U.S. EPA "State of VI Science" Workshop

Evaluating Alternative Vapor Intrusion Strategies Through Simulations Using Data-Rich Case Studies

Soil Gas Management Concepts

Presenter: Bo Stewart, Praxis Environmental

How do we bring sources of contaminant vapors 'under control'?

Presentation archived at https://iavi.rti.org/

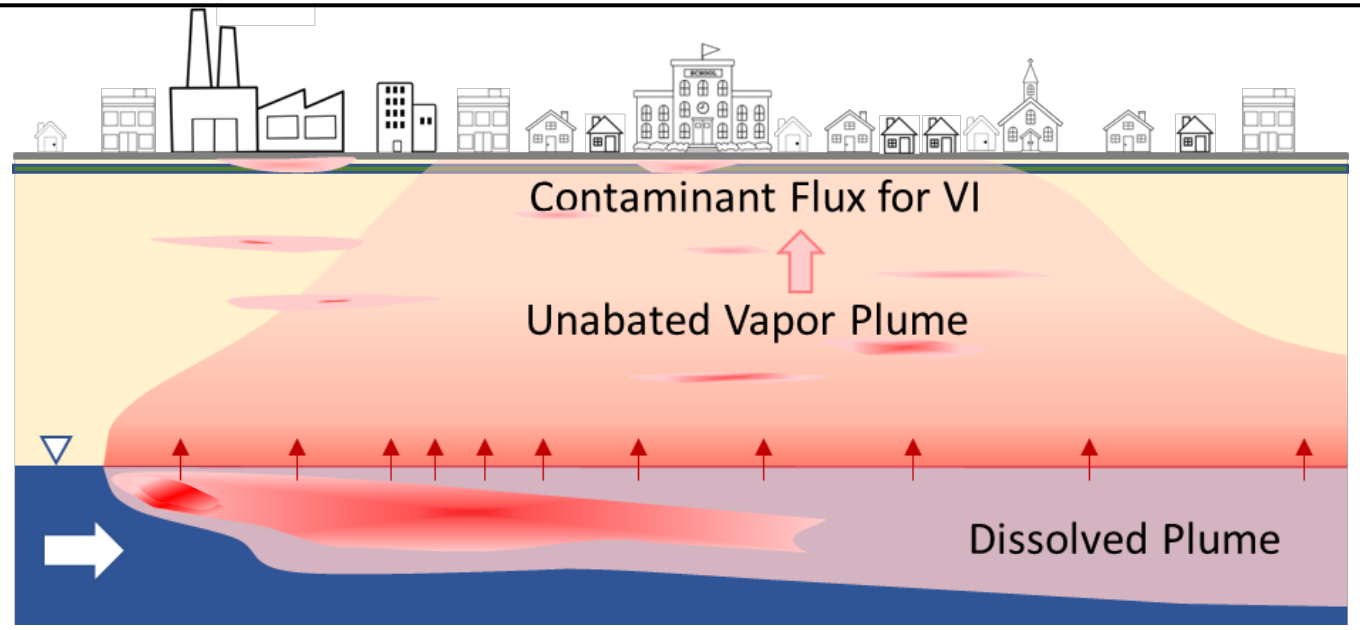
34th Annual International Conference on Soil, Water, Energy, and Air, March 18, 2025

Background & Context for Soil Gas Management

- **What "sources" exist for VI?**
  - Today's activities assume contaminated GW
- **What data are typically available for assessing VI potential?**
  - GW data from plume delineation (driver for VI investigations)
  - Indoor air (modest intrusion) and subslab (significant intrusion) sampling at structures
  - Shallow (2' to 5' bgs) external soil gas
- **What choices exist for mitigation/elimination of VI?**
  - Install barriers, if applicable (significantly intrusive)
  - Subslab de-pressurization (significantly intrusive, ongoing)
  - Soil vapor extraction (as close to source as possible)
  - Cleanup of the contamination groundwater (expensive, impractical?)

Background & Context for Soil Gas Management

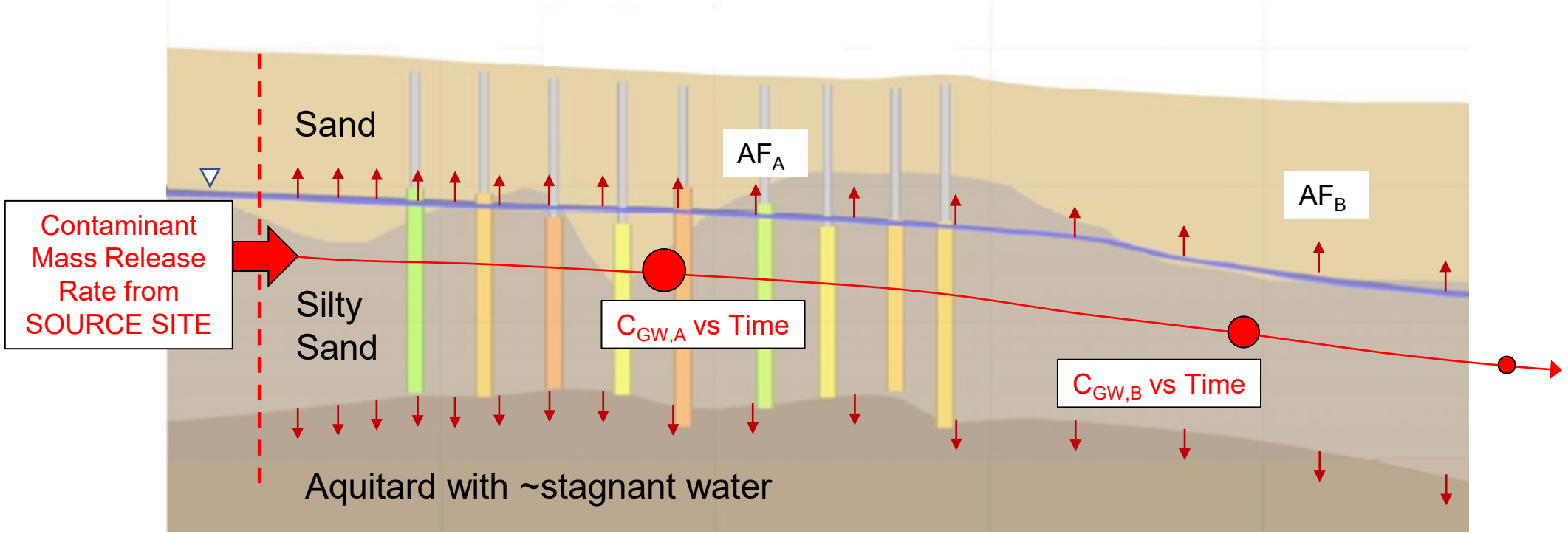
- **Local Vadose Zone**
  - Residual mass remains at levels resulting in significant rebound
- **Groundwater Plumes**
  - Primarily upward vertical vapor migration
  - Vapor plume is fed by volatilization from groundwater



Contaminated soil gas is a source of VOCs for VI

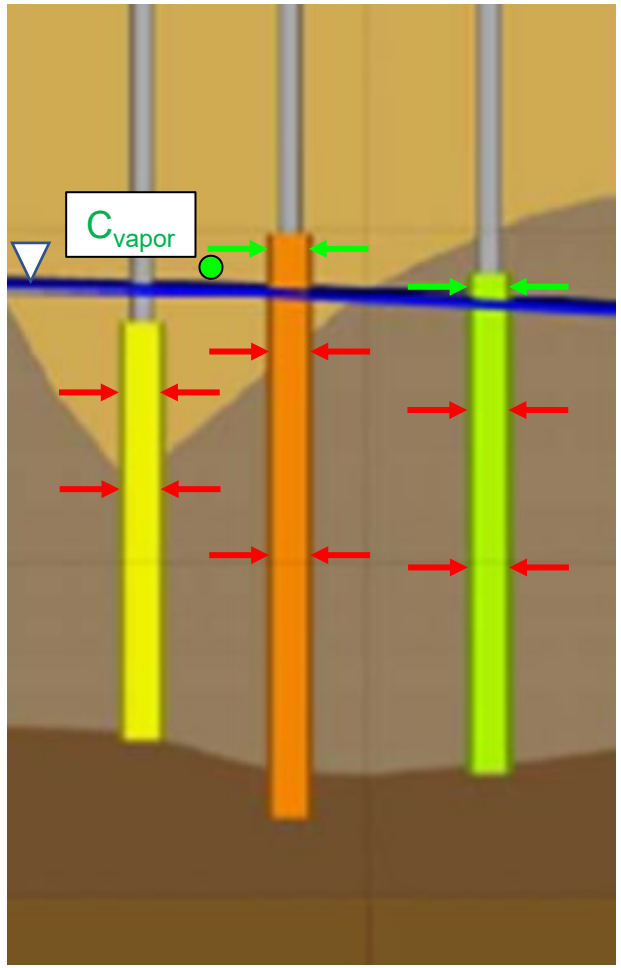
Contaminated groundwater is a source of VOCs for soil vapors

Anytown USA Groundwater Plume



Soils above the aquitard are primarily alluvial deposits, including clayey to sandy **silt**, **sand**, sand & gravel, silty sand, clayey sand, and sandy **clay**.

Why Sample Deep Soil Gas at Anytown USA?



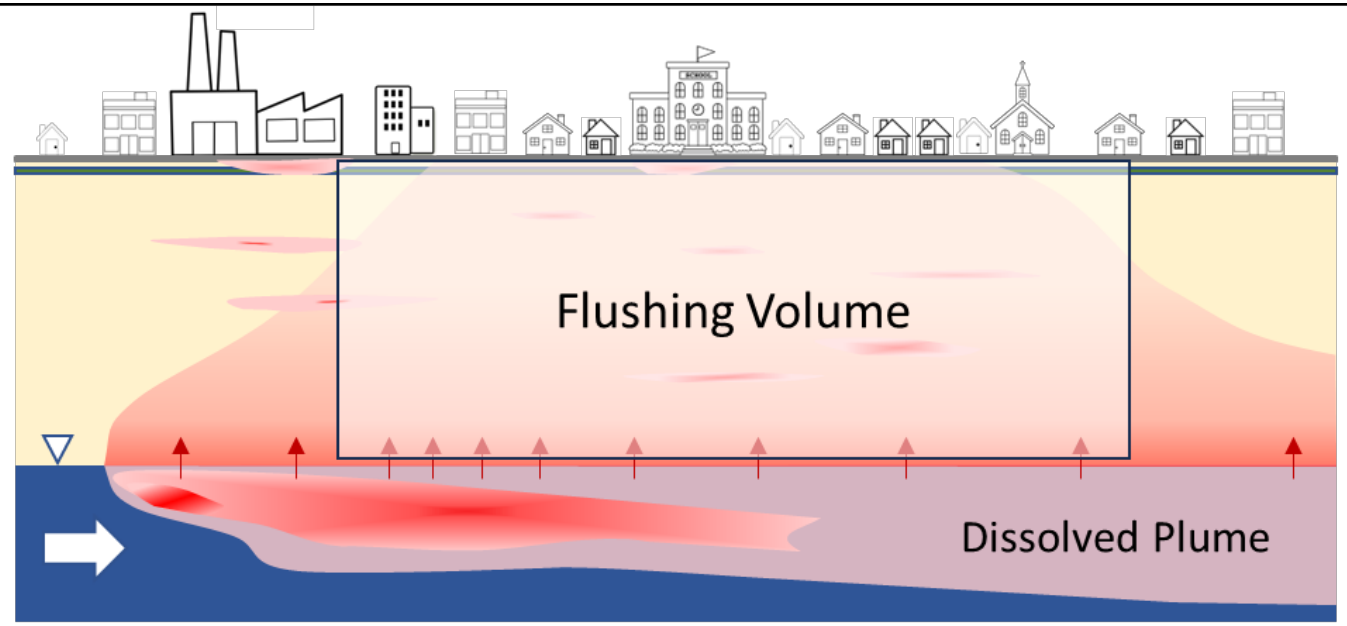
- Potential groundwater sources for vapor intrusion are commonly assessed based on groundwater concentrations
- The groundwater concentration is divided by Henry's constant to yield an estimated vapor concentration just above the water table
  - *Does Henry's Law yield a representative vapor concentration at the water table?*

$$C_{vapor} = C_{GW} / H$$

- What volume of water does the measured GW concentration represent? Henry's Law assumes it represents the water at the capillary fringe
  - *Why not simply sample vapors from open screen if available?*
- Deep soil gas can mirror the consistency of groundwater concentrations as compared to very shallow sampling which is impacted by weather, season, and human behavior

Background & Context for Soil Gas Management

- **Should we be waiting to eliminate vapor contaminants until they are next to the point-of-use?**
  - Subslab de-pressurization (SSD) systems are adjacent to people
- **Can we create a separation distance between contaminants and people?**
  - Flushing contaminants from the vadose zone down to the source(s) can create a buffer zone



Flushing numerous soil pore volumes removes vapors from permeable soils

Background & Context for Soil Gas Management

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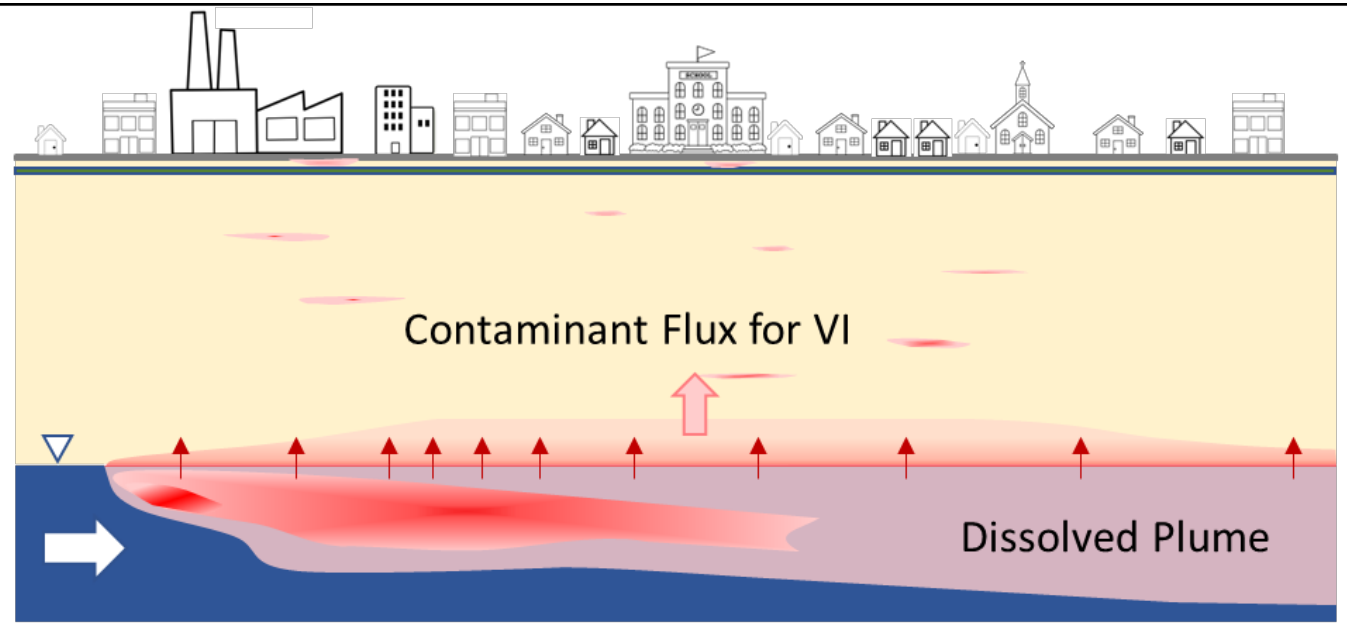


Feasibility determined by soil type, geology, depth to water, stored mass locations, etc., identical to SVE

How often does the flushing need to occur?

Design & Operational Concept for SGM

[Flushing Rate / Frequency] > [Vertical Mass Transport Rate]

⇒ ***Soil Vapor Concentration < VISL at Separation Distance***

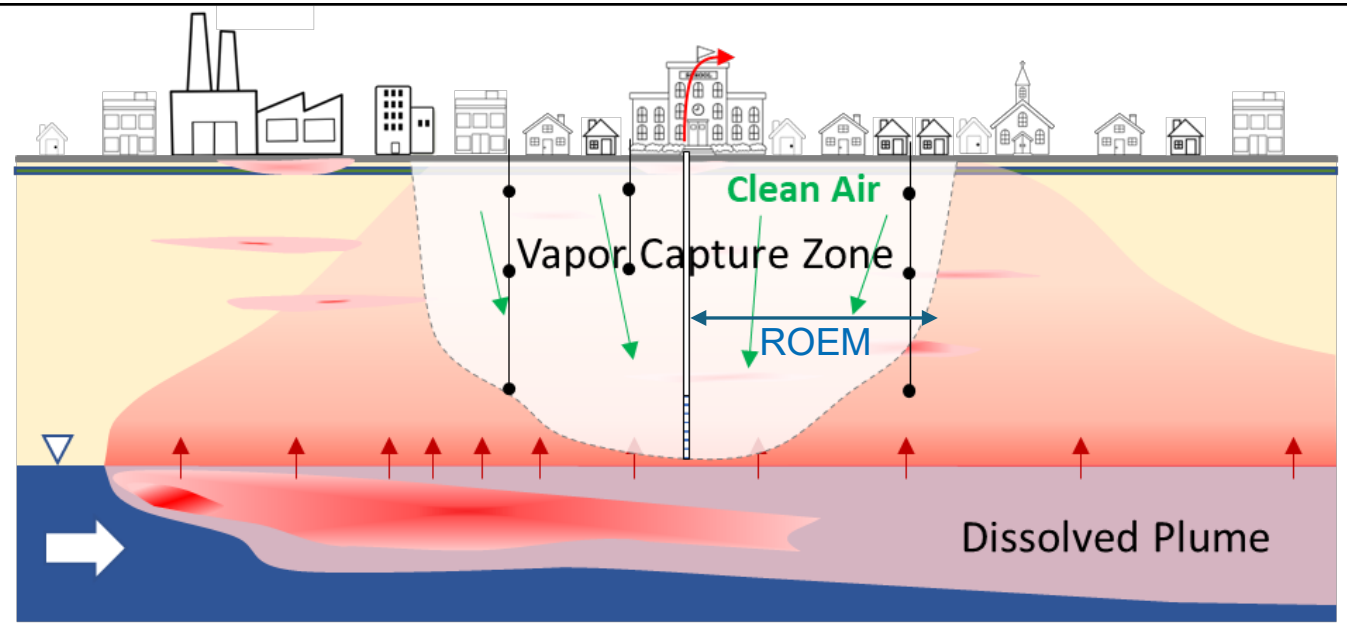
Design Parameters for Control of Contaminant Vapors:

- How far does one SVE well reach laterally?
  Radius of Effective Management (ROEM)
- What soil gas extraction rate is practical?
- What is the duration of extraction to provide adequate flushing?
- How frequently does the volume require flushing?
- What are appropriate “sentinel” depths and concentrations?
  Separation distance

Design & Operational Concept for SGM

- **Soil vapor extraction (SVE) has been employed for decades to flush contaminants from the vadose zone**
  - Well understood processes and timescales
  - Single well pilot testing can provide estimates for the design parameters

GW well with exposed screen for pilot test? Yes!



- **Lateral extent of flushing (ROEM)**
- **Practical extraction rate**
- **Duration of extraction to flush the volume reached**
- **Rate of "rebound", i.e., time for sentinel wells to exceed VISL-equivalent**

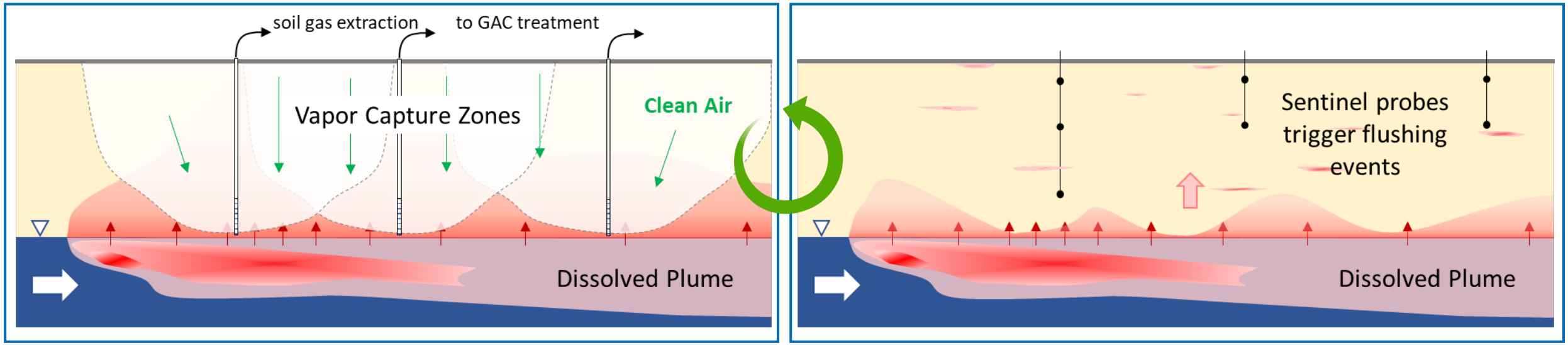
What do SVE Systems Look Like?

20-hp blower powered by a utility pole drop
(up to 600 scfm)

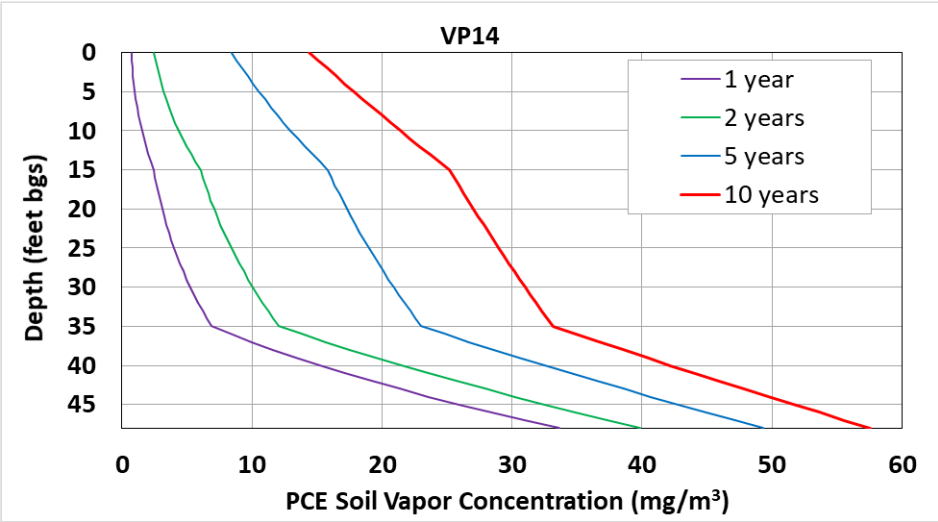
1-hp blower powered by a residential (15A) outlet
(up to 60 scfm)

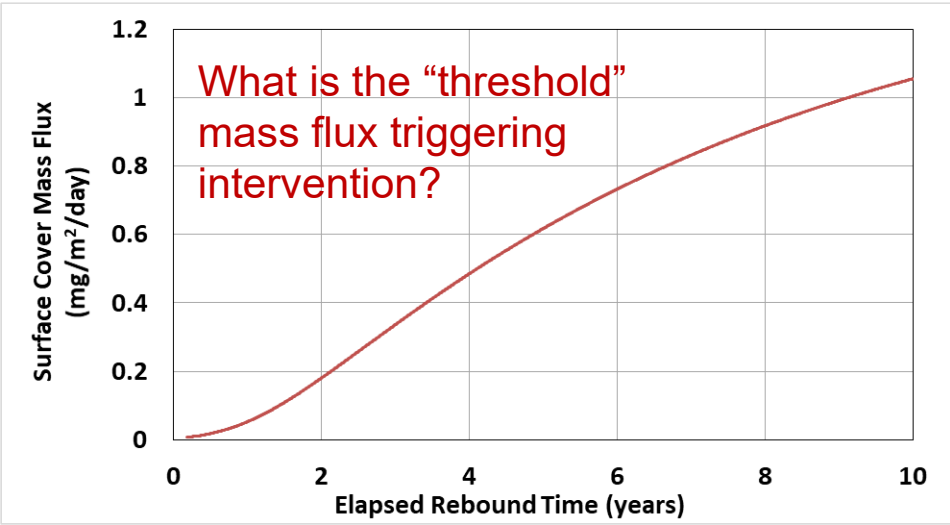
Design & Operational Concept for SGM

- **Rotate application of SVE across an array of wells covering area above the contaminated GW plume**
  - Flush numerous target pore volumes from a well and move to the next one
  - Monitor vapor concentrations across the vertical extent of the vadose zone
  - Repeat the rotation of extraction wells

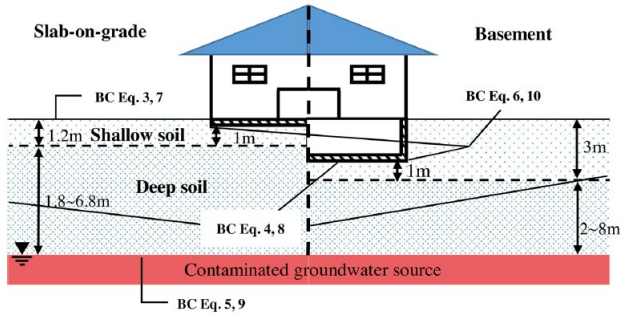


Timescales for Vadose Zone Transport

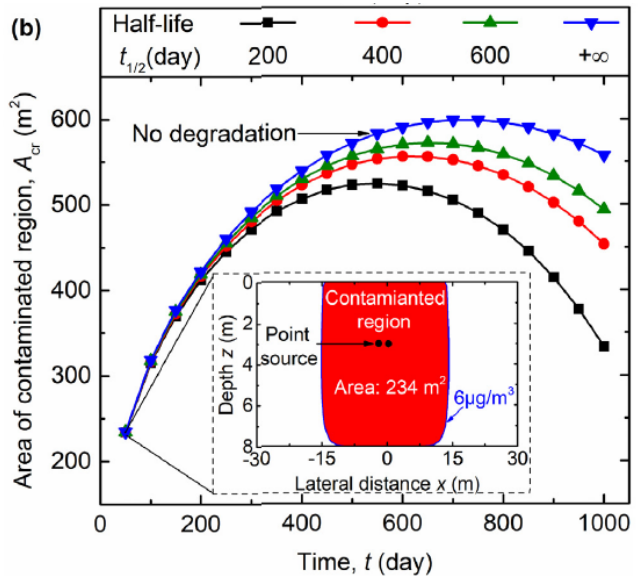




Attaining quasi-equilibrium in the vadose zone can take years



Numerous papers and studies investigate quasi-equilibrium; far fewer look at the transient behavior



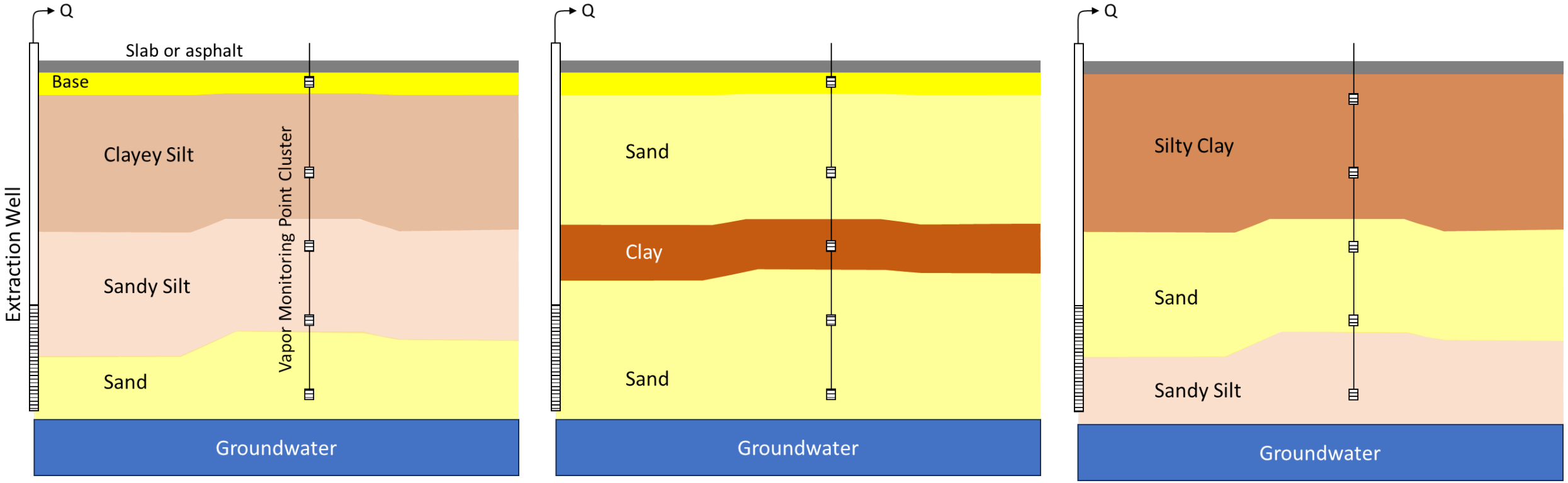
Ding et al. 2022, Science of the Total Environment 806 150370, https://doi.org/10.1016/j.scitotenv.2021.150370

Timescales for Vadose Zone Transport

Upward Mass Flux Rate and Applicability of SVE & SGM depends on hydrogeology

- *Depth to water*
- *Soil type, layering & sequencing*

⇨ **ROEM is primary cost driver**



Soil Gas Management at Anytown USA

Do off-site groundwater concentrations indicate a potential for VI?

- Data are collected as part of the groundwater plume delineation

If yes, do vadose zone soil gases indicate a potential for VI?

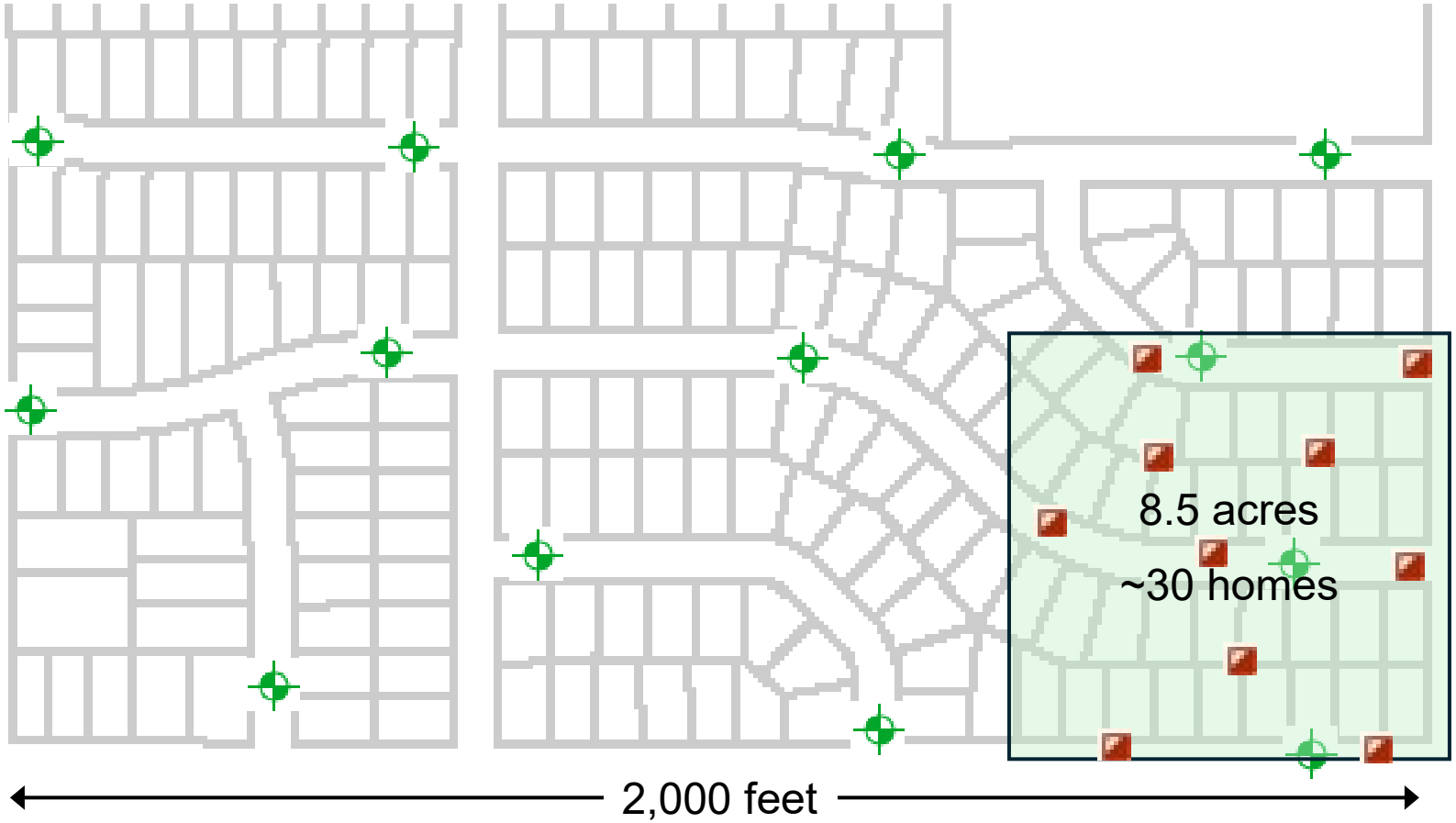
- Install and sample triple-nested vapor monitoring points (VMPs)

Do vadose zone soil gases indicate a potential for VI?

- No, perform semi-annual monitoring of triple-nested VMPs
- YES, implement active soil gas management

Soil Gas Management at Anytown USA

No VI potential from initial vadose sampling of 10 VMPs
- *perform semi-annual monitoring of triple-nested VMPs*



GW monitoring well

Triple nest VMP location

GW contamination transported from upgradient source(s)

Soil Gas Management at Anytown USA

YES, VI potential exists based on initial vadose sampling of 10 VMPs
- *Implement active SGM (~30 homes over 8.5 acres)*

- Install 1 extraction well (if no open MW screen) and run pilot test
- Monitor rebound in nearby triple-nested VMPs
- Design full system and develop Work Plan
- Install infrastructure (extraction wells and nested monitoring points)
  - 1-1.5 VMP per extraction well
- Procure SVE system and deploy
- Perform cyclic operation and quarterly monitoring

Soil Gas Management at Anytown USA

Pilot Test Results:

Base Case Design Parameters	Unit	Estimate
Single Well Radius of Effective Management	feet	**85**
Duration of Subsurface Flushing per Cycle	days	5
Timescale for Rebound of Vapor Concentrations	months	12
Surface Area Targeted for VI Mitigation	acres	8.5

Design Details:

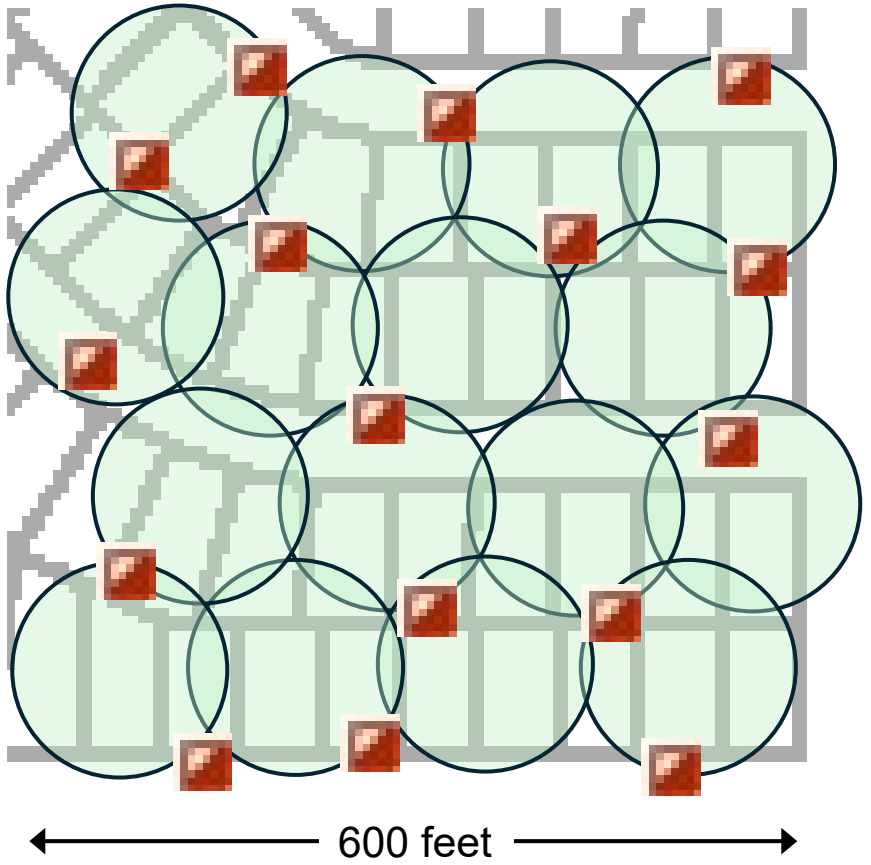
Base Design Details	Unit	Estimate
Number of Extraction Wells	-	**16***
Number of VMPs (~1.5 per extraction well)	-	24*
Rotation Frequency among Extraction Wells	weeks	1
Number of cycles per year	-	2
Surface Area Targeted for VI Mitigation	acres	8.5

*Total number including installs from initial investigation and pilot testing

Soil Gas Management at Anytown USA

SVE system = 0.75-hp blower powered by solar panels & GAC off-gas treatment

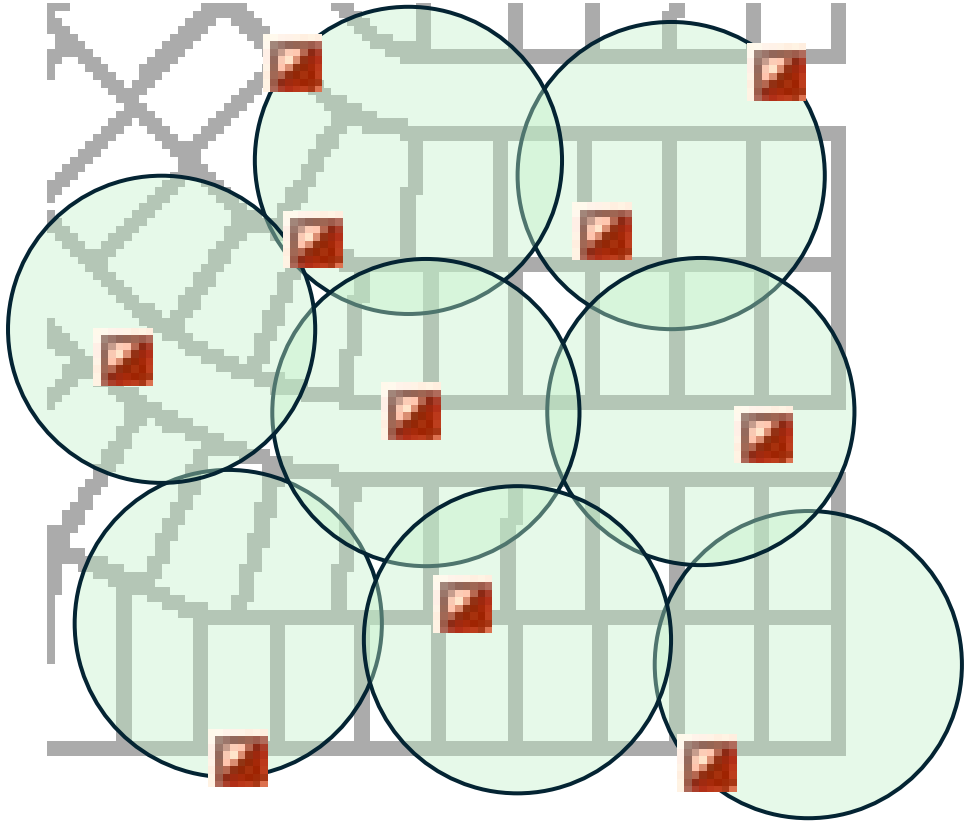
ROEM = 85 feet (16 wells)
1 system rotated weekly (4 months) twice per year



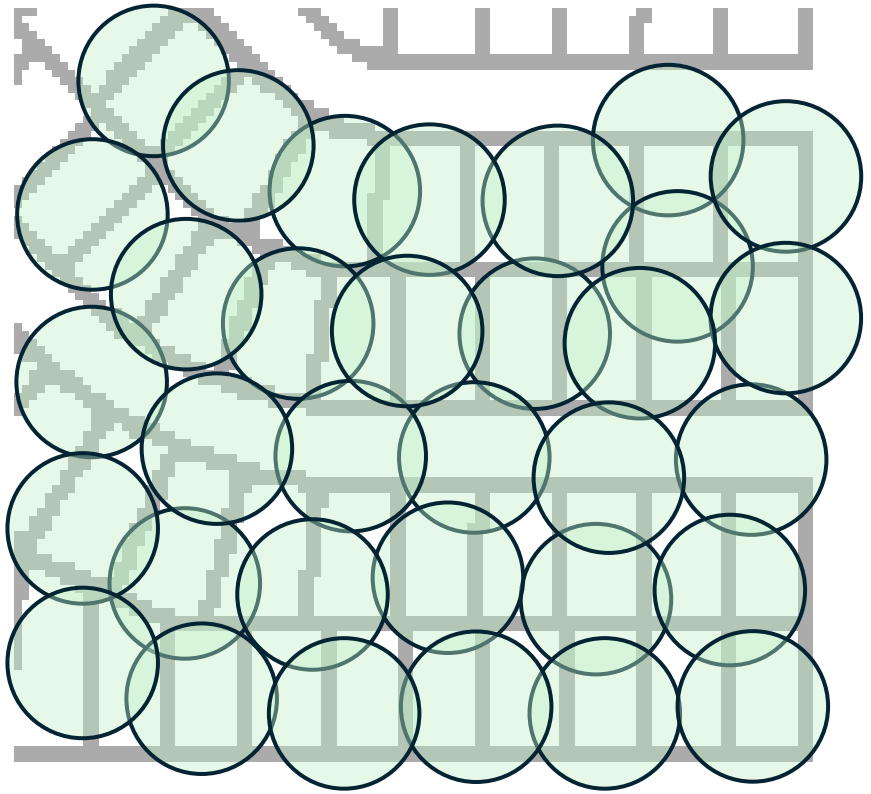
Triple nest VMP location

Soil Gas Management at Anytown USA

ROEM = 120 feet (8 wells)
1 system rotated bi-weekly twice per year

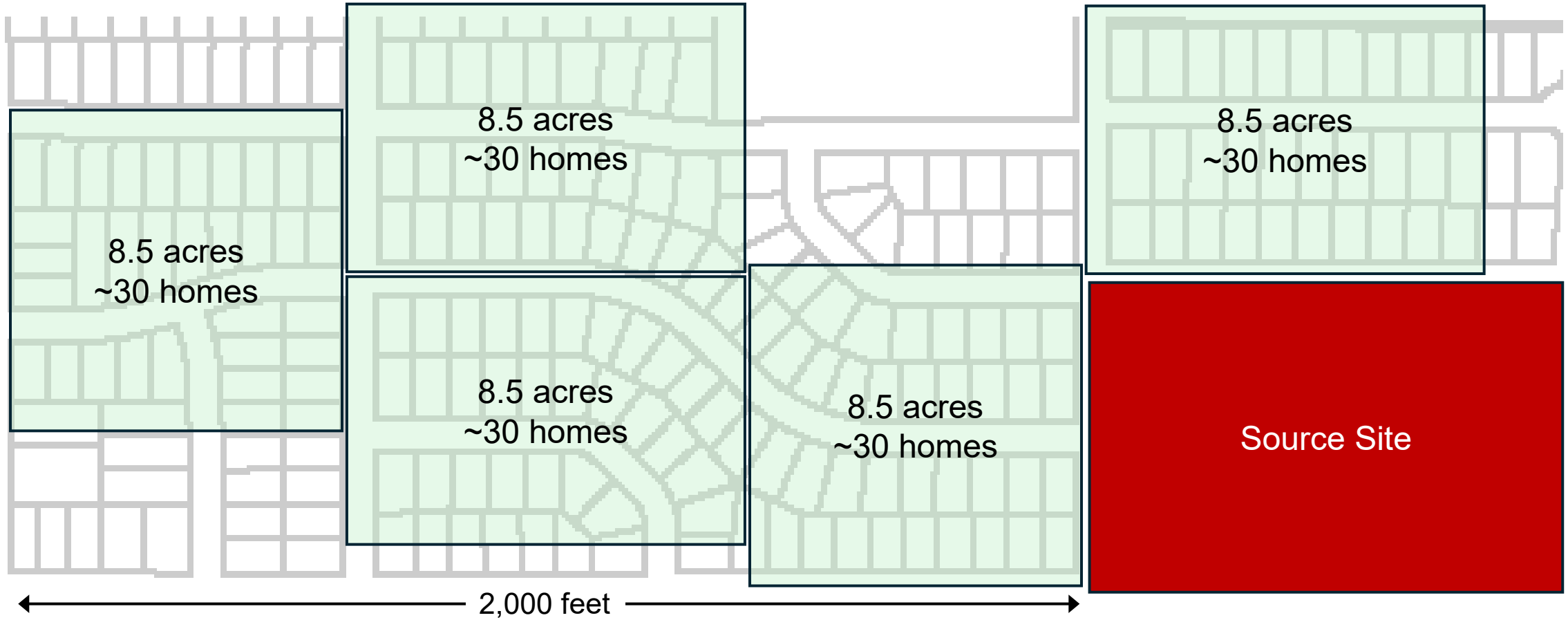


ROEM = 60 feet (33 wells)
2 systems rotated weekly twice per year



Soil Gas Management at Anytown USA

Implementation of SGM proceeds in parallel with GW plume investigation



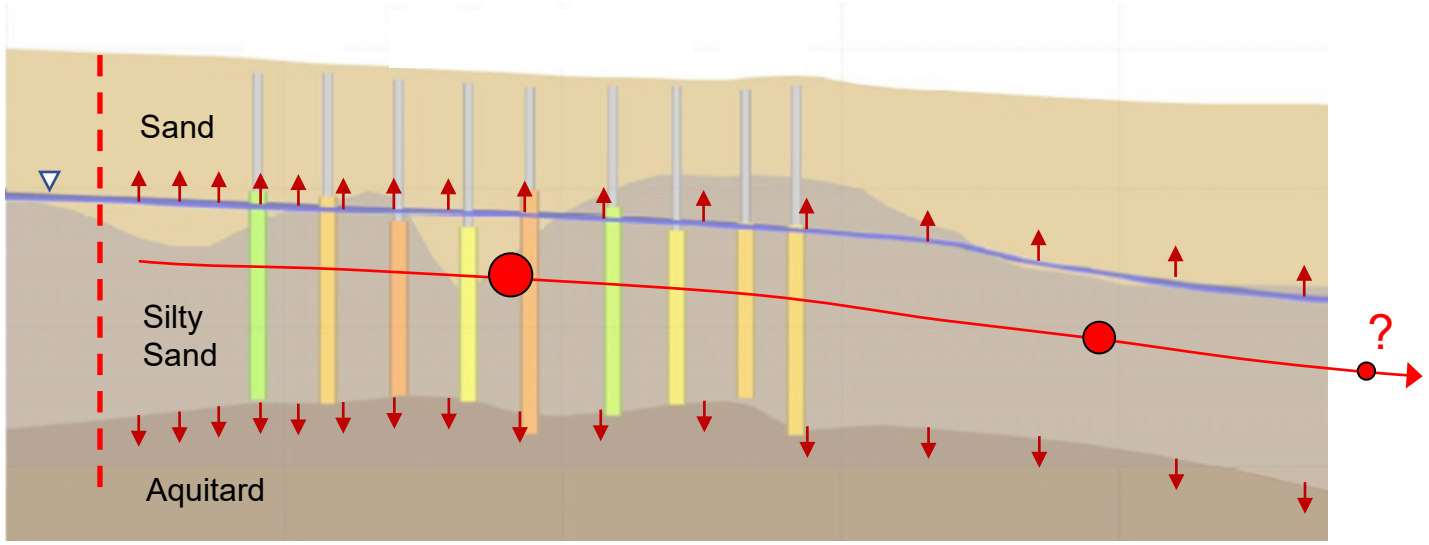
1” = 250’

Groundwater Remediation at Anytown USA

Recap of Site History up to Game Time 0:

- Chlorinated solvents released over decades
- Unknown mass released into the aquifer
- Decades of mass migration into the overlying vadose zone and low permeability lenses/layers, e.g., aquitard
- Mass release ceased at Time 0 (containment / cleanup)

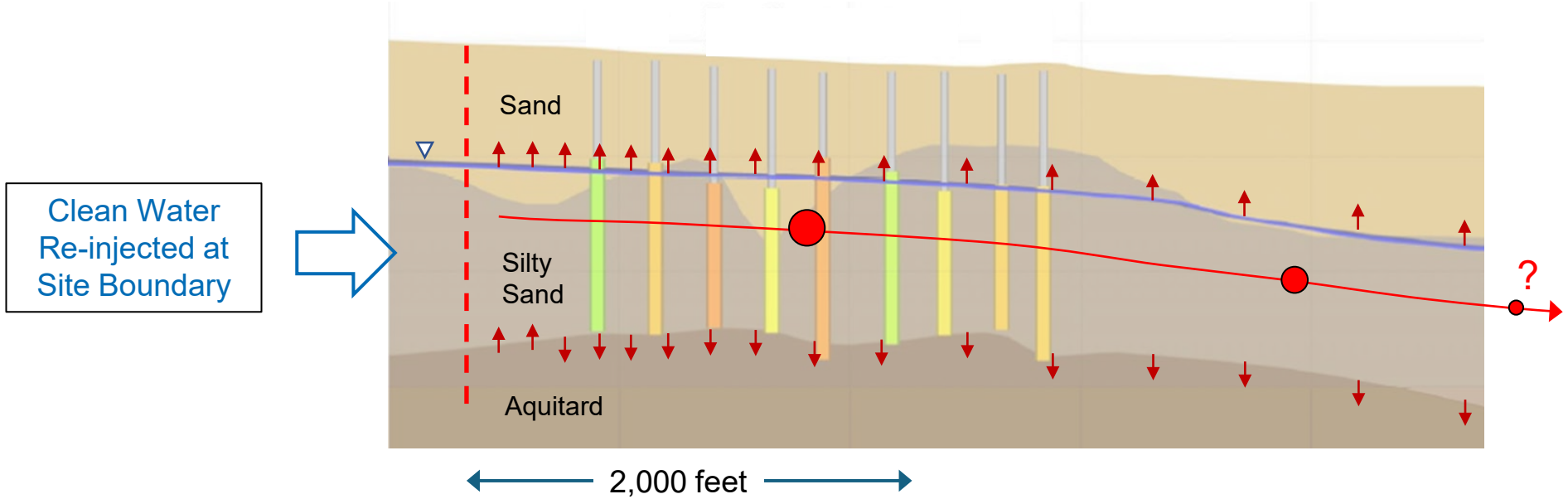
Contaminant Mass Release Rate from SOURCE SITE ENDS! Time =0



Groundwater Remediation at Anytown USA

Hydrogeology Information from Initial GW Investigation:

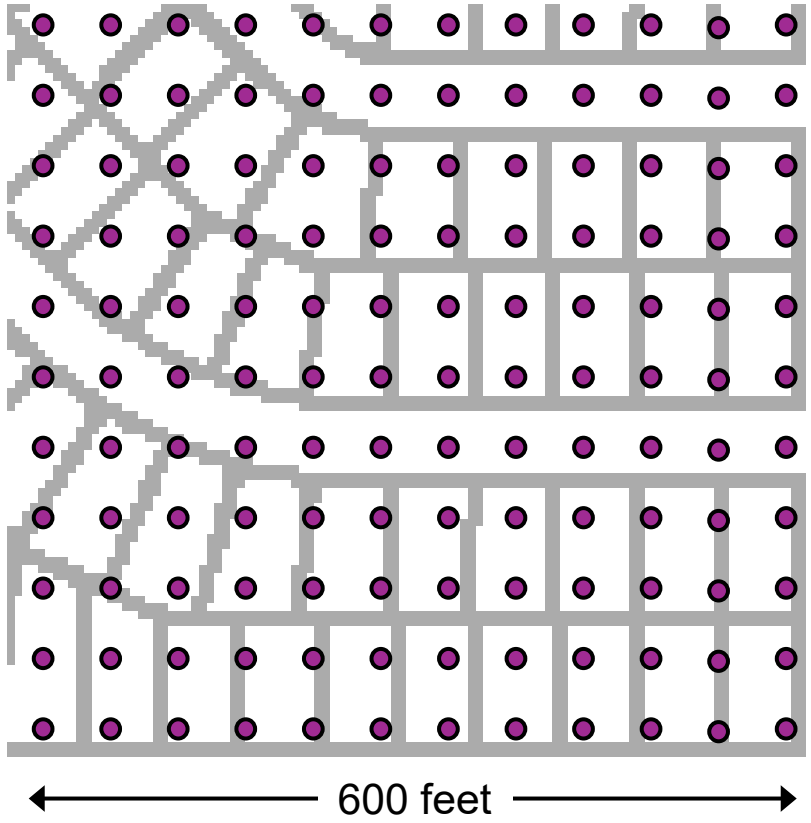
- Groundwater flow velocity ~2 feet per day
- Travel time for 2,000 feet is ~3 years
- Impact of containment takes years to move downgradient
- HOWEVER, residual contaminant mass is stored anywhere water does not readily flow (e.g., aquitard, silt lenses, clay lenses, vadose zone, etc.)



Groundwater Remediation at Anytown USA

Option to Remediate Groundwater:

- Treat contaminated GW with permanganate injections
- 30 house footprint requires ~130 injection points (2nd round 50%)
- Residual contaminant mass continues to feed contaminants back into permeable channels (i.e., back diffusion) and vadose zone (i.e., rebound)
- Residual mass necessitates the continuation of SGM for an additional 5 years – optimistic?
- Assume NO impact to adjacent 30-house footprints



QUESTIONS?
I’m available this evening for the price of a beverage

Next up is AJ to describe the game ….