Mass Flux Characterization for Vapor Intrusion Assessment

ESTCP ER 201503

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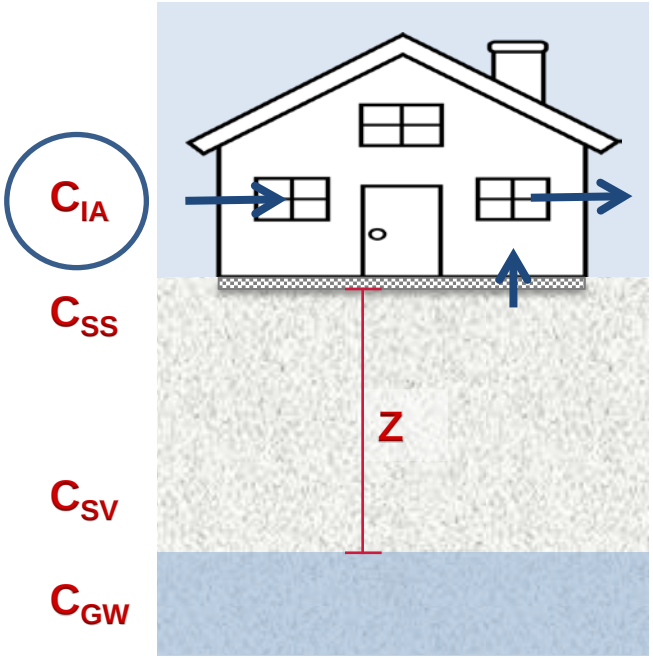
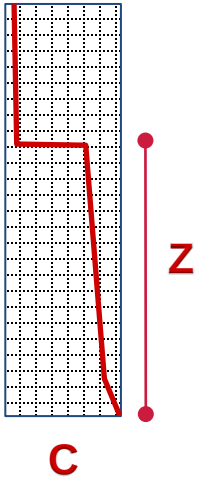
Project Team

Organization	Individual	Responsibility/Specialization
Geosyntec Consultants, Inc.	Helen Dawson	Principal Investigator; Project Manager
Geosyntec Consultants, Inc.	Todd McAlary	Technical Director
Geosyntec Consultants, Inc.	William Wertz	Co-Principal Investigator; Field Testing Manager
Geosyntec Consultants, Inc.	Hester Groenevelt	Data Validation/Data Management
Sanborn Head & Assoc	Daniel Carr	Co-Principal Investigator; Subsurface modeling
Navy	Kyle Kirchner	Site Selection; Test Planning Support
Air Force	Kyle Gorder	Field Sampling at HAFB
Neptune & Company	Paul Black	Statistical Support
Arizona State University	Paul Johnson	Academic Reviewer

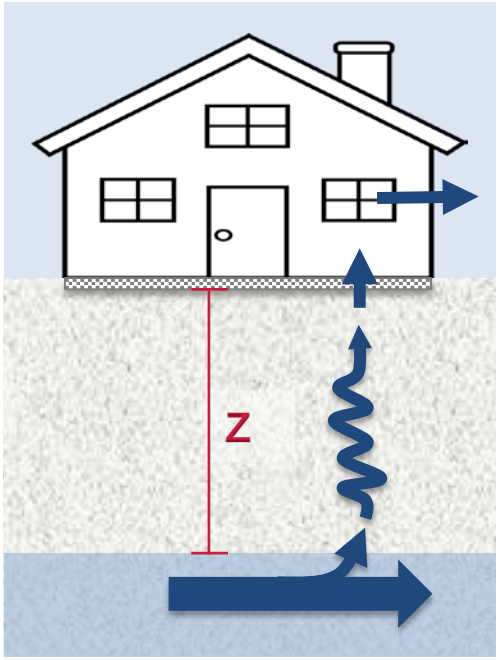
Vapor Intrusion Conceptual Models

Concentration





Mass Flux



$MF_{building}$
=
$MF_{foundation}$
=
MF_{soil}
=
$MF_{water\ table}$

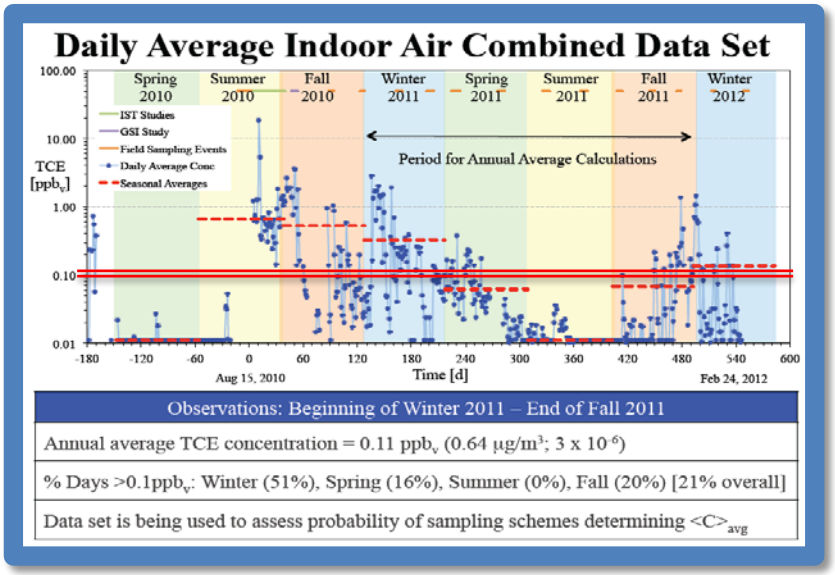
Attenuation Factors

Threshold

Variability in Indoor Air Concentrations

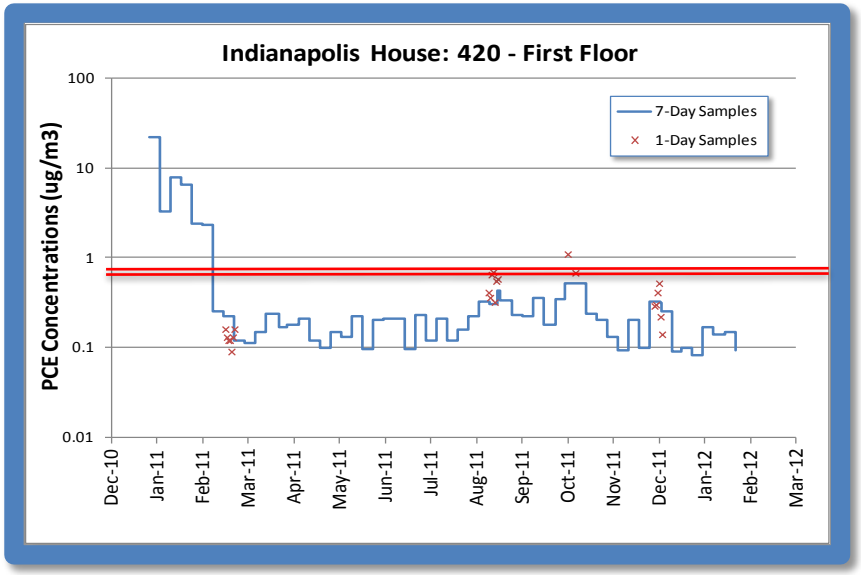
ASU House, HAFB

(Johnson et al, 2012)



Indianapolis House

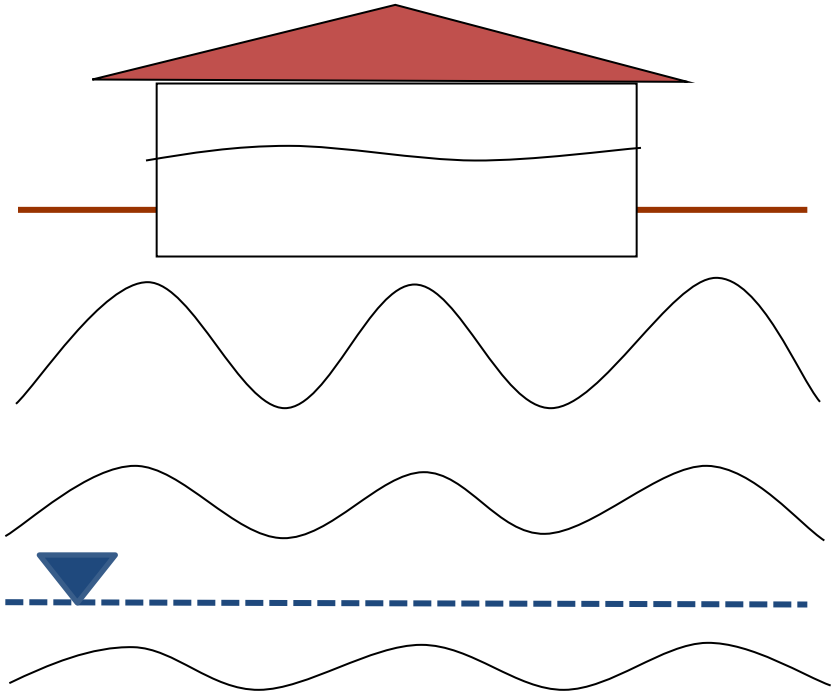
(EPA/600/R-12/673; Schumacher, 2012)



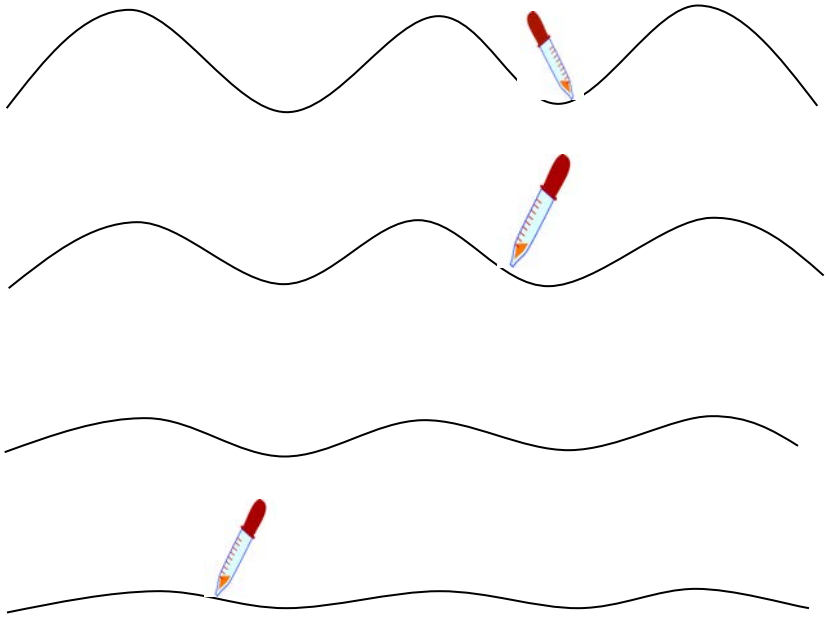
Greater than 1,000X variability in indoor air concentrations.
Most measurements are less than the long term mean.

Variability in VI Pathway Concentrations

Spatial Variability



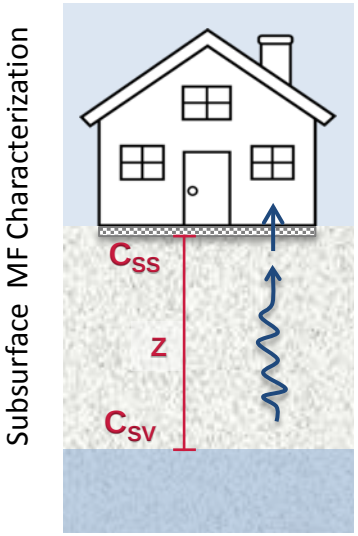
Temporal Variability



ESTCP ER-201503: Mass Flux Characterization

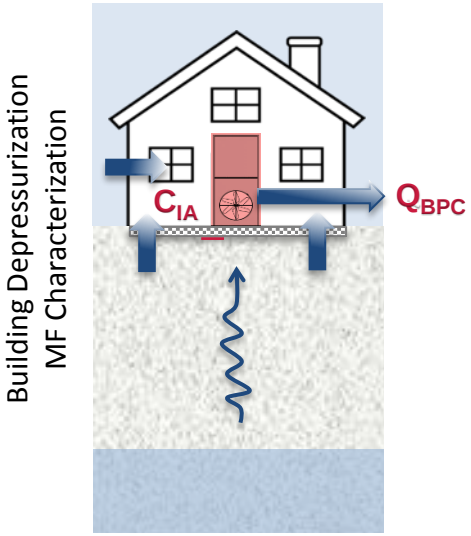
Conceptual Experimental Design

Diffusive Flux
MF1



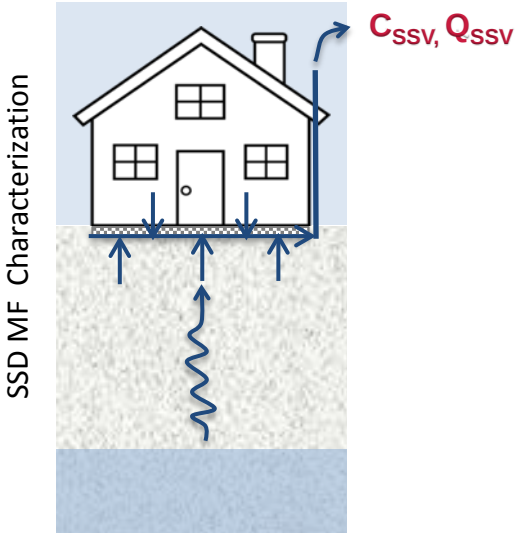
$$MF1 = - D^{eff} A_B \Delta C_{SV} / \Delta Z$$

Building Flux
MF2



$$MF2 = C_{IA} Q_{BPC}$$

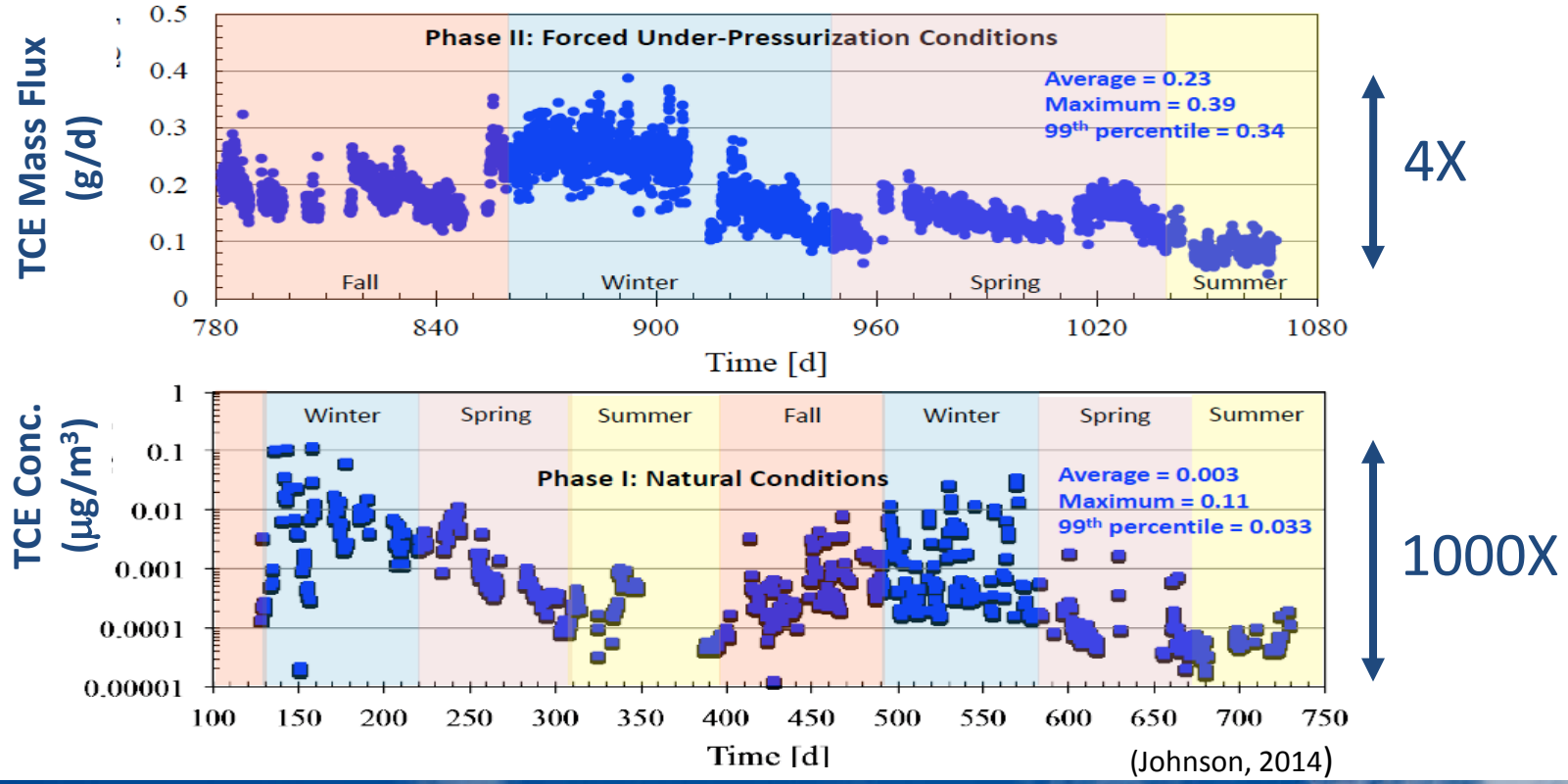
Sub-Slab Flux
MF3



$$MF3 = C_{SSV} Q_{SSV}$$

Benefits of Considering Mass Flux

- Mass flux is much less variable than indoor air concentrations.
- Mass flux characterization may expedite risk management decisions and reduce the need for long-term monitoring.



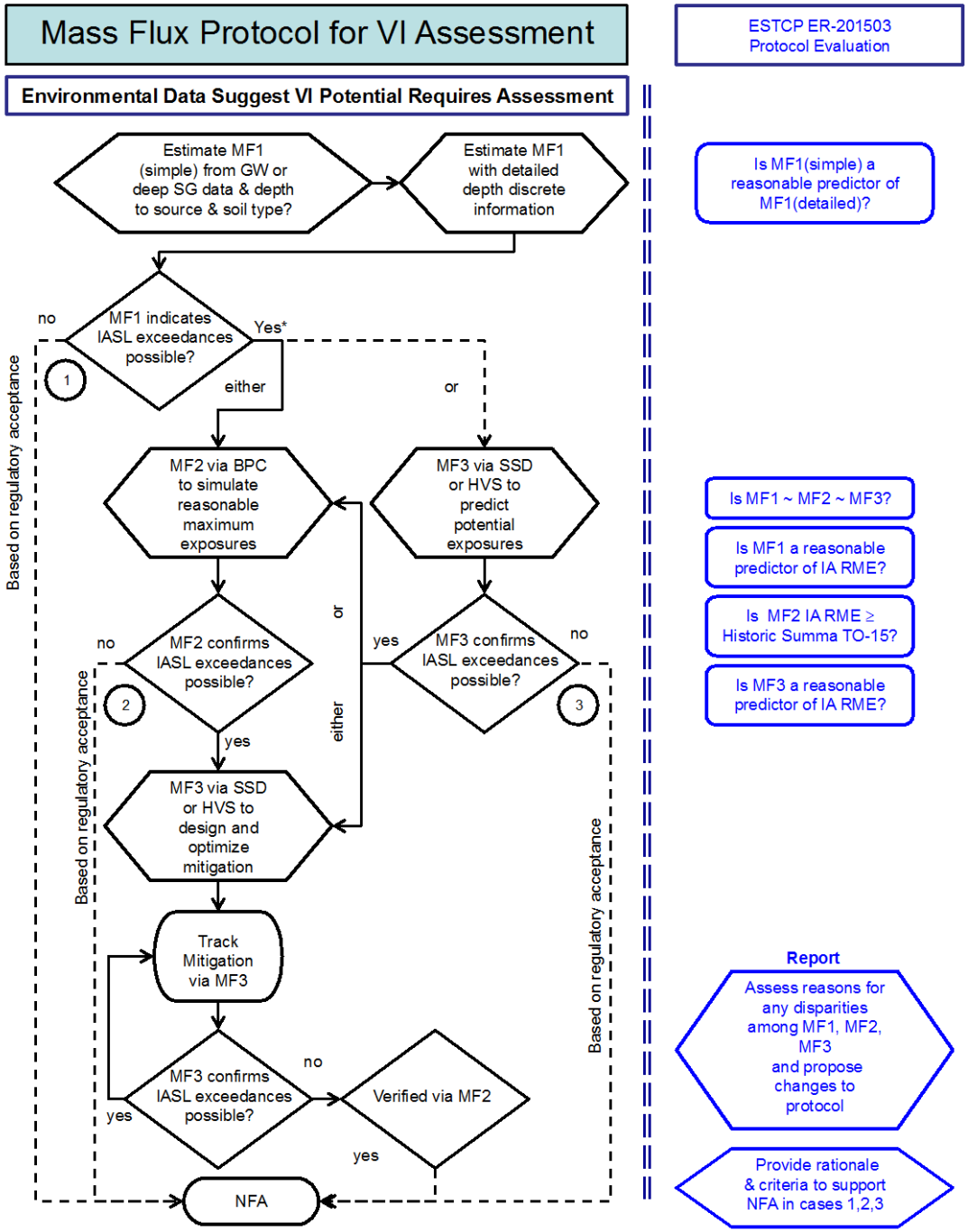
(Johnson, 2014)

Technical/Performance Objectives

- Demonstrate/validate mass flux characterization as a reliable and cost-effective approach for VI assessment and for developing exit strategies for VI mitigation systems.
- Document methods, outcomes, and performance.
- Document cost savings.
- Transfer technology to DOD staff and contractors.
- Facilitate recognition, acceptance, and approval by practitioners, responsible parties, and regulators.

Draft Protocol

- Preliminary assessment suggests potential VI impacts
- MF1 data assessment (if existing) or collection
- Compare MF1 to threshold
- MF2 and/or MF3 data collection
- Compare MF2/MF3 to threshold
- Mitigation or NFA



Geosyntec consultants

Number and Types of Samples

Component	Matrix	Number of Samples	Analyte	Location
Field Construction	Whole Soil	12 and 1 QA duplicate	Physical parameters[1]	4 exterior soil boring locations
	Whole Soil	12 and 1 QA duplicate	EPA's SW-846 Alternative Method 5035	4 exterior soil boring locations
Soil Gas Sampling	Soil gas: Field Measurement	During collection of lab samples	Organics via PID	Same location as lab samples
	Soil gas: Laboratory Measurement	66 = (22 per event) x (3 events)	EPA Method TO-15 SIM	5 ft, 12 ft, and 19 ft in each of 4 exterior soil vapor probe locations
Building Pressure Cycling	Indoor Air: Field Measurement	Continuously until steady VOC concentrations observed	Hapsite GC/MS	Building interior
	Indoor Air: Laboratory Measurement	8 = (4 per event) x (2 events)	EPA Method TO-15 SIM	Building interior
	Outdoor Air: Laboratory Measurement	2 (1 per event)	EPA Method TO-15 SIM	Upwind, building exterior
SSV System Sampling	Sub-Slab Soil Gas: Field Measurement	Over time until PID observations reach a dynamic equilibrium	Organics via PID	Existing SSV System Ventilation Pipes
	Sub-Slab Soil Gas: Laboratory Measurement	9 = (3 locations per event) x (3 events)	EPA Method TO-15 SIM	Existing SSV System Ventilation Pipes

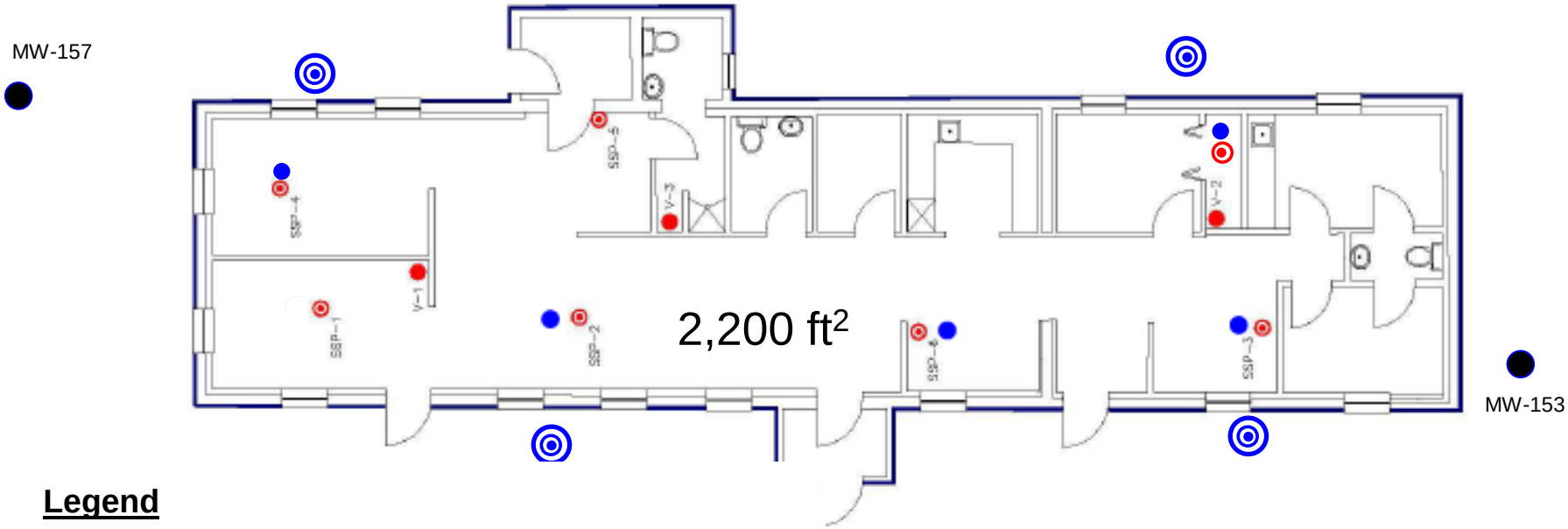
Demonstration Site 1 - Description

- Groundwater source
  - DTW~ 20 feet
  - Coarse to fine sand
- TCE concentrations
  - Groundwater 6.6 to 120 µg/L
  - Indoor air 20 to 59 µg/m^3 (pre-mitigation)
  - Sub-slab 86 to 29,019 µg/m^3
- Measured sub-slab mass flux (ER-201322)

Building 200, Raritan Arsenal, Edison, NJ

Building 200 Sampling Locations

Raritan Arsenal, Edison, NJ



Legend

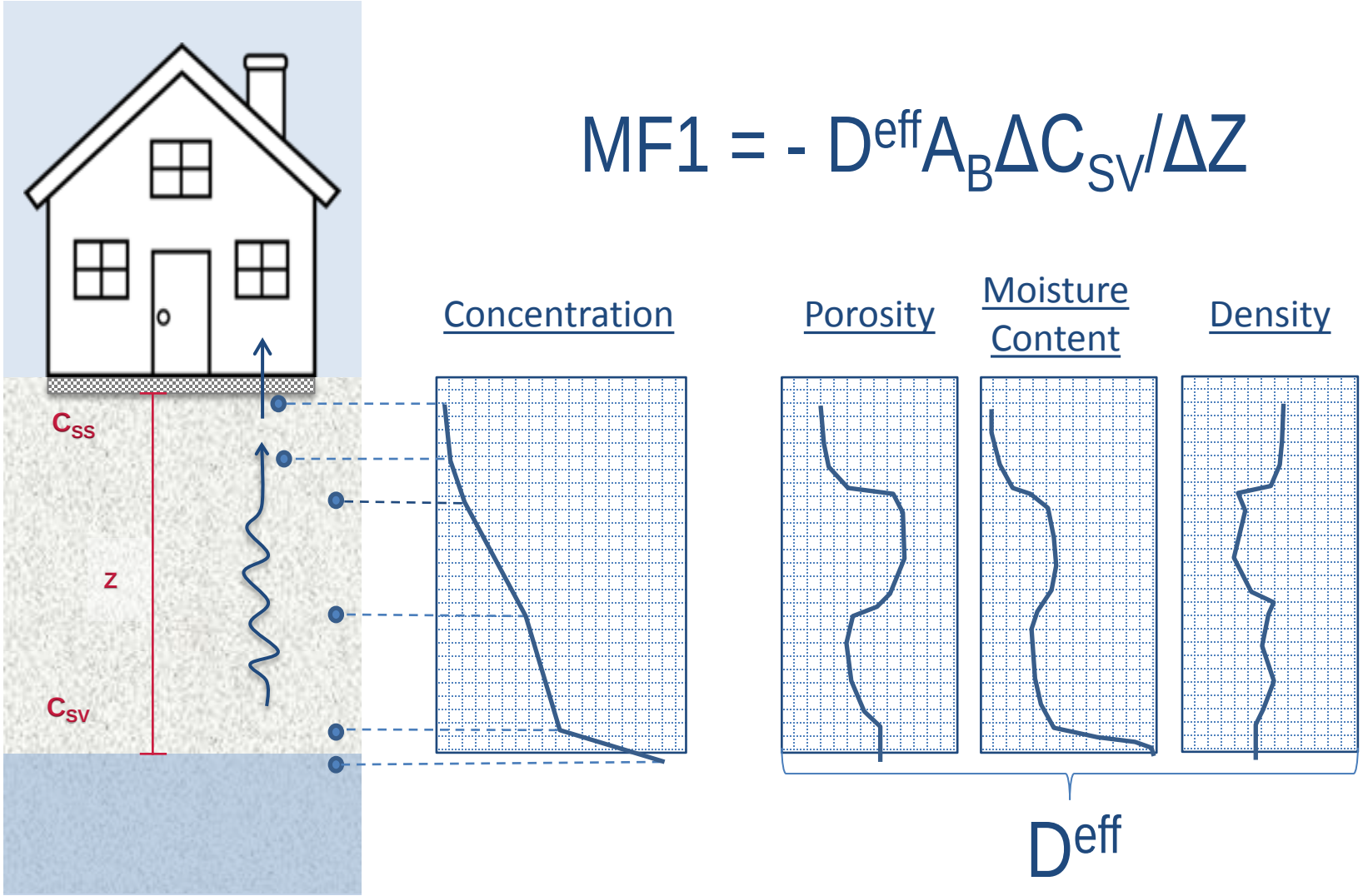
- SSV extraction point (existing)
- Sub-slab probe (existing)
- Proposed soil vapor probe (5 ft deep)
- Proposed multi-level soil vapor probe (12 ft, 19 ft)
- Groundwater monitoring well (location approximate)

Threshold Mass Flux ~ 0.02 g/day for TCE IA target of 3.0 µg/m^3 and air exchange rate of 0.5/hr.

Field Plan

- Days 1 & 2 (Thursday – Friday)
  - Collect vent pipe air for VOC analysis and measure flow rate in vent pipes of existing SSV system
  - Turn off SSV system
  - Field construction: conduct soil boring and collect whole soil samples; install nested soil vapor probes; install pressure differential monitors
  - Collect groundwater grab samples at water table
- Day 3 (Saturday)
  - Collect exterior soil vapor samples
  - Collect interior sub-slab and 5 ft soil vapor samples for VOC analysis
- Day 4 (Sunday)
  - Measure baseline indoor air concentrations
  - Depressurize building and measure indoor air concentrations
  - Pressurize building and measure indoor air concentrations

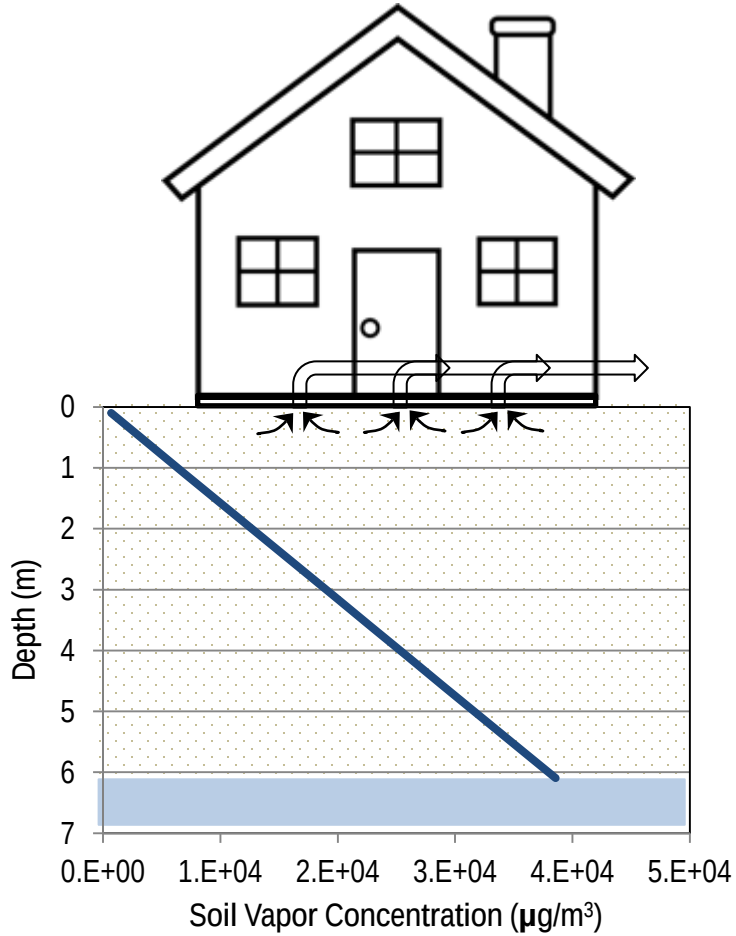
MF1: Diffusive Mass Flux



$$MF1 = - D^{eff} A_B \Delta C_{SV} / \Delta Z$$

MF1: Diffusive Mass Flux

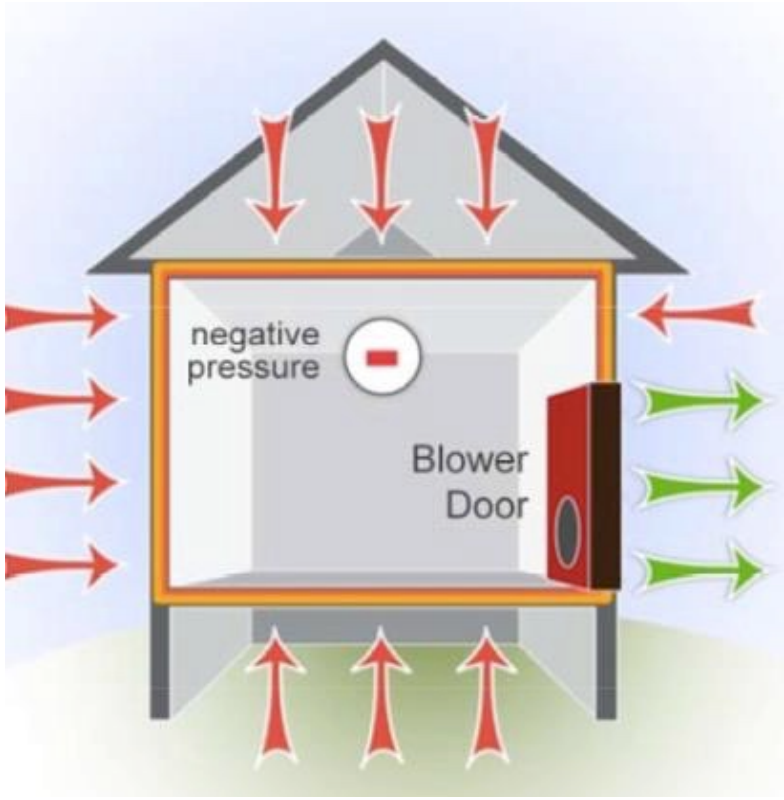
Estimated from Groundwater Concentration



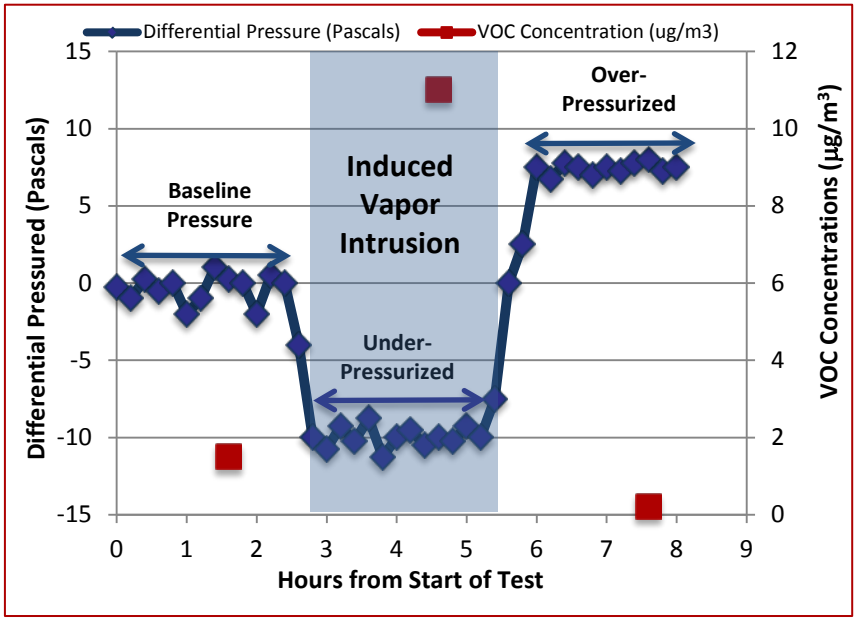
- Groundwater: 120 µg/L (max)
- Depth to water: 20 ft
- Vadose zone soil: sand; default soil properties
- Calculated mass flux
  - Mass transport rate ~0.13 g/day
- Exceeds threshold mass flux of ~0.02 g/day.

MF2: Building Pressure Cycling

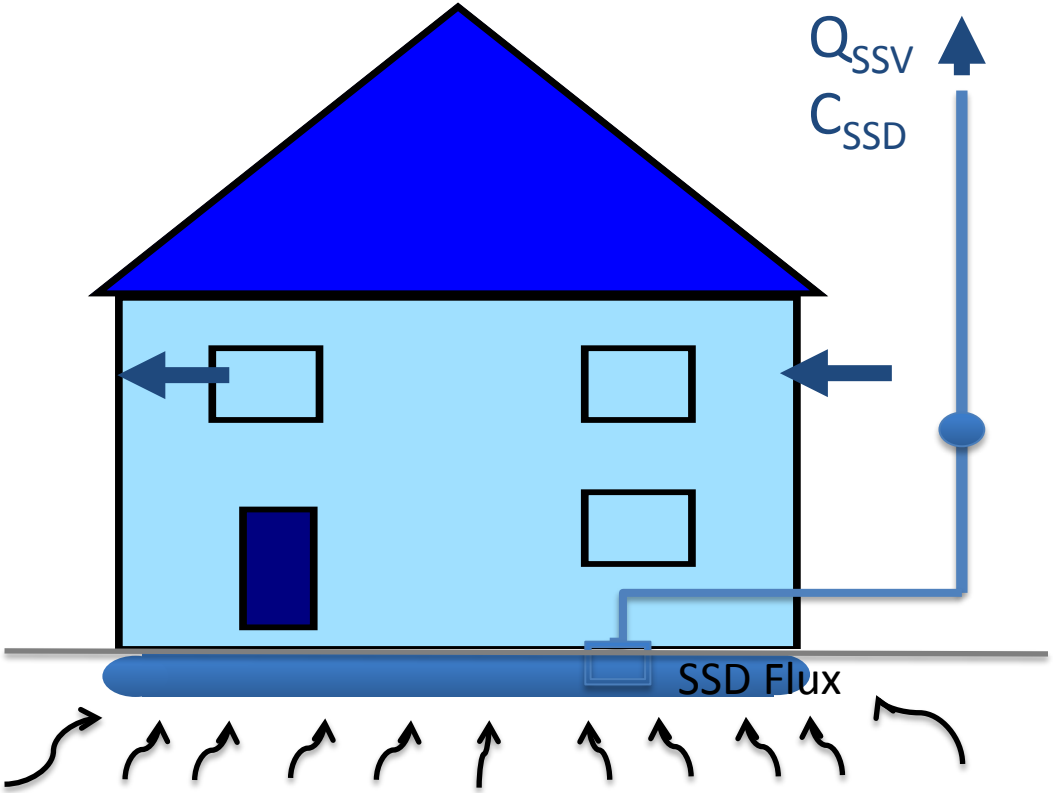
$$MF2 = C_{IA} Q_{BPC}$$



- Negative pressure: induces vapor intrusion
- Positive pressure: inhibits vapor intrusion
- For large commercial buildings, HVAC system can be adjusted to create pressure and vacuum conditions.



MF3: Forced Sub-Slab Depressurization



$$MF2 = Q_{SSV} \times C_{SSV}$$

1. Existing SSD system testing; or
2. High volume sub-slab sampling.

MF3: Sub-Slab TCE Mass Flux

- Building 200 SSV mass flux measurements from ESTCP ER-201322

Date	Stack Concentration ($\mu g/m^3$)	Stack Velocity (ft/min)	Stack Area (ft^2)	Flow Rate (cfm)	Mass Removal Rate (g/day)
JUL 2015	1200/300/1600	36/37/35	0.049	1.8	0.22
DEC 2016	1000	97	0.049	4.8	0.19
JAN 2016	700	134	0.049	6.6	0.20

- SSV mass removal rates exceeds threshold mass flux of ~0.02 g/day; SSV mitigation system is needed.
- Mass removal rate is similar to estimated diffusive mass flux (0.2 vs 0.13 g/day TCE).

Estimated Indoor Air Concentrations

- Indoor air concentrations estimated from MF3 are similar to pre-mitigation (2005) indoor air concentrations (20 to 60 µg/m^3)
- MF3 ~ MF2 = $C_{IA}\ Q_{bldg} = C_{IA}\ A_{bldg}\ H_{bldg}\ AER_{bldg}$
- Trichloroethene (C_{IA}):

Building Footprint (ft^2)	Building Height (ft)	Q_{build} (scm/d)	Air Exchange Rate (AER)* (/hr)	Indoor Air (µg/m^3)
2200	10	2690	0.18	**36**
2200	10	6724	0.45	**14**
2200	10	18827	1.26	**5**

* USEPA (2011). Exposure Factors Handbook: 10%, 50%, & 90% values of residential AERs.

Application to VI Risk Management

- Calculate RME indoor air concentration from mass flux:

$$IA_{RME} = MF_{1,\ 2,\ or\ 3} / (V_{bldg}\ AER)$$

- Calculate mass flux threshold from target indoor air concentration:

$$MF_{threshold} = IA_{target}\ V_{bldg}\ AER$$

IA	=	indoor air concentration
$MF_{1,\ 2,\ or\ 3}$	=	mass flux characterized by Methods 1, 2, or 3
AER	=	air exchange rate
RME	=	reasonable maximum exposure

Key Points

- Mass flux characterization has potential to improve VI assessment
  - Provide alternative lines of evidence
  - Address challenges due to spatial & temporal variability and preferential pathways
  - Reduce timeframe for and increase confidence in risk management decisions
  - Reduce VI assessment costs