Updating Site Conceptual Models for Potential Sewer Gas and Vapor Intrusion into Indoor Air from Breached Sewer Conveyance Systems.

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

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Site Conceptual Model: VOCs in Subsurface
Current Site Conceptual Model of VOC Exposure Mitigation

Zone of clean soil and groundwater; No exposure risk
- Upwardly migrating VOCs in soil as soil vapor
- VOCs in soil-groundwater (source)

Zone of VOC-impacted soil and groundwater; Possible exposure risk
- Vapor barrier with subslab depressurization
Vapor Intrusion and Sewer-Plumbing System
Pipe **exfiltration**: PCE enters transite/clay sewer pipe wall as a liquid and the soil as a gas; groundwater is degraded.

Lodi, California Sewer Lines:

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

2) PCE follows sewer lines.

(SWRCB, 1992)
Pipe **exfiltration**: PCE enters transite/clay sewer pipe wall as a liquid and the soil as a gas; groundwater is degraded.

Sewer pipes and utility trenches are conduits for subsurface impacts

PCE vapor heavier than air

High concentration PCE Liquids and Sludges

Lower pressure

High levels of PCE Vapor (higher pressure)

(SWRCB, 1992)

Jacobs, Jacobs & Pennell, 2015
Pipe exfiltration: PCE enters transite/clay sewer pipe wall as a liquid and the soil as a gas; groundwater is degraded.

LODI MODEL
Sewer pipes and utility trenches are conduits for subsurface impacts

(SWRCB, 1992)
Sketch of building with municipal wastewater collection system
Skuldelev, Denmark

(Riis et al., 2010)
PCE at elevated levels in sewer air OUTSIDE of mapped PCE plume

(Riis et al., 2010)
PCE Sewer Study, Skuldelev, Denmark

House Floorplan

Sub-slab
PCE 1.1 µg/ m³

14 µg/m³ CVOC

Indoor air
PCE: 12 µg/m³
TCE: 7 µg/m³
c-DCE: 5 µg/m³
Max 940 µg/m³ CVOC

Drain under kitchen sink
PCE: 810 µg/m³
TCE: 490 µg/m³
c-DCE: 590 µg/m³

37 µg/m³ CVOC

Sewer manhole
PCE: 660 µg/m³
TCE: 310 µg/m³
c-DCE: 260 µg/m³

Subslab Sampling

(Riis et al., 2010)
PCE Plume Interception Sewer Study: Infiltration

Boston, Massachusetts

(Pennell et al., 2013)
Vapor Intrusion Field Investigation: Boston, Massachusetts

PCE in bathroom air = 37 \mu g/m.

PCE in bathroom sewer pipe = 190 \mu g/m.

Pennell et al (2013)
Targeted Sampling

Jacobs, Jacobs & Pennell, 2015
Summary of Results

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


Jacobs, Jacobs & Pennell, 2015
Current Site Conceptual Model of VOC Exposure Mitigation

Alternate exposure pathways not included

Zone of clean soil and groundwater; No exposure risk

- Upwardly migrating VOCs in soil as soil vapor
- VOCs in soil-groundwater (source)

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

- Vapor barrier with subslab depressurization

Groundwater flow
Pipe infiltration: PCE enters 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)
Legacy Urban Sewer Systems:

1) Urban
2) Industrial
3) Pipes: 50 to 100+ Years Old
4) Redevelopment possible (change in use)
Example Wastewater Treatment Plant & Legacy Collection Systems
Range in Design Life of Pipes

- 75 to 100 years (optimal conditions)
- 50-60 years (reasonable lifespan)
- 25-35 years (low end)
Factors Reducing Life Span of Pipes

- Chemical reactions (corrosion)
- Biological attack (tree roots, microbes)
- Physical settling (soil compaction)
Data: Variations in Wastewater Flow (mgd)

12/23/09 to 3/9/10

Major Rain Events

Daily Fluctuations

These peaks likely not caused by rainfall events

(SASM SSRAP; RMC; 2010)
Wastewater Flow Components

RDI/I = Rainfall-Dependent Infiltration/Inflow

BWF = Diurnal Base Wastewater Flow

GWI = Groundwater Infiltration

Over 24 Hours (not to scale)
## Estimated Wastewater Flows (mgd)

### Notes:

2. ADWF = Average Dry Weather Flow (based on non-rainfall periods during January 2009 and 2010).

3. Peak RDI/I = rainfall-dependent I/I (for design event).

4. PWWF = Peak Wet Weather Flow (for design event).

5. WWPF = Wet Weather Peaking Factor (ratio of design event PWWF to ADWF).

### Peaking Factor:

8 to 33 times

(SASM SSRAP; RMC; 2010)

### Table:

<table>
<thead>
<tr>
<th>Subbasin</th>
<th>ADWF (mgd)</th>
<th>Peak RDI/I (mgd)</th>
<th>PWWF (mgd)</th>
<th>WWPF</th>
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</table>

Jacobs, Jacobs & Pennell, 2015
Sources of Inflow and Infiltration (I&I)
Evidence of Sewer Breaches

Cracked Sewer Pipe (Riis)

Corroded Sewer Pipe

Rootlets in Sewer

Separated Sewer Pipe

Cracked Sewer Pipes

Jacobs, Jacobs & Pennell, 2015
Evidence of Sewer Breaches

Leaking terra cotta sewer pipe

Smoke locates sewer leaks

Smoke testing verifies leaks in sewer lateral pipes

Gutter (rainwater) connected to sanitary sewer system

Jacobs, Jacobs & Pennell, 2015
On smoke testing, about 10% of sewer laterals leak
- About 120 visibly detectable smoke leaks
- About 2/3 (66%) of the 120 leaked (80)
  - At edge of AC pavement (road)
  - At gutter lip (road)

(P. Cavagnaro, Nute Engr., 2015 Personal Communication)
Small Northern California District: about 1250 homes 2009-2014; 6 Smoke Testing Projects

On smoke testing, about 10% of sewer laterals leak
- About 120 visibly detectable smoke leaks
- About 35 (of 120) houses (1/3) – leak within 5 ft of home
  - Failed cleanout seal or cap
  - Broken pipe seal

Estimated Lateral Leakage

(P. Cavagnaro, Nute Engr., 2015 Personal Communication)
Small Northern California District: about 1250 homes 2009-2014; 6 Smoke Testing Projects

On smoke testing; of sewer laterals leak:
- 5 laterals out of 1250 houses (0.4%) leak:
  ✓ Within 2-feet of building
  ✓ Underbuilding, or
  ✓ In the building vents
  ✓ (Rate = 1/250 houses)

Comments: 1\textsuperscript{st} estimate (<0.5%) leak. A full study is needed with scientific observations in all houses

(P. Cavagnaro, Nute Engr., 2015 Personal Communication)
UPDATES TO VI MODEL

Jacobs, Jacobs & Pennell, 2015
Vapor Leaks in Buildings
Floor drains without P-Trap seal could be conduits for migrating sewer gases.

Sewer gas blamed for southern Minnesota house explosion that injured man

By Sarah Stultz
Albert Lea Tribune
POSTED: 08/11/2012 12:01:00 AM CDT
UPDATED: 08/11/2012 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...
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 P-Trap

Jacobs, Jacobs & Pennell, 2014
Jacobs, Jacobs & Pennell, 2015
1. Cracked wet stack
2. Dry P-trap
3. Cracked vent stack
4. Loose fittings
5. Faulty wax ring seal
6. Leaking joints
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.
Potential Sources of VOCs:

- 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
- Illicit drug lab (with VOCs)
- Illegal chemical dumping
Implications of VOC Plumes and Legacy Sewer Systems
## Multiple Regulatory Jurisdictions

**Fragmented approach to regulatory authority of resources**

<table>
<thead>
<tr>
<th>Resource</th>
<th>Federal</th>
<th>State</th>
<th>Local</th>
</tr>
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<tbody>
<tr>
<td>Wastewater</td>
<td>US EPA</td>
<td>State Agency</td>
<td>Publicly Owned Treatment Works (POTW) or Municipality</td>
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<tr>
<td>Sewer Systems</td>
<td>US EPA</td>
<td>State Agencies</td>
<td>Local Department of Public Works or Sewer Agency</td>
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<tr>
<td>Public Health (Public)</td>
<td>US EPA</td>
<td>State Agency</td>
<td>County and City Environmental Health Agencies</td>
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<tr>
<td>Public Health (Workers)</td>
<td>OSHA</td>
<td>State OSHA Agency</td>
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<tr>
<td>Impacted Groundwater / Soil</td>
<td>US EPA</td>
<td>State Agencies (DTSC)</td>
<td>County and City Environmental Health Agencies</td>
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<td>Air Quality</td>
<td>US EPA</td>
<td>State Agency</td>
<td>Local Air District</td>
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<tr>
<td>Fuel in Underground Storage Tanks (USTs)</td>
<td>US EPA</td>
<td>State Agencies</td>
<td>Local Fire Agencies and Local Environmental Health Agencies</td>
</tr>
</tbody>
</table>
VOCs in Sewer Air Can Migrate Through Sewer System Outside of Plume Area

Conditions:

A

B

VOCs

crawl-space

A

C

VOCs

crawl-space

D

D

VOCs

Organic Vapors

VOC Contaminated Ground Water

Ground Water Table

VOCs in Sewer Air

Breached sewer line (and laterals to houses) containing VOCs in sewer air

Vapor barrier with subslab depressurization

Leaky vapor seals in house

Intact vapor seals

Zone of clean soil and groundwater

Breached sewer line (and laterals to houses) containing VOCs in sewer air

VOCs in Sewer Air

Sewer cracks or separations

UPDATES TO VI MODEL

Jacobs, Jacobs & Pennell, 2015
# Costs for Assessment and Mitigation Measures

<table>
<thead>
<tr>
<th>Building Mitigation</th>
<th>Relative Cost</th>
<th>Sewer Mitigation</th>
<th>Relative Costs</th>
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<tbody>
<tr>
<td>Site Inspection</td>
<td>Low</td>
<td>Video Inspection</td>
<td>Low</td>
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<tr>
<td>PID Screening</td>
<td>Low</td>
<td>PID Screening</td>
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<tr>
<td>Indoor Air Sampling</td>
<td>Moderate</td>
<td>Manhole / Cleanout Sampling</td>
<td>Moderate</td>
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<tr>
<td>Prioritize and develop building repair / maintenance plan</td>
<td>Low</td>
<td>Prioritize I&amp;I Projects, Community Meetings</td>
<td>Moderate</td>
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<tr>
<td>Plumbing Repairs: Fill P-Traps with water; tighten fittings, etc.</td>
<td>Low to Moderate</td>
<td>Replace Sewer Lines / Engineering</td>
<td>Enormous: Multi-Million Dollar Capital Improvement Projects</td>
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</table>
Evaluation and Actions

• Indoor Air Screening and Sewer Air Testing

• Building Inspection and Mitigation Implementation

• Legacy Sewer and Groundwater Plume Intersection Mapping and Screening

• Workshops and Training
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/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 likely contain VOCs, which infiltrates leaksy 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 Estinge (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.
Selected References


Selected References

• Johnson P.; Holton, C., Guo, Y.; Dahlen, P.; Luo, E.; Gorder, K., Dettenmaier, E., Lessons-learned from four years of intensive monitoring of a house over a dilute chlorinated hydrocarbon plume Oral Presentation at the Association of Environmental Health Sciences (AEHS) Vapor Intrusion Workshop, San Diego, CA. 2014.


• Riis, C. E.; Christensen, A. G.; Hansen, M.H.; and Husum, H. Vapor Intrusion through sewer systems: migration pathways of chlorinated solvents from groundwater to indoor air, presented at the Seventh Battelle International Conference on Remediation of Chlorinated and Recalcitrant Compounds, 2010.
Actively Looking for Research Partners

James A. Jacobs, P.G., C.H.G., C.P.G.; Clearwater Group
Tel: 510-590-1098
jjacobs@clearwatergroup.com

Olivia P. Jacobs, C.E.M.; Clearwater Group
oj@clearwatergroup.com

Kelly Pennell, Ph.D., P.E., University of Kentucky;
kellypennell@uky.edu

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