DoD Vapor Intrusion Handbook
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Vapor Intrusion Preferential Pathways

Purpose

This fact sheet prepared by the Department of Defense (DoD) Tri-Service Environmental Risk Assessment Workgroup (TSERAWG) relates to Sections 2, 3, 5, and Appendix D of the DoD Vapor Intrusion (VI) Handbook. This fact sheet includes: i) an updated conceptual model including scenarios for sites with higher and lower risk for VIPPs and ii) new methods for sampling preferential pathways. Unless a specific citation is provided, the information in this fact sheet is based on the findings from ESTCP Project ER-201505 on *Sewers and Utility Tunnels as Preferential Pathways for Volatile Organic Compound Migration into Buildings*.

> **What is a Vapor Intrusion Preferential Pathway?**
>
> *A **vapor intrusion preferential pathway** (VIPP) is typically defined as a high permeability conduit that can serve as a high-capacity transport pathway for vapors from a subsurface volatile organic compound (VOC) source area to or into a building. For example, a sewer line can serve as a preferential pathway connecting an area of contaminated groundwater to a building.*

Introduction

Why are VIPPs a concern?

A VIPP can enhance the migration of VOCs from a subsurface VOC source into a building resulting in VI impacts greater than would be expected based on VOC migration through the bulk-subsurface material (Figure 1). The lateral migration of VOCs through a preferential pathway is of particular concern because such migration can result in VI impacts to buildings located outside the known footprint of subsurface contamination which is typically the focus area for investigation of conventional VI. For that reason, this fact sheet focuses on sanitary sewers, utility tunnels, and similar subsurface structures that can serve as preferential pathways for lateral VOC migration into a building from a source not directly below the building.

The understanding of VIPPs has evolved since the mid-2010s. Historically, preferential pathways were typically not tested during initial VI site investigations. However, by the mid-2010s, a number of sites with VIPPs were documented in published literature (McHugh et al., 2017). In many cases, the importance of the VIPP was not identified until late in the VI investigation process; in other cases a VIPP was not identified until after conventional mitigation failed.

> **What is a Utility Tunnel?**
>
> *A **utility tunnel** or **utility corridor** is a passage built underground or aboveground to carry utility lines such as electricity, water, and sewer pipes. Communication utilities like fiber optics, cable television, and telephone cables are also sometimes carried. They may also be referred to as a **services tunnel, services trench, services vault,** or **cable vault.** Utility tunnels are often installed in large military facilities as well as industrial plants, large institutions such as universities, hospitals, and research labs. They are not typically installed in residential areas.*
>
> *A directly buried utility line is **not** a utility tunnel.*

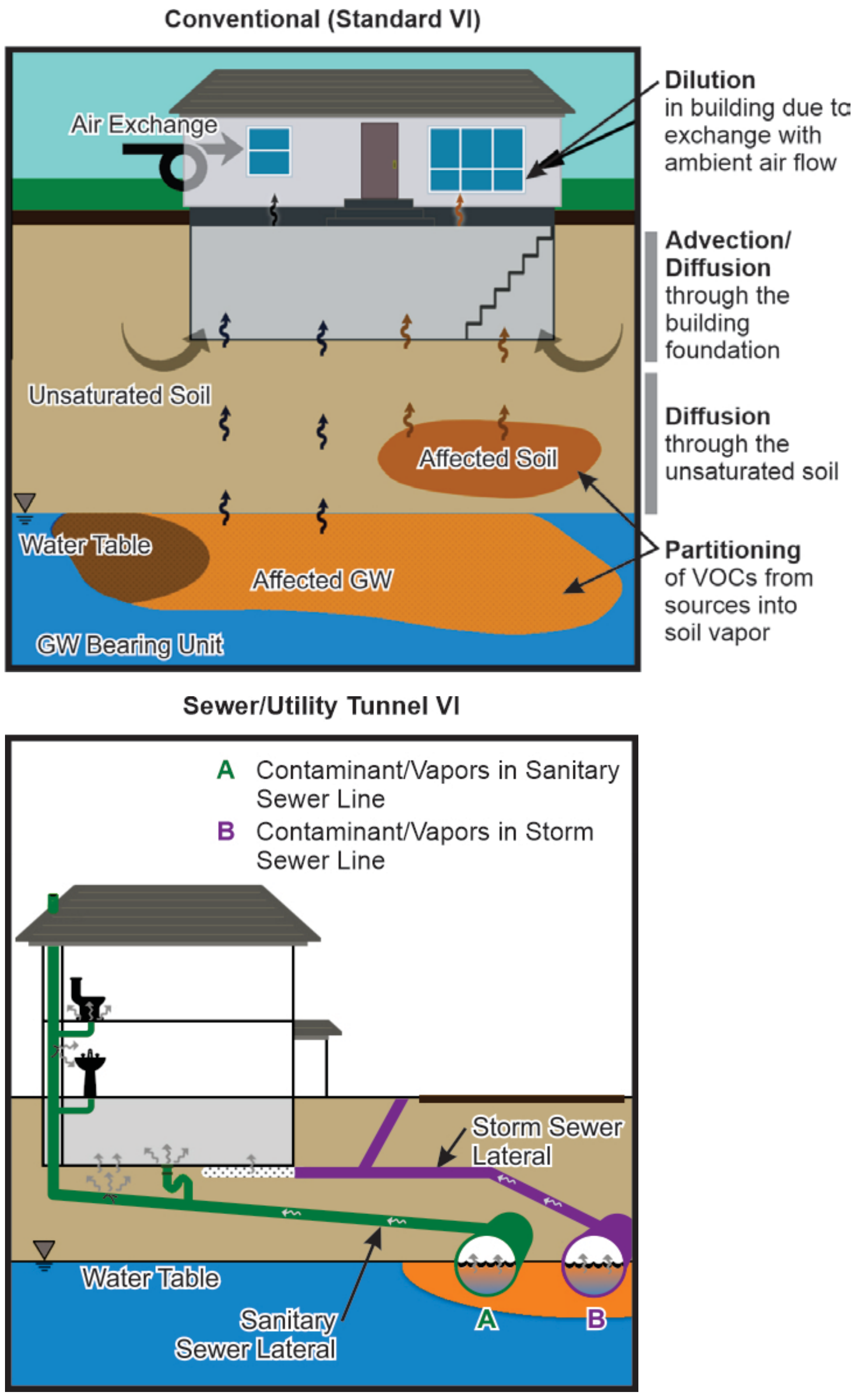


Figure 1: Conceptual Model for Conventional VI versus Preferential Pathway VI (Source: Modified from McHugh et al., 2017)

<u>Are foundation cracks and other building features considered VIPPs?</u>

No, they are not considered VIPPs. Most buildings contain some penetrations through the building foundation in the way of cracks, expansion joints, and plumbing that can serve as conduits for air flow through the foundation. Because these features are common to most buildings and do not extend beyond the building foundation, they are considered to be potential entry points for vapors but not "preferential pathways" for VI (Interstate Technology and Regulatory Council [ITRC], 2007). Therefore, these features are not addressed in detail in this fact sheet. Except for sources located directly adjacent to the building foundation, penetrations through the building foundation do not provide a continuous high capacity connection from the source area to the interior of the building. Nonetheless, high permeability building features can have an important influence on vapor entry into the building and the distribution of VOCs within the building. For example, VOCs may migrate within wall cavities, elevator shafts, stairwells, or open attic spaces. Although not considered VIPPs, such transport pathways can result in an unexpected distribution of VOCs within the building.

Conceptual Model for VIPPs

A VIPP requires the following:

- A subsurface source of VOCs (i.e., non-aqueous phase liquid [NAPL], soil contamination, or a groundwater plume);
- A sewer line, utility tunnel, or similar conduit connecting the subsurface source to a building; and
- A mechanism for VOC entry from the sewer/utility tunnel into the building (Beckley and McHugh, 2020).

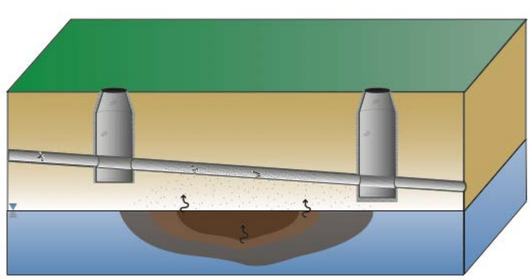
Most sewer lines are not water or gas and allow for infiltration of groundwater (if sewer line intersects groundwater) and infiltration of soil gas (if sewer line is in vadose zone) tight (United States Environmental Protection Agency [USEPA], 2000). The primary transport mechanism is VOC migration through the interior of sewers and utilities (i.e., inside "pipes" rather than through utility backfill material). Although some regulatory guidance documents suggest the potential for preferential vapor migration within permeable backfill around utility lines (e.g., New Jersey Department of the Environment [NJDEP], 2018), examples of such migration resulting in VI impacts have not been documented in published literature (McHugh et al., 2017). Note that vapor migration through backfill may be important in the limited situation of pressure-driven advective transport (e.g., landfill gas) if there is a large permeability contrast between the backfill and native material.

Higher Risk versus Lower Risk Scenarios for VIPP

VI investigation sites can be grouped into higher risk and lower risk categories for VIPPs based on the type of interaction between the subsurface conduit (e.g., sanitary sewer line, utility tunnel) and the VOC source such as contaminated groundwater.

Lower Risk Scenario

Indirect Interaction
Sewer in Vadose Zone above Plume



Higher Risk Scenario

Direct Interaction
Sewer Intersects Contaminated Groundwater

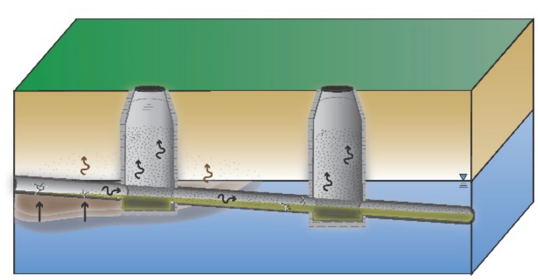


Figure 2: Lower Risk and Common Higher Risk Scenarios for VIPPs (Source: GSI)

As shown in Figure 2, sites with lower risk are characterized by an **indirect interaction** between the subsurface source and the subsurface conduit (i.e., the sewer or utility tunnel is located in the vadose zone above the groundwater plume, NAPL, or other VOC source).

As shown in Figure 2, sites with higher risk for VIPPs are characterized by **direct interaction** between the subsurface source and the subsurface conduit. The most common direct interaction between a sewer/utility tunnel and a VOC source is a sewer line intersecting a groundwater VOC plume. Less common higher risk scenarios include: 1) a subsurface conduit intersecting a VOC NAPL source area in the vadose zone, or 2) discharge of VOC-contaminated groundwater (e.g., from a pump and treat system) into a sewer line.

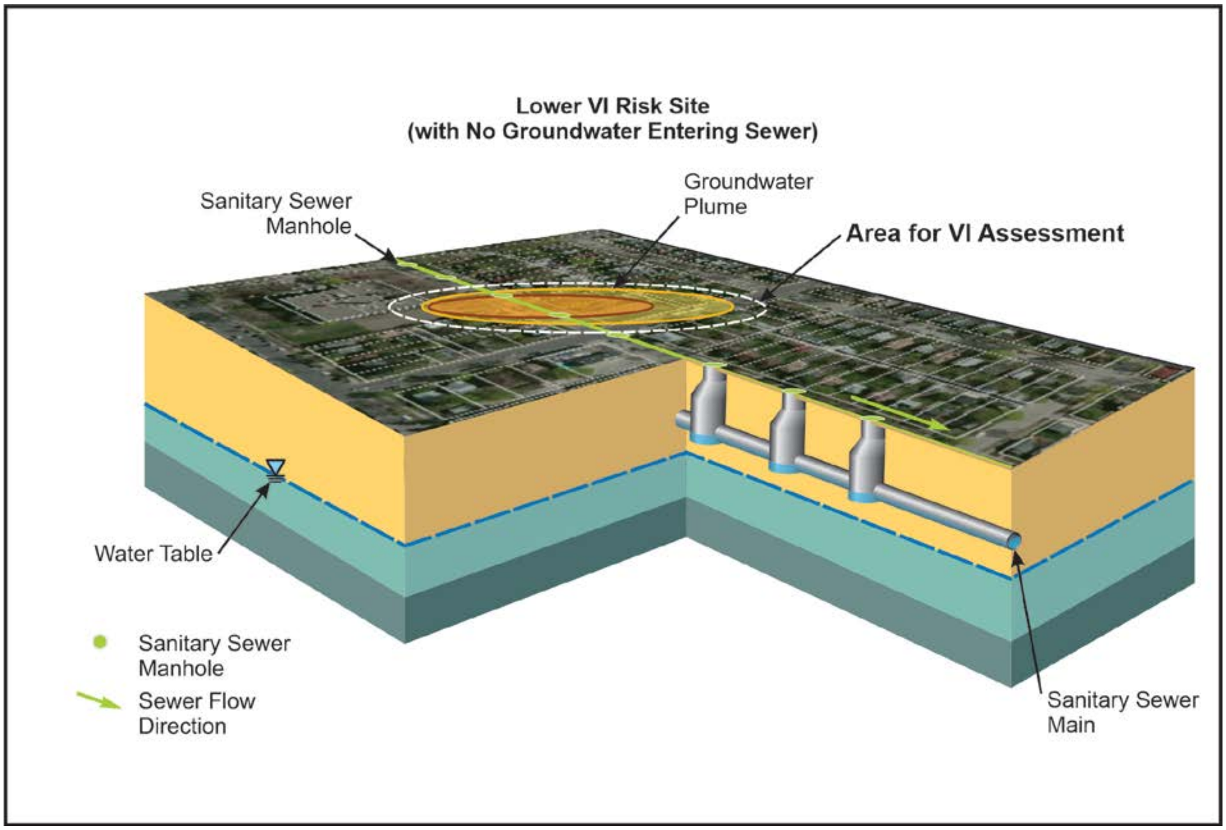
Migration of VOC vapors from groundwater plumes into the sewer/utility tunnel can occur at both higher risk or lower risk sites. However, VOC concentrations within the sewer/utility tunnel are generally observed at higher levels at sites with direct interaction between the subsurface conduit and the VOC source. Available studies do not support a determination of a source to sewer attenuation factor or evaluation of risk beyond “higher source concentration suggests higher risk.”

In addition, at sites where contaminated groundwater directly enters the sewer, downstream VOC migration in sewer liquid and vapor may result in impacts to buildings located away from the subsurface VOC source. For conventional VI investigations, the area for building testing is typically designated as the area above the footprint of subsurface impacts plus a buffer, commonly 100 feet (United States Environmental Protection Agency [USEPA], 2015). This 100 ft buffer is illustrated in Figure 3 (top panel). At sites where contaminated groundwater enters the sewer, the potential VIPP risk area can include the sewer line downstream of the VOC plume in groundwater. This downstream area may extend beyond the 100 ft screening distance commonly used to identify buildings at risk for VI (as shown in Figure 3, bottom panel).

Migration of VOCs within Sewers/Utility Tunnels

The migration of VOCs within sewer lines depends on whether the VOCs enter the sewer in the liquid phase or the vapor phase. When contaminated groundwater enters a sewer line, it flows downstream with the liquid flow in the sewer. VOCs partitioning from the liquid phase into the vapor phase can result in vapor impacts for an extended distance downstream of the subsurface source area. In these cases, the extent of downstream impacts depends on a number of factors and is difficult to predict; however, it is possible for these downstream impacts to extend well outside the footprint of the VOC plume in groundwater.

In the vapor phase, the direction of movement within a sewer or utility tunnel is somewhat less predictable compared to the liquids. Although vapor flow within a sewer line is generally in the same direction as liquid flow, vapor can also move limited distances in other directions. Regardless of the direction of vapor movement, when VOCs are <u>not</u> present in sewer liquids, the VOC concentrations in the vapor phase typically decrease quickly with distance away from the impacted liquid. This is because sewers and utility tunnels are designed to be vented, allowing both dilution of vapors with ambient air and escape of VOC vapors to the atmosphere. As a rule of thumb, when VOCs are not present in the sewer liquids, VOC concentrations in the vapor phase decrease by 80% or more within 500 ft outside of the subsurface VOC source area.



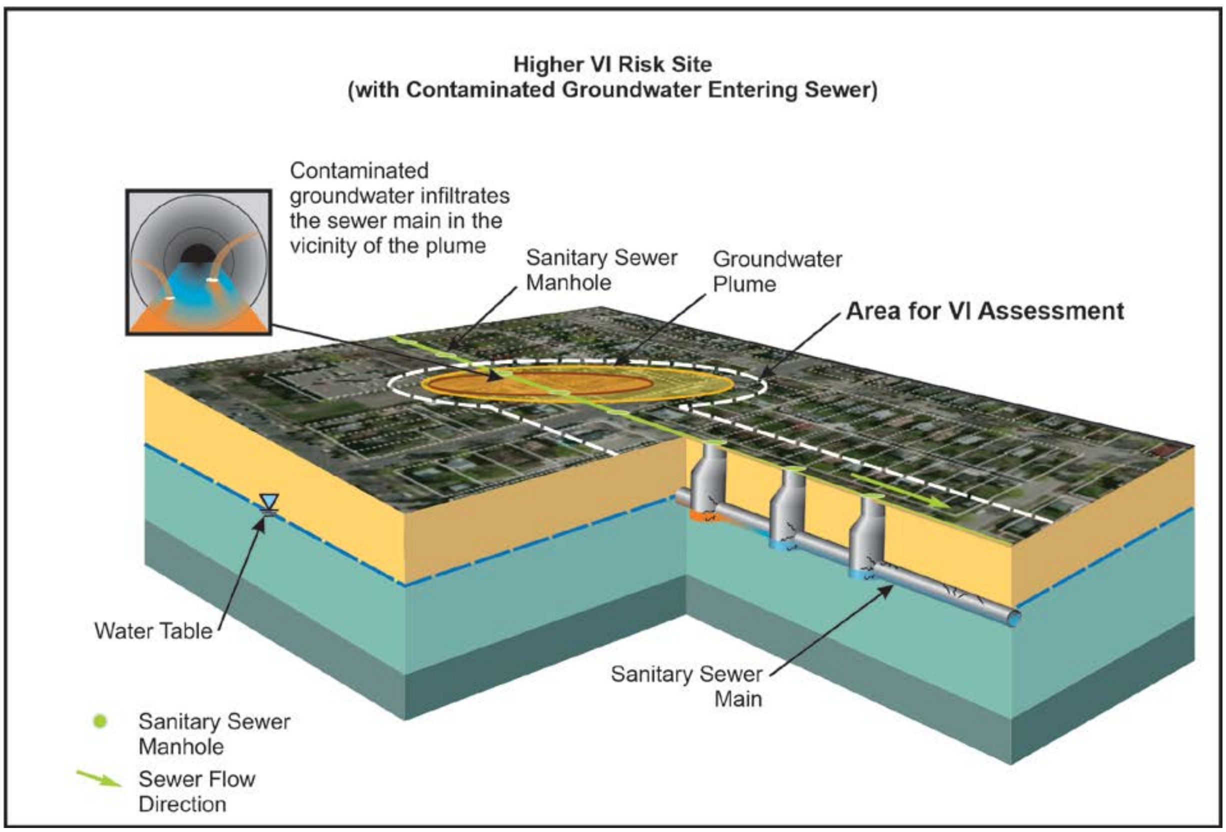


Figure 3: Sewer/Utility Tunnel VI Risk Area (Source: Battelle)

Migration of VOCs within Buildings

The potential for migration of VOCs from sewers or utility tunnels into buildings depends on the integrity of the connections to the specific building. Specific considerations are provided below for sanitary sewer lines, utility lines, and other sewer lines.

Sanitary Sewer Lines: Because sanitary sewers commonly generate noxious odors, building plumbing systems are engineered to prevent gas flow from the sewer into the building (Figure 4). However, failures in these systems can allow vapor entry through the point(s) of failure. In buildings with properly constructed and functioning plumbing, decreased transport potential / high attenuation in VOC concentrations is commonly observed between the sewer line and the building. However, less attenuation is observed in buildings with plumbing failures.

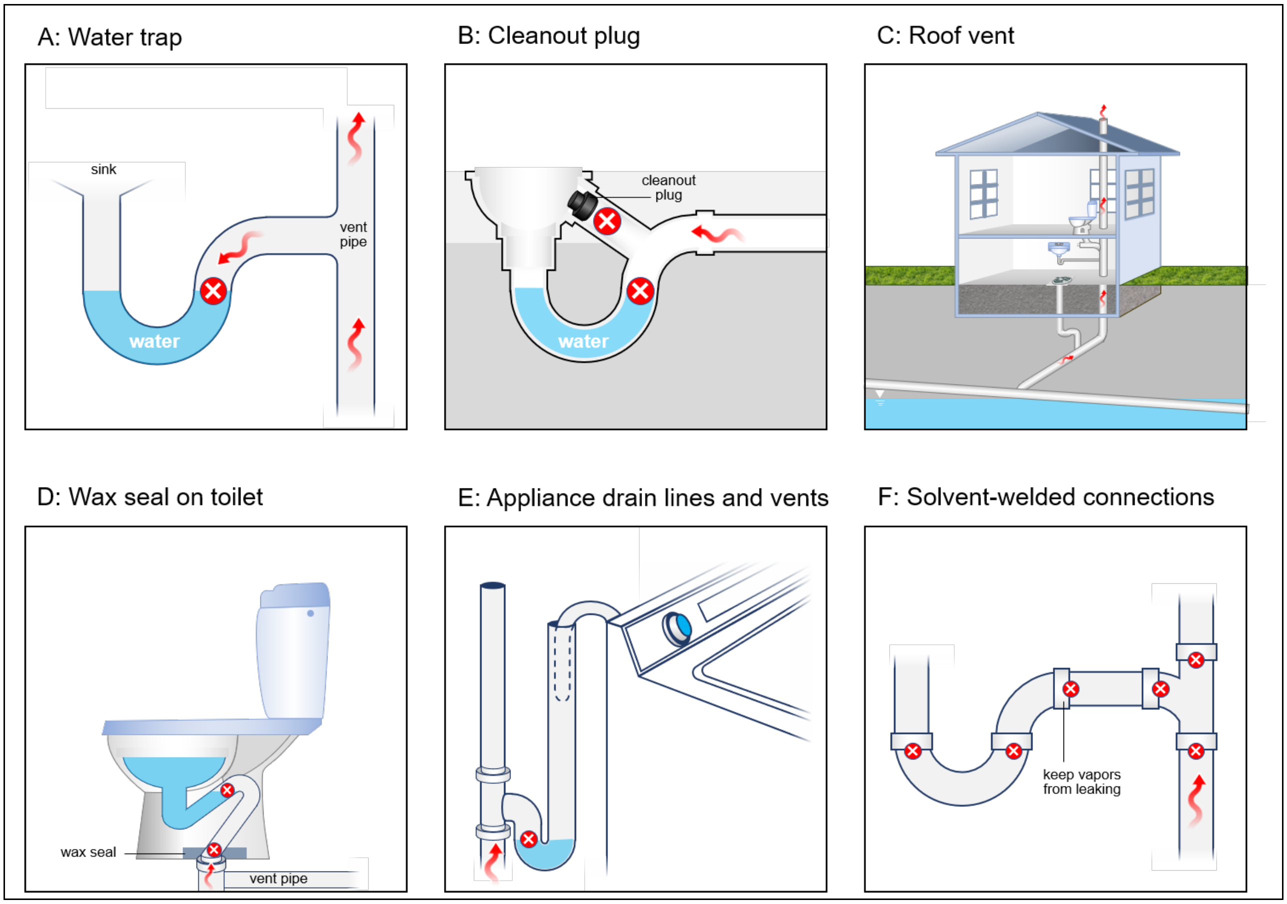


Figure 4: Property-Specific Barriers to Sewer Preferential VI Pathways (Source: GSI)

Utility Tunnels: At DoD facilities, telephone lines, electrical lines, and other utilities are often connected to buildings through utility tunnels. These tunnel connections may not include systems to limit gas flow because the tunnels may not be an expected source of noxious odors. As a result, VOC attenuation from utility tunnels into buildings is likely to be low compared to buildings with properly functioning sanitary sewer connections (i.e., less decrease in VOC concentration from the utility tunnel into the building compared to the sanitary sewer into the building).

Other Sewer Lines: Many building foundations have drain systems to prevent the infiltration of shallow groundwater or infiltrating storm water. In some areas, these drain systems are connected to the local storm sewer system or a separate land drain sewer system. In these cases, VOCs can migrate from the drain line to the building foundation and then migrate through the building foundation via the same mechanisms as with conventional VI (Guo et al., 2015).

VIPP Investigation

The potential for sewers and utility tunnels to act as preferential pathways for VI should be evaluated in conjunction with standard VI investigations. Guidance for VIPP investigation was developed as part of ESTCP Project ER-201505 (McHugh and Beckley, 2018b) and is available at:

https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Emerging-Issues/ER-201505

In summary, the investigation process involves the following steps:

Initial Screening to Identify Site as Higher or Lower Risk for VIPPs

Initial screening is a desktop exercise to categorize sites as higher risk or lower risk with respect to the potential for a VIPP to influence VI.

Higher risk sites are characterized by: 1) the potential for higher VOC concentrations within the sewer or utility tunnel based on its direct interaction with the subsurface VOC source, and 2) sites where VOCs may migrate through the sewer or utility tunnel through the entry of contaminated groundwater. These conditions result in possible VI into buildings located outside of standard VI screening distances. Higher risk sites merit sampling of the sewer or utility tunnel during the initial VI field investigation phase.

At lower risk sites, VOC vapor concentrations in sewers/utility tunnels tend to be lower and more localized. Therefore, a conventional VI investigation that is conducted in accordance with applicable regulatory guidance and includes indoor air testing should be sufficient. Early sampling of the sewer or utility tunnel is not recommended for sites with lower risk for VIPPs. However, these sites may warrant further testing based on the results of a conventional VI field investigation. For example, VI data from the field may suggest that VIPPs are important (e.g., VOC concentrations in indoor air exceed sub-slab VOC concentrations and no indoor VOC source is identified).

If a single subsurface VOC source interacts with multiple sewers/utility tunnels or if multiple VOC sources are present at a site, then the risk classification can be applied separately to each VOC source and sewer/utility tunnel combination.

Field Investigation for Sites with Higher Risk for VIPPs

Sewer/utility tunnel sampling is recommended for sites with higher risk for VIPPs based on the initial screening process. Investigation typically does not require entry into the sewer line or utility tunnel. However, if entry is required, field crews should comply the Occupational, Safety, and Health Administration’s (OSHA's) confined space entry standard.

For example, initial field testing may consist of vapor samples from the three highest risk sewer/utility tunnel access locations to evaluate whether additional investigation is warranted. The highest risk locations are access points located within or immediately downstream of the area where the sewer or utility tunnel interacts with the contaminated groundwater or NAPL area (see Figure 5).

Access points are typically manholes or other locations where a sample line can be run for sample collection. If more than three access points are available, the three points within or downstream of the highest concentration groundwater/NAPL area should be selected. The site conceptual model, groundwater investigation results, and plume maps can be used to identify the area of highest groundwater concentration/NAPL.

Figure 5: Example Initial Field-Testing Locations (Source: GSI)

For each location, samples are collected as follows:

- If the groundwater elevation varies seasonally such that the water table fluctuates above and below the sewer/utility tunnel, then sampling should be conducted during the period with the higher water table.
- Passive sampling of sewers is challenging because the passive sampling equipment must be left in place for a period of hours to days and may be impacted or destroyed by storm events or other factors.
- For sanitary sewers, samples should be collected when baseline flow is relatively low, such as between 9 am and 3 pm for residential areas. For all sewers, samples should not be collected within 48 hours of a rainfall event of more than 0.1 inches.
- Minimize opening manhole covers prior to sampling by 1) threading measurement or sampling equipment through vent holes, or 2) opening covers just enough to insert the equipment into the manhole.
- Using a water level meter or weighted string, measure the distance from the access point to the bottom of the sewer/utility tunnel or the depth to any liquid (whichever is shallower).
- Collect a grab vapor sample from a depth of 1 foot above the bottom or liquid level using nylon or Teflon® tubing extended through the access point (see Figure 6).
- The sample can be collected using any appropriate vapor sampling device, but will typically be collected using a Summa-type canister. When using a Summa-type canister for sample collection, a flow controller is not required.
- Typical air sampling quality assurance steps should be taken. For example, leak testing can be conducted using a shut-in test for the entire

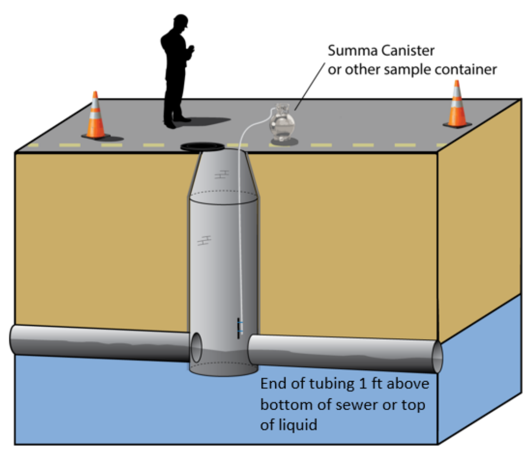


Figure 6: Vapor Sample Collection from Sewer (Source: GSI)

sampling train prior to extending the sample tubing into the manhole. In addition, the sample tubing can be purged of ambient air prior to sampling.
- A video showing sample collection is available at: https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Emerging-Issues/ER-201505/ER-201505

Tracer testing conducted for ESTCP Project ER-201505 indicated that a sewer to indoor air attenuation factor of 0.03 (33x attenuation) is a reasonable upper-bound attenuation factor for initial evaluation of VOC concentrations in sewers. The attenuation factor of 0.03 is based on the study of residences and small / medium commercial /industrial buildings and may be overly conservative for sewers attached to large industrial or buildings with high air exchange rates such as hangers and some warehouse buildings. Because of the uncertainty associated with attenuation factors in the presence of VIPPs, this value is provided for informational purposes. This value has not been adopted as a default attenuation factor for application at DoD sites.

When three sewer locations are included in the initial testing, the maximum VOC concentration across the three locations should be compared to screening values. Use of the maximum concentration for initial screening serves to offset some of the uncertainty associated with both spatial and temporal variability in VOC concentrations. If the maximum VOC concentrations exceed the sewer screening concentrations, then further testing may be warranted to delineate the extent of vapors within the sewer and potential impacts to buildings.

Consideration of Temporal Variability in Sewer Vapor VOC Concentrations

If the VOC concentrations from initial field testing are below screening values, additional sampling may be considered to address temporal variability. Studies of temporal variability within sewer lines showed much higher variations in VOC concentration over a timescale of months compared to a timescale of days (Guo et al., 2020; McHugh and Beckley, 2018a). Among other implications, these results indicate that short-term, time-integrated samples (e.g., 24-hour Summa canisters or 1-week passive sorbent samples) provide little value over grab samples.

If VOC concentrations measured during the initial testing step are close to screening values, quarterly sampling may be appropriate to obtain a better understanding of long-term average VOC concentrations in the sewer. Resampling within a few days of the initial testing is unlikely to provide a significantly more accurate understanding of the long-term average VOC concentration in the sewer line (McHugh and Beckley, 2018b).

Typical Background VOC Concentrations in Sewers

Interpretation of sewer vapor data should include consideration of background. Because most buildings are connected to sanitary sewers, sanitary sewers are the most common conduit for sewer/utility tunnel VI. In addition to acting as preferential pathways for VI, sanitary sewers may contain VOCs from other sources such as the permitted or non-permitted disposal of VOC-containing waste. Table 1 summarizes typical background concentrations of VOCs in sewers.

As shown in Table 1, a number of VOCs are commonly detected in vapor samples collected from sewer manholes. Levels of cis-1,2-dichloroethene (cis-1,2-DCE), a product of biodegradation of trichloroethene (TCE) in the subsurface, were detected in 55% of background samples suggesting that unidentified subsurface VOC sources (e.g., unidentified VOC plumes) are an important source of VOC detections in background sewer manholes within urban or industrialized areas. This conclusion relies on an assumption that the cis-1,2-DCE originated from biodegradation of TCE in groundwater rather than biodegradation of TCE within the sewer line. This assumption is reasonable because 1) the residence time for TCE within the sewer (i.e., minutes to hours) is likely too short for significant biodegradation and 2) the biodegradation of TCE to cis-1,2-DCE requires anaerobic conditions which are less likely to occur in sewer lines where the flow of shallow water over a rough surface promotes oxygenation.

Table 1 also shows that other VOCs such as acetone, toluene, and tetrachloroethene (PCE) were detected in 90% or more of the background samples. The high detection frequency indicates that direct disposal into sewers is also an important source of the VOCs found in the sewer lines. For the VOCs that are most commonly risk drivers at corrective action sites (e.g., benzene, PCE, TCE), the concentrations detected in background were typically low (i.e., median <20 $\mu g/m^3$).

Table 1: Typical Background VOC Concentrations in Sewer Vapor

Analyte	No. Manholes Tested	No. Samples	Det. Freq (%)	10th ($\mu g/m^3$)	Median ($\mu g/m^3$)	90th ($\mu g/m^3$)	Maximum ($\mu g/m^3$)
Common Chlorinated VOCs at Remediation Sites							
Tetrachloroethene	20	31	90%	0.35	3.2	68	550
Trichloroethene	19	30	70%	0.56	2.6	16	85
Dichloroethene, cis-1,2-	20	31	55%	0.35	0.67	7.5	20
Common Petroleum VOCs at Remediation Sites							
Benzene	55	98	79%	0.32	1.1	4.3	89
Toluene	56	99	98%	1.5	20	280	3300
Ethylbenzene	56	99	74%	0.27	1.4	8.9	190
Xylene, m,p-	57	100	83%	0.82	3.4	21	57
Xylene, o-	58	101	78%	0.34	1.2	4.4	16
Other VOCs							
Acetone	56	99	100%	15	47	200	4000
Bromodichloromethane	58	101	86%	0.44	16	86	540
Butanone, 2- (MEK)	57	100	86%	1.9	4.3	14	66
Carbon disulfide	58	101	99%	3	20	180	940
Carbon tetrachloride	58	101	60%	0.41	0.73	4.4	6
Chloroform	103	249	82%	1	26	360	4000
Chloromethane	58	101	94%	1.1	2	12	100
Dibromochloromethane	58	101	69%	0.67	5.2	33	99
Dichlorodifluoromethane	58	101	77%	1.2	2.3	9.8	38
Methylene chloride	58	101	97%	0.74	5.1	35	110
Trichlorofluoromethane	58	101	53%	1.1	1.8	11	8.4

Notes: 1) Vapor samples were collected from background manholes located away from known groundwater plumes. 2) Background values were developed for ESTCP ER-201505. See McHugh and Beckley (2018b) for details on the data and calculations underlying this table.

In summary, a variety of VOCs are commonly present in sanitary sewers at detectable concentrations. As a result, the detection of VOCs in a sewer sample should not be considered as definitive evidence that a specific subsurface source has impacted the sewer. However, note that, for most VOCs, background concentrations are usually below sewer screening levels for VI (when those screening values are calculated from indoor air screening levels using an attenuation factor of 0.03).

VIPP Mitigation

Sewer/utility tunnel VI may be mitigated at any of three steps along the VOC transport route: 1) entry of VOCs into the sewer, 2) migration within the sewer main line, or 3) migration of VOCs from the sewer into the building.

Entry of VOCs into Sewer or Utility Tunnel: Contaminated groundwater commonly enters a sewer line or utility line through cracks or unsealed joints present in the area where the line passes through the contaminant plume or source area. The infiltration of contaminated groundwater can be reduced or eliminated by installing a liner such as a cured in-place pipe (CIPP) in the sewer line and manholes within the plume area. However, some infiltration of contaminated groundwater may continue if the liner is not completely sealed. As alternatives, damaged sewer lines can be replaced with new pipe with water-tight seals between pipe sections, or sewer lines can be re-routed to avoid the contaminated area.

Ventilation of the Sewer Main or Utility Tunnel: VOC migration from sewers and utility tunnels into buildings can be controlled by negative pressure ventilation of the sewer line. Within the depressurization zone, this will draw vapors from the sewer to the ventilation points allowing for treatment and/or discharge to the atmosphere.

Migration of VOCs from the Sewer into the Building: For some buildings, repair or proper maintenance of the building plumbing (e.g., adding water to a dry p-trap) may be sufficient to prevent VOC migration from the sewer into the building. Alternatively, a check valve for both liquids and gas can be installed within the sewer line. A liquid and gas check valve allows the flow of liquid down the sewer line but prevents the flow of either liquids or gas upwards towards the building. This type of check valve can be installed in the sewer lateral to protect an individual building or within a sewer main line upstream of the VOC source to protect all structures upstream of the check valve.

Any engineering control used to mitigate a VIPP may require monitoring to ensure effectiveness.

Regulatory Guidance on VIPPs

Regulatory guidance in many jurisdictions is being revised to account for the improved understanding of preferential pathways that has resulted largely from research conducted in the last 5 years. It is advisable to verify the status of guidance during the planning stages of investigation and mitigation programs.

Disclaimer

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References

Beckley, L. and T. McHugh. 2020. "A conceptual model for vapor intrusion from groundwater through sewer lines." Sci Total Environ 698. https://doi.org/10.1016/j.scitotenv.2019.134283.

Guo, Y., P. Dahlen, and P. Johnson. 2020. "Temporal variability of chlorinated volatile organic compound vapor concentrations in a residential sewer and land drain system overlying a dilute groundwater plume." Sci Total Environ 702. https://doi.org/10.1016/j.scitotenv.2019.134756.

Guo, Y., C. Holton, H. Luo, P. Dahlen, K. Gorden, E. Dettenmaier, and P. Johnson. 2015. "Identification of Alternative Vapor Intrusion Pathways Using Controlled Pressure Testing, Soil Gas Monitoring, and Screening Model Calculations." Environ. Sci. Technol. DOI: 10.1021/acs.est.5b03564.

Interstate Technology and Regulatory Council (ITRC). 2007. Vapor Intrusion Pathway: A Practical Guideline. Interstate Technology and Regulatory Council.

McHugh, T. and L. Beckley. 2018a. Conceptual Model for Sewer/Utility Tunnel Vapor Intrusion, ESTCP Project ER-201505, Version 2.

McHugh, T. and L. Beckley. 2018b. Final Report: Sewers and Utility Tunnels as Preferential Pathways for Volatile Organic Compound Migration into Buildings: Risk Factors and Investigation Protocol, ESTCP Project ER-201505, Version 2.

McHugh, T., P. Loll, and B. Eklund. 2017. "Recent advances in vapor intrusion site investigations." Journal of Environmental Management 204: 783-792. http://dx.doi.org/10.1016/j.jenvman.2017.02.015.

New Jersey Department of Environmental Protection (NJDEP). 2018. Vapor Intrusion Technical Guidance Version 4.1. Site Remediation and Waste Program Management. January.

United States Environmental Protection Agency (USEPA). 2000. Exfiltration in Sewer Systems. EPA/600/R-01/034. Available at: https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=99137

USEPA. 2015. OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air, OSWER Publication 9200.2-154, June.