Vapor Intrusion:
Sampling, Analysis, and Other Considerations
with Mitigation Case Studies

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Haley & Aldrich
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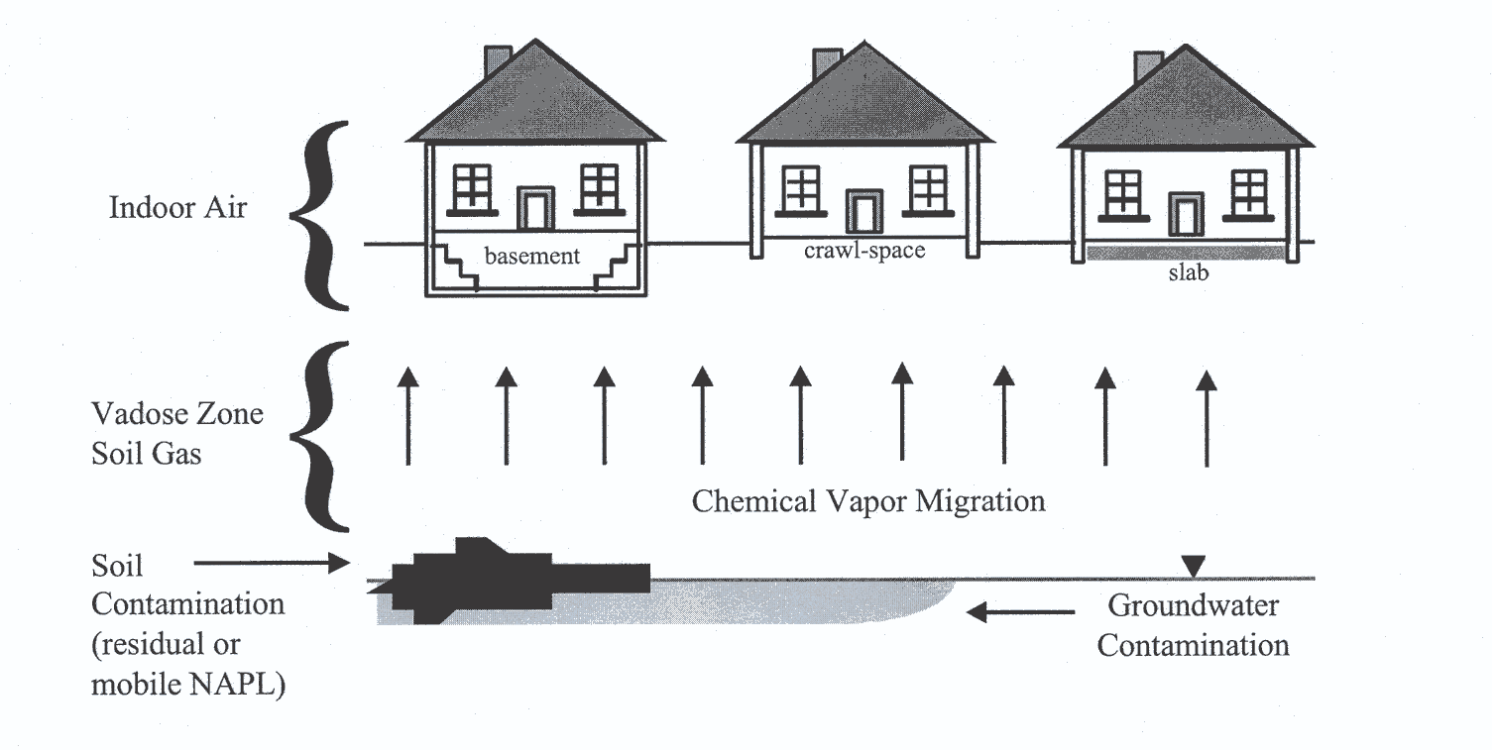
Ohio EPA Certified Professionals Training Course

Outline

- Vapor Intrusion Overview and VI Regulatory Landscape
- Recent Changes and Focus on PVI
- IA Background Considerations
- Sampling and Analysis
- Mitigation Case Studies

Typical Conceptual Model of Vapor Intrusion



Key Point: "Volatile chemicals" does not mean just VOCs

VI Pathway: Main Transport Mechanisms

- Diffusion of vapors from sources in the unsaturated zone
- Diffusion of vapors from sources in shallow ground water
- Advective/convective transport of vapors
- Vapor migration through preferential pathways

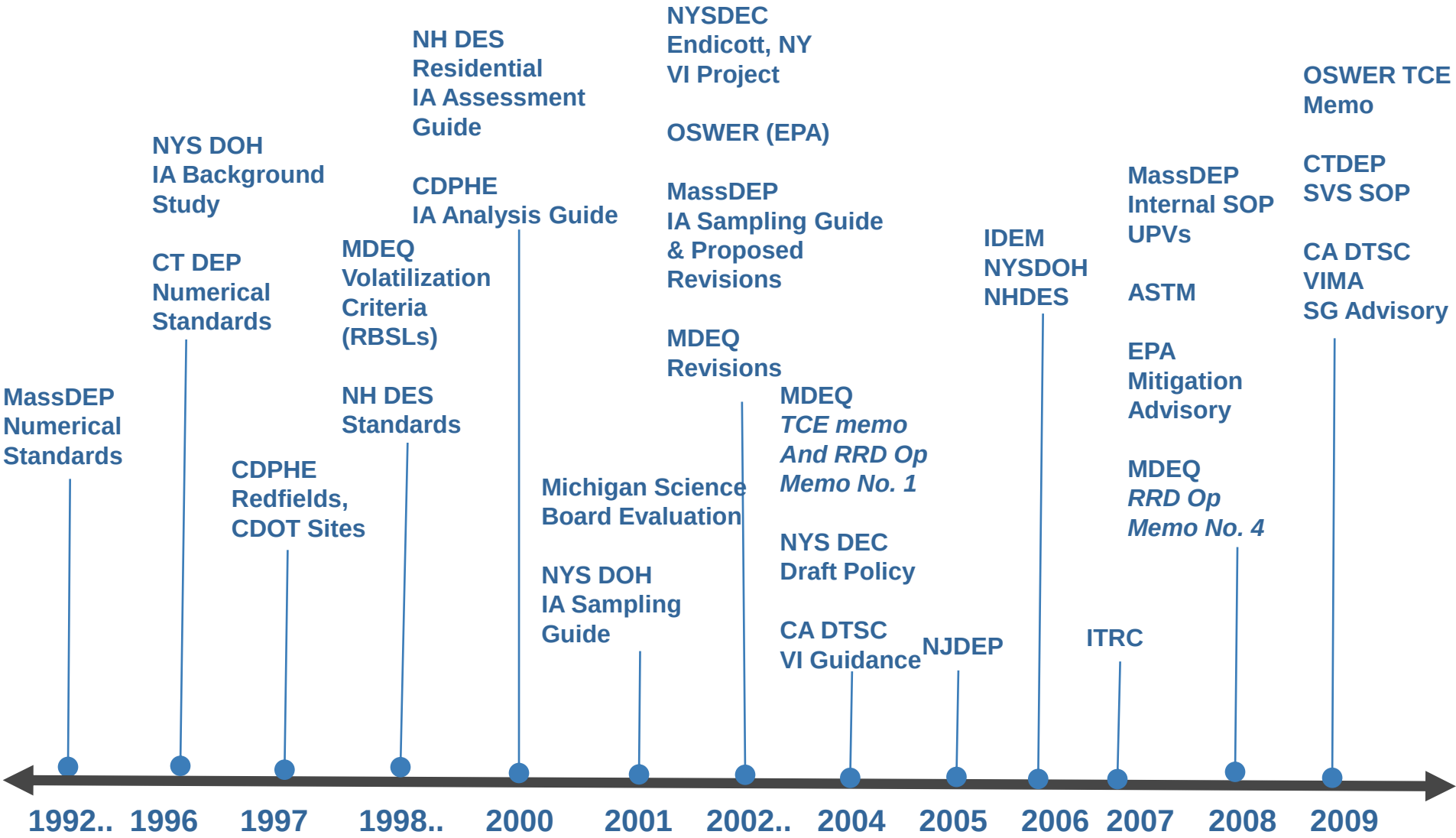
Key Point: Understanding soil and groundwater is prerequisite to developing a VI CSM and developing a sampling strategy.

Introduction to Vapor Intrusion

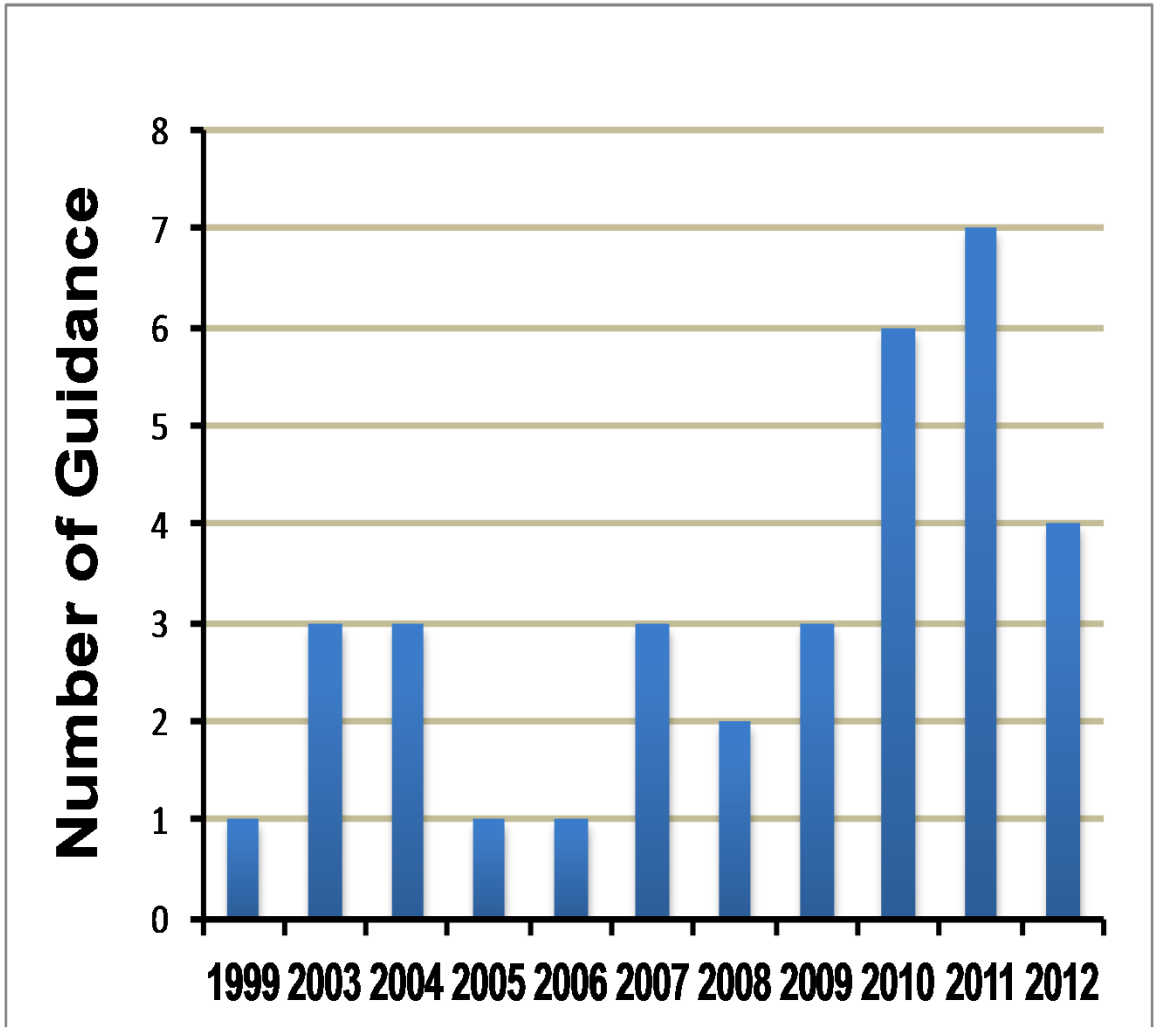
- EPA and many states use a 3-Tier approach to evaluate sites:
  - Tier 1 – Simple Screen
    - Are any VOCs present?
  - Tier 2 – Simple screen
    - Are VOCs above de minimis levels
  - Tier 3 – Site-specific evaluation

Key Point: **For the VI pathway to be complete, there must be a source, a mechanism for transporting contamination, and a potential receptor.**

History of VI Guidance Development



Year Guidance was Issued



17 new guides or updates since 2010

Eklund, et al; 2012

Recent and Scheduled Federal Changes and Updates

- AEHS/EPA Public Listening Session (March 2011/April 2011)
- Background indoor air concentrations paper (June 2011)
- TCE IRIS Assessment - September 2011 (previously 1989)
  - *cancer and non-cancer toxicity, oral and inhalation; mutagen*
- PCE IRIS Assessment - February 2012
  - *cancer and non-cancer toxicity, oral and inhalation; not classified as a mutagen*
- EPA's VI Database Evaluation and Screening Level Calculator – March 2012
- Petroleum Vapor Intrusion Guidance for LUST and ITRC PVI – April 2012
- Lessons learned from Radon paper – *2012*
- Final Subsurface Vapor Intrusion Guidance - *30 November 2012*

Attributes of CT, NY, and NJ Programs

	CT	**NY**	**NJ**
Trigger distance (feet)	GW: 15H; 15V	DOH: none DEC: *not* 100	100H; 100V PHCs: 30H: 30V
Modeling vs. Measurement	Measurement	Measurement	Measurement
Numerical criteria	IA, SV, and GW	IA (5 compounds*)	IA, SV, and GW
Background #s incorporated?	Yes	Yes	No
Analyte list	Full-suite (RCPs)	SV: "wide range" IA: site-related	Full suite TO-15 (first round*)
Outdoor air sampling?		Yes	Yes
Hypothetical future use?	Yes	Yes	Yes

*** Changes expected**

New Jersey (2012)

Table 3-2

Recommended Minimum Number of Sub-Slab Soil Gas Samples

Square footage of floor	Number of Sub-Slab Soil Gas Samples
Up to 1,500	2
1,501 to 5,000	3
5,001 to 10,000	4
10,001 to 20,000	5
20,001 to 50,000	6
50,001 to 250,000	8
250,001 to 1,000,000	10
>1,000,000	12+

Table 3-3

Recommended Minimum Number of Indoor Air Samples

Square footage of floor	Number of Indoor Air Samples
Up to 1,500	1-2
1,501 to 5,000	2
5,001 to 10,000	3
10,001 to 20,000	4
20,001 to 50,000	5
50,001 to 250,000	6
250,001 to 1,000,000	9
>1,000,000	9+

ug/m^3, mg/m^3, ppbV, and ppmV

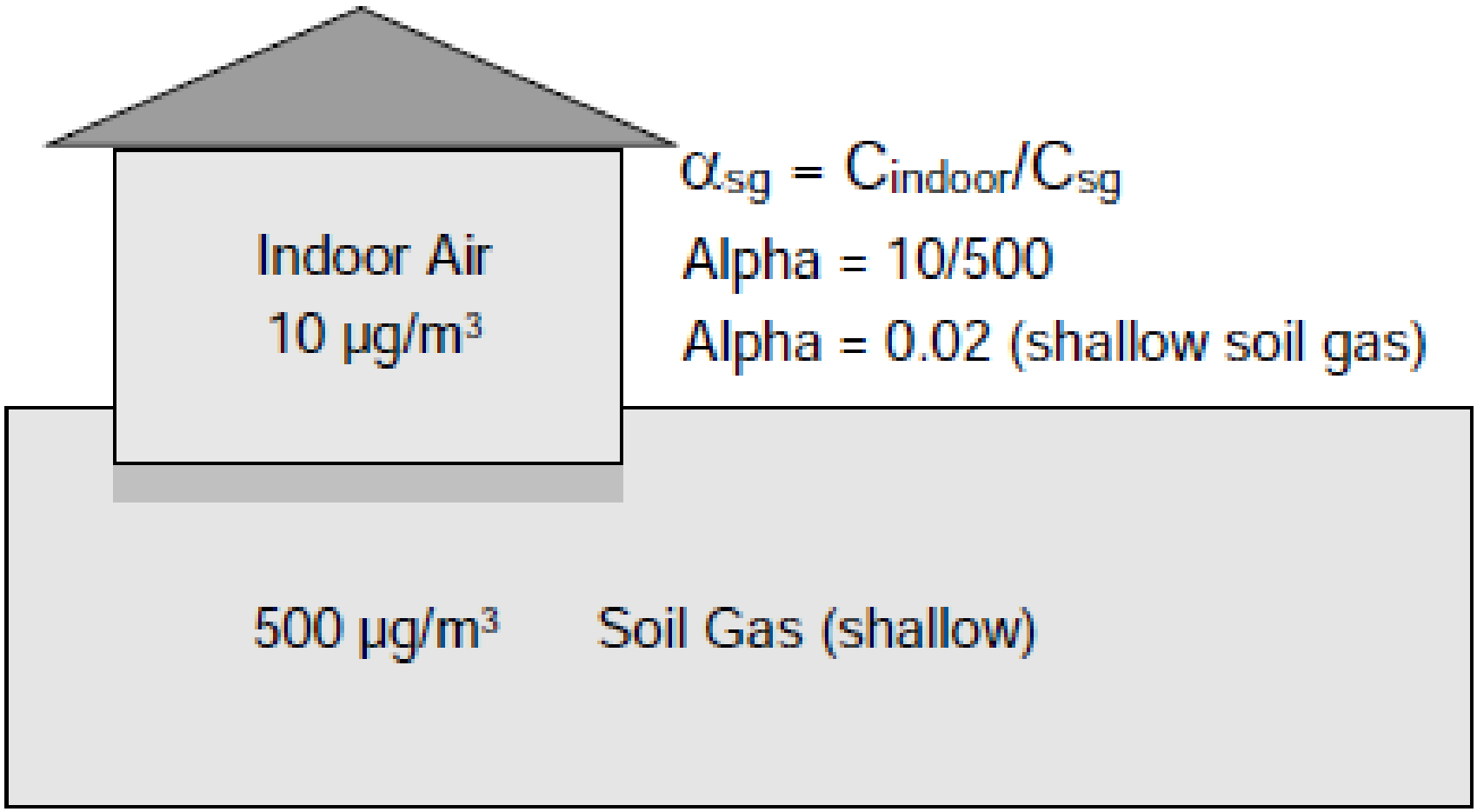
- indoor air units are not expressed on a mass-per-mass basis, even though they are sometimes given as ppm or ppb

- units of ppm and ppb in gas systems are commonly calculated on a volume-per-volume basis, which is why they are more accurately termed ppmV and ppbV

conversions

- Calculation includes temperature (K) and pressure (kPa); requires knowledge of compound specific molecular weights
- Simplified as:
  - **ppbV = (24.45 x ug/m3)/MW where MW=molecular weight in g/mole**
  - **Or… ug/m3=(MW x ppbV)/24.45**
  - **For example, 1 ug/m3 TCE (MW=131.4 g/mole) → 0.186073 ppbV TCE**
- The number 24.45 in the above equations is the volume in liters that a mole of a gas occupies when the pressure is at STP*

Attenuation Factor Concept



$\alpha_{sg} = C_{indoor}/C_{sg}$

Alpha = 10/500

Alpha = 0.02 (shallow soil gas)

Attenuation Coefficients

- Groundwater values generally 0.001
- Deep soil gas generally 0.01
- Shallow soil gas values are more variable: 0.001 to 0.1
  - One Western state uses 1 as a default assumption
- Crawl space values are 1 in all 10 states that give values.

Eklund, et al; 2012

Vapor Intrusion at α = 0.1

For 2,000 sq. ft. house with 9 ft. ceilings and 0.5 ACH,

Qsoil = 15 cfm

Eklund, et al; 2012

Influences on VI Evaluations

- Indoor air background sources
- Biodegradation
- Preferential pathways
- Land use

Indoor Air Background Sources

- Background refers to constituents that are not influenced by the releases from a site, and is usually described as naturally occurring or anthropogenic (USEPA, 2002a)
- Some states incorporate background concentrations into their VI criteria
- Some states consider background contamination during the investigative phase
- USEPA has developed a database and technical paper on national indoor air background levels. For more information:
  - "The Inside Story: A Guide to Indoor Air Quality"

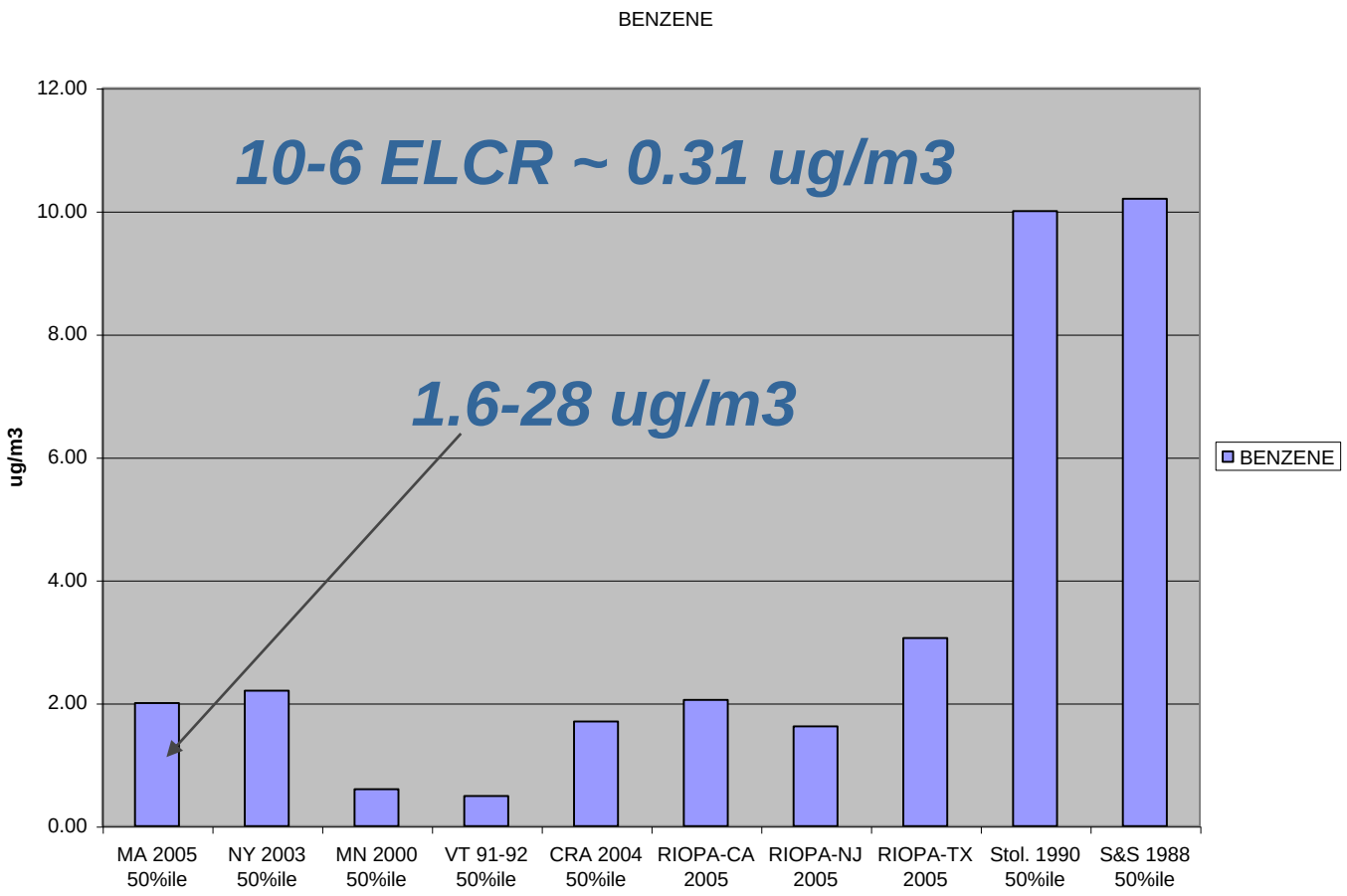
    http://www.epa.gov/iaq/pubs/insidest.html
  - Background paper, Dawson et al, June 2011

Indoor Air Background

- *"One of the most difficult facets of investigating VI is the interpretation of the available information and the subsequent conclusions reached on the completeness of the pathway. This task is complicated by the impact of background contaminant sources on the overall indoor air quality."*

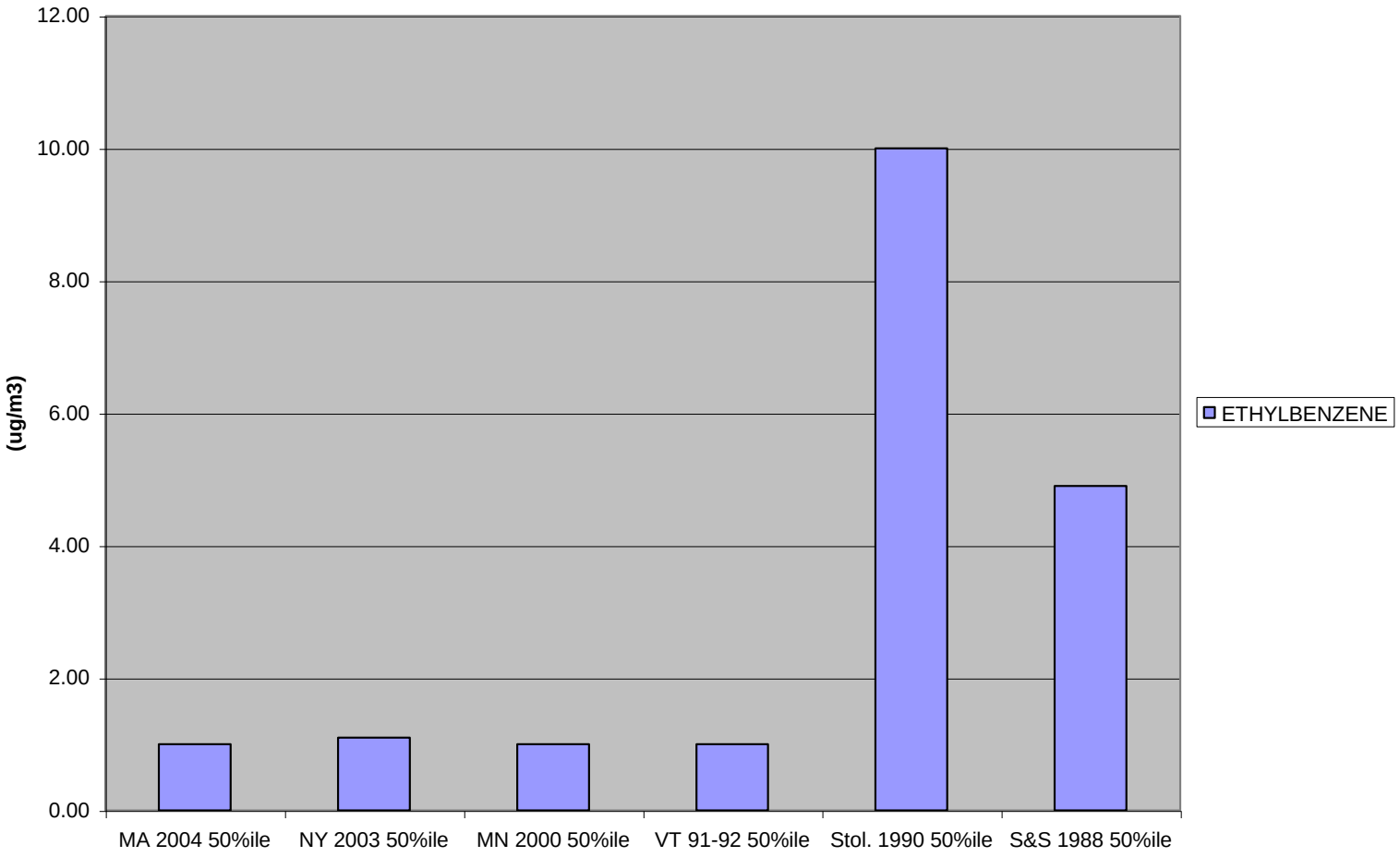
- *"…..the most critical point is in the assessment of indoor air data as it relates to background contamination."* - NJDEP 2012

Benzene Background Comparison



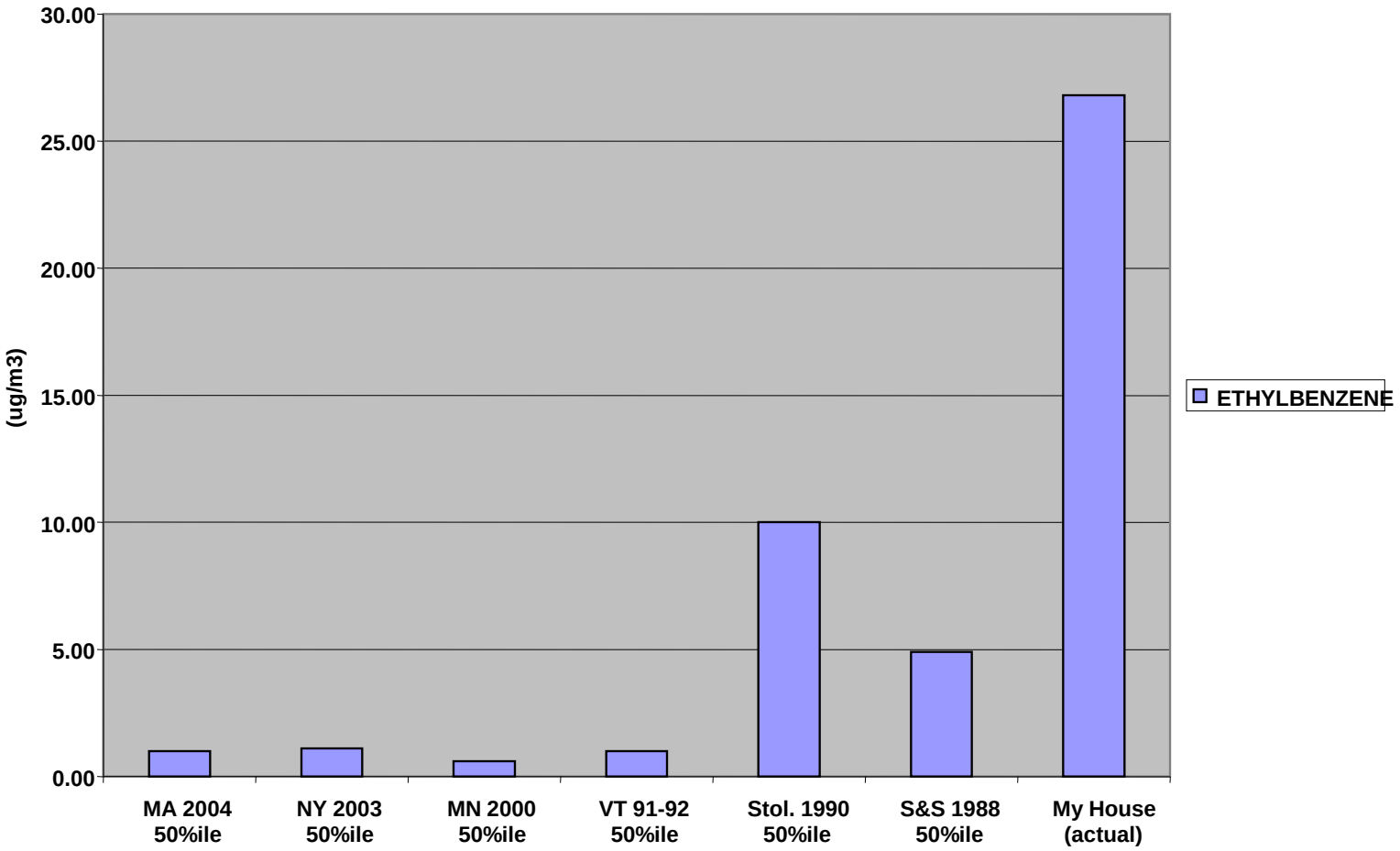
Rago et al, 2007

Ethylbenzene* Background Comparison

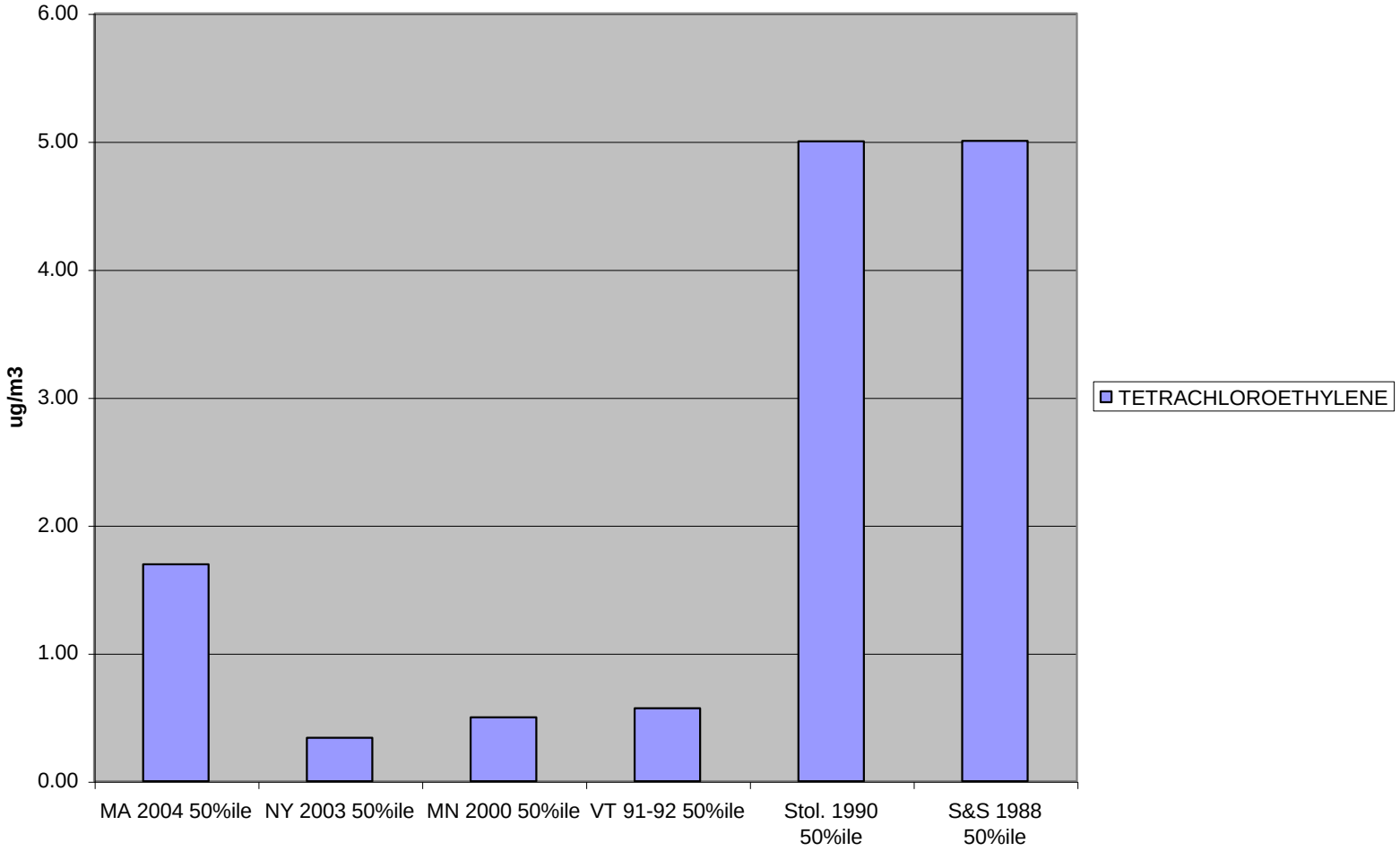


Rago, 2005

Ethylbenzene Background Comparison (with my house)

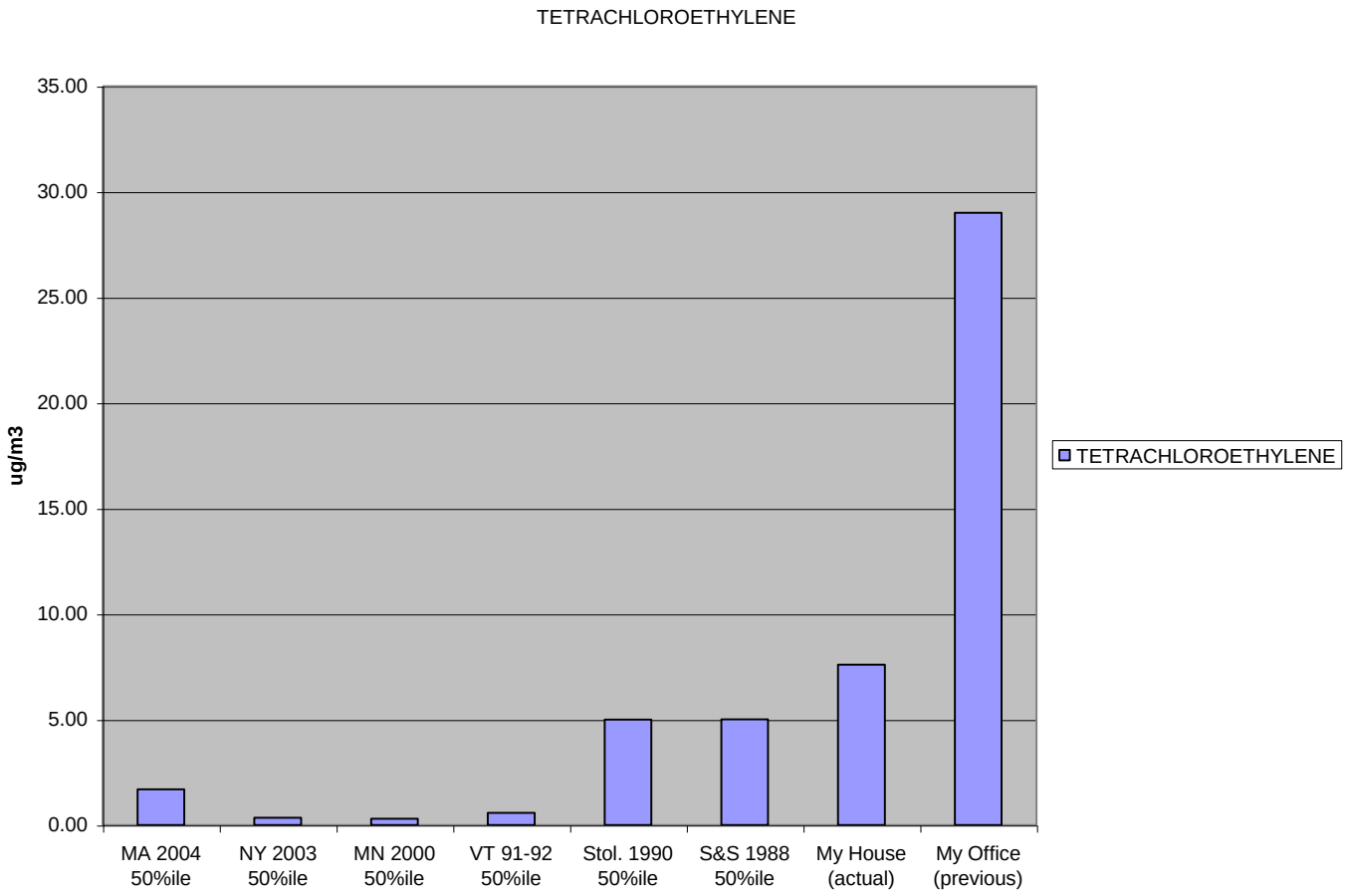


Tetrachloroethylene Background Comparison

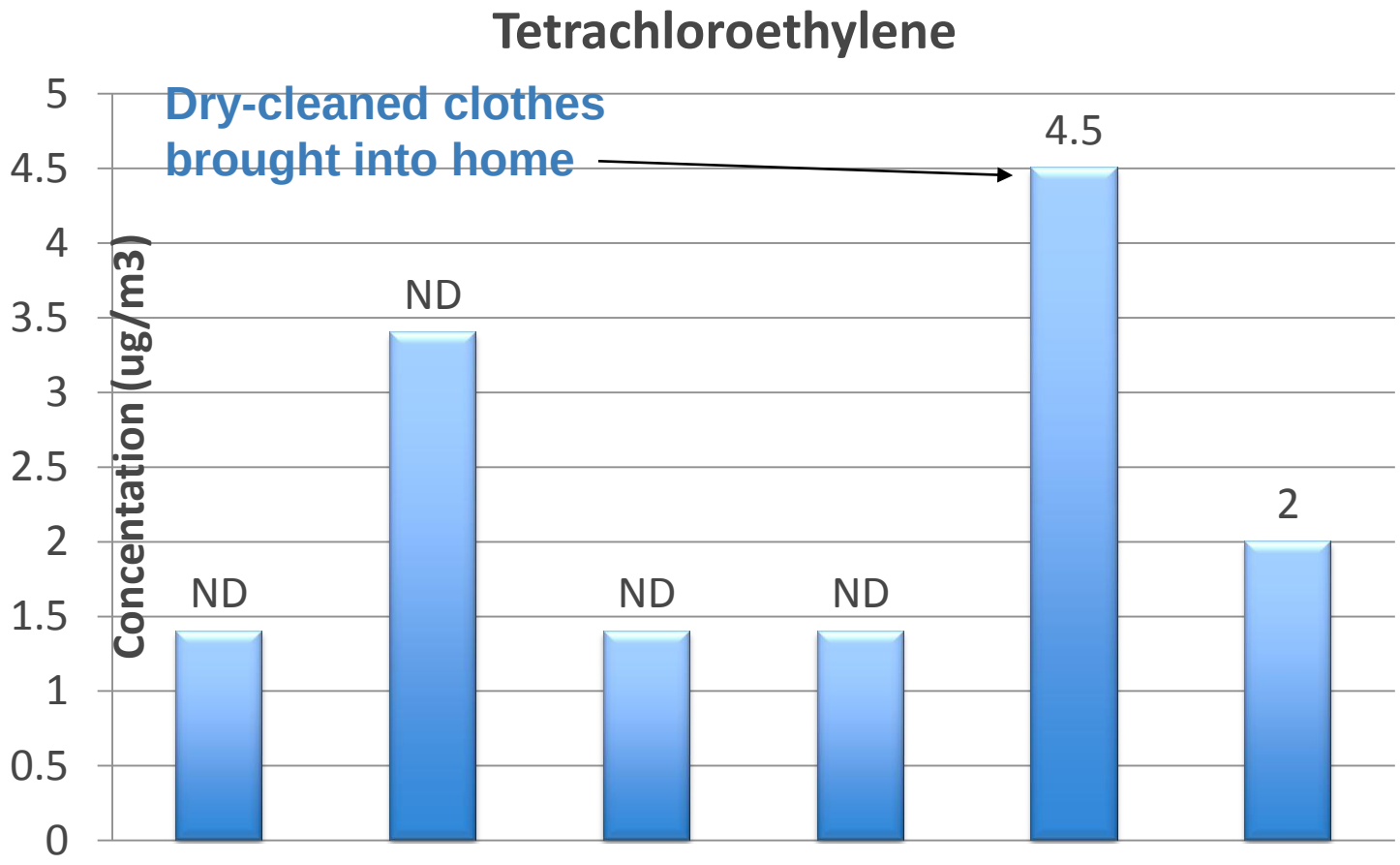


Rago, 2005

Tetrachloroethylene Background Comparison (with my house and my office)



Daily Residential Indoor Air Data



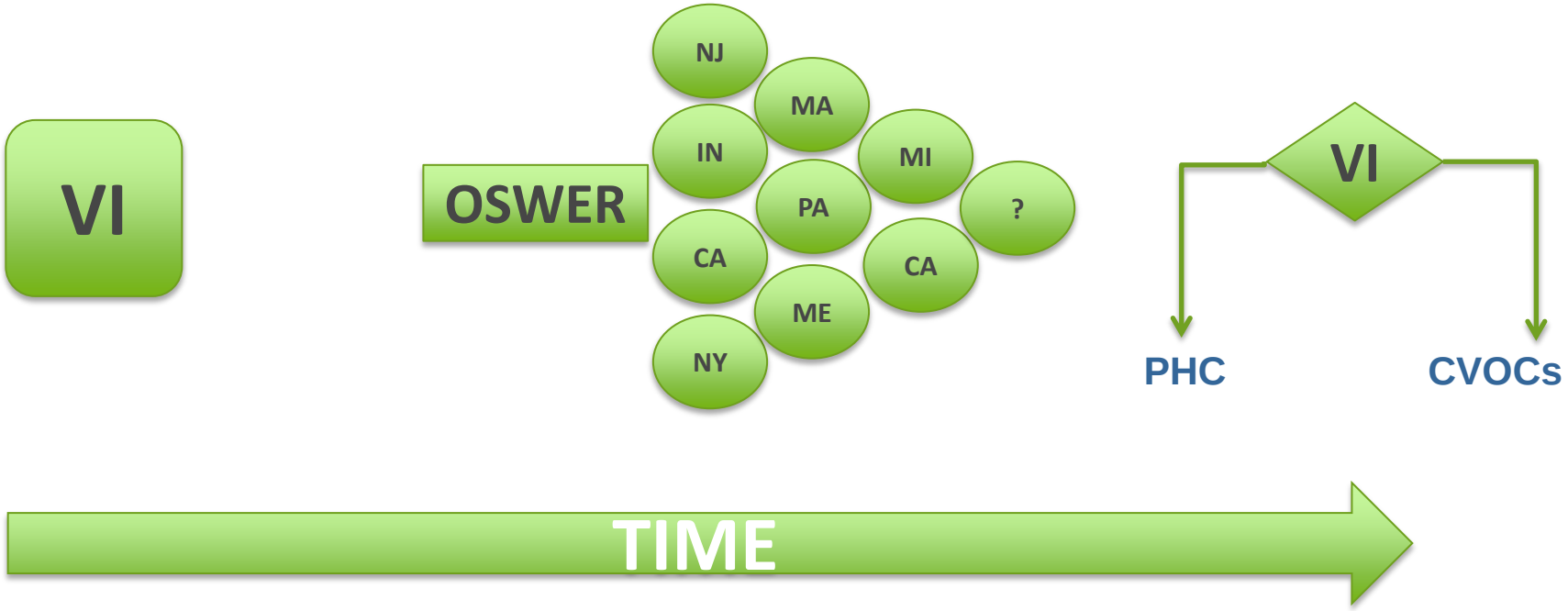
Rago el al, 2010

Biodegradation

- Petroleum hydrocarbons such as BTEX compounds are know to readily biodegrade to CO_2 under the right conditions (presence of microbes and O_2)

- EPA and some states recognize this and now have guidance for evaluating VI at petroleum sites

Petroleum Hydrocarbons And Chlorinated Hydrocarbons Differ In Their Potential For Vapor Intrusion - US EPA OUST; September 2011



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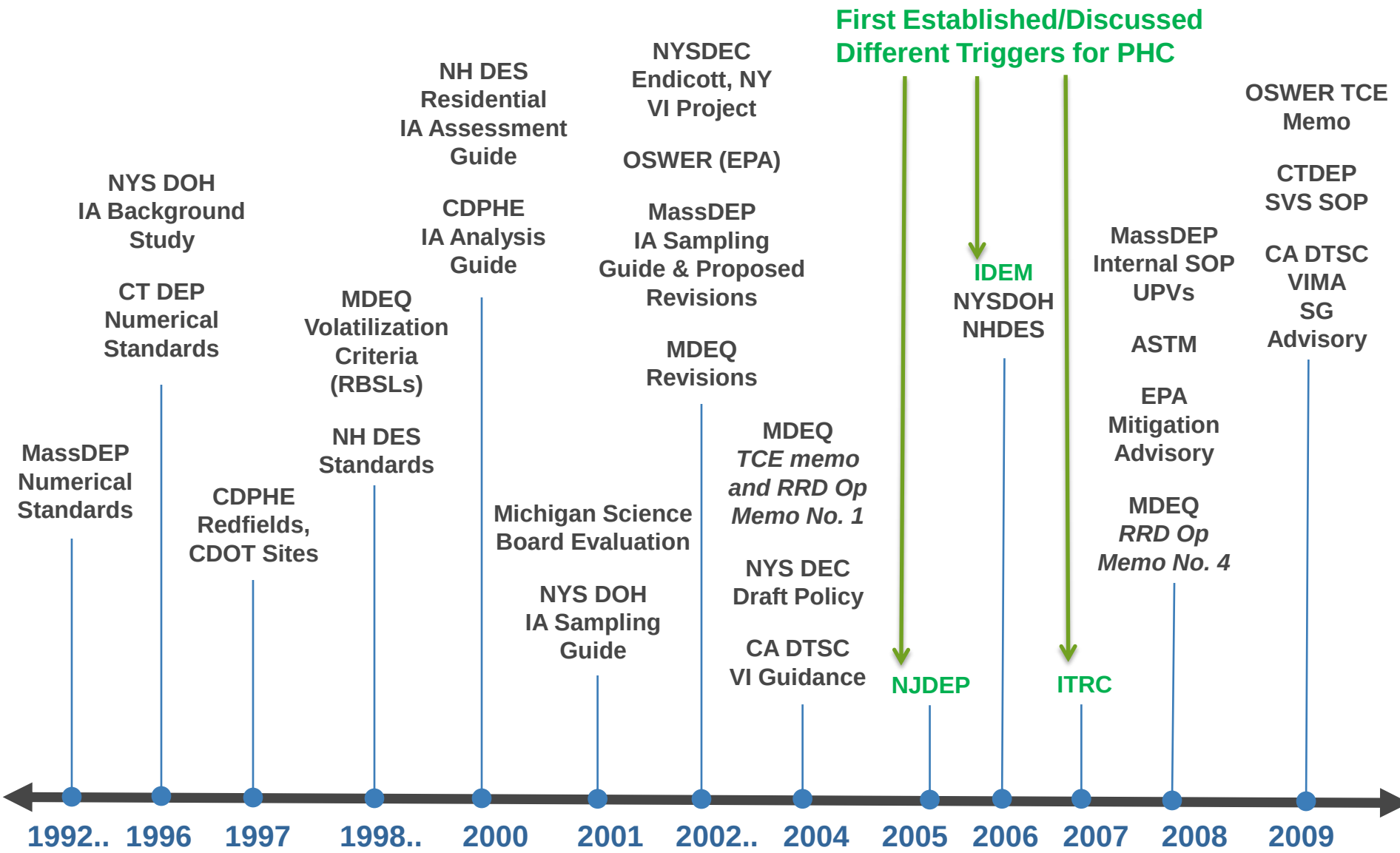


Recent Updates from the States that show PHC Implications

- Washington Department of Ecology (2009)

  - PHC have same 100 ft trigger distance as CVOCs, but assumed 10X additional PHC attenuation (of their 0.1 default)

- Maine DEP (2009)

  - 30 ft trigger distance allowed for PHC, but same 0.02 attenuation factor

- Massachusetts DEP (2010 draft)

  - Default alpha of 0.02 for CVOCs; Default alpha of 0.001 for PHC

Recent Updates from the States that show PHC Implications

- Indiana DEM (RCG Draft 2011)
  - Default sub-slab alphas of 0.1 for residential and 0.01 for “some” commercial/industrial
  - Default exterior SG alphas of 0.1 for shallow (5-15 ft) and 0.01 for deep (>15 ft)
  - “Free product” trigger of 30 feet
  - concentration of benzene in GW under building greater than 1,000 ug/L or GW > VI GWSLs in direct contact with slab
  - less than five ft of clean, unsaturated soil with an oxygen content greater than 5% exists between the residual petroleum and the building
    - *“Well-oxygenated soil promotes biodegradation of petroleum vapors. A sufficient thickness (separation distance) of unsaturated, oxygenated soil between the source and the building may permit sufficient biodegradation to prevent VI.” (Davis, 2009; Luo et al., 2009, Lundegard, 2008; Patterson and Davis, 2009; U.S. EPA, 2010).*

Recent Updates from the States that show PHC Implications (continued)

- Indiana DEM (Final 2012)

  - Same as 2011, except:
    - Under PHC, clarified ”Free product” as “LNAPL” *(MGP DNAPL?)*
    - Default sub-slab alphas of 0.1 for residential and commercial/industrial (0.01 for some C/I)
    - Default residential and C/I shallow exterior soil gas alphas of 0.1 (0.01 for some C/I)
    - Default residential and C/I deep exterior soil gas alphas of 0.01 (0.001 for some C/I)

Recent Updates from the States that show PHC Implications (continued)

- New Jersey DEP (January 2012)
  - Still a 30-foot trigger distance (horizontal and vertical) for PHC-related groundwater (100 ft for CVOCs); 100-foot critical distance criterion shall be used for all free product, PHC-related or otherwise
  - Default attenuation factor of 0.02 for CVOCs and PHC, but an additional attenuation factor of 0.1 was incorporated into the default GWSL for PHC (e.g., BTEX)
  - Documents PHC aerobic biodegradation (Roggemans et al. 2001, Lahvis et al. 1999, Devaull et al. 1997) and relaxes earlier evidence that oxygen > 4% needed for biodegradation (DeVaull et al. 1997): oxygen threshold may be lower, between 1-2% (Roggemans et al. 2001, Abreu et al. 2009)
- May 2012: 30 ft trigger for petroleum NAPL

Preferential Pathways

- Site conditions that result in significant lateral transport, enhanced convective flow, or a source within a building
  - Large subsurface utilities (e.g. storm drains)
  - Basement sumps
  - Elevator shafts
  - Natural conditions
- Models typically assume soil gas convection
- May see atypical diffusion
- COCs entry into building through cracks is considered common
  - Utility connections may or may not be considered preferential pathways

Land Use

- Current vs. future use?
- Commercial vs. residential?
- Institutional restrictions?
  - Transactional considerations?
- Sensitive populations?
- Municipal zoning laws?

Community Outreach/Relations

- Sensitive topic in community
- Challenges may build from public perceptions
- Develop communication strategies
- Challenge of balancing stakeholder needs with cost/feasibility, while maximizing public health protection
- Sensitivity is critical

Typical VI Measurements Options

Widely Used Options:

- Indoor Air
- Sub-Slab Soil Gas
- Shallow Soil Gas

Other Options to Consider:

- Emission Flux
- Building Ventilation

Multiple Lines of Evidence

- Soil gas spatial concentrations
- Groundwater spatial data
- Background sources (internal and external/ambient)
- Building construction and current condition
- Sub-slab soil gas data
- Soil gas data
- Indoor air data
- Constituent ratios
- Soil stratigraphy
- Temporal patterns

Analytical Considerations

- Program Design
  - Data Quality Objectives
  - Importance of QA/QC
- Analytical Methods
  - VOCs
  - PAHs
  - Passive methods
- Media certification

Data Quality Objectives

- Define/identify
  - Study goals
  - Contaminants of concern
  - Regulatory screening levels
- Complete
  - Pre-sampling building survey
    - Interior survey
    - Site screening
- Choose/establish
  - Sampling and analytical method
  - Reporting limits
- Collect
  - Samples
  - Quality assurance (QA) samples
- Establish
  - Validation procedures

Choosing the Correct Method

- Target Analyte Lists
  - Determined by your contaminants of concern
- Reporting Limits
  - Determined by RBCs from agency
- Methodology
  - Determined by answers to 1 & 2
- Media Certification
- Laboratory Certification

Laboratory Certification

Some state regulatory agencies across the country require laboratories to be certified (by method or matrix) to conduct air analysis

Some states' requirements may be more stringent than the method's QA/QC requirements

Recommend: use a lab that has at least a NELAP certification for method

NELAP= National Environmental Laboratory Accreditation Program

Active vs. Passive

Active sampling- known volume of air collected by actively extracting the sample

- Canister, tedlar bag, syringe, tube

Passive sampling- adsorbent material exposed to air/vapor for certain period of time

TO-15

- Sampling & Analysis for subsets of the 97 hazardous VOCs listed in Title III of the 1990 Clean Air Act.
  - Lab must demonstrate capability of stability & recovery of all analytes
- Reporting limits :
  - Full scan: 0.2 to 0.5 ppbv (~1 ug/m^3)
  - SIM: 0.002 to 0.010 ppbv (0.011 to 0.02 ug/m^3)
- Calibration standards:
  - NIST traceable <u>gaseous</u> standards
  - Primary standards (from supplier) must have stability guarantee certificate
  - Secondary standards (prepped by lab) are allowed a 30 day HT
- Samples collected in canisters
  - Holding times: VOCs stable for up to <u>30 days</u>

TO-15 Prep

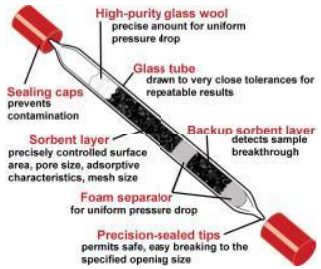
- Canister & Flow Controllers
  - *One of the most critical QA/QC pieces for the method is the media certification*

SVOC collection

- No specific method for soil gas collection
- Methods used are modifications to ambient air collection methods
  - Modified versions: low flow pump
- TO-13A:
  - PAHs and many other 8270 compounds;
- TO-4A:
  - Pesticides & PCBs (including congeners);
- PUF/XAD media for sample collection
- Samples chilled <4C

Collection of VOCs on Absorptive Media

- No specific method for soil gas collection
- Use modification to EPA TO-17
- Samples collected on a sorbent tube with use of pump
- Collect duplicate samples per sampling point
- CAUTION: If elevated levels are expected, collect distributed volume pairs
- Samples chilled <4C



www.skcinc.com

www.sensidyne.com

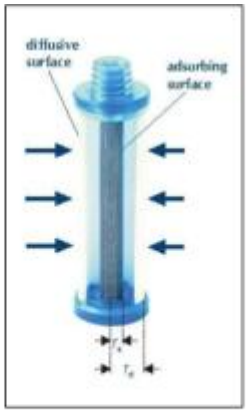
Use of Passive Samplers

Pros:

- Smaller than canisters
- Simpler Protocols (reduce fees for sampling crews)
- Longer-term sample (potentially minimize temporal variability)

Waterloo Membrane Sampler ™

ATD Tube



Radiello™

SKC Ultra II

Limitations:

•Must be deployed for 1-7+ days

•May have issue with over-saturation

•Not all are technically feasible approaches for soil vapor:

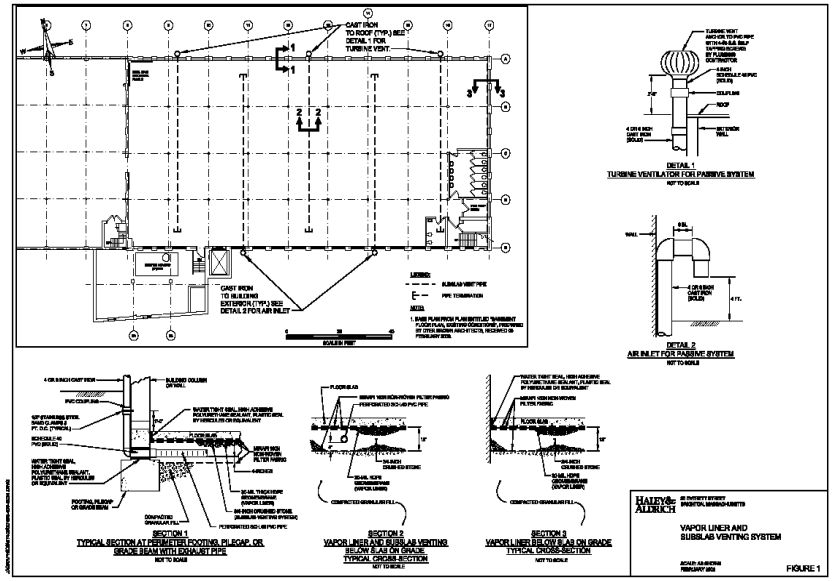
•Some are only semi-quantitative

Historical Use of Passive Samplers

- Diffusive samplers have been used for years for monitoring ambient air and workplaces
- Radon: most devices use a passive diffusion approach
- Concentration reported as mass per sampler
- Calculation needed for quantifying the result

VI Mitigation Case Studies

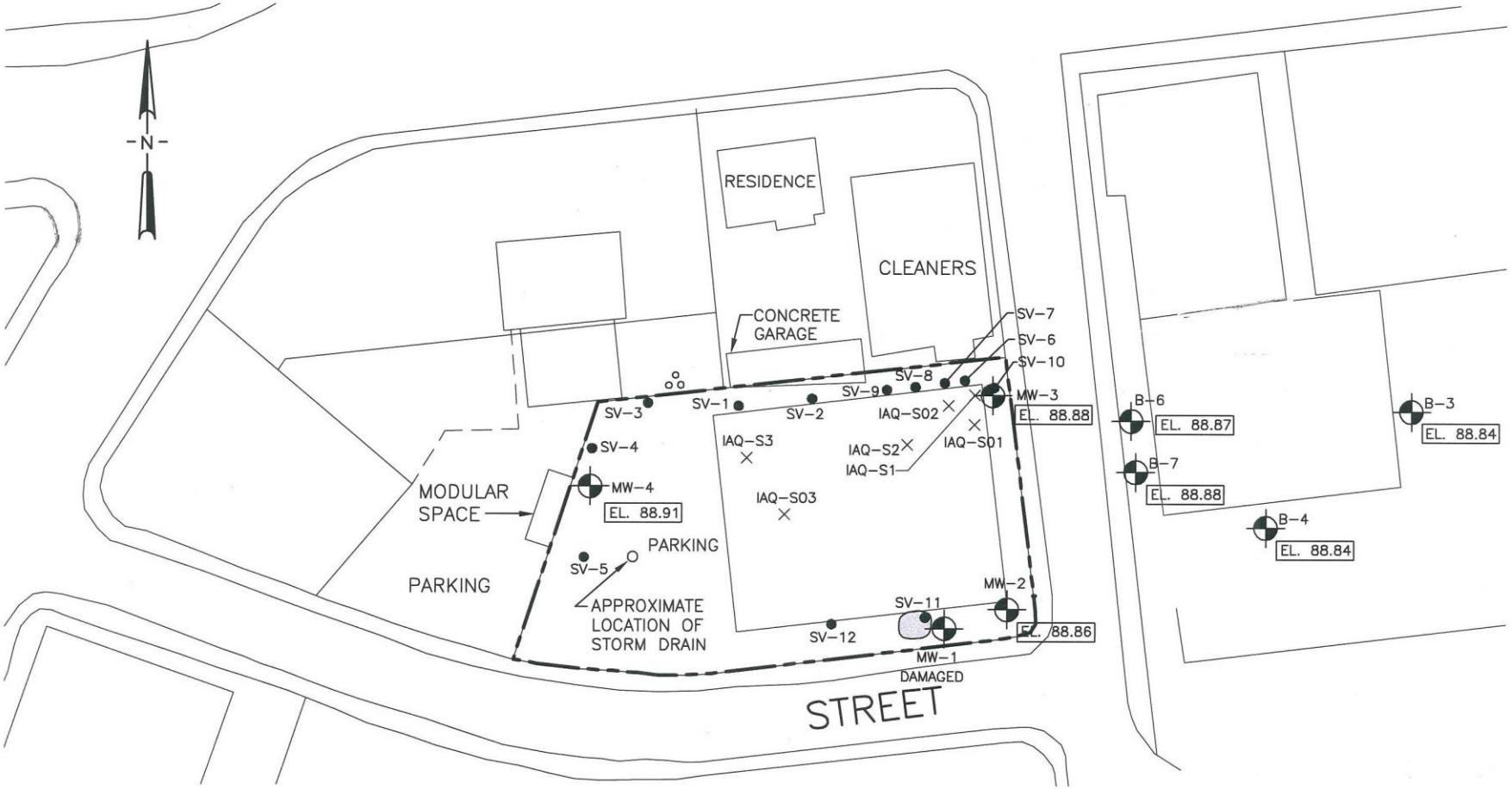
- New Construction/Passive
- Retrofit/Active



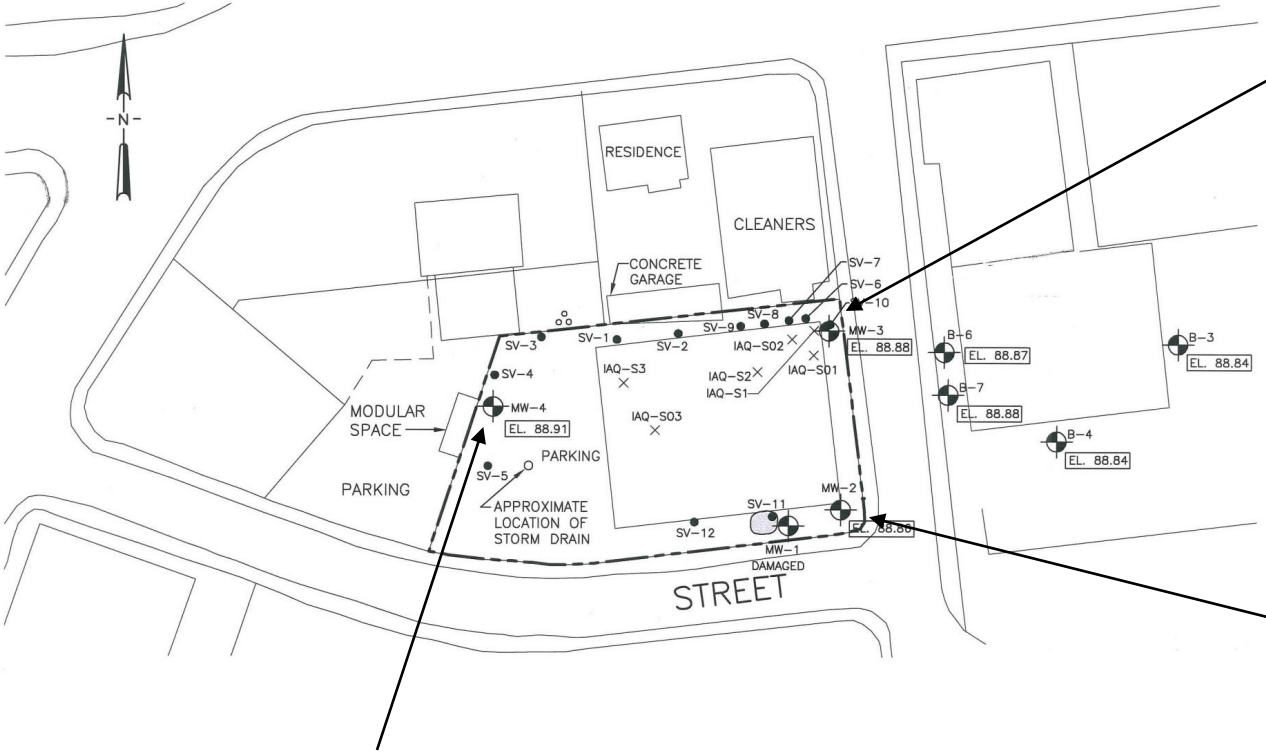
Case Study #1
Site: Former Electronics Parts Distribution Location

- Due Diligence Conditions: adjacent dry cleaner identified as potential source of legacy chlorinated solvents
- Groundwater < VI targets; soil < VI targets
- Other circumstances: slab on grade; cinder block walls; vacant (almost); no basement

The Site


N
RESIDENCE
CLEANERS
CONCRETE GARAGE
SV-7
SV-6
SV-10
SV-8
SV-9
MW-3
EL. 88.88
SV-3
SV-1
SV-2
IAQ-S02
IAQ-S01
IAQ-S3
IAQ-S2
IAQ-S1
IAQ-S03
SV-4
MW-4
EL. 88.91
MODULAR SPACE
PARKING
PARKING
SV-5
APPROXIMATE LOCATION OF STORM DRAIN
SV-11
SV-12
MW-2
EL. 88.86
MW-1
DAMAGED
STREET
B-6
EL. 88.87
B-7
EL. 88.88
B-4
EL. 88.84
B-3
EL. 88.84

Groundwater (VI criteria = 3,000 ug/L)

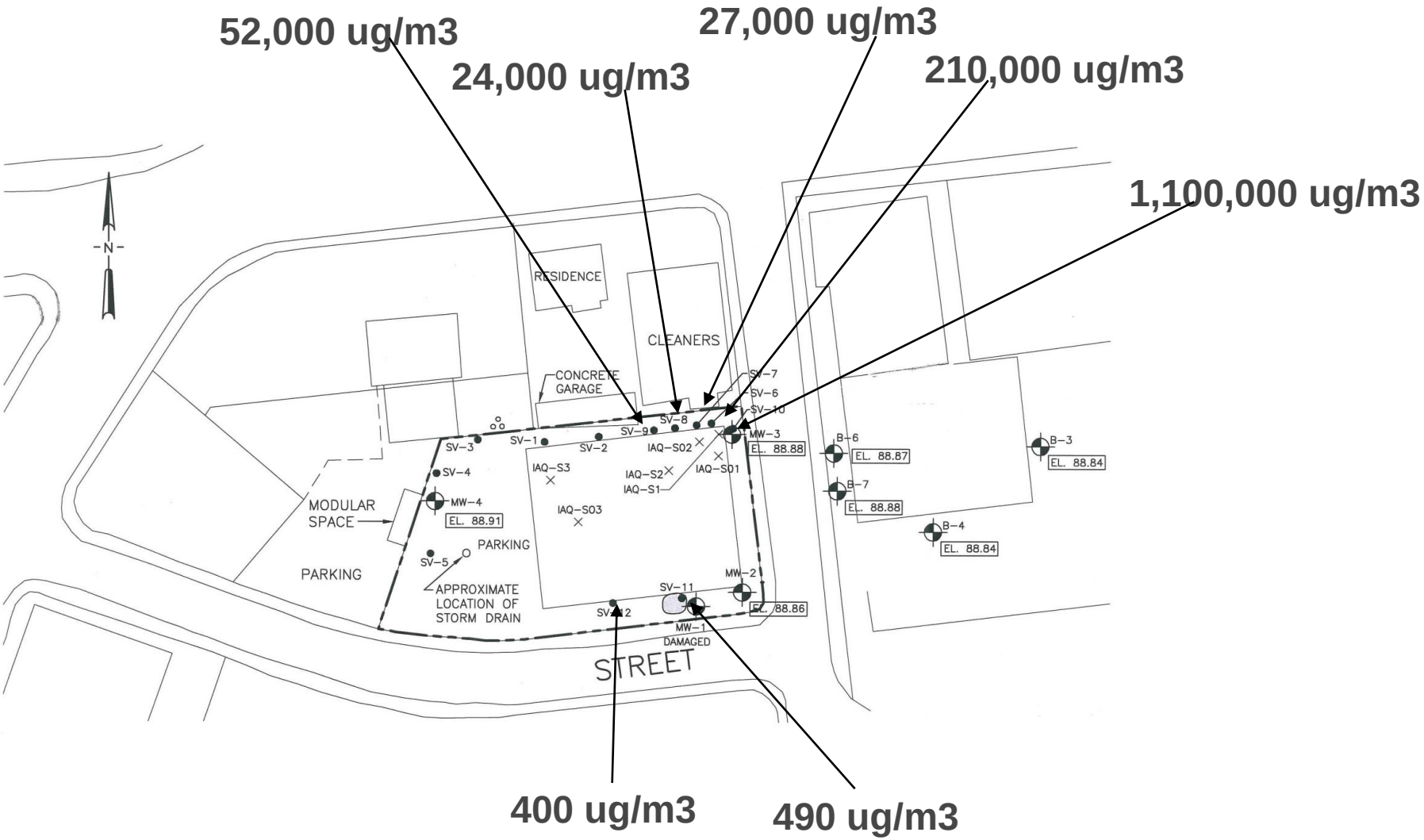


PCE 1,000 ug/L

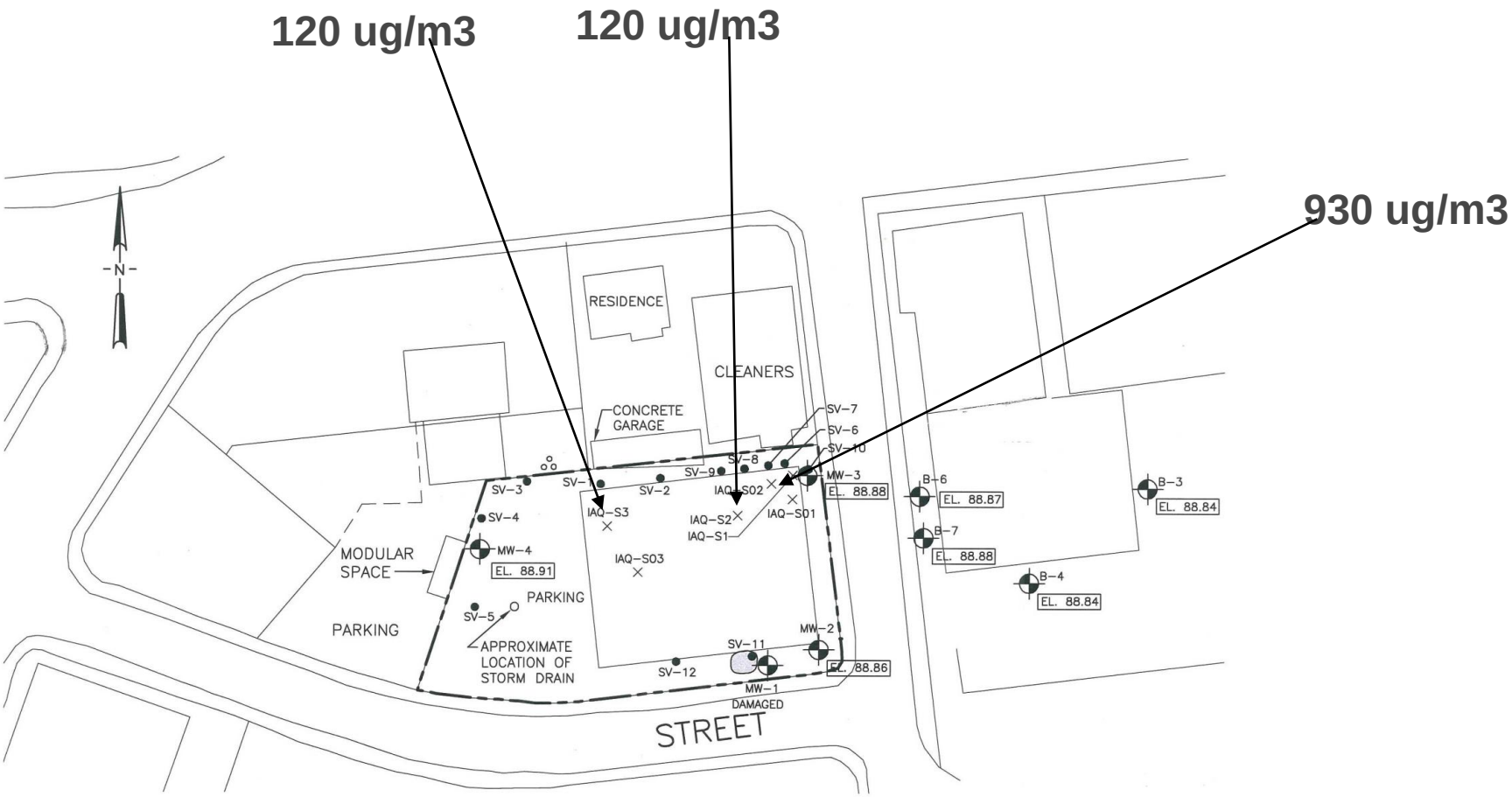
PCE 5 ug/L

PCE < 1 ug/L

Soil Vapor PCE Concentration



Initial Indoor Air PCE Concentration



Next Steps

- Transaction moves forward
- After building completely vacated, enter and observe space. Significant differential settlement - up to ¾” (likely: slab on grade, cinder block walls on piles)
  - field PID measurements up to 40 ppm
- Return and seal floor slab cracks
- Remove carpet and seal expansion joints (up to 1/8”)

Some data

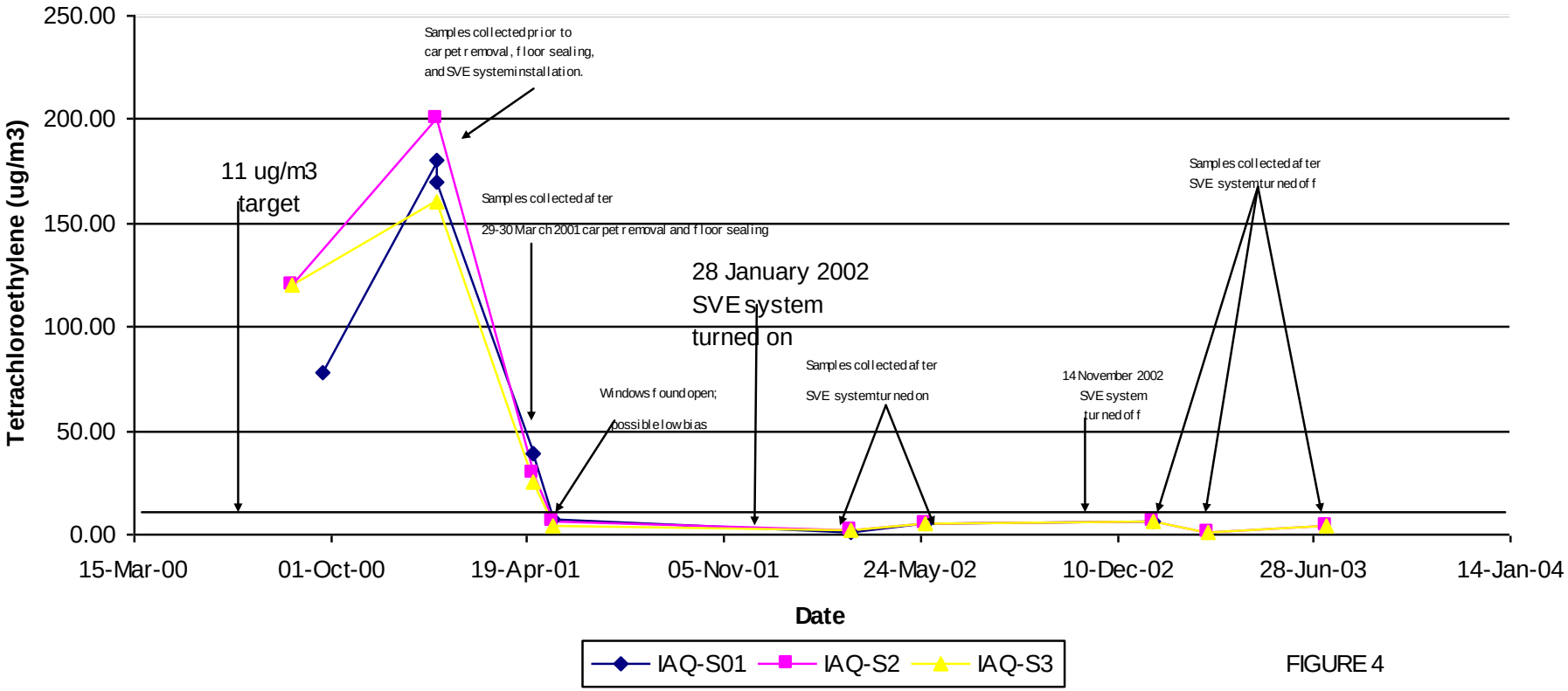


FIGURE 4

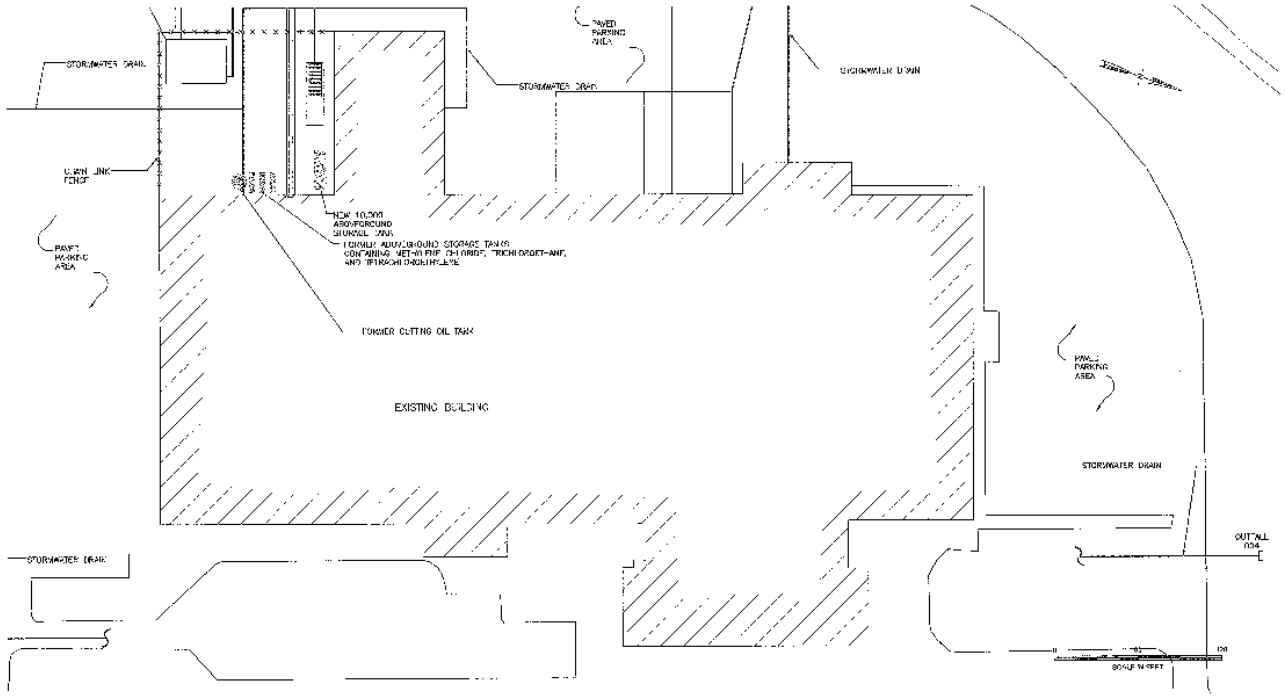
Lessons and Closure:

- Building vacant for two years
- Under state regulatory vehicle, remedy implemented by adjacent property owner
- Concentrations reduced to “background”
- Some cost recovery ongoing

Case Study #2
Site: Former Precision Instrument Facility

- Conditions: potential source of legacy chlorinated solvents
- Property to be redeveloped
- Soil and groundwater > targets at southwest end of building

The Site


STORMWATER DRAIN
PAVED PARKING AREA
STORMWATER DRAIN
STORMWATER DRAIN
CHAIN LINK FENCE
NEW 10,000 ABOVEGROUND STORAGE TANKS
PAVED PARKING AREA
FORMER CUTTING OIL TANK
EXISTING BUILDING
PAVED PARKING AREA
STORMWATER DRAIN
OUTFALL 004
STORMWATER DRAIN
SCALE IN FEET

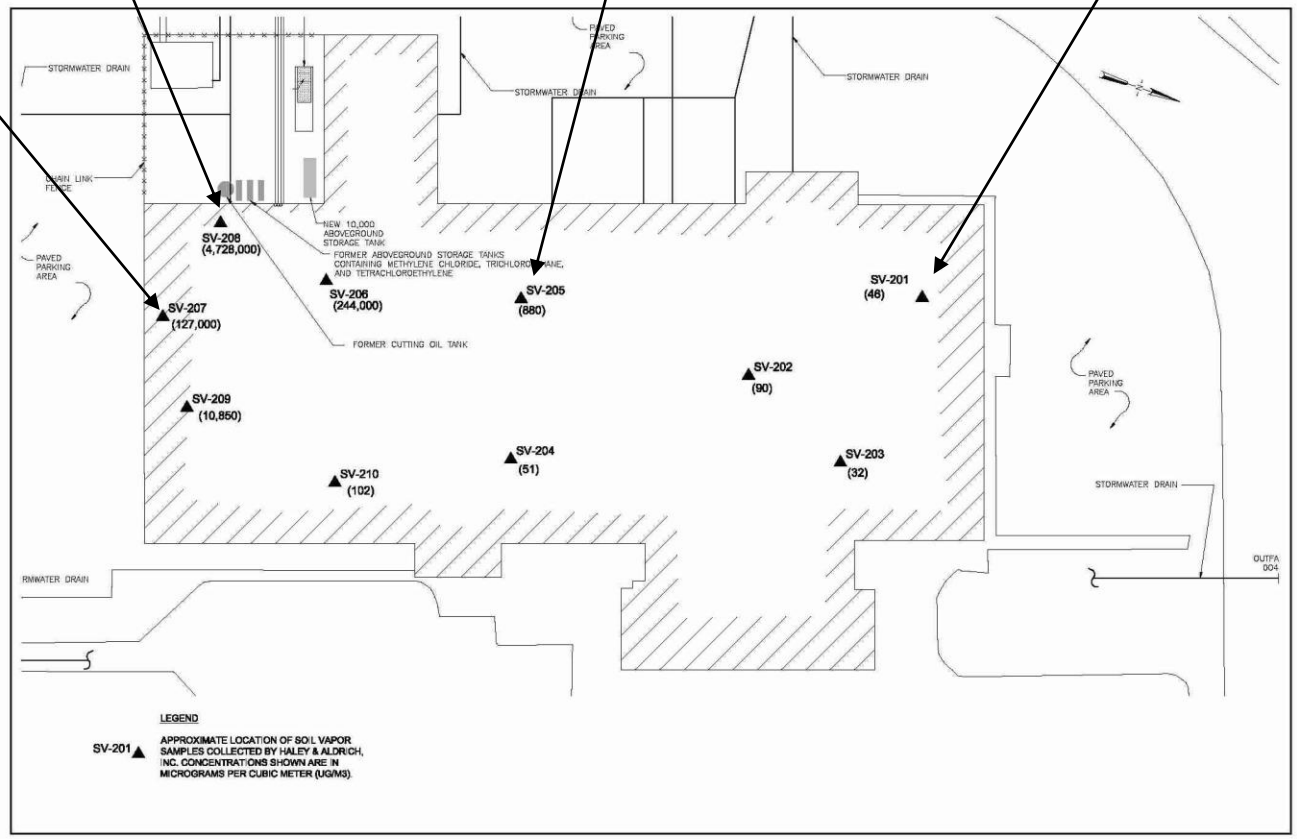
Soil Vapor PCE Concentration

4,728,000 ug/m3

880 ug/m3

46 ug/m3

127,000 ug/m3

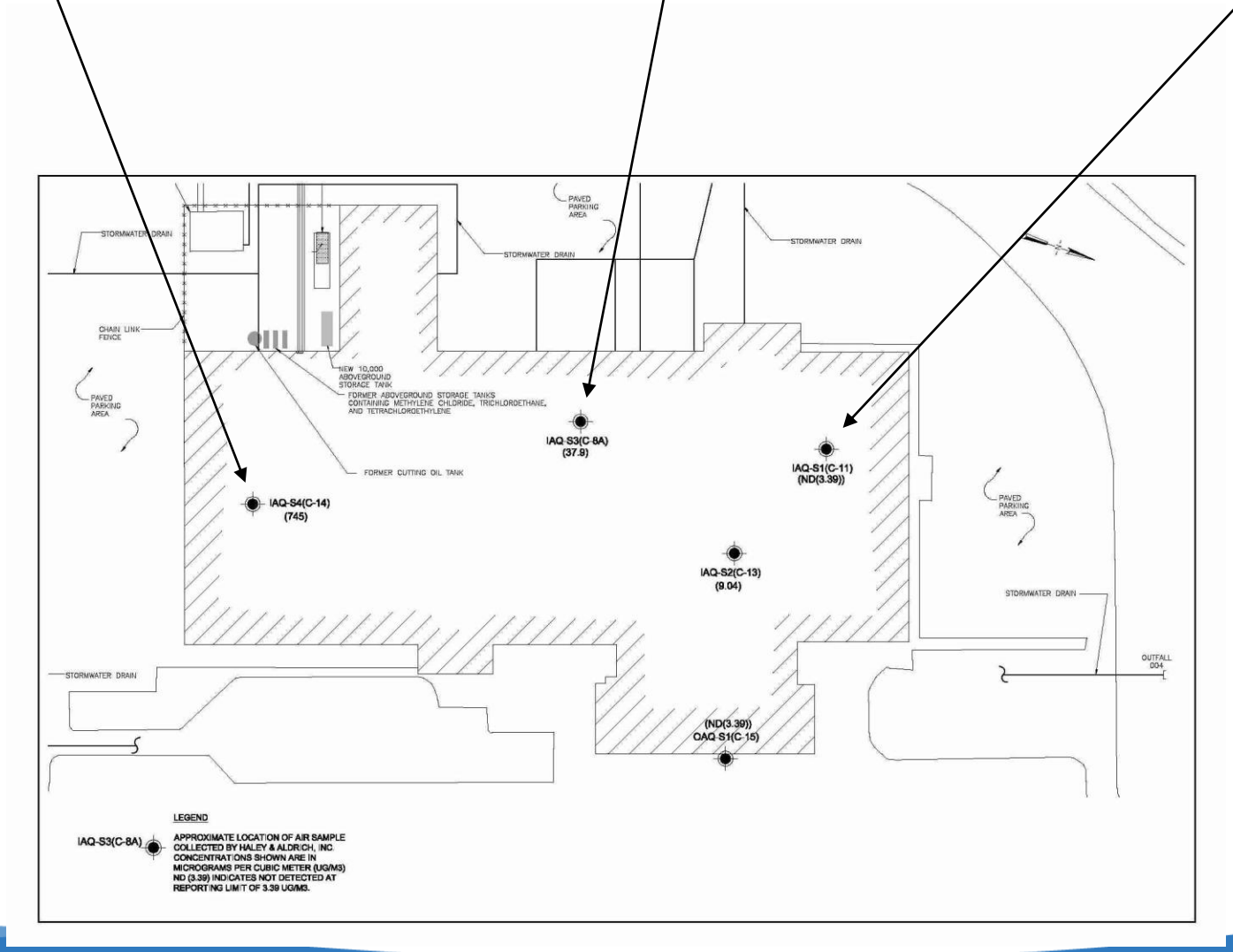


Indoor Air PCE Concentration

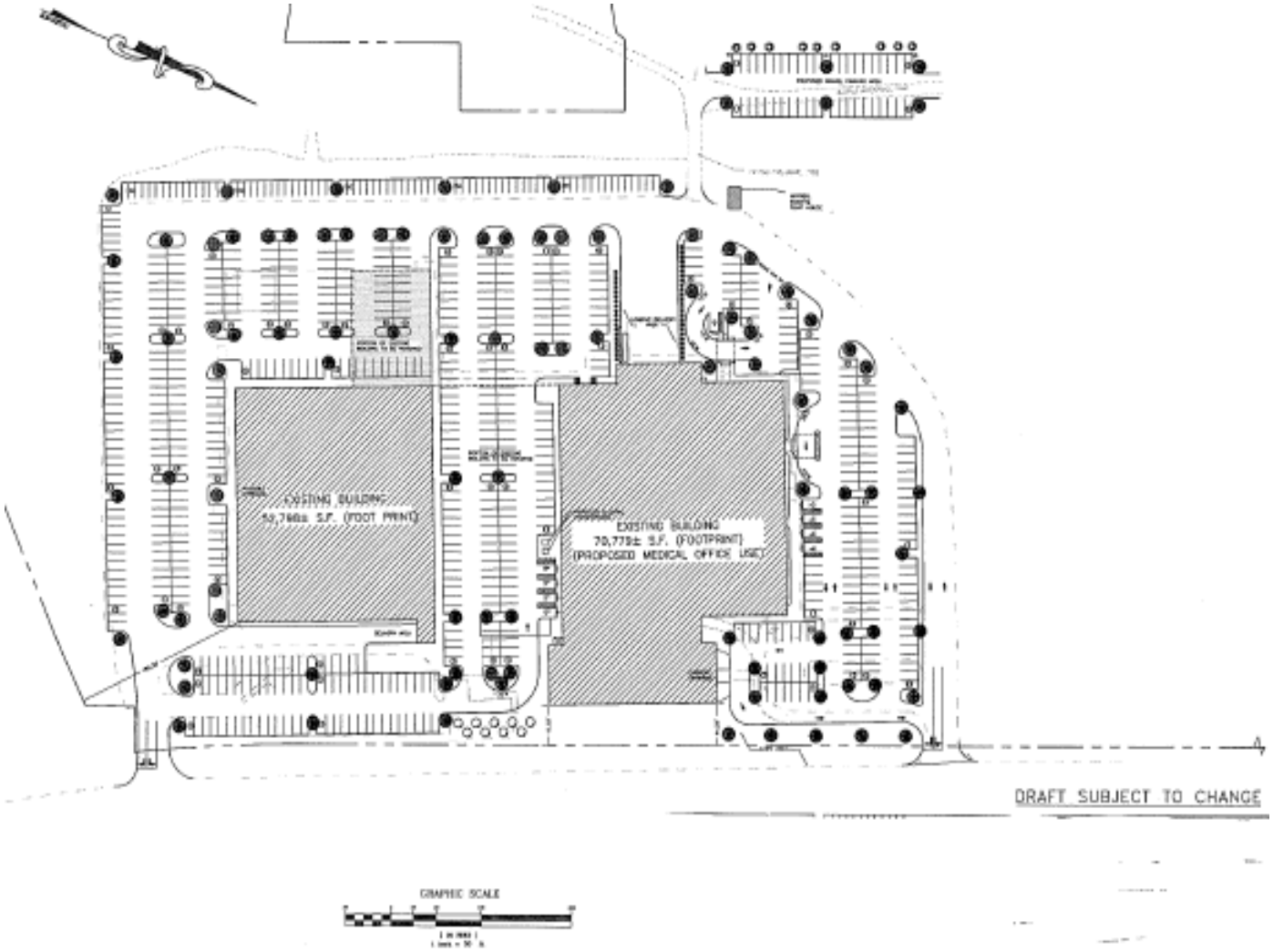
745 ug/m3

37.9 ug/m3

ND(3.39 ug/m3)



Redevelopment Plans



Trenching for new utilities

Installation of slotted pipe

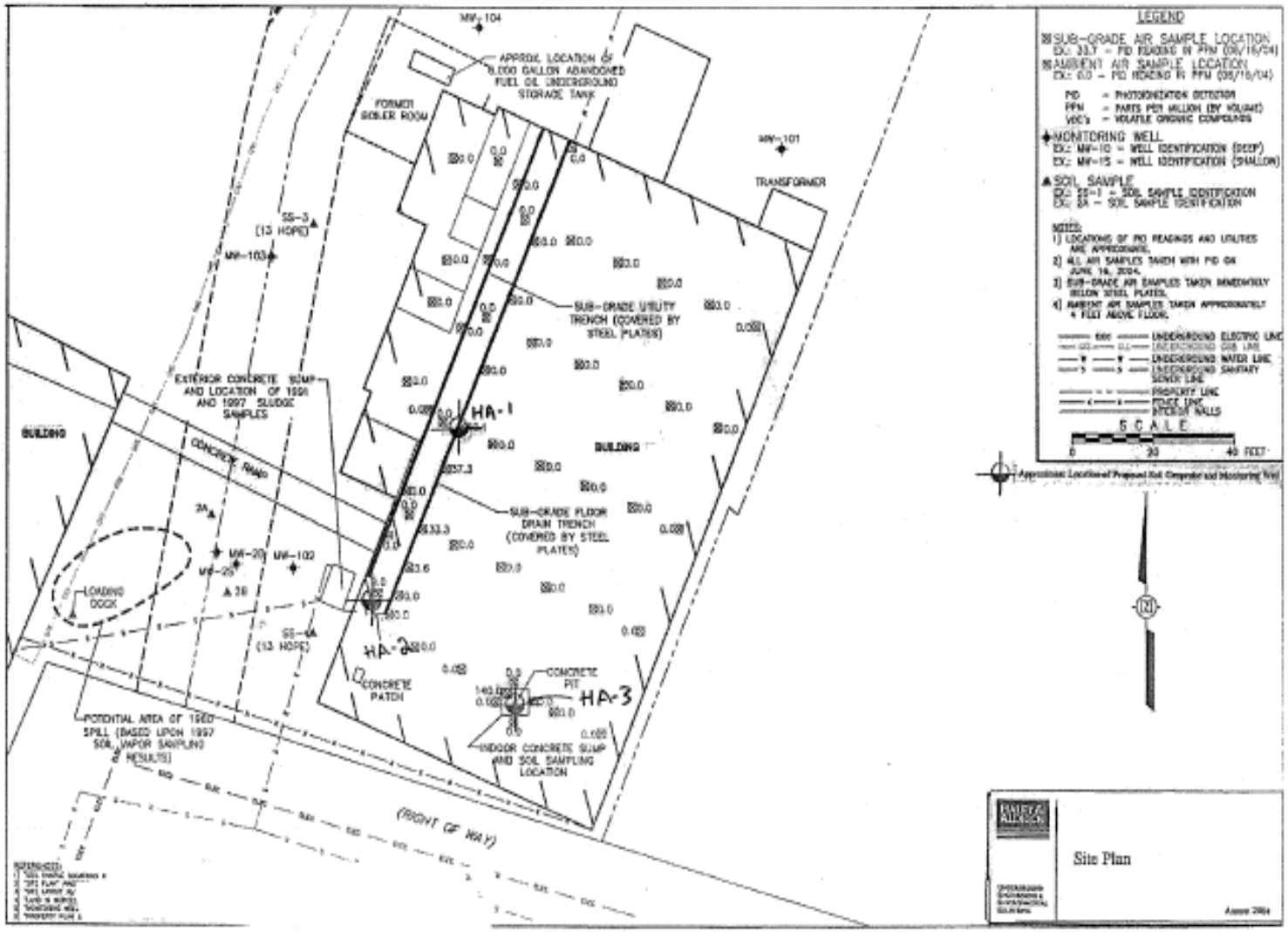
Lessons and Closure:

- Building vacant before and during redevelopment
- Remedy being implemented by property owner
- Pre-acquisition soil vapor concentrations < targets
  - Slotted pipe installed as a protective measure and to satisfy tenant

Case Study #3
Site: Former Pressed Metal Company Site

- Conditions: adjacent source of legacy chlorinated solvents; active plumbing/HVAC supply chain;
- soil and groundwater >>> targets; covered trench drain, covered sump; 130,000 ug/L TCE in well next to interior sump
- very old building; large garage doors open often to allow customer and forklift access

The Site

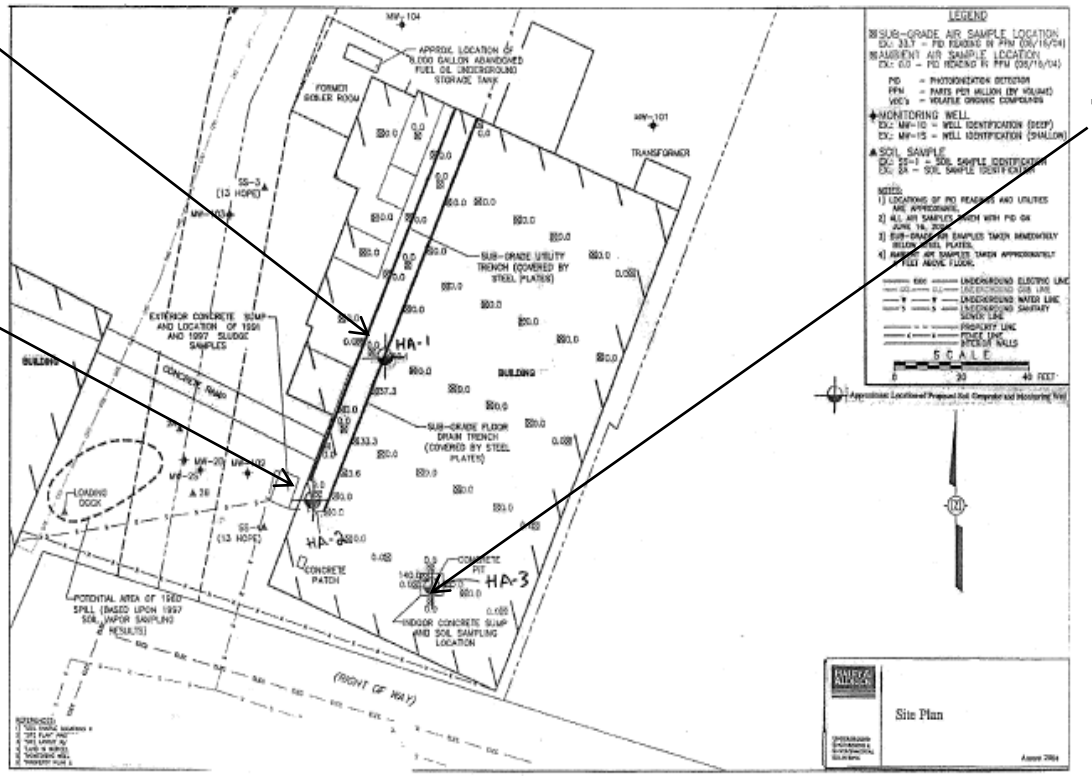

LEGEND
SUB-GRADE AIR SAMPLE LOCATION
AMBIENT AIR SAMPLE LOCATION
MONITORING WELL
SOIL SAMPLE
SCALE
MW-104
APPROX. LOCATION OF 8,000 GALLON ABANDONED FUEL OIL UNDERGROUND STORAGE TANK
FORMER BOILER ROOM
MW-101
TRANSFORMER
SS-3 (13 HOPE)
MW-103
SUB-GRADE UTILITY TRENCH (COVERED BY STEEL PLATES)
EXTERIOR CONCRETE SUMP AND LOCATION OF 1996 AND 1997 SLUDGE SAMPLES
HA-1
BUILDING
CONCRETE RAMP
SUB-GRADE FLOOR DRAIN TRENCH (COVERED BY STEEL PLATES)
MW-20
MW-102
LOADING DOCK
SS-4 (13 HOPE)
HA-2
CONCRETE PATCH
CONCRETE PIT
HA-3
INDOOR CONCRETE SUMP AND SOIL SAMPLING LOCATION
POTENTIAL AREA OF USED SPILL (BASED UPON 1997 SOIL VAPOR SAMPLING RESULTS)
(RIGHT OF WAY)
Site Plan

Groundwater (VI criteria = 300 ug/L)

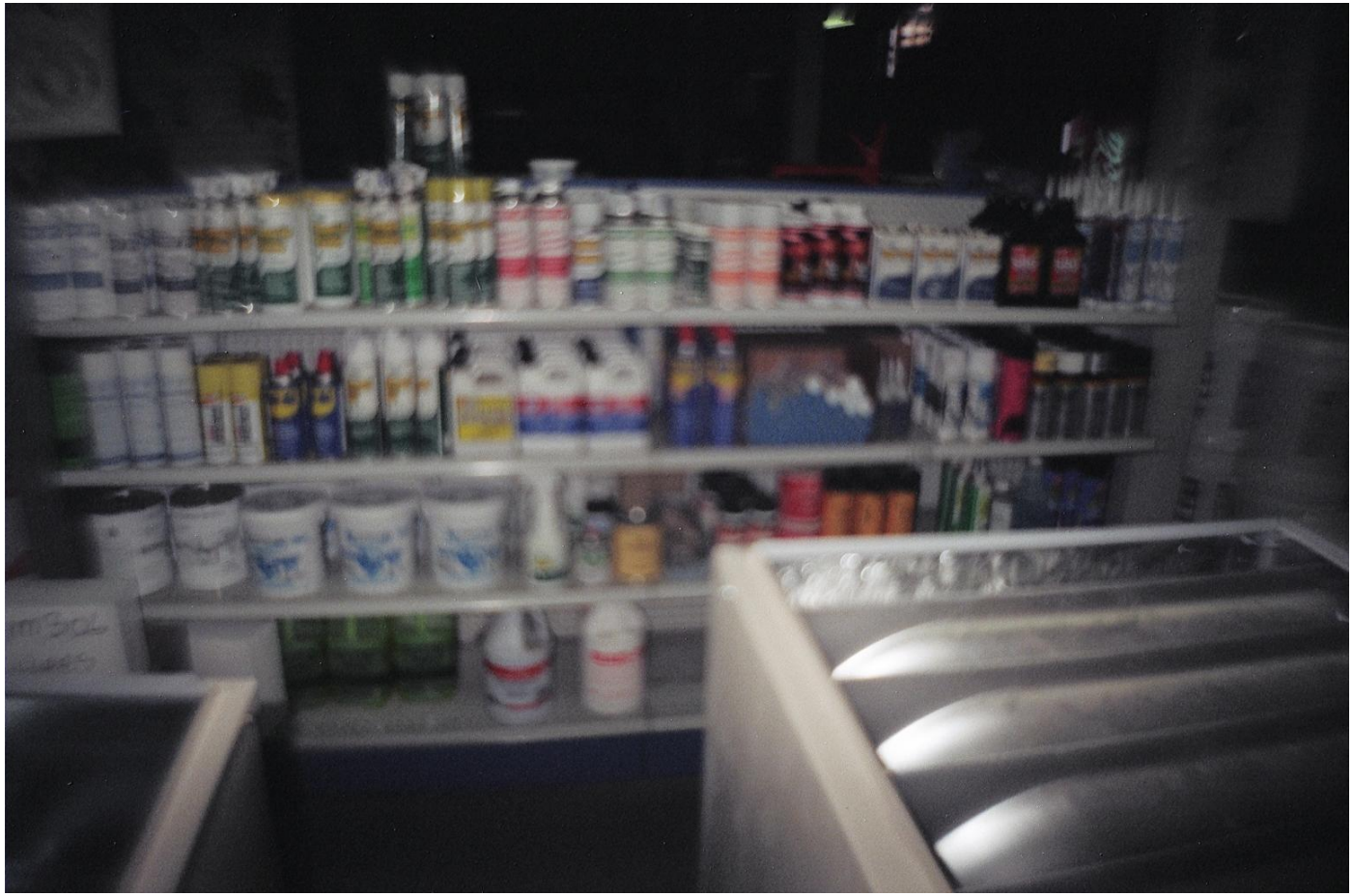
TCE 7,000 ug/L

TCE 3,400 ug/L

TCE 130,000 ug/L



TCE for sale!



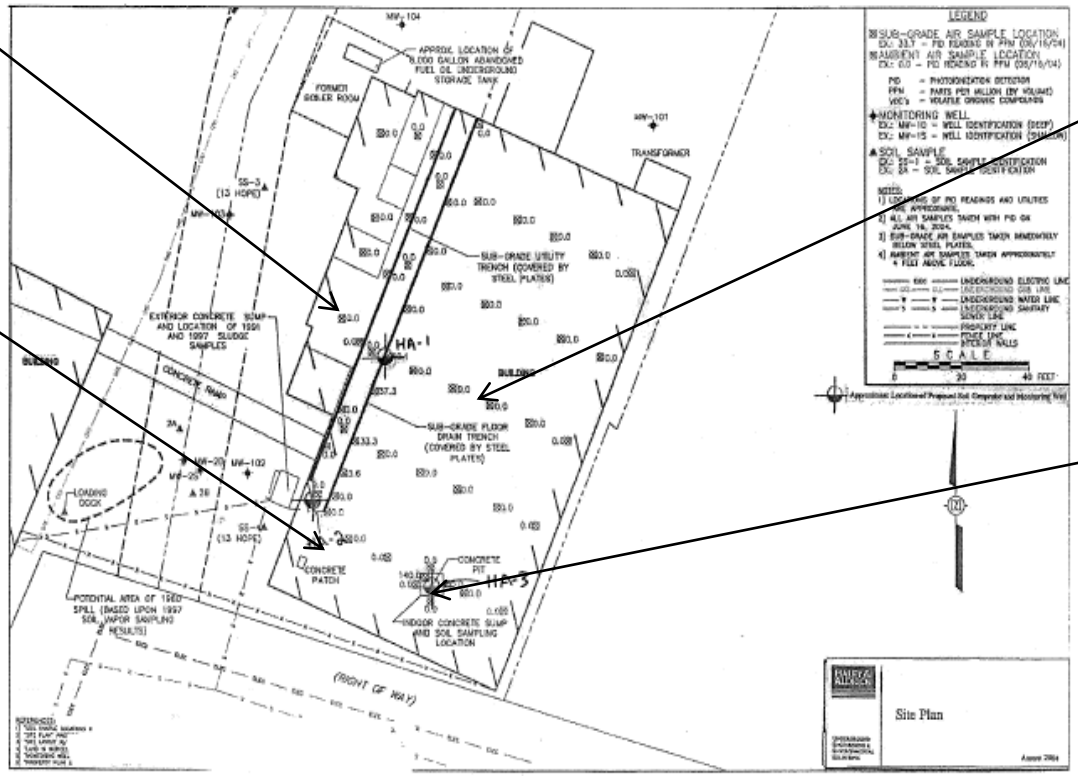
Initial Indoor Air TCE Concentration

TCE 476 ug/m3

TCE 349 ug/m3

TCE 469 ug/m3

TCE 486 ug/m3



Temporary Remedy (ongoing)/closure

- $500; 9,000 cfm fan (36”)
  - Concentrations reduced to ~29 ug/m3 TCE
  - Concentrations increased to ~132 ug/m3 TCE
    - ???

Case Study #4
Site: Former MGP Site

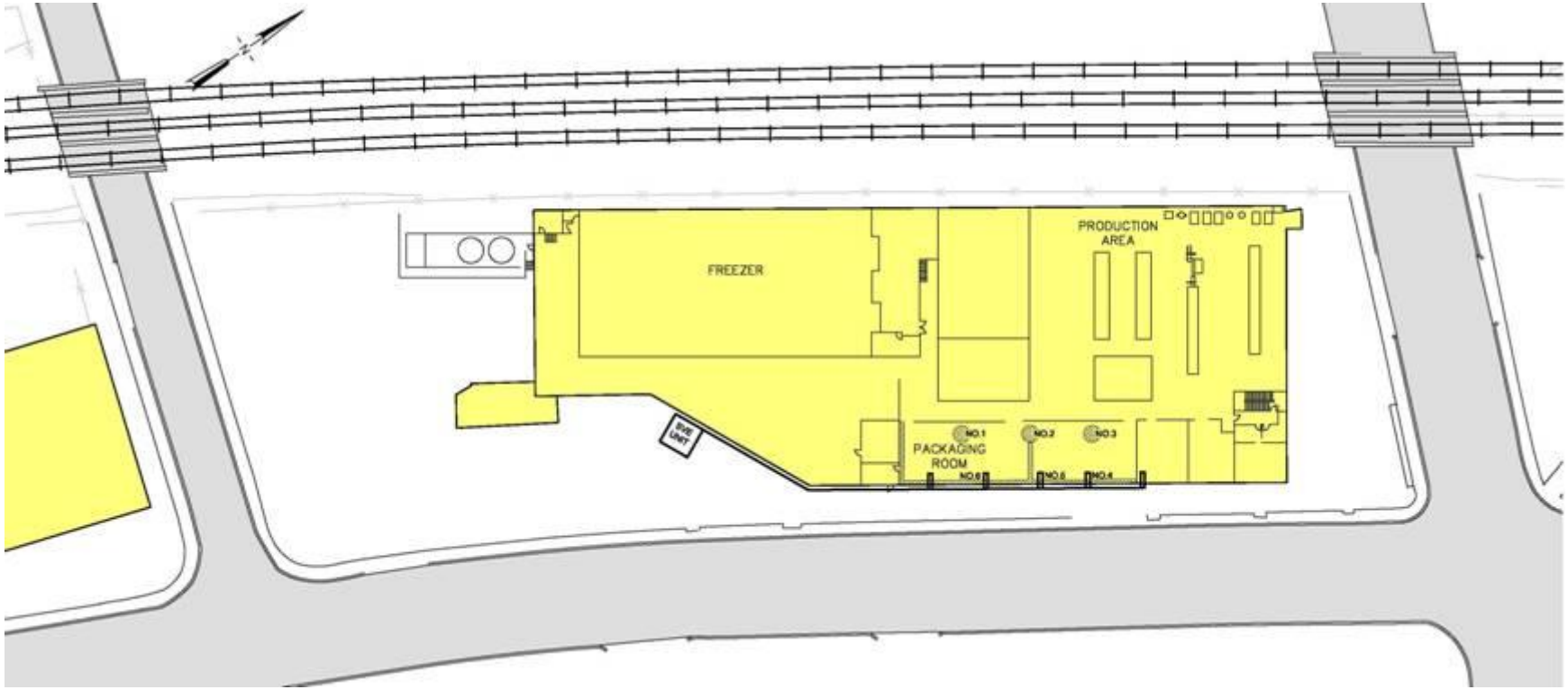
- Constructed over former purifier house structures
- Legacy NAPL, drip pots, other structures
- Now a commercial food service bakery
- Large ovens, freezers, vent fans
- Initial indoor air benzene ~197 ug/m3

The Site

Assessment and Remedies

- SF6 tracer studies indicate VI at column joints – 1998
- Temporary remedy: epoxy sealing – 1999
- Simple, temporary “sub-slab” depressurization system - 2000
  - Piping and manifold largely hand-installed
  - 3 HP blower with explosion proof motor
  - Carbon treatment; GC analysis of vapor
  - Telemetry added to system

Plan Detail


FREEZER
PRODUCTION AREA
PACKAGING ROOM
NO.1
NO.2
NO.3
NO.4
NO.5
NO.6
FIRE UNIT

Other circumstances/closure

- Toluene at 2,000 ug/m3 at one location
  - Facility spray painting file cabinets
- Toluene acting independently of other site COC
  - Packaging room tape tested via ASTM D5116-97 (chamber test)
    - Per roll emission rate =46.6 ug h^{-1} toluene at 24 h
    - Chamber sample 696 ug/m3 toluene
- Urban area; indoor air < outdoor air
- Simple, temporary system is creating sufficient conditions to mitigate VI

Case Study #5 – Strip Mall with Former Dry Cleaner

- Tenants included clothing store, barber shop and pizza parlor; Soil vapor concentrations of up to 150,000 ug/m^3 PCE detected beneath basement of pizza parlor; PCE detected in restaurant space at concentrations of up to 45 ug/m^3

- Subslab depressurization selected to mitigate VI; diagnostic testing to design depressurization system completed during off hours to minimize disruption to restaurant

Case Study #5 (cont.)

- Diagnostic testing demonstrated effective ROI of up to 0.016 in. H_2O at 20 ft. from pilot suction pit
- System designed and installed with suction pits in basement of restaurant
- Following system startup, measureable vacuum detected in vacuum monitoring points, but only up to 0.008 in. H_2O
- Efforts to troubleshoot did not indicate problems with blower system
- However, front door of pizza shop was difficult to open

Case Study #5 (cont.)

- Arranged temporary shutdown of large exhaust fan
- differential pressures of up to 0.014 in. H_2O measured at all locations in building footprint
- differential pressure readings increased and decreased when the exhaust fan was cycled on and off
- Solution: additional suction pits were installed to provide better coverage and dilution air to vacuum blower was balanced
- negative pressure field of up 0.015 in. H_20 measured even while exhaust fan operating

Case Study #6 – Residential condominium

- Building downgradient from operating dry cleaner
- Soil vapor concentrations of up to 25,000 ug/m^3 of PCE measured under slab on grade unit; PCE measured in indoor air in residential unit up to 25 ug/m^3
- Subslab depressurization selected to mitigate VI risk with diagnostic testing completed; system installed consisting of 8 suction pits to depressurize 10,000 ft^2 footprint
- Negative pressure field of greater than 0.02 in. H_20 documented within footprint following start up
- Subsequent IA testing indicated PCE concentrations of less than 1 ug/m^3 approximate 2 weeks after start up

Case Study #6 (cont.)

- Post-mitigation IA concentrations consistent over more than 6 months
- IA samples in one area contain 250 ug/m^3 of PCE
- Reinspected area and identified a can of “Sheila Shine” and used rags
- New building manager recently hired; employees normal use of Sheila Shine to clean stainless steel elevator doors
- Removed material and rags; PCE in indoor air less than 1 ug/m^3 when sampled approximately one week later

Take Home Messages

- VI is continuing to be an evolving science with regulatory oversight/involvement increasing
- Management of VI sites can be inconsistent, unpredictable, and resource-intensive
- Focus tends to be on chlorinated VOCs; practitioners increasingly recognize that petroleum hydrocarbons (from petrogenic and pyrogenic sources) are subject to biodegradation and confounded by background
- Assessment and mitigation must be managed with additional sensitivity
- Transactional SVI risks can be managed
- Future trends may include more reliance on preemptive installation of mitigation systems; large building mitigation is often a cost-effective solution, especially when implemented during construction/redevelopment

Thank You!

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