ITRC's PVI Assessment Strategy

Key topics

- **What**: Screening distance concept
- **Why**: Case for change
- **How**: Screening distance application
- Supporting science

Afternoon

Petroleum VI Screening

↓

Investigative Approach

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Data Evaluation

↓

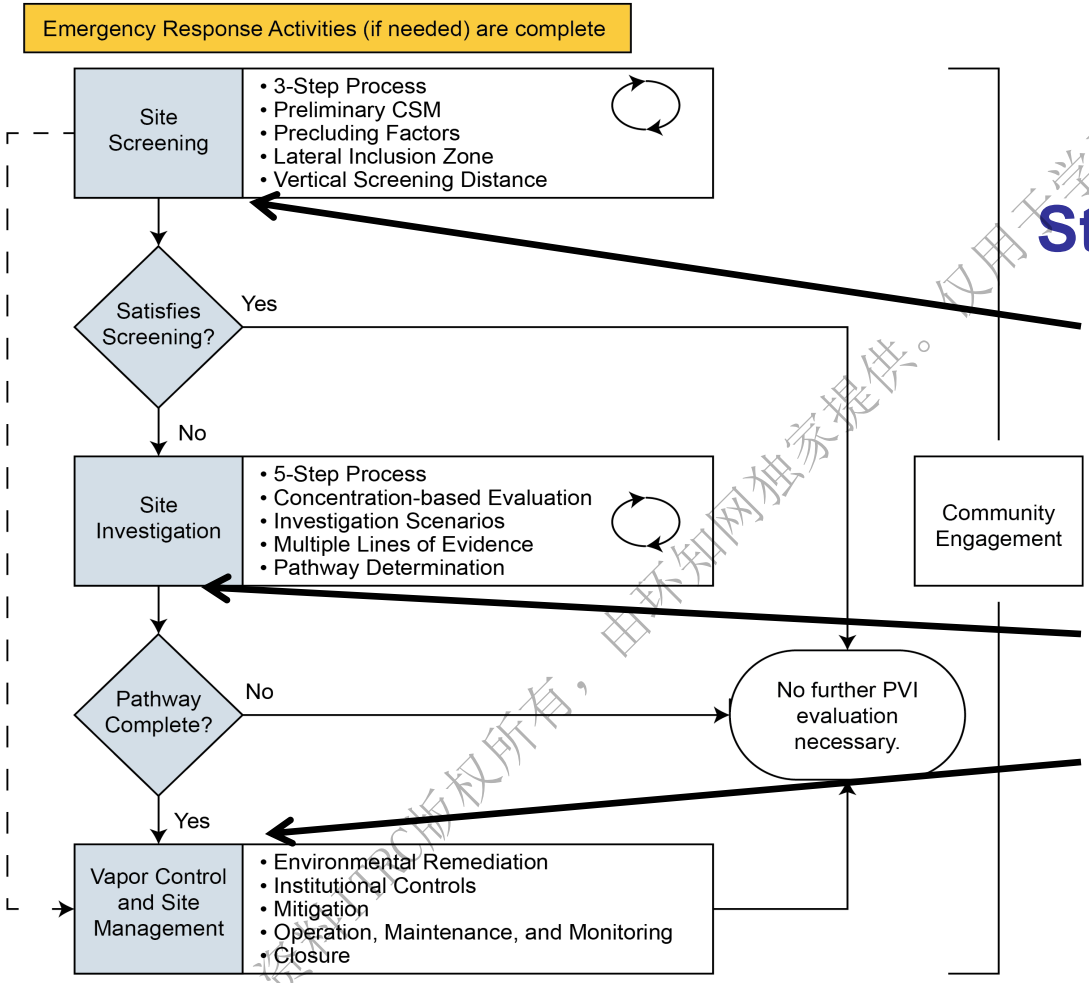
Vapor Control and Site Management

↓

General Remediation

ITRC's PVI Assessment Strategy

Figure 1-2. PVI strategy flowchart



Strategy includes:

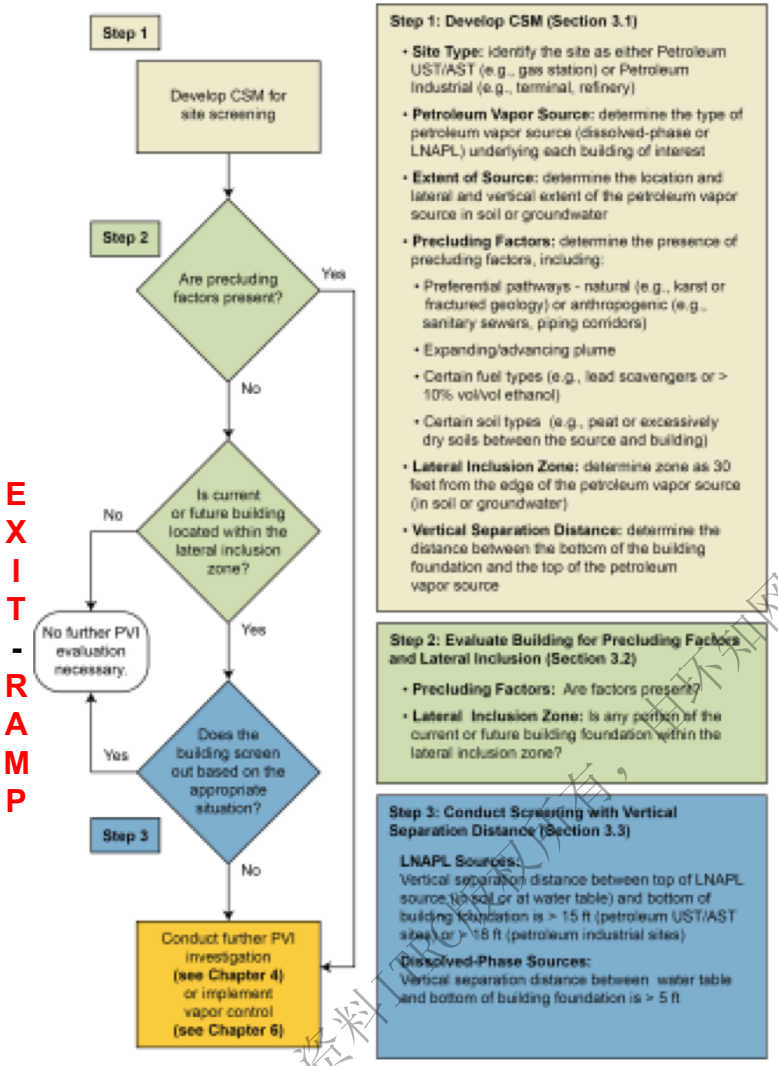
Site screening using Vertical screening distance

Site investigation

Vapor Control and Site Management

ITRC PVI-1, Figure 1-2

Steps 1-3: Site Screening



Step 1: Develop preliminary conceptual site model (CSM)

Step 2: Evaluate site for precluding factors and lateral inclusion

Step 3: Screen building using vertical separation distance

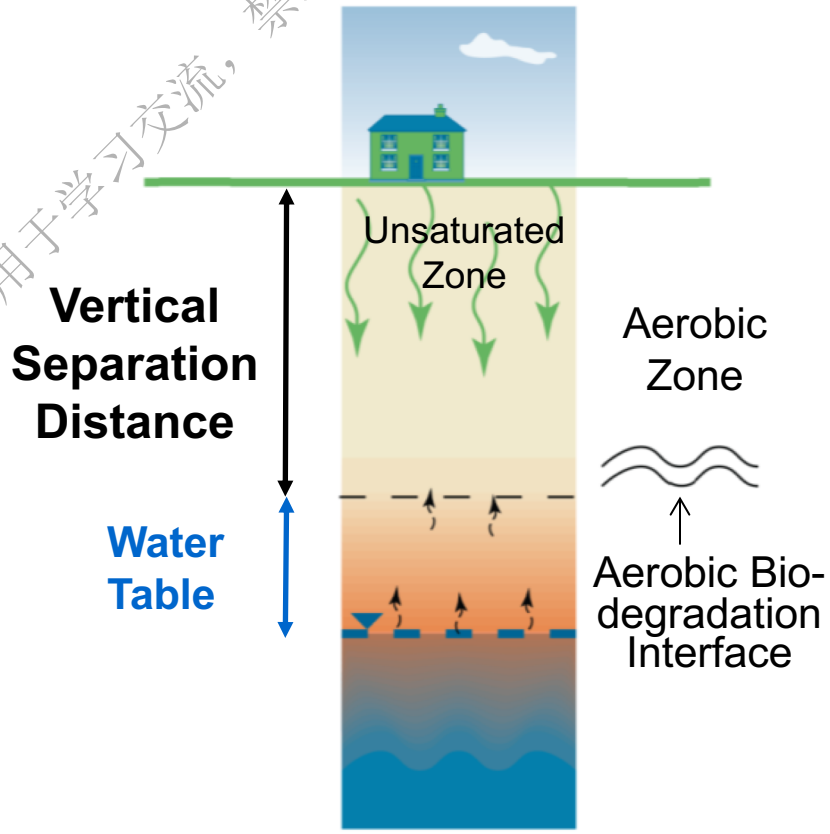
ITRC PVI-1, Figure 3-2

Vertical Screening Distance

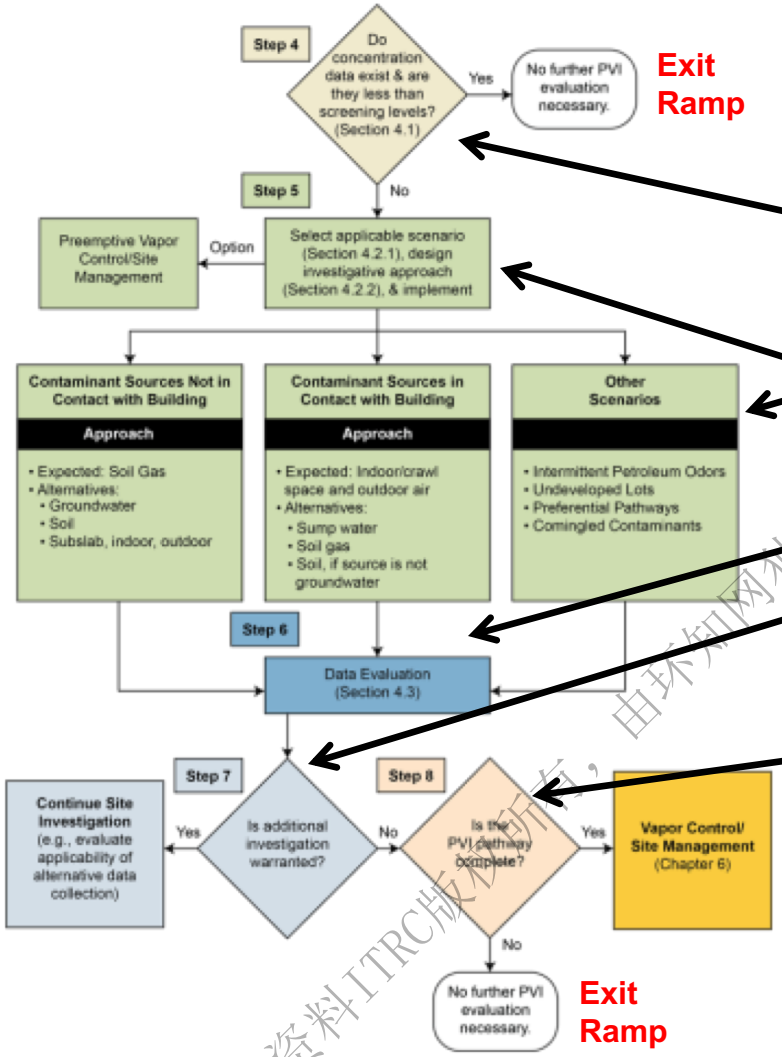
- New method for PVI screening based on a ***vertical screening distance***

  DEFINITION: Minimum soil thickness between a petroleum vapor source and building foundation necessary to effectively biodegrade hydrocarbons below a level of concern for PVI

- Approach expected to improve PVI screening and reduce unnecessary data collection



Steps 4-8: VI Investigation



If screening process does not allow elimination of PVI pathway:

Step 4: Conduct concentration-based evaluation using existing data

Step 5: Select and implement applicable scenario and investigative approach

Step 6: Evaluate data

Step 7: Decide if additional investigation warranted?

Step 8: Decide if the PVI pathway complete?

ITRC PVI-1, Figure 4-1

Current Approach to PVI

Site Investigation

Vapor Control & Management

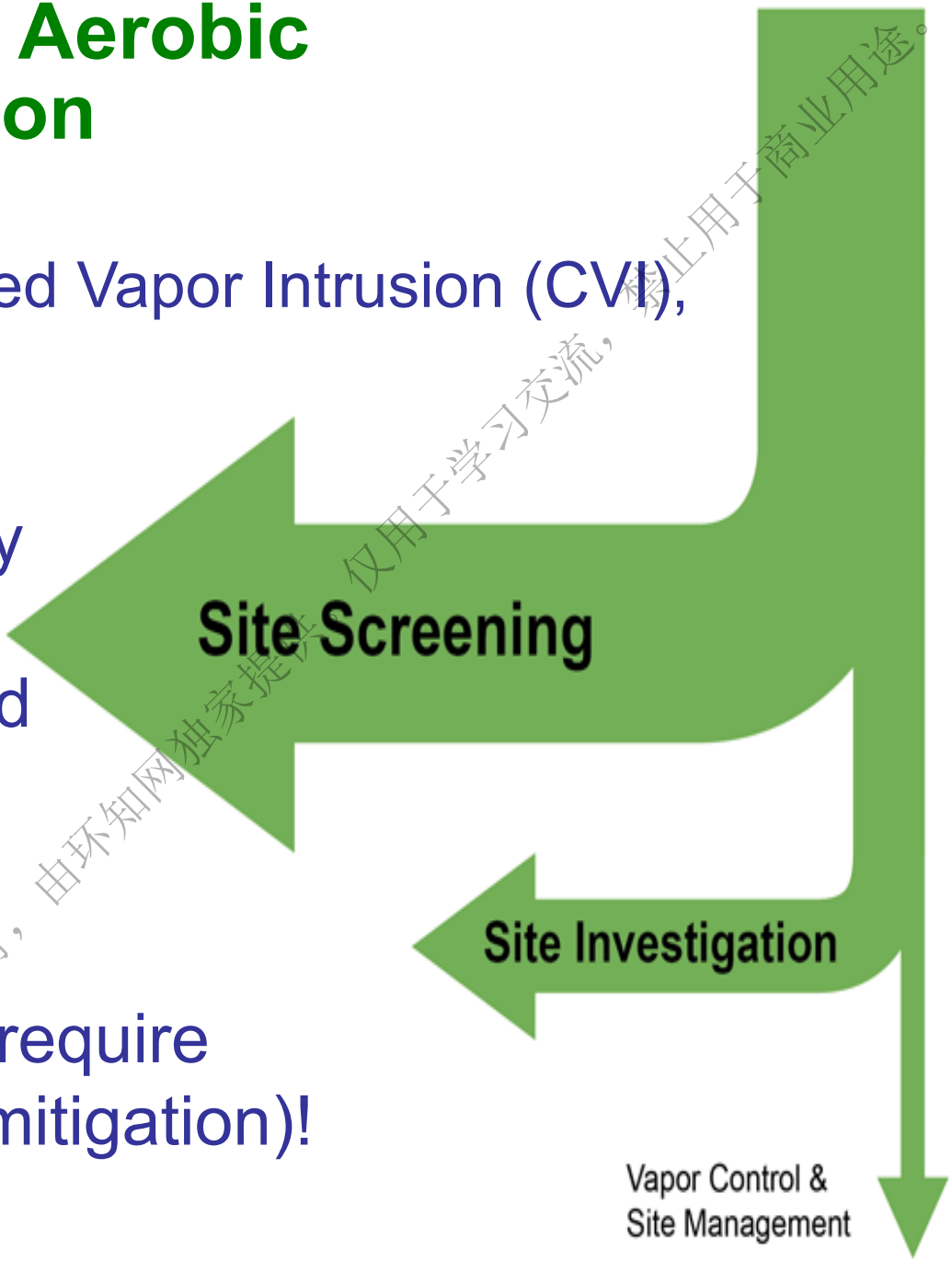
Is there an effective way to screen out potential PVI sites prior to a full VI investigation while still being protective of human health?

The Effect of Aerobic Biodegradation

Unlike Chlorinated Vapor Intrusion (CVI),

the vast majority of PVI sites can be screened out . . .

. . . and do not require vapor control (mitigation)!



The ITRC Solution – Guidance

Petroleum Vapor Intrusion (PVI): Fundamentals of Screening, Investigation, and Management

Available at: http://www.itrcweb.org/PetroleumVI-Guidance/

Type of Petroleum Sites

Source: BP

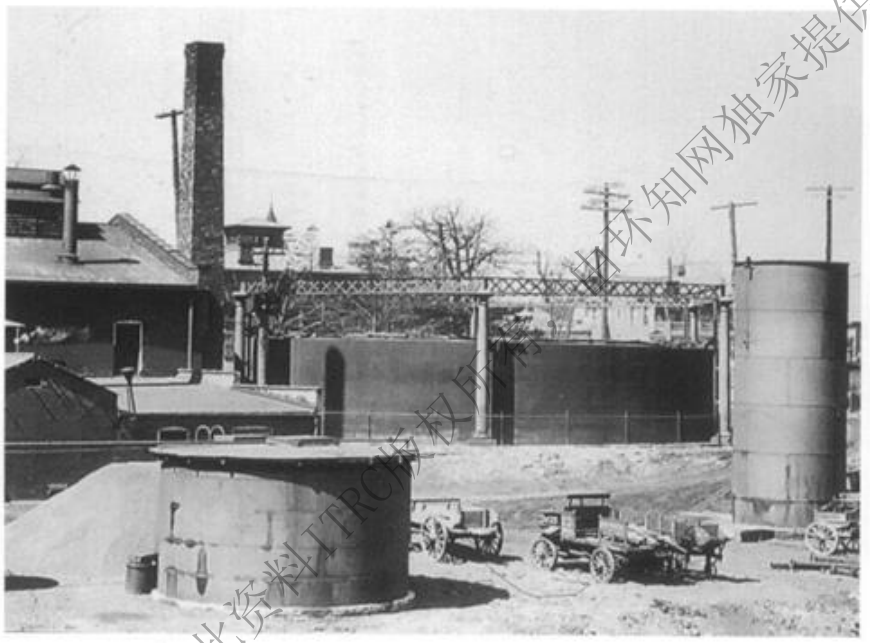
- Gasoline and diesel USTs
- Commercial/home heating oil USTs
- Refineries
- Bulk storage facilities
- Pipeline/transportation

Source: T. Ririe

Types of Petroleum Sites (continued)

- Oil exploration/production sites
- Former Manufactured Gas Plants
- Creosote facilities
- Dry cleaners using petroleum solvents

Source: T. Ririe



Source: We Energies

Learning Objectives
Steps 1-3 Site Screening

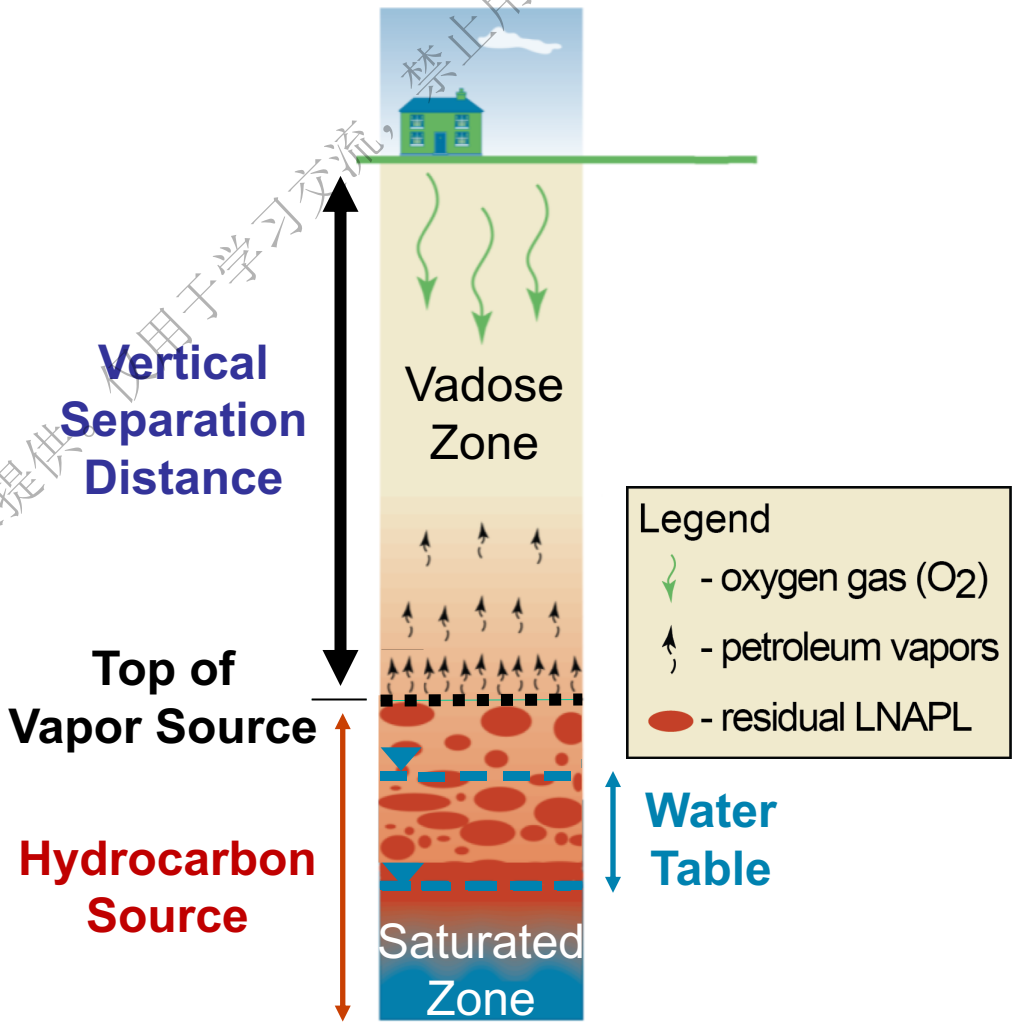
During these steps you will:

- **Understand** the screening distance concept and why it was developed
- **Apply** the screening distance approach
- **Justify** the use of this scientifically-based screening process

Screening Distance Concept: Vertical Separation Distance

Vertical **Separation** Distance

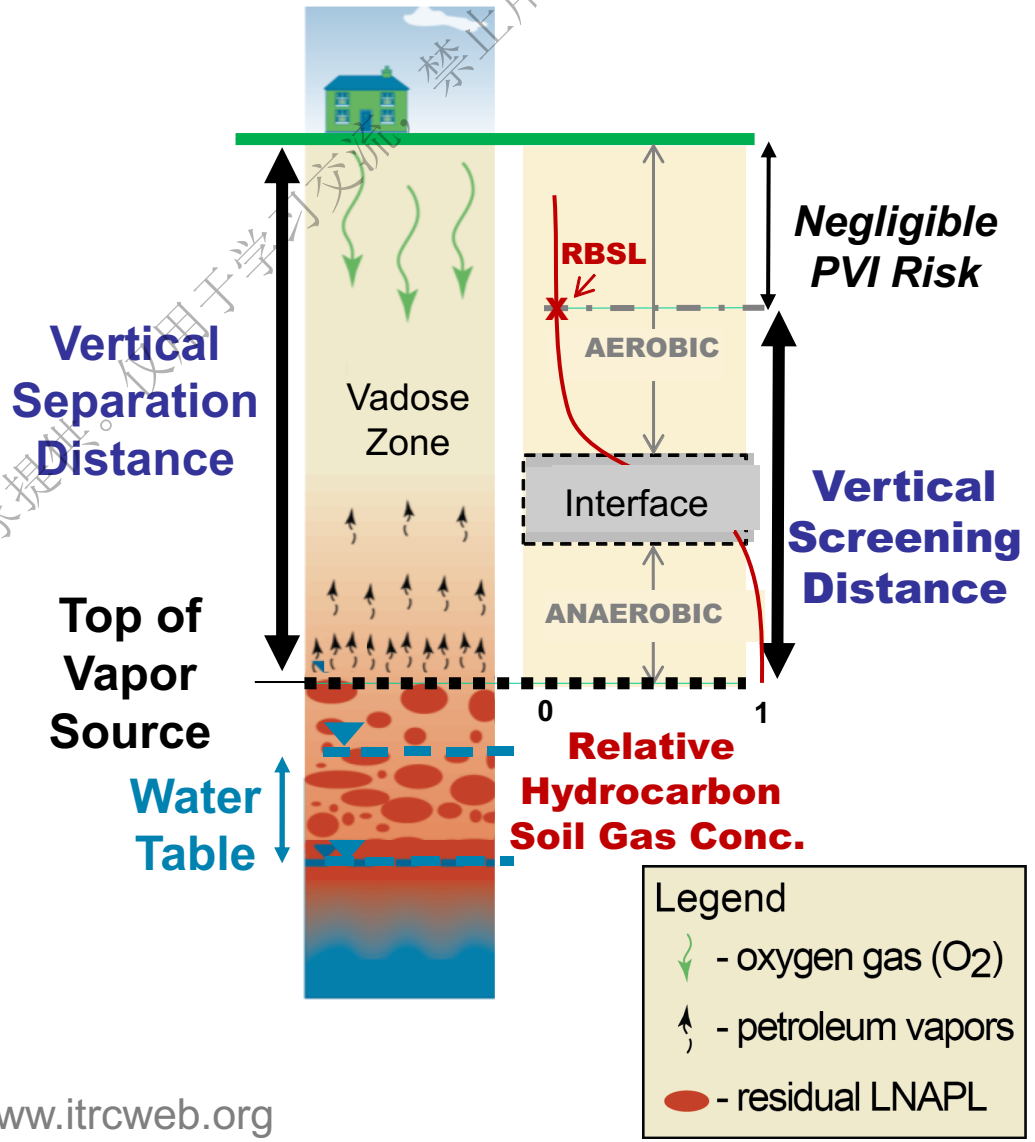
- Definition: "distance between top of petroleum vapor source (LNAPL or dissolved) and bottom of building foundation"
- Top of petroleum vapor source:
  - LNAPL:
    - Top of LNAPL smear zone
    - Top of residual-phase LNAPL source in the vadose zone
  - Dissolved:
    - Maximum anticipated water table elevation



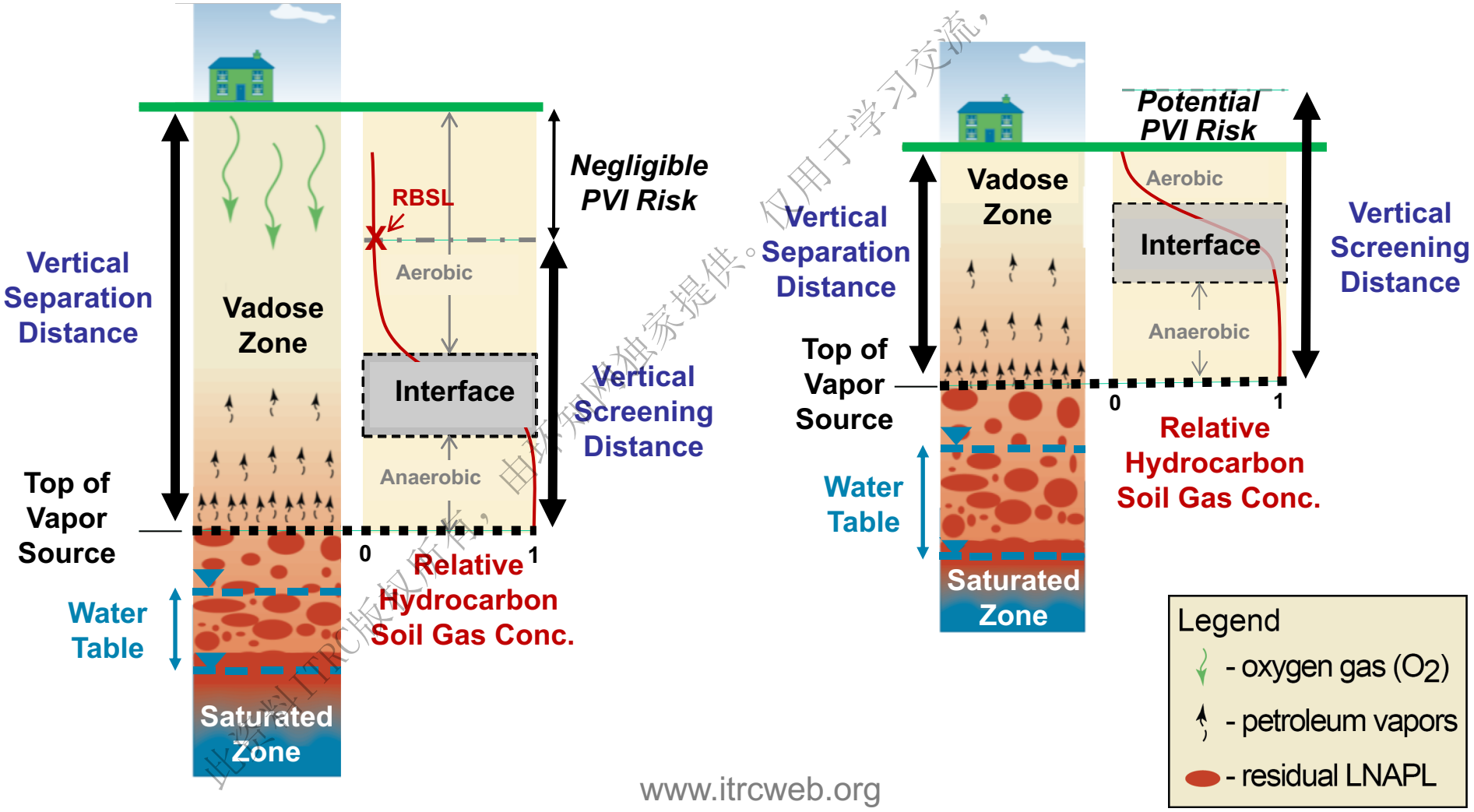
Screening Distance Concept:
Vertical Screening Distance

Vertical **Screening** Distance:

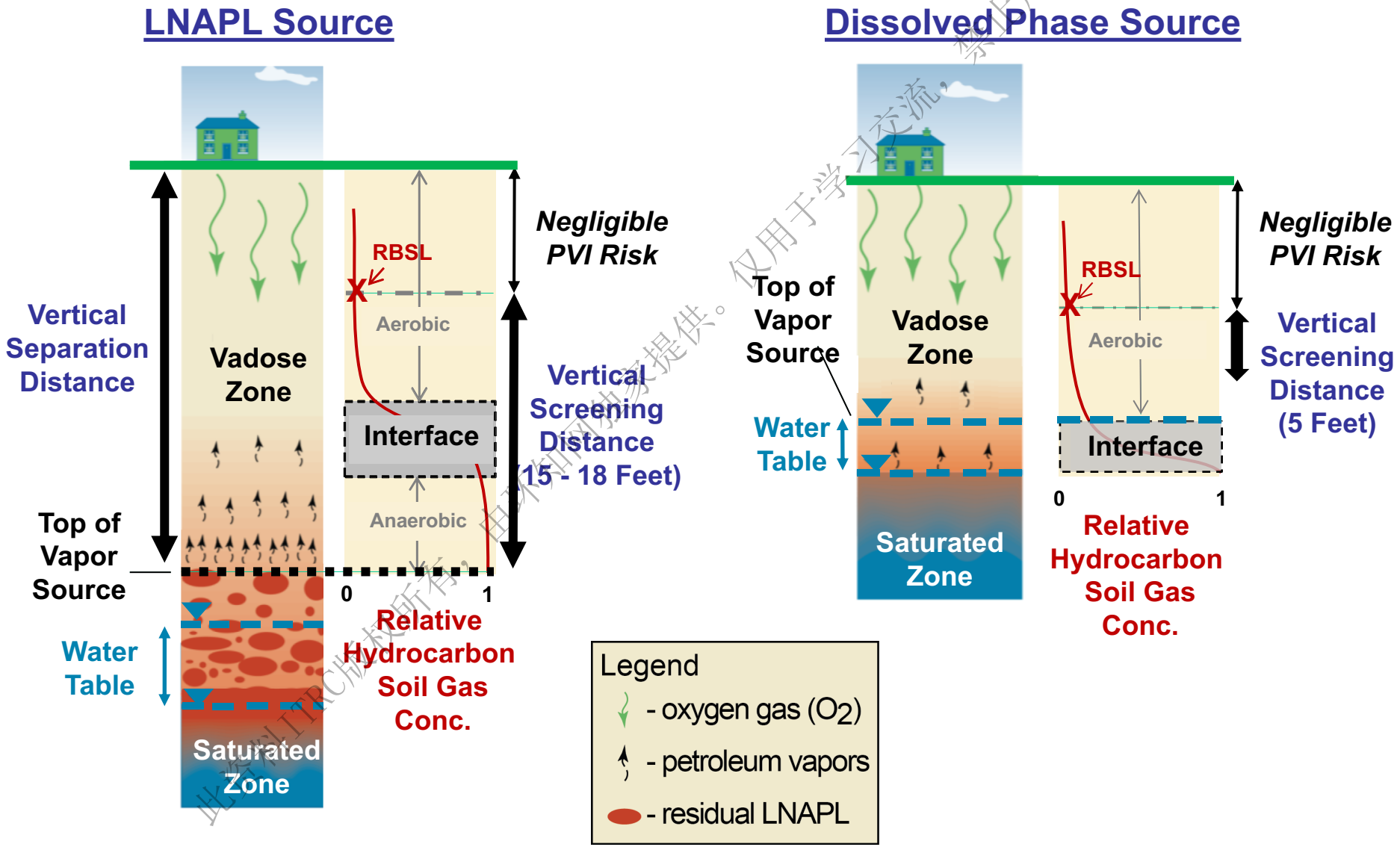
- Definition: "minimum soil thickness between a petroleum vapor source and building foundation necessary to biodegrade hydrocarbons below a level of concern for PVI (i.e., RBSL in soil gas)"
- Derived from empirical studies
  - Dependent on source type (dissolved vs. LNAPL), site type (UST vs. industrial), and hydrocarbon type
  - Based on most conservative distance (benzene)



Vertical Screening Distance Concept
Screen Out, Screen In



Vertical Screening Distance Concept
Source Type Matters



Screening Distances – A New Concept?

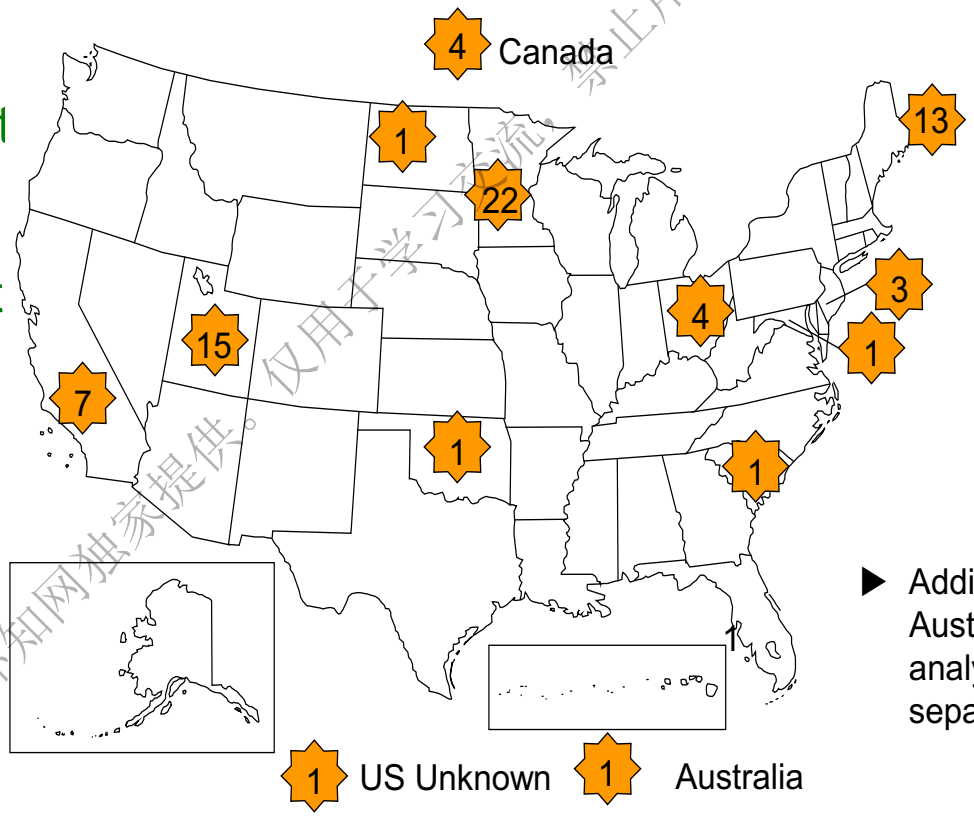
- ***No,*** some agencies have separate distances for PVI (vs. CVI) and for dissolved-phase vs. LNAPL sources

GUIDANCE	VERTICAL SCREENING DISTANCE (FT)	
	DISSOLVED-PHASE	LNAPL
Connecticut DEP (2003)	30	30
Pennsylvania DEP (2004)	15 – 30	100
New Hampshire DES (2006)	30	30
ASTM (2008)	30	100
Wisconsin DNR (2010)	5	30

- **What's new?** Vertical screening distances have been recently refined based on evaluation of ***lots of field data!***

Vertical Screening Distances – Empirical Studies

- Dissolved phase
  - All site types = 5 feet
- LNAPL
  - UST (AST) = 15 feet
  - Industrial = 18 feet (Limited data set)
- 1,000's of data pairs, 100's of sites
- Similar results – different databases, methods, and assumptions

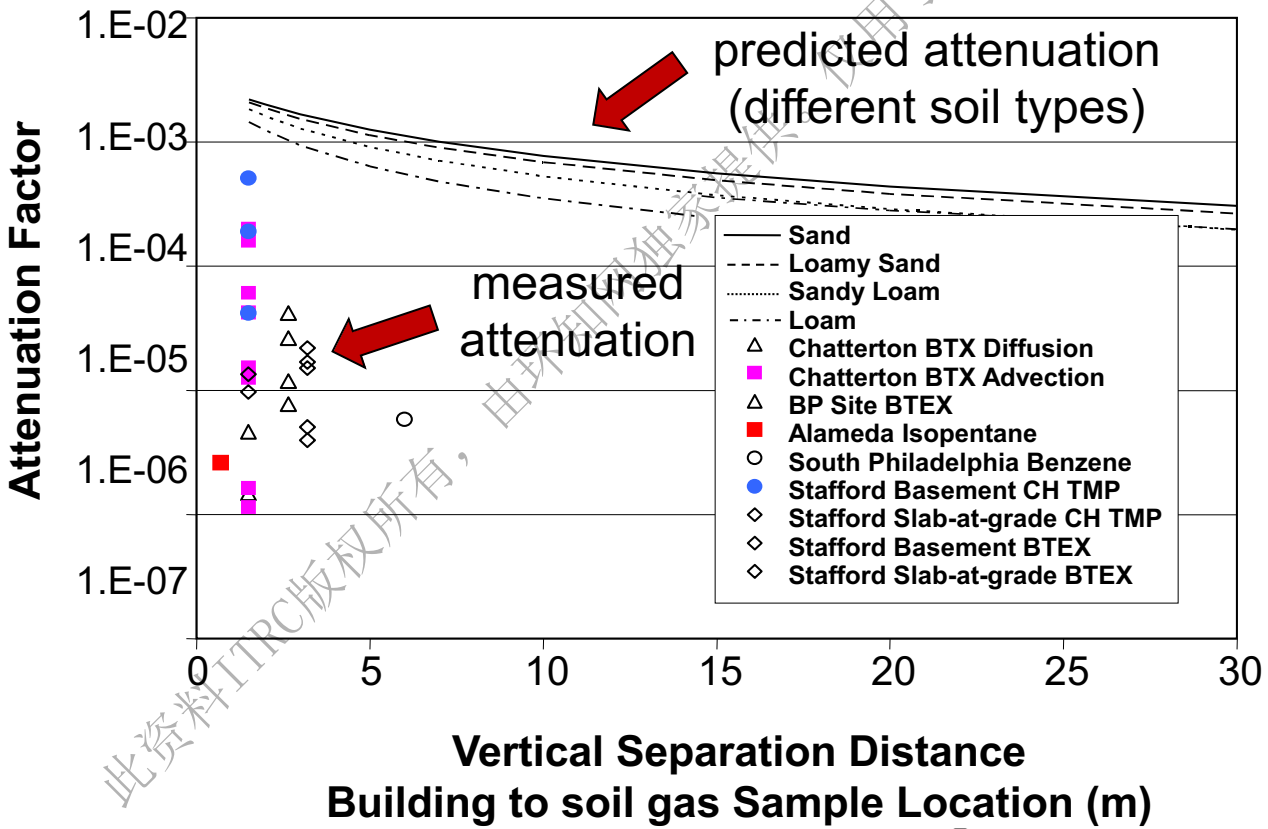


- Additional 124 Australian sites analyzed separately

Case for Change – Round 1

Need to Focus Resources on Sites that Pose Greatest Risk

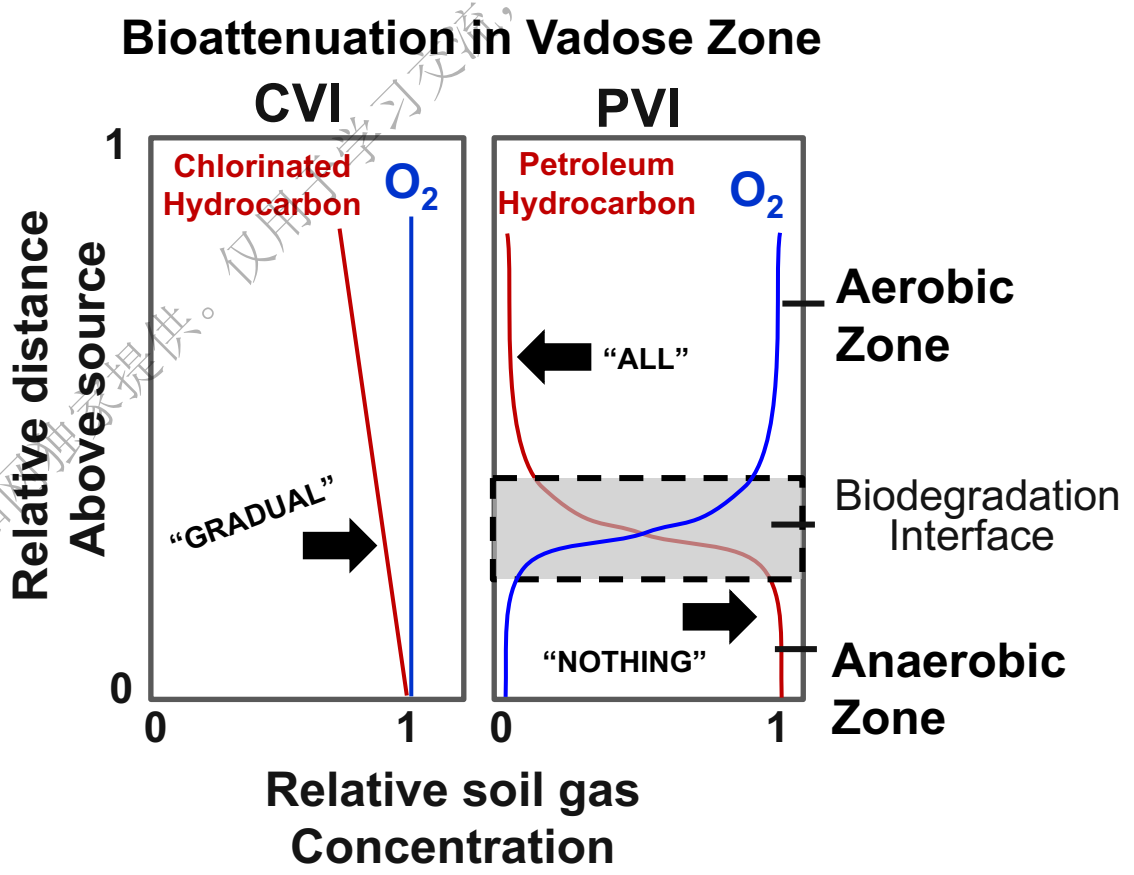
- PVI screening level concentrations for soil and groundwater are generally conservative – drive unnecessary site PVI investigations
- Measured attenuation orders of magnitude < predicted by transport modeling using Johnson and Ettinger (1991)



Modified from Hers, 2005

Case for Change – Round 2
Bioattenuation – a Key Differentiator

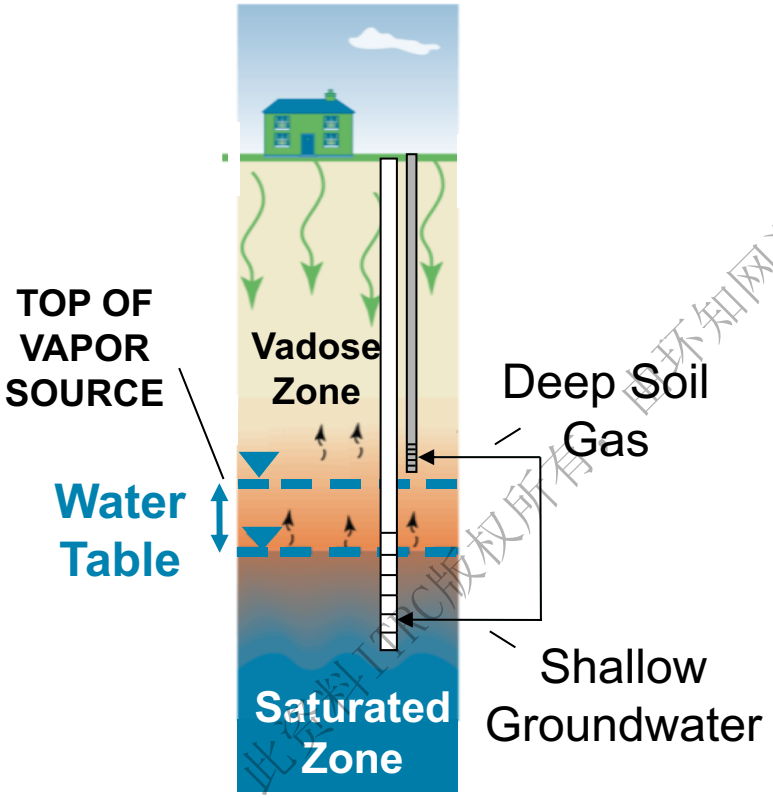
- Bioattenuation in vadose zone - "all or nothing"
  - Rate of biodegradation >> rate of diffusion/ advection at some critical distance above PVI source
  - Behavior lends itself to screening based on vertical separation distance
- ***CVI ≠ PVI site screening***



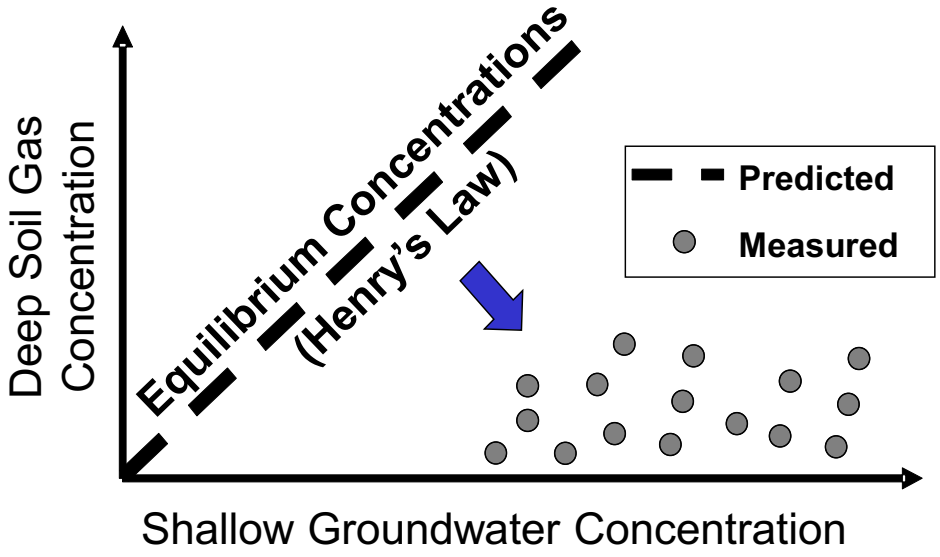
Case for Change – Round 3
Value of Soil Gas and Groundwater RBSLs

- Measured soil gas concentrations << predicted based on equilibrium partitioning (Henry's Law) (e.g., dissolved-phase sources)
- Deep soil-gas and shallow-groundwater concentrations not well correlated

Dissolved Phase Source

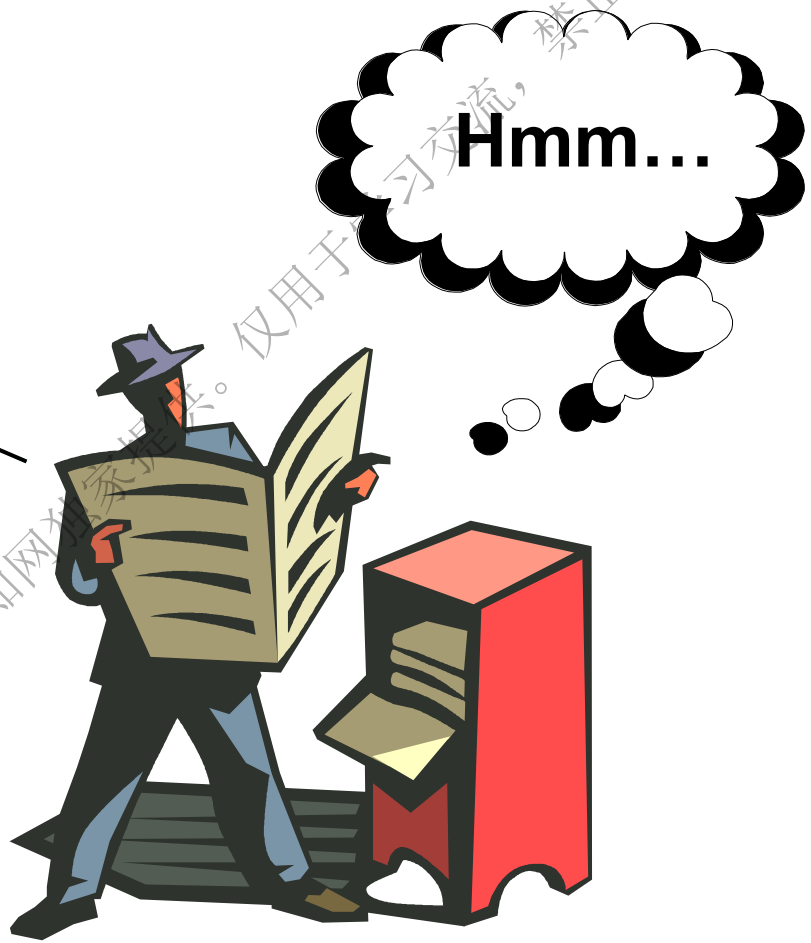


"Paired" Soil Gas – Groundwater Concentrations (e.g., benzene)



Case for Change – Round 3
Value of Soil Gas and Groundwater RBSLs

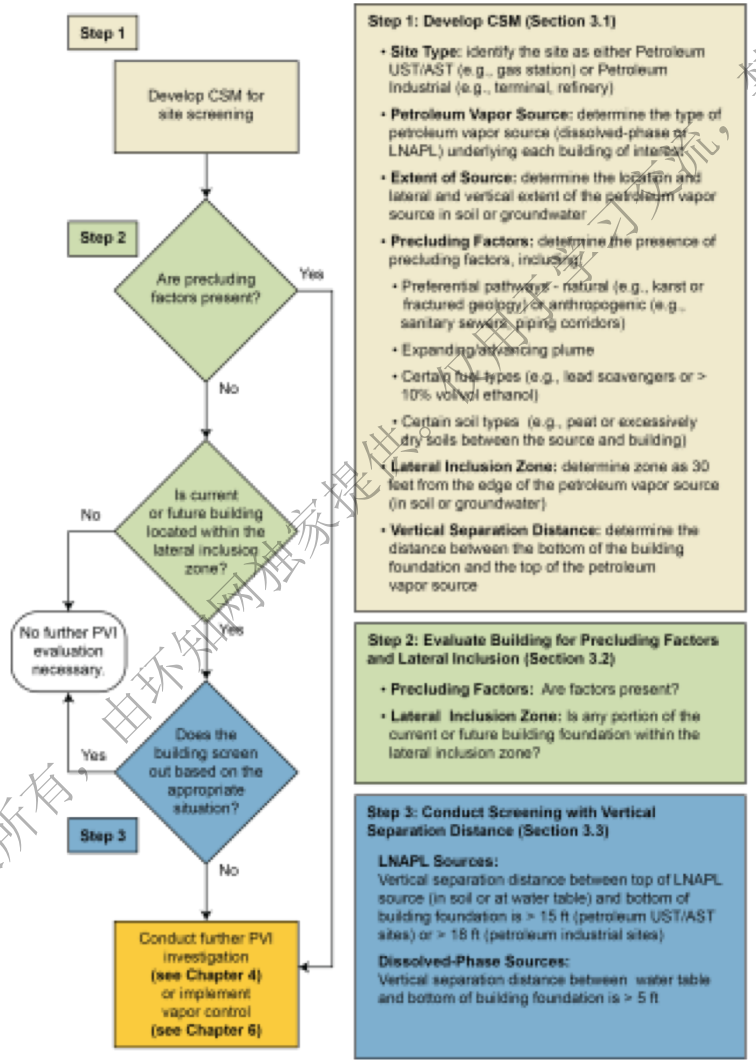
PVI RBSL LOOK-UP TABLES



Key Points

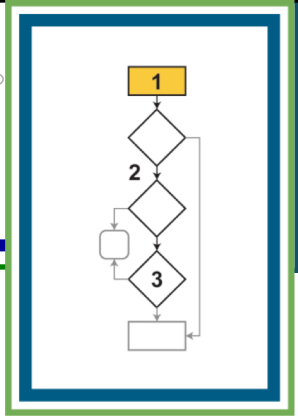
- PVI ≠ CVI site screening
  - Biodegradation
  - Source type
- Tier I screening levels in groundwater (and soil) have less relevance for PVI
- "All or nothing" biodegradation behavior in vadose zone lends itself to use of screening distances
- Screening distances are not new; simply a recent refinement for PVI
- Screening distances vary depending on source type, site type, & hydrocarbon type

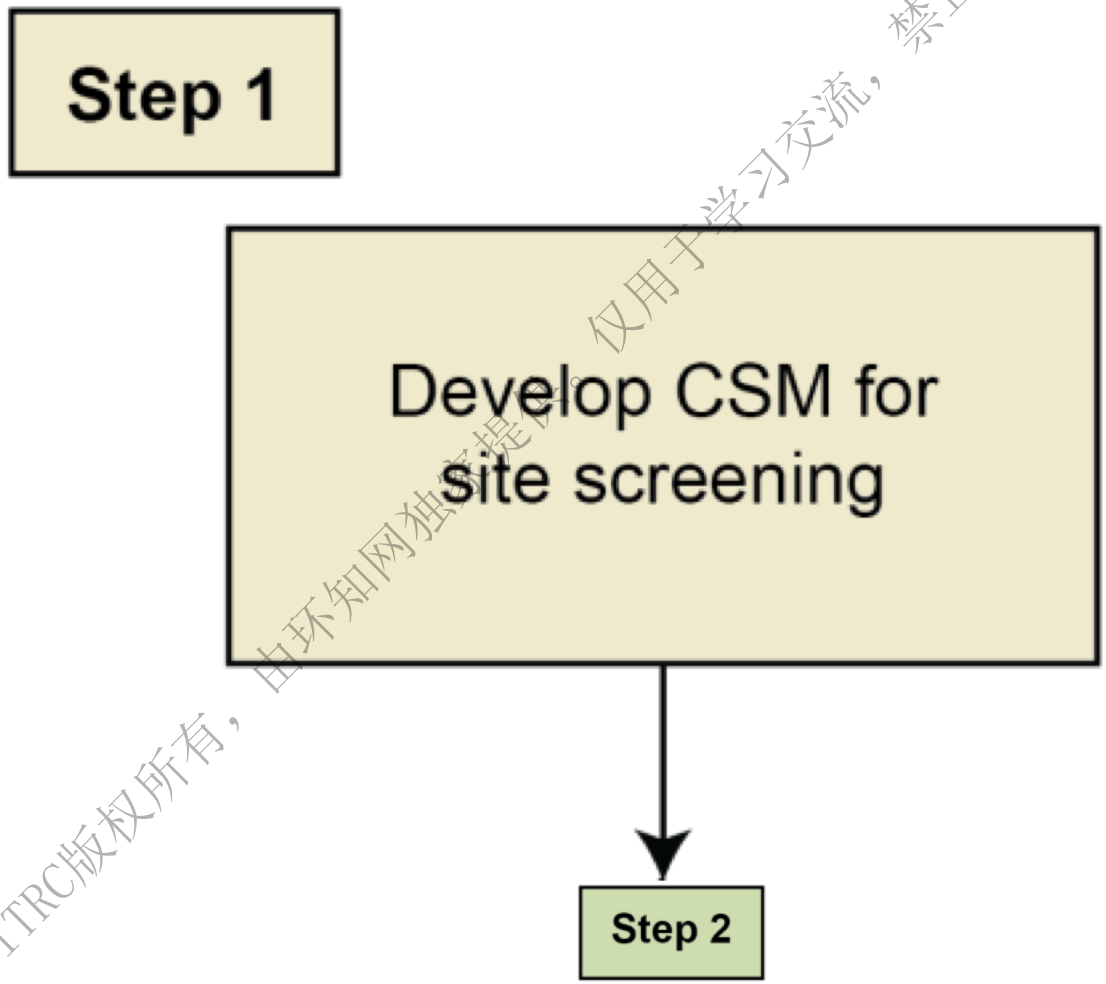
Applying the Site Screening Process



ITRC PVI-1, Figure 3-2

Step 1: Develop Conceptual Site Model (CSM)





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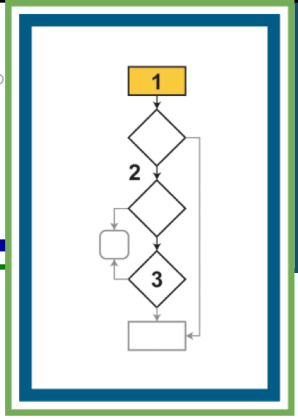
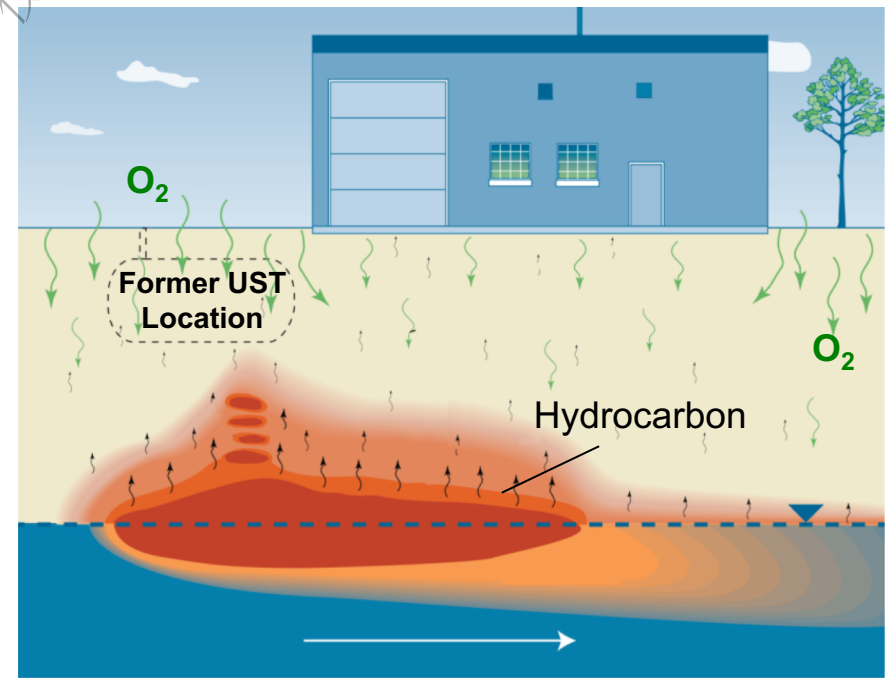
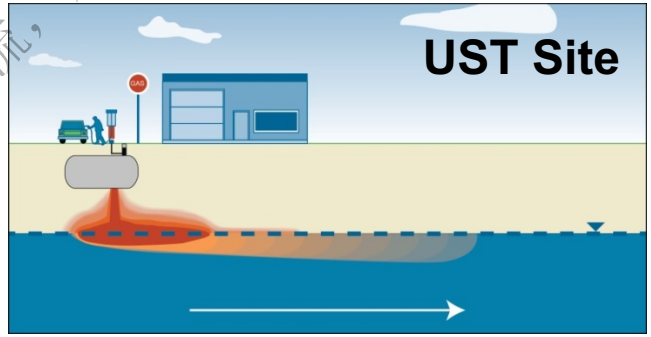


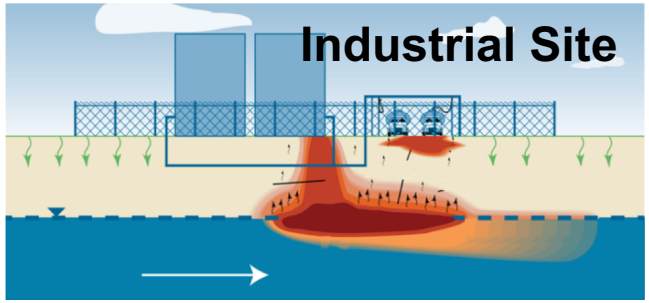
- Preliminary CSM **based on** soil and groundwater data
  - Pre-existing data ***(existing site)***
  - Data collected during **an initial site assessment** ***(new site)***
- Gather sufficient data on sources, pathways, receptors to support screening distance application
- **Soil gas, indoor air data not necessary** at this stage



Step 1: Develop CSM
Site Type

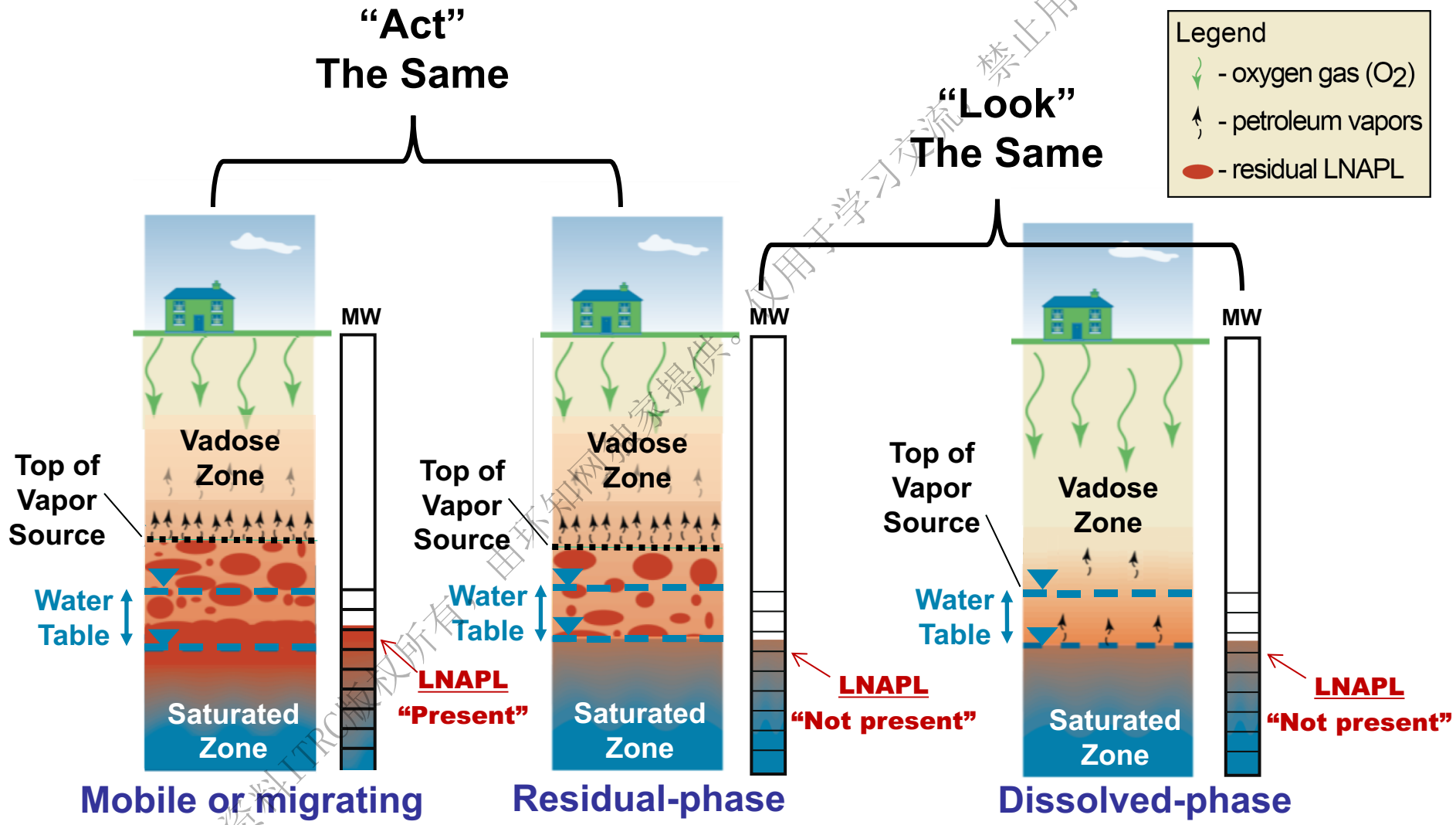
- Petroleum UST sites (some may have ASTs w/ < 30,000 gal capacity)
  - e.g., service stations or similar; release volume = 10,000 – 100,000 gal
- Petroleum industrial sites
  - e.g., terminals, refineries, pipelines; release volume = 100,000 – 1,000,000+ gal
- Effect of site type on site screening
  - difference in distance = 3 feet; may relate to the volume of LNAPL released





CAUTION vertical screening distances for Petroleum Industrial Sites derived from relatively small population of sites (9) in USEPA database

Step 1: Develop CSM
Petroleum Vapor Source



MW = monitoring well

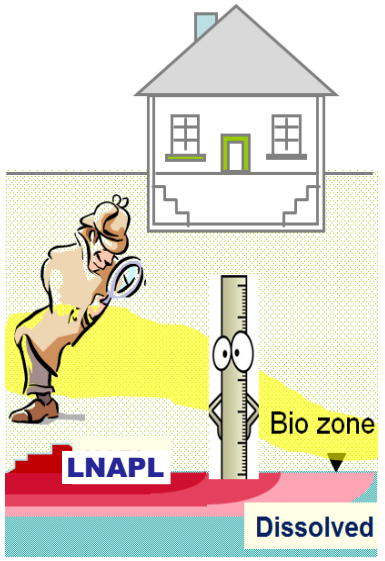
General LNAPL Indicators

Indicator	Comments
Groundwater	
• benzene: > 1 - 5 mg/L • $TPH_{(gasoline)}$: > 30 mg/L • BTEX: > 20 mg/L • current or historical presence of LNAPL (including sheens)	• no specific hydrocarbon concentration in groundwater that defines LNAPL because: - varying product types - degrees of weathering
Soil	
• current or historical presence of LNAPL (staining) • benzene > 10 mg/kg • $TPH_{(gasoline)}$ > 250 - 500 mg/kg **US EPA OUST - $TPH_{(gasoline)}$ > 100 (fresh); > 250 (weathered, diesel)** • ultraviolet fluorescence (UV) or laser induced fluorescence (LIF) fluorescence response in LNAPL range • PID or FID readings > 500 ppm	• **use of TPH soil concentrations as LNAPL indicators should be exercised with caution**: - can be affected by the presence of soil organic matter - TPH soil concentrations are not well correlated with TPH or O_2 soil gas concentrations
Location relative to UST system (e.g., tank, dispenser, pipework) or AST	
• adjacent (e.g., < 20 feet) from a known or suspected LNAPL release or petroleum UST/AST equipment	• probability of encountering LNAPL increases closer to release location

ITRC PVI-1, Table 3-1. General LNAPL indicators for PVI screening

Step 1: Develop CSM
Extent of Source

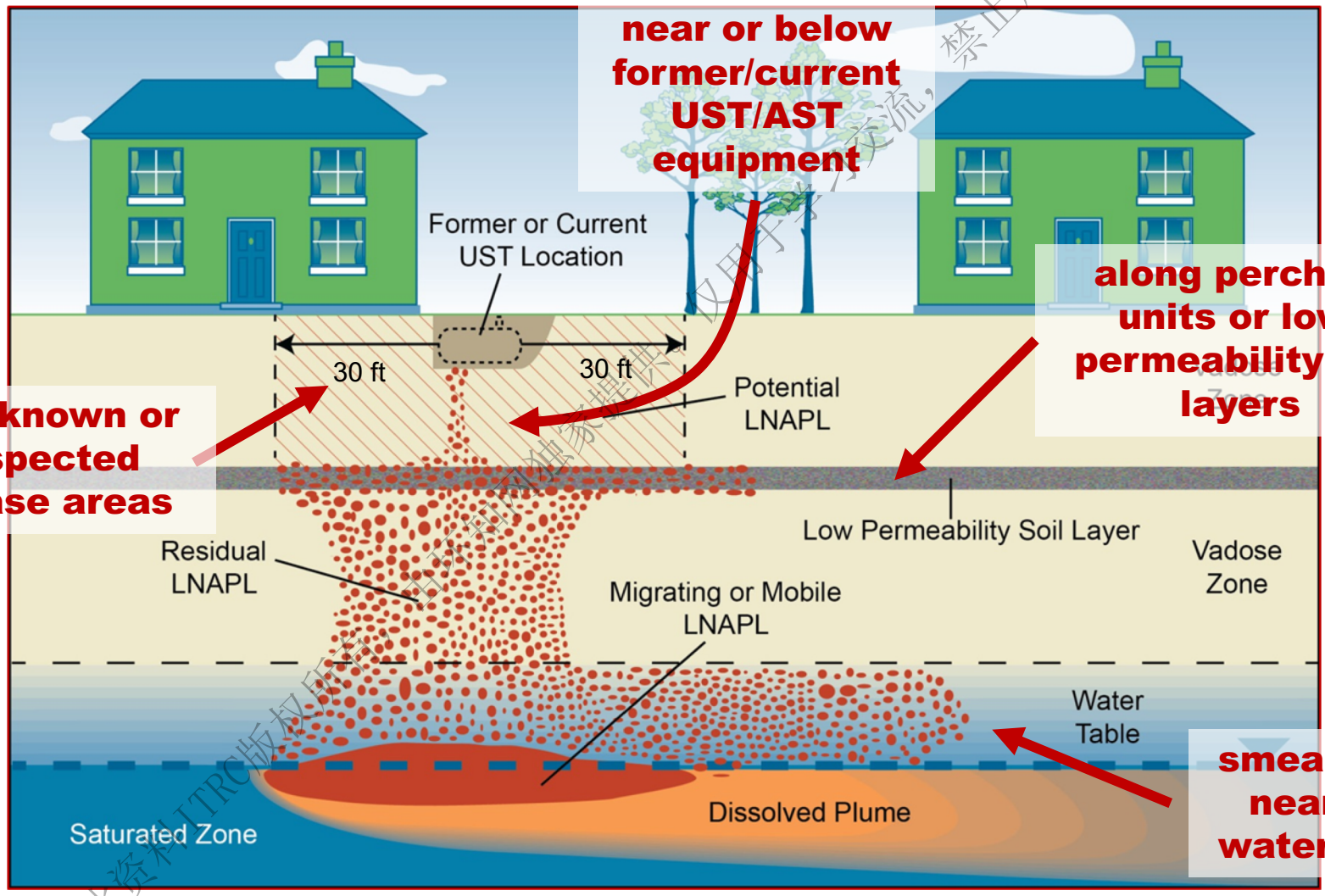
- **Vertical**: (accuracy generally ~1-2 feet)
  - **LNAPL** – identify/delineate sources above water table using Multiple Lines of Evidence (MLE) approach (e.g., indicators) consistent w/ LNAPL CSM
  - **Dissolved** – maximum anticipated water-table elevation



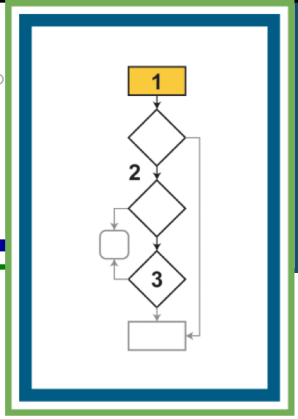
- **Lateral**: (accuracy generally ~10s of feet)
  - **LNAPL** – define using MLE approach consistent w/ LNAPL CSM; **residual LNAPL always extends beyond where mobile or migrating LNAPL is present**
  - **Dissolved** – define using Maximum Contaminant Levels (MCLs), Detection Limits (DLs), or other criteria (agency specific)

NOTE: Screening distance method places added emphasis on proper soil characterization during borehole development (e.g., monitoring well installation)

Higher Probability LNAPL Locations



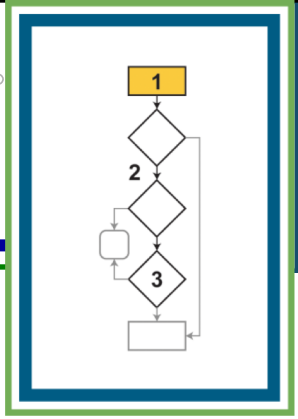
Step 1: Develop CSM
Precluding Factors



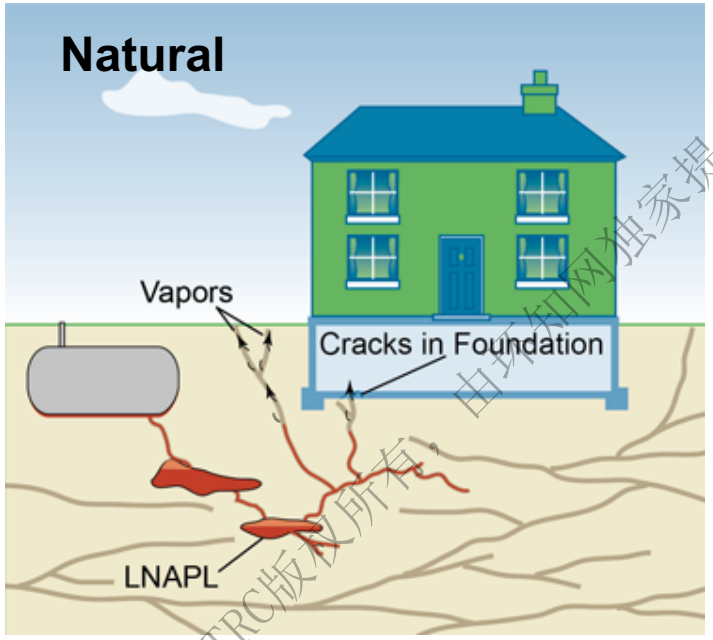
- Definition: Site-specific conditions which preclude (prevent) the application of site screening
- Types
  - Preferential pathways
  - Expanding/advancing plume
  - Certain fuel types
  - Certain soil types

NOTE: US EPA PVI (2013) guidance also includes extensive impermeable surface cover (ice, concrete) and very large buildings (> 66 feet in length and width).

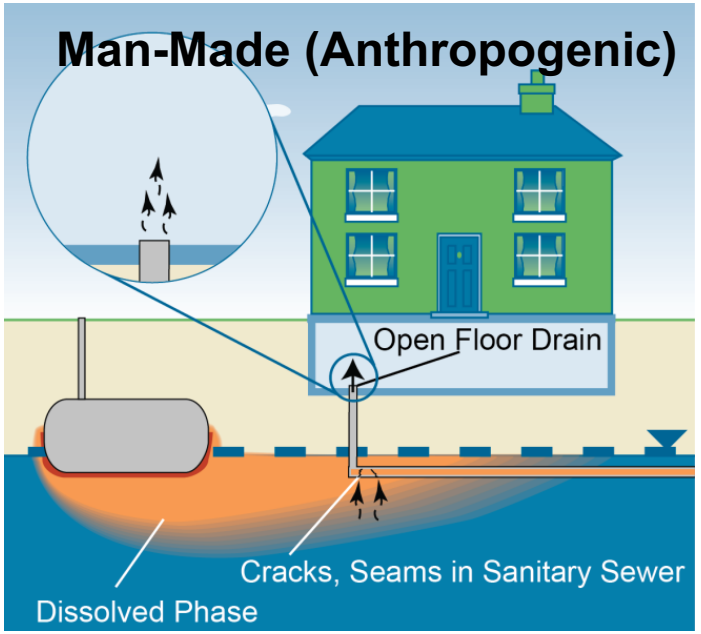
Precluding Factors
Preferential Pathways



- Preferential pathways can be natural (karst or fractured geology) or man-made (sewers, gravel backfill, etc.)
  - Must intersect both source and building foundation
  - Often associated with odors (emergency response)

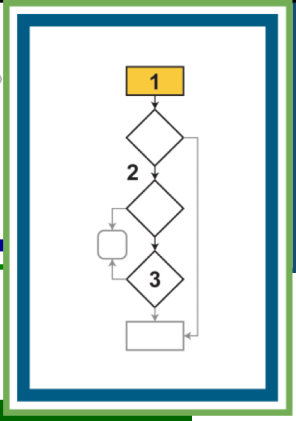


Fractured or karst geology



Conduit (sewer) intersecting source and building foundation

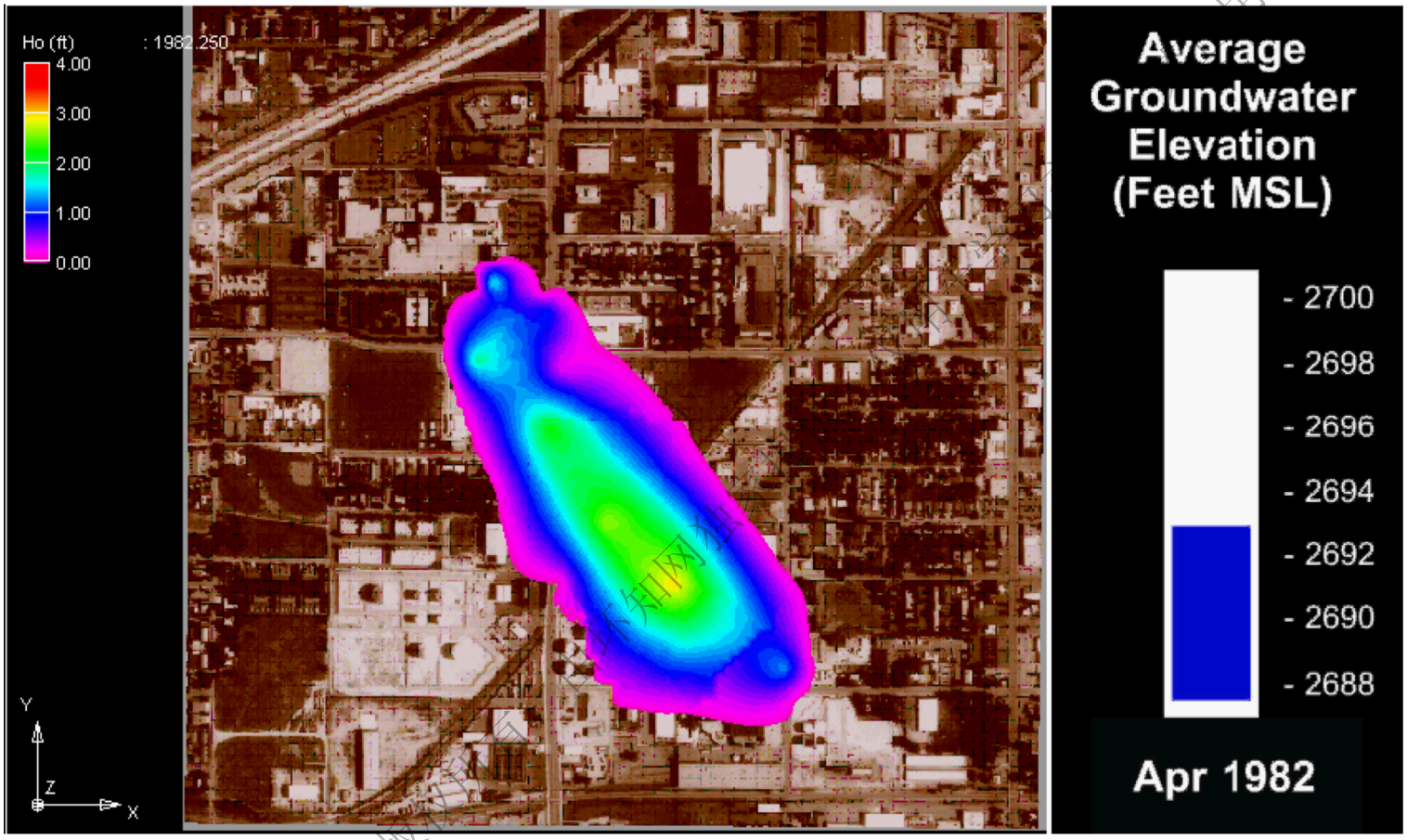
Precluding Factors Expanding/Advancing Plume



- Lateral inclusion zone will increase w/ expanding/advancing plume

LNAPL Migration - General Lines of Evidence	
Gauging Data	Need to account for water-table fluctuations
Groundwater Monitoring Data	Expanding, stable, shrinking
LNAPL Velocity	LNAPL baildown tests; LNAPL gradients; Darcy's Law
LNAPL Thickness > Critical Thickness	~2 – 2.5x capillary zone thickness
Age of release	Release abatement, timing, weathering
Recovery Rates	Decreasing LNAPL recovery rates
Laboratory/Field Tests	Saturation, tracers

LNAPL Thickness Monitoring Over Time (Refinery)

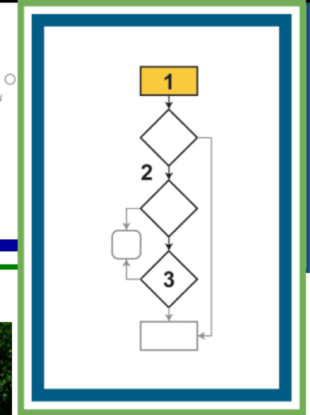


From API Interactive NAPL Guide, 2004

(available under "Links" at http://www.clu-in.org/conf/itrc/iuLNAPL)

- Measured LNAPL depth in monitoring wells: 0 to 3 feet
- Seasonal water table variation: 8 foot range

Precluding Factors
Certain Fuel Types



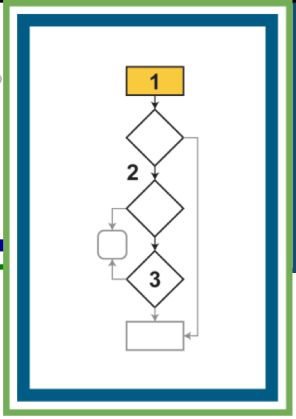
- Historical fuels containing lead scavengers [1,2-dichloroethane (1,2 DCA); ethlylene dibromide (EDB)]
  - Volatile
  - Highly toxic (low RBSLs)
  - Relatively persistent

- Future fuels containing > 10% vol/vol ethanol
  - Methane generation more significant for gasoline releases containing >10% vol/vol ethanol (Ma et al. 2012)

- No evidence from soil gas databases; insufficient data to document PVI risk

See also ITRC's Biofuels: Release Prevention, Environmental Behavior, and Remediation (Biofuels-1, 2011)

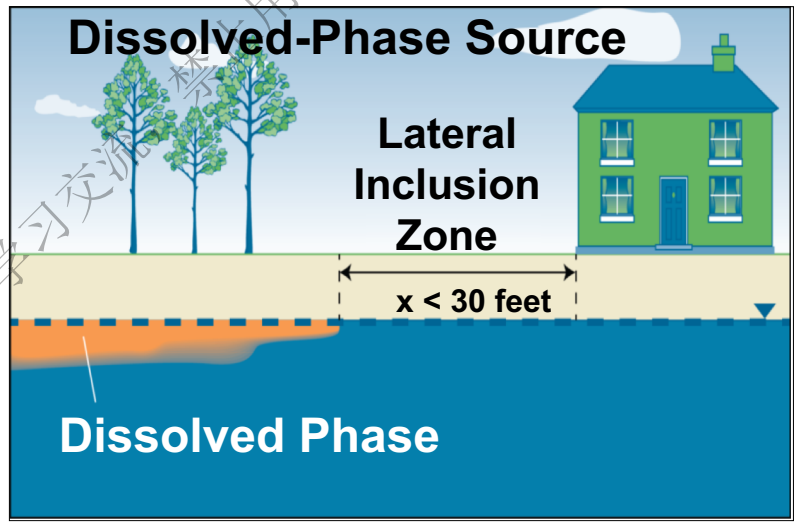
Precluding Factors
Certain Soil Types

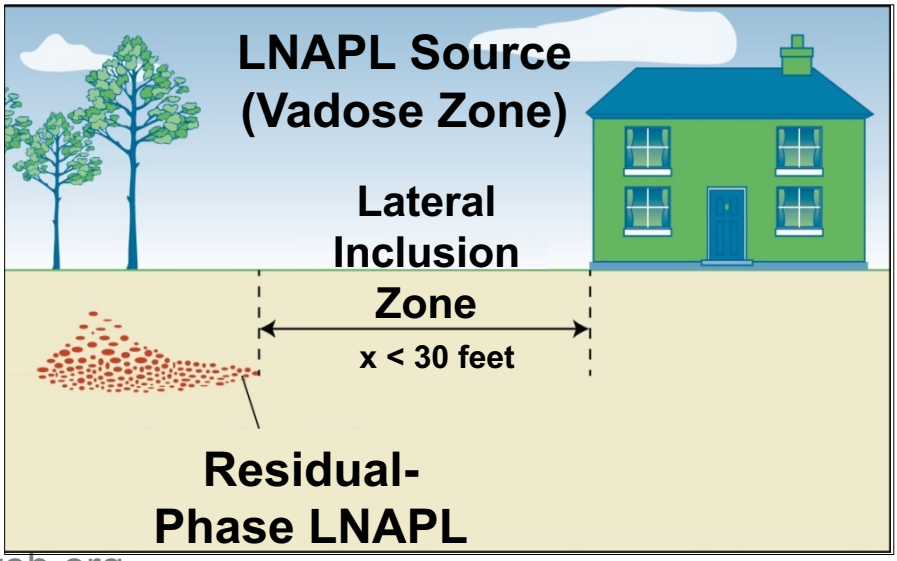


- Certain soil types
  - High organic-rich soils (e.g., > 4% organic carbon - peat) can compete for oxygen (reduce availability for biodegradation)
  - Excessively dry soils (e.g., desert environments) may have insufficient moisture to support biodegradation
- No evidence in soil gas databases (limited potential occurrence); insufficient data to document PVI risk

Step 1: Develop CSM
Lateral Inclusion Zone

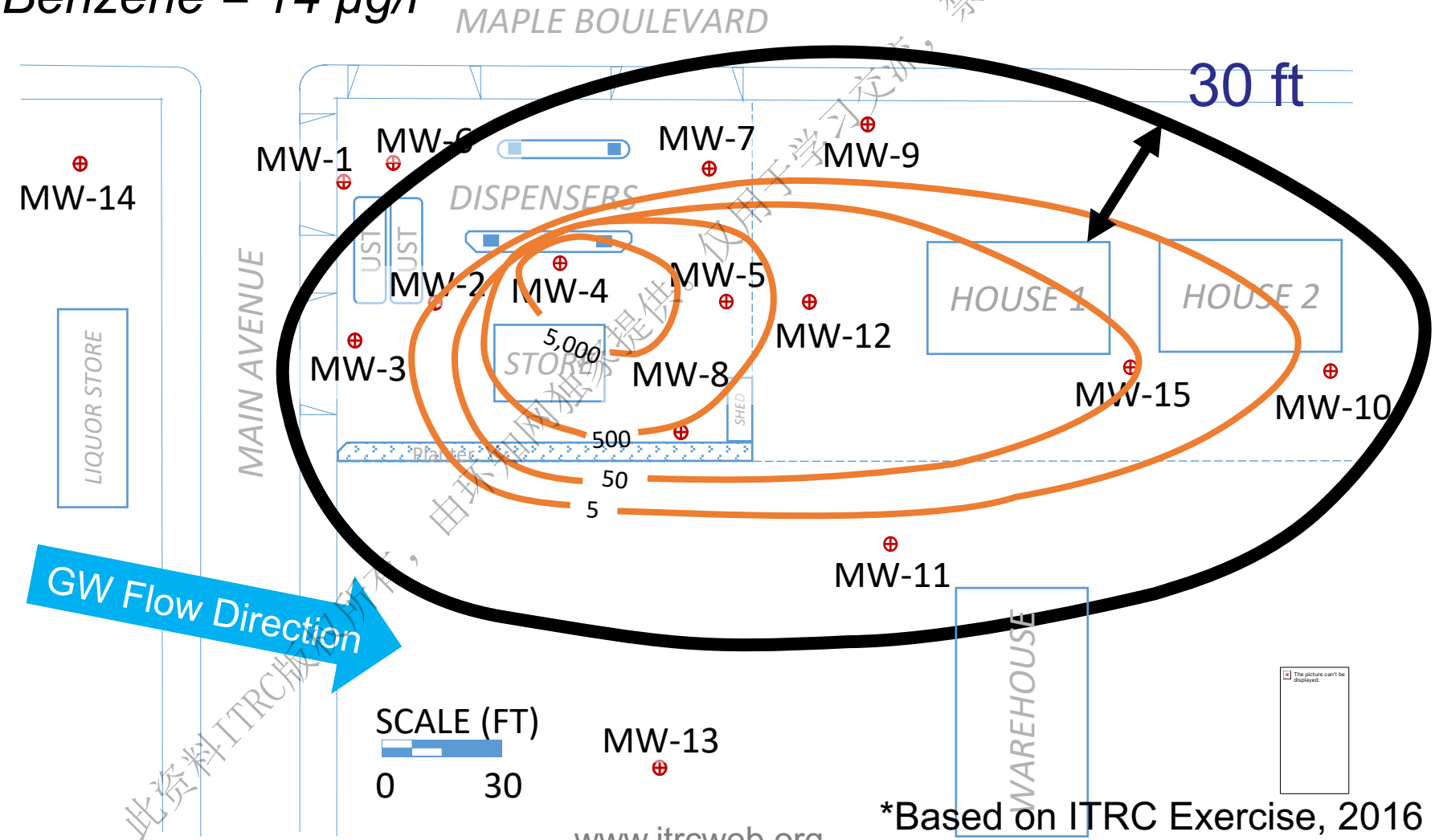
- Lateral inclusion determines which buildings get screened in
- A "buffer zone" to account for uncertainty in knowing exact edge/extent of LNAPL or dissolved-phase plume (flow)
  - 30 feet from ***edge*** of PVI source to building unless site data prove otherwise
  - 30 feet is conservative relative to vertical screening distance - vertical and lateral should be the same (US EPA, 2013; Lahvis et al., 2013)
  - 100 feet assumed prior to empirical studies





Step 1: Develop CSM Lateral Inclusion Zone

Benzene = 14 µg/l

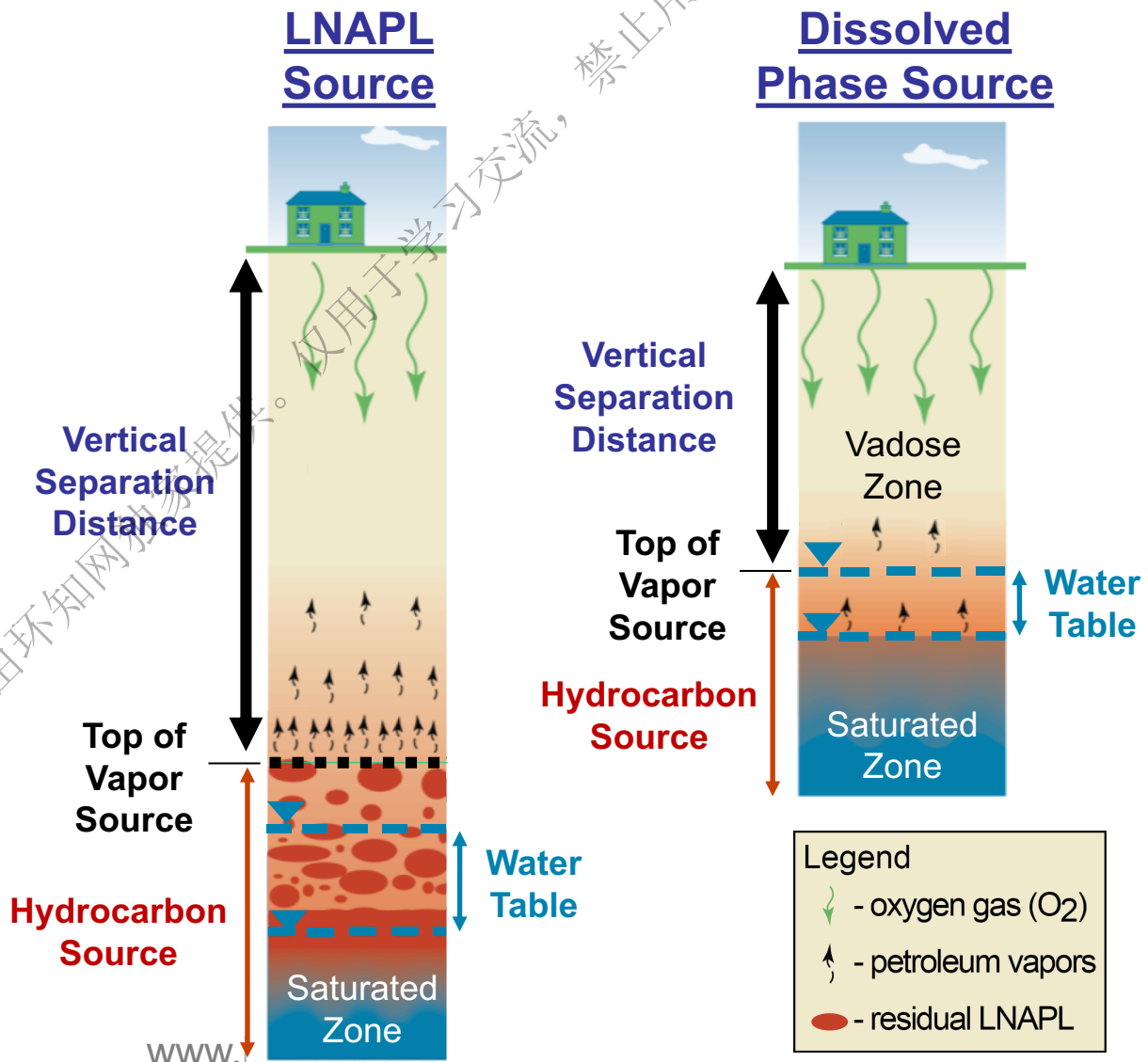


*Based on ITRC Exercise, 2016

Step 1: Develop CSM
Vertical Separation Distance

Measured from top of the petroleum vapor source to the bottom of the building foundation

- Consider water table fluctuations if possible
- Some uncertainty in water-table fluctuations factored into the derivation of vertical screening distances

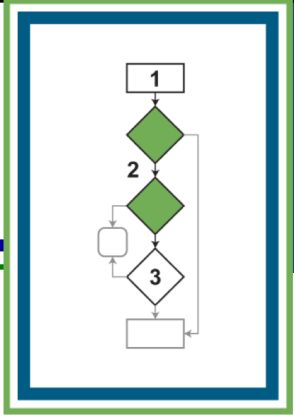


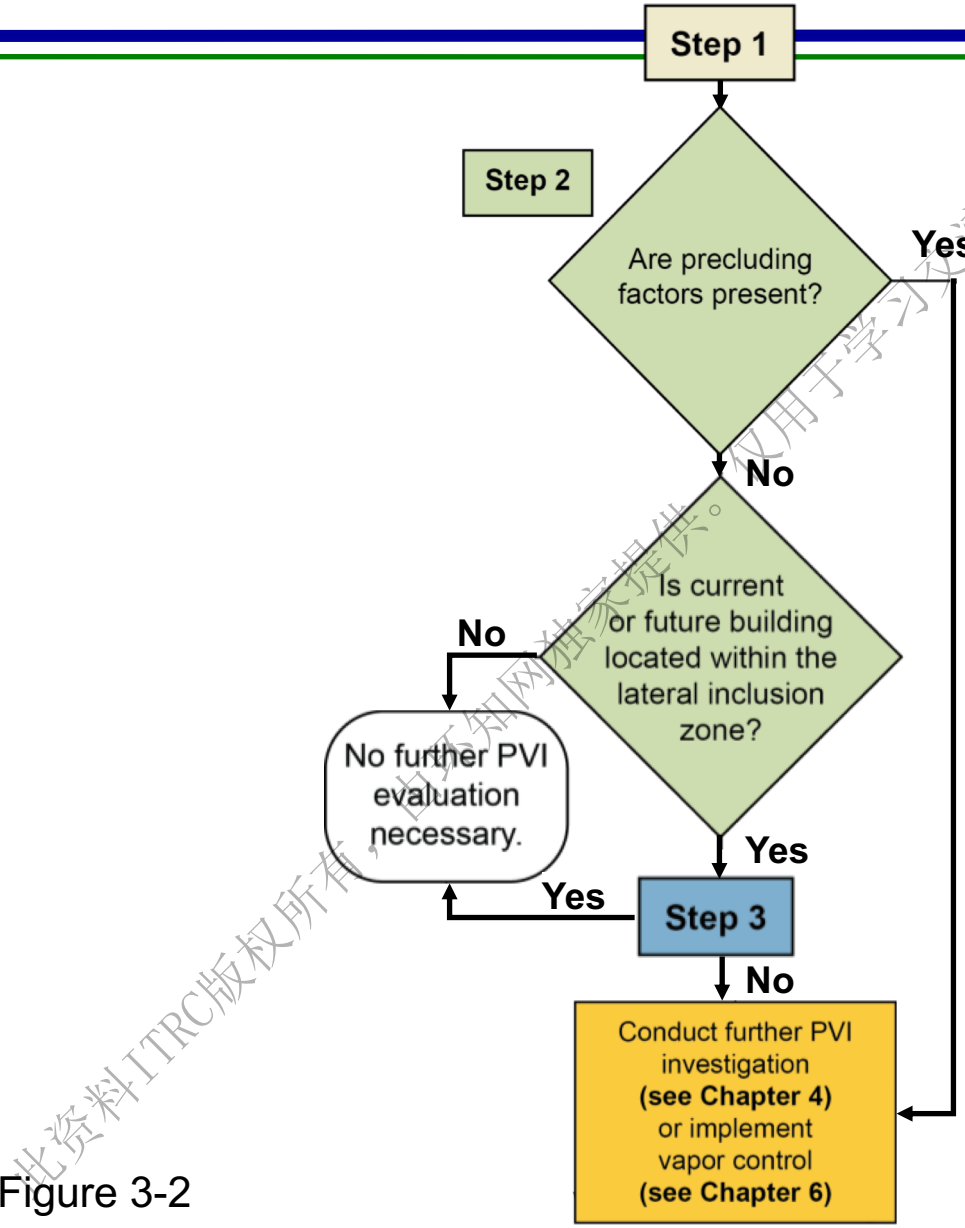
Step 1: Key Points

Preliminary CSM based on **pre-existing** data or **data collected during an initial site assessment**

- Site type (UST or Industrial)
  - Minor effect; limited data on Industrial sites
- Petroleum vapor source (LNAPL vs. dissolved)
  - Differentiation requires proper soil/groundwater characterization
- Extent of source
  - LNAPL (MLE approach); dissolved (MCLs, DLs, or other)
- Lateral inclusion zone
  - 30 feet unless sufficient data to defend shorter distance
- Precluding factors
  - Not expected to be a common occurrence
- Vertical separation distance
  - Different ways to determine top of vapor source
  - Screening distances based on limited understanding of top of source (conservative)

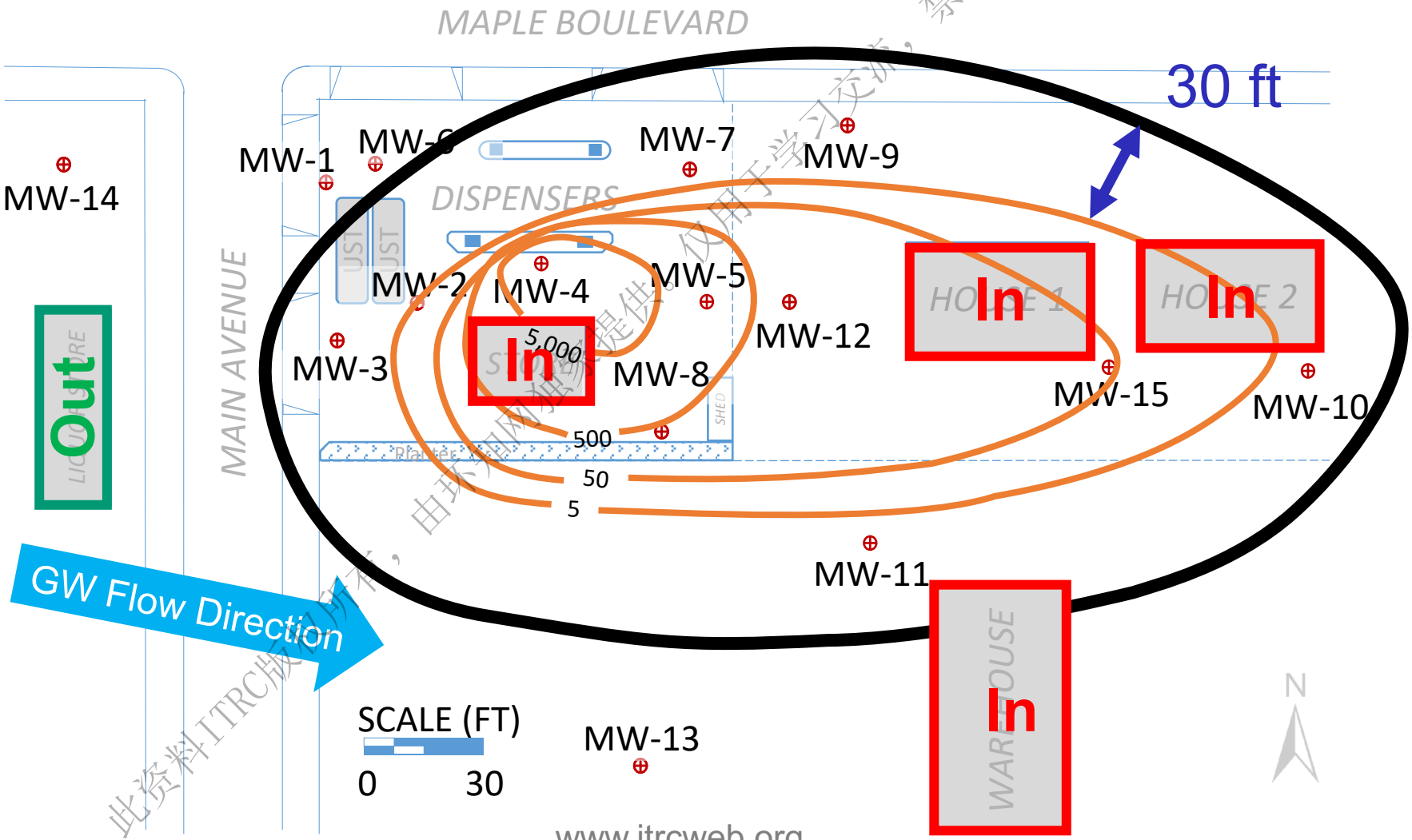
Step 2: Evaluate Building for Precluding Factors & Lateral Inclusion



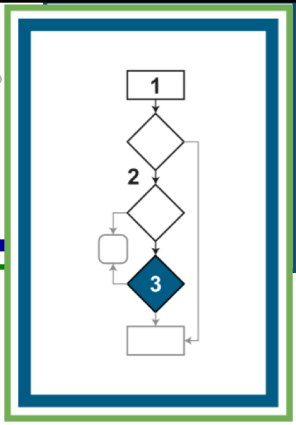


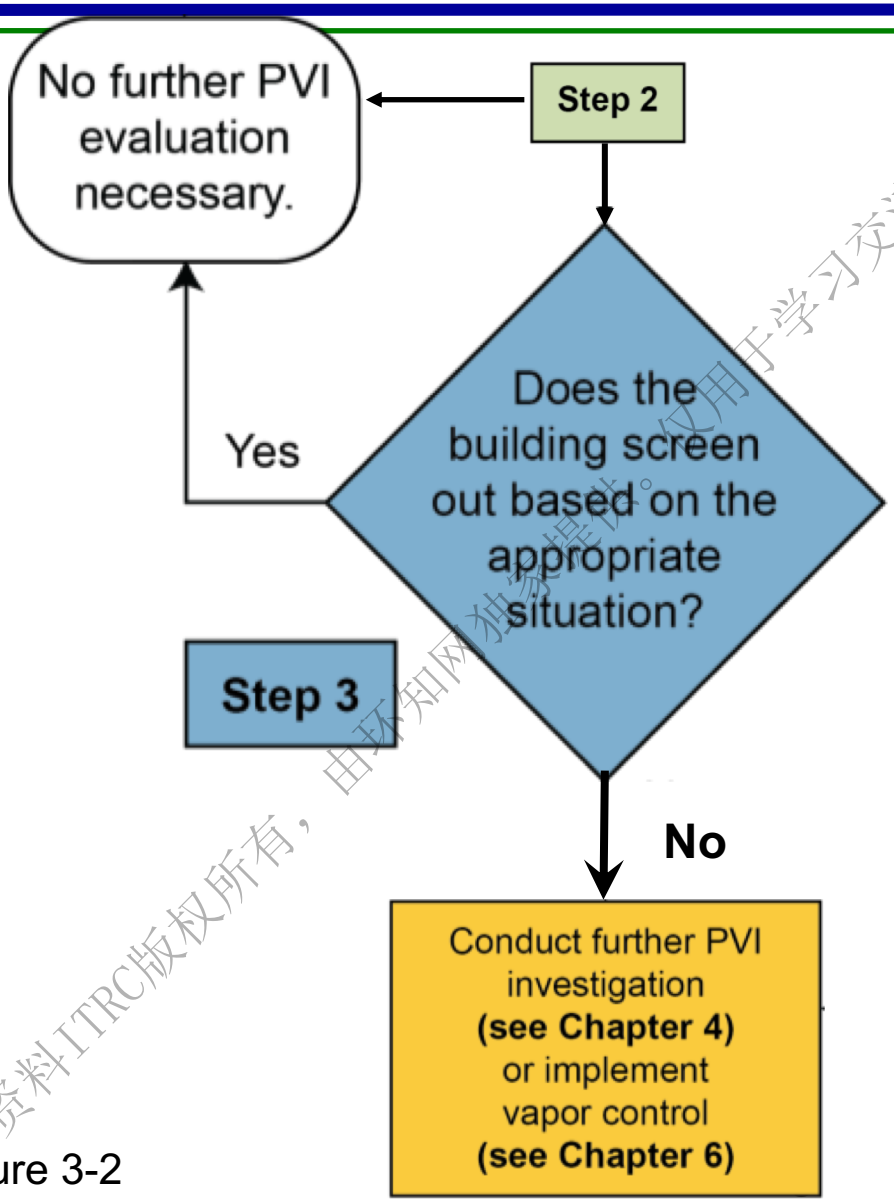
ITRC PVI-1, Figure 3-2

Step 2: Precluding Factors and Lateral Inclusion



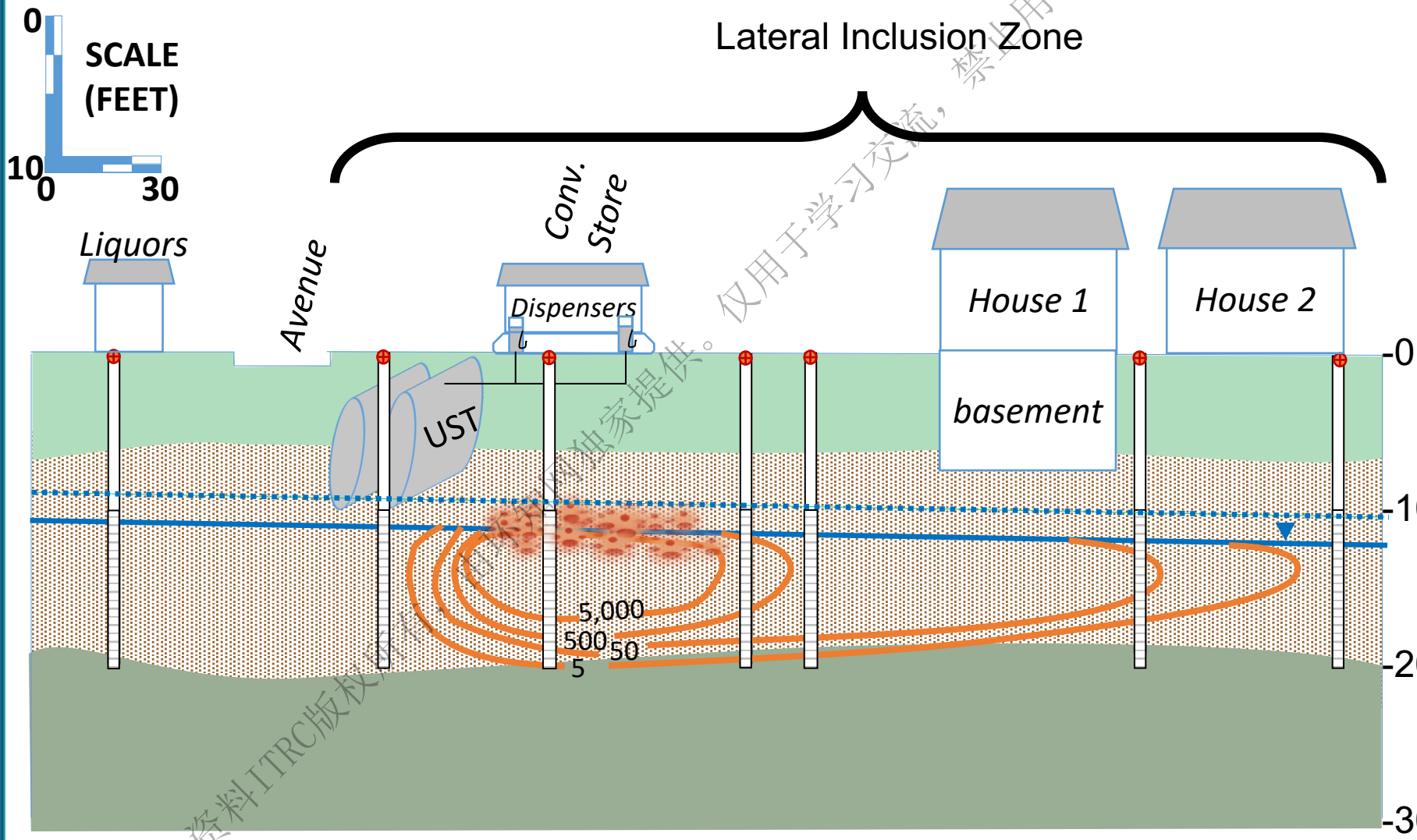
Step 3: Conduct Screening with Vertical Separation Distance



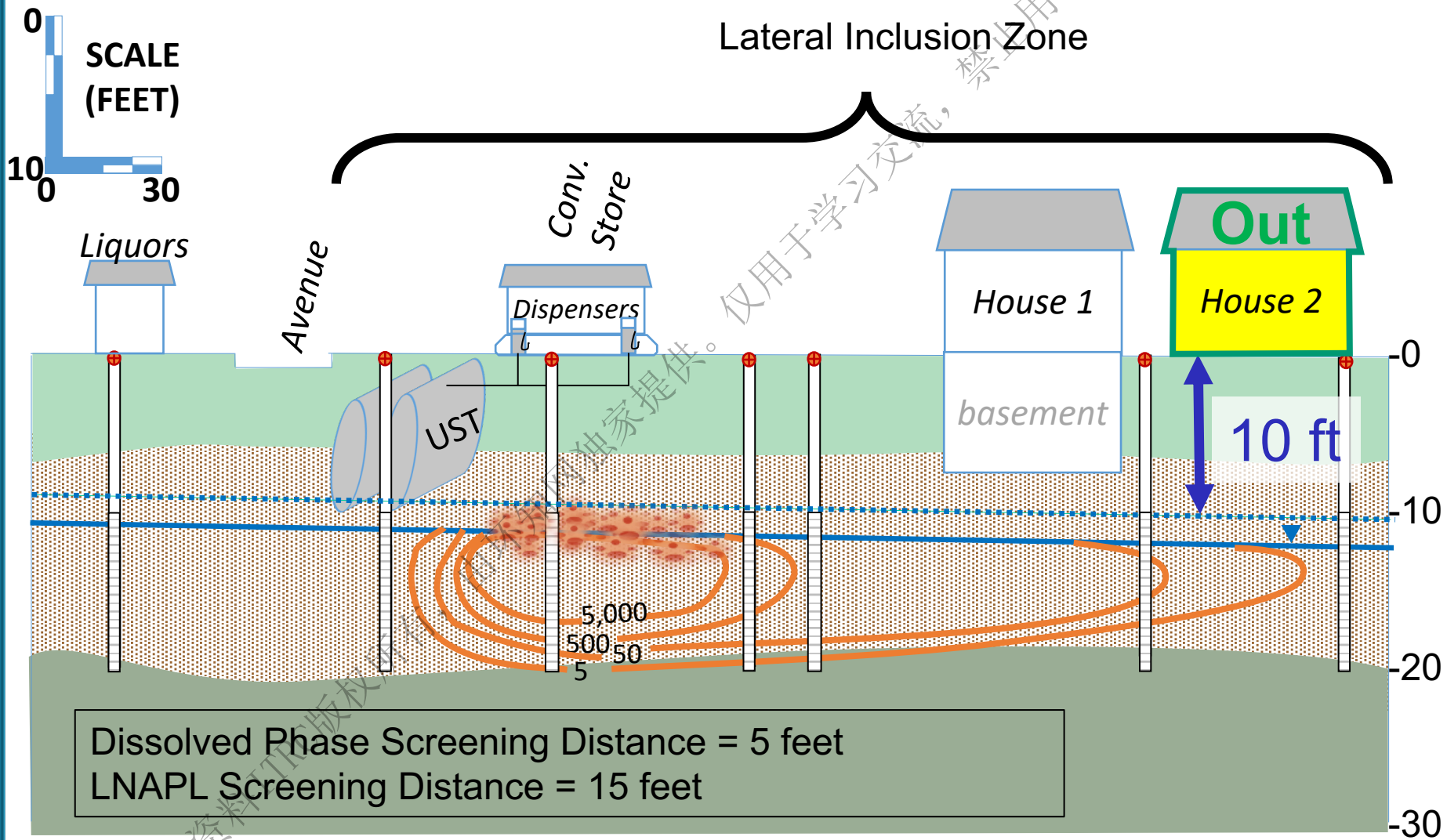


ITRC PVI-1, Figure 3-2

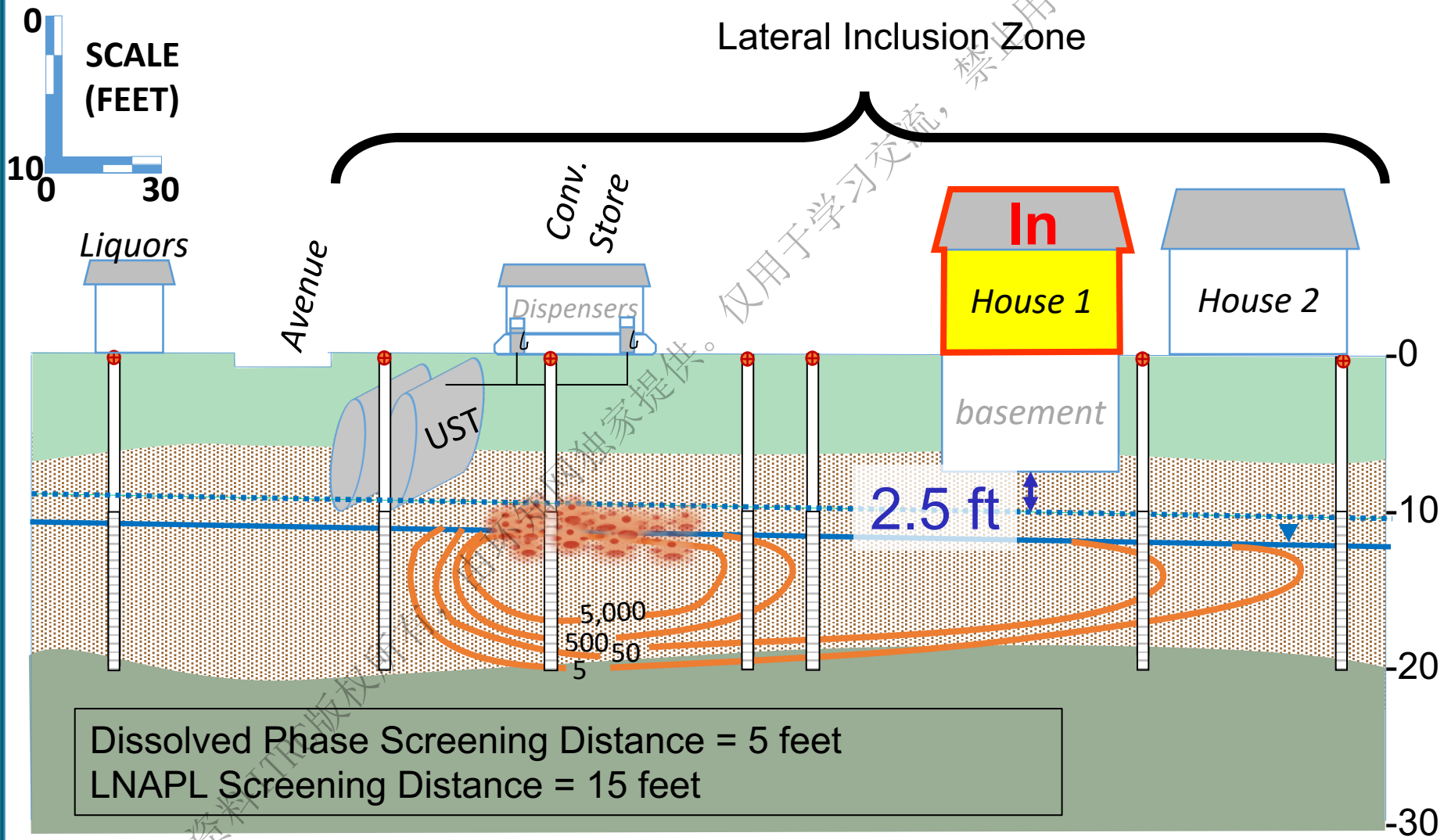
Vertical Screening



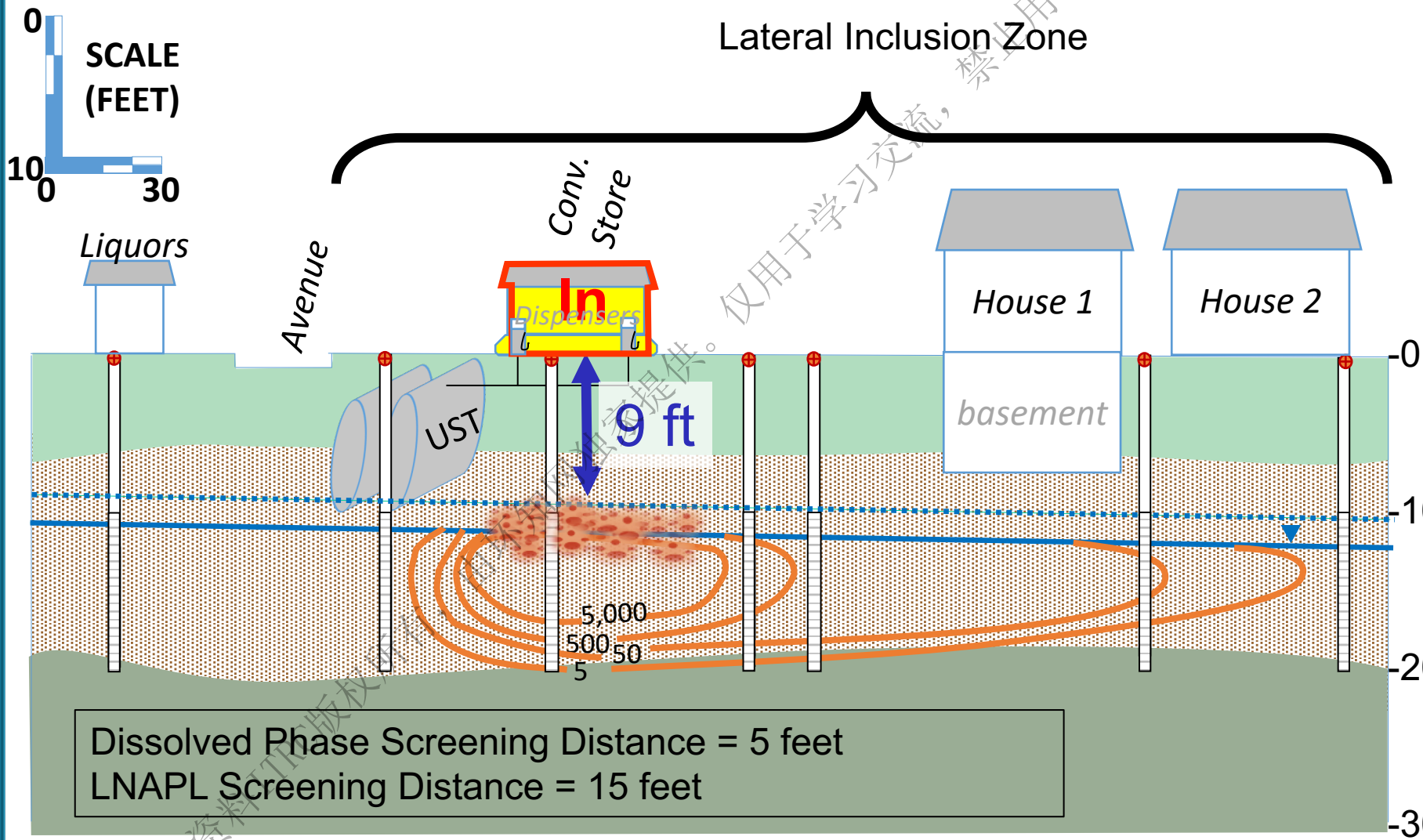
Vertical Screening: House #2



Vertical Screening: House #1

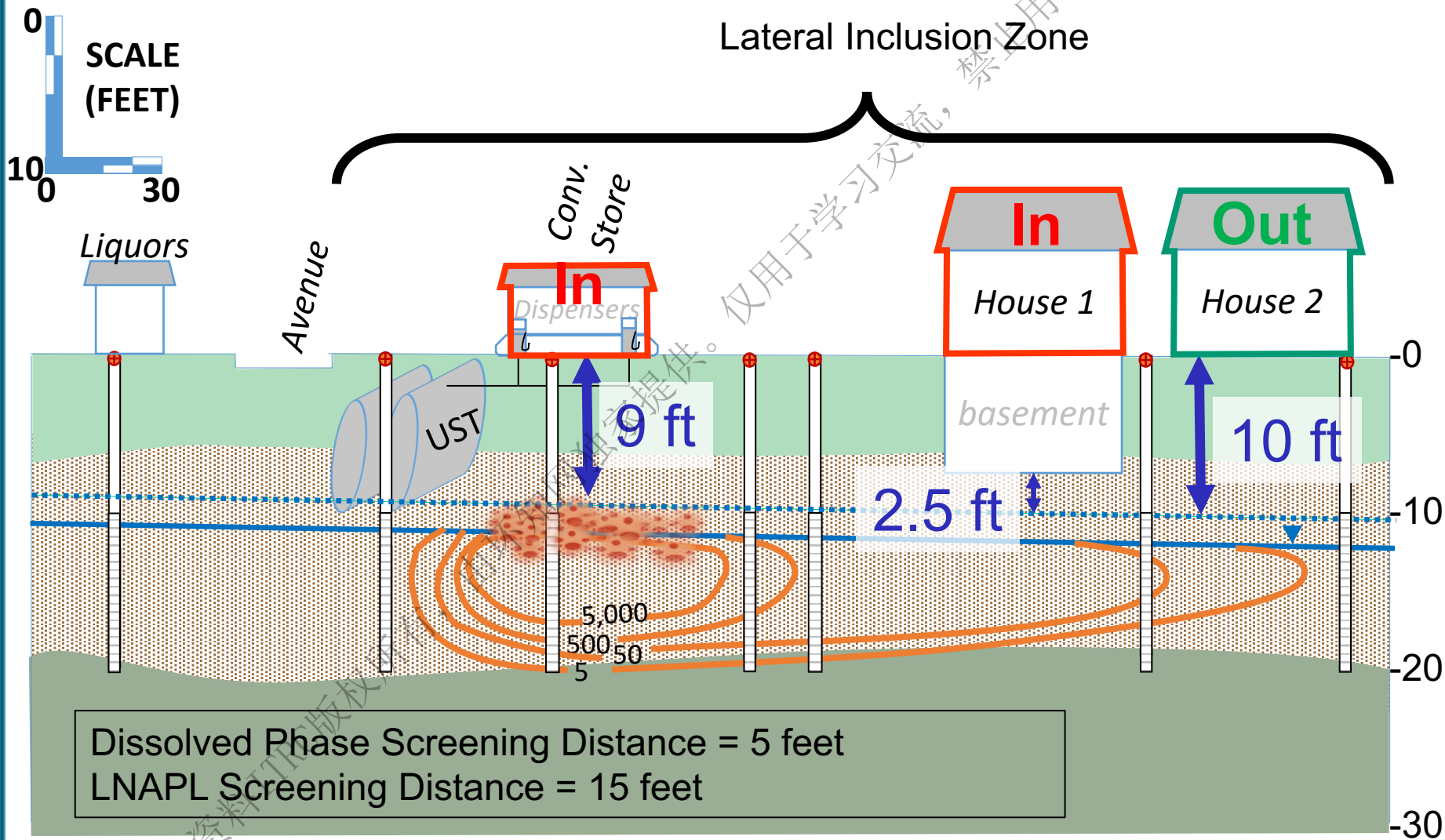


Vertical Screening: Store



Dissolved Phase Screening Distance = 5 feet
LNAPL Screening Distance = 15 feet

Vertical Screening Summary



Vertical Screening Summary

Building	Source Type	Vertical Separation Distance (feet)	Screen Out?
Convenience Store	Residual LNAPL	9	No
House #1	Dissolved Phase	2.5	No
House #2	Dissolved Phase	10	Yes
Warehouse	Dissolved Phase	~10	Yes

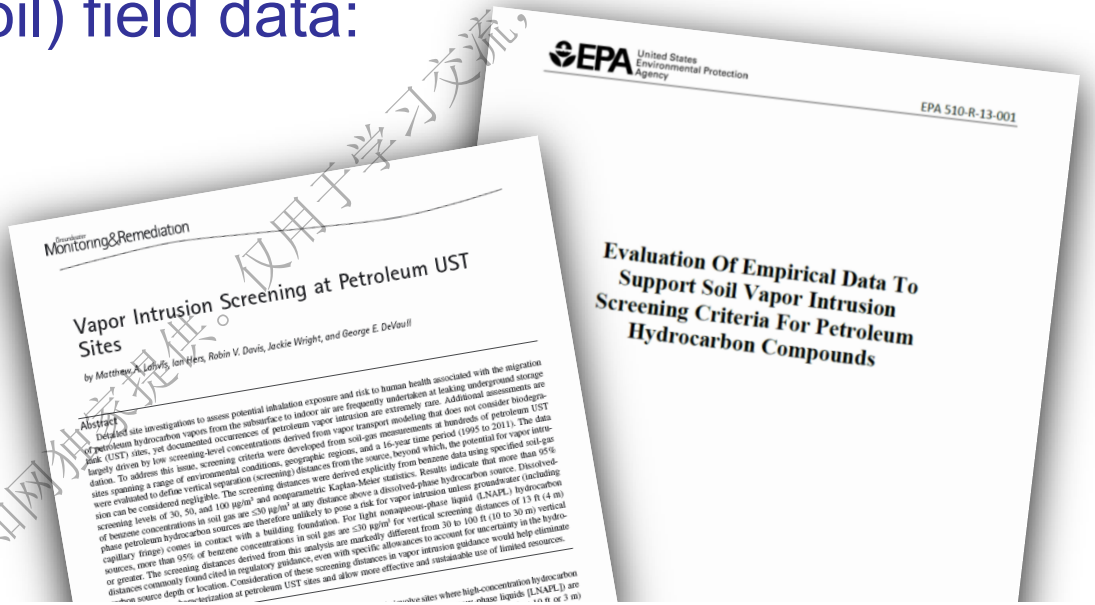
We Expect That Some of You Have Questions...

- How were the vertical screening distances derived?
- What are the key findings of the empirical studies?
- Are vertical screening distances supported by modeling?
- Are O_2 soil-gas concentration measurements necessary for site screening?
- What about future construction?

NOTE See full list of FAQs in Appendix F, Technical Information to Support Site Screening

FAQ: How were the vertical screening distances derived?

- Based on analysis of a large body of empirical (soil gas, groundwater, and soil) field data:
  - US EPA (2013a)
  - Lahvis et al. (2013a)
  - Davis (2009, 2010)
  - Peargin and Kolhatkar (2011)
  - Wright (2011; 2013)

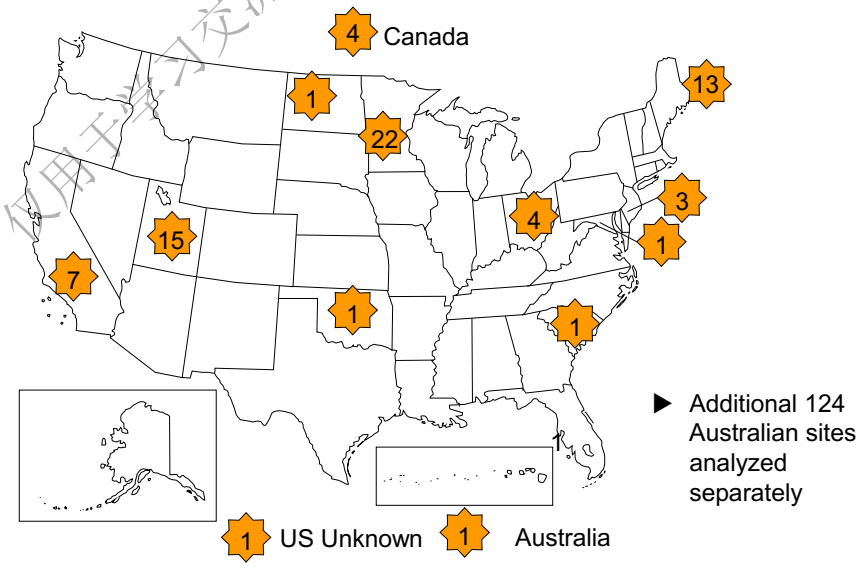


US EPA. 2013a. *Evaluation of Empirical Data and Modeling Studies to Support Soil Vapor Intrusion Screening Criteria for Petroleum Hydrocarbon Compounds*. http://www.epa.gov/oust/cat/pvi/PVI_Database_Report.pdf

Lahvis, M. A., Hers, I., Davis, R. V., Wright, J., DeVaull, G. E. . 2013a. *Vapor Intrusion Screening at Petroleum UST Sites*. Groundwater Monitoring & Remediation. no. 33 (2):53-67.

US EPA Database
Spans Range of Anticipated Environmental Conditions

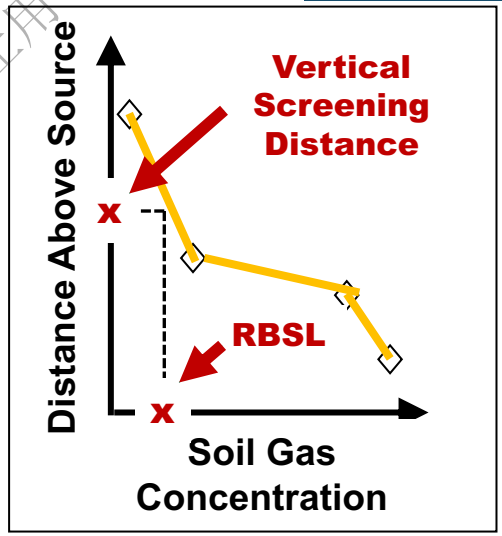
- Initial database developed by Robin Davis (Utah DEQ)...later expanded (Ian Hers, Golder Associates)
- Lots of data!
  - 74 sites (mainly gasoline)
  - 829 paired groundwater and soil gas concentration data (mainly UST/AST sites)
  - 38 sites with soil vapor data below buildings
  - 124 additional sites (Australia) analyzed separately (EPA, 2013; Lahvis et al. (2013)



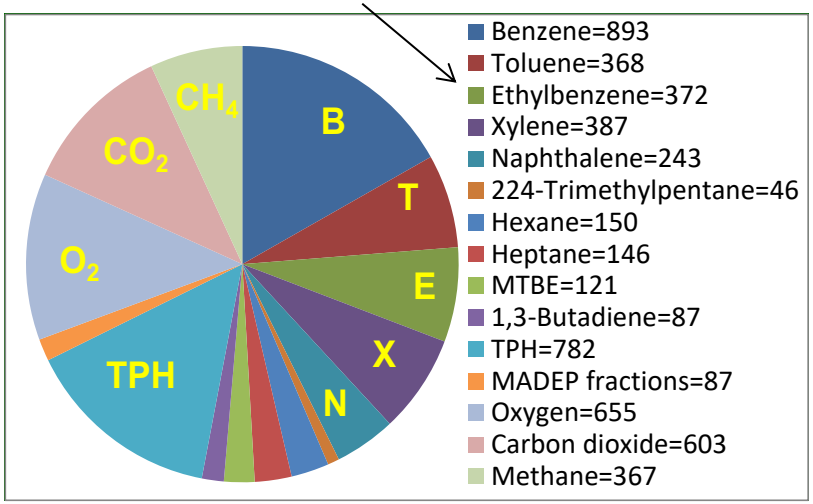
- Extensive QA/QC (review of SI reports)
- Range of environmental and site conditions; geographical regions
- 16-year time period (1995 – 2011)

Screening Distance Derivation
Objective/Assumptions

- **Objective**: derive distance above petroleum vapor source where hydrocarbon soil gas concentrations fall below level of concern (risk-based screening level) for PVI
- **Key assumption**: when PVI risk becomes negligible (RBSL, probability of occurrence – e.g., 95%)
- Derivation:
  - Source type (dissolved, LNAPL)
  - COPC type (benzene, xylenes, hexane, naphthalene, TPH fractions)
  - Site type (UST, non-UST)
  - Soil type (fine and coarse-grained)
  - Surface cover (pavement, building foundation, and open ground)



Chemical = Number of measurements

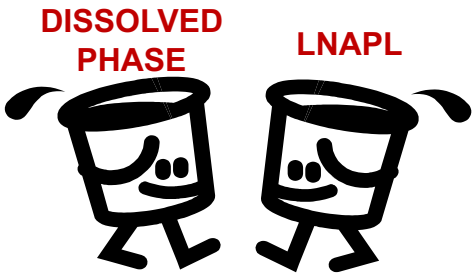


Source: US EPA, 2013

Screening Distance Derivation
Dissolved and LNAPL Source Differentiation

- Soil gas classified by source type (LNAPL vs. dissolved) using LNAPL indicator criteria
  - Presence/absence of LNAPL
  - Groundwater concentration data
  - Proximity to former/current UST/AST infrastructure

  *** soil data factored into < 2% of cases*



- Top of LNAPL smear zone uncertain – results in inherent conservatism in vertical screening distances

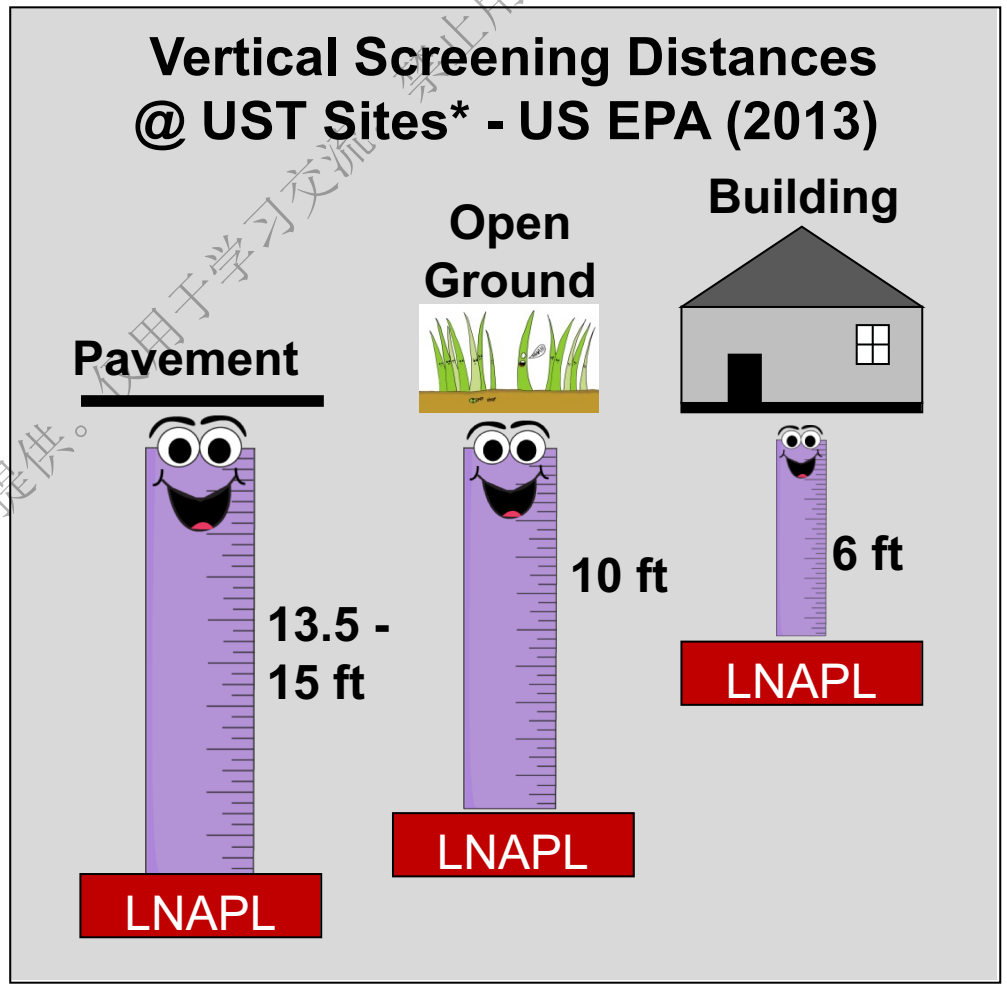
FAQ: What were the key findings of the empirical studies?

- Similar screening distances derived for LNAPL and dissolved-phase sources from different databases, methods, and assumptions

Reference	Database	Dissolved Phase (feet)	LNAPL (feet)	Benzene soil gas Screening Level (µg/m³)	LNAPL Indicator Concentration Criteria (µg/L)
US EPA OUST (2013)	US EPA (2013) 74 sites 829 data pairs	0 – 5.4	UST: 13.5 – 15 Industrial: 18-20 *limited data set*	50, 100	C_{gw} benzene > 5,000 C_{gw} TPH > 30,000
Lahvis et al. (2013)	US EPA (2013) Wright (2012) 120 sites 828 data pairs	0	UST: 13.5	30, 50, 100	C_{gw} benzene > 15,000
Davis (2009)	62 sites 735 data pairs	5	UST: 8 Industrial: 30 *limited data set*	complete attenuation	C_{gw} benzene > 1,000 C_{gw} TPH > 30,000
Peargin and Kolhatkar (2011)	25 sites 218 data pairs	0	15	300	520
Wright (2012)	124 sites 1080 data pairs	5	13	50	1,000

Sensitivity to Surface Cover, Soil Type

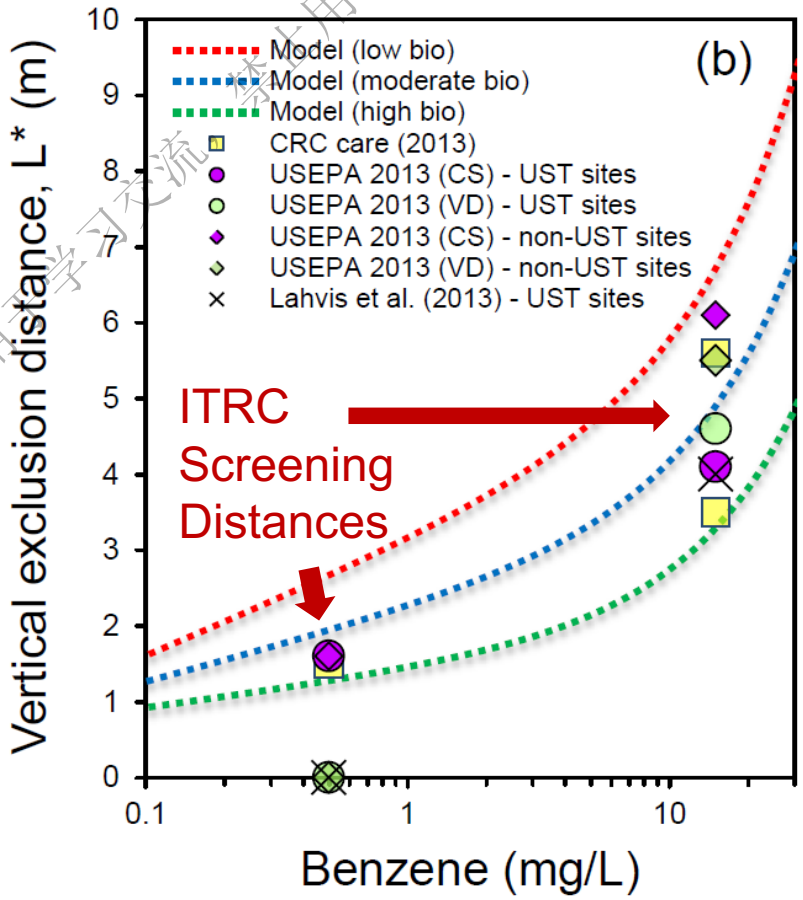
- Effect of surface cover on vertical screening distances was inconclusive
- Soil type had a negligible effect on vertical screening distances for wide range of conditions (clays, sands)



* *For benzene to attenuate below 100 μg/m³ in soil gas*

FAQ: Are the screening distances supported by transport modeling?

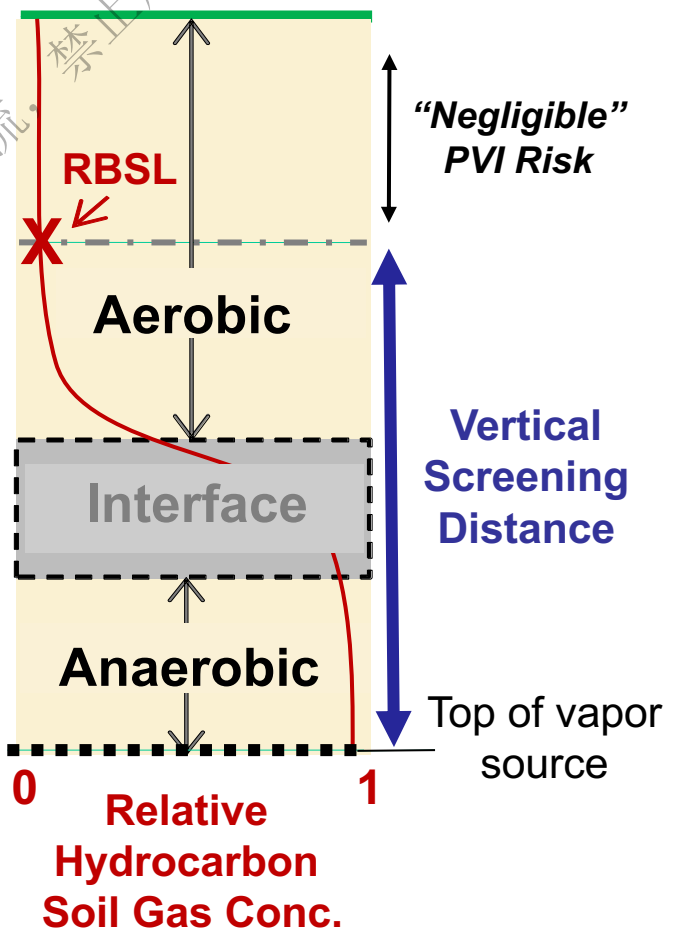
- ***Yes***
  - Abreu and Johnson (2005, 2006)
  - DeVaull (2007)
  - Abreu et al. (2009)
  - Davis et al. (2009)
  - US EPA (2013a)
  - Verginelli and Baciocchi (2014)
- Models generally under-predict biodegradation (more conservative)
- Empirically derived screening distances consistent with those predicted by Verginelli & Baciocchi assuming reasonable biodegradation assumptions



Modified from Verginelli and Baciocchi, 2014

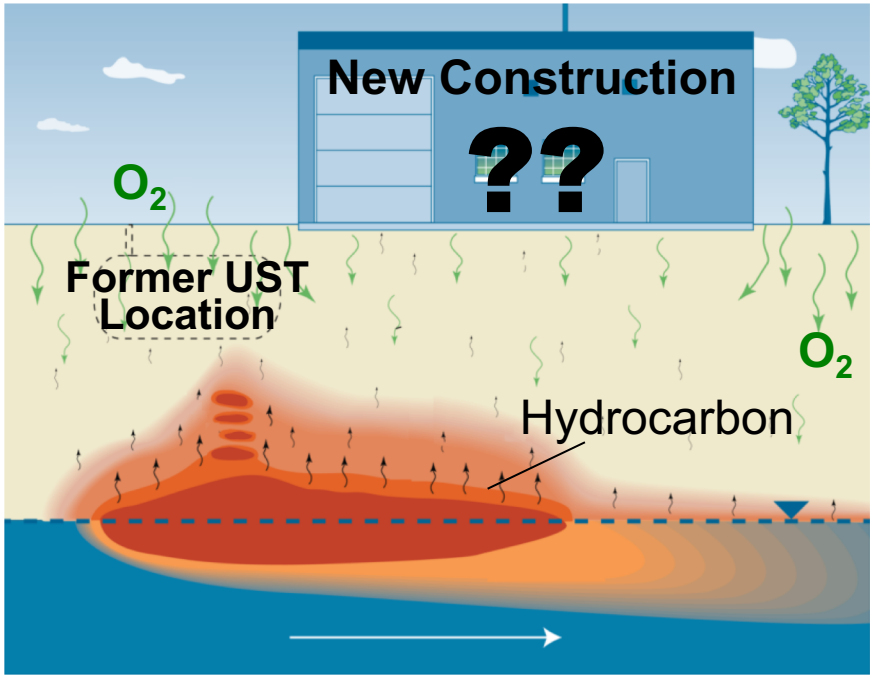
FAQ: What About Oxygen (O_2) Soil Gas Measurements?

- O_2 can be affected by:
  - low permeability or highly saturated soil layers (including surface soils post rain events, ice, pavement)
  - large building foundations (US EPA OUST - > 66 feet in length and width)
  - gasoline containing > 10% vol/vol ethanol
- O_2 soil gas not necessary to "prove" screening distances (not used in screening distance derivation)
- **identification of primary and secondary LNAPL sources in vadose zone** during preliminary site investigation (CSM development) **is critical**
- collection of O_2 soil gas data is important in further investigation (Steps 4 – 6)



FAQ: What About Future Construction?

- Vertical screening distances can still be used to screen out sites with future construction given that:
  - Empirical database from UST sites (Lahvis et al., 2013) included:
    - 11% of soil gas samples collected below building foundations
    - 45% of soil gas samples collected below relatively impervious cover (e.g., concrete, asphalt pavement)
- ***Note***: **if further site investigation required**, soil gas samples collected in absence of where future building planned may not be representative of future condition



Steps 1-3 Site Screening Summary

- Use of screening distances is expected to improve PVI screening (minimize unnecessary site investigations)
- Use requires development of a Preliminary CSM based on soil and groundwater data that is either readily available or collected during an initial site assessment
- Screening distances:

Source	UST/AST Sites	Industrial Sites
Dissolved	5 feet	5 feet
LNAPL	15 feet	18 feet

- Vertical building separation distance > vertical screening distance = "screen out"; otherwise "screen in"
- Screening distances are well supported by empirical data and generally by modeling studies