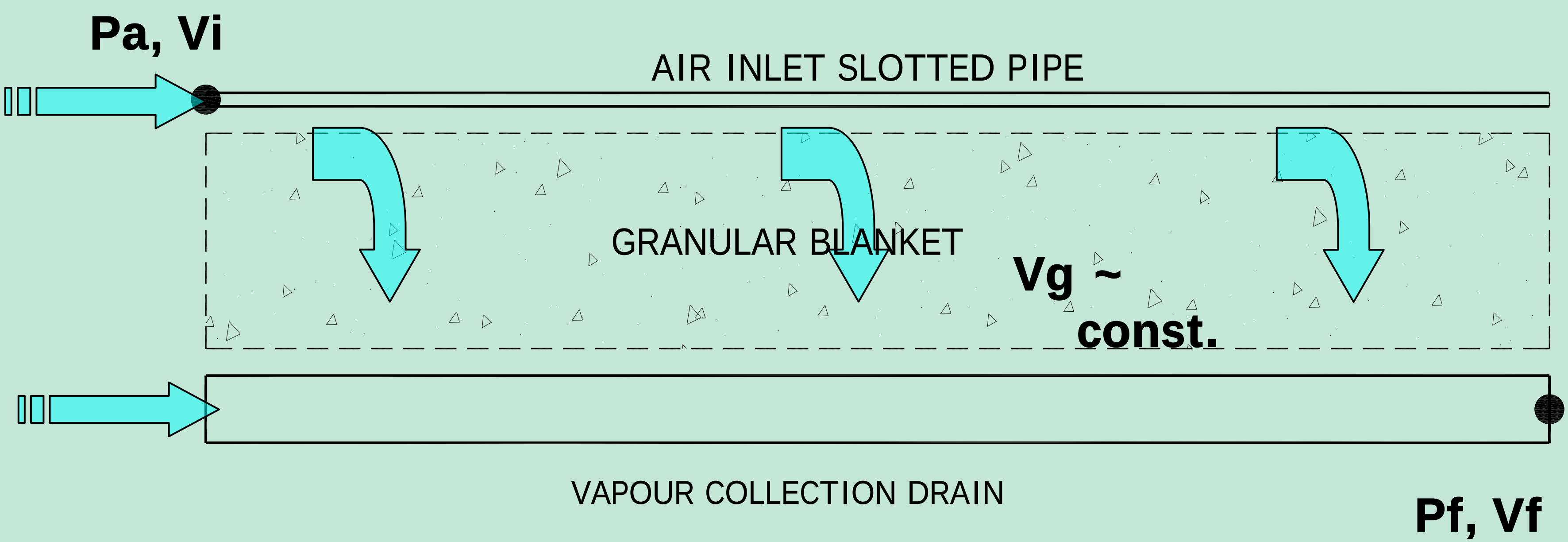
- Objective is to enable design/optimization of subslab venting layer and piping based on desired pore flushings
- Couples flow through piping and soil based on civil engineering principles
- Spreadsheet model developed by Golder

# Golder Venting Model

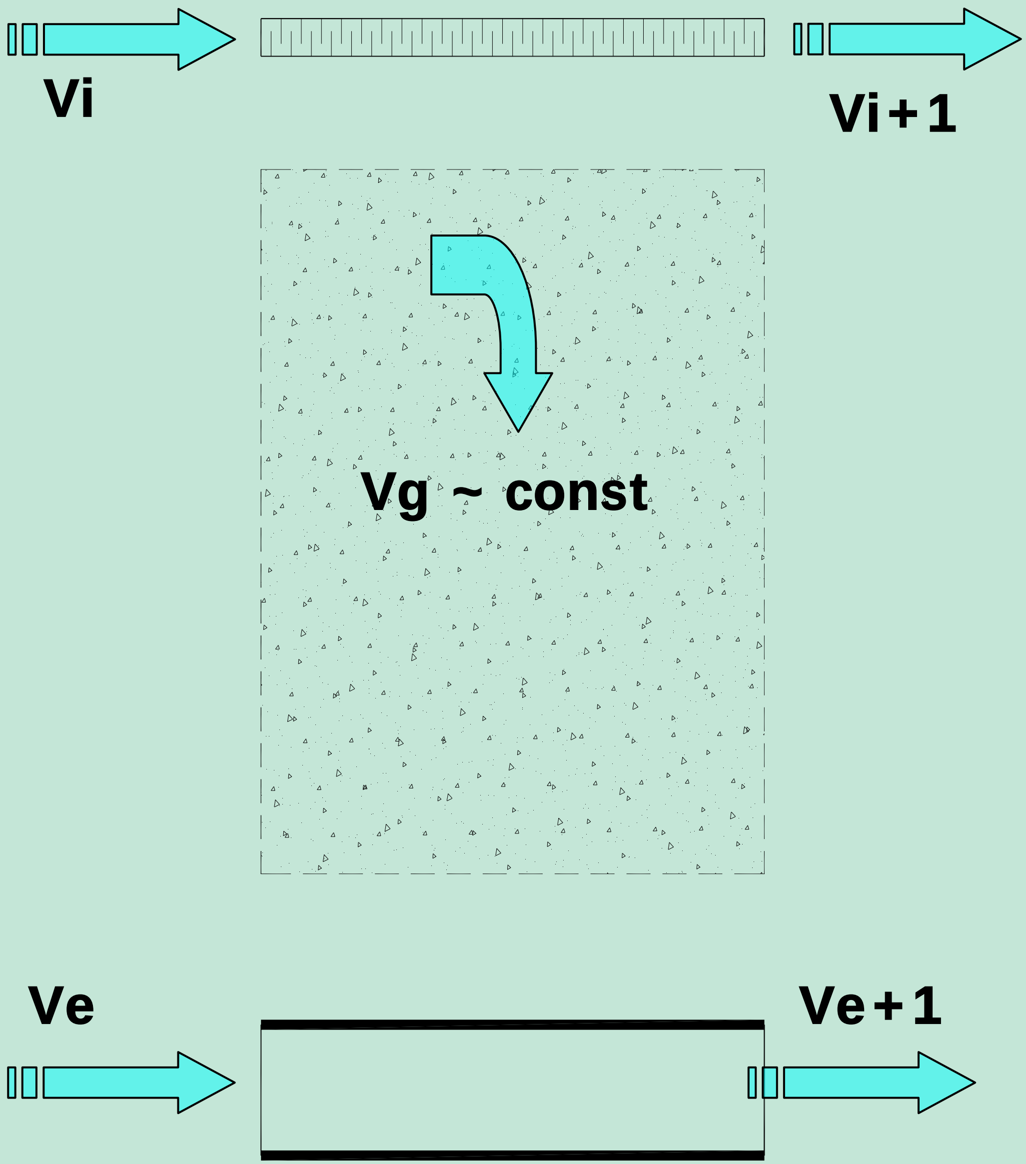
**BASIS RESULTS / ASSUMPTIONS**

- Bernoulli Law
- Mass Conservation Principal
- Extended Darcy's Law

[illegible] pressure losses in soil and piping



# Golder Venting Model Discretisation




**Darcy's Law Air Flow**

$q = k/\mu \; \Delta P_{soil}/\Delta X_{soil}$

**Gravel Air Conductivity**

$$k_a = k_{wg} \frac{\rho_a \cdot \mu_w}{\rho_w \cdot \mu_a}$$

Where:

- $\rho$ = air/water density (Pa/m2);
- $\mu$ = air/water dynamic viscosity (Pa/sec).

**Gravel Blanket Flow**

$$Q = \left[ \frac{A \cdot t \cdot n}{N \cdot En} \right]$$

Where:

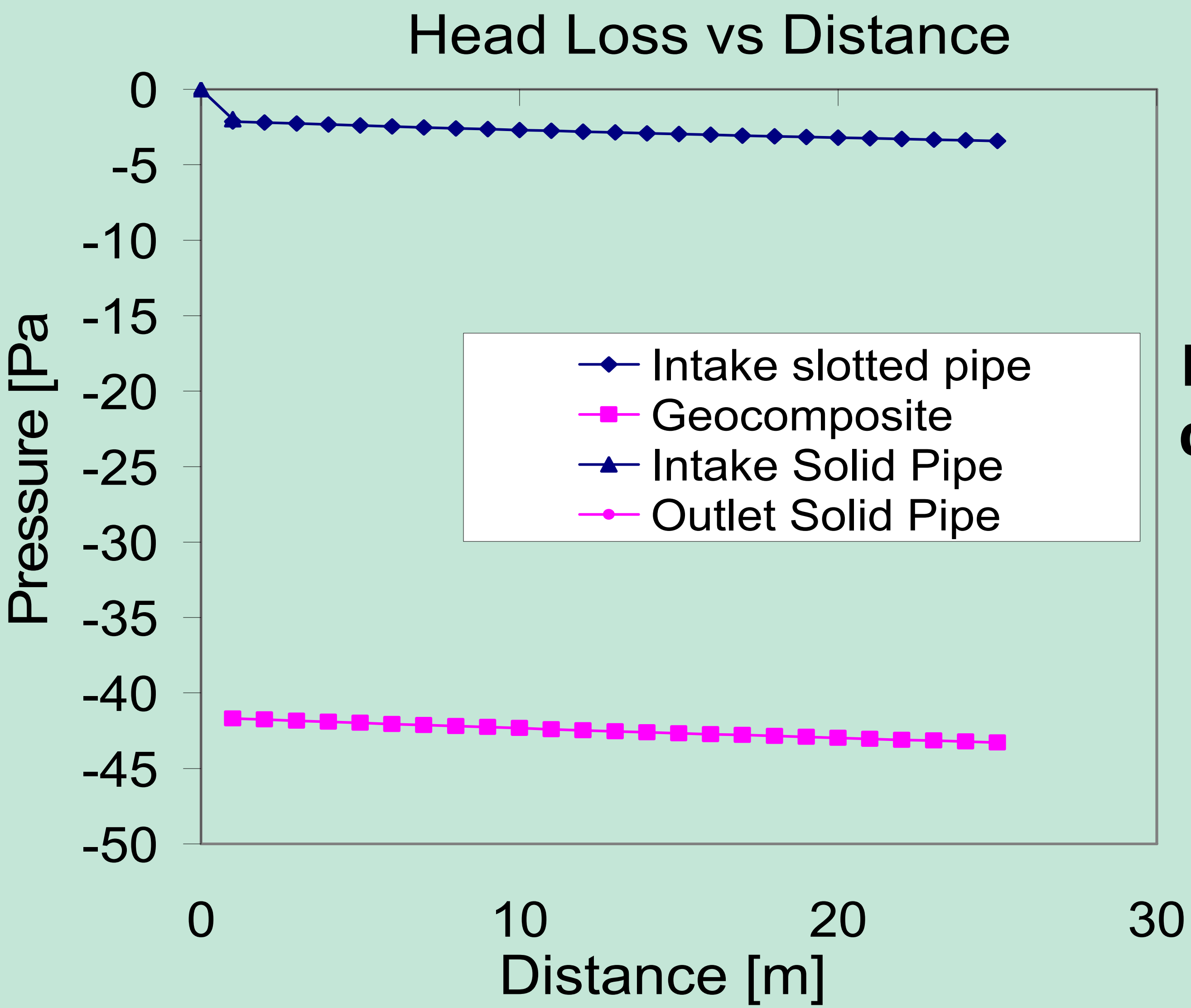
A = Building footprint area

n = Gravel Blanket Porosity

N = no of conceptualised corridor

En = no of desired exchange per hour

# Golder Venting Model Results




**From this pumps can be sized**

# Conclusions

- Subslab venting typically combined with barrier is effective technology for reducing VI
- Large range of options for design, but little design guidance or tools, nonetheless we can improve upon "a liner and some whirligigs should work?"
- Assessment tools can couple vapour intrusion modeling and civil engineering design mitigation modeling
- Opportunities for optimization of design
- Solutions will be site specific (e.g., may be different for methane compared to chlorinated solvent sites)