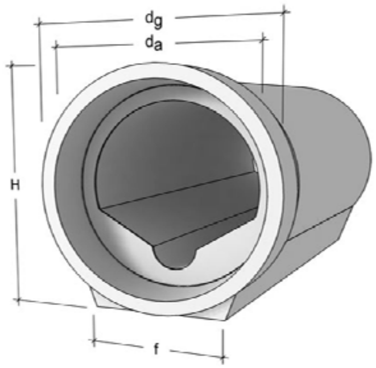
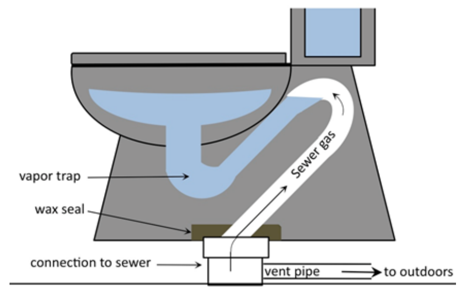
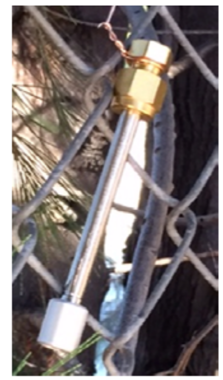
Presented to the AEHS
26th Annual International Conference
San Diego, California March 23, 2016

SANITARY SEWER CONTAMINANT MIGRATION STUDY







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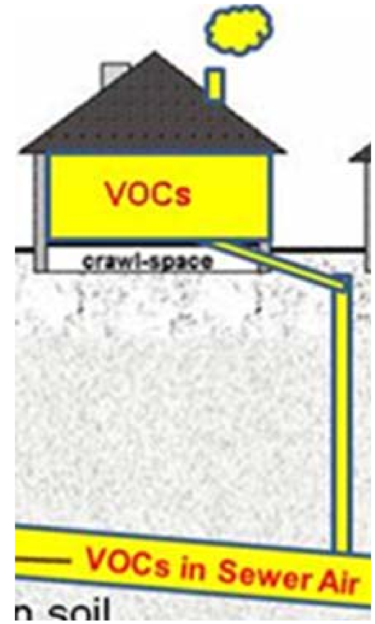

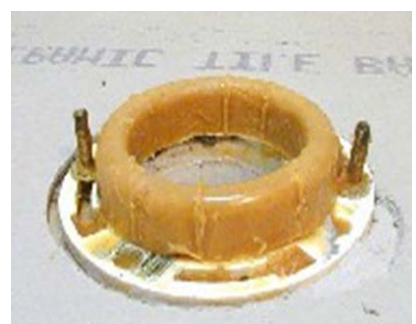

Presented to the AEHS
26th Annual International Conference
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Exposure Pathway Analysis Using Passive Diffusion Air Sampling Methods to Sample Sewer Air in Manholes and Cleanouts

MANHOLE TO CLEAN OUT:

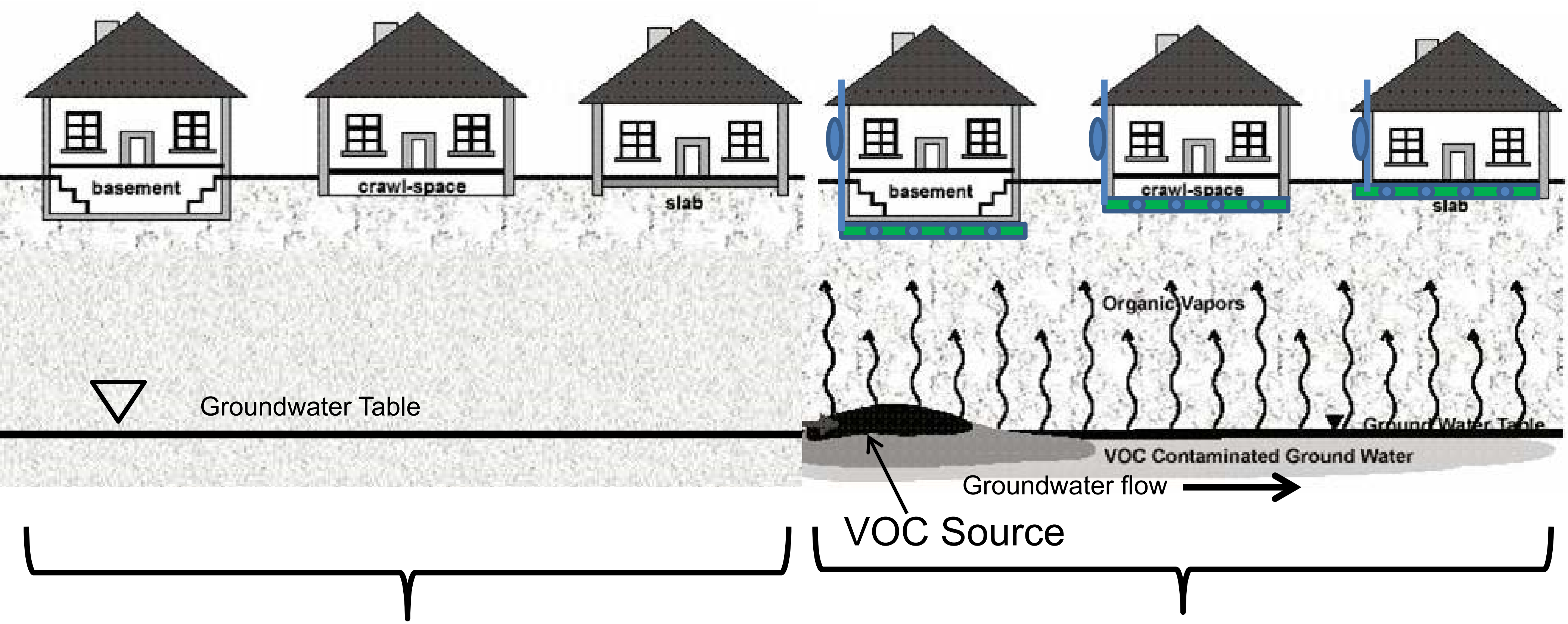
PASSIVE SEWER AIR SAMPLING

Presence of VOCs in Sewer Manhole as a Predictor of VOCs in Sewer Lateral Cleanouts

Olivia P. Jacobs, C.E.M.; Clearwater Group
James A. Jacobs, P.G., C.H.G., C.P.G.; Clearwater Group
Kelly Pennell, Ph.D., P.E., University of Kentucky

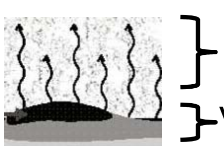
Example of Manholes with Deployed Passive VOC Samplers

Current Site Conceptual Model of VOC Exposure / Mitigation



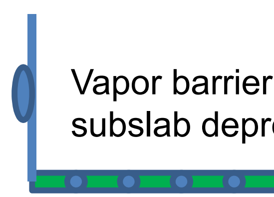
Zone of clean soil
and groundwater;
No exposure risk

Zone of VOC-impacted
soil and groundwater;
Possible exposure risk



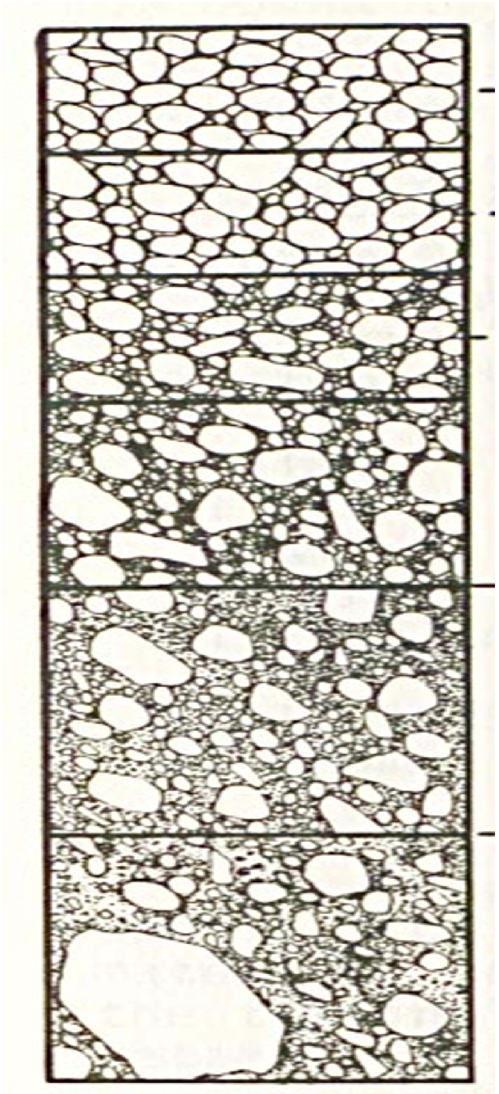
Upwardly migrating VOCs in soil as soil vapor

VOCs in soil-groundwater (source)

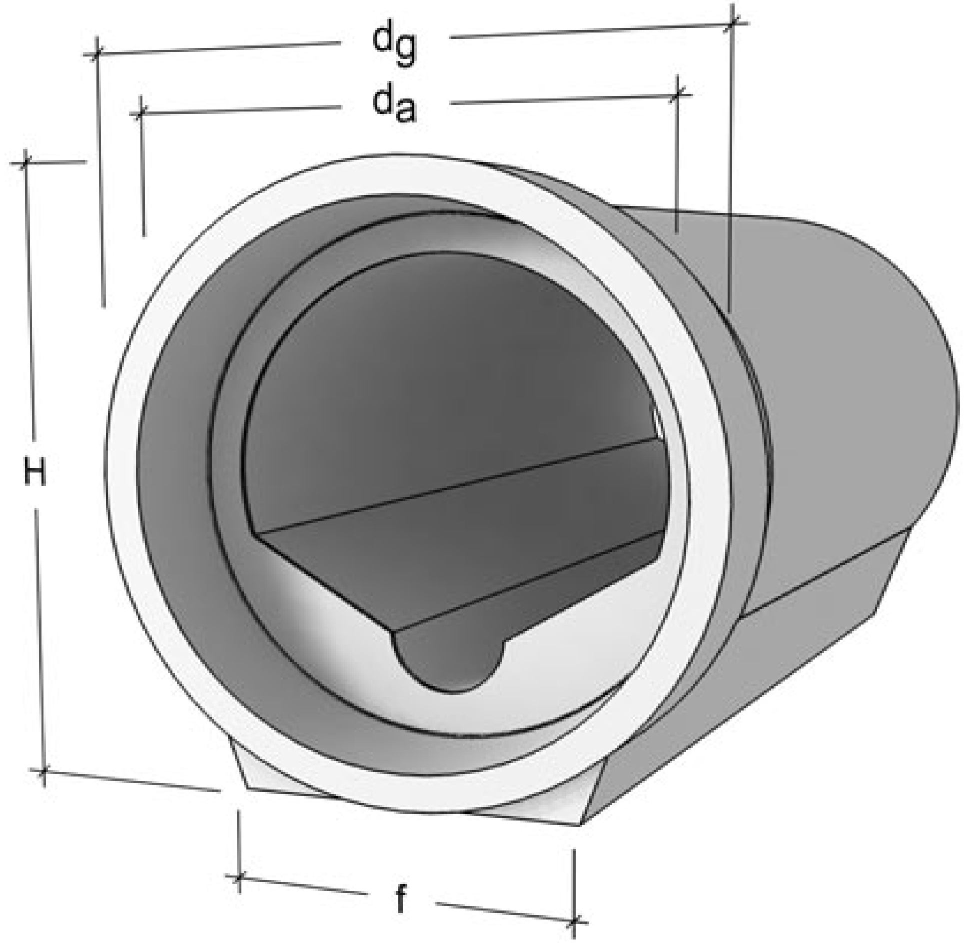


Vapor barrier with
subslab depressurization

Transport through Soil vs. Pipe



Soil



Pipe

Jacobs and Jacobs, 2015

VOC Migration Through the Sewer

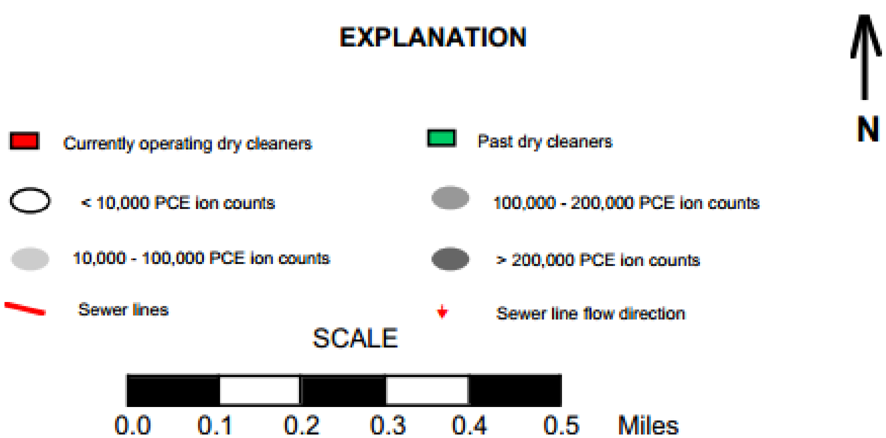
Vapor Intrusion and Sewer-Plumbing Systems

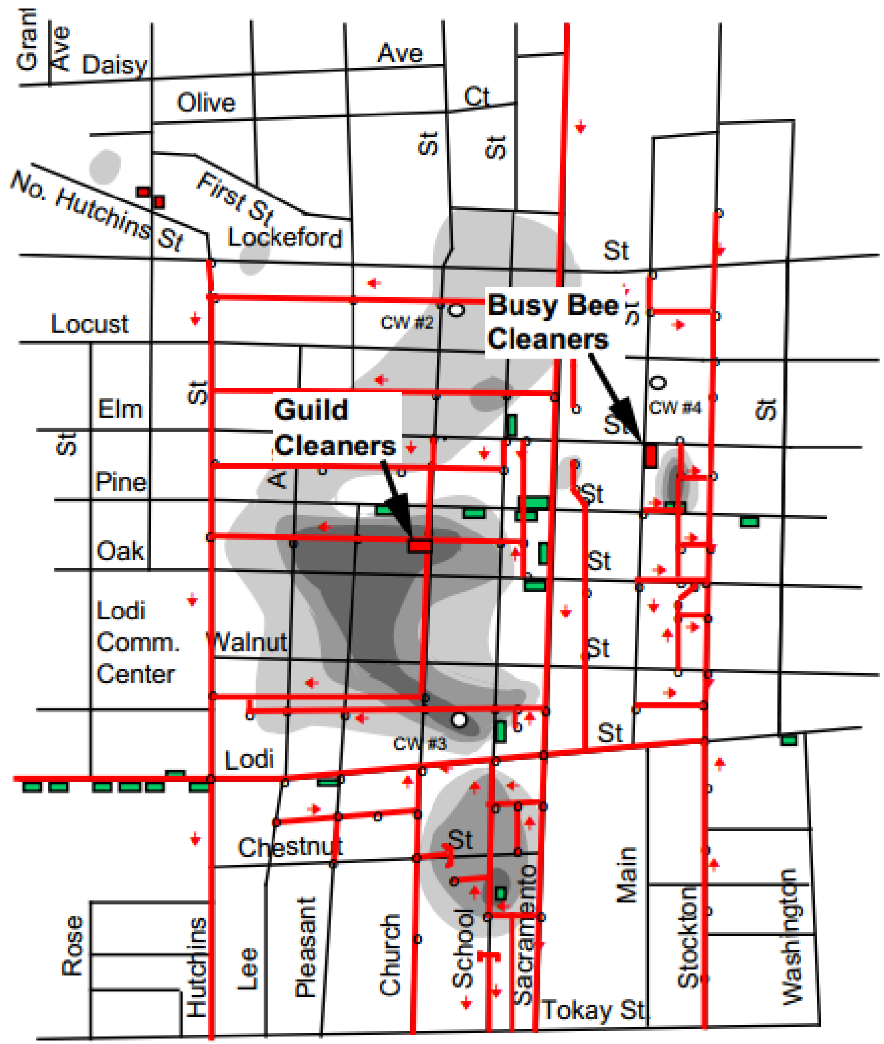
VOCs Release / Migration

Lodi, California Sewer Lines:

1) **Sewer pipes and utility trenches are conduits for subsurface impacts; and**

2) **VOCs released from sewer lines.**

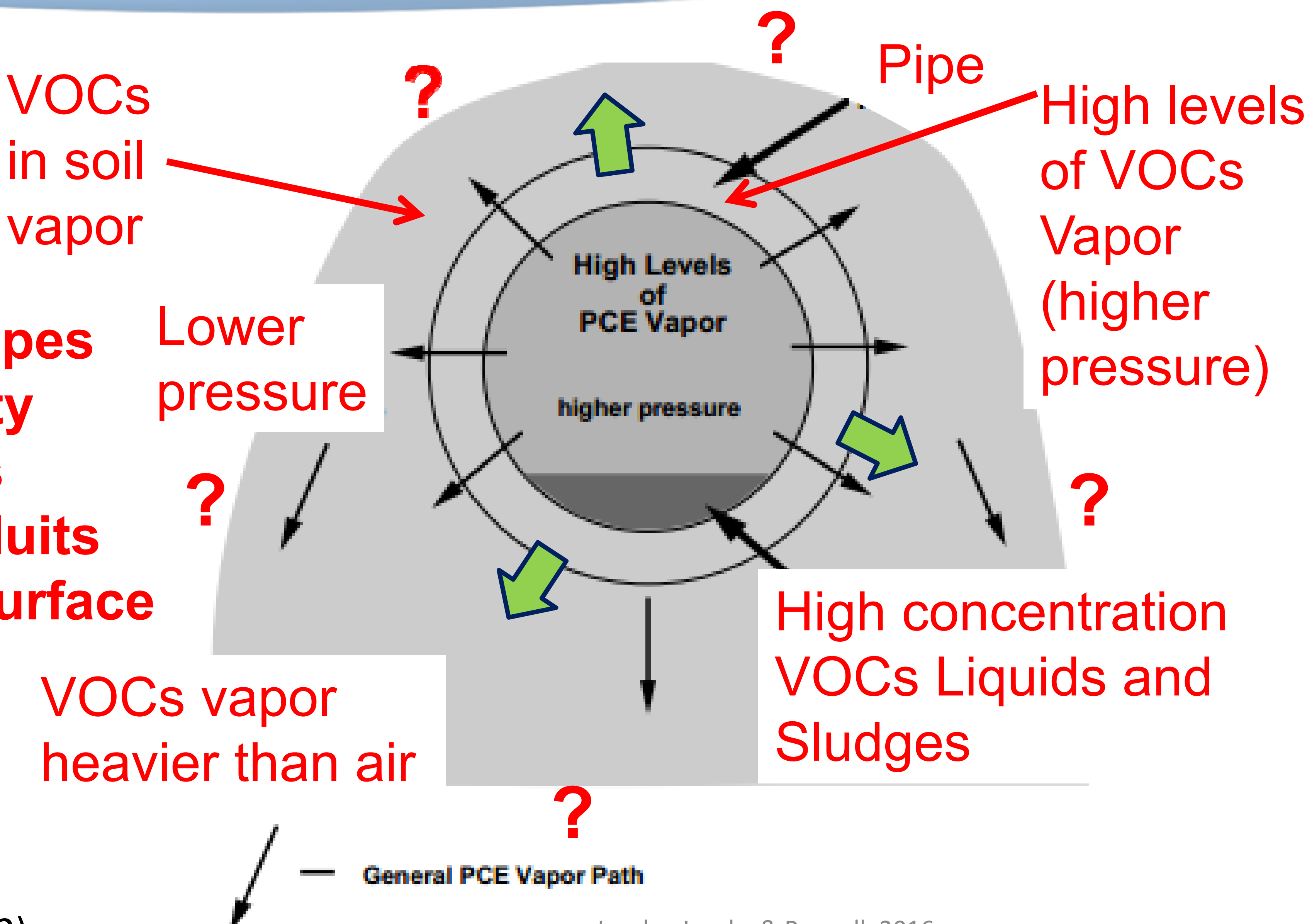




(SWRCB, 1992)

Pipe **exfiltration**: VOCs in liquid, soil, and gas; migrate in groundwater.

Sewer pipes and utility trenches are conduits for subsurface impacts

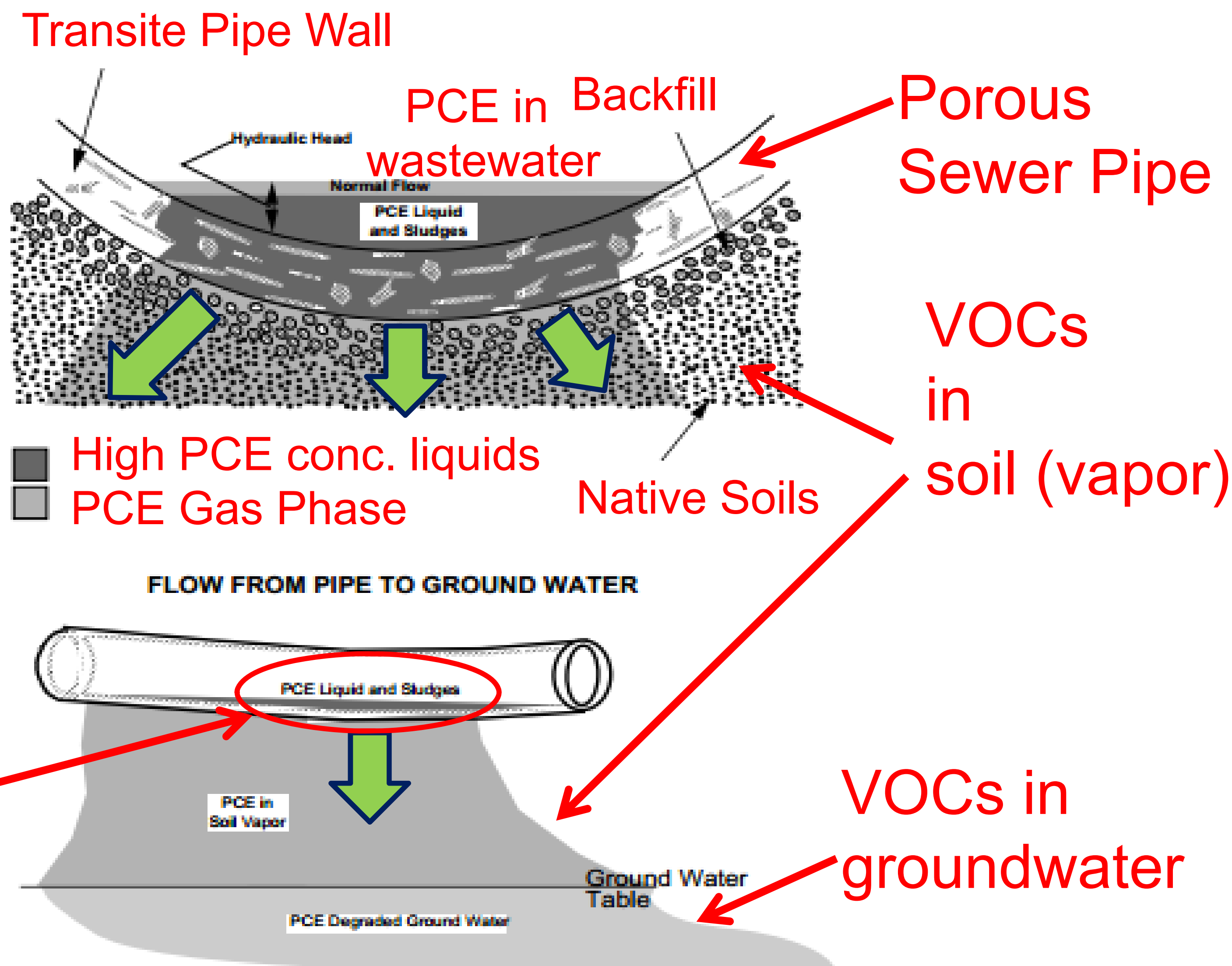


(SWRCB, 1992)

VOCs enter sewer pipes as VOC liquid/sludge discharges and leak into soil and groundwater. VOCs persist along release pathway.

LODI MODEL

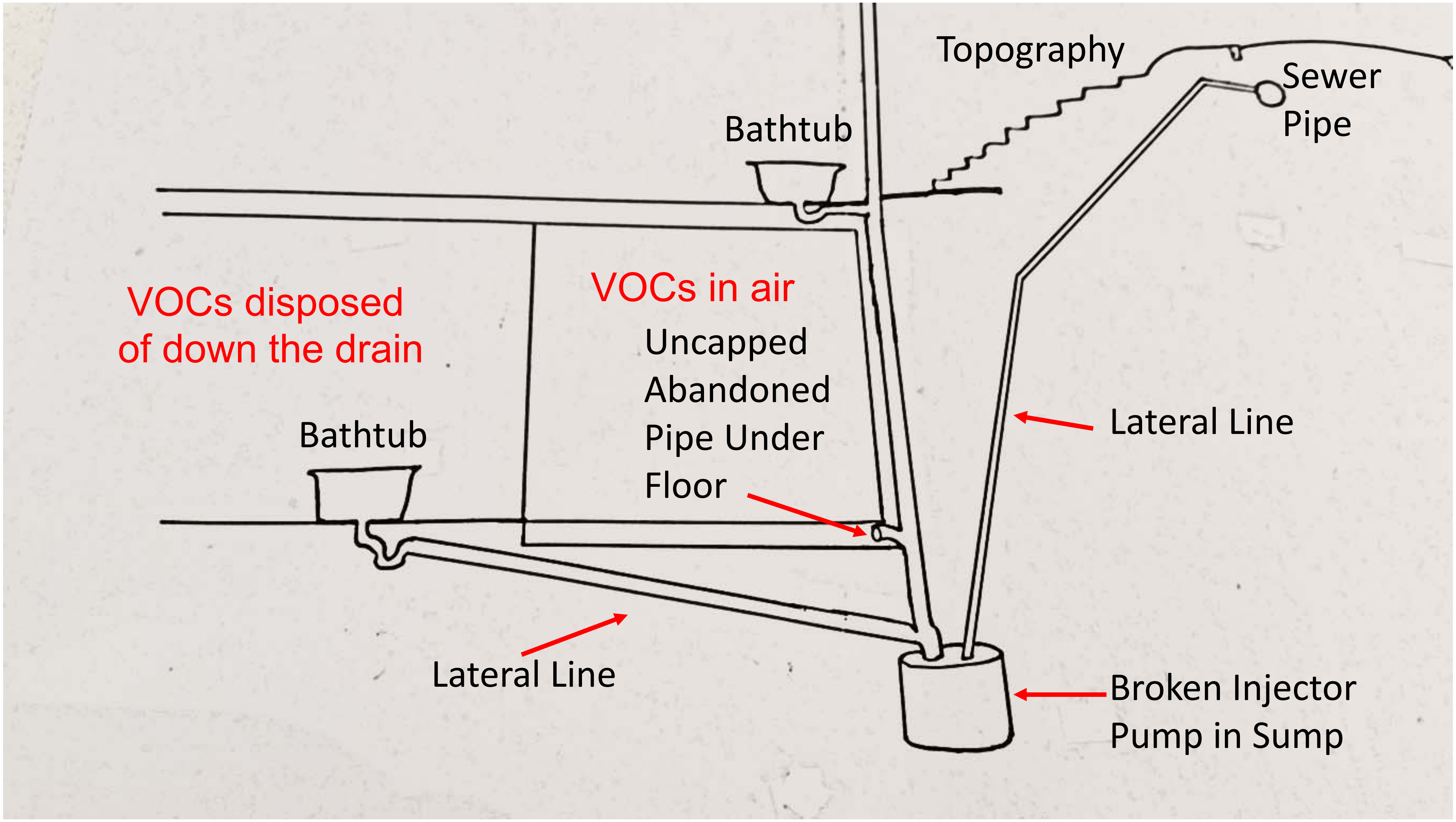
Sewer pipes and utility trenches are conduits for subsurface impacts



(SWRCB, 1992)

Jacobs, Jacobs & Pennell, 2016

Plumbing Failure likely Cause of VOCs in Indoor Air



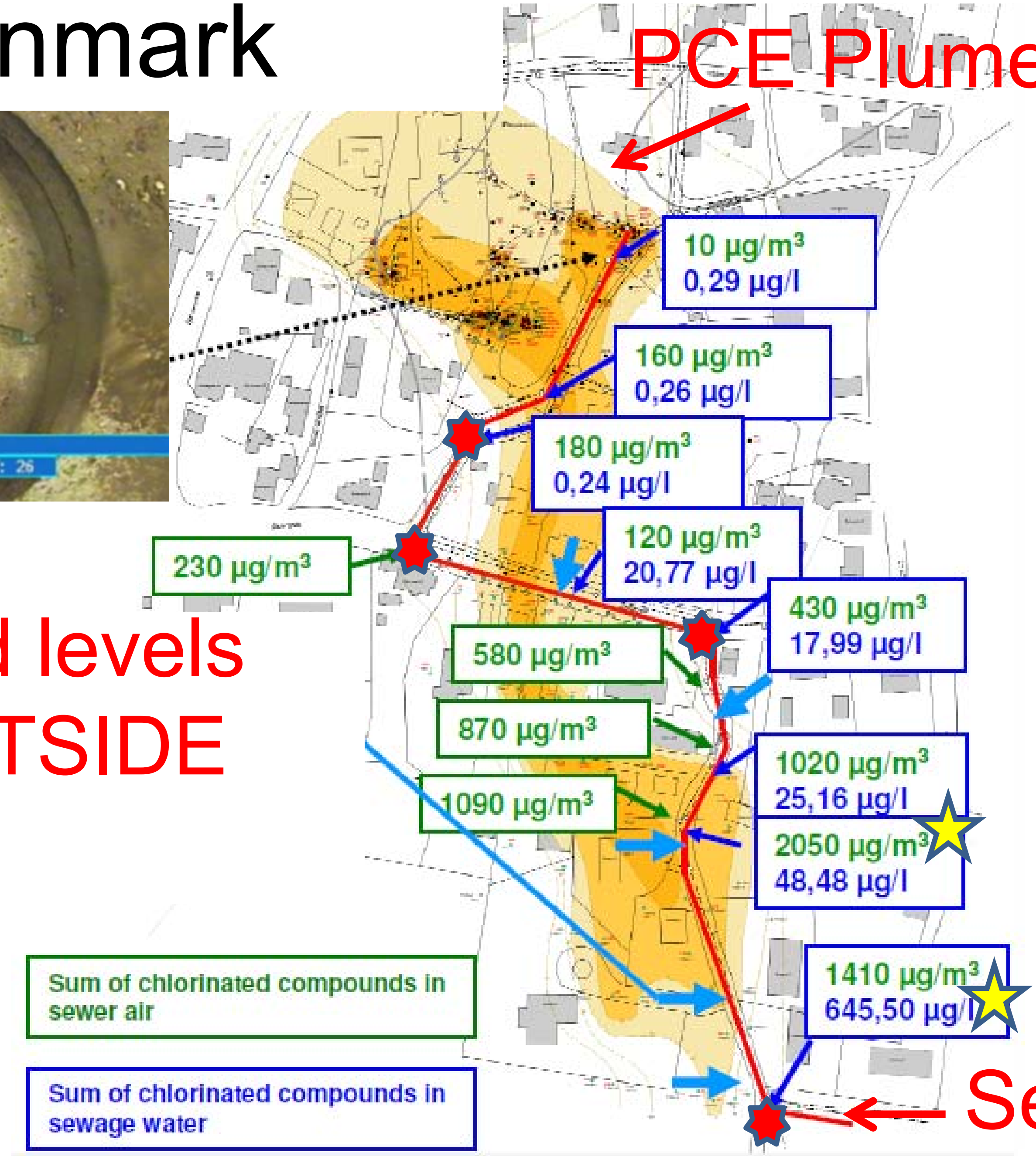
Jacobs, Jacobs & Pennell, 2016

Sewer Line and Housing Indoor Air Sampled - Denmark

Skuldelev, Denmark

(Riis et al., 2010)

VOC Sewer Liquid and Air Study Skuldelev, Denmark

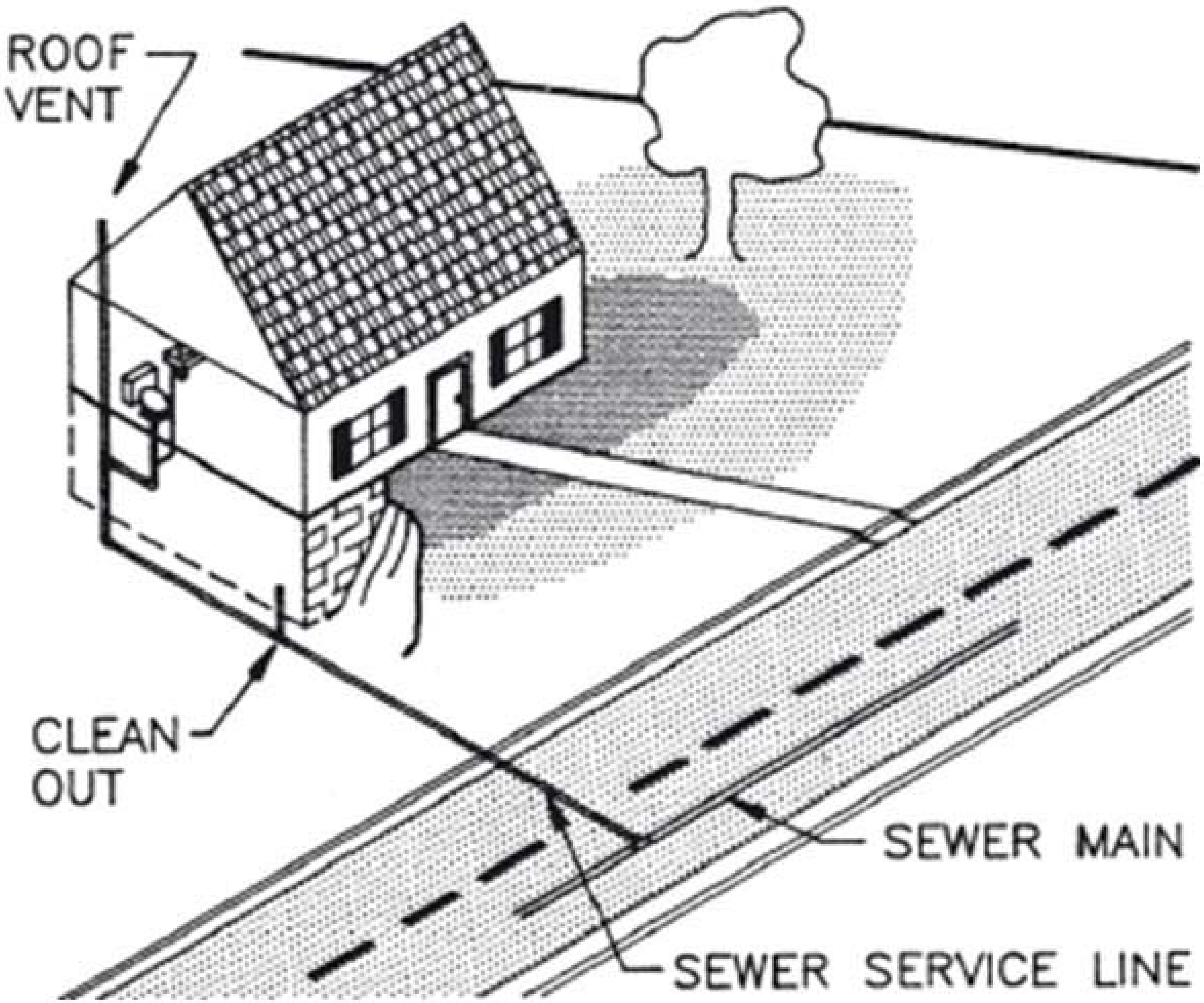


PCE at elevated levels in sewer air OUTSIDE of mapped PCE plume

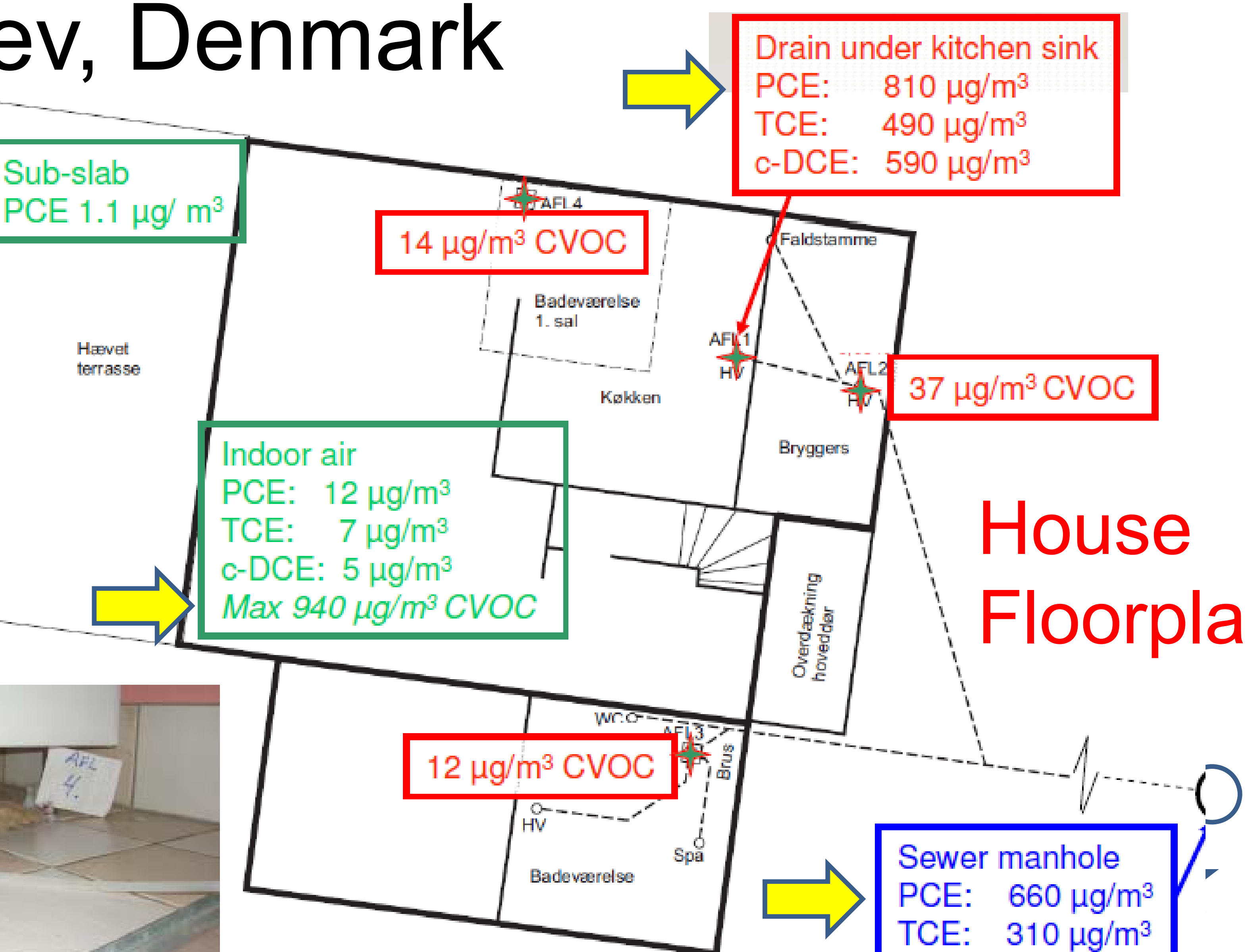
(Riis et al., 2010)

Jacobs, Jacobs & Pennell, 2016

Connectivity of all municipal pipes in wastewater collection system



VOC IA Studv leads to Sewer Study, Skuldelev, Denmark



House Floorplan

Sub slab Sampling

(Riis et al., 2010)

Subslab Depressurization System Iterative Indoor Air Study

Metro-Boston Area, Massachusetts

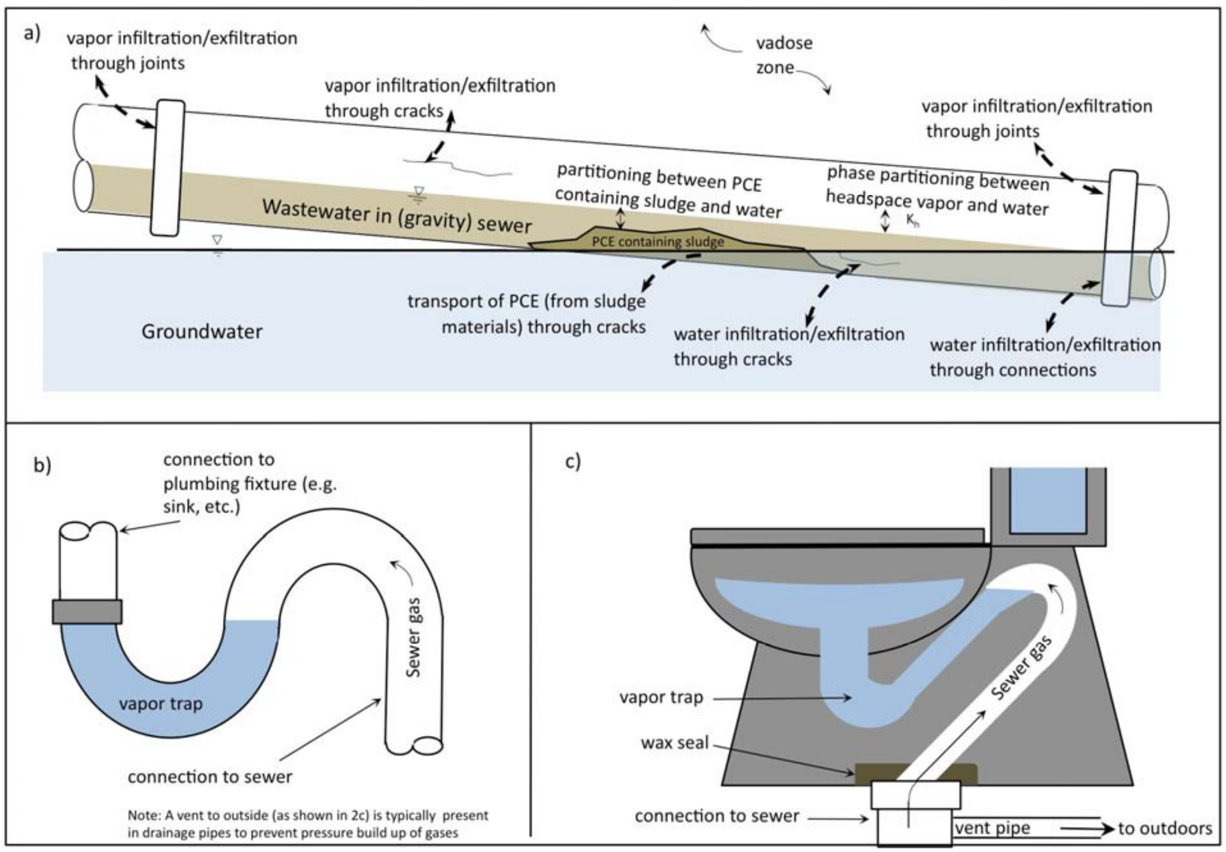
(Pennell et al., 2013)

Jacobs, Jacobs & Pennell, 2016

Tale of the Failed Toilet Seal

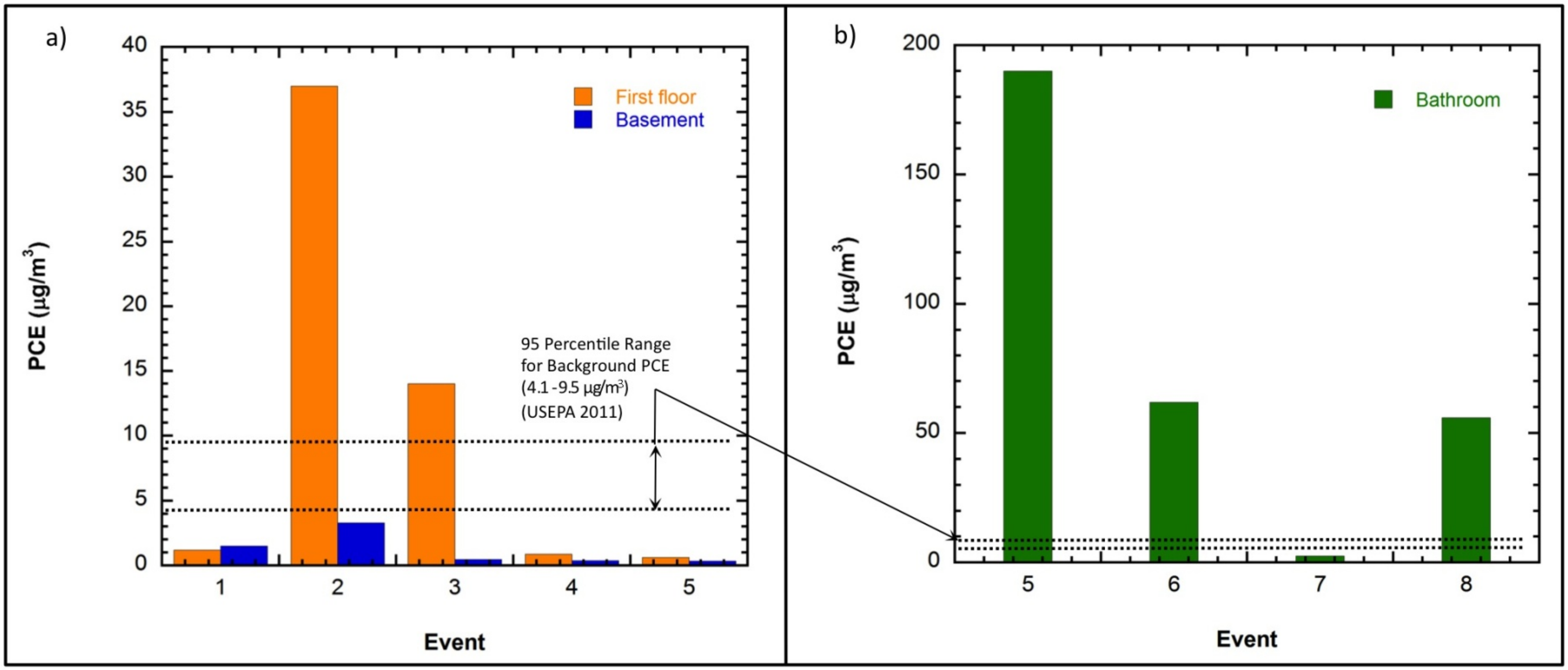
PCE in bathroom air = 37 µg/m³.

PCE in bathroom sewer pipe = 190 µg/m³.



Pennell et al (2013)   Jacobs, Jacobs & Pennell, 2016

Findings: PCE from Sewer Air Showing High Variability



1) PCE from sewer air; and
2) High variability in PCE concentration over time

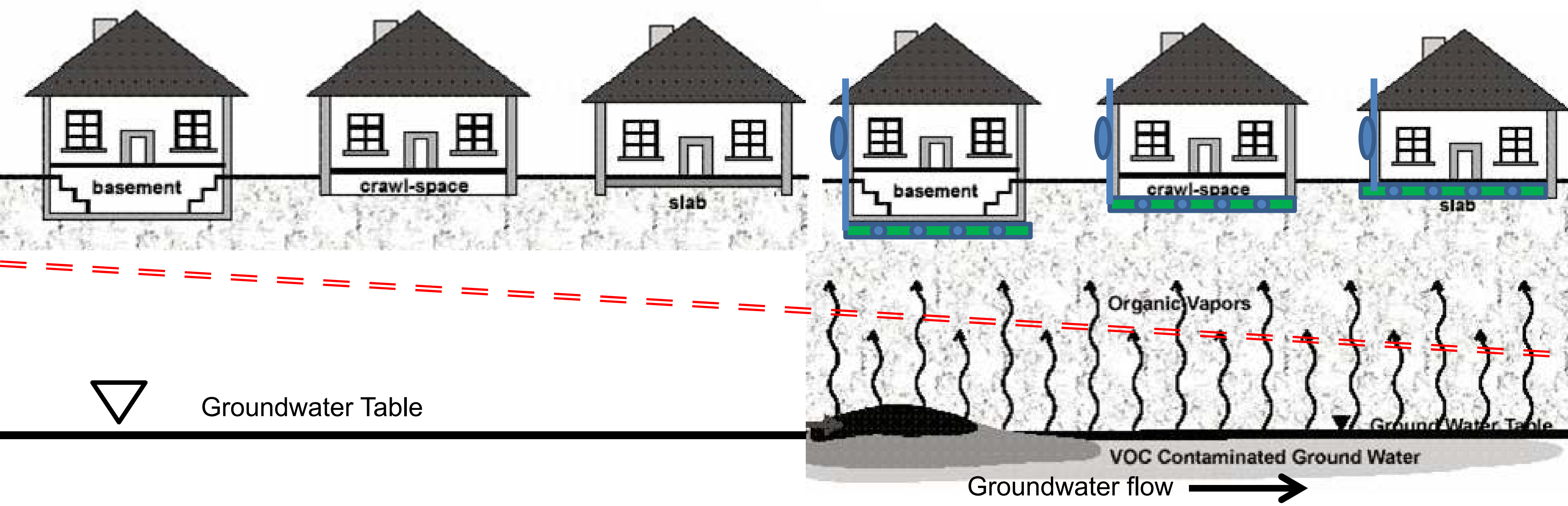
Superfund Research Program

Pennell et al (2013)

UK see blue. go green.

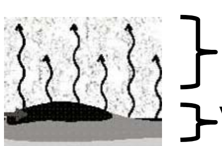
Revisit VOC Exposure Model

Alternate exposure pathways not included



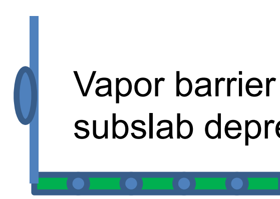
Site Conceptual Model Missing:

- Sewer Lines
- Land Drains
- Storm Drains
- Utility Trenches



Upwardly migrating VOCs in soil as soil vapor

VOCs in soil-groundwater (source)

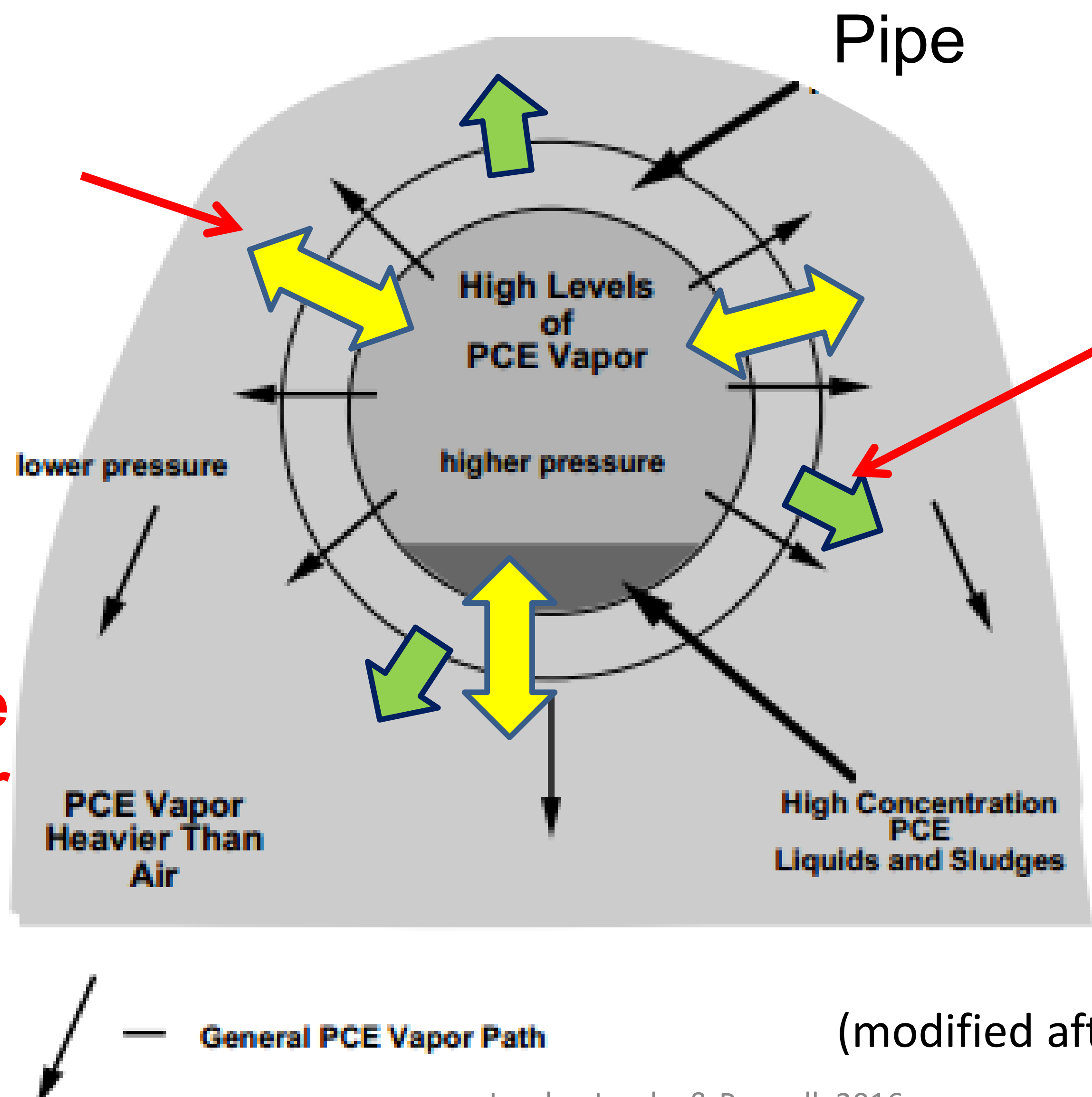


Vapor barrier with subslab depressurization

Pipe **infiltration**: VOCs do enter transite/clay sewer pipe wall as a liquid or as a gas.

UPDATE: VOCs Migrate OUT OF and INTO Sewer Lines

2) Exposure may be outside of groundwater plume area.



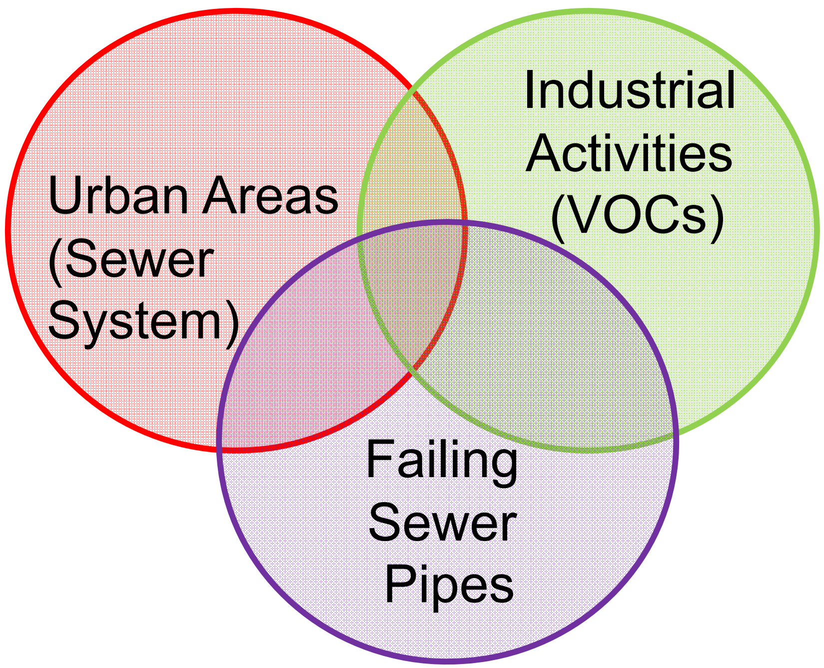
LODI MODEL: VOCs and Liquids

(modified after SWRCB, 1992)

Entry of VOCs in Liquid and Soil Vapor into Sewer System

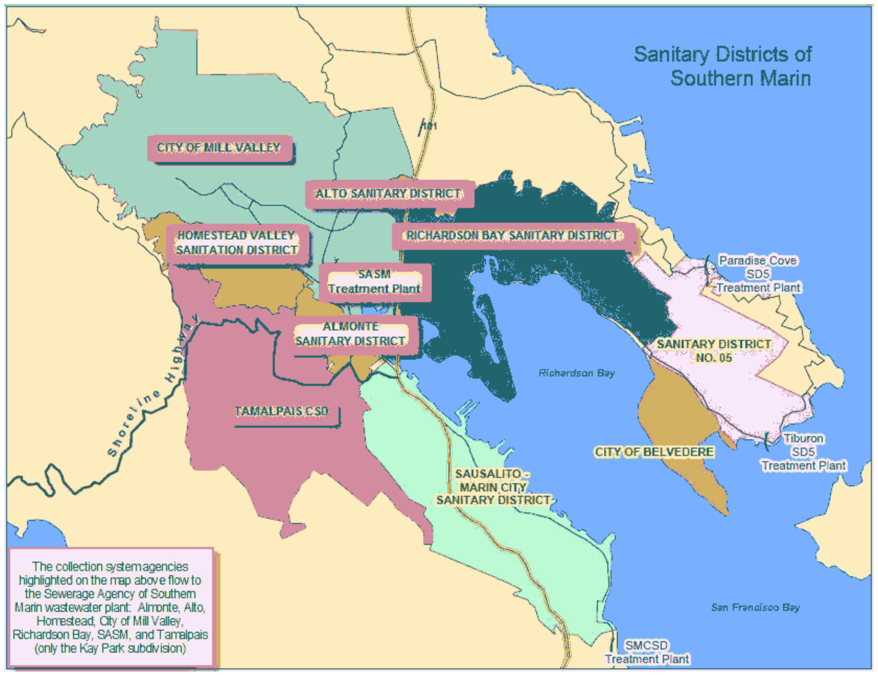
Optimum Conditions:

1) Urban Areas with Centralized Wastewater Plants
2) Industrial Activities with VOCs
3) Failing Sewer Pipes



Jacobs, Jacobs & Pennell, 2016

Example Wastewater Treatment Plant and Legacy Collection Systems



Map of a System

Aerial View of Plant

Typical 1950s sewer pipe connection seals (bell and spigot) age and are not anticipated to be water/vapor tight

Jacobs, Jacobs & Pennell, 2016

General Infrastructure Design Life and Causes of Failure

PIPE DESIGN LIFE:

- 75 to 100 years (optimal conditions)
- 50-60 years (reasonable lifespan)
- 25-35 years (low end)

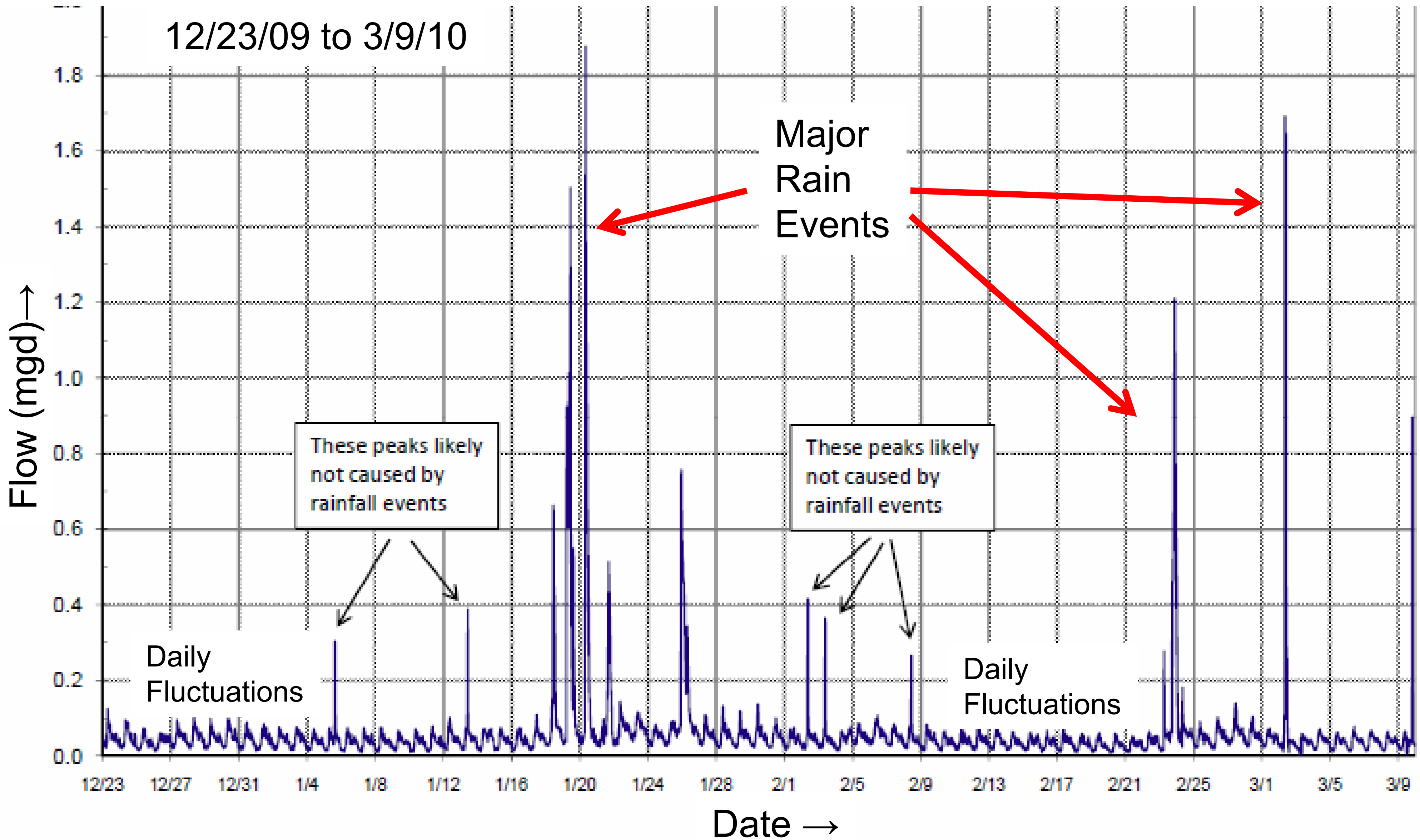
Cast iron pipe

CAUSES OF PIPE FAILURE:

- Chemical reactions (corrosion)
- Biological attack (tree roots, microbes)
- Physical settling and pipe separation
- Cracking of pipes

Sewer System Sewage Volume

Data: Variations in Wastewater Flow (mgd)



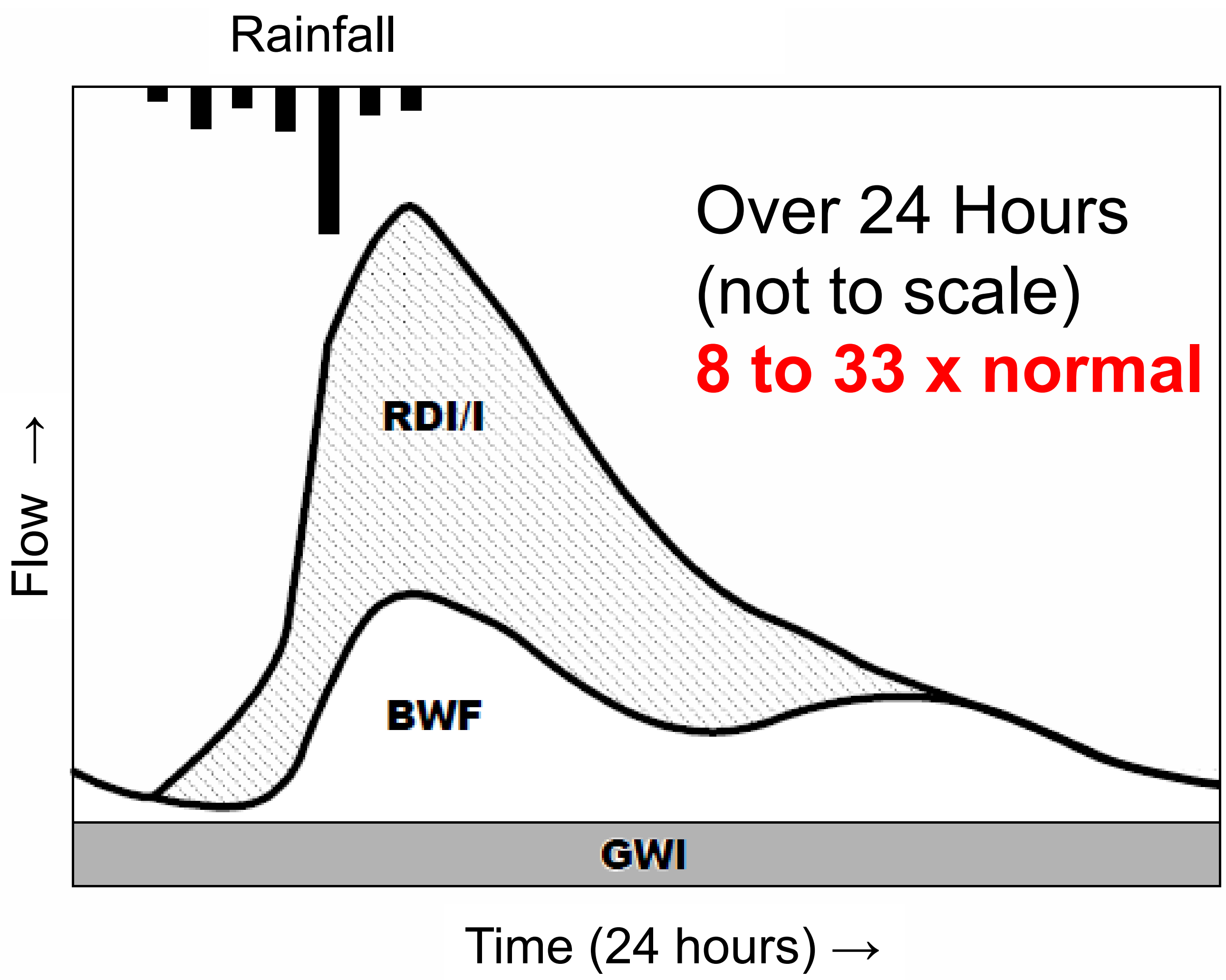
(SASM SSRAP; RMC; 2010)

Base Flow versus Rainfall Infiltration Addition

RDI/I = Rainfall-Dependent Infiltration/Inflow

BWF = Diurnal Base Waste-water Flow

GWI = Ground-water Infiltration



Examples of Sewer Pipe Integrity Loss

Cracked Sewer Pipe (Riis)

Corroded Sewer Pipe

Rootlets in Sewer

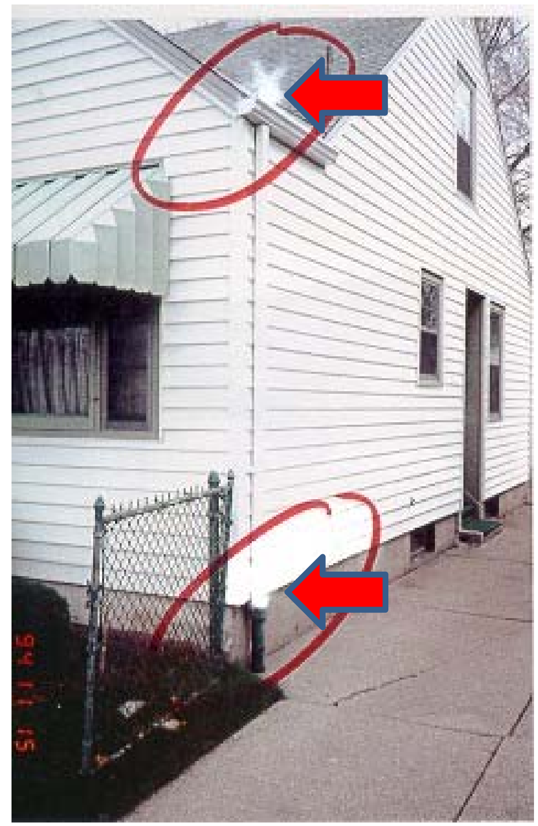
Separated Sewer Pipe

Cracked Sewer Pipes

Evidence of Types of System Leaks

Leaking terra cotta sewer pipe

Smoke locates sewer leaks

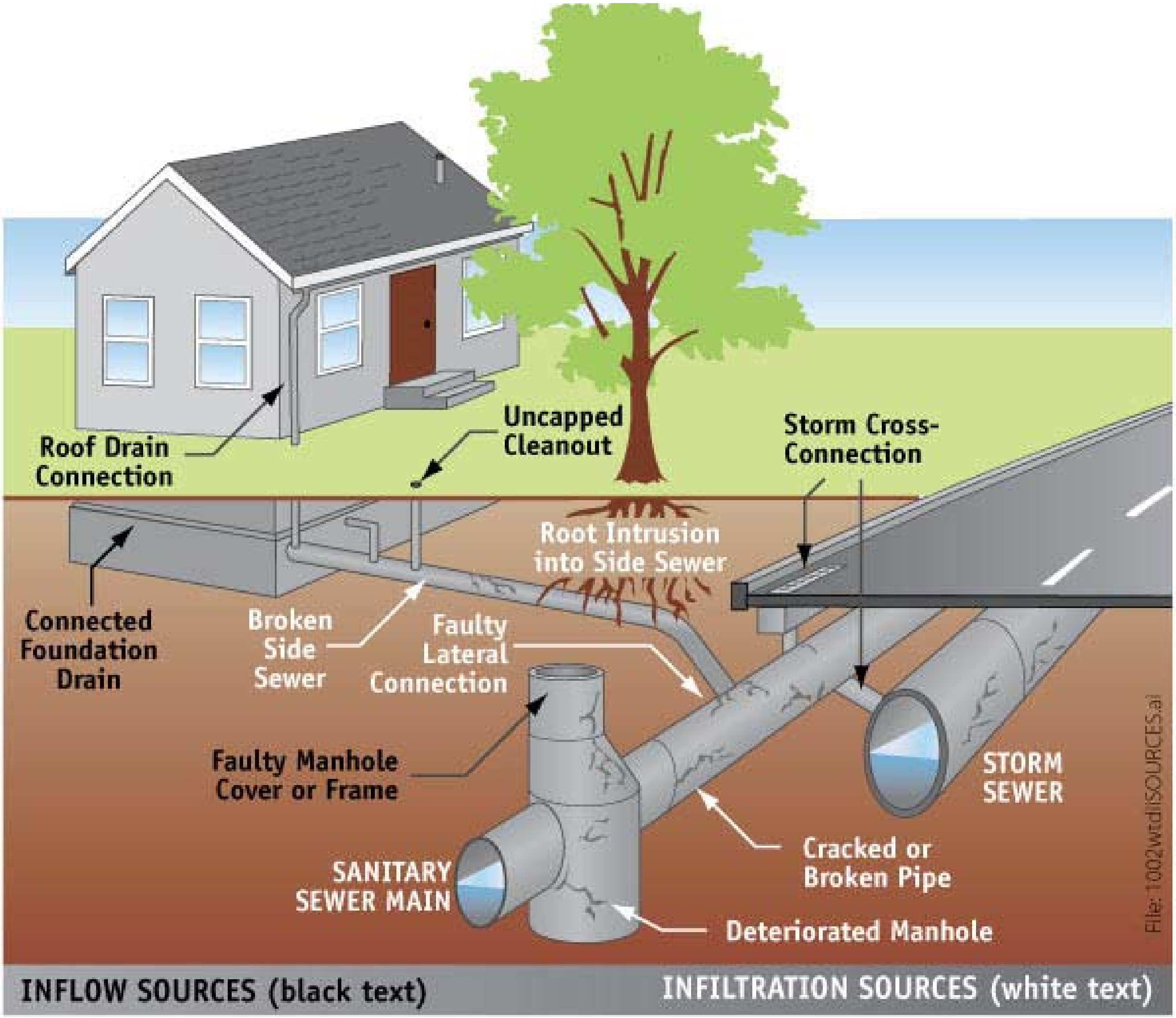


Gutter (rainwater) connected to sanitary sewer system

Smoke testing verifies leaks in sewer lateral pipes

Jacobs, Jacobs & Pennell, 2016

Sources of Inflow and Infiltration (I&I)



http://www.cityoflakeport.com/

Sources of VOCs in Sewer Air

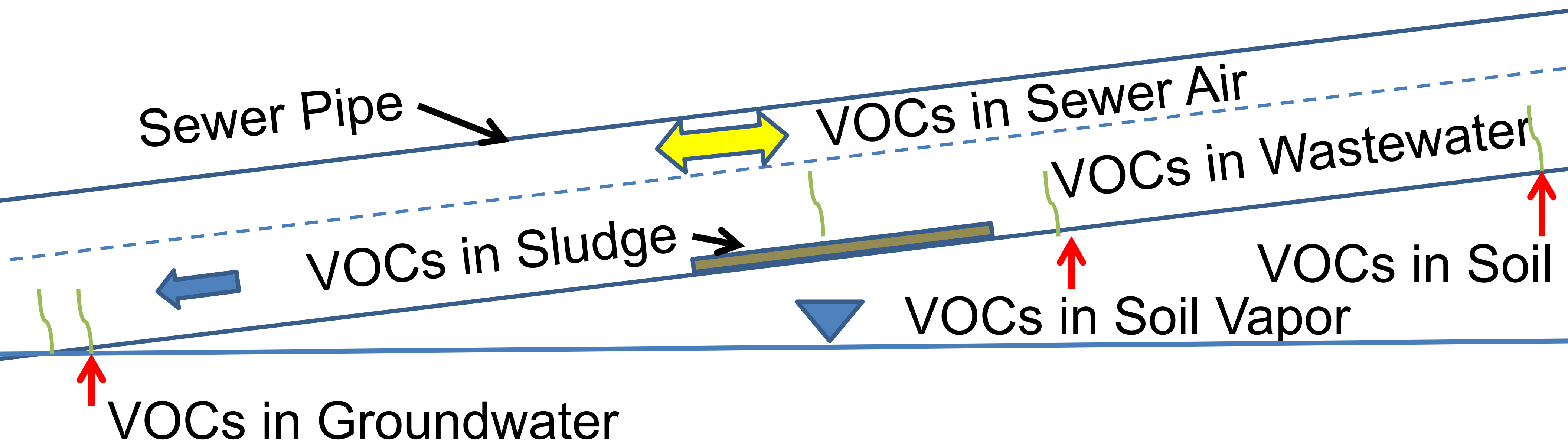
LEGEND

Sewer Pipe Crack or Separation

Wastewater Flow Direction

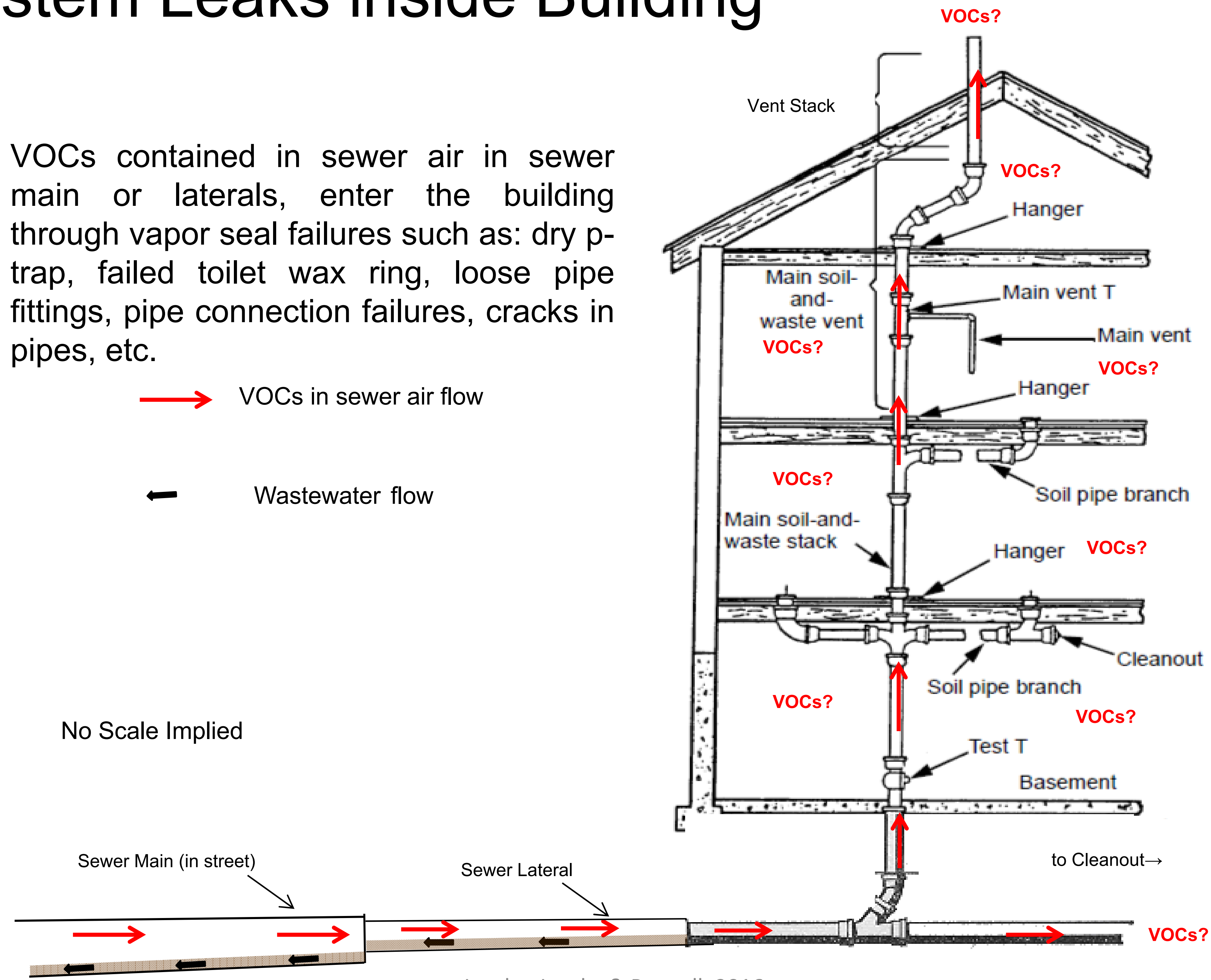
Sewer Air Flow Direction

Note: Cascading: drops in wastewater elevation in manholes causes VOC release to sewer air



System Leaks inside Building

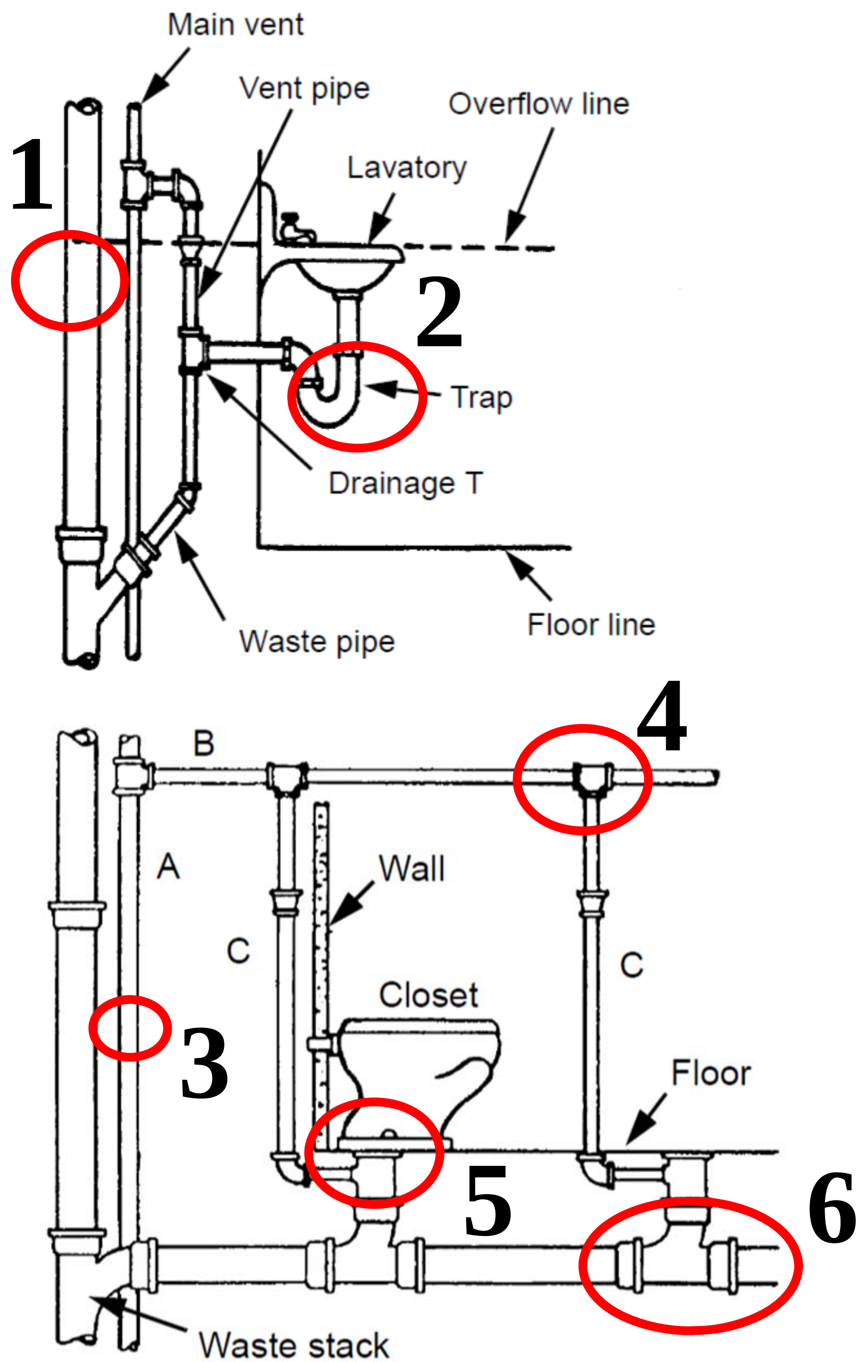
VOCs contained in sewer air in sewer main or laterals, enter the building through vapor seal failures such as: dry p-trap, failed toilet wax ring, loose pipe fittings, pipe connection failures, cracks in pipes, etc.



Jacobs, Jacobs & Pennell, 2016

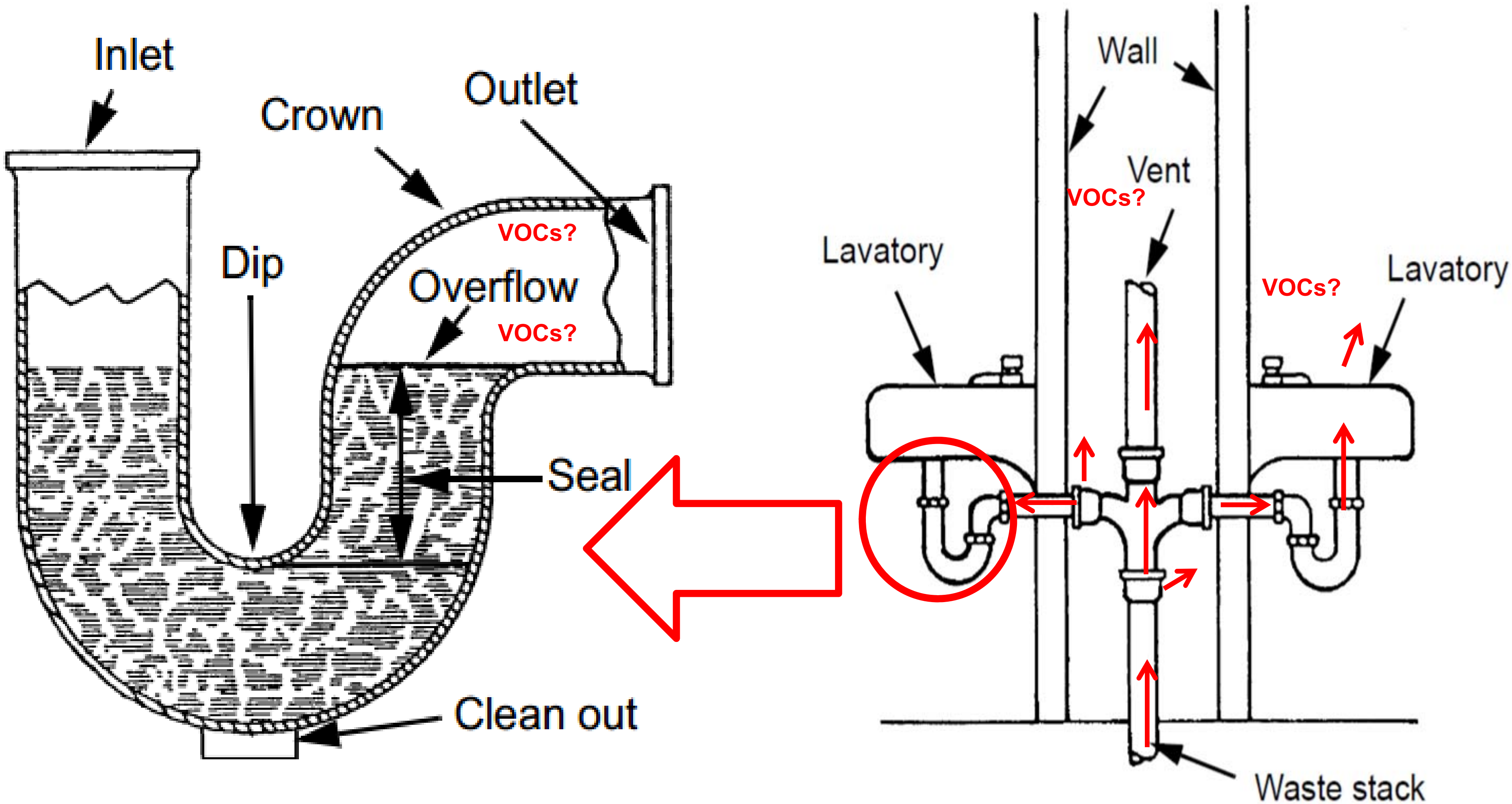
Typical Leak Locations

1. Cracked wet stack
2. Dry P-trap
3. Cracked vent stack
4. Loose fittings
5. Faulty wax ring seal
6. Leaking joints



Legend—
A - Main vent
B - Branch of the main vent
C - Individual fixture vents

VOCs in P-Traps and Walls



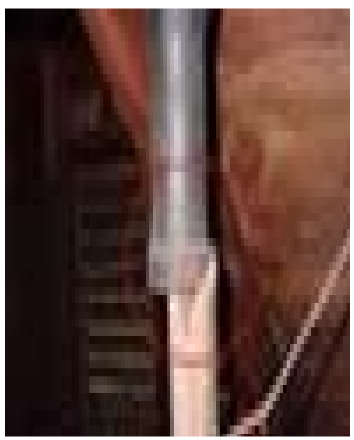
Real World Examples: Plumbing Breaches

Misaligned Attic Vents

Visible Leakage from Sewer Pipes

Roof Vent with Debris

Broken Connections



Misaligned Vent

Vent under Sink

Sink without a P-Trap

Jacobs, Jacobs & Pennell, 2016
Jacobs, Jacobs & Pennell, 2014

Example of Sewer Vapor Seal Failure

Floor drains without P-Trap seal could be conduits for migrating sewer gases.

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Sewer gas blamed for southern Minnesota house explosion that injured man

By Sarah Stultz
Albert Lea Tribune

Click to know what happens next with this story TRAQ IT

POSTED: 06/11/2012 12:01:00 AM CDT
UPDATED: 06/11/2012 07:12:37 PM CDT

FREEBORN, Minn. -- Fire officials confirmed Monday that gas from an uncapped sewer line caused the explosion at a house north of Freeborn on Friday that badly burned a man.

Freeborn Fire Chief Steve Siepp and a representative from the state fire marshal's office investigated the explosion on Monday morning.

Siepp said they concluded that sewer gas from an uncapped line had backed into the house, and the gas was ignited when Ralph William Yotter, 75, came into the house and turned on a light switch.

Yotter suffered burns to his face and body and remained in serious condition at Regions Hospital

Jacobs, Jacobs & Pennell, 2016
Jacobs, Jacobs & Pennell, 2014

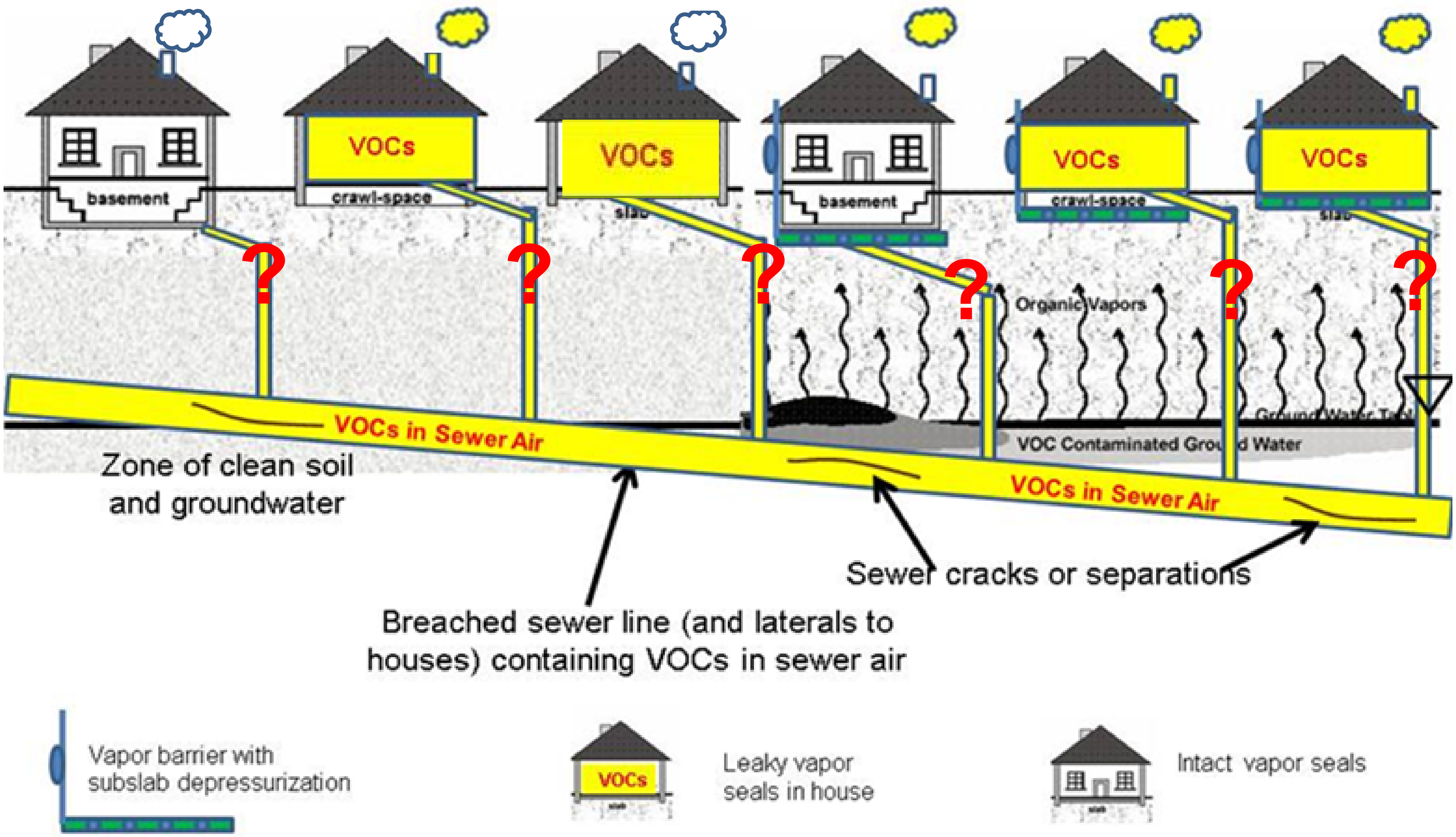
Potential Sources of VOCs in Sewer System

- Disposal of VOCs in sewer (sludge in pipes; leaks to soil)
- Sewer intercepts VOC-impacted soil and groundwater
- Nearby gasoline station, dry cleaner, industrial facility, or migrating contaminant plume
- Legally permitted VOC pump and treat discharges
- Sump pumps and building dewatering
- Illicit drug lab (with VOCs)
- Illegal chemical dumping

Jacobs, Jacobs & Pennell, 2016

Updates to Vapor Intrusion Model

VOCs in Sewer Air Can Migrate Through Sewer System Outside of Plume Area



Literature Review and Search for Sewer Air Project – Spring 2015

Feature

One Alternate Exposure Pathway of VOC Vapors from Contaminated Subsurface Environments into Indoor Air – Legacy Sewer-Plumbing Systems

By James A. Jacobs, Olivia P. Jacobs, and Kelly G. Pennell

Abstract

Sewer-plumbing systems, land drains and subsurface utility conduits/lines/trenches are alternate exposure pathways for volatile organic compounds (VOCs) in the shallow subsurface to migrate into indoor air. Sewers which are well past their design life, or legacy sewers, allow for leakage into and out of the pipes. Legacy sewers that intercept VOC-contaminated groundwater or vapor likely contain VOCs in the sewer air. This article highlights an often overlooked implication of legacy sewers and their interception of VOC plumes—the potential for VOC-impacted sewer air to enter indoor air spaces.

Introduction

Sewer systems were designed to deliver residential, commercial, and industrial liquid wastes to treatment plants without loss of wastes in transit. Sewer-plumbing systems inside buildings were designed to properly vent

Nationwide, legacy sewer lines are unintended conveyance systems for VOCs in sewer air. VOC-impacted groundwater (and vapor in the vadose zone) infiltrates leaky sewer trunk lines and laterals. The VOCs volatilize from the sewer/groundwater liquids into sewer air, which allows for migration throughout the sewer system, and into indoor air through failed vapor seals in plumbing systems.

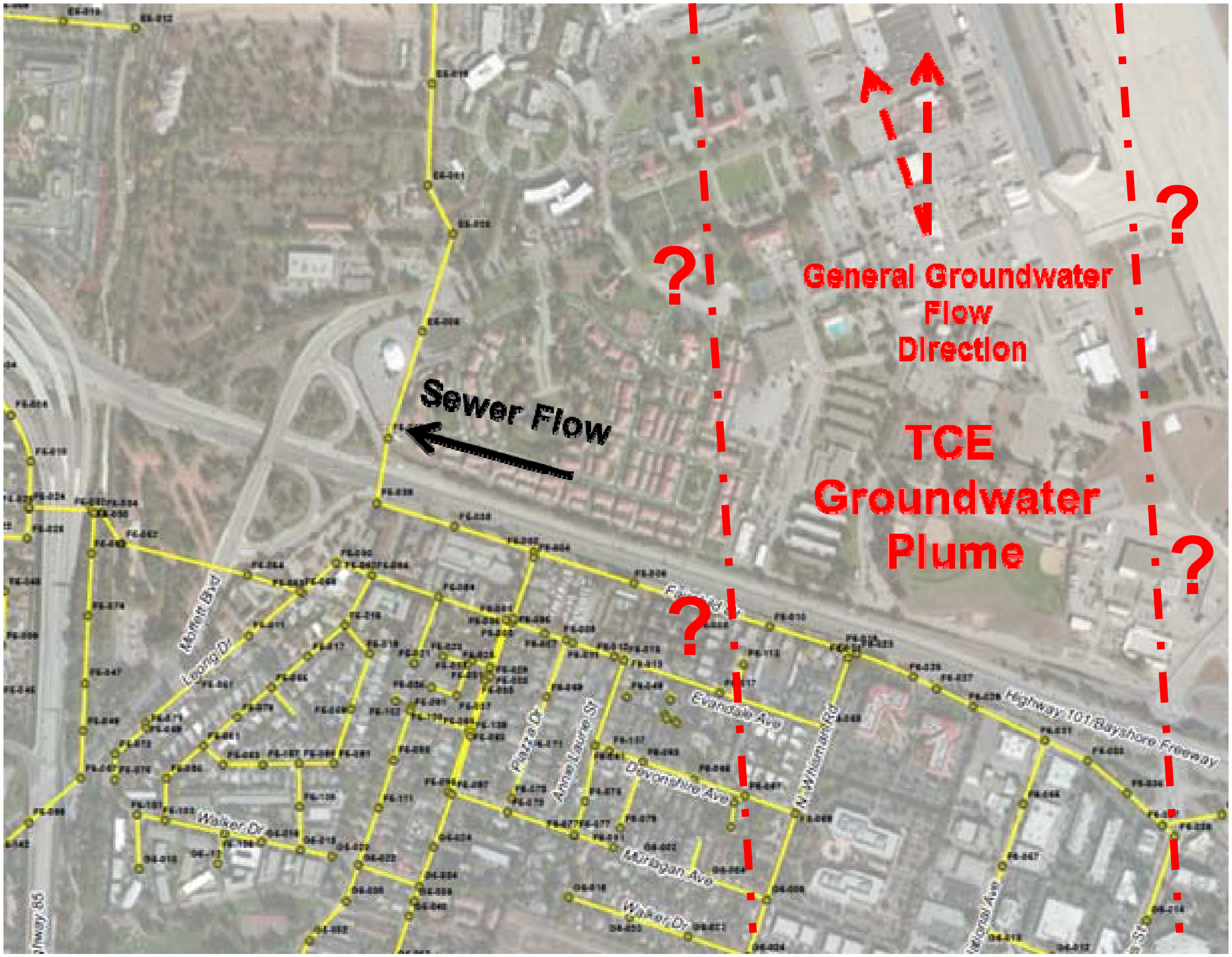
This paper presents (1) currently used vapor intrusion conceptual models, (2) leakage and pipe damage as documented in a northern California sewage conveyance system, (3) two case studies demonstrating the presence of VOCs in indoor air resulting from the intersection of breached sewer systems with failed plumbing seals and PCE plumes, and (4) recommendations.

Indoor Air Quality Studies

There are many sources of indoor air pollution, but one that has captured the attention of regulators and managers of hazardous waste sites is the transport of subsurface vapors into indoor air spaces (i.e. vapor intrusion). U.S. EPA (2002) developed a series of models for estimating indoor-air concentrations of VOCs and the associated health risks from subsurface vapor intrusion into buildings. These vapor intrusion models were based on the analytical solutions of Johnson and Ettinger (1991) for contaminant partitioning and subsurface vapor transport into buildings. Figure 1 shows a common site conceptual model for VOC vapor intrusion, based on US EPA (2002) and modified by others. Since that time, several revisions to the vapor intrusion models have been made and a series of new models have been developed.

Jacobs, Jacobs & Pennell, 2016

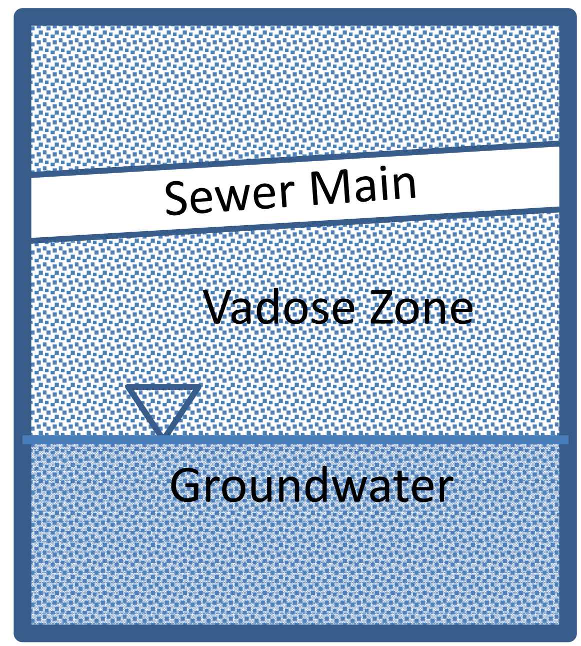
Example TCE Site with Iterative Investigations in Process



Groundwater = 3 to 4 ft below the bottom of the sewer main

VOCs in sewer

Cross-Section of Subsurface



Jacobs and Jacobs, 2015

Study Area Project Criteria

1) Target compound for which there is any documented detection is of public health interest (TCE);

2) Public access to sampling locations (City qualifies). Cleanouts are at property line. Local Sewer Agency is cooperative and shares system as-built data (City qualifies);

3) Health-directed higher level government Study Area with unidentified boundaries; area in which TCE data has already been collected in a step-wise fashion; there is a mission to further identify the presence of TCE exposure. Scientific interest in collection of the next-step data as additive to the existing data-set; and

4) Funding, sewer and vapor sampling experience.

Criteria to Select Sample Method

Passive samplers were selected for screening purposes.

Sampling Challenge	Passive Sampler Capability
Grab samples of Highly Variable Concentrations will measure Peaks and Troughs which are not representative	Exposure over 7 days which provides long duration, time integrated results to overcome temporal variability
Moisture included in the grab sample impacts lab analysis	Hydrophobic adsorbents assist with low detection limit
Technical – many moving parts and operator needed	Module (no moving parts) is deployed and collected

BEACON ENVIRONMENTAL SERVICES, INC.

Example of Manholes with Deployed Passive VOC Samplers

Jacobs, Jacobs & Pennell, 2016

Example of Sewer Lateral Cleanouts

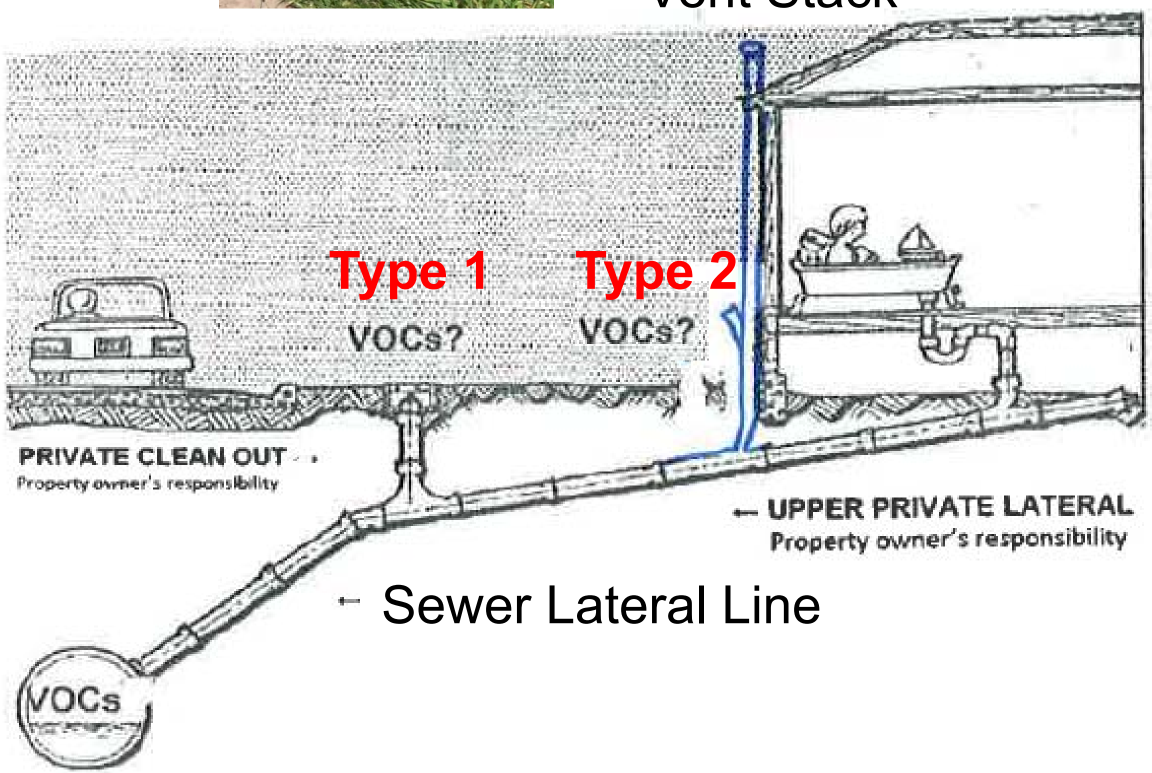
Lid on

Lid off, plug out

Two Cleanout Sampling Locations

Type 1

Vent Stack



Sewer Lateral Line

Main Sewer Line

Type 2

:obs, Jacobs & Pennell, 2016

Range of VOC Concentrations (µg/m^3) Passive Screening Samplers

Compound	TCE	PCE	Chloroform
Sample Location			
Manhole (15)	ND – 201.77	ND – 182.79	ND – 2.69
Sewer Lateral (Cleanouts) (21)	ND – 107	ND – 173	ND – 8.95

Jacobs, Jacobs & Pennell, 2016

Percent of Manholes (15) and Cleanouts (21) Above Lab Reporting Levels

Compound	TCE	PCE	Chloroform	VOCs (incl. Toluene)
<u>Sample Location</u>				
Manhole (15)	13/15 87%	12/15 80%	7/15 46%	15/15 100%
Sewer Lateral (Cleanouts) (21)	11/21 52%	11/21 52%	6/21 29%	12/21 57%

Passive Screening Survey Conditions:

1) Project area wastewater sewer flow direction is cross-gradient to main groundwater flow direction;
2) Storm drains also exist in general east to west flow direction (same as sewers); and
3) VOCs from a variety of possible (unidentified) sources: soil vapor, pipe residue, groundwater, wastewater, pump and treat water, dewatering water, etc.

Predictive Model: VOCs in lateral when same VOC is detected in adjacent manhole

Percent laterals (cleanouts) which also contain compound when VOCs are detected in manhole:

Compound	**TCE**	**PCE**	**Chloroform**
Manhole Maximum ($\mu g/m^3$)	201.77	182.79	2.69
Sample Location			
If Manhole has VOCs and is upstream of the cleanout	61%	75%	25%
If Manhole has VOCs and is downstream of the cleanout	61%	61%	38%

Note: the number of laterals between manholes was not identical and the distribution of Laterals along the main was not uniform.

Jacobs, Jacobs & Pennell, 2016

Low Cost Mitigation Measures: Example of Venting and Plumbing Repairs

Venting: Fans with carbon packs and air pressure indicators placed in manholes, cleanouts or along vent lines and powered by battery, electrical or solar. Example:

Plumbing Mitigation Measures: Repair vapor seals (P-traps), wax seals (toilets). Install vapor barrier box prior to building.

Selected References

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THANK YOU!

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